WATER RESEARCH FOUNDATION

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EPA

Utility Guidance for Mitigating Catastrophic Vegetation Change in Watersheds

Subject Area: Water Resources and Environmental Sustainability

Utility Guidance for Mitigating Catastrophic Vegetation Change in Watersheds

ADVANCING THE SCIENCE OF WATER®

About the Water Research Foundation

The Water Research Foundation (formerly Awwa Research Foundation or AwwaRF) is a member-supported, international, 501(c)3 nonprofit organization that sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

The Foundation's mission is to advance the science of water to improve the quality of life. To achieve this mission, the Foundation sponsors studies on all aspects of drinking water, including resources, treatment, distribution, and health effects. Funding for research is provided primarily by subscription payments from close to 1,000 water utilities, consulting firms, and manufacturers in North America and abroad. Additional funding comes from collaborative partnerships with other national and international organizations and the U.S. federal government, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated.

From its headquarters in Denver, Colorado, the Foundation's staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

The results of research are disseminated through a number of channels, including reports, the Web site, Webcasts, conferences, and periodicals.

For its subscribers, the Foundation serves as a cooperative program in which water suppliers unite to pool their resources. By applying Foundation research findings, these water suppliers can save substantial costs and stay on the leading edge of drinking water science and technology. Since its inception, the Foundation has supplied the water community with more than $460 million in applied research value.

More information about the Foundation and how to become a subscriber is available on the Web at **www.WaterResearchFoundation.org**.

Utility Guidance for Mitigating Catastrophic Vegetation Change in Watersheds

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FOREWORD

The Water Research Foundation (Foundation) is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of consultation with subscribers and drinking water professionals. Under the umbrella of a Strategic Research Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection. The Foundation also sponsors research projects through an unsolicited proposal process; the Collaborative Research, Research Applications, and Tailored Collaboration programs; and various joint research efforts with organizations such as the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, and the Association of California Water Agencies.

This publication is a result of one of these sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry's centralized research program but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the Foundation's staff and large cadre of volunteers who willingly contribute their time and expertise. The Foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants and manufacturers subscribe based on their annual billings. The program offers a cost-effective and fair method for funding research in the public interest.

A broad spectrum of water supply issues is addressed by the Foundation's research agenda: resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide the highest possible quality of water economically and reliably. The true benefits are realized when the results are implemented at the utility level. The Foundation's trustees are pleased to offer this publication as a contribution toward that end.

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Thank you all very much.

EXECUTIVE SUMMARY

Watershed vegetation plays an enormously important role in protecting the quality and quantity of drinking water. Watershed vegetation controls erosion, captures sediments, and filters contaminants, helping to ensure a clean water supply. Vegetative cover also regulates surface runoff, affecting water availability at different points in time. Even the best watershed protection programs, however, often fail to plan for potential large-scale alterations to vegetative cover that can threaten source waters and drinking water supplies. Both natural and human-caused events can cause large-scale changes in vegetation over various time scales. Events may occur singly, or as a part of "event cascades" in which one event, such as wildfire, triggers subsequent events, such as mudslides or exotic species invasions. Utility managers need guidance on the actions that can be taken to minimize the risk of harm from these events and avoid severe impacts to water treatment processes.

RESEARCH OBJECTIVES

The purpose of this project is to provide utilities with the information and tools they need to plan for and respond to large-scale vegetation change in their watershed. The primary objectives of this project are to:

1. Help utilities better assess the risks they face with respect to large-scale vegetation change in their watershed
2. Provide specific information on the changes in water quality and water quantity that can occur after different events (e.g., fire, storm, urbanization)
3. Provide information on potential management strategies that can either help reduce the risk of large-scale vegetation change or mitigate the impacts of these changes
4. Provide a series of case studies to document utility experiences and "lessons learned"

Eight watershed events were included in this project to cover all the major types of watershed impacts. Natural events include wildfire; storm events such as hurricanes, tornadoes, and floods; mudslides; insect pests and pathogens; and drought. Human-caused events, many of which occur gradually and are often not readily apparent, include invasive species, timber harvest, and land conversion, such as agricultural development or urbanization.

APPROACH

Information for this report was gathered from a structured literature search of published and "gray" literature on watershed impacts and from a series of case study interviews with individual utilities. The focus for the literature search and for the interviews was to identify information of specific relevance to water utilities.

RESULTS

Results of the literature search and case studies highlighted many commonalities between different large-scale events with respect to their impacts on vegetation and soils and subsequent impacts on source water quality and quantity. For water utilities, the key issue is to determine whether large-scale events pose a risk of producing variability in key physical, chemical, and microbiological water quality parameters that would be outside the range for which their water treatment facilities were designed. In these situations, utilities can attempt to meet "the influent challenge" with either significantly modified operating practices or redesign of facilities (often very expensive), or choose to engage in watershed management actions that can prevent or reduce the risk of impacts from large-scale events.

CHANGES IN VEGETATION AND SOILS

All of the events highlighted in this report can cause significant impacts to vegetation and soils. Fire, timber harvest, and storms can remove vegetation across wide areas of a watershed. Urbanization and agriculture replace natural vegetation with impervious surfaces or cropland. Insect infestations and pathogens, as well as invasive species, tend to affect species composition and diversity, although widespread areas of dead vegetation can occur with severe outbreaks. Drought can weaken or kill vegetation depending on the drought's severity or duration.

Soils are impacted indirectly when vegetation is weakened or killed because roots are lost from the system, leading to an increase in erosion potential. Individual events also can have specific impacts on soils. Fires can create "hydrophobic" soils with decreased water infiltration. Timber harvest and storms also can result in physical impacts to soils. Insect infestations and invasive species can result in changes in soil properties, depending on the specific species involved (e.g., widespread death of hemlocks can decrease soil pH).

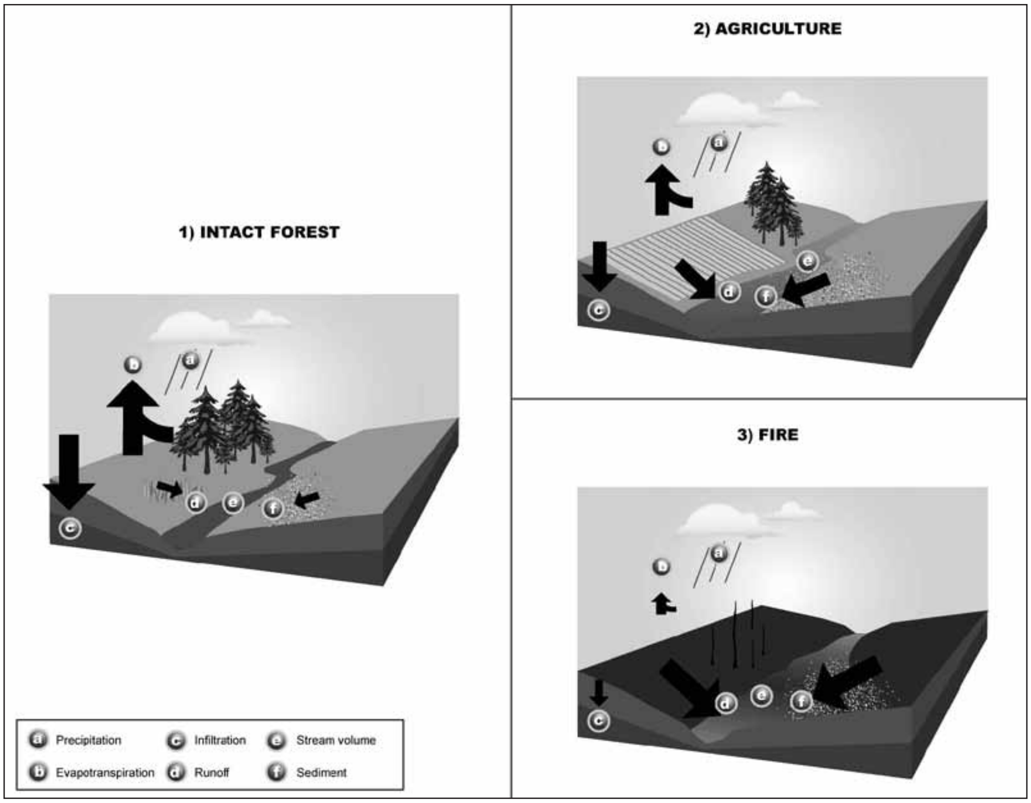
EFFECTS ON WATERSHED PROCESSES

There are significant commonalities across events in the ways in which changes in vegetation and soils result in impacts to watershed processes. For all events, any large-scale changes to watershed vegetation can lead to significant changes in the amount of water that flows across a watershed and in water quality. Figure ES.1 depicts the difference in runoff and sedimentation for intact forests versus forests impacted by fire or agricultural conversion. In intact forests (1), evapotranspiration and infiltration rates are high, leading to low runoff and sedimentation. Conversion to agriculture (2) is associated with periodic disturbance of vegetation and soil compaction; this reduces evapotranspiration and infiltration and increases runoff and sedimentation. Fire (3) removes vegetation and makes soil surfaces impermeable, dramatically reducing evapotranspiration and infiltration and increasing runoff and sedimentation. Other events have similar impacts on surface water quality and quantity similar to the events shown in Figure ES.1 as examples.

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

Losses in vegetation can lead to increases in water volume by (1) increasing surface runoff and (2) decreasing water uptake by vegetation. When the physical barrier of vegetation is removed and vegetation is not taking up water for transpiration, water flows much more rapidly across the watershed, reducing infiltration and increasing the amount that reaches surface waters.

Intact, well functioning terrestrial ecosystems also are critical to maintaining water quality through soil stabilization and control of nutrients and other pollutants. Plants have extensive rooting systems that minimize soil movement. Plant leaves, stems and trunks also intercept rain, preventing rain drops from dispersing soil. When plants disappear, soils can move more easily and



The sizes of arrows indicate the size of the flux. In intact forests (1), evapotranspiration and infiltration rates are high, leading to low runoff and sedimentation. Conversion to agriculture (2) is associated with periodic disturbance of vegetation and soil compaction; this reduces evapotranspiration and infiltration and increases runoff and sedimentation. Fire (3) removes vegetation and makes soil surfaces impermeable, dramatically reducing evapotranspiration and infiltration and increasing runoff and sedimentation.

Figure ES.1 Key hydrological processes in (1) intact forests, (2) intensive agriculture, and (3) forests after wildfire

this loss of soil stability can increase sedimentation to rivers and reservoirs. Vegetation also plays a key role in containing nutrients that can contaminate rivers and streams. Large scale disturbances can stop plant uptake of soil nutrients, leading to greater nutrient concentrations in streams. If plants are killed by wildfire or disturbance, the nitrogen and phosphorous in their leaves and stems can also be released to local streams and rivers.

MANAGEMENT STRATEGIES

A variety of management strategies are available to water utilities to prevent or reduce the risk of harm from large-scale watershed vegetative change events. Some events, such as catastrophic wildfire and insect infestations, can be prevented or minimized by watershed management that reduces fuel loads, increases species and age-class diversity, and promotes overall watershed health. Human-caused events such as timber harvest, urbanization, and agriculture can be avoided or minimized if a utility is able to purchase vulnerable land or obtain conservation easements that restrict these activities. Impacts from these events also can be minimized through the use of best management practices (e.g., to reduce the amount of soil erosion and sediment loadings).

When events do occur, management strategies are available to minimize the harm to source water. For example, sediment traps and sediment management plans can minimize turbidity increases for influent waters if the large-scale event cannot be prevented. Actions to minimize algal growth in reservoirs also can benefit influent water quality.

CHAPTER 1
INTRODUCTION

Watershed vegetation plays an enormously important role in the quality and availability of drinking water. Watershed vegetation controls erosion, captures sediments, and filters contaminants, helping to ensure a clean water supply. Vegetative cover also regulates the rate at which water either runs off across the surface or infiltrates into the soil, affecting water availability at different points in time.

The importance of protecting watershed vegetation to ensure a healthy water supply has long been recognized by forward-thinking water utilities and municipalities. Boston, New York, Seattle, San Francisco, and other cities all began watershed protection programs in the 1800s and have continued those programs to the present. Recent reports by the U.S. Environmental Protection Agency (USEPA) and jointly by the Trust for Public Land and the American Water Works Association (AWWA) highlight case studies of cities, counties, and states engaged in source protection and watershed management, together with a set of best practices for developing comprehensive source water protection plans (USEPA 1999, Ernst 2004). In fact, a study of 27 water utilities found that treatment and chemical costs decreased by 20% for every 10% increase in forested cover in the watershed (up to approximately 60% forest cover; Ernst, Gullick, and Nixon 2004).

Despite this long-standing recognition of the importance of protecting watershed vegetation, even the best watershed protection programs often fail to plan for potential catastrophic or large-scale alterations to vegetative cover that, in turn, threaten source waters and drinking water supplies. Both natural and human-caused events can cause large-scale changes in vegetation over various time-scales. Natural events include wildfire; storm events such as hurricanes, tornadoes, and floods; mudslides; and forest disease or infestation. Human-caused events, many of which occur gradually and are often not readily apparent, include invasive species, timber harvest, and land conversion, such as agricultural development or urbanization. Events may occur singly, or as a part of "event cascades" in which one event, such as wildfire, triggers subsequent events, such as mudslides or exotic species invasions.

Many utilities do not fully understand how large-scale changes in vegetation can impact source waters or what options are available for preparing for or responding to vegetation changes in a cost-effective manner. Yet without preparing for and taking action against these potential impacts, utilities risk increased water treatment costs and potentially permanent damage to the watershed processes that generate a reliable supply of clean water.

This Water Research Foundation research project was developed to fill this gap by providing a guidance document to water utilities to help them better understand (1) the potential dangers of large-scale vegetation changes that threaten source water, and (2) preparation or response strategies that utilities can undertake. The results provide comprehensive information on the specific water quality risks that can result from different natural and human-caused events that cause large-scale vegetation changes. The results also provide information on approaches to prevent or mitigate these risks, where possible. This will help guide utilities as they consider developing strategies and response plans to address the potential impacts of large-scale vegetation changes in their own watersheds.

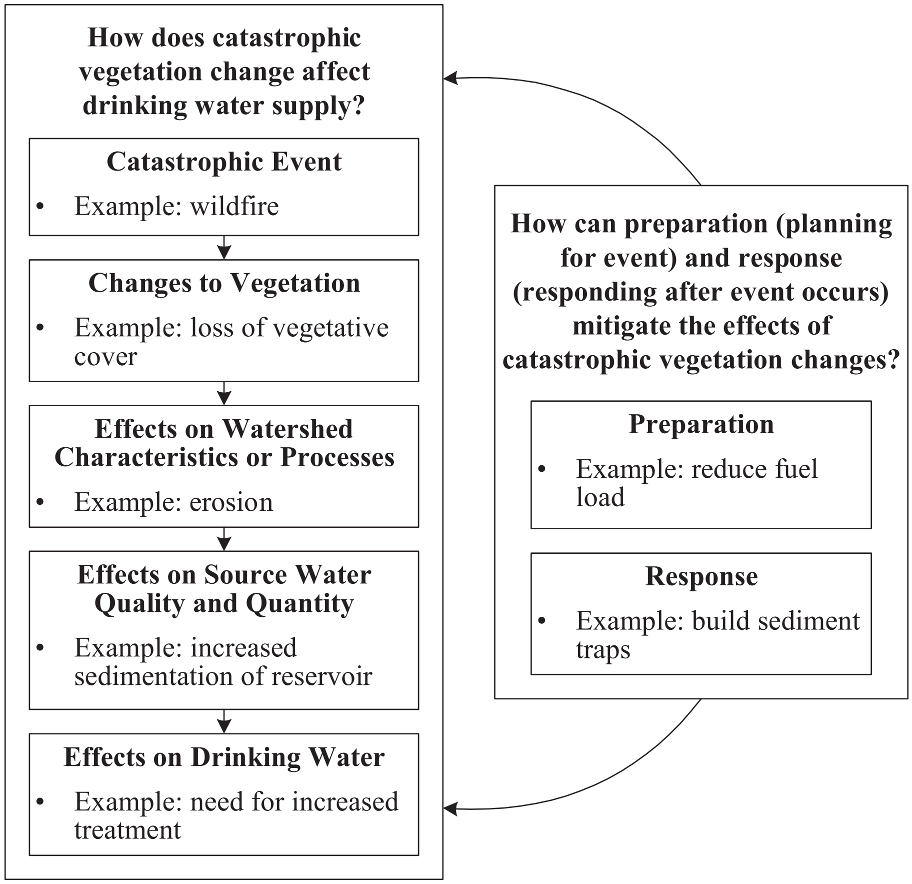


Figure 1.1 Conceptual model to guide project

PROJECT OBJECTIVES

Most water utilities lack the information needed to make cost-effective and environmentally sound decisions about the best response to large-scale vegetation change in their watersheds—a problem for which there is no "one size fits all" solution. Utilities face different risks depending on the ecological and sociological characteristics of their watersheds and on their own systems for collecting, storing, treating, and distributing water. A utility in a sparsely developed forested area might face a high risk of wildfire and little risk of urbanization; a utility in a fast-growing coastal region might face a high risk of urbanization as well as a high risk of hurricane or flooding damage. A utility with a filtration exemption from the USEPA faces different risks from a utility with a conventional filtration and treatment system. Thus, utilities need information and tools to help them assess their specific risk to large-scale vegetation change.

Once an assessment of key risks has been made, utilities then need to make decisions about possible responses. These decisions require understanding the key linkages from an initial large-scale event to the ultimate effects on drinking water supply and treatment (Figure 1.1). Utilities also need to understand the variety of strategies that can include preparation or prevention strategies to reduce the risk of large-scale events occurring or reduce the size or scope of these events and response strategies to reduce the watershed impacts that can occur following vegetation changes, or protect collected source water or treatment processes from impacts. Understanding the costs and benefits of a wide range of strategies is important because the specific circumstances faced by a utility will determine which strategies are feasible or cost-effective. Clearly, a utility that does not own any of its watershed land faces a different set of choices from a utility with sole control over its watershed.

The objective of this project is to provide utilities with the information and tools they need to plan for and respond to large-scale vegetation change in their watershed. Specifically, the authors seek to (1) help utilities better assess the risks they face with respect to large-scale vegetation change in their watershed; (2) provide specific information on the changes in water quality and water quantity that can occur after different events (e.g., fire, storm, urbanization); (3) provide information on potential preparation and response strategies that can either help reduce the risk of large-scale vegetation change or mitigate the impacts of these changes; and (4) provide a series of case studies to document utility experiences and "lessons learned." Ideally, utilities will use this information to develop and implement a comprehensive and forward-looking plan to respond to large-scale vegetation change in their watershed. This type of plan would help minimize the risk that large-scale vegetation change would lead to disruptions in water supply or costly additional water treatment.

CHALLENGES FACED BY UTILITIES THREATENED BY LARGE-SCALE VEGETATION CHANGE

Utilities threatened by catastrophic or large-scale vegetation change in their watersheds face a variety of potential challenges to source water quantity and quality. One major risk results from different events that can increase erosion in a watershed and cause increased turbidity of source water. Water with high turbidity can have significant detrimental impacts on treatment processes. Slow sand filtration beds, for example, can be clogged by source water with a high clay content. Conventional coagulation and flocculation treatment also can be disrupted by source water with high turbidity, requiring additional chemical additions and coagulation time to achieve desired end-points (Crittendon et al. 2005). After major fire and storm events, impacts to water quality from increased sediment loads can occur within hours and persist for more than a decade (Wondzell and King 2003). Large-scale vegetation change can cause other changes to source water quality, including increases in contaminants such as cyanide, hydrocarbons, manganese, fertilizers, pesticides, and salt that can all either increase needs for water treatment or have negative impacts on the quality of finished water.

Large-scale vegetation change can impact the quantity and timing of water availability. The total volume of water obtained from a watershed can increase if vegetation cover is removed. However, this decrease in vegetation cover can lead to increased "flashiness" in streams, with larger and faster stream-flows following rainfall or snowmelt events. These changes can make capturing and storing water more difficult or require larger reservoirs. In contrast, the replacement of native vegetation by non-natives sometimes can result in decreased water yields if the invaders have higher biomass and transpiration rates than the native species (van Wilgen, Cowling, and Burgers 1996).

The challenges faced by water utilities from large-scale vegetation change will depend as much on the specifics of their water collection, storage, and treatment systems, as on the nature of the vegetation change itself. Thus comprehensive planning for large-scale vegetation change needs to take into account the specifics of each water utility's situation.

WHY PREPARATION AND RESPONSE STRATEGIES CAN BENEFIT WATER UTILITIES

To minimize the negative impacts of catastrophic events on drinking water quantity and quality, utilities and other stakeholders can respond with a variety of strategies. The best strategies will take into account factors such as the speed at which the triggering event occurs, the predictability and likelihood of an event, and the magnitude of the immediate and cumulative impact to water supply and treatment needs. Based on this analysis, a utility can evaluate which kinds of preparation or response strategies will be environmentally appropriate and cost-effective.

In some cases, preparation can involve implementing prevention strategies that can greatly reduce the risk that a trigger event will occur or that it will cause large-scale vegetation change. Appropriate watershed management techniques, for example, may be able to reduce the risk of wildfire or invasive species to a sufficient extent that the impacts from such an event on vegetation cover would be relatively minor. The impacts of land conversion can be reduced through various land management strategies in watershed areas, including land purchase, partnerships with local communities, and conservation easements.

When large-scale events cannot be prevented, the risk to drinking water supplies from these events sometimes can be mitigated with actions appropriate for particular risks in particular watersheds. Maintenance of natural buffer areas around reservoirs is an example of a mitigation activity that can reduce the impact of land use change (such as timber harvest or urbanization) in other parts of the watershed (NALGEP, TPL, and ERG 2003).

Finally, management actions can form the basis of a response strategy that seeks to minimize the financial impact of changes in source water quality or quantity resulting from large-scale vegetation change. For example, a utility may bypass a slow-sand filtration bed in response to temporary high turbidity events. Or a utility that has multiple sources of water supply (such as well fields in addition to surface water) may increase the use of an alternate water supply during a time when diminished raw water quality would increase the cost of water treatment. Water restriction plans also can diminish the demands on a utility during a time when the treatment system is under stress.

SUMMARY OF THE PROJECT APPROACH

The overall approach to this project consisted of two key components: a literature search and utility interviews and case studies. The literature search and data review was undertaken to understand the current state of knowledge of the impacts of trigger events on (1) large-scale vegetation change, (2) changes in source water quality and quantity, and (3) water treatment. A series of utility interviews then formed the basis for case studies that explored the experience of individual utilities with respect to the challenges they have faced or expect to face in the future from large-scale vegetation change. Information from the literature search and the interviews was then synthesized to provide a comprehensive picture of the specific impacts of different trigger events on source water quality and quantity and water treatment processes.

STRUCTURE OF THIS RESEARCH REPORT

This report is designed to provide utilities with a resource document they can use to help develop and implement cost-effective preparation and response strategies to cope with the risk of large-scale vegetation change. Chapter 2 describes the implications of changes in watershed vegetation for drinking water treatment. Chapters 3 through 10 are organized by the different events (wildfire, timber harvest and logging roads, storms, urbanization, insect pests and pathogens, invasive plant species, agriculture, and drought). Each chapter provides an overview of the event, its impacts on source water quality and quantity, the implications of these changes for water treatment and water supply, and management actions that can prevent or minimize harm. Chapter 11 presents conclusions, including a summary table that links events, the vegetation and soil changes that occur, the effects of these changes on watershed processes and source waters, the implications for treatment, and examples of preparation/prevention strategies and response strategies. Chapter 12 provides a concise list of recommendations to utilities.

The experiences of water utilities that are summarized throughout chapters 3 through 10 are further supported in Appendix A by individual case study "vignettes" that summarize utility interviews and describe how utilities have faced impacts from large-scale vegetation change and adopted different types of preparation and response strategies. Appendix B provides a guide to on-line resources that can help utilities assess their risk to different large-scale events. Finally, an electronic bibliography attached to this report provides additional resources for utilities wanting to do additional research on this topic.

CHAPTER 2
IMPLICATIONS OF CHANGES IN WATERSHED SOILS AND VEGETATION FOR DRINKING WATER TREATMENT

Whenever substantial changes in watershed soils and vegetation occur, there can be profound implications for drinking water treatment plants that depend on surface waters. There are many scenarios of soil and vegetative change and an equally large number of water treatment issues associated with each type of change. There are nonetheless some common themes which can provide a framework for taking inventory of the specific effects of watershed disturbance processes and possible countermeasures, as well as a means of identifying the consequences at a water treatment plant. These common themes are presented and discussed in this chapter.

Much of the literature reviewed in the development of this report reflects a communications gap between the knowledge of watershed processes and the knowledge of water treatment processes. The framework described in this chapter is intended to close that gap by connecting watershed disturbance processes to the implications for water treatment in a manner that can then be used as a template to evaluate any scenario of vegetative change.

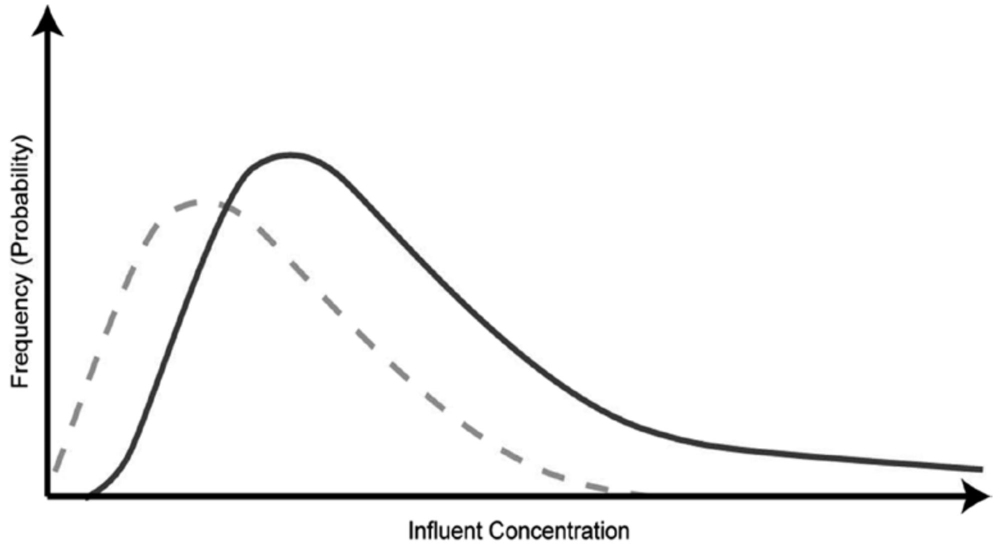
THE INFLUENT CHALLENGE

The central objective of a drinking water treatment plant is the production of high quality potable water—on a reliable basis. Reliability is essential because public health and critical community services are at stake. A high degree of reliability is achieved in drinking water treatment by applying the principles and practices of industrial process control. Treatment processes are designed and operated in a manner that accommodates a given degree of variability in the physical, chemical, and microbiological parameters of the influent water entering the plant and produces finished water that is within a narrow range of tolerance for the same physical, chemical, and microbiological parameters as well as for byproducts of disinfection that result from interactions during treatment. This ability to systematically and sustainably suppress the variability of key parameters is referred to as "meeting the influent challenge to the plant" (see Figure 2.1).

In a nutshell, watershed vegetation helps to dampen and stabilize the variability of key physical, chemical, and microbiological water quality parameters in the surface waters from which drinking water treatment plant influents are drawn. Disturbances in watershed soils and vegetation can shift or amplify the variability of these parameters. If such changes produce a degree of variability that is outside the range for which the plant was designed, "the influent challenge" must be met with either significantly modified operating practices or redesign of facilities.

MEETING THE INFLUENT CHALLENGE

Filtration and disinfection are well established practices that have been at the heart of surface water treatment for the last century. However, both filtration and disinfection can be applied along a gradient of intensity, sophistication, and expense according to the degree of influent challenge that is to be met. At one extreme, watersheds such as those serving San Francisco, Portland (Ore.), New York City, and Boston are in such pristine condition that filtration facilities have not been required and strong disinfectants such as free chlorine and ozone provide adequate treatment. At the other extreme, there are many more cities drawing supplies from rivers that require extensive



Disturbances of watershed vegetation and soils can increase the variability of influent water quality parameters (from dashed to solid line, above). This presents greater technological and operational challenges to drinking water treatment plants.

Figure 2.1 Watershed disturbance and influent concentrations

chemical and physical treatment (coagulation-flocculation-sedimentation) even before the filtration step. This "pretreatment" combination is so prevalent it is called "conventional treatment."

Chemical and physical pretreatment (i.e., treatment applied before filtration) is the primary mechanism by which the challenge posed by the variability of surface water supplies is met. Determining the best type of pretreatment, filtration technology, and disinfection is unique to the nature of the influent challenge at each location. For example, there are many "direct filtration" water treatment plants that face influent challenges lying between the above-described extremes. The level of pretreatment is not as great as in plants employing full "conventional treatment." "Lime softening" plants, on the other hand, provide a high degree of pretreatment similar to "conventional treatment" plants but also include additional steps to reduce the hardness of the water in areas where it is naturally elevated.

The chemical and physical pretreatment processes employed before filtration are designed to achieve multiple water treatment objectives. A primary objective is the removal of suspended solids which is measured as the turbidity of the water. This involves the removal of two types of suspended solids—those that will settle out of suspension and those that will not because they are colloidal particles held in suspension by electrical charges. Common colloidal particles include color compounds, clays, decaying organic matter, and micro-organisms. Chemical coagulants—aluminum and iron salts, and synthetic polymers—are used to destabilize the electrical forces sustaining the colloidal suspension (coagulation), enabling the particles to agglomerate (flocculation) and form a mass that can be removed (sedimentation) prior to filtration.

A paradigm shift has occurred in pretreatment over the course of the last decade. The objectives of chemical and physical pretreatment have been broadened considerably beyond turbidity removal to encompass the minimization of disinfection byproduct formation. When water is disinfected, some portion of the chlorine used combines with natural organic compounds to form chlorinated organics that are the source of a variety of health concerns governed by new Safe Drinking Water Act (SDWA) regulations. Previously, chlorine had been introduced early in the pretreatment process in order to ensure adequate disinfection. Chlorine also served other purposes as an oxidizing agent to condition other types of impurities for further treatment and removal. However, the new paradigm emphasizes optimization of coagulation processes for the removal of organic carbon to the greatest extent possible before application of chlorine.

As a result of these complications, "meeting the influent challenge" has become a much more complex optimization problem. The chemistry and physics of the pretreatment process have been raised to a much higher art form that must address all the natural variability pertaining to the multiple objectives of removing both turbidity and organic carbon while still providing adequate disinfection.

Fortunately, the chemical and physical pretreatment processes at many water treatment plants are quite robust and capable of meeting a substantial degree of variability in influent conditions. Prior Water Research Foundation research (Pyke et al. 2003) has shown that increases in the levels of suspended solids and natural organic matter can be met with increased coagulant dosages, albeit at increased operating expense.

Ultimately, however, there are limits to how much variability pretreatment processes can absorb. Conventional treatment or lime softening plants that have some operating flexibility via pretreatment may still be forced to consider expensive changes such as alternative disinfection methods due to conflicts between competing objectives when attempting to re-optimize an existing plant to simultaneously control turbidity, microbial contamination, and disinfection byproducts in the increasingly complex regulatory environment. In extremely constrained circumstances, advanced processes such as activated carbon or membrane filtration may be required.

Plants with limited operating flexibility that are suddenly confronted with adverse changes in watershed conditions may face significant capital expenses to undertake multiple modifications. Consequences of adverse watershed disturbances may be most significant for the numerous water supplies that employ various forms of "direct filtration" systems which are designed to use much more limited pretreatment processes on naturally low turbidity waters. In these circumstances, related influent conditions such as low alkalinity may be ill-suited to enhanced pretreatment. The only solution may be to add expensive advanced treatment processes such as membranes after filtration.

Unfiltered water systems are the most vulnerable to watershed disturbances since they rely on pristine watershed conditions to accomplish many of the same things achieved by treatment processes. Once degradation of the watershed progresses past a certain point, there is no choice but to build a filtration plant at great expense.

The new paradigm in surface water treatment ushered in by recent SDWA rules employs a comprehensive and dynamic approach to establishing disinfection requirements that uses watershed management, source water monitoring, treatment process optimization, and additional margins of safety to provide a robust approach to assess the degree of disinfection required to meet the challenge inherent in the variability of surface waters.

The Long-Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) defines quantitative intervals of additional treatment required as a function of the influent concentration of microbial pathogens in the water. This is accomplished in the "bin classification" system devised as part of the LT2ESWTR Source Water Monitoring Guidance Manual (USEPA 2003b) and further elaborated in the LT2ESWTR Toolbox Guidance Manual (USEPA 2003a). The requirements are summarized in Table 2.1. As an alternative to the bin classification that relies on expensive and sophisticated monitoring for *Cryptosporidium*, the LT2ESWTR also allows small water systems

Table 2.1
LT2ESWTR bin classification system

Influent *Cryptosporidium* concentration [# cysts per liter (L)] based on running annual average of monthly or bimonthly samples	Bin classification	Additional treatment required (# of logs of reduction in influent cyst concentration)
< 0.075	1	None
≥ 0.075 and < 1.0	2	1 to 1.5
≥ 1.0 and < 3.0	3	2 to 2.5
≥ 3.0	4	2.5 to 3

Source: Derived from material in USEPA (2003b).

to use *E. coli* data as a substitute. Under that approach, systems are classified in Bin 1 if average annual *E. coli* are less than 50 per 100 milliliters (mL).

In summary, there is some capacity to meet the influent challenge through operating flexibility. But when that capacity is exceeded, much more expensive responses are required involving potentially significant capital expenditures to enhance filtration, disinfection, and disinfection byproduct control. Possible triggers for major process changes include changes in the following parameters that could result from dramatic changes in watershed conditions:

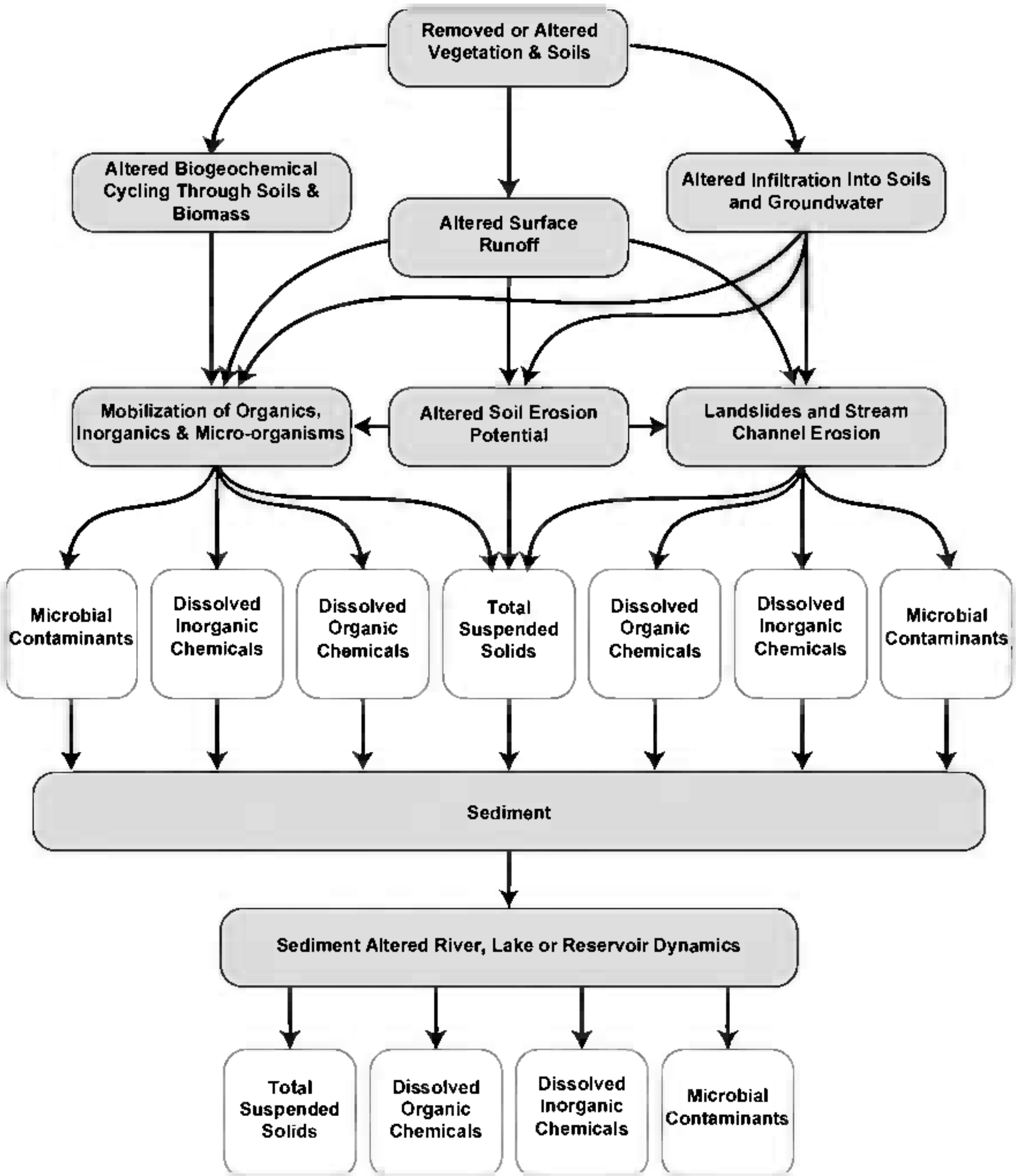
- The nature and quantity of suspended solids
- The nature and quantity of total organic carbon (TOC)
- The level of microbial contamination

Significant and sustained changes in these parameters could render the existing treatment plant design inadequate, requiring additional pretreatment processes, different filtration technologies, alternative disinfectants, advanced technologies (e.g., activated carbon, membranes), or all of the above.

Beyond the above-described influences on the influent challenge to water treatment plants, there is also the potential for watershed changes to increase concentrations of specific organic and inorganic contaminants that pose threats to public health such as pesticides, herbicides, other synthetic organic compounds, fertilizers, minerals, and heavy metals. These may require capital and operating expenditures to provide additional advanced treatment processes such as activated carbon, ion exchange, activated alumina, and membrane treatment.

CHARACTERIZING CHANGES IN THE INFLUENT CHALLENGE RESULTING FROM CHANGES IN VEGETATION AND SOILS

Figure 2.2 presents a generalized cause-effect flow diagram depicting the processes through which changes in watershed vegetation and soils can produce changes in the influent challenge to downstream water treatment plants. The numerous impact pathways converge on several general categories of water quality parameters—suspended solids, dissolved organic chemicals, dissolved inorganic chemicals, and microbial contaminants. The diagram and its description are intended to provide a guide for characterizing the impacts of individual scenarios of vegetative change.



Changes in watershed vegetation affect various ecological processes, including biogeochemical cycling, surface water runoff and groundwater recharge. These effects influence the mobilization of potential contaminants as well as soil movement, which alters the amount of total suspended solids and other contaminants found in surface waters. Contaminants can also be deposited into river, lake or reservoir sediments, from which they might be re-mobilized if sediments are re-suspended.

Figure 2.2 Impacts of soil and vegetation change on water quality parameters

Changes in Vegetation and Soils

The scenarios considered in this report involve either sudden or gradual changes in the nature of the vegetation and soils within a watershed. Whether the event under study is a raging wildfire or the steady, year-over-year encroachment of urbanization, the overall question to be examined is how runoff into surface waters from the new land condition will differ from that produced by the pre-existing land condition.

Wildfires, storms, or pest infestations can produce dramatic and immediate changes to influent water that can result in significant short-term challenges to water treatment as well as long-term impacts. In contrast, increases in urbanization, logging, agriculture, or grazing over the long-term will produce more gradual effects on influent water.

In all instances, changes in vegetative cover and soil properties can influence the manner in which water moves through a watershed. These changes in vegetation and soils affect the timing and amount of water that infiltrates into the ground, flows over land, or is evaporated or transpired. Together, these hydrologic processes determine the timing and quantity of water flow in streams and rivers. In addition, changes in hydrology and erosional processes associated with watershed changes lead to corresponding changes in the downstream transport of the organic matter and inorganic and organic chemicals that eventually become a part of the influent challenge at downstream water treatment facilities.

Altered Surface Runoff

Altered surface runoff is probably the single most obvious change brought about by alteration of soil properties or vegetative cover after large-scale watershed events. In general, decreases in vegetative cover resulting from different watershed events will increase the volume and velocity of surface runoff and increase the amount of sediment transported in that runoff. Runoff increases when vegetative cover is lost because a substantial portion of rain and snow is intercepted by vegetation. Interception is highest in forests compared to grasslands and in coniferous forests compared to hardwood forests (Swanson et al. 2000). In Massachusetts, 20–30% of rain and snow is estimated to be intercepted by the forest canopy (Massachusetts Department of Conservation and Recreation 2007); similar interception rates (22%) were measured in a Pacific Northwest redwood forest (Reid and Lewis 2007). The loss of overstory vegetation means that more rain and snow will reach the ground directly, resulting in an increase in surface runoff. In addition, understory vegetation and organic materials, such as duff on the forest floor, provide important interception of rainfall before it reaches the ground surface. This greatly reduces the "splash erosion" that results from the direct impact of raindrops on the soil surface. Loss of understory vegetation and organic materials can therefore increase erosion rates substantially, even when overstory vegetation remains intact.

In addition, direct changes to soils, such as increased water repellency ("hydrophobicity"), can result from watershed events such as fire. These soil changes can magnify the impacts of vegetation loss by decreasing water absorption into soils and increasing surface runoff and erosion (Schultz et al. 1992).

Over the long-term, losses of vegetation and their accompanying root systems can lead to substantial increases in erosion resulting from surface runoff. Root systems hold soils together against erosive forces, while decaying organic matter from plant materials contributes to soil structure and strength. Their removal results in increased runoff and erosion in a watershed.

Altered Biogeochemical Cycling

Most chemicals are somewhat water soluble, and therefore hydrology plays an important role in nutrient cycling and the transport of contaminants adsorbed to sediments carried in runoff (Swanson et al. 2000). These processes are strongly influenced by large-scale alterations to the type and extent of watershed vegetative cover. Vegetation and soils provide natural stores of organic and inorganic chemicals. When vegetation is suddenly removed, as in the case of wildfire, storm events, pest infestations, and logging operations, these chemicals may be washed away or become adsorbed to sediments eroded from the bare soil surface. Nutrients are recycled by the decomposition and leaching of plant tissues, and therefore the more vegetation that is damaged and dies, the greater the likelihood of nutrient release from a watershed (Swanson et al. 2000). In addition, when vegetation is lost, the uptake of nutrients and other chemicals from the soils decreases substantially. The combination of increased release from soils and decreased uptake from vegetation can lead to sharp increases in the concentrations of nutrients and contaminants in influent waters. In addition, the chemical nature of the organic plant material that is carried downstream as either suspended or dissolved organic carbon can pose a potential challenge to downstream water treatment plants.

When vegetative cover is gradually converted from one type to another, such as replacement of cropland by suburban development, the quantity of sediments, nutrients, and other chemicals in runoff may also change. For example, agricultural chemicals such as herbicides and pesticides may decrease while petroleum-derived compounds, such as polycyclic aromatic hydrocarbons (PAHs), may increase as a result of urbanization.

Altered Infiltration Into Soils and Groundwater

The chemical and physical properties of soils, including texture, structure, organic matter content, nutrients, and acidity [typically measured on a potential of hydrogen (pH) scale], determine the soil's susceptibility to erosion (erodibility) and the soil's ability to grow plants and transmit water. The presence of vegetation and organic materials at the soil surface slows runoff, favoring infiltration and ponding versus overland flow and erosion. More runoff infiltrates soils with high organic matter content. Plant root systems and decaying plant materials within soils also promote infiltration. Removal or alteration of these beneficial features can reduce infiltration, causing soils to become saturated more quickly, and generating more runoff and erosion (Swanson et al. 2000).

Infiltration of water into soils can be affected directly by changes in soil properties. Erosion of fine particles can block pore spaces in soil and decrease infiltration rates. The heat of an extreme event also can dry soil to such an extent that it repels water (becomes "hydrophobic"). The "non-wettability" of soil caused by drying can last for a few weeks after fire. Burned vegetation also can leach chemicals that can make soils more hydrophobic and decrease infiltration rates (Schultz et al. 1992).

Mobilization of Organic Matter, Organic and Inorganic Chemicals, and Micro-organisms

When vegetative changes affect biogeochemical cycles in a manner that increases the physical and chemical availability of materials, there is an increased potential that they will be transported downstream dissolved in water or adsorbed to sediments, especially if there are simultaneous increases in surface runoff and soil erosion and decreases in uptake by vegetation. Some materials may be carried away as suspended solids while others may be dissolved and carried away in solution.

Altered Soil Erosion Potential

Changes in vegetative cover change the nature of the underlying soils because of the close connections between vegetation and soils. This is true regardless of whether the change involves a drastic removal of vegetation or the replacement of one type of land cover with another. For example, the type and quantity of organic matter in soil depends heavily on the overlying vegetation, which determines the kind and amount of leaf litter that gets incorporated into the soils as well as sources of belowground carbon such as roots. Changes in vegetative cover that result in decreased levels of organic matter in soil can increase erosion potential. Increased erosion potential not only increases the level of suspended solids appearing in surface waters downstream, but there is also potential to change the nature of the particles (e.g., introducing clays that are more difficult to remove in water treatment plants).

Landslides and Stream Channel Erosion

Some of the most significant impacts of vegetative change scenarios result from the cumulative effects of increased erosion potential at a larger scale. Often the soils that are most easily destabilized by vegetative change are the same ones that were unstable in the first place—such as clay materials that play a major role in landslides, mudslides, and other earth movements. For example, the steep slopes of the Pacific Northwest, already prone to landslides, are at increased risk for shallow and rapid landslides after timber harvesting (Robison et al. 1999). Even apparently stable and inactive slopes can be subject to massive erosion events following an intense fire or other large-scale event (Schultz et al. 1992). Sediment deposits from landslides have been responsible for increased levels of suspended solids continuing for many years after the initial event because they mobilize sources of sediment that were previously geologically bound.

A similar impact has been attributed to increases in stream channel erosion resulting from increased runoff and erosion following a major change in land cover. Subsequent continuation of stream channel erosion can also mobilize sediment deposits that had previously been geologically sequestered, yielding long-term increases in suspended solids. In addition, materials released from geological storage may produce different types of suspended particles, such as clays, that present a more difficult challenge to treatment plants.

Sediment-Altered River, Lake, or Reservoir Dynamics

Sediment produced by all of the above-described erosive forces can also cause direct physical damage to water supply facilities by accumulating in river channels, lakes, and reservoirs in a manner that requires expenditures for its physical removal. The effect of sediment deposits on the morphology of lakes and reservoirs can also help to induce eutrophic conditions that further increase the challenge and cost of water treatment. Nutrients carried with sediments may further exacerbate this problem. The main nutrients affecting ecological processes in surface waters are nitrogen (primarily as nitrate) and phosphorus (primarily as phosphate). Excess concentrations of these nutrients in lakes and reservoirs may result in algal blooms, increasing turbidity and biological oxygen demand (BOD).

RESPONDING TO CHANGES IN THE INFLUENT CHALLENGE

The water quality impacts of vegetative change converge into several categories of contaminants that have significance for water treatment. Table 2.2 summarizes these relationships at the most generic level to provide a template for evaluating and mitigating specific impacts of vegetative change.

By far the most common implication for water treatment will be a need for increased coagulant dosages. In addition to removing suspended solids and reducing the level of organic carbon in the water, the coagulation and filtration processes will reduce all types of contaminants to some extent due to the fact that many of them may be chemically or physically bound to suspended particles.

Increased coagulant dosages produce increased operating costs (Pyke et al. 2003). While not trivial, these increased operating costs are small by comparison to all of the other treatment implications listed in Table 2.2 that involve much more significant capital costs.

When the existing treatment process is incapable of meeting a change in the influent challenge with improved coagulation, a plant may need upgrade or replacement, or supplementation with advanced removal processes. For example, a direct filtration plant designed to treat low turbidity water with limited chemical pretreatment may have to be modified or replaced if significantly greater coagulation is required. Alternatively, it may be possible to enhance the performance of an existing plant by supplementing the existing treatment with membrane technology. These solutions involve significant capital expenditure. There is, therefore, a strong incentive to avoid such changes if possible. Direct filtration plants exist on watersheds that were probably fairly well-protected by vegetative cover when they were initially built. The potential to mitigate impacts of vegetative change in such watersheds is therefore very important.

It has been asserted that cost-effectiveness of mitigation measures is much greater in smaller watersheds than in larger ones (Pyke et al. 2003). That is probably too simple a generalization, however, since the cost of mitigation is more precisely a function of the size of the area that requires mitigation, which may not encompass the entire watershed. As described in subsequent chapters, many of the most logical mitigation measures involve control of surface runoff and erosion in order to limit impacts of increased suspended solids and sedimentation downstream. These measures can have the effect of reducing the need for increased coagulation and, like coagulation, they will also reduce the levels of other contaminants that are being carried along.

The most challenging impacts of vegetative change might result when the effect is not only to increase the amount of turbidity in the water but to also change the nature of the particles. The release of clays and fines from road cuts, landslides, and stream channel erosion can be more difficult to overcome even with increased coagulation. Similarly, vegetative changes can cause a change in the chemical composition of the dissolved organic carbon in the runoff from a watershed, reducing the effectiveness of coagulation and altering the formation of disinfection byproducts. In such circumstances, advanced treatment systems employing activated carbon or membranes may be required to remove organic carbon and meet disinfection byproduct standards. Additionally, changes in disinfectant use could be needed.

In addition to the increased difficulties of meeting standards for turbidity, disinfection and disinfection byproducts, vegetation, and soil changes can result in the release of other organic and inorganic chemical contaminants that may require expensive advanced treatment processes such as activated carbon, ion exchange, activated alumina, or reverse osmosis.

Table 2.2
Water quality impacts of soil and vegetative changes and possible implications for water treatment

		Organics			Inorganics	
	Suspended solids	TOC	Synthetic chemicals	Nutrients (nitrogen and phosphorus)	Minerals and metals	Microbial contaminants
Water quality impacts of soil and vegetative change	• Increased levels of total suspended solids (TSS) • Changes in types of suspended particles • Sediment deposition	• Change in level of TOC • Changes in type of TOC	• Release of pesticide and herbicides from vegetation and soils	• Changes in nutrient retention in vegetation and soils • Increased nitrate and ammonia	• Release of minerals and metals from vegetation and soils and sediments	• Altered habitat for animal populations; can affect coliform, giardia, etc. • Release of pathogens from soil and sediments
Possible water treatment implications	• Increased coagulant dosages • Membranes • Plant overhaul or upgrade • River, lake, or reservoir dredging	• Increased coagulant dosages • Activated carbon • Membranes	• Activated carbon	• Ion exchange for nitrate removal • Algae removal due to eutrophication	• Ion exchange • Activated alumina • Reverse osmosis	• Increased disinfectant dosages • Alternative disinfectants (e.g., ozone)

CHAPTER 3
WILDFIRE

Wildfire can have a dramatic impact on a watershed and drinking water supplies. In just a few hours, a mature forest with clear, high-quality streamflow can turn into a blazing inferno. After the fire is put out, charred hillsides are vulnerable to erosion and mudslides that fill up streams with ash, silt, and mud. Water utility managers must suddenly cope with a dramatic change in the quality of their source water that impacts all of their treatment processes and results in significant additional costs. Utilities that have planned for these events, however, may be able to put into place emergency management strategies that can minimize the impact to treatment and the risk of financial harm.

EFFECTS ON VEGETATION AND SOILS

In locations where fire is a necessary part of the ecology of a watershed (e.g., Agee 1993), the absence of fire can have negative impacts on vegetation health and on source water quality and quantity. However, severe fires that burn large areas at high intensity can devastate vegetation and source waters. Unfortunately, decades of fire suppression in many areas have degraded vegetation because of the lack of fire, and also increased the risk of catastrophic fire in these same locations.

Wildfire can destroy both the overstory vegetation and ground cover (i.e., duff, grasses, and other understory plants) and expose bare mineral soil to overland flow (Robichaud 2000). If a fire eliminates most or all of the vegetative cover in an area, interception of precipitation will decrease and there may be flooding during subsequent storms, resulting in erosion and sedimentation of downstream waters (see Box 3.1) (Pierson, Robichaud, and Spaeth 2001; Pierson, Spaeth, and Carlson 2001; Veenhuis 2002; Driscoll, Carter, and Ohlen 2004; Murphy et al. 2006; Ravi et al. 2006; Robichaud and Elliot 2006).

Watershed responses to fire depend on fire severity and frequency. Factors that influence these characteristics include the quality and quantity of fuels, soil properties, watershed topography, climate, and weather. The amount of vegetative cover that is lost and litter on the forest floor are directly proportional to fire severity (Elliot 2006).

Factors That Influence Fire Severity

The severity of a wildfire, defined as the impact a fire has on soils, vegetation, watershed condition, and structures, is generally a function of the size and intensity of a fire. Fire size is a measure of how large an area is burned by a fire. Fire intensity is a measure of the "heat dose" of a fire—how hot a fire burns combined with the length of time that a fire burns in a particular location (Gurevitch, Scheiner, and Fox 2002). The most significant effects result from the highest intensity fires, which often occur after long periods of fire suppression. These high intensity fires may severely alter the ecosystem and hydrology in the burned area. Factors that affect the size and intensity of a fire include the following:

- **Type and condition of vegetation** control how much fuel is available for the fire to burn. Greater amounts of dead or dry vegetation in an area mean that more fuel is available to carry the fire. Dead grass burns quickly and easily but will not sustain a

Box 3.1 Water quality implications of wildfires in residential areas

In late October 2007, a series of wildfires swept across Southern California, destroying more than 500,000 hectares (1,235,527 acres) of land and more than 1,500 homes (Figure 3.1). These fires bring the typical suite of risks associated with wildfire—dramatic increases in surface runoff and sedimentation. However, wildfires that affect residential areas likely have additional risks associated with them, which are just beginning to be understood.

To better understand the potential adverse affects of fire in wildlands and residential areas, the U.S. Geological Survey (USGS) sampled surface ash and soils from 28 different sites in Southern California wildfire areas (Plumlee et al. 2007). Much of the analysis associated with these samples is still being conducted, but a preliminary report suggests that residential ash is extremely high in alkalinity (i.e., ash pH ranged from 12.5 to 12.7) (Plumlee et al. 2007). This contrasts with wildland ash samples, which had milder pH levels (ranging from 9.8 to 10.9). The caustic alkalinity in surface ash in residential areas might be transferred to surface waters through surface runoff after rains.

In addition, fires in residential areas were found to have elevated levels of a variety of metals, including arsenic, lead, antimony, copper, and zinc (Plumlee et al. 2007). While preliminary tests suggest that these metals are not very soluble in their current form, further tests are needed. If washed into surface waters and sediments, these metals may be suspended in water, posing a water quality problem. Furthermore, various studies suggest that household fires may release other toxins, including dioxin and volatile organic compounds (Ruokojarvi, Aatamila, and Ruuskanen 2000; Austin et al. 2001; Carroll 2001). While these studies focused on small-scale fires, which are unlikely to affect water quality, large-scale fires that consume many households may release dangerous levels of these chemicals to rivers and reservoirs. More research needs to be done to better characterize the risks that large-scale residential fires pose to water resources.

Source: NASA 2007.

Figure 3.1 NASA satellite image of the southern California fires taken on October 25, 2007. Red areas indicate active fires.

fire for very long. Large trees can be hard to ignite but can burn for weeks. Vegetation of multiple heights can provide a fuel "ladder" that can carry a ground fire into the crowns of trees.

- **Weather conditions** during a fire play an important role in determining the size and speed of a fire as well as affecting the probability that a fire occurs at all. Weather conditions control the moisture content of the fuel and can promote fire spread through wind. Hot, dry, windy conditions increase the size and intensity of a fire, while cool and wet conditions can extinguish a fire or limit its spread. Fires ignited in multiple locations by lightning strikes may increase in size and intensity faster than fires ignited in a single location.
- **Past fire history** also controls the availability of fuel. An area that has burned recently will have less fuel available for a new fire.
- **Surrounding land use** affects fire spread in a landscape. Roads and developed areas can form effective barriers to the spread of small fires, although large fires can jump highways and burn houses and developments.
- **Fire management policies** affect the type and degree of fire suppression efforts. Some areas are targeted for a "let burn" policy, while other areas, especially those with an extensive urban-wildland interface, will receive intense suppression efforts.
- **Fire suppression resources** influence how well fire management policies can be implemented. For example, although an area may have an aggressive fire-suppression policy in place, it could lack the financial and personnel resources needed to carry out that policy, especially in situations where multiple large wildfires happen simultaneously across a region.

Factors Affecting the Frequency of Wildfire

The frequency of fire is affected by regional differences in vegetation type, landscape, and climate. Fire frequency is generally measured as a "fire return interval," which is the length of time between fires. Fire return intervals are ecosystem-dependent, with some systems evolving with frequent fire and others with very infrequent fire. Fire frequency has implications for fire severity and therefore, the extent of disturbance an ecosystem typically experiences after fire. Fire severity is generally much lower when fires occur frequently.

Understanding the expected fire return interval for a particular watershed can help utility and watershed managers determine the potential need for fire suppression as a management practice. In locations where fire suppression practices have reduced fires below the expected return interval, watershed managers can expect increased fuel loads and shifts in vegetation composition. These vegetation changes increase the risk of severe fires that can remove all vegetation, leaving the land vulnerable to significant increases in erosion (Kilfore and Taylor 1979; USGS 1998; Glitzenstein, Streng, and Wade 2003; Hastings, Smith, and Jacobs 2003; Robichaud 2005; Colorado State Forest Service 2007).

The fire return interval depends on the community structure of a specific ecosystem and on the temporal variability in climate. For example, natural fires are rare or absent in coastal forests in the Pacific Northwest because cool, wet conditions prevent the spread of fire and the occurrence of lightning is lower than in other locations more prone to fire, such as the Southwestern United States (U.S.). Natural fires are also rare or absent in southwestern deserts despite hot, dry conditions because sparse vegetation prevents fire spread. In contrast, fire return intervals are short

Table 3.1
Natural fire return interval and intensity for various regions and ecosystems within North America

Region/ecosystem	Fire return interval	Intensity
Eastern deciduous forest (wetter regions)	Natural fires rare or absent	—
Eastern deciduous forest	Approximately 25 years	Low
Southeastern pine forest	1–25 years	Low
	200–1,000 years	High
Florida Everglades (sawgrass prairie)	1–25 years	Low
	200–1,000 years	High
Boreal forest	25–100 years	High
Prairie (Nebraska, Oklahoma)	1–25 years	Low
	200–1,000 years	High
Great Lakes pine and boreal forest	25 years	Intermediate-high (surface fires)
	100–300 years	High (crown fires)
Rocky Mountain forests (lower elevations)	25 years	Intermediate (surface fires)
	100–300 years	High (crown fires)
Chaparral (Texas to California)	25–100 years	Intermediate
Montane meadows (Rockies and Sierras)	Approximately 25 years	Low
Southwest pinyon-juniper woodland	Approximately 25 years	Low
Western forest (high elevation)	25–100 years	High
Sierra mixed coniferous forest	1–25 years	Low
	200–1,000 years	High
Pacific Northwest, coastal forest	Natural fires rare or absent	—
Southwest desert	Natural fires rare or absent	—
California, redwood forest	25 years	Intermediate (surface fires)
	100–300 years	High (crown fires)
Western montane pine forest	1–25 years	Low
	200–1,000 years	High
Western mountains subalpine forest	Greater than 100 years	High
Northwestern wet coastal montane forest	Greater than 100 years	High
Hawaiian rainforests	Greater than 100 years	High

Source: Derived from material in Gurevitch, Scheiner, and Fox 2002.

(1–25 years) for prairie ecosystems that are characterized by a buildup of dry grasses, very hot and often dry summers (especially toward the western part of the region), and frequent thunderstorms and lightning strikes.

Table 3.1 illustrates the regional and ecosystem variability in fire return intervals and intensity for broad regions within the continental U.S. (Gurevitch, Scheiner, and Fox 2002). Many ecosystems have different return intervals for fires of different intensities. For example, low intensity ground fires in southeastern pine forests may occur with a return interval of 1–25 years, while a high-intensity crown fire that kills mature trees may occur every 200–1,000 years.

Source: Photo courtesy of Denver Water.

Figure 3.2 Sedimentation damage after the Hayman fire in Colorado

EFFECTS ON WATERSHED PROCESSES

High intensity fires can completely consume organic matter in surface soils, destroying soil structure and decreasing soil permeability. Fires consume organic materials that protect the soil surface and retard runoff, and also create soil water repellency that leads to overland flow. Hotter fires also burn more vegetation and plant residues on the soil surface. All of these effects increase the amount of runoff to surface waters (Pierson 2000) and erosion potential (Megahan and Hornbeck 2000). Fire decreases infiltration rates by breaking apart soil structure, reducing soil porosity, and leaving ash and charcoal residues, which can clog soil pores.

Increases in runoff and stream flow after intense fires are often accompanied by declines in water quality from sedimentation (Figure 3.2), with the worst water quality often observed at highest stream flows (Robichaud et al. 2003; Driscoll, Carter, and Ohlen 2004). For example, in rangelands in the mountains above Boise, Idaho, areas experiencing high intensity fires showed approximately 30% higher runoff rates than those experiencing moderate fires; sediment yield also increased many fold after intense fires (Pierson, Spaeth, and Carlson 2001).

Lower intensity fires, including prescribed fires, tend to have fewer problems with runoff and associated sedimentation problems (Harvey et al. 1989, Baker 1990, McNabb and Swanson 1990). For example, a severe fire in Arizona increased sediment losses by nearly two orders of magnitude over a moderate fire in the same ecosystem (Table 3.2). In California, a wildfire burned over an area in which a prescribed burn had already taken place five years earlier; the prescribed burns were found to produce less sediment than the high-intensity wildfires. This experiment also showed that prescribed burns may reduce the impact of future wildfires (Wohlgemuth 2001). The loss of ground cover and root mass from a low-intensity (or high-intensity) fire can increase erosive potential because raindrops can regain terminal velocity after falling 60 feet from the upper forest canopy and fewer roots are present to stabilize soil on steeper slopes. Thus, a ground cover

Table 3.2
First-year sediment losses after wildfires in conifer forest habitats

Forest type	Fire type	Sediment loss (milligrams per hectare)	Reference
Ponderosa pine, Arizona	Control	0.003	Campbell et al. 1977
	Wildfire	1.3	
Ponderosa pine, Arizona	Wildfire, low	0.003	DeBano, Folliott, and Baker 1996
	Wildfire, moderate	0.02	
	Wildfire, severe	1.6	
Mixed conifer, Arizona	Control	< 0.001	Hendricks and Johnson 1944
	Wildfire, 43% slope	72	
	Wildfire, 66% slope	200	
	Wildfire, 78% slope	370	
Ponderosa pine/Douglas fir, Idaho	Wildfire	9	Noble and Lundeen 1971
Ponderosa pine/Douglas fir, Idaho	Clearcut and wildfire	210	Megahan and Hornbeck 2000
Ponderosa pine/Douglas fir, Oregon	Wildfire, 20% slope	1.1	Robichaud and Brown 2000
	Wildfire, 30% slope	2.2	
	Wildfire, 60% slope	2.5	
Ponderosa pine, Colorado	Wildfire, 25 to 43% slope	8 to 10	Benavides-Solorio 2003

Source: Derived from material in Robichaud et al. 2003.

of plants and young trees is necessary for protecting the soil from rain erosion (Massachusetts Department of Conservation and Recreation 2007).

Rains that immediately follow a fire can have devastating effects on water quality because there has not been sufficient time to allow for revegetation of the disturbed area. If enough time has passed to allow for revegetation, water infiltration will be enhanced and plant transpiration will remove some water before it reaches streams or reservoirs; this will reduce flows as well as effects on water quality. Clearly, the amount of precipitation and the intensity with which the precipitation falls are as important as its timing. Larger rain events are more likely to lead to larger impacts on both surface water quantity and quality. Larger, faster flows allow less water to infiltrate into soils and also carry more sediment and debris into surface waters.

In general, effects of fire scale with the size of the fire (Baker 1990). As fires increase in size, the area covered by impermeable soils increases and the area covered by vegetation decreases; this leads to higher surface runoff and greater volumes of water in proximate rivers, streams, and lakes (McMichael and Hope 2007). Larger fires also increase sedimentation as well as the amount of plant matter left behind to decompose, which may lead to elevated nutrient concentrations after fires.

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

The most important consequences of fire for drinking water are sediment, turbidity, water temperature, and increased nutrients in surface waters (Landsberg and Tiedemann 2000, Elliot 2006). Fire also adversely impacts water quality by heating the soil and killing soil organisms, thereby altering nutrient transformation rates and bioavailability.

Table 3.3
Percent change in pre- and post-fire nutrient, suspended sediment, and average annual mass loadings for the Salt River

Constituent	% change 1 year post-fire	% change 2 years post-fire
Nutrients		
Total organic carbon	4,334%	—
Dissolved organic carbon	470%	-92%
Total phosphorus	1,241%	-100%
Dissolved phosphorus	417%	-96%
Total nitrogen	4,935%	-100%
Ammonia	2,059%	-93%
Nitrate-nitrite	755%	-84%
Other		
Suspended sediment	135%	-42%
Stream discharge	-34%	-18%

Source: Derived from material in Westerhoff, Gill, and Lohman 2005.

Decomposing plant material remaining after a fire can lead to increased nutrient concentrations in streams (Baker 1990). Decomposition of plant material after even low-intensity fires can lead to elevated concentrations of nutrients in nearby waters (Stephens et al. 2004). Although sediment and nutrient loads may increase dramatically for one year, these effects may disappear by the second year post-fire (Table 3.3).

Contaminants commonly mobilized by fire include nutrients such as nitrogen (as nitrate) and phosphorous; metals such as mercury and magnesium; calcium; sulfur; cyanide; and carbon (Caldwell, Canavan, and Bloom 2000; Westerhoff, Gill, and Lohman 2005; Cottingham 2006; Crouch et al. 2006; Murphy et al. 2006). Water quality may also be affected by fluctuations in pH, alkalinity, and the increased presence of organic and inorganic contaminants in streams and reservoirs after a fire (Cottingham 2006).

If a burn becomes too hot, soil organisms can be killed, altering nutrient transformation rates and bioavailability. Nitrogen becomes a concern to water quality when the nitrogen in the soil is converted to the nitrate (NO_3^-) form. Nitrate is very mobile and is easily transported in water. It is mostly a concern for groundwater, but nitrate can also enter surface waters. Phosphorous, nitrogen, and carbon in reservoirs can lead to algal blooms and taste and odor problems.

Organic material in the water is also a concern. When carbon treatment is needed, the cost can be very high. Another treatment concern involves disinfection byproducts (DBPs) that are caused when dissolved organic material reacts with chlorine.

Box 3.1 presented earlier in this chapter, discusses some of the water quality consequences of recent fires in residential areas of Southern California.

MANAGEMENT STRATEGIES

Management strategies to reduce the impacts of fire on source water focus on actions that minimize or reduce the spread of fire through forest management and fuel reduction. After an event takes place, management strategies include actions that focus on keeping sediment out of surface water supplies and reservoirs (Figure 3.3).

The most significant consequences of fire for drinking water quality are increased sedimentation of surface waters, suspended sediments (turbidity), nutrients, and water temperature (Landsberg and Tiedemann 2000). Management strategies therefore seek to reduce the magnitude and extent of these changes below thresholds that will trigger the need for additional treatment.

Emerging technologies for fire prevention include automated video surveillance systems that employ a combination of long-range cameras, image processing software, and geographic information systems (GIS) to aid in remote wildfire detection. Automated lightning detection systems (ALDS) have been developed with the goal of locating lightning strikes and allowing early suppression of lightning-caused fires.

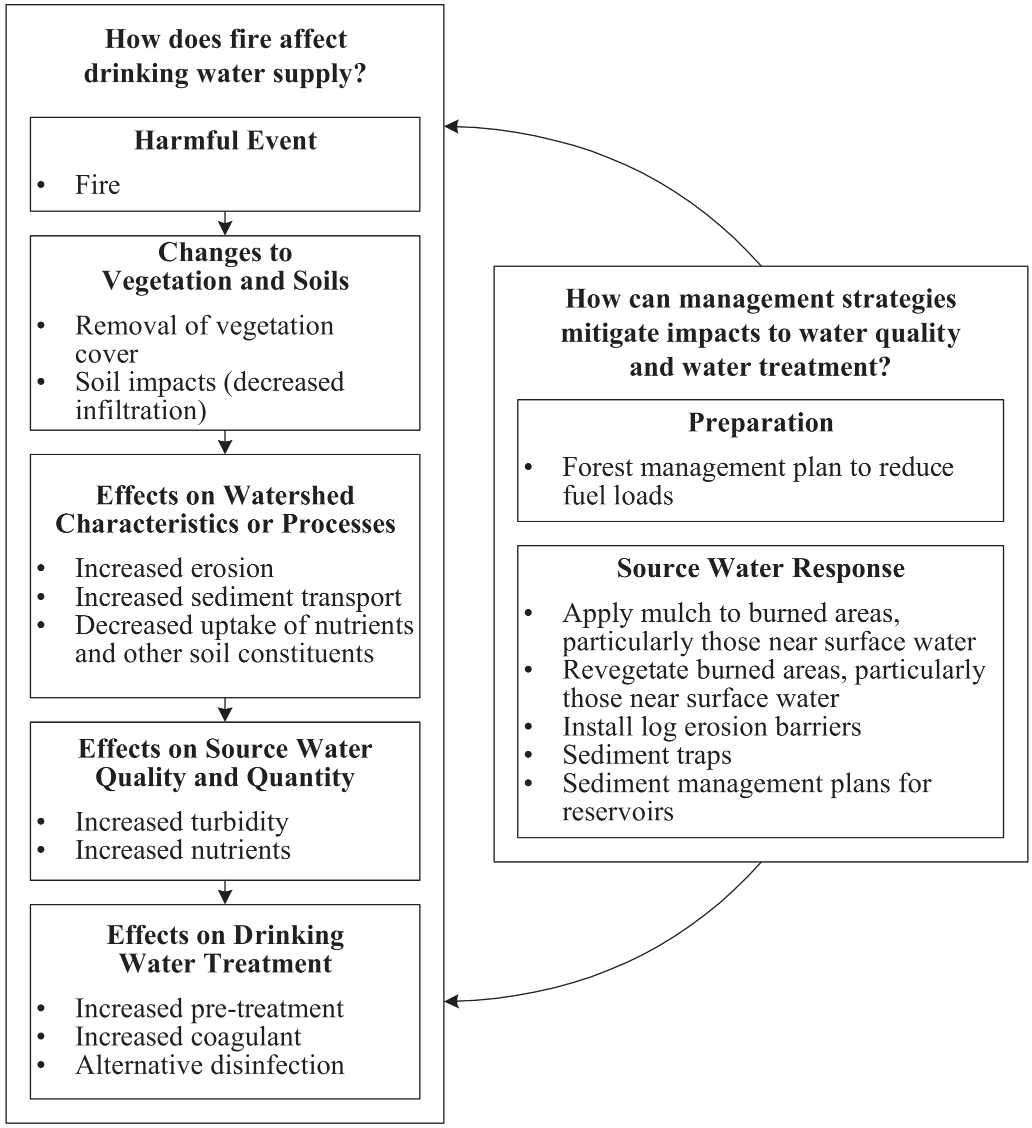
Increasingly, watershed restoration efforts are conducted to prepare for fires and reduce their potential impacts. Prescribed burns and other forest-thinning strategies are effective. However, care must be taken to (1) limit fire severity, (2) avoid burning on steep slopes, and (3) limit burning on sandy or water-repellent soils (Landsberg and Tiedemann 2000).

Sediment traps may be installed to prepare for or respond to fires. Sediment traps usually consist of piles of rock that allow water to flow through, but leaving sediment and debris behind.

Burned Area Emergency Rehabilitation (BAER) is a strategy for controlling erosion after a fire. Much of the ground cover is burned away by fires, exposing soils to the direct impact of rain. Depending on the severity of the fire, the soil itself may become hydrophobic, i.e., it may repel water. Under these conditions, erosion post-fire can be significant if rain occurs. After a fire, BAER teams, composed of various technical experts, are formed to survey the damage and implement a program to control erosion. Details on BAER are available from the National Park Service at http://www.fws.gov/fire/ifcc/esr/home.htm.

Polyacrylamides (PAMs), which are synthetic substances that can bind soil particles together, have been in use since the 1990s to help control erosion on irrigated agricultural fields. They have more recently been tested for use in postfire rehabilitation. A four-year study of the Hayman Fire burned area showed reductions in sediment yields the first year after PAM application, but in subsequent years the reduction was not significant (MacDonald 2008; MacDonald and Robichaud 2008). However, tests of a formulation known as WSPAM (water soluble polyacrylamides) resulted in improved revegetation, reduced soil erosion, and reduced soil hydrophobicity at the Red Bull Fire site near Provo, Utah (Davidson 2008). These studies suggest that PAM could be an effective tool for reducing postfire erosion, but the effectiveness of PAM may vary according to the soil conditions of the burned areas (MacDonald 2008). Techniques such as mulching, log erosion barriers, wattles, seeding, and scarification are used to help protect sensitive areas from erosion after a fire. Though these techniques may make little difference following intense rain events greater than 40 millimeters (mm) per hour, after small rain storms, reduction in first year erosion rates can be substantial. Erosion rates are reduced by 60–80% using engineered wood straw and straw mulch, by 50–70% using contour-felled log erosion barriers, and by 19% using hydromulch (Robichaud and Elliot 2006).

New techniques for post-fire management are continually being developed. In Colorado, biosolids application to the Buffalo Creek wildfire led to an increase in the grass-vegetation cover and reduced the potential for erosion and sediment loss (Meyer et al. 2001).



In this case, fire removes vegetation and increases soil erodibility, resulting in increased vulnerability to erosion after storm events. Source water is impacted through increased turbidity after storm events and decreased uptake from vegetation. Catastrophic wildlife can be prevented through forest management that reduces fuel laddering and even-aged stands. Utilities can minimize impacts to source water through sediment traps or other sediment management plans. If impacts to source water are not prevented, utilities will need to respond to lower quality influent water at the treatment plant with increased pre-treatment or additional treatment steps such as activated carbon to reduce taste and odor problems.

Figure 3.3 Conceptual model showing linkages between a large-scale watershed event (fire) and impacts to source water, with opportunities for utility intervention and response

ADDITIONAL INFORMATION

Extensive information on post-fire management is available. An important reference on the impacts of logging after fire is:

- McInver, J.D. and L. Starr (tech. eds.). 2000. *Environmental Effects of Post-Fire Logging: Literature Review and Annotated Bibliography*. Gen. Tech. Rep. PNW-GTR-486. USDA Forest Service, Pacific Northwest Research Station, Portland, Ore.

A classic reference for reforestation practices in southwestern Oregon and northern California is:

- Hobbs, S.D., S.D. Tesch, P.W. Owston, R.E. Stewart, J.C. Tappeiner II, and G.E. Wells (eds.). 1992. *Reforestation Practices in Southwestern Oregon and Northern California*. Forest Research Laboratory, Oregon State University, Corvallis.

CHAPTER 4
TIMBER HARVEST AND LOGGING ROADS

The large-scale removal of vegetation from timber harvest and logging roads can result in a variety of adverse impacts on watershed hydrology and erosional processes. Excess sediment is the greatest concern. Erosional processes on bare landscapes may produce short-term releases of sediments to downstream surface waters, chronic erosion, or sudden catastrophic events such as landslides.

EFFECTS ON VEGETATION AND SOILS

When vegetative cover is removed by timber harvest or the construction and use of logging roads, interception of precipitation is reduced and more water reaches the ground. Where bare surfaces are produced, soil compaction can reduce the rate of infiltration. As a result, most of the precipitation reaching the ground is carried downstream in overland flow. Though this may result in an initial increase in water yield in some logged watersheds, this advantage is usually outweighed by a greater potential for higher peak flows, which can lead to significant downstream flooding depending on how much vegetation is lost and over what period of time (Jones and Grant 1996).

Tree felling by itself is not a major cause of erosion and sediments in harvested watersheds (Stednick 2000). Logging roads contribute substantially more sediment, and increased erosion from logging roads may continue even after the roads are no longer used (Reid and Dunne 1984, Elliot 2000). It has been estimated that, on a per unit area basis, logging roads contribute more sediment than all other forest activities combined (Furniss, Roelofs, and Yee 1991). Additionally, roads may act to intercept and re-route stormwater, altering the hydrology of a watershed (Wemple and Jones 2003).

EFFECTS ON WATERSHED PROCESSES

Studies indicate that if more than 15–20% of the forest canopy is removed, there will be an increase in downstream flows, with the greatest increase in the first few years after harvesting (Harr et al. 1975). However, it can take decades for streamflow to return to its original level, with the rate of recovery depending on the type of forest and land type (Adams and Ringer 1994).

In forests where snowfall is a significant source of annual precipitation, spring peak flows increase when less snow is intercepted. The snow that reaches the ground melts more quickly from direct contact with the sun and the heat carried by winds, resulting in rapid runoff of potentially large quantities of water (Moore and Wondzell 2005). Harr et al. (1975) suggested that if over 12–15% of the surface area is compacted, such as is usually the case for logging roads, there may be substantial increases in peak flows during storms, in addition to significant erosion. Effects are more complex where rain on snow events occur. In these situations, canopy removal may function to decrease peak flows by slowing snowmelt depending on the timing and amount of precipitation and the pattern of canopy openings in a given watershed (Coats and Miller 1981).

When the reduction in infiltration in a watershed is less than the average rate of rainfall, soils are likely to become saturated, leading to even greater runoff. When both surface soil and litter are dislodged, the subsoil, which is less porous and cohesive, is exposed. Exposed subsoil combined with compacted soils add further to erosion (Poff 1996).

The legacy of tree cutting includes reduced root strength and increases in soil water, raising the risk of shallow landslides (Sidel, Pearce, and O'Loughlin 1985). In the Pacific Northwest, where the steep slopes are already prone to shallow, rapidly moving landslides, the risk for landslides in harvested areas is increased for several years, compared to undisturbed areas and forested areas with trees over 10 years of age (Robison et al. 1999).

The impact of roads in forested watersheds may also be significant. The presence of impermeable surfaces, such as roads, alters the characteristics of the soil and the associated hydrology (Wemple and Jones 2003). Roads may intercept overland or subsurface stormflow and alter the drainage characteristics of a watershed into a stream (Swanson et al. 2000, Wemple and Jones 2003). In addition to the contributions of nonpoint source pollution and increased flow from roads, these impacts may cause changes in stream baseflow and alter erosion and deposition patterns throughout the watershed.

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

Studies of harvested watersheds indicate that increases in sediment yield (the sediment actually delivered to stream channels) are usually only temporary because the additional sediment declines as finer particles are deposited and depositional areas revegetate. Because most eroded sediments are deposited on the landscape as they are transported, usually only a small amount (less than 10%) actually reaches downstream surface waters (Stednick 2000). In fact, studies indicate that the volume of sediment decreases exponentially as it is transported (Megahan and Hornbeck 2000).

Nonetheless, increased runoff in logged watersheds combined with increased erosion may lead to higher sediment yields under some circumstances. Extreme storms after extensive logging can result not only in high rates of erosion, but also in substantial alterations to stream channel morphology. When excessive runoff flows across bare soil on steep slopes, slope failures and debris flows may occur, contributing to stream bank erosion, channel scour, and the deposition of eroded materials in stream channels in downstream areas (Sullivan, Lisle, and Dolloff 1987). Under these conditions, turbidity, organic carbon, and suspended solids increase.

Sediments in runoff also carry nutrients and other water pollutants. Nutrient transport may increase as a result of soil leaching and erosion. When this occurs, nutrients and other potential pollutants can become adsorbed to eroded sediments and transported downstream (Harr and Fredriksen 1988, Cafferata and Spittler 1998, Dahlgren 1998, Grace 2004, Jordan 2006). Cut vegetation has the additional impact of disrupting the natural cycling of nutrients, adding to the nutrients released to runoff (Swank and Johnson 1994). As a result of these processes, downstream waters may show elevated nutrient levels, particularly nitrogen as nitrate.

A study in Oregon found changes in nutrient cycling varied depending on harvesting practices. Nitrate increased most where logging residue was left to decompose naturally, increasing more than sixfold during the high-flow season for seven years after logging. Where logging slash was broadcast burned, nitrate increased fourfold and was nearly gone within six years (Harr and Fredriksen 1988).

A number of studies show that in most logged watersheds there is limited potential for nutrients to build up in downstream surface waters because the period of nutrient transport is usually brief and nutrient inputs are diluted by increases in runoff (Currier 1980).

Box 4.1 Southern Appalachian Mountains

High elevation spruce-fir forests in the Southern Appalachian Mountains sometime exceed the drinking water standard for nitrogen. Average nitrogen concentrations of 5 mg/L, with higher reported maximum values, occur in some streams in this area (Silsbee and Larson 1982). Factors possibly contributing to the elevated nitrogen concentrations include atmospheric nitrogen deposition and low nitrogen uptake rates due to the mature nature of these forests (Silsbee and Larson 1982). The Southern Appalachians receive relatively high rates of atmospheric nitrogen deposition compared to the rest of the region (Johnson and Lindberg 1992).

Within the first year after an area is logged, there are increases in annual water yields, stream sediment, and nitrate concentrations (Harr and Fredriksen 1988, Dahlgren 1998, Keppeler 1998, Lewis 1998). These stream attributes recover to baseline conditions at different rates.

Annual streamflow rates generally recover to baseline conditions between 2 and 7 years after logging (Hornbeck, Rierce, and Federer 1970; Keppeler 1998). In most cases, nitrate concentrations are well below the drinking water standard of 10 milligrams per liter (mg/L) (Binkley and Brown 1993) and decline to background levels between 1 and 7 years (Vitousek and Melillo 1979, Hornbeck and Martin 1986, Harr and Fredriksen 1988, Megahan and Hornbeck 2000); sediment loads recover to pre-logging levels between 2 and 6 years (Lewis 1998, Grace 2004). Other hydrologic parameters such as storm flow and minimum flow recover at different rates and generally on longer time-scales. For example, one study found that storm flows were still higher than baseline after eight years (Hicks, Beschta, and Harr 1991) and two studies found that minimum flows were still elevated above pre-logging levels after 10 and approximately 25 years (Hicks, Beschta, and Harr 1991; Keppeler 1998).

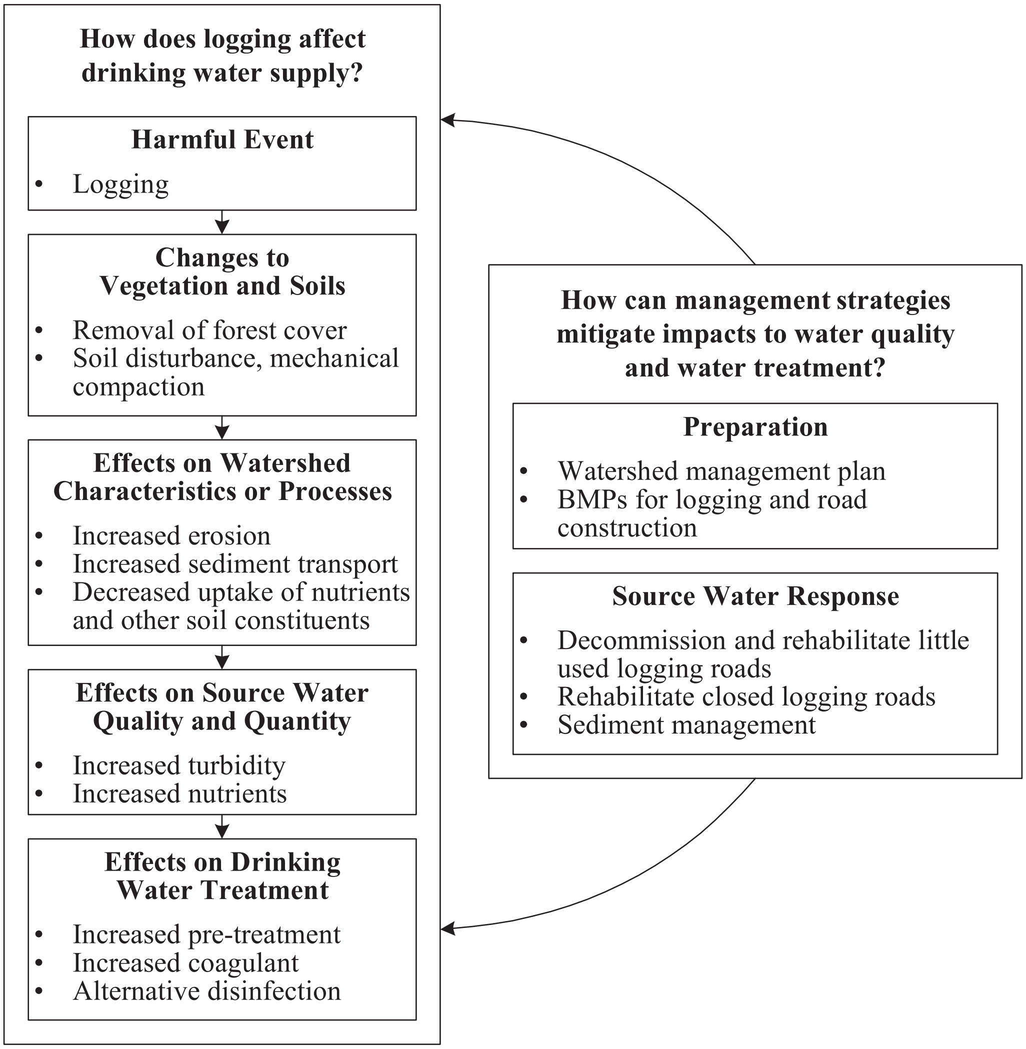
In areas of nitrogen saturation, however, such as in forests subject to high levels of atmospheric deposition of nitrogen (Box 4.1), increased nitrate concentrations in soil water and streams are sometimes observed (Stednick 2000). In these areas, increases in nitrate in surface waters can be sudden and dramatic if the nitrogen accumulated in forest soils is unexpectedly released as a result of disturbance by logging activities. Excavated areas are more likely to erode and are the slowest to revegetate (Burroughs and King 1989).

MANAGEMENT STRATEGIES

Management strategies to reduce the impacts of timber harvest and logging roads on source water include actions to either reduce or limit these activities in a watershed or to have best management practices (BMPs) adopted that minimize erosion and sediment transport, especially from logging roads. After an event takes place, management strategies include actions that focus on keeping sediment out of surface water supplies and reservoirs (Figure 4.1).

Sediment Control

In general, increases in sediment yields from timber harvest practices are short-lived (Stednick 2000). Once vegetation begins to grow again, erosion decreases substantially. However, there can be significant, ongoing surface erosion from logging roads, and sometimes, catastrophic failure of culverts during major storm events (Cedarholm, Reid, and Salo 1981; Elder et al. 2000; Elliot 2000). Road treatments can substantially reduce such impacts. For example, Harr and Nichols



In this case, extensive logging and associated road construction remove forest cover and disturb soils resulting in increased erosion and sediment transport, especially following large storm events. Utilities may have opportunities to prevent or reduce watershed impacts through influencing the adoption of watershed management plans that either restrict or limit logging and road construction or require BMPs for these activities. Utilities also may work to ensure that any unused logging roads are rehabilitated and revegetated. If watershed impacts cannot be prevented, then utilities may limit impacts to source waters through constructing sediment traps where feasible and implementing sediment management plans for reservoirs. If impacts to source water are not prevented, utilities will need to respond to high-turbidity influent water at the treatment plant with increased pre-treatment or other treatment requirements such as alternative disinfection.

Figure 4.1 Conceptual model showing linkages between a large-scale watershed event (logging) and impacts to source water, with opportunities for utility intervention and response

Box 4.2 Case study: Managing forested watersheds to promote diversity

The Massachusetts Water Resources Authority (MWRA) manages one of the largest unfiltered watersheds in the country. The MWRA faces many challenges in maintaining a clean drinking water supply, including a variety of natural disturbances such as wildfire and major storms. MWRA's management focuses on maintaining a healthy, diverse forest that will not be devastated by a single event. In forested areas, commercial logging companies are given contracts to harvest trees in a patchwork pattern using "uneven-aged silviculture" and "regeneration silviculture" logging techniques. These logging techniques are used to deliberately structure the forest, optimizing age-class and species diversity in the watershed. Based on ecological principles, the MWRA believes that diversity of species composition in the forest is their strongest defense against large-scale vegetation disturbance events. Diversity provides redundancy, helping the forest to both resist and recover from disturbance. Commercial logging companies that operate within the MWRA's watersheds are green certified by the Forest Stewardship Council. This approach also generates revenue for the utility. The MWRA generates an average of $600,000 annually by allowing commercial logging companies to operate in their watershed.

(1993) showed that road failures and sediment yield are significantly reduced by road "stormproofing" and "decommissioning." Prior to treatment, they found sediment yield from roads in the basin they studied was 110 times that of undisturbed forests and six times greater than from lands destabilized by timber harvest. After treatment, only one landslide occurred in the basin, as a result of a 50-year storm, whereas 17 road-related landslides had occurred during 2–5 year interval storms prior to treatment.

Recovery of Vegetative Cover

Regeneration refers to the natural re-growth of vegetation following disturbance, whereas revegetation refers to active management to promote growth. Where trees are harvested, regeneration generally occurs within two years. However, regeneration may not occur for at least 3–5 years in areas with skid trails, logging roads, or intensive site preparation (Stednick 2000). Loss of vegetation and soil compaction reduce soil fertility, and therefore active revegetation is sometimes needed, particularly in areas where mineral soils are exposed or disturbed (USEPA 1993).

Management for Diversity

It is increasingly recognized that the recovery of formerly logged watersheds and resistance to catastrophic events that may occur before full recovery is achieved, such as intense precipitation events and fire, are likely to be greatest in vegetated areas with high diversity. Where more vegetation types are available to regenerate a site, the likelihood of successful regeneration increases (Box 4.2; ESA 2000).

ADDITIONAL INFORMATION

There are many handbooks and guidance manuals of BMPs for harvested watersheds. The original source for most of these documents is:

- USEPA (U.S. Environmental Protection Agency). 1993. Management measures for forestry. Chapter 3 in *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA 840-B-92-002. January. Available: http://www.epa.gov/owow/nps/MMGI/Chapter3/index.html.

References on road BMPs include:

- Burroughs Jr., E.R. and J.G. King. 1989. Reduction of Soil Erosion on Forest Roads. General Technical Report INT-264, U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, Utah.
- Grace III, J.M., R. Rummer, B. Stokes, and J. Wilhoit. 1998. Evaluation of erosion control techniques on forest roads. *Transactions of the American Society of Agricultural Engineers* 4:383–391.
- Moll, J.E. 1996. A Guide for Road Closure and Obliteration in the Forest Service. USDA, Forest Service, San Dimas Technology and Development Program, San Dimas, Calif. June.
- USDA (U.S. Department of Agriculture) Forest Service. 1998. Forest Service Roads: A Synthesis of Scientific Information. USDA Forest Service, Washington, D.C.
- Weaver, W.E. and D.K. Hagans. 1994. *Handbook for Forest and Ranch Roads, A Guide for Planning, Designing, Constructing, Reconstructing, Maintaining, and Closing Wildland Roads*. Prepared for the Mendocino County Conservation District in Cooperation with the California Department of Forestry and Fire Protection and the USDA Soil Conservation Service. June.

CHAPTER 5
STORMS

Storms in a watershed in the form of excess precipitation and winds can dramatically alter vegetation cover, increase erosion and runoff, mobilize pollutants, and have significant impacts on drinking water sources. Similar to fire, smaller storms usually occur more frequently while larger storms occur rarely.

EFFECTS ON VEGETATION AND SOILS

Storms impact vegetation primarily through physical disturbance. Severe storms can remove a large area of vegetation very quickly, or the effect of a storm can be quite patchy over the landscape. Wind and rain on hillslopes may cause landslides that deliver large amounts of sediment and debris to downstream waters (Bradley, Grindeland, and Hadley 2001). Ice storms may remove canopy vegetation, exposing understory plants that are otherwise protected (Van Dyke 1999, Cowell and Dyer 2002). Hurricanes and tornadoes can uproot trees and disturb soil sediments and nutrients (Gurevitch, Scheiner, and Fox 2002; Balthis, Hyland, and Bearden 2006; Van Metre et al. 2006).

The impact of a storm in any given watershed will depend on the type and condition of vegetation in the watershed and existing land uses. In some forested watersheds, managed landscapes may be more vulnerable to catastrophic storms than natural landscapes. For example, a massive blowdown in Oregon's Bull Run River watershed in the early 1980s occurred along clear cut and road edges (Franklin and Forman 1987, Sinton et al. 2000). In the Northeast, older stands, especially mature white pine forests, are at higher risk of blowdown than other trees (Lorimer and White 2003).

Some effects of storms provide benefits to forests. Windthrow, for example, is considered an essential process in stand development, generating structural complexity such as logs and small openings in the canopy (Sinton et al. 2000, Franklin et al. 2001). Winds also contribute to soil mixing, which speeds soil development and increases soil fertility (Bormann et al. 1995).

EFFECTS ON WATERSHED PROCESSES

Removal of vegetation by storms, especially over a large, contiguous area, can lead to dramatic increases in runoff, erosion, and sediment delivery to downstream waters. The large-scale loss of vegetation may reduce interception, and where soils are bare or saturated from the storm, infiltration may be substantially reduced. This will lead to more overland flow and higher surface water volumes down-slope. Water pollutants are often transported adsorbed to sediments.

A storm may occur in just a few hours but its impacts may last for months and even years. In the immediate aftermath of a storm, devegetated areas are more vulnerable to erosion and mudslides. Sullivan, Lisle, and Dolloff (1987) documented several examples in northern California where extreme storms after extensive logging resulted in substantial alterations to stream channel morphology. Streambeds were raised as much as 4 meters (m), stream widths were doubled, stream channels were shifted, and stream banks were eroded.

Box 5.1 Event cascade: A disaster after the disaster

When fires in steep terrain are followed by rain, the resulting runoff and erosion may result in the transport of high levels of sediment, organic debris, and chemicals that can degrade downstream source waters. Such an "event cascade" took place when a severe thunderstorm occurred two months after a wildfire in the Buffalo and Spring Creek watersheds near Denver, Colorado. The storm produced substantial erosion and in-channel sediment deposits up to 4 m thick. A massive volume of organic debris and sediment were deposited in the Strontia Springs Reservoir, which supplies drinking water to the cities of Denver and Aurora. Associated with the debris was an increase in manganese, which increased the chlorine demand of water treated for municipal use. The event cost Denver Water $24 million in sediment removal operations. Initial deposition of sediment to the reservoir was 52,000 cubic meters (m^3) of coarse sand and gravel, which created a delta near the upper end of the reservoir, and another 100,000 m^3 of silt and clay near the dam. Subsequently, another 200,000 m^3 of coarse sand and gravel and an unmeasured amount of silt and clay were deposited. Sediment from the initial post-fire erosion is still stored in stream channels in the watersheds, where it may be a long-term supply of sediment to the reservoir or may eventually be stabilized by riparian vegetation until a new erosional cycle is initiated by another disturbance (Martin and Moody 2000, 2001; Moody and Martin 2001).

Storms may initiate "event cascades" in landscapes recently disturbed by other events. Box 5.1 describes the dramatic impact of severe thunderstorms in a recently-burned watershed that released a massive amount of sediment to a downstream reservoir.

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

Factors that influence the degree of impact a storm may have on water quantity and quality scale with storm size and intensity (Balthis, Hyland, and Bearden 2006; Van Metre et al. 2006). Pollutants are often mobilized by storms and carried to downstream waters. Yeakley et al. (2003) found that hurricane-related damage to vegetation in the southern Appalachians led to a doubling of stream water nitrate concentrations. After a hurricane in the forests of Puerto Rico, stream water nitrate, ammonium, and potassium concentrations increased 119%, 182%, and 102%, respectively (Schaefer et al. 2000). These vegetation-related impacts have the potential to last for months to years—much longer than the direct effects described above. Hurricane-related flooding can wash significant amounts of animal waste from agricultural operations into surface waters, or can lead to malfunctioning or overflowing of sewage treatment plants, sending untreated sewage into receiving waters (Mallin et al. 1999).

Severe rainstorms on bare slopes in logged watersheds may produce landslides that wash large volumes of sediment down-slope. The dead vegetation left behind decomposes in place, and when this organic matter is transported downstream later on it can elevate TOC in surface waters. Landslides after intense rainfall are a particular concern in logging areas along the Pacific Coast. If a landslide occurs, there can be little to prevent severe sediment loading to stream channels, sometimes resulting in bank overflow and flooding downstream. Channel sediment and sediment from landslides usually break through most vegetated buffers of the usual width (Franklin 1992).

Box 5.2 Newport News Waterworks, Virginia

Newport News Waterworks receives water from six watersheds, including five reservoirs and one river. They are challenged by a number of large-scale vegetation events including hurricanes and floods. In 2003, Hurricane Isabelle dramatically affected the watershed. The associated wind (primarily from tornadoes and downbursts) opened a large canopy, conservatively estimated at 50,000 trees. The trees did not come down in a single block but in many smaller blocks and swaths. The damage was described as looking like it came from a series of tornadoes.

Immediately after the hurricane, the utility experienced reservoir sediment problems, partly because the reservoir was stirred up directly by the storm. They had to shut down the treatment plants because the storm caused the water column to turn over, which completely changed the water chemistry.

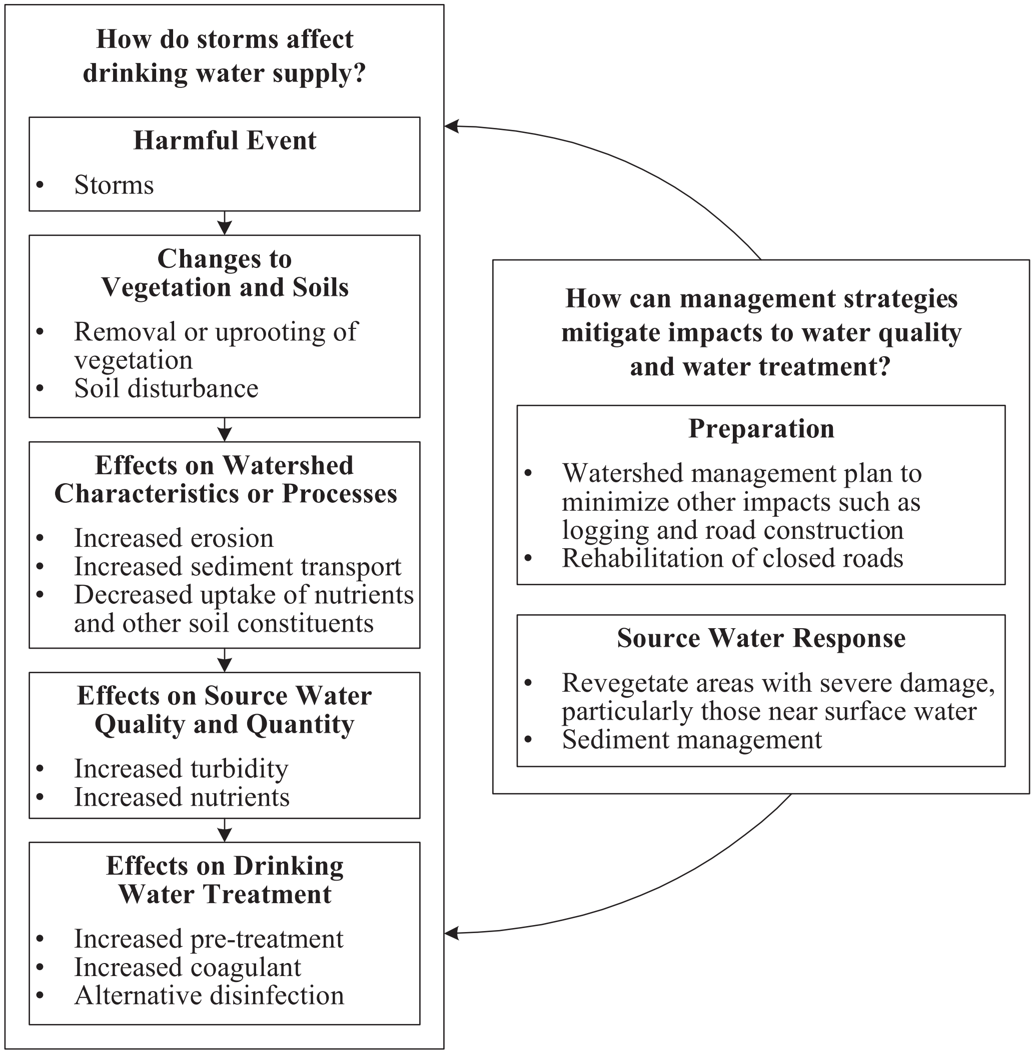
The utility also faced a fire hazard from the downed trees. Therefore, they solicited bids from loggers to remove the trees for their salvage value. Most of the damaged area was left to regenerate naturally, but in areas with particularly severe damage, the utility planted vegetation. The utility has a forest management plan that helps them determine where to allow natural regeneration and where to manage revegetation.

There was no long-term damage to the watershed or water quality; in fact, the hurricane helped diversify the ecosystem. However, an event such as this requires some immediate action as well as ongoing monitoring to ensure that there are no additional effects on water quality and that vegetation recovers as expected.

MANAGEMENT STRATEGIES

Management strategies to reduce the impacts of storms on source water focus on actions that prevent potential sources of sediment from developing (e.g., minimizing logging and road construction). After an event takes place, management strategies include actions that focus on keeping sediment out of surface water supplies and reservoirs (Figure 5.1). The appropriate management strategy for any given storm event must balance immediate needs to protect water quality with the importance of storms and other disturbance events for the long-term health of a watershed. Silvicultural practices for the particular type of storm event are often required in the immediate aftermath of a storm (e.g., Barry et al. 1998; Van Dyke 1999; Bragg, Shelton, and Ziede 2003). At the same time, storms can serve an important function by clearing areas for regeneration. This can start the process of succession, where succession is the ecological term used to describe the changing patterns of community composition from colonization of a barren area to fully grown, mature vegetation. Floodplain forests can be dependent on flooding to open up bare spaces and allow new trees to become established and grow. Smaller disturbance events, those that may remove one or a few trees or a small patch of grassland, also can restart succession in the small patch where the disturbance occurred. Box 5.2 describes the complex management issues faced by the Newport News Waterworks following a hurricane.

Additional Information



In this case, storms remove vegetation cover and disturb soils resulting in increased erosion and sediment transport. Utilities may have opportunities to prevent or reduce watershed impacts from storms through limiting other activities, such as logging or grazing, that can reduce vegetation cover and increase the risk of erosion. If watershed impacts cannot be prevented, then utilities may limit impacts to source waters through constructing sediment traps where feasible and implementing sediment management plans for reservoirs. If impacts to source water are not prevented, utilities will need to respond to high-turbidity influent water at the treatment plant with increased pre-treatment or other treatment requirements such as alternative disinfection.

Figure 5.1 Conceptual model showing linkages between a large-scale watershed event (storms) and impacts to source water, with opportunities for utility intervention and response

- Barry, P.J., C. Doggett, R.L. Anderson, and K.M. Swain. 1998. How to Evaluate and Manage Storm-damaged Forest Areas. USDA Forest Service Southern Regional Management Bulletin No. R8-MB 63.

CHAPTER 6
URBANIZATION

Urbanization is the conversion of natural landscapes or agricultural lands into housing, commercial areas, industry, and other urban or suburban land uses. Though effects may be gradual, and therefore can be planned for, urbanization can drastically change the vegetative cover of a region, replacing vegetated areas with impervious surfaces. The term impervious surface refers to land cover, both natural and human-made, that water cannot pass through. The main categories of impervious surfaces are (1) rooftops, (2) transportation systems (e.g., roads, sidewalks, parking lots), and (3) recreational facilities (e.g., playgrounds, tennis and basketball courts) (USEPA 2005).

EFFECTS ON VEGETATION AND SOILS

The percentage of impervious surface is used to measure the extent of land conversion in an urbanizing watershed. In general, there is a linear relationship between the amount of impervious surface and the amount of runoff (USEPA 2005). However, the volume and rate of runoff is more variable for any given amount of impervious cover. Depending on the degree of impervious cover, the annual volume of storm water runoff can increase from 2 to 16 times the predevelopment amount (Schueler 1994).

EFFECTS ON WATERSHED PROCESSES

In natural landscapes, with little if any impervious surface, there is usually very little or no surface runoff. However, when precipitation falling on impervious surfaces cannot infiltrate into the soil, it becomes part of the overland flow until it reaches a pervious area where infiltration is possible, or it continues downstream until it reaches some type of surface receiving water. When high volumes of runoff reach stream channels, they carry along high loads of sediments, nutrients, and other contaminants from urban activities (USEPA 2005).

It is estimated that runoff and pollutant loadings in an urbanized watershed can increase significantly with as little as 10% of the land cover converted to impervious surfaces (Schueler 1994). As tree canopy is replaced by roofs in developed areas, interception declines. At the same time, pavement and compacted soils reduce infiltration, and overland flow increases. The increased runoff moves rapidly over impervious surfaces, often causing stream bank erosion, channel incision, and sediment deposition in downstream river and stream channels.

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

Vegetation loss in suburban and urban areas can have significant implications for water quality. When runoff passes over impervious surfaces, it is not filtered through soils or vegetation. As a result, impervious surfaces increase watershed runoff and pollutants carried in runoff, including sediments, nutrients, metals, pathogens, organic carbon, and other constituents that impair water quality (Bhaduri et al. 1997, Pyke et al. 2003, Long and Plummer 2004, Brett et al. 2005). Urban runoff is now one of the leading sources of water quality impairment (USEPA 2005).

There are several nonpoint sources of nutrients in urban areas, mainly fertilizers in runoff from lawns, pet wastes, failing septic systems, and atmospheric deposition from industry and automobile emissions. Urban streams have been shown to have the second-highest nitrate and total phosphorus levels, second only to agricultural streams (Barth 1995). Excessive nutrient levels in receiving waters can lead to exceedence of drinking water criteria (10 mg/L for nitrate-nitrogen), although monitoring data suggest that urban sources of nitrate are not high enough to pose a human health risk.

However, moderately high concentrations of nutrients can result in eutrophication of lakes and reservoirs, where phosphorus is typically a limiting nutrient. Surface algal scum, water discoloration, and the release of toxins from sediment can also occur in association with algal blooms. Excessive sediment can clog water intake structures and cause taste and odor problems in drinking water (USEPA 2005).

Urban runoff also often contains elevated levels of pathogenic organisms, including bacteria, viruses, and protozoa. USEPA reports that the bacteria standard is one of the most commonly violated water quality standards in surface waters. Two protozoa of major concern as waterborne pathogens are *Giardia lamblia* and *Cryptosporidium parvum*. *Cryptosporidium* has become an increasingly serious pathogen problem in urban areas (USEPA 2005).

MANAGEMENT STRATEGIES

Management strategies to reduce the impacts of urbanization on source water include actions to either reduce or limit development in a watershed through zoning, purchase, or conservation easements. Other management actions include having BMPs adopted that minimize runoff from urban areas by minimizing impervious surfaces and including buffer zones (Figure 6.1).

Runoff Control

There are four major runoff management principles described by USEPA in its recent document on urban water quality (USEPA 2005):

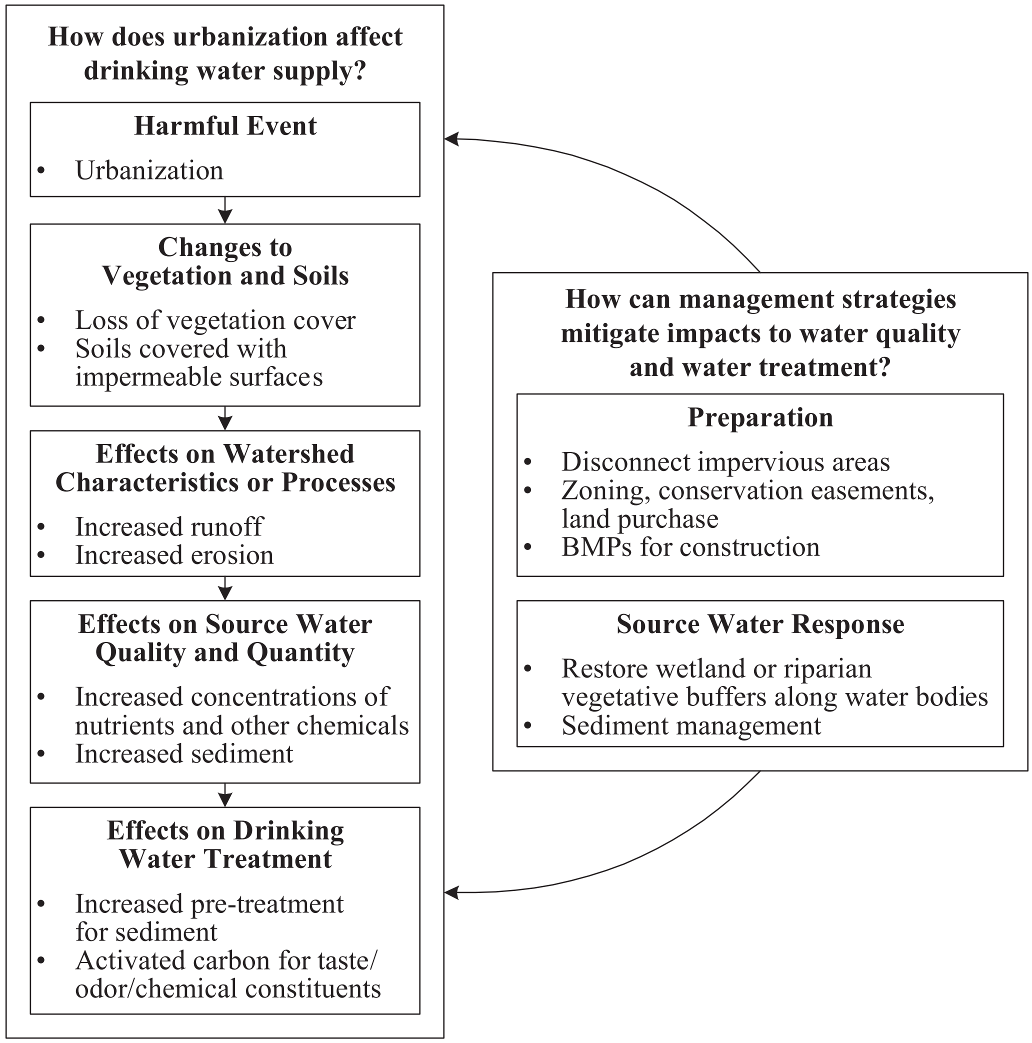
- Minimize the amount of impervious land coverage and disconnect impervious areas
- Promote infiltration
- Prevent polluted runoff by not allowing pollutants and runoff to mix
- Remove pollutants from runoff before allowing it to flow into natural receiving waters

A simple tool, the *Impervious Cover Model*, is available to project the current and future quality of surface waters at the subwatershed scale based on impervious cover (Caraco et al. 1998). The model predicts potential, not actual, stream quality based on the average behavior of multiple indicators over a range of imperviousness.

TSS is an indirect measure of other pollutants carried by runoff, because nutrients (phosphorus), metals, and organic compounds are typically attached to sediment particles. Removal of 80% of TSS is assumed to control heavy metals, phosphorus, and other pollutants (USEPA 2005).

Land Conservation

Many utilities, particularly in urban areas, believe that land acquisition is one of the most important strategies they can use to protect their source waters and water quality. The amount and spatial pattern of urbanization in a watershed depends primarily on social, economic, and political



In this case, increased urbanization in a watershed removes vegetation and increases the amount of impermeable surfaces. This reduces infiltration and increases runoff and soil erosion. Source water is impacted through increased concentrations of sediment and chemicals associated with urban areas (such as motor oil and heavy metals). Preparation measures include zoning, conservation easements, and land purchase to reduce urbanization. Construction practices that minimize impermeable surfaces and leave vegetated buffer areas can minimize impacts. Utilities can minimize impacts to source water through sediment traps or other sediment management plans. If impacts to source water are not prevented, utilities will need to respond to lower quality influent water at the treatment plant with increased pre-treatment or additional treatment steps such as activated carbon to decrease the concentration of other harmful chemicals.

Figure 6.1 Conceptual model showing linkages between a large-scale watershed event (urbanization) and impacts to source water, with opportunities for utility intervention and response

Box 6.1 Protecting urbanizing watersheds with land conservation

With a Growing Greener grant from the Pennsylvania Department of Environmental Protection, the Natural Lands Trust, Philadelphia Water Department, and the Delaware Valley Regional Planning Commission developed the Schuylkill Watershed Priority Lands Strategy. The Strategy uses GIS modeling to identify areas within the Schuylkill Watershed that are the most important to preserve over the next 20 years for ecological and drinking water source protection. Because developed land in the watershed is expected to increase by 40% over this period, the Strategy is a way to identify high priority areas to protect from development. The Philadelphia Water Department developed a model to identify areas of the watershed that are most important for drinking water source protection. The model ranks all lands (on a scale from 1 to 10) that are not already developed or protected for their importance to protecting clean surface water and groundwater. The Strategy is the basis for proactive land conservation in the watershed. The Strategy grew out of meetings of the Schuylkill Action Network (SAN) Land Protection Collaborative, which focuses on preserving high-valued land in the Schuylkill Watershed. The SAN is one of the leading organizations in the U.S. to develop collaborative watershed protection to improve raw drinking water quality. More information is available at: http://www.schuylkillprioritylands.org.

factors related to development. Development activities reflect land ownership, land-use restrictions, local land management plans, land-use history, and regional social and economic conditions. The Philadelphia Water Department is one of several water utilities in urban areas that are finding innovative ways to protect watershed lands from development (see Box 6.1).

ADDITIONAL INFORMATION

Information on Land Conservation

- Trust for Public Land. 2005. Source Water Protection Handbook: Using Land Conservation to Protect Drinking Water Supplies. Available: http://www.tpl.org/tier2_kad.cfm?folder_id = 1385.
- Trust for Public Land. 2004. Protecting the Source: Land Conservation and the Future of America's Drinking Water. Available: http://www.tpl.org/tier2_kad.cfm?folder_id =1385.

Guides on BMPs in Urban Watersheds

- USEPA (U.S. Environmental Protection Agency). 2005. *National Management Measures to Control Nonpoint Source Pollution from Urban Areas.* EPA-841-B-05-004. November 2005. http://www.epa.gov/owow/nps/urbanmm/index.html.
- Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing. Washington Metropolitan Water Resources Planning Board, Washington, D.C.
- Urban Best Management Practices. Metropolitan Washington Council of Governments, Washington, D.C.

- USEPA (U.S. Environmental Protection Agency). 1993. Management measures for urban areas. Chapter 4 in *Guidance Specifying Management*.
- Measures for Sources of Nonpoint Pollution in Coastal Waters. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, D.C. Available: http://www.epa.gov/owow/nps/MMGI/Chapter2/index.html.

Information on BMP Effectiveness

The American Society of Civil Engineers, in cooperation with USEPA, has compiled the *International Stormwater Best Management Practices Database*, which contains performance data from more than 200 management practice studies. The database is available at: http://www.bmpdatabase.org/.

USEPA published the Preliminary Data Summary of Urban Storm Water Best Management Practices in 1999. The document summarizes information and data on the effectiveness of management practices to control and reduce pollutants in storm water. The report also provides information on expected costs and environmental benefits of management practices. The document is available for download in PDF format at: http://www.epa.gov/ost/stormwater/usw_a.pdf.

Urban BMP effectiveness documents from The Center for Watershed Protection http://www.cwp.org include:

- Runoff Reduction Method Technical Memo. Authors: Center for Watershed Protection and Chesapeake Stormwater Network Released: 2008. Uses extensive background research on BMP performance to determine the ability for the BMP to reduce the overall volume of runoff in addition to pollutant removal.
- National Pollutant Removal Performance Database Technical Brief (Version 3.0). Authors: L. Fraley-McNeal, T. Schueler, R. Winer Released: 2008. The database was statistically analyzed to derive the median and quartile removal values for each major group of stormwater BMPs.
- National Pollutant Removal Performance Database for Stormwater Treatment Practices, version 2. Authors: R. Winer Released: 2000. Contains summaries of more than 135 urban pollutant removal monitoring studies. Includes a statistical and graphical comparison of removal rates for six groups of stormwater management practices: ponds, wetlands, open channels, filters, infiltration, and on-site devices.

CHAPTER 7
INSECT PESTS AND PATHOGENS

Insect pests and plant pathogens (e.g., bacteria, viruses, fungi) can alter vegetation and have significant impacts on a watershed and the drinking water produced by that watershed. Unlike sudden events such as wildfire and storms, the water quality impacts from insect pests and pathogens tend to unfold over years or even decades. When pests and pathogens are the only source of vegetation impact to a watershed, water utility managers can adapt over time to changes in the quality of source water. However, pests and pathogens also can increase fire risk because of the increase in standing dead vegetation.

EFFECTS ON VEGETATION AND SOILS

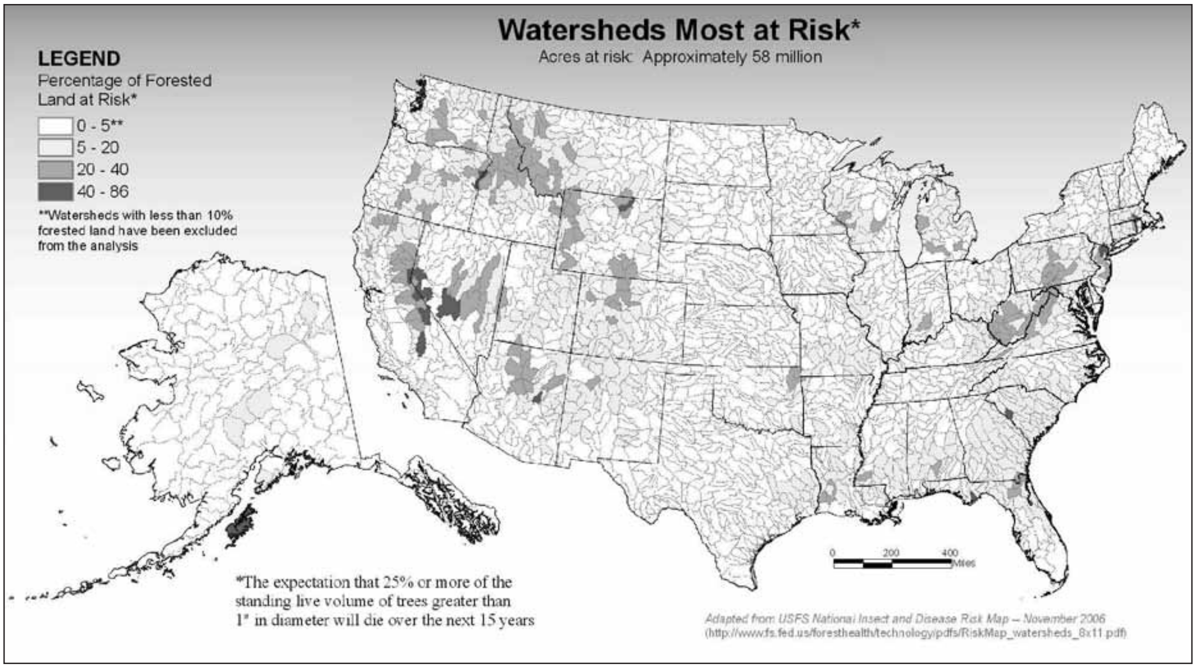
Native insect and pathogen disturbances can be part of the natural cycle of forest growth and regeneration. Certain forest types, such as pine forests in western North America, have adapted to the ongoing presence of native pine beetles, so that a recurring cycle of insect outbreaks, tree mortality, fire, and regeneration is characteristic of the ecosystem (Logan and Powell 2009). However, non-native pests and pathogens, as well as native pests that have extended their ranges or increased in severity because of changes in climate, can cause significant damage to vegetation.

Factors Affecting the Size and Intensity of Outbreaks

On a regional basis, disease outbreaks and insect infestations are highly dependent on climate, on the condition of the host vegetation, and on the internal dynamics of the insect or pathogen populations. Generally, the severity of an outbreak is related to the size of both the host and pathogen populations. Insect outbreaks occur when a mass attack of insects are able to overcome the defensive mechanisms of host trees. These defensive mechanisms also are dependent on climate and can be weakened by drought and heat stress (Colorado Division of Forestry 2004).

Because insects are cold-blooded organisms, temperature has a significant effect on insect life cycles. If temperature patterns are favorable for insect growth and result in a large emergence of adults at the appropriate time of year, an outbreak can occur (Logan and Powell 2001). For example, for mountain pine beetles, which are a significant threat to forests in the western United States, outbreaks occur when spring and summer temperatures are warm enough to allow a life cycle to be completed in a single year. When spring and summer temperatures fall below a threshold, more than one year is needed to complete the beetle life cycle. This delay leads to high rates of beetle mortality during the winter and a low likelihood of outbreak (Logan and Powell 2001). Spruce beetles also have temperature-regulated life cycles. Models show that warmer summer temperatures increase the likelihood of large outbreaks and accelerated mortality of spruce trees (Hansen, Bentz, and Turner 2001).

Changes in the frequency and spatial extent of insect infestations have been attributed to changes in the spatial patterns of forest vegetative cover over the past several decades, largely due to harvesting practices. In interior northwest forests, for example, there has been a loss of large overstory trees and the vegetative cover has become highly fragmented into small, disconnected patches. An increased dominance of shade-tolerant conifers, along with increases in multi-layered



Source: Adapted from USFS 2006.

Figure 7.1 Watersheds most at risk from insect and disease, as of November 2006

host patches, spatial aggregation of host patches, and in some cases increased host patch density, have resulted in significant increases in insect infestations (Hessburg and Smith 1999).

Regional Vulnerability

Different regions and ecosystems are vulnerable to different insect pests and pathogens (Table 7.1). Whether or not serious outbreaks of these pests and pathogens occur depends on regional climate conditions and on the condition of the host ecosystem. The U.S. Department of Agriculture (USDA) Forest Service considers the watersheds most at risk to insect pests and pathogens to be those where there is an “expectation that 25% or more of the standing live volume of trees greater than 1” in diameter will die over the next 15 years.” According to their 2006 analysis, there are approximately 58 million acres of forest in this risk category. In the western United States, the forests of the Sierra Nevada Mountains on the California/Nevada border are most at risk to pests and pathogens, while in the eastern United States, the forests of the Allegheny Mountains in Pennsylvania, Virginia, and West Virginia are most at risk to pests and pathogens (Figure 7.1).

In the boreal forests and subalpine forests of the northern and western United States, pine beetles and spruce budworms are common insect pests that have complex relationships with fire cycles. For example, in the western subalpine forests, spruce budworms and pine beetles kill standing, mature trees. The dead trees remain standing and become very dry, increasing the chances that they will burn in a fire or blow down in a windstorm. These insects evolved as a part of the fire cycle and contribute to the changing fuel loads and timing of fires (Bergeron and Leduc 1998, Hale 2001, Howe and Baker 2003). Recently burned trees are generally less vulnerable to beetle infestation (Howe and Baker 2003); unless they are not killed outright but are damaged and weakened,

Table 7.1
Significant insect and pathogen forest pests by region, categorized by impact

Impact categories include impact if introduced, impact if spreads, currently having lesser impacts, and currently having major impacts.

Insect or pathogen	Host trees	Northeast states	Southeast states	North- and south-central states	Rocky Mountain states (north- and southwest)	Pacific states (north- and southwest)	Source
		1 = Impact if introduced; 2 = Impact if spreads; 3 = Lesser impacts; 4 = Major impact					
Alder dieback	Alders	1	1	1	1	1	a
Ambrosia beetle (*Xylosandrus crassiusculus*)	Oaks, elms, sweetgum, and other hardwoods in N.C., La., Texas		3	3			a
Ambrosia beetle (*Xylosandrus glabratus*)	Sassafras, redbay, and other Lauraceae		3				a
Ambrosia beetle (*Xylosandrus mutilatus*)	Pines, hardwood trees, and shrubs in Miss.		3				a
Asian gypsy moth	Hardwood and coniferous species	1	1	1	1	1	a
Asian longhorned beetle	Maple and various hardwood species	2	2	2	2	2	a
Balsam wooly adelgid	Balsam fir; Fraser fir; true firs (*Abies*)	3	4	3	3	3	a
Beech bark disease	American beech	4	4	2			a
Brown longhorned spruce beetle	Red spruce	2	2	2	2	2	a
Butternut canker	Butternut	4	4	4			a
Cactus moth	Prickly pear cacti		4	2	2	2	a
Chestnut blight	American chestnut and Allegheny chinkapin	4	4	4			a
Chestnut gall wasp	American chestnut and Allegheny chinkapin	4	4	4			a
Chilean carpenter worm	Oaks, alder, willows, elms, other hardwoods	1	1	1	1	1	a

(continued)

Table 7.1 (Continued)

Insect or pathogen	Host trees	Northeast states	Southeast states	North- and south-central states	Rocky Mountain states (north- and southwest)	Pacific states (north- and southwest)	Source
		1 = Impact if introduced; 2 = Impact if spreads; 3 = Lesser impacts; 4 = Major impact					
Citrus longhorned beetle	Maples and various hardwood species	1	1	1	1	1	a
Common or larger pine shoot beetle	Pine species	3	2	3	2	2	a
Dogwood anthracnose	Flowering dogwood	4	4	4		4	a
Dutch elm disease	American elm and other elm species	4	4	4	4	4	a
Emerald ash borer	Ash species	2	2	2	2	2	a
Eurasian nun moth	Hardwood and coniferous species	1	1	1	1	1	a
European gypsy moth	Oaks and various hardwood species	4	4	4	2		a
European larch canker	Larch					3	a
European oak bark beetle	Oaks and other hardwoods	1	1	1	1	1	a
European spruce beetle	Spruce forests (*Picea engelmannii*)	1		1	1	1	a
Fusiform rust	Loblolly and slash pine	4					b
Hemlock wooly adelgid	Eastern hemlock; Eastern and Carolina hemlocks	4	4	2			a
Introduced banded elm bark beetle (*Scolytus schevyrewi*)	Various elms				3	3	a
Larch casebearer	Tamarack; larch	3		3	3	3	a

(continued)

Table 7.1 (Continued)

Insect or pathogen	Host trees	Northeast states	Southeast states	North- and south-central states	Rocky Mountain states (north- and southwest)	Pacific states (north- and southwest)	Source
		1 = Impact if introduced; 2 = Impact if spreads; 3 = Lesser impacts; 4 = Major impact					
Lobate lac scale	Wax myrtle, cocoplum, myrsine, tropical woody dicots		4				a
Mediterranean pine engraver beetle	Conifers, especially pines (Calif.)					4	a
Mountain pine beetle (*Dendroctonus ponderosae*) and bluestain fungi (*Ceratocystis* spp.)	Lodgepole pine				4	4	c
Oak dieback	Oaks	1	1	1	1	1	a
Ohi'a rust	Myrtaceae		3				a
Phytophthora root rot	American chestnut and Allegheny chinkapin	4	4	4			a
Pine flat bug	Alder, birch, willow, other hardwoods and conifers	1	1	1	1	1	a
Pine pitch canker	Pines (Calif., Ore.)					4	a
Port-Orford-cedar root disease (*Phytophthora lateralis*)	Port-Orford-cedar					4	a
Red-haired or golden-haired pine bark beetle	Pines	2					a
Shot-hole borer (*Xyleborus similis*)	Broad range of hardwoods and pines in Texas			3			a
Southern pine beetle (*Dendroctonus frontalis*)			4				d
Spruce aphid (*Elatobium abietinum*)	Engelmann spruce, Colorado blue spruce				4	3	a

(continued)

Table 7.1 (Continued)

Insect or pathogen	Host trees	Northeast states	Southeast states	North- and south-central states	Rocky Mountain states (north- and southwest)	Pacific states (north- and southwest)	Source
		1 = Impact if introduced; 2 = Impact if spreads; 3 = Lesser impacts; 4 = Major impact					
Spruce beetle (*Dendroctonus rufipennis* Kirby)	Spruce species				3	3	e
Spruce budworm (*Choristoneura fumiferana; C. occidentalis*)	Abies balsamea, *Picea glauca*, and *P. mariana*	4		4		4	f
Sudden oak death pathogen (*Phytophthora ramorum*)	Oak species and other woody plants	2	2	2		3	a
Unnamed *Phytophthora* disease	Beech, rhododendron, tulip tree, magnolia	1	1	1	1	1	a
White pine blister rust	Eastern white pine; white and 5-needle pines (*Pinus* subgenus *Strobus*)	4	4	4	4	4	a
Woodwasp (*Sirex noctilio*) and associated fungus	Pine species	1	1	1	1	1	a

Sources: Derived from material in:
a. The Nature Conservancy 2004.
b. USDA Forest Service 2008.
c. Hale 2001, Williams and Birdsey 2003.
d. Johnson, Henderson, and Harris 1987; Paczkowski 1988; Williams and Birdsey 2003.
e. Howe and Baker 2003.
f. Bergeron and Leduc 1998, Williams and Birdsey 2003.

in which case they may be more vulnerable to infestation (McCullough, Werner, and Neumann 1998). The dynamic between infestation and fire helps reduce the severity of impacts from either individual event (Bergeron and Leduc 1998, Hale 2001, Howe and Baker 2003). However, fire suppression practices in the West for the last 100 years have altered the community structure of western forests, thereby altering the frequency, timing, and severity of insect outbreaks (Bergeron and Leduc 1998, Hale 2001, Howe and Baker 2003).

In the northeastern United States, hemlock woolly adelgid, beech bark disease, and gypsy moths are significant pests and pathogens that can have an impact on forest ecosystem processes (Lovett et al. 2006). Hemlock wooly adelgids feed on hemlock twigs and usually cause mortality within four to five years of establishment on a tree, while beech bark disease causes mortality over a slower period of 10 years or more (Lovett et al. 2006). Gypsy moth caterpillars are considered serious pests because they can defoliate over 500 species of broad-leaved and coniferous trees, leading to tree mortality (USDA 2005). Oaks and aspens are considered to be preferred host species. Similar to pine and spruce beetles, gypsy moth life cycles are driven by temperature. In particular, gypsy moth establishment can occur if there is enough winter cold to complete diapause, summer temperatures are warm enough to complete a one-year life cycle, and egg-laying (oviposition) occurs early enough in the year to complete pre-diapause development before winter (Logan et al. 2007).

In the Southeast, beech bark disease, butternut canker, and chestnut gall wasp can have major impacts on characteristic hardwood species of southern forests. Southern pine beetle and fusiform rust are some of the pests and pathogens that can pose a threat to pine forests. Balsam and Fraser fir are candidate species for listing under the Endangered Species Act due to the balsam woolly adelgid (Ward and Mistretta 2002).

EFFECTS ON WATERSHED PROCESSES

Insect pests and pathogens can cause severe damage to vegetation, including reduced growth rates, impaired (or eliminated) reproduction, and death. When there is a large and severe presence of pests or pathogens, this is referred to as an "infestation." Large-scale infestations may lead to significant changes in the community structure and age of a plant community. In many cases, the plants that remain can survive after an initial attack, but are then more vulnerable to other potentially damaging events such as fire or storms.

Pathogens cause vegetation loss or damage primarily through defoliation or death. Insect pests and diseases are often specific to a single kind of host plant, such as oaks, or even to a single species. The effect of the infestation on the whole ecosystem depends on the importance of the host plant within the ecosystem.

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

Impacts from pests and pathogens on water quantity and quality have not been well studied. For small to moderate outbreaks, it is unlikely that surface waters will be significantly affected. In such cases, some vegetation die-off will occur. Since outbreaks tend to be species-specific, effects in mixed forests or grasslands will be patchy, affecting only one of many species. Effects are likely to be transient, as dead vegetation is replaced by species unaffected by the disease.

However, there are examples of massive pest outbreaks affecting surface waters (Leuschner, Shore, and Smith 1979). For example, gypsy moth outbreaks have led to increases in water yield, and in the mid-Atlantic, gypsy moth related tree mortality led to dramatic rises in stream nitrate concentrations (Lovett et al. 2006). It is also thought that in mid-Appalachian forests in the 1980s and 1990s, gypsy moths likely contributed to elevated levels of nitrate export to streams (Eshleman et al. 1998). Bark beetle attacks in the Bavarian Forest National Park elevated stream nitrate concentrations for at least seven years (Huber 2005).

Recent massive pine beetle outbreaks in western North America (Figure 7.2) are also likely to have impacts on water quantity and quality In British Columbia, beetles have infested an area three times the size of Maryland, devastating huge swaths of lodgepole pines (Natural Resources Canada 2008). At the current rate of spread, it is estimated that 50% of mature pines in the area will be dead by the end of 2008 and 80% by 2013. Losses of trees on this scale will increase water yields over the short-term, with this effect disappearing over time as either pines regenerate or new species grow in their place. Water quality may suffer as well when dead trees and insects decompose and their nutrients are released to nearby streams.

Large scale die-offs also increase the risk of wildfire and the associated impacts to water quality caused by fire. In these cases, the interaction between pests and pathogens and subsequent wildfire may be more significant to water quality than the impacts of the pests and pathogens on their own.

MANAGEMENT STRATEGIES

Management strategies to reduce the impacts of insect pests and pathogens on source water focus on actions that reduce the spread of pests and pathogens within a watershed. If a large-scale die-off occurs, preventing impacts to source water is difficult (Figure 7.3).

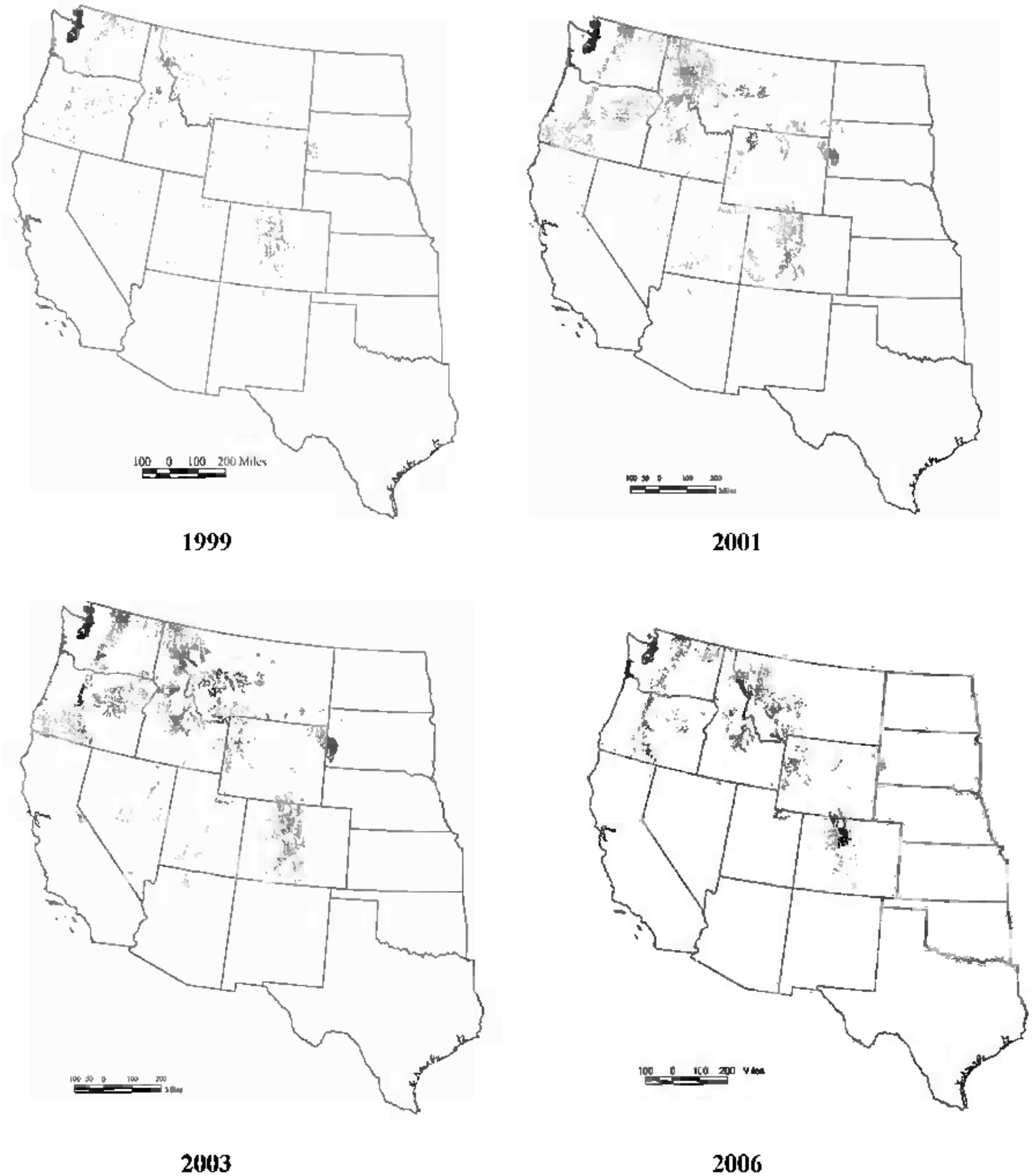
Integrated pest management (IPM) involves a combination of prevention and control strategies, and has been particularly effective in protecting forests from insect infestations. Some of the most successful controls include silviculture, biological control, chemical, bioengineering, quarantine, and sanitation strategies (Ward and Mistretta 2002):

- Silviculture techniques to eliminate diseased vegetation
- Biological control—introduction of other insects that are natural predators
- Chemical control—pesticides
- Bioengineering—favoring and propagating resistant individuals
- Quarantine—restricting the movement of live plants across state boundaries
- Sanitation—removal of infected or pest-infested materials from an ecosystem

The practices that will apply for any particular outbreak will depend on current environmental conditions at the site and the particular insect involved. Box 7.1 describes how one utility is treating an insect outbreak with predator insects.

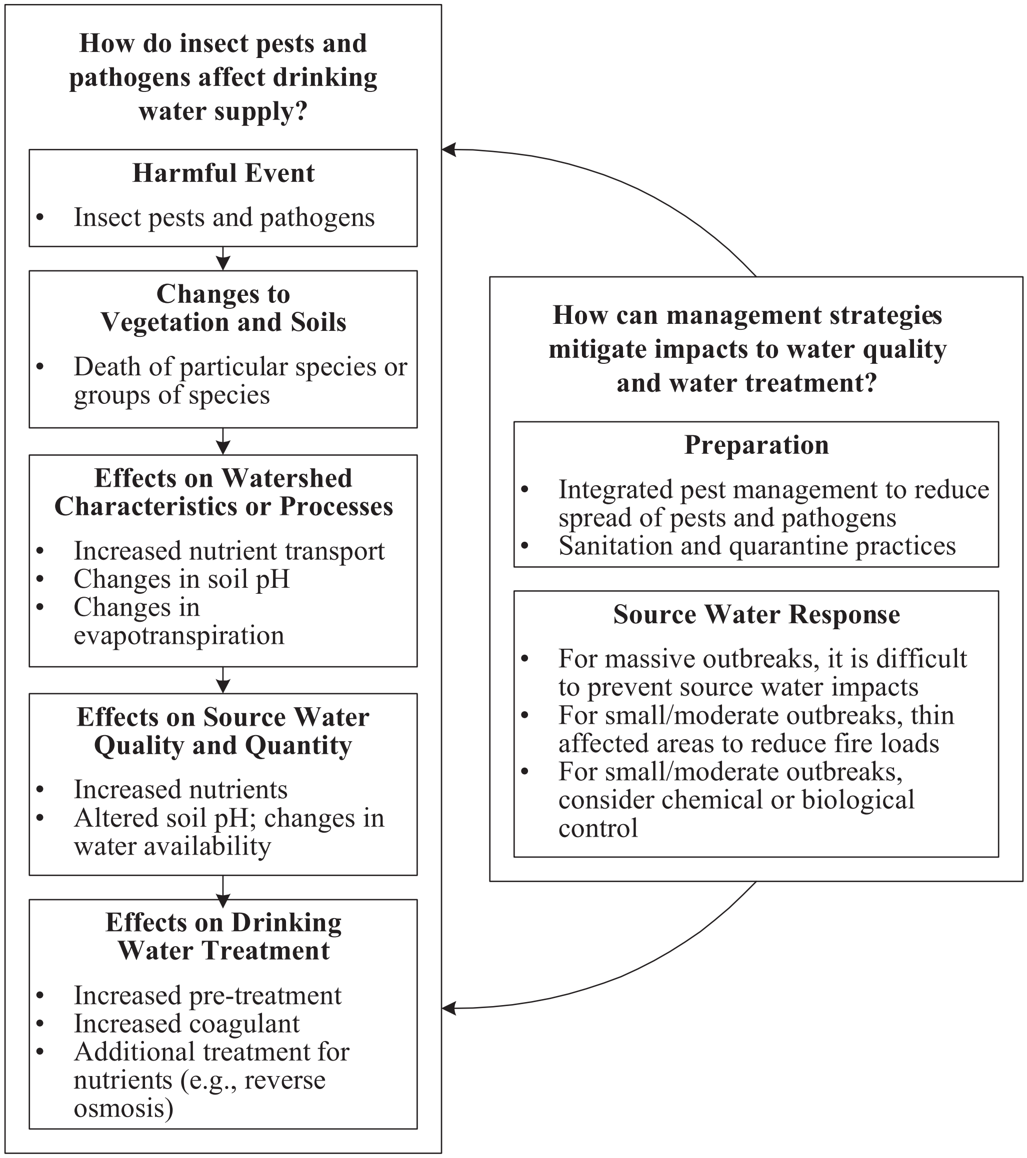
ADDITIONAL INFORMATION

- Canadian Forest Service Forest Service Research Lab Web site http://cfs.nrcan.gc.ca/general/pathology provides information about pathology and links to scientific articles.
- University of California, Davis, links to IPM Web sites, including IPM centers: http://www.ipm.ucdavis.edu/GENERAL/links.html.



Sources: USDA Forest Service 2000, 2003, 2004, 2007.

Figure 7.2 Sequential maps of mountain pine beetle outbreak areas, showing spread in outbreak areas from 1999 to 2006



In this case, insect pests and pathogens attack specific species or groups of species, leading to a large volume of dead biomass and decreased diversity. Utilities may have opportunities to reduce the impacts of insect pests and pathogens through adoption of IPM strategies that use chemical, biological, or mechanical controls to avoid pests. Quarantine and sanitation practices also reduce the risk of spread. If watershed impacts cannot be prevented, then utilities may limit impacts to source waters through removal of dead vegetation under a salvage logging contract or other management plan. If impacts to source water are not prevented, utilities may need to respond to influent water with higher nutrient concentrations and altered pH. Impacts to water quantity may also occur.

Figure 7.3 Conceptual model showing linkages between a large-scale watershed event (insect pests and pathogens) and impacts to source water, with opportunities for utility intervention and response

Box 7.1 Asheville Water Services Department, North Carolina

Wooly adelgid infestation is a major concern for the Asheville Water Services Department (AWSD); Asheville, N.C. This insect could potentially destroy the hemlock population within the utility's North Fork watershed. The AWSD is releasing predator beetles in the area, at a cost of $10,000 for 5,000 beetles, in an effort to save as many trees as possible. The effectiveness of the counterattack is still not known. If unsuccessful, acres of dead hemlock could acidify the soils, which could lead to a pH change in source waters. Water temperatures could rise and sedimentation could increase as a result of the vegetation loss, and together these changes could lead to taste and odor problems in drinking water. A change in pH may force modifications to the treatment process. However, if the beetle release effort fails, the high species diversity within the forest is expected to lead to the replacement of hemlock by another species within two to five years, minimizing long-term impacts to the watershed.

- University of Minnesota, Radcliffe's IPM World Textbook on the Web at: http://ipmworld.umn.edu/.
- USEPA Office of Pesticides Programs publications, online at: http://www.epa.gov/oppfead1/Publications/catalog/.
- U.S. Congress, Office of Technology Assessment. *Biologically Based Technologies for Pest Control*. OTA-ENV-636. U.S. Government Printing Office, Washington, D.C. September 1995.

CHAPTER 8
INVASIVE PLANT SPECIES

Invasive species are defined as species that are non-native to the ecosystem being considered and whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Executive Order 13112). Invasive species are abundant almost exclusively as a result of anthropogenic influences. Human migration, transportation, and trade move species across ecosystems and even continents. Most species transported in this way do not thrive; only a small percentage of those species that survive a new environment will eventually become invasive and cause economic or environmental harm (Mack et al. 2000).

In this chapter, the focus is on invasive plant species that can affect source water quantity or quality. The effects of any given invasion are highly variable and depend on local climate and hydrology, the ecology of the plant community experiencing the invasion, and the characteristics of the invading species. In general, however, the invasion of plant species with characteristics that are distinct from the native species (such as the invasion of grass into a shrub community) will have greater impacts than the invasion of species that resemble native species in their ecological functioning (Cronk and Fuller 1995).

The vulnerability of the native plant community will also depend on vulnerability to other disturbance events. Invasive plants often become dominant after a fire or storm event that kills or damages native vegetation and allows invasive species to become established. In California, drought conditions tend to favor non-native invasive grasses with large seed stores and aggressive growth patterns that crowd out native bunchgrasses (EBMUD 2001).

These effects of invasive species can be costly for local communities. Purple loosestrife, for example, which was introduced as an ornamental plant in the early 19th century, is now found in riparian areas throughout the U.S. Control costs for loosestrife are now over $45 million per year (Pimentel et al. 1999).

EFFECTS ON VEGETATION AND SOILS

Invasive plant species may lead to significant changes in watershed vegetative cover, water availability, and the composition and diversity of the plant community. In addition to replacing native vegetation, the invaders may alter the ecosystem in ways that modify natural disturbance regimes. For example, the invasive cheatgrass (*Bromus tectorum*) has seriously altered the fire regimes where it occurs from an average return interval of 60–110 years to 0–3 years because of the increased fuel loading caused by the buildup of dry grass (Ziska, Reeves, and Blank 2005). Cheatgrass forms a dense carpet of vegetation that out-competes native grasses and shrubs. When it dries, it produces a very flammable cover that often burns completely, without allowing native plants to re-establish. It is thought that in pinyon-juniper woodlands, the combination of cheatgrass and fire may effectively prevent the re-establishment of the original woodlands (Mitchell 2000).

Invaders sometimes completely transform the native vegetative cover. The Florida Everglades, for example, has been transformed from a seasonally flooded marsh to a forest of invasive trees (Mack et al. 2000).

EFFECTS ON WATERSHED PROCESSES

Studies of the hydrological impacts of invading terrestrial plants show that changes in vegetation can have significant impacts on water resources at both local and landscape scales (Le Maitre 2004). The effects of invasions on watershed processes can be dramatic if an invasive becomes a widespread, dominant member of a plant community. The native shrub communities of South Africa, for example, were invaded by a variety of non-native trees, which used much more water than the native plant community. As a result, there have been major alterations to local rivers, and some now have little or no flow (van Wilgen, Cowling, and Burgers 1996). While invasive aquatic plants, such as Eurasion watermilfoil (*Myriophyllum spicatum),* can have important effects on aquatic ecosystem processes in rivers, lakes, and reservoirs, the focus here is on the influence of invasive terrestrial species on water quality and quantity.

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

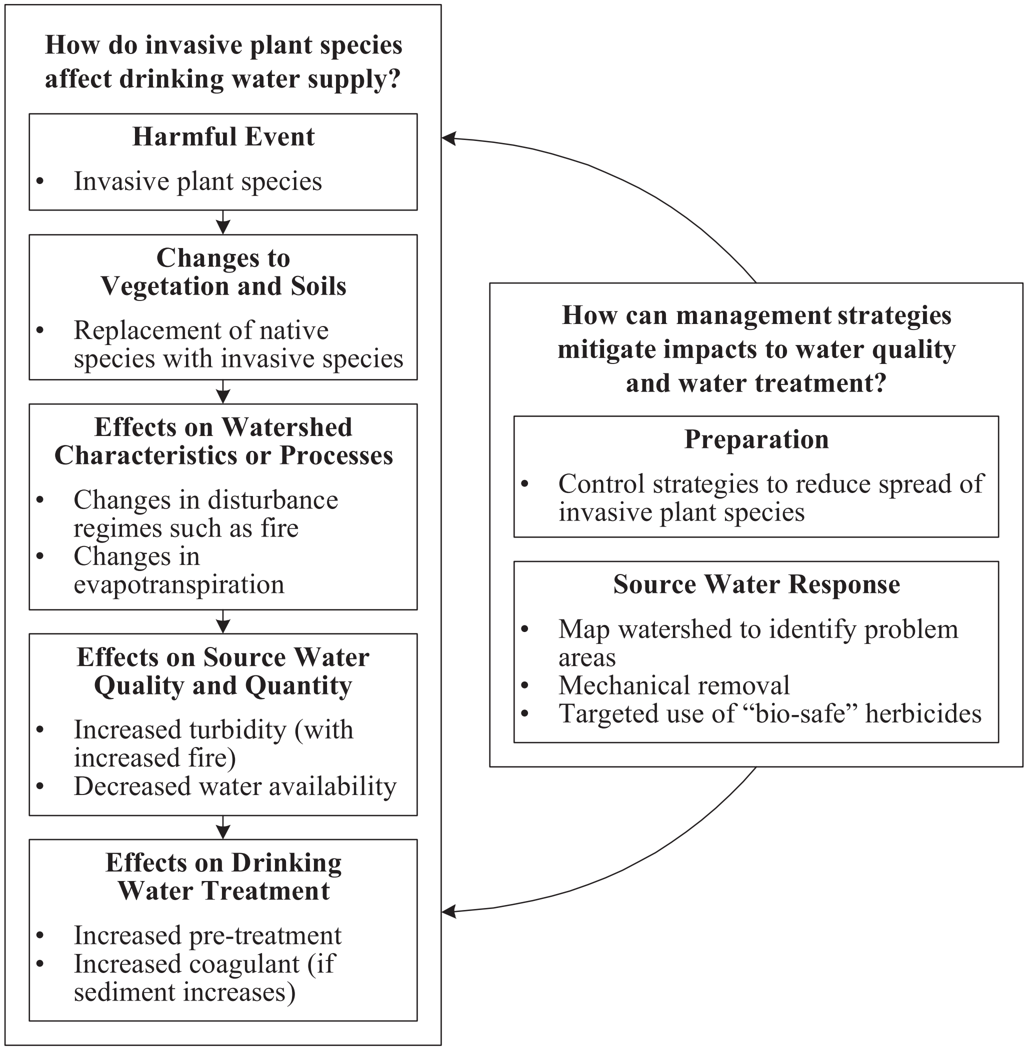
Terrestrial invasive plants pose a threat to water quality when they spread to such an extent that they reduce overall vegetation cover and thereby increase erosion and runoff or shade out desirable grasses that are more effective at capturing and holding rainfall.

Similar to insect pests and pathogens, the water quality impacts from invasive species tend to unfold over years or decades, and generally occur only when invasions become a large-scale problem. For example, the invasion of tamarisk (*Tamarix* spp.) into riparian areas of southwestern North America has decreased water availability in some areas because tamarisk can transpire significantly more groundwater than native riparian vegetation (Hart 2003).

MANAGEMENT STRATEGIES

Management strategies to reduce the impacts of invasive plants on source water focus on actions to reduce the spread of invasive species through a variety of control methods (Figure 8.1). Eradication of invading plant species is often difficult, unless the invasion is discovered early. If ongoing monitoring is conducted, it is usually possible to detect and often eradicate an invading plant species before it spreads. Once it becomes widespread, however, an invading plant can be difficult to eliminate. Under these circumstances the objective becomes one of control, using chemical, biological, or mechanical methods, depending on the characteristics of the particular invader (Mack et al. 2000). Box 8.1 describes the experiences of one utility.

While efforts to manage invasive species can in many cases improve water resources, such efforts can also have negative impacts on water quality and quality. For example, removing large swaths of invasive riparian species, if not accompanied by proper re-vegetation, can lead to increase erosion and sediment loads in surface waters. Burning vegetation to control an invasive plant, while effective, can have serious impacts on water quality and quantity, as described in chapter 3. The use of herbicides, if done at large scales and/or through aerial spraying, can contaminate drinking water. It is therefore critical that the benefits of invasive species control measures are carefully weighed against potential impacts on water quality and quantity, as well as the environment in general.



In this case, invasive plant species lead to changes in vegetation cover and may also alter disturbance regimes. Utilities may have opportunities to reduce the impacts of invasive species through control programs that reduce the cover and spread of invasive species. If the invasive species cannot be prevented, then utilities may adopt management strategies to combat other related impacts such as increased erosion or increased risk of fire. Impacts to influent water will depend on the specific invasive species but may include increased turbidity and decreased water availability.

Figure 8.1 Conceptual model showing linkages between a large-scale watershed event (invasive plant species) and impacts to source water, with opportunities for utility intervention and response

Box 8.1 The Salt Lake City Water Department

The Salt Lake City Water Department manages a 185 square mile (mi^2) watershed that includes undeveloped mountain ecosystems, several large ski areas, and some large homes. Poised on the edge of the Great Basin Desert, in the second driest state in the U.S., Salt Lake City seeks to protect its limited water resources as much as possible. Because the city has "extraterritorial jurisdiction," it is able to pass ordinances for protecting its watersheds and the quality of its drinking water supply.

The utility has observed a continual decline in water quality over the last 15 years, likely due to development in the watershed and the presence of invasive weeds. Noxious weeds such as dyer's woad (*Isatis tinctoria*) are driving out native vegetation, which may alter hydrology and water quality and provide fuel for wildfires. The extensive root system of dyer's woad contains large nutrient reserves which make the weed difficult to control.

The utility has started a new weed management program. They completed a fuels assessment on the property that included mapping areas with significant noxious weed infestations. The on-ground response actions are in the early stages of implementation and include mechanical weed-pulling using community volunteers and herbicide spraying in some areas using a biodegradable, bio-safe herbicide.

Several agencies are working cooperatively to manage and remove weeds from public lands. The utility feels that community education about the watershed and the role that recreation plays in water quality will also help them improve conditions in the watershed. They are considering options for a recreational user education program, wash areas to help prevent the spread of weeds, and other innovative BMPs.

ADDITIONAL INFORMATION

- The Invasive Plants Web site provides information on invasive plants and their control: http://invasiveplants.net/.
- Another useful resource is the Web site of the USDA's National Biological Control Institute: http://www.aphis.usda.gov/.

CHAPTER 9
AGRICULTURE

Agriculture, including both farming and grazing, can result in significant impacts to watershed hydrology, erosional processes, and the chemistry of surface waters. In addition to increasing siltation of surface waters from increased erosion, farming and livestock grazing often introduce nutrients, pesticides, and bacteria to nearby waterways. Irrigation practices divert water from other basins and channelize streams to convert them to irrigation canals.

EFFECTS ON VEGETATION AND SOILS

Agriculture impacts local water sources through large-scale, frequent disturbance of vegetative cover and soils. Factors affecting the impacts of agriculture in a watershed include the type of agriculture, the intensity of cultivation practices, the historic ecology of an area, surrounding land use, the regional climate, and the seasonality of the crop (USEPA 1993, 2000).

While irrigated agriculture decreases water availability, farming also can lead to higher runoff during rainfall events. The increase in runoff results from the regular disturbance that farm vegetation and soils receive in preparation for planting and during harvest, which reduces vegetative cover and increases soil compaction (Shelby et al. 2006).

Highly managed grazing systems involve maintaining grazing animals in a defined, enclosed area and allowing them to consume most or all of the vegetation in that area. The removal of vegetative cover leads to soil loss, soil compaction, and degradation of soil structure. As soil surfaces become compacted from the movement of animals, soils erode and sediments are delivered to nearby waters (USEPA 1993).

Grazing can also result in the conversion of the vegetative cover to a vegetation type that is less palatable to animals. In some grassland and shrubland ecosystems, however, sustainable grazing practices can maintain native vegetation cover because the ecosystems evolved with grazing animals. In these cases, grazing may not have a discernible impact on vegetation cover or water quality.

EFFECTS ON WATERSHED PROCESSES

Most farming in the U.S. is monotypic, meaning farmers grow a single crop over a specific geographic area and prevent the growth of other species. This sort of agriculture generally involves inputs of significant concentrations of chemical fertilizers, pesticides, and herbicides.

As vegetative cover is removed by grazing, there is an increase soil exposure, soil compaction, and damage to soil structure, which reduce the soil's infiltration capacity. As a result, runoff, sediment loading, and nutrient concentrations may all increase (Stout et al. 2000, Emmerich and Heitschmidt 2002). When cows are allowed to graze near or within stream channels, stream banks may collapse and waste from grazing cows introduces fecal coliform and nutrients directly to surface waters (Brenner 1995).

Herbaceous vegetation has the greatest capacity for filtering sediment because it provides stem complexity on the surface of the forest floor, which slows the flow of water, thereby allowing suspended sediment to settle out. As grasses and grass-like plants are reduced, infiltration rates decline. When grasslands transform into shrub-dominated vegetation communities, they are difficult to return to grassland through grazing management (Laycock 1991).

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

The primary agricultural nonpoint source pollutants are nutrients, sediment, animal wastes, salts, and pesticides (USEPA 1993, 2000). In addition, pathogens such as *E. coli, cryptosporidium,* viruses, *and Giardia lambia* may enter waterways from agricultural areas used for animal production, such as grazing areas. Runoff from bare soils in farmed or grazed areas increases erosion and sediment delivery to surface waters. High fertilization rates on cropland contribute high concentrations of nutrients (Lehrter 2006). Nitrogen (as nitrate and ammonia) and phosphorous are two of the most significant nutrients released from agricultural lands (Ahearn et al. 2005). High concentrations of nutrients can lead to excess nutrient loadings to downstream water bodies and associated algal blooms, necessitating more intensive water treatment. Pesticides also are used heavily in agriculture, and drain to surface waters.

MANAGEMENT STRATEGIES

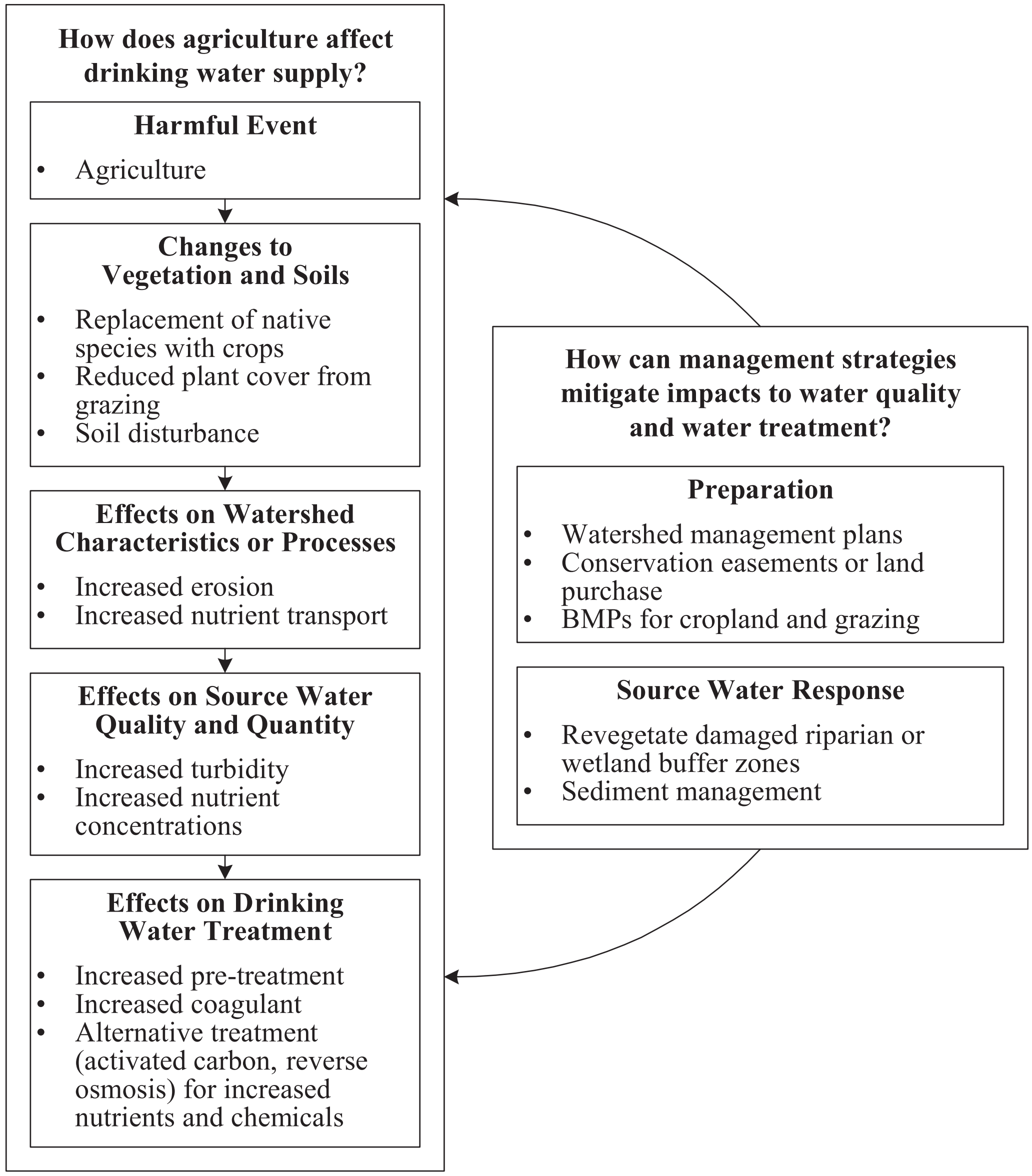
Management strategies to reduce the impacts of agriculture on source water include actions to either reduce or limit agricultural activities in a watershed or to have BMPs adopted that minimize erosion and sediment transport (Figure 9.1). More specifically, USEPA (2000) is a comprehensive document describing management practices for controlling the delivery of pollutants from agricultural lands to receiving waters in terms of three main goals:

- Minimizing the pollutants available (source reduction)
- Retarding the transport and/or delivery of pollutants, either by reducing water transported, and thus the amount of the pollutant transported, or through depositioning the pollutant
- Remediating or intercepting the pollutant before or after it is delivered to the water resource through chemical or biological transformation (USEPA 2000)

Strategies for protecting source waters on or near grazing lands focus on managing the timing, frequency, duration, and season of livestock grazing. This helps to minimize soil compaction and preserve the soil's infiltration capacity. Rotational grazing is a prescribed grazing schedule in which two or more grazing units are alternately rested and grazed in a planned sequence over a period of years (USEPA 2000).

The CORE 4 Conservation Practices Training Guide, developed for the agricultural community by the USDA National Resources Conservation Service, discusses four primary strategies for reducing nonpoint sources of pollution from croplands (NRCS 1999). The strategies are complementary and are used as an integrated system. The four strategies include:

- ***Conservation Tillage.*** Leaving crop residue (plant materials from past harvests) on the soil surface to reduce runoff and soil erosion, conserve soil moisture, help keep nutrients and pesticides on the field, and improve soil and water quality; crops are grown with minimal cultivation of the soil so that plant residues are not completely incorporated and most or all remain on top of the soil. This practice is critical to



In this case, agriculture leads to changes in vegetation cover through cropping and grazing practices. Utilities may have opportunities to reduce or prevent agriculture through watershed management plans, conservation easements, land purchase, and other land protection strategies. BMPs can reduce the impacts of agriculture on source water through planting of buffer strips, managing crop nutrients, and minimizing chemical use. If extensive conventional agriculture or widespread grazing occurs in a watershed, then influent water may be degraded by increased turbidity, increased nutrient concentrations, and increased concentrations of herbicides and pesticides. Increased algal growth in reservoirs also can occur from runoff from agricultural areas.

Figure 9.1 Conceptual model showing linkages between a large-scale watershed event (agriculture) and impacts to source water, with opportunities for utility intervention and response

reducing phosphorus losses because the residue provides cover and thereby reduces nutrient runoff and erosion by water.

- ***Crop Nutrient Management.*** Managing and accounting for all nutrient inputs to ensure that nutrients are available to meet crop needs while reducing nutrient movements off fields; it also helps prevent excessive nutrient buildup in soils.
- ***IPM.*** Using a variety of methods for keeping insects, weeds, disease, and other pests below economically harmful levels, while also protecting soil and water quality.
- ***Vegetated Buffers.*** Involving a range of vegetated buffer types, from simple grassed waterways to riparian area buffers; vegetated buffers impede runoff and help filter nitrogen and phosphorus from runoff; the root systems of the plants hold soil in place, thereby decreasing the velocity of runoff and preventing erosion, and at the same time, the vegetation and soils strain and filter sediments and chemicals; buffers provide an additional barrier of protection by capturing potential pollutants that might otherwise move into surface waters.

The USEPA (2000) discusses four additional agricultural BMPs that can provide increased protection and benefits:

- ***Irrigation Water Management.*** Reducing nonpoint source pollution of ground and surface waters caused by irrigation systems.
- ***Grazing Management.*** Minimizing the water quality impacts of grazing and browsing on pasture and range lands.
- ***Animal Feeding Operations (AFOs) Management.*** Minimizing impacts of AFOs and waste discharges through runoff controls, waste storage, waste utilization, and nutrient management.
- ***Erosion and Sediment Control.*** Conserving soil and reducing the mass of sediment reaching a water body, protecting both agricultural land and water quality and habitat.

New York City has developed a comprehensive water management strategy that integrates three programs to control nonpoint sources in their watershed: the Watershed Agricultural Program (WAP), the Watershed Forestry Program, and Stormwater Pollution Prevention Plans. Box 9.1 describes how their WAP seeks to integrate agricultural BMPs.

ADDITIONAL INFORMATION

The Natural Resources Conservation Service (NRCS) maintains a National Handbook of Conservation Practices, updated continuously, which details nationally accepted management practices. These practices can be viewed at the USDA-NRCS Web site at http://www.nrcs.usda.gov/technical/efotg/.

Other comprehensive guides include:

- Stewart, B.A., D.A. Woolhiser, W.H. Wischmeier, J.H. Caro, and M.H. Frere. 1975a. Control of Water Pollution From Cropland, Volume I: A Manual for Guideline Development. Prepared by USDA-Agricultural Research Service and EPA-Office of Research & Development.

Box 9.1 New York Watershed Agricultural Program

New York has developed an innovative WAP that is a voluntary partnership between the city and upstate dairy farmers. The purpose of the WAP is to design and implement "whole farm planning." Whole farm plans are comprehensive strategies for controlling pollution at individual farms. Phosphorus and pathogens are the main pollutants of concern. The plans are prepared by local teams that include professional staff from the County Soil and Water Conservation District, Cooperative Extension, and the National Resources Soil Conservation Service. The plans control pollutant sources and implement controls from the scale of the landscape to the stream (USEPA 1999, NRC 2000).

The types of controls include:

- ***Pollutant Source Controls***, e.g., herd health maintenance, management of grass or hay production to reduce the need for fertilizer, and IPM to reduce pesticide use.
- ***Landscape Controls***, e.g., barnyard improvements, manure storage, scheduled and direct spreading of manure, and composting to control the application of animal waste to the land.
- ***Stream Corridor Controls***, e.g., streambank stabilization, animal watering systems, and vegetated buffers to slow and reduce pollutant loadings to streams.

- Stewart, B.A., D.A. Woolhiser, W.H. Wischmeier, J.H. Caro, and M.H. Frere. 1975b. Control of Water Pollution From Cropland, Volume II: An Overview. Prepared by USDA-Agricultural Research Service and EPA-Office of Research & Development.
- USEPA (U.S. Environmental Protection Agency). 1993. Management Measures for Agricultural Sources. Chapter 2 in *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA 840-B-92-002. January. Available: http://www.epa.gov/owow/nps/MMGI/Chapter2/index.html.
- USEPA (U.S. Environmental Protection Agency). 2000. *National Management Measures for the Control of Nonpoint Pollution from Agriculture.* EPA-841-B-03-004. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

CHAPTER 10
DROUGHT

Drought can have a variety of impacts on a watershed and the drinking water produced by that watershed. Similar to insect pests and pathogens, the water quality impacts from drought tend to unfold over time as a drought progresses. Droughts have obvious impacts on water quantity, but also can impact water quality through decreased vegetation cover, increased erosion, and increased fire risk.

Drought can be defined as a "moisture deficit bad enough to have social, environmental or economic effects" (The Drought Monitor 2006). Droughts occur because of lower than normal precipitation levels and, therefore, reduced water availability. Drought may occur on a short timescale, such as over one growing season, or over much longer periods of time, such as several years.

EFFECTS ON VEGETATION AND SOILS

Drought impacts vegetation and soils in a different manner from disturbances such as fire or storms. Instead of physical disturbance of the vegetation such as occurs with a severe storm, a drought will cause changes to the health of the vegetation. Drought conditions can reduce the vigor of existing perennial vegetation such as trees and make it more difficult for new plants to become established. Vegetation that regrows annually such as grasses and herbaceous plants ("forbs") may be reduced or absent in a drought. Long-term, severe droughts may lead to significant loss of plant biomass, exposing bare soil and effectively creating a disturbance similar to physical disturbances such as fires or windstorms. In the 1950s, a severe drought in the American Southwest caused significant widespread mortality of ponderosa pine at lower elevations and resulted in a widespread shift from forest conditions to piñon-juniper woodland that has persisted for more than 40 years (Allen and Breshears 1998).

Soil is affected by drought most obviously by drying. Soil chemistry may be altered as well. For example, pastures planted with legumes such as alfalfa can experience increased leaching of nitrate from soil under dry conditions (Stout et al. 2000). Because a drought can expose more bare soil, erosion can increase when precipitation events happen.

EFFECTS ON WATERSHED PROCESSES

The impacts of drought-induced vegetation changes on watershed processes depends on the intensity of a drought and the ecosystem where the drought occurs. Drought also increases the risk of other large-scale watershed events, such as fire and insect damage.

Drought Intensity

The intensity of a drought is determined by a number of factors, including the duration of drought, the season in which drought occurs, the magnitude of the reduction in precipitation and water availability, the frequency of drought, and the ecosystem in which drought occurs. A severe drought can be caused by any of the factors individually or by the interaction of several factors together.

The length of a drought may be very short, occurring over one growing season, or very long, occurring across several growing seasons. For example, in the southwestern U.S., the period of 1951–1956 is considered the worst drought of the 20th century, with some areas experiencing precipitation less than 85% of average levels for more than 10 years between the period 1942–1956 (Swetnam and Betancourt 1998). Drought length may combine with other factors to impact the severity of drought. A long drought, no matter the severity in terms of actual reduced water availability, will be more severe than a short drought as the effects compound over time.

The seasonality of drought may impact the severity and importance of drought. For example, in the Rocky Mountains, precipitation falling as snow during the winter and spring is the most significant source of water in the immediate foothills and plains. A winter and spring drought has a more significant impact on water availability and vegetation than a drought during the summer. However, in other regions and ecosystems, such as the Midwest or Northeast, drought during the spring and summer growing season would have the most significant impact on vegetation because demand for water is low in the winter.

The magnitude of drought, defined by the percent reduction in precipitation from average conditions, plays an important role in determining drought severity. One method of measuring the magnitude of drought is with the "Standardized Precipitation Index," which provides a standardized probability where zero means that rainfall equals the median precipitation amount and negative values indicate rainfall below the median amount.

The frequency of drought is another important variable contributing to the severity of drought events. In arid regions where drought conditions are common, vegetation is adapted to dry conditions, so short-term droughts may have minimal impacts on vegetation. In humid regions where droughts are rare, short-term droughts can have larger impacts on vegetation. In any location, a drought that follows shortly after a previous drought will have a more severe impact if vegetation and soils had not fully recovered from the previous drought.

Ecosystem Impacts

The ecosystem in which a drought occurs has a major influence on the impact of drought. As discussed above, ecosystems adapted to dry conditions are less susceptible to drought and will experience less severe effects than ecosystems without adaptations to dry conditions.

Because the severity of a drought depends on many factors, various methods have been developed to try to quantify the overall magnitude of drought. For example, the Palmer Index is a commonly used drought index. It uses temperature and rainfall information in a formula to determine dryness. Drought is shown as minus numbers; for example, minus 2 is moderate drought, minus 3 is severe drought, and minus 4 is extreme drought. The National Drought Mitigation Center tracks droughts across the U.S. using the "Drought Monitor," which is based on "a synthesis of multiple indices, outlooks and news accounts, that represents a consensus of federal and academic scientists" (The Drought Monitor 2006).

Drought clearly directly decreases water availability in the near-term, but it also can have longer-term effects on quantity and quality that are mediated through changes in vegetation. For example, in areas with intensively managed grazing, drought-related losses in vegetation can lead to elevated levels of nitrate leaching (Stout et al. 2000). If plants and microbes are not around to take up the nitrogen provided through fertilizers or nitrogen-fixing plants, that nitrogen can move into surface waters when it rains (Stout et al. 2000). However, another study that examined whether drought exacerbated grazing impacts on runoff and nutrient and sediment yield found no such effect (Emmerich and Heitschmidt 2002).

Drought also can weaken plants and make them more vulnerable to pest infestations. Among the best examples is the recent pine beetle outbreak in British Columbia (see chapter 7), which has been exacerbated by drought. As more vegetation dies off over time from such extreme outbreaks, runoff will likely increase later on.

Drought increases vulnerability to fire, either directly through killing plants or indirectly, through increasing vulnerability to pest infestations. Standing dead vegetation means higher fuel loads for fires. As described in chapter 3, intense fires can cause flooding, erosion, and sedimentation of streams, rivers, lakes, and reservoirs.

EFFECTS ON SURFACE WATER QUANTITY AND QUALITY

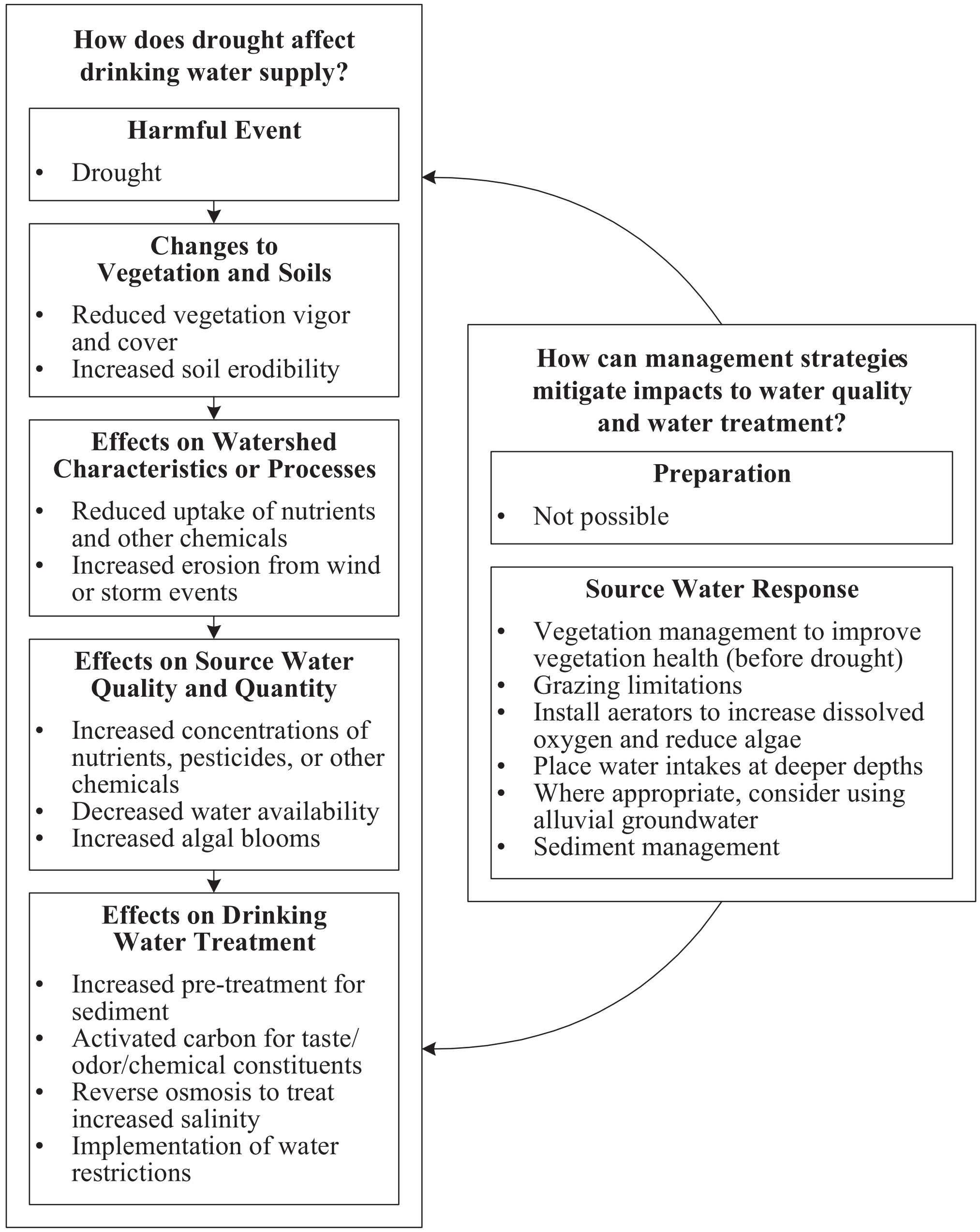
Obviously, drought can have significant impacts on water availability. However, there is rarely a simple linear relationship between the percentage decrease in precipitation during a drought and the decrease in water supplies for a water utility. Factors that affect how a drought translates into reduced water supplies include the intensity and seasonality of a drought, the size of the impacted watershed, whether streamflows are controlled by upstream structures or not, the status of water rights and other water users who may have higher priorities during drought, the status of any critical habitat needs for endangered species that would require minimum flows, and the location and potential vulnerability of water intake structures (Knutson, Hayes, and Phillips 1998). Utilities need to understand their specific situation to estimate how different types of drought events would impact water supply.

Water quality impacts from drought also can be significant. The loss of vegetation and associated plant roots can increase sheet erosion from exposed ground surfaces during rainfall events. Wind transport of soil and sediment during drought also contributes to erosion and can increase the turbidity of streams, rivers, and reservoirs (Knutson, Hayes, and Phillips 1998). Lower water levels in surface water bodies result in increased turbidity, increased salt concentrations, increased water temperature, changes in pH, and decreased dissolved oxygen. Concentrations of other chemicals such as nutrients and pesticides also can increase when water availability declines. Algal growth can increase during drought. Drying of wetlands during drought can impact wetland function significantly. In areas where wetlands provide important benefits to water quality, these benefits can be lost during a time of drought.

Drought also significantly increases the risk of wildfire. This can have negative impacts on water quality if the fire reaches catastrophic levels. In areas that require fire to maintain forest health, drought can be beneficial for leading to conditions where prescribed fire or "let burn" policies can be successful.

MANAGEMENT STRATEGIES

Because drought is an event that cannot be prevented, management strategies need to focus on responses to drought-induced changes in water quantity and quality (Figure 10.1). Many utilities have drought management plans in place to curtail demand through various voluntary or mandatory programs. The development of these management plans is beyond the scope of this report. Here, the focus is on management strategies utilities can take to minimize impacts to water quantity and quality to the extent possible.



In this case, drought reduces vegetation vigor and vegetation cover and increases soil erodibility, resulting in reduced nutrient uptake and increased vulnerability to wind and water erosion. Source water is impacted through increased concentrations of nutrients, pesticides, or other chemicals; increased turbidity after storm events; decreased water availability; and increased risk of algal blooms in lakes and reservoirs. No prevention measures are possible for this event. Utilities can minimize impacts to source water through sediment traps or other sediment management plans and by controlling algal growth in reservoirs. If impacts to source water are not prevented, utilities will need to respond to lower quality influent water at the treatment plant with increased pre-treatment or additional treatment steps such as activated carbon to reduce taste and odor problems and decrease the concentration of other harmful chemicals.

Figure 10.1 Conceptual model showing linkages between a large-scale watershed event (drought) and impacts to source water, with opportunities for utility intervention and response

Box 10.1 Coping with salt water incursions during drought, Virginia

Newport News Waterworks receives water from six watersheds, including five reservoirs and one river. Droughts can have a significant effect on water quality for this area. The river supplying water for Newport News is tidal, and during droughts, flow in the river is reduced. Reduced flow into the estuary can lead to upstream salt excursions, as far up as the treatment plant. Both the 2002 and the 2007 droughts caused increased salinity in the river. In response to saline excursions, the utility has built a reverse osmosis plant that they can use to treat the saline water during droughts or other events (such as a large storm) that could eliminate the barrier dam between salt and fresh waters.

Drought stress on vegetation and soils is exacerbated by other sources of stress. Vegetation that is healthy and in good condition can resist drought better than weak or diseased vegetation. Therefore, all the management strategies used to create healthy forest or rangeland conditions will minimize drought impacts. Reducing or minimizing additional disturbances during drought, including animal grazing, also can help protect vegetation and soil during vulnerable times.

Utilities also can minimize drought impacts through appropriate management of reservoirs and other utility infrastructure. Water aerators can reduce algae growth and increase dissolved oxygen in reservoirs. Other treatments to control algae may be required as well. The placement of water intake structures at deeper depths within reservoirs can minimize impacts from droughts, but at a significant expense. For example, the Southern Nevada Water Authority is currently building a new water intake structure for Lake Mead at a deeper water level because drought in the Colorado River basin has lowered lake levels and threatens a current water intake structure (Southern Nevada Water Authority 2008).

In coastal areas, drought can cause changes in the boundary zone between freshwater and salt water. Decreased flow in rivers can allow saltwater to move farther upstream and threaten water supplies. Box 10.1 describes how Newport News Waterworks has responded to this threat.

ADDITIONAL INFORMATION

This article describes the extensive vegetation change that occurred after the 1950s drought in the American Southwest:

- Allen, C.D. and D.D. Breshears. 1998. Drought-induced shift of a forest-woodland ecotone: Rapid landscape response to climate variation. *Proceedings of the National Academy of Sciences* 95:14839-14842. Available: http://www.pnas.org/cgi/content/full/95/25/14839.

This Web site provides weekly updates of drought conditions across the U.S.:

- The Drought Monitor. 2006. Drought Monitor: State-of-the-Art Blend of Science and Subjectivity. Available: http://www.drought.unl.edu/dm/classify.htm. Accessed September 24, 2007.

This reference provides an overview of how municipalities can reduce risk of impacts from drought:

- Knutson, C., M. Hayes, and T. Phillips. 1998. How to Reduce Drought Risk. Western Drought Coordination Council: Preparedness and Mitigation Working Group. March.

CHAPTER 11
CONCLUSIONS

When large-scale damage to watershed vegetation occurs, the most important question facing the water utility is whether subsequent changes to watershed processes will have the potential to impair downstream water quality and place new demands on drinking water treatment processes. Although the details of watershed processes are complex, our research indicates that the changes most critical for drinking water supplies can be summarized in terms of a few key watershed processes and related effects on water quantity and quality. This concluding chapter and Table 11.1 summarize our conclusions about key connections from the initiating event, to changes in vegetative cover and watershed processes, to effects on water quality parameters and treatment processes.

Once watershed vegetation is lost or damaged to a significant degree, there are changes in soils and biogeochemical cycling, decreased water infiltration, and increased surface runoff and erosion. These changes mobilize organic matter, organic and inorganic chemicals, and microorganisms that may be carried downstream in runoff or bound to eroding sediments. In turn, the type and quantity of sediments and contaminants that are deposited or dissolved in drinking water sources ultimately dictate treatment needs.

Just as different initiating events affect the same key watershed processes, these impact pathways converge on several general categories of water quality parameters:

- Suspended solids
- Dissolved organic and inorganic chemicals
- Total organic carbon
- Microbial contaminations

Persistent or severe changes in these parameters can necessitate additional pretreatment processes, filtration technologies, disinfectants, advanced technologies, and in some cases changes to treatment facilities requiring significant capital and operating expenditures.

By far the most common treatment change involves increased coagulation dosages. The coagulation and filtration process reduces all types of contaminants to some degree. But when increased coagulation is not sufficient to meet the influent challenge resulting from changes in vegetative cover and related watershed processes, a facility may need upgrade or replacement, or supplementation with advanced removal processes such as membrane technologies. All of these changes to treatment processes will increase costs, in some cases to a significant degree. Therefore, there is strong motivation to identify and implement strategies to mitigate the potential adverse effects of large-scale changes in vegetation.

Results of our literature review and case studies indicate that until now most mitigation strategies have involved responding to adverse impacts only after water quality is threatened. However, increasingly watershed managers are taking advantage of the many planning opportunities and preparation strategies that can minimize the extent and degree of adverse effects resulting from vegetation changes, thereby minimizing the need for expensive changes to treatment processes.

Although the report identifies a large number and variety of mitigation strategies, our case study participants stressed that one of the most important strategies is the acquisition of watershed lands, with priority placed on intact forests and vegetated riparian buffer strips. It is generally

Table 11.1
Summary of connections from initiating event, to changes in vegetative cover and watershed processes, to effects on water quality parameters and treatment processes

Event	Vegetation and soil changes	Effects on watershed processes	Effects on source waters	Implications for treatment	Examples of preparation and prevention strategies	Examples of response strategies
Wildfire	Removes vegetation, makes soil surfaces impermeable	Decreased infiltration; decreased nutrient uptake; increased erosion and sediment transport	Increased sedimentation, TSS, TOC, nutrients, taste and odor problems	Increased pre-treatment and coagulant; alternative disinfection; activated carbon to reduce taste and odor problems	Reduce fuel loads and even-aged stands; use automated surveillance systems to increase fire detection	Install sediment traps; use mulching, log erosion barriers, seeding, etc. to reduce erosion; apply biosolids to increase success of revegetation; form BAER teams
Timber harvest and logging roads	Removes forest cover and increases soil disturbance and compaction	Increased erosion and sediment transport	Increased sedimentation, TSS, TOC	Increased pre-treatment and coagulant; alternative disinfection	BMPs for logging and roads; culvert repair	Identify potential slide areas; revegetate harvested slopes
Storms	Removes or uproots vegetation and disturbs soil	Increased erosion and sediment transport	Increased TSS and sediment loadings	Increased pre-treatment and coagulant; alternative disinfection	Rehabilitate abandoned roads	Install sediment traps, develop sediment management plans for reservoirs
Urbanization	Reduces plant uptake of soil nutrients and creates greater nutrient loadings to downstream surface waters; reduces soil stability and increases sedimentation	Increased runoff, downstream flooding, and nutrient and sediment loadings	Increased nutrient and pollutant concentrations, sediment loadings and TSS	Increased pre-treatment for sediment; activated carbon for taste/odor/chemical constituents	Land purchase; conservation easements; zoning changes; reduced impervious surfaces; increased vegetated buffer strips	Remove pollutants from runoff before it flows to receiving waters; monitor for increased levels of waterborne pathogens (especially *Cryptosporidium*, *Giardia*)

(continued)

Table 11.1 (Continued)

Event	Vegetation and soil changes	Effects on watershed processes	Effects on source waters	Implications for treatment	Examples of preparation and prevention strategies	Examples of response strategies
Insect infestations	Reduces vegetation growth rates; impairs reproduction; increases mortality rates	Decreased nutrient transport; increased evapotranspiration changes in soil pH	Increased nutrients; changes in water availability	Increased pre-treatment and coagulant; additional treatment for nutrients (e.g., RO)	IPM to reduce spread; sanitation and quarantine practices	Limited response options if pest impacts are widespread
Invasive plants	Replaces native vegetation; results in less biodiversity	Changes evapotranspiration and disturbance regimes (e.g., fire)	Increased TSS (with increased fire); decreased water availability (depending on vegetation changes)	Increased pre-treatment and coagulant	Control strategies to reduce spread of invasives	Actions depend on specific impacts of invasives
Agriculture	Replaces native vegetation with crops; reduces plant cover from grazing; disturbs soil	Increased erosion and sediment and nutrient transport	Increased TSS, TP, TN, TOC, fertilizers	Increased pre-treatment and coagulant; alternative treatments (e.g., activated carbon, RO) for increased TOC and TP, TN	Riparian buffer strips; rotational grazing; livestock exclusion; conservation tillage; conservation easements	Nutrient and algae management for reservoirs
Drought	Decreases health and vigor of vegetation and establishment of new plants; increases soil erodibility	Reduced plant uptake of nutrients; increased erosion from wind or storms; increased risk of event cascades (e.g., fire, insects)	Decreased water availability; increased salinity; increased risk of algal blooms	Increased pre-treatment for sediment; activated carbon for taste/odor/ chemical constituents; use of RO to treat increased salinity	Not possible	Establish "trigger levels" for initiating extra conservation measures; limit grazing; algal control for reservoirs

RO = reverse osmosis; TN = total nitrogen; TOC = total organic carbon; TP = total phosphorous; TSS = total suspended solids known that well-managed forests provide the greatest opportunity for generating an ongoing supply of high quality drinking water. In fact, we found clear evidence that the costs to protect watersheds to enhance natural filtration are substantially less than the cost to build and operate filtration facilities.

These findings lead to the general conclusion that consideration of catastrophic changes to watershed vegetation is an important element of source water protection planning and management. In the final chapter to this report, we outline a number of recommendations for accomplishing this goal.

RESEARCH NEEDS

With the exception of wildfire, we found little quantitative information on water quality effects from the events we examined. Though many utilities conduct regular water quality monitoring, these data are seldom analyzed before and after catastrophic vegetation changes. There is also little information concerning the costs incurred by implementing mitigation strategies compared to the "avoided costs" of additional treatment. The relative risk of water quality impairment from a particular type of event will depend on whether the event is severe enough or likely to persist long enough to require treatment or infrastructure changes. In some cases, a rare but high impact event may require the development of an expensive prevention strategy to minimize the serious harm to water quality that is otherwise likely to occur. Or it may be necessary to plan for an alternative water supply during or immediately after particular events. Some events that are ongoing, such as urbanization, may not require action until some critical "threshold" is crossed. Monitoring data collected before and after events are needed to identify such thresholds. In general, information on water quality effects and the costs of treatment or mitigation to minimize effects is needed for utilities to (1) weigh the relative risks of decreased water quality against the relative costs to minimize impairment, (2) rank trade-offs among water quality risks and the costs of alternative approaches for minimizing risks, and (3) compare costs relative to other utility expenses.

CHAPTER 12
RECOMMENDATIONS TO UTILITIES

A number of principles for source water protection planning and management emerge from this research. Most importantly, although catastrophic events such as those discussed in this report may have a low probability, the potential impacts can be substantial, and therefore these events should be considered as part of any source water protection program. Planning could proceed as follows:

- Identify the types of large-scale events that may occur in your watershed
- Survey and map areas of existing damage and areas that are likely to be particularly sensitive to future events
- Assess the relative risks of particular events
  - Consider both the likelihood of occurrence and the relative magnitude of likely impacts
  - Identify potential event cascades
- Identify key vulnerabilities and treatment concerns for each type of event
- Identify specific actions that may be needed before, during, and after events
- Create a “toolbox” of mitigation techniques specific to your watershed
- Track the success of mitigation strategies (qualitatively at a minimum and quantitatively when possible) and make changes as needed
- Monitor water quality during and after events and use monitoring results to identify critical thresholds that could trigger the need for additional treatment unless mitigation actions can eliminate threshold effects
- Meet regularly with stakeholders to identify anticipated land use changes and actions that may be needed to prevent or minimize changes to major damage to vegetative cover
- Promote ongoing communication between source water protection managers and water treatment staff

Among the most critical of these activities will be promoting interactions among source water protection managers and treatment staff. Several of our case study participants noted that there is often little understanding among treatment staff of how source water protection can help reduce novel demands on treatment processes. Likewise, it is critical that source water protection planners understand the implications of watershed changes for drinking water treatment and the effectiveness of alternative treatment strategies.

APPENDIX A
CASE STUDIES OF PREVENTION AND RESPONSE STRATEGIES

THE MASSACHUSETTS WATER RESOURCES AUTHORITY

Key message: Forest vegetation is actively managed to minimize the size and intensity of disturbances and preserve high-quality surface water necessary for an unfiltered treatment system.

Utility representative:	Jonathan Yeo
Title:	Director, Division of Water Supply Protection
State:	Massachusetts
Web site:	http://www.mwra.state.ma.us/

Watershed Description

The MWRA manages one of the largest unfiltered water supply systems in the country. More than half of the land within the system is protected as open space and a significant portion is owned by MWRA. Three major watersheds feed the Ware River, the Quabbin Reservoir, and the Wachusett Reservoir. Together, they provide public water to all of greater Boston and several small communities in western Massachusetts. The watersheds are primarily forested (77%), but also contain a mixture of open water, wetlands, agricultural lands, commercial and industrial lands, and recreation areas. MWRA actively manages the forestland to protect surface water resources so it can continue to operate the reservoirs as an unfiltered surface water supply. A Source Water Protection Plan was completed in June 2002 and a Watershed Protection Plan for the entire system is being revised (http://www.mass.gov/dep/water/drinking/).

Water Treatment Plants

MWRA's John Carroll Water Treatment Plant, which serves metropolitan Boston, uses ozonation for primary disinfection and chlorination for residual disinfection, adds sodium carbonate and carbon dioxide for pH and alkalinity control, and fluoridates the treated water. The smaller Chicoppe Valley aqueduct system uses chlorination for primary disinfection, but MWRA is considering ultraviolet (UV) disinfection in the future.

Events of Concern and Protection Strategies

Insect infestations, storms (e.g., ice, wind, hurricane, snow/runoff, rain), and wildfire (especially following drought) can devastate forests. The consequential loss of vegetation can affect surface water quality by increasing soil erosion and sediment load. The extent of vegetation loss depends on the severity of the event and overall forest health, so managing and protecting the forest are critical to protecting surface water quality. To do this, MWRA applies management actions focused on improving age class and species composition diversity within the forest. Management objectives include maintaining an under-story to support future growth, a mid-story for rapid nutrient uptake, and an over-story that can regulate organic decomposition, supply seeds, and provide deep roots for water filtration and soil retention. Improving these elements can protect the forest from damaging events and enhance recovery when large-scale disturbance events occur.

To ensure success, MWRA carefully monitors the size, age, and species composition of trees and other plants in the forest. Information is gathered every 5 to 10 years from Continuous Forest Inventory plots established in the 1960s. Within the forests, canopy layers are balanced by an "uneven-aged silviculture" approach that uses commercial logging to thin and harvest trees in a patchwork pattern. The goal is to ensure that no single event will devastate the entire forest, but rather will only affect smaller stands of trees. In this way, adverse impacts on water quality and quantity are mitigated by the remaining intact stands. The regeneration management strategy also includes controlled deer hunting, regeneration silviculture, and supplemental planting. MWRA protects the water supply from pathogen contamination using a harassment program that discourages roosting of gulls and geese near surface water resources. Forest management generates revenue of approximately $600,000 per year from logging contracts. Quabbin forestry is "green certified" by the Forest Stewardship Council (http://www.mass.gov/envir/forest/pdf/forestgreencertificationhandout.pdf).

FAIRFAX WATER

Key message: Increasing urbanization is threatening raw water quality in two watersheds of importance to the Fairfax County Water Authority (Fairfax Water). Both span multi-jurisdictional areas, making watershed management challenging. In Virginia, regional point and non-point source water protection measures have been established to help maintain public water supply protection. A voluntary, regional-based partnership of water utilities and government partners has been formed where water supplies cross state boundaries to give water utilities a stronger voice in watershed protection efforts.

Utility representative:	Greg Prelewicz
Title:	Chief, Source Water Planning and Protection
State:	Virginia
Web site:	http://www.fairfaxwater.org/index.htm

Watershed Description

Fairfax Water supplies water for nearly 1.5 million people in northern Virginia from two watersheds: the Occoquan Reservoir watershed (590 mi^2) and the Potomac River watershed (11,000 mi^2). Both the Potomac River and Occoquan Reservoir watersheds have experienced an increase in urbanization over the last 50 years.

About 400,000 people live in the Occoquan watershed, which crosses six local jurisdictions in Virginia. Land use includes residential areas of varying densities (20%); forest or idle land such as meadows, undeveloped land, or managed forest (50%); agricultural areas (20%); and miscellaneous uses (10%).

The Potomac River watershed upstream of the Fairfax Water intake crosses four states: West Virginia, Maryland, Virginia, and Pennsylvania. Land use includes residential areas of varying densities (10%), forest or idle land such as meadows, undeveloped land, or managed forest (50%); agricultural areas (30%); and miscellaneous uses (10%).

A Source Water Assessment was completed by the utility and can be found at: http://www.fairfaxwater.org/water/swap.htm.

Water Treatment Plants

The utility operates two treatment plants: The James J. Corbalis, Jr. Water Treatment Plant (WTP), which utilizes the Potomac River; and the Frederick P. Griffith, Jr. WTP, located near the Occoquan Reservoir. Both plants use flocculation, sedimentation, ozonation, and chloramination treatment methods, incorporating deep bed granular-activated carbon filters. The plants treat a combined average of around 160 million gallons per day (MGD). Approximately 55% of the source water is from the Potomac River and 45% is from the Occoquan Reservoir.

Events of Concern and Protection Strategies

In the early 1970s, in response to concerns increased over declining water quality in the Reservoir, the Virginia State Water Control Board adopted "a Policy for Waste Treatment and Water Quality Management in the Occoquan Watershed." The policy recognized that highly advanced wastewater treatment would be required to maintain the public water supply. The Occoquan Reservoir is one of the largest indirect potable re-use reservoirs in the country, with a highly advanced wastewater treatment plant, the Upper Occoquan Service Authority, about 5 miles from the upstream limits of the reservoir (17 miles from the intake). Further, a non-point source management program was created, funded by Fairfax Water and the watershed jurisdictions, to develop technical guidance and maintain a linked watershed and reservoir computer model to simulate water quality in the Reservoir with changes in land-use. In addition to these management measures, Fairfax County, Va., took major steps in the early 1980s to protect lands in the Occoquan watershed by "downzoning" nearly 41,000 acres. Seventeen percent of the Occoquan watershed, or roughly 64,500 acres, lies in the county. The remaining portion of Fairfax County that was not downzoned, the county created a Water Supply Protection Overlay District, requiring more stringent stormwater management controls to reduce phosphorus concentrations from runoff.

A cooperative partnership with other utilities was formed for the Potomac River (the Potomac River Drinking Water Source Protection Partnership), and Fairfax Water is a participant. The cooperative is sharing existing source water assessments among the various utilities and working together to gather additional data.

The partnership has identified several issues of importance and has formed workgroups focused on pathogens, emerging contaminants, disinfectant byproduct precursors, urban issues, agricultural issues, and development of an early warning and emergency response system. Each of the workgroups has identified objectives, activities, and milestones for its focus topic. By carrying out these workgroup activities, a more thorough understanding of potential contaminant sources will be developed, prioritization of protection areas will be established, and watershed protection activities that are most likely to positively impact drinking water quality will be identified. As funding becomes available, these watershed protection activities will be implemented.

The partnership regularly holds meetings and workshops on topics of importance. Some of the recent accomplishments of the partnership include:

- Completion of a *Cryptosporidium* Source Tracking project. This project, funded by a USEPA Regional Applied Research Effort grant and by contributions from partnership

members, helped to improve the understanding of the types and the sources of cryptosporidium in basin waters.
- Held a regional tabletop exercise to test emergency response and communication plans for the water supply in the Washington, D.C. metropolitan area, including facility response plans under a major Oil Spill release scenario, and allow participants to discuss steps to be taken to better prepare for future water system-specific emergency incidents.
- Held several workshops on the emerging challenge related to endocrine-disrupting compounds (EDCs) and pharmaceuticals and personal care products (PPCPs) in source waters.
- Held informative workshops on roadway deicing chemicals, pathogens, land conservation, efforts, and agricultural activities

More information on the Potomac Drinking Water Protection Partnership can be found at http://www.potomacdwspp.org.

NEWPORT NEWS WATERWORKS

Key message: Newport News Waterworks receives water from six watersheds threatened by large-scale vegetation change events, including hurricanes, floods, drought, and urbanization. The utility does not own all of the land within their watershed, and has little authority in land planning and zoning. They are working with state government agencies to protect the watersheds.

Utility representative:	Dave Morris
Title:	Natural Resources Manager
State	Virginia
Web site:	http://www.nngov.com/waterworks

Watershed Description

Newport News Waterworks manages six watersheds including five reservoirs and one river, and supplies water to over 400,000 people in the Cities of Hampton, Newport News, Poquoson, and portions of York County and James City County. The City of Newport News owns 8,000 acres of park and forest land within the regional watershed. One of the watersheds is 45 mi^2. The watersheds include both urban and forested areas; white oak and hickory are the predominate vegetation in the forestland.

The watershed crosses five jurisdictions, and the utility's involvement in each jurisdiction varies. The utility is often involved either formally or informally with zoning and planning processes. They strive to develop relationships with local governments so that they are consulted when new projects arise. They do not have jurisdiction within the river, with the exception of the Chesapeake Bay Act, which requires that all watersheds serving the Chesapeake Bay meet specific water quality standards. Newport News Waterworks owns land surrounding all the reservoirs.

The source water protection plan varies in each watershed. The regional planning agency (which serves 11 cities and counties) developed a Source Water Assessment with a consultant and a forest management plan has been in place since the mid-1940s.

Water Treatment Plant Description

Newport News operates two fairly new treatment plants that treat 46 MGD annually. The plants are similar; both use screening, ozone, clarification, filtration, and then chloramines as the final disinfectant. However, the way the plants remove alum (used for coagulation) is different. One plant uses a middle water column to remove the floc and the other plant uses dissolved air filtration. Newport News also has a reverse osmosis plant for desalinization and removal of chlorides. Water is mixed in a clearwell for consistency.

Treatment modifications are generally the result of algae build-up in the lakes. Algae levels are constantly monitored and, when necessary, copper sulfate is applied. Seasonal increases in nutrient levels are natural but may be further elevated by urbanization. Water quality monitoring equipment is in place to obtain data used to adjust treatment as necessary.

The utility has already made some modifications to the treatment plants to accommodate the Disinfection Byproduct Rule (the switch to ozone) because their water is high in organics.

Events of Concern and Protection Strategies

The major events threatening the Newport News watersheds include hurricanes, ice storms, wildfire, and invasive species. Winds from Hurricane Isabelle in 2003 opened a large canopy in the watershed, which was conservatively estimated at 50,000 trees. In the short-term, the winds agitated the reservoirs and increased sediment suspension, which caused the utility to shut down the treatment plants. The utility salvage-logged much of the downed white oak and hickory and then replanted some areas with fast-growing pine, leaving other areas to regenerate naturally. Revegetation occurs rapidly within the watershed, and within a year the area had established abundant grasses, vines, and other opportunistic plants.

Wildfires are prevented and managed by the use of many roads and trails that act as barriers or fire breaks. Emergency response is fast and fires are quickly suppressed so water quality impacts are minimal.

Recent droughts—one in 2002 and the severe 2007 drought—have been more severe than previous droughts in the area. Droughts lead to lower flows in the river, which being near the coast causes saline excursions upriver. When drought is severe and flow gets very low, the saline excursions can reach the treatment plant. The utility has to cut off their pumps in low-flow periods to avoid salinity in the drinking water. When this happens, they augment the water supply with groundwater and water from upstream reservoirs.

Newport News is working on further diversification of the watershed to protect against sedimentation. Having a diversified watershed is a significant asset; it prevents major vegetation change events in a single watershed from affecting the entire system. Another major asset to the utility is the Chesapeake Bay Act, which gives them added authority regarding drinking water quality throughout their source watersheds.

PHILADELPHIA WATER DEPARTMENT

Key message: The utility operates two large watersheds that cross multiple lines of jurisdiction and are threatened by increasing development. Through a collaborative effort with the Natural Lands Trust (NLT) and the Delaware Valley Planning Commission, the utility prioritized lands for source water protection. They are currently working with other municipalities to implement protection strategies to protect high-priority areas.

Utility representative:	Jason Hunt
Title:	Manager, Source Water Protection Program
State:	Pennsylvania
Web site:	http://www.phila.gov/water/

Watershed Description

The Philadelphia Water Department draws water from two watersheds: the Schuylkill River watershed and the Delaware River watershed. The Delaware watershed is the largest (7,500 mi^2), while the Schuylkill watershed covers 2,000 mi^2. The Schuylkill watershed includes forest (32%), agricultural land (34%), and developed land (28%) (Philadelphia Water Department 2002). The Delaware watershed is 68% forested, 18% agriculture, and 14% developed land (Philadelphia Water Department 2007).

A significant portion of the watersheds are owned by the utility; other landowners include private parties and other government agencies across multiple counties. Philadelphia Water has performed a Source Water Assessment and has Source Water Protection Plans for the watersheds. The utility plays an integral role in decision-making and management practices within the city limits of Philadelphia but less outside the city limits.

Water Treatment Plant Description

Philadelphia Water operates three treatment plants that treat an annual average of 290 MGD. All three plants use conventional treatment methods: natural settling in reservoirs, disinfection with sodium hypochlorite, coagulation, flocculation, sedimentation, filtration, and final treatment with fluoride, zinc orthophosphate (to minimize corrosion), and ammonia (to minimize the chlorine taste).

While the utility does not anticipate any changes to the treatment plants in the near future, major land use changes in the Delaware River watershed could result in reduced flow into the estuary. Saltwater could then flow up into the river and create additional treatment needs, such as desalinization. Though possible, this scenario is extremely unlikely and is behind some of the management decisions the utility has made regarding development.

Events of Concern and Protection Strategies

The Philadelphia Water Department has not experienced any major vegetation changes to date; however, urbanization and development leading to flashy flow in the rivers, flooding, bank erosion, and increased sediment are of concern. As stated above, in an extreme case of development, reduced river flow could, conceivably, lead to salinization of source waters. Through modeling exercises, the utility is evaluating watershed management options aimed at minimizing the current impacts of urbanization and preventing future problems, exemplified on the extreme end by salinization of the river.

Their most important prevention strategy is land prioritization within the watershed, which was developed directly from the build-out plan modeling exercise. They worked with the Delaware

Valley Planning Commission and the NLT to develop a tool to identify areas where protection will provide the greatest return for protection of water quality and critical habitat. Because they do not own all of the watershed, the biggest challenge will be implementing protection strategies based on the land prioritization study. They are discussing opportunities for land conservation and protection with other municipalities to preserve land for water quality.

ASHEVILLE NORTH CAROLINA WATER RESOURCES DEPARTMENT

Key message: The utility is using a biological strategy (beetle releases) to prevent hemlock devastation from non-native insects. They also developed a response strategy to prevent destructive flooding from hurricanes.

Utility representatives:	Lee Hensley and Leslie Carriero
Title:	Water Production Superintendent
State:	North Carolina
Web site:	http://www.ashevillenc.gov/departments/water_services/default.aspx?id = 556

Watershed Description

The primary sources of water for the City of Asheville are springs, streams, and lakes in the North Fork watershed in Black Mountain to the northeast. The watershed includes 22,000 acres of protected mountain forests owned by the city, and contains the North Fork and Bee Tree reservoirs. The watershed is 75 to 80% deciduous forest dominated by yellow poplar and oak hickory. The remaining 20 to 30% of the watershed is eastern hemlock-dominated conifer stands. The forests are dynamic, with new seedlings sprouting in the first few years following events such as storms or wildfires.

The Mills River to the south provides a secondary source of water and although the water is not pristine, it is good quality. The Mills River watershed covers 47,440 acres and lies mostly (75%) in the Pisgah National Forest. It contains a mixture of forest, farmland, and low-density development. The Water Resources Department manages the Mills River watershed cooperatively with local landowners.

Water Treatment Plants

The North Fork Water Treatment Plant uses a conventional system to treat water from the North Fork watershed. Incoming water is pretreated with chlorine and mixed vigorously with alum to begin the coagulation process, and then the water is transferred to flocculation basins for further mixing and coagulation. Water from the basins is passed through a dual sand-anthracite filter, treated again with chlorine, and then pumped to a storage tank called a clearwell. Water from the clearwell is pH-adjusted with caustic soda. Chlorine, orthophosphate (for corrosion control), and sodium bicarbonate are added inline on the way to distribution.

The Mills River Treatment Plant uses a similar treatment process but treats the water with ozone instead of chlorine as a disinfectant. Together, the plants produce 21 to 22 MGD of treated water (annual average). The majority (17 MGD) of water is from the North Fork Water Treatment Plant.

Events of Concern and Protection Strategies

Several environmental events, including insect infestation, wildfires, and hurricanes, threaten watershed health and proper function of the reservoirs. Wooly adelgid infestation is a major concern that could potentially destroy the hemlock population within the North Fork watershed. The Water Resources Department is releasing predator beetles to the area, at a cost of $10,000 for 5,000 beetles, in an effort to save as many trees as possible. The effectiveness of the counterattack is still not known. If unsuccessful, significant vegetation loss could occur within the North Fork watershed. Hemlock is an acidic tree species, and acres of dead trees could acidify the soils, which could lead to a pH change in source waters. Water temperatures could rise and sedimentation could increase as a result of the vegetation loss, and together these changes could lead to taste and odor problems in drinking water. A change in pH may force modifications to the treatment process. Currently, the pH of source waters ranges from 6.0 to 6.4. However, if the beetle release effort fails, species diversity within the forest is high and the hemlocks will be replaced by another species within two to five years, minimizing long-term impacts to the watershed, which would help mitigate the effects of Hemlock die-off.

Wildfires can be prevented or the damage can be minimized by forest management practices, however, public opinion has limited the acceptability of intensive management techniques such as prescribed fire or timber harvest. Therefore, the Water Resources Department is developing wildfire response strategies to deal with major fire or massive tree loss (anticipated to occur within the next five years).

Although inland, Asheville occasionally experiences flooding from hurricanes but does not have the wind storms or massive devastation usually seen in coastal communities. Hurricanes Francis in 2004 and Ivan in 2005 convinced the utility of the need for hurricane response strategies to prevent flooding. The reservoirs did not have sufficient capacity to contain the heavy rainfall and large volumes of water had to be released to prevent it from overtopping the dam. The heavy volume of water released caused a break in the main water line, and the City of Asheville was without water for several days as a result. Based on recommendations from an engineering study, the reservoir levels are now maintained at a lower level to provide more storage so that water can be released slowly.

GREENVILLE WATER SUPPLY

Key message: Greenville Water Supply owns and controls 100% of two of the three watersheds that supply water for the City of Greenville, South Carolina. As a result, these two watersheds require minimal management to maintain high water quality. The third watershed is threatened by urban and agricultural areas. The utility is working to create and maintain positive and effective relationships with the landowners and other stakeholders in this watershed to protect the source water.

Utility representative:	K.C. Price
Title:	Water Resources Manager
State:	South Carolina
Web site:	http://www.greenvillewater.com/default.asp

Watershed Description

Greenville Water maintains three watersheds that supply water for the City of Greenville, South Carolina. They own 100% of the land in two of the watersheds: the Table Rock watershed (9,633 acres) and the North Saluda watershed (16,183 acres). Greenville Water also receives water from the Keowee watershed, which is 377 mi^2, but they do not own any of the land. The Keowee watershed is primarily residential, private ownership and includes some agriculture and mountain forest land. The residential area is mainly concentrated near Lake Keowee. Lake Keowee is owned by Duke Energy, and the utility extracts water based on an agreement with the owner. The watersheds that Greenville Water owns are old growth forest, primarily hardwoods, dominated by poplar and oak.

Greenville Water has 100% input on land decisions, including zoning and planning, within the watersheds they own; Greenville owns the land and The Nature Conservancy monitors the watersheds to ensure compliance with conservation easements. The two groups are committed to maintaining a pristine forest and protected watershed. Greenville does not have authority in the Keowee watershed but is invited to provide outside opinion for actions within the Keowee watershed as a water quality expert. The state performed a source water assessment for the watersheds.

Water Treatment Plant Description

Water from the Table Rock and North Saluda watersheds is treated at a state-of-the-art facility that uses alum coagulation, dissolved air flotation, and filtration. The plant treats an average of 50 MGD with a maximum capacity of 75 MGD. The Atkins plant (receiving water from the Keowee watershed) uses alum coagulation, conventional sedimentation, and filtration and treats an average of 20 MGD with a maximum capacity of 60 MGD. No adjustments to the treatment process have been necessary at either plant.

Events of Concern and Protection Strategies

In the forested watersheds owned by Greenville, the major event of concern is wildfire, though they have not had a major fire in a very long time. Other potential concerns include southern pine beetle and wooly adelgid infestations, and small patches of invasive kudzu that, if left untreated, could become a problem. The policy is to allow natural conditions to occur in the watersheds As a result of this policy, the watershed has enough diversity to withstand vegetation change events and minimize effects of these events on a watershed scale.

The utility has staff that patrol and maintain access to the watersheds, spot fires, and fight fires when they happen. The watershed has an extensive set of fire roads to allow quick access when fires are spotted. They man a fire tower adjacent to one of the reservoirs that is staffed during dry periods, they work with the forestry department to respond to fires, and have the ability to fight fires themselves until the forestry department (or other) firefighters arrive. Additionally, they have good relationships with landowners adjacent to the watershed; in many cases, watershed personnel have keys to gates, giving them quicker access to areas of the watershed that could otherwise be difficult to reach. With these measures, they are generally able to keep fires to a few acres at most. They do not do any prescribed burning or timber harvesting.

In the Keowee watershed, the primary events of concern are agriculture and development. Greenville Water is beginning to see some impacts in the watershed from these two activities;

however, they have not seen a change in raw water quality in the last 20 years. Greenville Water works closely with the owners of Lake Keowee and Duke Energy to coordinate effective water management plans. The utility participates in public outreach programs, conservation programs, and actively works with other concerned groups such as the Friends of Lake Keowee (FOLKS). Greenville Water Supply monitors reservoir water quality every month for phosphates and nitrogen compounds, and conducts algal counts. In conjunction with FOLKS, the Greenville Water System monitors fecal coliform levels to help monitor the raw water quality of Lake Keowee. They also monitor raw water turbidity, temperature, and pH on a continuous basis. If these parameters change significantly, they will evaluate their management and treatment.

ORANGE WATER AND SEWER AUTHORITY

Key message: The utility has worked cooperatively with local, county, and municipal governments to limit development and urbanization in the privately owned watersheds to protect water quality.

Utility representative:	Ed Holland
Title:	OWASA Planning Director
State:	North Carolina
Web site:	http://www.owasa.org/

Watershed Description

Orange Water and Sewer Authority (OWASA) obtains its source water from two watersheds—each with a drainage area of approximately 30 mi^2. More than 90% of the watershed land is privately owned and used for agriculture or low-density residential housing. Approximately 60% of the watersheds are in mixed pine/hardwood forest land cover; 15% is cropland; 15% is pasture; and about 10% is low-density rural/residential development.

The utility's most direct control over land use decision-making is through its own extension policies; i.e., in order to sustain a low-density development pattern, OWASA prohibits the extension of its water or sewer lines into the watersheds of its two water supply reservoirs. OWASA has no planning or zoning authority in the watersheds. The watersheds are zoned for five-acre (minimum) residential lots, which are served by individual wells and septic systems.

The State of North Carolina performed source water assessments for all surface water sources in the state. The utility had previously conducted independent watershed studies of its own.

Water Treatment Plant Description

OWASA uses conventional alum coagulation, sedimentation, filtration, and chloramines for disinfection in its treatment plant. The plant treats an average of 8 to 9 MGD. No treatment changes are currently being considered for the plant. OWASA has, however, considered in-lake management options for dealing with cyanobacterial (blue-green algae) blooms in the reservoirs. OWASA is not proceeding with any changes in reservoir treatment.

Events of Concern and Protection Strategies

Increases in nutrients and pollutants associated with development and suburbanization are the most significant threats to water quality in this watershed. Major storm events, including the refilling of its reservoirs after extended periods of drought-induced drawdowns, have been associated with periods of higher than normal TOC concentrations in the source water. Drought and climate change are among OWASA's long-term water supply concerns for the future. The most significant treatment concerns are periodic blue-green algae blooms and occasional exceedences of trihalomethane (THM) and/or haloacetic acid (HAA5) standards in the finished water, which appear to be associated with reservoir refilling events as noted above.

The major focus of OWASA's prevention strategy has been to limit development in the watersheds, generally through non-structural land-use management. The utility has also protected 1,000 acres of watershed land through fee simple acquisition and conservation easements.

ST. PAUL REGIONAL WATER SERVICES

Key message: St. Paul Regional Water Services receives water from two watersheds threatened by urban development and agriculture. With the guidance of an outside consultant, they were able to identify needs and focus efforts within one of the watersheds to maximize water quality improvements. They are currently engaged in a multi-agency funded study analyzing total maximum daily loads (TMDLs) from the Mississippi River to direct watershed management improvements for the second watershed.

Utility representative:	John G. Blackstone
Title:	Source Water Protection Manager
State:	Minnesota
Web site:	http://www.stpaul.gov/index.asp?NID=75

Watershed Description

St. Paul Regional Water Services manages two watersheds: the Mississippi River watershed (20,000 mi^2) and the Vadnais Lake Area Water Management Organization (VLAWMO) watershed (23.5 mi^2). The VLAWMO watershed is primarily urban, while the Mississippi River watershed is mixed use including forest, agriculture, and urban areas. The Mississippi River watershed covers several ecoregions, including Minnesota wetlands (10 mi^2), northern lakes and forests (10,000 mi^2), north central hardwood forest (8,900 mi^2), and western corn belt plains (1,000 mi^2).

The utility owns very little land in either watershed. The land is primarily privately held, owned by other public owners, or state and federal governments. As a municipal corporation, St. Paul Regional Water Services does not have a role in zoning or planning. The VLAWMO has a management plan for their district and the utility completed a source water protection plan that encompasses both watersheds. A source water assessment has been completed for the Mississippi River watershed.

Water Treatment Plant Description

St. Paul Regional Water Services uses conventional treatment. Water is softened with granulated activated carbon filters, which were just installed. The average daily production is 45 MGD.

In response to recent taste and odor issues, which were attributed to elevated phosphorous, the utility installed granulated activated carbon filters. Additionally, they have aerated the reservoir to improve source water quality and increased their water quality monitoring program. They may include micro filtration in the treatment process in the future.

Events of Concern and Protection Strategies

The primary water quality concerns for the St. Paul Regional Water Services are elevated phosphorous levels in source water, coming primarily from urban runoff associated with development (especially in the VLAWMO) and a small agricultural basin in the Mississippi River watershed. Agriculture has existed in this watershed for 150 years and significantly impacts water quality in the watershed. Other upstream concerns include invasive species and runoff caused by logging.

The utility worked with a consultant to develop a model based on TMDLs for the VLAWMO watershed. Using this model for guidance, they actively managed the reservoir and the urbanized watershed to decrease phosphorous concentrations in water from 50 parts per million (ppm) to 35 ppm. Management activities included installing impoundments and attenuation devices to slow the rate of runoff to the reservoirs. For example, they diverted a creek so the water would meander through a vegetated area before reaching the river.

The utility is currently working on a similar process with the Minnesota Pollution Control Agency to evaluate TMDLs within the Mississippi River watershed. They have worked with farmers in the agricultural water basin to encourage the use of buffer strips to attenuate runoff. Once the TMDL studies are completed, they will work with state and local agencies to improve water quality in the Mississippi River watershed. Action categories include source water protection education and awareness, urban stormwater management, agricultural management, transportation and corridor spills management, commercial and industrial management, well and individual sewage treatment system management, data collection and analysis management, and administration. Because the utility does not have jurisdiction in the watersheds, they must rely on state agencies to enforce watershed protection measures. They participate in regional projects and worked with the state legislature on a clean water legacy bill that was passed by Minnesota voters in November 2008. In the past, the legislature has not been able to fund the utility and watershed protection efforts sufficiently. The utility hopes this bill will give them the funding and public support needed to make significant improvements in their watersheds.

The utility spent several million dollars on prevention/response strategies in the VLAWMO watershed to reduce phosphorous concentrations in source water. At this time, only the TMDL study has been implemented in the Mississippi River watershed. Their proactive approach, as opposed to a previous response-based approach, reduced the need for emergency response. The utility does have emergency response actions in place for accidents or spills. Finally, they are looking into building an interconnect between Minneapolis and St. Paul so that the cities can supply each other with water in the event of a major water quality problem.

CITY OF BEND WATER DIVISION

Key message: The City of Bend is required to meet more stringent federal water treatment rules by 2012 which will surpass the existing surface water system treatment requirements, currently an exempt, non-filtered disinfection process. In addition to meeting the new criteria, new treatment options could also "fireproof" the watershed so that, in the event of a fire, they will be prepared for the subsequent increase in turbidity. They are studying the feasibility of including UV disinfection and/or membrane filtration for meeting the new treatment requirements, and are also evaluating the potential for adding hydroelectric generation as part of the pipeline replacement phase of the project which would provide additional revenue and offset energy requirements of any final treatment process which is selected.

Utility representative:	Tom Hickmann
Title:	Assistant Supervisor for the Water Division Manager
State:	Oregon
Web site:	http://www.ci.bend.or.us/depts/public_works/water/index.html

Watershed Description

Bridge Creek watershed provides, on average, about 50% of the City of Bend's drinking water supply. The remaining 50% is obtained from groundwater wells. The U.S. Forest Service (USFS) owns 100% of the Bridge Creek watershed, which has no roads or human inhabitants. The drainage boundary is 2,300 acres, but the administrative acreage extends to 7,700 acres. Vegetation within the watershed is primarily old-growth forest dominated by lodgepole pine (300 to 400 years old), some high-altitude fir and spruce, hemlock (5 to 6 feet tall), and ponderosa pine (planted post-fire). Nine percent of the watershed was burned in a stand-replacing fire in 1979 and was salvage-logged; ponderosa pine were hand-planted at lower elevations in the burned area.

The watershed was established by the U.S. Department of Agriculture in 1926. After the SDWA passed, a memorandum of understanding was established that required the City of Bend and the USFS to consult before initiating actions within the watershed. The utility maintains a good relationship with the USFS and they work cooperatively on many projects of varying size. The organizations share one employee, who acts as a liaison between the two groups.

Water Treatment Plant Description

The City of Bend currently is operating with a surface water filtration exemption and their only form of treatment is disinfection with chlorination. The amount of chlorine needed is established by monitoring the source water quality. The surface water supply treatment process provides approximately 5 MGD in the winter and 10 MGD in the summer. Surface water is delivered 11 miles downhill to town by a transmission main and is preferred over groundwater because it is less expensive to deliver to customers, as no pumping is required.

The City of Bend plans to upgrade and replace its transmission pipelines and evaluate how to best meet its new treatment requirements and anticipate/eliminate risk from a future fire that will increase sediment loads. Options for the city are to upgrade to UV disinfection or also add membrane filtration. There is 1,000 feet of elevation change from the intake facility to the reservoirs, so the city is also looking into the feasibility of generating hydroelectric power for revenue and to offset the energy needs of the treatment process that is ultimately selected.

Events of Concern and Protection Strategies

Fire is a major concern within the watershed. Late-August lightning storms are typical and can spark devastating wildfires. In 1979, a stand-replacing fire burned 9% of the watershed within a very steep canyon immediately upstream of the intake. The burned area was salvage-logged. After the fire, the ground was hard, and there were turbidity problems which put the surface water exemption criteria at risk, following even small rainfall events. The utility created terraces on the south slope using logs and metal posts that successfully reduced or prevented sedimentation.

Post-fire temperatures were elevated 2 to 3 degrees Fahrenheit (°F) within the river above normal temperatures for the season. Because this is an unfiltered water supply, temperature is automatically taken into account when the water is treated and the temperature change did not impact normal treatment practices. The forest service planted mature ponderosa pine and lodgepole pine because the ground was initially too fused for seed germination (roots could not penetrate the hard ground). Eventually the soil broke down and plants were able to grow and regenerate naturally. Within seven years post-fire, the planted trees were nearly knee-high, and 28 years later the vegetation in the burn area is very thick.

The utility is prepared to quickly call on resources such as smoke jumpers, who can respond in 14 minutes. The City of Bend assists normal USFS fire prevention activities and helps to monitor the watershed with its fire patrols. In preparation for a possible fire, they are completing a feasibility study for implementing significant upgrades to the treatment process, including potential for UV disinfection and membrane filtration, because after the fire they expect to lose their filtration exemption due to turbidity, and are looking into using hydroelectric power for revenue and to offset energy needs of the selected treatment process. The utility is fortunate to also have a secondary source of water, groundwater wells, and supplements surface water when sediment/turbidity levels in the surface water become too high to meet water quality regulations. Loss of surface water would have a significant impact on customers if it occurred during peak summer irrigation season when both surface water and groundwater sources are required to meet seasonal peak demands.

CITY OF CALGARY WATER SERVICES

Key message: The City of Calgary draws water from two separate watersheds, the Elbow River and the Bow River. Both watersheds are affected by urban development and agriculture and will likely be significantly affected by climate change. Expected climate changes in Alberta are likely to reduce flow in both rivers, potentially limiting the utility's ability to store, treat, and distribute adequate water in the future.

Utility representative:	John Jagorinec
Title:	Senior Water Quality and Regulatory Analyst
Province:	Alberta, Canada
Web site:	http://www.calgary.ca/portal/server.pt/gateway/PTARGS_0_2_780_237_0_43/http%3B/content.calgary.ca/CCA/City+Hall/Business+Units/Water+Services/ Water+Services.htm

Watershed Description

Calgary Water obtains water from the Elbow River watershed, which covers 1,230 square kilometers (km^2), and the Upper Bow River watershed consisting of 7,700 km^2. The primary vegetation type is foothills grasslands (foothills fescue and foothills parkland). The Elbow River provides water to half a million people and the Bow River (with 10 times the flow of the Elbow River) supplies another half million people.

The utility owns 2% of the land in the Elbow River watershed and none of the land in the Upper Bow River watershed. Some of the land in both watersheds is preserved as provincial and national parks but the majority of the land is privately owned by First Nation's people and farmers. There is substantial residential community development occurring in the Elbow River watershed.

Outside the city limits, the utility has very little authority or involvement with decision-making affecting the watersheds. The city recently passed an environmental reserve set-back policy of 50 m or more along waterways for both rivers. Active involvement with the stakeholder groups helps to keep the utility apprised of actions within the watershed. Several stakeholder groups are currently developing watershed management plans for both rivers. The Elbow River Watershed Partnership is including a riparian assessment on 10 locations in the Elbow River watershed. Calgary Water has an extensive monitoring network, especially on the Elbow River, including substantial historical data. Water quality data show a long-term trend of slowly deteriorating water quality.

Water Treatment Plant Description

Calgary Water operates two water treatment plants that together treat 169,211,000 cm^3 per year. Both plants are undergoing significant upgrades costing the utility $300 million (Canadian $). The Bow River treatment plant upgrades are nearly complete and the Elbow River plant upgrades have started. The upgrades will allow them to produce a constant amount of water, regardless of turbidity.

The Bearspaw Water Treatment Plant (on the Bow River) treats source water by pre-chlorination, ballasted flocculation using an active flow system, filtration (dual media sand and anthracite), and air scrubbing for backwashing. They use potassium permanganate for pretreatment and recycle the water from the ballasted flocculation back through the plant. Additionally, they concentrate the sediment waste in centrifuges and ship the final product to a landfill. Finally, they post-chlorinate and fluoridate the water. UV treatment will be added by 2012.

The Glenmore Water Treatment Plant is currently a conventional plant that uses pre-chlorination, potassium permanganate, traditional sedimentation (alum), filtration (dual media), and post-chlorination. By 2012, this treatment plant will have all the same features as the Bearspaw Treatment Plant with the addition of powdered-activated carbon and possibly UV disinfection.

Events of Concern and Protection Strategies

Wildfire is an event of concern, especially in the upper Elbow River, which is forested and has not experienced fire in the watershed recently. The watersheds are logged, producing large clearcut areas that are then used for recreation (e.g., four-wheelers). The reduction in vegetation due to logging or recreational activities may result in increased sedimentation. Several large rain events in the last decade have produced flooding and erosion in areas where riparian vegetation was lost. Calgary Water has dedicated resources to establish emergency response protocols and evaluate their effectiveness through mock scenarios. To prepare for events, they have exercises in which they respond as if a real event is taking place (e.g., wildfire response actions). These exercises include practicing notification protocols to ensure contact information is correct and evaluating if emergency response plans are appropriate.

Recently, pine bark beetles have become a threat in the watershed. They are present mostly in the Bow River. However, the trees in the Elbow River watershed are relatively small (less than 4–6 inches or 9–16 centimeters in diameter), which may be too small to host a large beetle infestation.

Urbanization is also a significant concern in the watersheds. The adjacent municipality, which is an urban municipality, is constructing larger-acreage developments. Calgary Water has observed deteriorating water quality in the land under development. The City of Calgary has planned and implemented prevention strategies internally but they do not have control or authority outside the city. They face a challenge in trying to encourage a change in Provincial legislation to improve water quality protection laws. Calgary Water believes that a definitive study showing the effects of vegetation loss on water quality is critical for success. To accomplish their goal of protecting their drinking water source, Calgary Water is working with watershed interest groups and conducting research to ensure continued watershed protection.

The Elbow River has a low flow (10 times lower than the Bow River; each river supplies half the water for the City of Calgary) and climate change may further decrease the river's flow. Studies predict that glaciers at the heads of both rivers will disappear within 50 years; the Bow River gets approximately 50% of its flow from the glaciers and the other 50% from groundwater. Models also predict increased rainfall and higher temperatures for the area, which will result in a drier climate. Currently, runoff occurs in the first week of June. If warming causes earlier snowmelt runoff, this could result in very dry conditions and low flow by August. Additionally, rainfall changes may affect reservoir levels and Calgary Water may not be able to store enough (or capture enough) water to meet demand later in the season.

CITY OF HILLSBORO WATER DEPARTMENT

Key message: Sedimentation caused by impacts to logged areas in the watershed are threatening water quality within the watershed. The city does not own land above the intake and has been working with landowners to protect source water and has developed response plans to better handle large sediment events.

Utility representative:	Niki Iverson
Title:	Water Resources Manager
State:	Oregon
Web site:	http://www.ci.hillsboro.or.us/Water/

Watershed Description

The Tualatin River watershed drains 712 mi^2 in northwestern Oregon. The basin supports a growing population of more than 350,000 and a wide range of urban, agricultural, and forest-derived activities. Land within the basin is owned by government agencies and private parties, with a substantial amount of land owned and operated by private timber companies. The City of

Hillsboro is the managing agency for two water supply agencies, the Joint Water Commission (JWC) and the Barney Reservoir Joint Ownership Commission, which serve most of Washington County. The JWC has contracted storage with the Bureau of Reclamation in Scoggins Reservoir (Henry Hagg Lake) in the upper Tualatin basin. Barney Reservoir is located at the headwaters of an adjacent watershed, the Trask River. Water released from Barney Reservoir enters the Tualatin River via an aqueduct and pipeline over a low Coast Range divide.

The water supply agencies managed by the City of Hillsboro own less than 1% of the watershed, including a storage reservoir, land around the reservoir, and property around two drinking water plants.

Above the water source intakes (one for each treatment plant) the vegetation is northwest fir forest (dominant species include Douglas fir, alder, and mixed hardwoods) and agriculture (including berries, nursery supply, and grass seed). Forest vegetation is a patchwork with stands at multiple ages. There is a small section of old-growth forest. Logging has occurred in some areas creating re-growth stands of different ages.

The City of Hillsboro does not have an official role in decisions about land use and land management within the watershed. Decisions are made by a county planning and zoning process, by the State of Oregon (for state-owned forest land), by the federal government (Bureau of Land Management), and by private owners. The city provides public comments on proposed land use changes when possible and appropriate. The City of Hillsboro does not have control over zoning and planning above their watershed intake point.

A Source Water Assessment for the watershed has been completed. The watershed does not have a comprehensive vegetation or land-use management plan. The Hillsboro Water Department has an annual flow management plan that regulates and coordinates releases from dams and water management. Because the basin can be fully appropriated during low-flow periods in the summer, some water users need to use storage rights during those times. Currently, there are no plans to develop a basin-wide management plan.

Water Treatment Plant Description

The Hillsboro Water Department operates two different water treatment plants with two separate intake points: a slow sand filtration plant and a conventional dual-media plant. Average daily demand is 37 MGD. Peak demand in the summer is 60 MGD.

Increased turbidity following storm events has shut the slow sand filtration plant down for up to three days and forced changes to the dual-media plant operations, including higher frequency filter backwashing and a substantial increase in chemical consumption. The modifications have improved finished water quality, even during storm events.

The City of Hillsboro is planning to double treatment capacity within the next seven years to accommodate a regional interconnection project between Hillsboro and Portland (see below). They also are exploring additional treatment processes to handle large turbidity events and to address the associated taste and odor problems. The utility would like to add additional treatment steps within the next two years to comply with the new Disinfection Byproduct Rule.

Events of Concern and Protection Strategies

Logging is a major activity in the Hillsboro watershed. Severe storms events that impact areas with recent logging activity and cause increased turbidity and landslides in the watershed are the main event of concern. Increases in clear-cut logging combined with a larger number of severe storms or rain-on-snow events in the past one to three years have produced more devastating events within the watershed.

Sediment transport and nutrient runoff is the highest during the first three years following logging. Large-scale storm events in the watershed indirectly affect vegetative cover by causing erosion and landslides that hinder revegetation. Logging across non-perennial streams has been one of the biggest issues because setbacks are only required on perennial streams, which may have large sediment flushing events after storms. Recovery in logged areas is promoted through revegetation, which is aimed at keeping out invasive species (primarily blackberry) and increasing timber stock for the future. Recovery is hampered when logging has taken place on steep slopes and landslides have occurred, limiting the amount of revegetation.

A severe storm in December 2007 delivered 7” of rain in two days and caused massive landslides in areas with recent clear-cut logging. These landslides resulted in a 10-foot elevation gain in the city’s water supply reservoirs because of the massive erosion that occurred. Additionally, the utility suspects that increased turbidity in the watershed after large storm events is causing blue-green algal blooms in drinking water reservoirs. They do not currently have definitive evidence but have started a monitoring program to examine this issue in more detail.

Getting other stakeholders and landowners to implement BMPs remains the biggest challenge for the utility. The City of Hillsboro works in a partnership with land owners to try to reduce erosion and protect the water resource. As appropriate, the city provides comments on Bureau of Land Management environmental assessments for timber contracts and works with private timber companies to increase the use of forestry BMPs. The city also comments on road-building plans and logging plans. When erosion is observed, the Water Department contacts the landowner to suggest preventive measures, such as placing straw bales to reduce sediment transport into streams. Logging companies that are working to achieve sustainable certification for their timber lands are generally willing to cooperate and communicate with the utility. In response to comments from Hillsboro, one logging company has increased logging setbacks from streams and implemented erosion control structures (hay bales).

The utility is working with a local university to develop water quality monitoring for one of the drinking water reservoirs (Barney Reservoir) that has experienced blue green algal blooms recently and eventually implement real time monitoring on the Tualatin River upstream of the treatment plant. The city monitored Scoggins Reservoir for seven years gathered extensive background water quality data. That monitoring program will likely be implemented again. The city is spending approximately $80,000 in 2008 to develop a water quality monitoring plan for the reservoir. In 2009, the city will spend approximately $70,000 for equipment and improved water quality monitoring. Real-time monitoring would give plant operators adequate time to prepare for a large sediment pulse. The data would be provided to landowners to help demonstrate the link between land management practices (e.g., logging on steep slopes) and water quality impacts.

The City of Hillsboro is in the planning stage for a regional interconnection plan with the City of Portland to supply an alternate source of water. The main barrier to interconnection is figuring out how to pay for a large-scale capital improvement project between multiple regional agencies. The JWC has a successful curtailment plan in place and has been able to reduce demand through voluntary measures. They have also developed a communication plan for emergencies with a messaging system with prepared text that coordinates with other public information systems.

TACOMA WATER

Key message: The utility has established good working relations with multiple landowners within its watershed to ensure long-term protection of the high-quality source water.

Utility representative:	Chris McMeen, Bryan King, Jeff Gillard
Title:	Water Quality Section Manager, Watershed Manager, Watershed Forester (respectively)
State:	Washington
Web site:	http://www.ci.tacoma.wa.us/water/

Watershed Description

The Green River watershed is located in King County and serves as Tacoma Water's primary water supply for Pierce County. The watershed is primarily second-growth conifer forest and covers 147,394 acres. The dominant species throughout the watershed are Douglas fir and hemlock.

The majority of the watershed (51%) is owned by several government agencies (10% belongs to Tacoma Water), and the remainder is owned and operated by the logging industry (49%). Tacoma Water has developed a watershed management plan, however, because there are multiple land owners in the watershed they do not have full control over management decisions. The utility cannot veto a project or application but they can comment and provide input. They review applications for work within the watershed and meet with landowners on a semi-regular basis to discuss ongoing and proposed projects. The utility's relationships with owners and other utilities in the watershed are good.

A source water assessment was performed several years ago and the utility has a habitat conservation plan for the watershed. Just above the Tacoma Water intake is a federal flood control dam run by the U.S. Army Corps of Engineers (ACE). The dam is used to manage flow to prevent floods and augment stream flows in the summer. Recently the dam has been used to store water for municipal uses. The utility does not have authority to regulate this dam, however it is in regular communication with ACE personnel on planning, construction, and operational activities.

Water Treatment Plant Description

Unfiltered water is treated and piped to the service area. If turbidity in the river is excessive, it is blended with very low turbidity groundwater from seven wells that each provide up to 12 MGD (when the well field is full). The treatment process includes ozonation, chlorination, fluoridation, and corrosion control with sodium hydroxide (NaOH) (for pH control). Tacoma Water treats an average 60 MGD (annually) with a peak capacity of 167 MGD. The annual average is expected to increase in the near future. Tacoma Water operates on surface water treatment facility and several groundwater treatment facilities. Treated ground- and surface-water is blended in the distribution system and at various in-town storage facilities. If a major event impacted surface water quality or quantity, a higher percentage (30–50%) of groundwater could be used to supplement the water supply.

Events of Concern and Protection Strategies

Wildfire is a major concern in the Tacoma watershed. The utility maintains an enhanced readiness to fight fires and has access control to the entire watershed. Additionally, they equip some vehicles for use as first-responders in the event of a fire. Tacoma maintains a surveillance and patrol presence through four full-time Watershed Inspectors.

Tacoma Water experiences a major flood about every 10 years. The ACE operates a dam above the intake for Tacoma Water to regulate water levels in the Green River. While the dam protects the very large river basin below, its operation significantly affects upstream water levels and vegetation along the waterway, leading to increased erosion and sediment loading. Additionally, the watershed collects much snow and rain and snow events occasionally cause major slides and flooding. To prevent damage from floods, the utility is increasing the capacity of selected culverts in the watershed and converting some to bridges. This will increase the capacity of replaced culverts to meet the needs of 100-year floods. This effort is also in response to a commitment to remove fish blockages in the watershed, and improve access to additional spawning habitat.

Tacoma Water is working with the University of Washington, Seattle Public Utilities, and other nearby utilities (e.g., Vancouver) to study potential watershed effects due to climate change. The watersheds are in ecologically transitional areas and may be especially vulnerable to climate change as a result of their location and ecological and hydrologic characteristics. Predictions suggest that supply may be reduced 4 to 8% by the year 2075.

USFS land at the top of the watershed is not very accessible, so public recreation is minimal, but present. Further use restrictions are the most significant preventative measure for ensuring high-quality water for the future. While restriction may not be possible, Tacoma Water maintains good relationships with landowners and other stakeholders in the watershed to ensure watershed protection. Landowner agreements stipulate Tacoma Water cannot stop activities they do not agree with but they can make suggestions or offer to pay the additional costs to improve the activity, if necessary.

The Watershed is traversed by a Burlington Northern-Santa Fe rail line. Five to six trains per day go through the watershed, in many areas traveling adjacent and parallel to the river. The utility works with the railroad when there is a derailment to ensure rapid protection of source water. Other water quality concerns related to human use include road building, logging, and contamination. However, because of new laws, logging practices have improved and represent a lower risk than in past decades.

The utility believes that the most effective strategy they employ is working with other stakeholders in the watershed (i.e., other landowners and agencies). Tacoma Water currently spends $500,000 to $1 million per year on prevention strategies, including $500,000 per year on culvert replacement, bridge replacement, individual projects, and staff salaries. These investments are always subject to revision as needs change.

DENVER WATER

Key message: Denver Water's best defense against severe events such as fire is the diversity of its source waters. Following a catastrophic fire the utility proactively contributed to revegetation efforts and built sediment trap dams to reduce the severity of impacts. Subsequently, the utility is working with state agencies to prevent future fires in the watershed.

Utility representative:	Brian Good
Title:	Director of Operations and Maintenance
State:	Colorado
Web site:	http://www.denverwater.org/

Watershed Description

The source waters for Denver are the South Platte River and its tributaries and the mountain watersheds west of Denver. The utility owns 53,000 acres of its watershed, the rest is federally or privately owned and operated. Denver Water maintains 13 reservoirs within the watersheds: Dillon, Eleven Mile Canyon, Cheesman, Gross, Antero, Marson, Ralston, Strontia Springs, Long Lakes, Platte Canyon, Soda Lakes, Williams Fork, and Wolford Mountain. Additionally, Denver Water uses some underground reservoirs throughout the city to supply water to the Denver metropolitan area.

The Denver watershed consists primarily of alpine and sub-alpine Ponderosa Pine forest. Nearly all of Denver's water supply comes from mountain snowmelt.

Water Treatment Plant Description

Denver Water operates three main treatment plants: Marston, Moffat, and Foothills. The Marston and Foothills treatment plants receive water from the South Platte watershed and Dillon Reservoir (which is in the Blue River watershed). Moffat's source water comes from the Williams Fork and Frasier River watersheds. Before distribution, raw water at all three plants goes through a five-step treatment process: coagulation and flocculation, sedimentation, filtration, disinfection and fluoridation, and corrosion control. The amount of water distributed by each plant varies annually depending on watershed-specific snowfall and scheduled maintenance, but Foothills and Marston generally provide 80% of total demand.

Events of Concern and Protection Strategies

The Buffalo Creek fire in 1996 was immediately followed by a massive rain event, which washed large amounts of sediment and debris into Denver Water's Strontia Springs Reservoir. Denver Water was very limited in its ability to manage the impacts of this fire as it did not occur on land owned by the utility. They were not able to assist with or help direct mitigation efforts, though their source waters were impacted by the fire.

In 2002, the biggest fire in Colorado history—the Hayman Fire—burned 138,000 acres, all of which were in Denver Water's source watersheds. Denver Water quickly built sediment traps along tributaries to Cheesman Reservoir which prevent large volumes of sediment mobilized by the fire from reaching the reservoir. The traps are cleaned annually or as needed. In addition to preventing sediment from reaching Cheesman, Denver Water manages the water level of Strontia Springs Reservoir in order to minimize the amount of sediment entering the treatment system. By managing the inflow/outflow ratio, the utility can force sediment to flow past treatment plant intake towers, preventing the treatment system from becoming clogged with sediment (Brian Good, Denver Water, Director of Operations and Maintenance, personal communication, October 8, 2007). Mitigation efforts at Strontia Springs Reservoir caused by the Buffalo Creek and Hayman fires will cost the utility $24 million—primarily the cost of removing sediment from the reservoir.

Following the Hayman Fire, Denver Water participated in seeding and revegetation efforts in burned portions of its watershed. Soils can become compact and hardened following fire; workers drove all-terrain vehicles over this hardened soil, often dragging chains or sections of fence, to break it up and make it more suitable for re-seeding (Brian Good, Denver Water, Director of Operations and Maintenance, personal communication, October 8, 2007). The utility's participation in mitigation efforts following the Hayman Fire have been limited to the 8,000 acres of land they own around Cheesman Reservoir. If possible, the utility would have participated in mitigation efforts throughout the watershed that would have further limited impacts. By fall 2007, Denver Water had spent approximately $17 million on post-fire mitigation efforts following the Hayman fire. Building the sediment trap dams along Turkey and Goose creeks cost $1.4 million, and removing sediment from behind the sediment traps costs $300,000 per year. Immediately following the fire, the utility spent $6–7 million on mitigation efforts, ongoing efforts are included in funding provided to the State forester.

By the summer of 2007, significant areas within the Denver watersheds (especially in Summit and Grand counties) were affected by bark beetle infestation. Many dead trees are being removed but many are inaccessible and will be left standing. Those dead trees that are not removed are significantly more vulnerable to blowing down in a storm or burning than surrounding trees. If (or when) these affected areas burn, Denver Water will face additional challenges related to sedimentation in their source waters.

Because it does not own all of the land in its watershed, Denver Water is limited in the extent to which it can directly manage and protect its source waters. However, most of the watershed is federally owned and operated, which provides some level of protection even without additional source water protection measures. In the mid-1980s, Denver Water began working on prevention measures in its watershed. The utility has a contract for $150,000 annually, pays an additional $150,000 to $200,000 to fund actual projects, and the State Forester leverages additional funds to help support these projects. to the State Forester for thinning and other forest management work in its watersheds. Mitigation efforts have been effective. The utility consistently meets or exceeds water quality standards; the only complaints following the Hayman Fire were related to taste and odor associated with ash (Brian Good, Denver Water, Director of Operations and Maintenance, personal communication, October 8, 2007).

EAST BAY MUNICIPAL UTILITY DISTRICT

Key message: The utility developed an ecologically based watershed management plan that seeks to protect water quality and important biological resources using tools such as carefully controlled livestock grazing to manage vegetation for fire control.

Utility representative:	Stephen Abbors
Title:	Manager of Watershed and Recreation
State:	California
Web site:	http://www.ebmud.com/

Watershed Description

The East Bay Municipal Water District (EBMUD) is located in the San Francisco Bay area and supplies 1.3 million people with drinking water and sewer services (EBMUD 1996).

EBMUD draws water from two watersheds: the watershed lands in the East Bay area and the Mokelumne River watershed in the foothills of the Sierra Nevada mountains. EBMUD owns and operates six water treatment plants that process and filter over 375 MGD (EBMUD 1996). About 90% of EBMUD's source water originates from the Mokelumne River watershed and the remaining 10% is comprised of runoff within the East Bay watershed. Water from the Mokelumne River is stored in the Pardee and Camanche reservoirs and conveyed via the Mokelumne Aqueducts to the East Bay. Water from the East Bay watershed is stored in five terminal reservoirs: Briones, San Pablo, Upper San Leandro, Chabot, and Lafayette. The Chabot and Lafayette reservoirs serve as emergency supply sources only (EBMUD 1996).

EBMUD's two watersheds are similar in their level of development and population density. The Mokelumne River watershed is located primarily within the El Dorado and Stanislaus National Forests and has a small urban population. Most of the area is protected and undeveloped and 75% of the watershed is forested. The main commercial activity within the watershed is logging. Similarly, the East Bay watershed, although close to a large urban area, is mostly undeveloped. Agriculture is the main commercial activity within the East Bay watershed.

Water Treatment Plants

Water treatment includes filtration through sand and anthracite or carbon. Each water treatment plant also provides disinfection, fluoridation, and corrosion control. EBMUD's primary water source, the Mokelumne River watershed, requires only minimal treatment to meet quality and health standards.

Events of Concern and Protection Strategies

EBMUD aggressively protects and manages source water quality, and has developed an integrated, nine-part Source Water Protection Strategy focused on protecting water quality and biological resources by promoting biodiversity. Individual management plans (e.g., fire management, rangeland management) supplement conservation and source water protection measures. Water quality protection includes identification and quantification of contaminant sources before management and control strategies are developed and implementation prioritized. The utility considers maintenance of plant cover "essential to optimize the primary watershed functions of capture, storage, and release of high quality water" (EBMUD 2001).

Other source water protection initiatives include watershed land acquisition and protection and land management and control. Because the Mokelumne River watershed is located in a relatively pristine environment, most of EBMUD's land management efforts are focused on the East Bay watershed. Wildfires and droughts are the types of large-scale events that pose the largest threats to water supplies within this watershed. Livestock grazing is used as a tool to manage vegetation in support of watershed management goals. Carefully managed light to moderate seasonal grazing helps minimize impacts to water quality (EBMUD 1996, 2001).

EBMUD has developed a set of fire prevention strategies for the East Bay watershed based on National Forest Fire Laboratory fuel models. For each vegetation type, the models provide information on site-specific fuel characteristics, flammability, seasonal trends, and overall susceptibility. To reduce or remove vegetation and associated fire hazards on district lands, EBMUD uses a combination of fuel treatments that are part of their Strategic Fuel Modification Network (SFMN). The strategy is based on the "Firebreak within a Fuelbreak" concept, with the main goal of reducing fuel loading in tall grassland fuels from 3 tons per acre (normal annual production) to 0.5 to 0.75 tons per acre. By doing so, EBMUD can lessen the risk and severity of wildfires, particularly in areas with high fuel intensity. Fuel treatments include biological, manual, mechanical, and chemical vegetation treatments in areas with high fire risks.

Biological treatment refers to using cattle, goats, and horses to clear vegetation and prevent the encroachment and regrowth of brush in grassland habitats through grazing. Grazing is a cost-effective method for managing flashy fuels over large areas. Manual treatments, which include pruning, limbing, thinning, chipping, and multicutting, are used to clear wooded areas and thick underbrush. In addition, prescribed burning is used sparingly to thin vegetation in areas that are difficult to access and to promote the establishment of native grasslands and biodiversity of particular plant communities.

Mechanical treatments such as brush crushing, mowing, disking, and horse logging target heavier fuel type. Horse logging involves the removal of felled trees by horses instead of the use of heavy equipment. This practice reduces habitat damages and is used to thin heavily wooded areas and to remove dead tree trunks. Chemical treatments are used to prevent regrowth of undesirable vegetation. Natural fire barriers, such as riparian areas and rock outcroppings, are also part of the SFMN.

Detailed maps showing fire severity levels for different fire seasons and environmental conditions for each of the 33 Fire Management Units (FMUs) in the East Bay watershed have been prepared. Annual fire management protocols are developed for each FMU (EBMUD 2000).

Droughts are a regular occurrence, affecting not only water quantity, but also its quality by changing vegetation patterns and soil chemistry. In dry years, reservoirs collect less water and parched soils erode and cause sedimentation of the reservoirs. Prolonged drought leads to an overall reduction in plant biomass and changes the biodiversity of the watershed. Water- and heat-stressed vegetation may become more vulnerable to pest infestation, and non-native invasive grasses with large seed stores and aggressive growth patterns crowd out native bunchgrasses (EBMUD 2001).

MARIN MUNICIPAL WATER DISTRICT

Key message: Fire suppression tactics historically applied in the West have put the forested watershed at high risk for severe fires. Diseases and invasive species also threaten vegetation health within the watershed. Some members of the public are opposed to herbicide use in weed management.

Utility representative:	Mike Swezy, Larry Grabow, Bob Castle, Janet Klein
Title:	Watershed Manager, Lab Manager, Water Quality Manager, Vegetation Ecologist (respectively)
State:	California
Web site:	http://www.marinwater.org/

Watershed Description

Marin Municipal Water District uses water from two major watersheds: Mt. Tamalpais and Soulajule/Nicasio to supply nearly 200,000 customers with high-quality water. The utility owns 19,000 acres within the two drainage basins. This includes 100% of the Mt. Tamalpais watershed, a small percentage of the Soulajule/Nicasio watershed, and the land surrounding five of seven reservoirs within the watershed. The two other reservoirs drain water from 36,000 acres of privately owned land. Vegetation on Mt. Tamalpais is coniferous and hardwood forest, dominated by oak, chaparral, grasslands, and other forest types. The Soulajule/Nicasio watershed consists of dairy ranches, hobby ranches, and residential development, as well as grasslands, shrublands, and a small amount of forestland.

The utility has control over land use decisions and management in the Mt. Tamalpais watershed. In the Soulajule/Nicasio watershed, they have influence but not authority in zoning and planning. Since 1977, the utility has requested that landowners enter into a water protection agreement for projects within the Soulajule/Nicasio watershed. The county shares watershed proposals from landowners with the water district and helps to obtain the water protection agreement within permits. The agreements give the utility some authority on privately owned land and are, as often as possible, made for large parcels before they are divided, so the agreement carries forward when the land is subdivided.

The utility developed a vegetation management plan in 1995 and updated it in 2008. It provides a resource management plan for the watersheds and includes trail and road management plans to manage sediment and protect endangered fish species such as coho and steelhead salmon. Source Water Assessments have been completed for the watershed, as required by the State of California and federal regulation. A Sanitary Report for the watershed was also completed.

Water Treatment Plant Description

The Marin Municipal Water District operates two conventional treatment plants that treat 32,000 acre-feet of water annually. Both plants use the same treatment process. The process begins with a flash mix for initial coagulation, followed by rapid mixing to do tapered flocculation. Water then enters a clarifier with separate flocculation and sedimentation zones, overflows into a settled water channel, and then goes to rapid sand filters (anthracite on top of silica sand). Ferric chloride is added for coagulation to reduce TOC and the water is disinfected using free chlorine; pH is adjusted and a corrosion control inhibitor is also added to the final product.

The utility collects data to quantify changes in finished water quality. They recently switched from alum to ferric chloride to comply with the Disinfection Byproduct Rule. During algae blooms in reservoirs (brought on by eutrophication—possibly from added phosphorous), the utility adds copper sulfate in granular form directly to the mats.

Cryptosporidium levels throughout both watersheds are low and the utility does not anticipate a need for treatment changes. The utility is evaluating the potential to build a desalination plant to use water from San Francisco Bay as an alternate source.

Events of Concern and Protection Strategies

Complete fire suppression has been the standard management technique for many years in the West, leading to increased fuel loads and fire dangers. In the Marin watersheds, managed thinning or prescribed burning are not politically favorable management options. The utility focuses on fire prevention at the urban-wildland interface by pushing the fire breaks closer to residences to improve their protectiveness.

Sudden oak death is prevalent and has led to thousands of acres of dead and standing tan oak trees throughout the watersheds. As a result, the watersheds have high fuel loads and a catastrophic fire could occur in the Mt. Tamalpais watershed. The utility cannot prevent the spread of sudden oak death at this point; they manage the problem primarily by removing dead trees to reduce the fuel load and create fire breaks. However, they limit removal in order to prevent invasive species progression into former tan oak areas.

Invasive and exotic species are a major problem throughout the watersheds. Invasive shrubs such as French broom and scotch broom are established in the oak forest understory. Invasive species in the grassland habitats include yellow starthistle, goat grass, and medusa head. The utility has tried various levels of burning and manual control to fight grassland invasive species. The utility used herbicides very effectively for a number of years in its IPM program, and is interested in using this weed management technique again. However, some members of the public are adamantly against any use of herbicides in the watershed and have succeeded in forcing the utility to go through an extensive risk assessment and environmental documentation process, to be able to re-integrate herbicide use into their extensive mechanical removal program. Aquatic weeds, including Eurasian aquatic milfoil and ludwigia, also occur and may increase phosphorous levels in mountain reservoirs.

The utility views the strong public opinion against herbicide use as a significant barrier to effective watershed management. They have used herbicides in the past, in very small amounts, to retard weed regeneration. The treatment plant monitoring program is thorough and herbicides have never been detected in source waters or at the treatment plant. The level of invasion is significant and the utility cannot keep up with regeneration through mechanical means alone. They feel that using small amounts of herbicides, in combination with other methods, would make significant impacts and allow them to reach a point where they might, in the future restore native vegetation rather than only treating invasions that have occurred.

SALT LAKE CITY UTILITIES DEPARTMENT

Key message: The Salt Lake City Utilities Department manages a watershed that water supply users also enjoy for recreation. The watershed contains hiking and biking trails and four major ski resorts that are easily accessed from Salt Lake City. Currently, dedicated funds are used to purchase and protect land within the watershed. The utility has initiated a public education campaigns through signage in the watershed that capitalizes on increasing the public's environmental awareness and concern to gain acceptance for watershed protection and, as a result, help to reduce impacts to water quality from recreation and development in the watershed.

Utility representative:	Florence Reynolds
Title:	Water Quality and Treatment Administrator
State:	Utah
Web site:	http://www.slcgov.com/Utilities/

Watershed Description

The Salt Lake City Department of Public Utilities manages a 185 square mile watershed that includes undeveloped mountain ecosystems, a public open space trail system, several large ski areas, and large, expensive homes. The watershed supplies more than 60% of the drinking water to Salt Lake City and also provides year-round recreational opportunities for city residents and visitors. The watershed is made up of alpine tundra, mountain brush, gamble oak, big toothed maple, aspen, conifer species, grasses, and sage brush.

The majority of the watershed (65%) is owned by the USFS. The utility/city/county owns approximately 18% of the watershed, and 19% is privately owned. The privately owned land includes residences and a portion of some ski area land (the majority of the ski areas are on USFS land).

Salt Lake City Utilities Department has developed a comprehensive watershed management plan. A Source Water Assessment was also completed for the watershed in 1999. The utility has obtained Congressional authority allowing the Forest Service to protect the watershed as a water supply and has State authority, as a City of the First Class, to protect their watershed to the headwaters. They work with the county and the local health department to assure that appropriate BMPs are considered for construction and development in the watershed both before and after development or construction activities. The Salt Lake City Department of Public Utilities can establish requirements for new development in the watershed, but they cannot prevent or stop construction when all requirements are met.

Water Treatment Plant Description

Salt Lake City Department of Public Utilities operates three treatment plants, all three plants receive water from snowmelt. Two of the plants treat 20 MGD, these receive water directly from streamflow. The third plant treats 42 MGD and receives water from a two-reservoir system; a 20,000 acre-foot reservoir feeds a 2,000 acre-foot reservoir, which is the intake point for treatment. Each facility is independent and the utility does not have the ability to blend water until it is in the distribution pipeline. A conventional treatment process is used, with multimedia filters and chlorine disinfection. The City of Salt Lake City buys approximately 34 MGD wholesale from other entities.

The Salt Lake City Utility Department is not considering major treatment modifications at this time. The source water streams are clean—with low TOC, bacteria, and cryptosporidium. If TOC levels get too high in the source water, they will make appropriate changes to meet regulations. However, some wholesalers who sell them water are considering changes including adding ozone, chlorine dioxide, and UV. Wholesalers have already made some changes to lower DBPs.

Events of Concern and Protection Strategies

The utility has observed that over the last 15 years, there has been a marked increase in use and development in the watershed and invasive weeds have greatly increased. Near the city, noxious weeds are driving out native vegetation, which may alter hydrology and water quality and provide fuel for wildfires. In response, the utility has started a new weed management program. They have completed a fuels assessment on the property and created maps identifying areas with significant noxious weed infestations. They are considering implementing a recreational user education program, providing wash areas for mowing equipment to help prevent the spread of weeds and improve BMPs in the watershed. In addition, they are working with a local researcher studying the effectiveness of planting low isoprene (a volatile compound produced by plants that may contribute to greenhouse gases) emitters after removing nonnative species. Several agencies are working cooperatively to manage and remove weeds from public lands.

Road salt, used as a deicer in the winter, is contributing to elevated salt levels in the source water, which directly impacts water quality and vegetative growth. The utility monitors water quality by analyzing samples for temperature and chemical concentrations.

The utility has purchased land within the watershed in the last several years with money collected from water sales: a monthly $1 charge from every bill is designated for purchasing land and water rights in the watershed. They plan to continue this practice for land acquisitions in the future. In addition, the utility works closely with other landowners. For example, they started a program with the National Forest Foundation Ski Conservation Fund (http://www.natlforests.org/ski_conservation_fund.html) to collect additional money from guests of the ski resort ($1 per night, adding up to approximately $70,000 per year) to support watershed protection. One of the biggest challenges has been getting support for purchasing land since watershed land values are highly over estimated by the property owners, resulting in difficulty in setting a purchase price. Recently, general environmental awareness has increased within the community, making it easier for the utility to increase and improve watershed management. The utility plans to capitalize on this with a public campaign highlighting the importance of protection to ensure continued high water quality while allowing increasing recreational use.

SAN FRANCISCO PUBLIC UTILITIES COMMISSION

Key message: The San Francisco Public Utilities Commission considers land acquisition in urbanized watersheds and legal protection of natural areas the most critical elements of a source water protection plan.

Utility representative:	Joseph P. Naras
Title:	Watershed Resources Manager
Web site:	http://www.sfwater.org/

Watershed Description

The San Francisco Public Utilities Commission (SFPUC) is a department of the City and County of San Francisco that supplies high quality water to about 2.4 million residents in San Francisco, Alameda, Santa Clara, and San Mateo counties in the San Francisco Bay Area. About 15 percent of the water is from local rainfall in the East Bay and San Francisco Peninsula, while 85 percent comes from the protected watershed of the Upper Tuolumne River, which collects snowmelt from the Sierra Nevada Mountains, flows into the Hetch Hetchy Reservoir in Yosemite National Park, and is then carried by gravity about 160 miles to the San Francisco Bay Area through a system of pipelines and tunnels. SFPUC-owned watersheds in the Bay Area include the Peninsula Watershed and the Alameda Watershed. The Peninsula Watershed is located in San Mateo County, about 13 miles south of San Francisco, and consists of 23,000 acres of forested hills, coastal scrub, and grasslands and includes three drinking water reservoirs. The SFPUC owns another 36,000 acres of rolling grasslands and native oak woodlands in the Alameda Watershed in the East Bay. Most of the watershed area drains into the San Antonio and Calaveras reservoirs; the rest drains into the upper portions of Alameda Creek.

Water Treatment Plant Description

The SFPUC water quality protection is focused on the three major components: water source, treatment, and distribution. The utility applies a multi-barrier approach to maintain high quality drinking water involving watershed protection, filtration, and disinfection.

SFPUC maintains strong source water protection. Over 85% of the drinking water supply originates from the nearly pristine conditions of the Hetch Hetchy Reservoir, which is an unfiltered drinking water supply. The remaining supplies are from the Alameda and Peninsula watersheds, which are mostly under the SFPUC's control. Source water protection in these watersheds focuses on erosion control and land acquisition.

The utility operates two water treatment plants. Hetch Hetchy water requires minimal treatment and no filtration. Water from the Alameda watershed is treated with chemical addition, coagulation, mechanical flocculation, sedimentation, dual-media filtration, and disinfection with sodium hypochlorite. The Peninsula treatment plant also uses pre-oxidation with ozone prior to coagulation.

The distribution system is showing signs of age and disease outbreaks have occurred due to breaches in the integrity of the system. This may warrant a risk assessment to determine which system improvements are highest priority. There are ongoing improvements to the disinfection process. In 2004, the utility began disinfecting the distribution system with chloramines, which reduced disinfectant residuals and disinfection by-products, helping satisfy new federal regulations. In 2005, the utility improved corrosion control for lead and copper with system-wide fluoridation and pH adjustment. By 2012, ultraviolet (UV) treatment is planned prior to chlorination as an additional disinfectant for Hetch Hetchy Reservoir water. Ozone is sometimes used as a disinfectant but taste and odor concerns are being studied.

Events of Concern and Protection Strategies

SFPUC considers land acquisition for watershed protection and restoration a high priority and one of the most effective mitigation strategies. Watershed lands are acquired by conservation easements, fee title, and or public/private partnerships.

The possibility of a catastrophic fire in the Peninsula Watershed is a major concern for the utility. The watershed has not had a significant fire in over 100 years and, therefore, there has been a substantial accumulation of fuels. This is addressed by using a mowing pattern that creates a "mosaic" that takes into account fire movement and creates "fuel breaks" (i.e., "safe zones"). Fuel breaks are important in SFPUC's urbanized watersheds to protect nearby homes and a variety of human activities. Prescribed burns are employed only after mowing is completed to minimize the risk that the fire will become uncontrolled and cause significant damage.

A significant concern in the last five to ten years is sudden oak death, which is caused by a fungus. The trigger is unknown and at present there is no cure. This is important in terms of fire management because it creates more fuel.

Another concern is an increase in the frequency and levels of algal growth in Peninsula reservoirs due to increased nutrient loadings. Excess algae produce taste and odor problems and limit the capacity of treatment facilities. SFPUC is evaluating a hypolimnetic oxygenation system for algal control in the Calaveras Reservoir in the Alameda Watershed. The system is designed to prevent anoxic conditions that increase reservoir nutrient levels and enhance algal production. If algae management is unsuccessful, there may be a need for additional treatment (clarification) or additional oxidation.

SWEETWATER AUTHORITY

Key message: Recent wildfires have threatened water quality in the watershed by increasing erosion and sediment load to two reservoirs. Sweetwater Authority is updating their treatment plant to deal with increased sediment and is working with federal and state watershed landowners to improve long-term protection and management of the watershed.

Utility representative:	Don Thomson
Title:	Water Quality Superintendent
State:	California
Web site:	http://www.sweetwater.org/

Watershed Description

Sweetwater Authority obtains water from the 115,000-acre (180-square mile) Sweetwater River watershed. They own 895 acres around the Sweetwater Reservoir and another 3,292 acres around Loveland Reservoir. The largest portion of the watershed is State Park with a smaller section maintained as a golf course. Approximately 300,000 people currently reside within the Sweetwater River watershed and that number is projected to increase rapidly. Vegetation in the watershed consists primarily of riparian willow woodlands, coastal sage scrub, chaparral, and oak/pine woodlands.

Sweetwater Authority does not have direct jurisdiction within the watershed. They have been monitoring development in the watershed since the late 1970s and continue to review proposals for all new development. The utility provides comments on new development regarding impacts to water resources to the County Department of Planning and Land Use or other agencies and departments with jurisdiction.

A Sanitary Survey was completed in June 2007 and a Source Water Assessment was performed in 2003.

Water Treatment Plant Description

The treatment plant incorporates a modified conventional process to treat 20 MGD, with a design capacity of 30 MGD. Treatment includes chlorine dioxide disinfection, coagulation (using ferric chloride and cationic polymer), flocculation, sedimentation, anthracite coal, sand and gravel filtration, and clear well storage prior to distribution.

Sweetwater Authority is planning a significant upgrade to their current plant as a result of increased sedimentation within the watershed and higher polymer and chemical use requirements. To do this, they are replacing and expanding the chemical treatment facility. This includes building a new tank farm with increased bulk storage for coagulant (ferric chloride) and ferrous chloride. The plant expansion is also being driven by the age of their existing tanks and feeders and the need for increased storage to ensure compliance with the enhanced coagulation requirements of the Disinfection Byproduct Rule.

Events of Concern and Protection Strategies

Increasing urbanization and recent wildfires have caused subsequent erosion and increased sediment load to the reservoirs. The 2003 Cedar Fire and the 2007 Harris Fire destroyed thousands of acres of vegetation in the Sweetwater River watershed. In response, the utility removed dead trees and is working on invasive species management. Fortunately, the winters following the fires were mild, and gentle rains minimized runoff and associated erosion and sediment transport. Increased aluminum, iron, and manganese concentrations associated with runoff after the Harris Fire were measured. These metals are naturally occurring in area soils and it is believed the increased concentrations were related to increased erosion following the fire.

A large part of the watershed is within the Cleveland National Forest. The utility works with the USFS to manage and protect endangered wildlife habitat and riparian habitat for the native leaf-billed barrio. A large portion of the protected acres was burned in the recent wildfires, which has the potential for erosion. The utility and the USFS coordinate with the Federal Emergency Management Authority, and restoration of the utility's Habitat Maintenance Program may receive funding to address the aftermath of the fires and prevent further degradation of habitat.

Residential development within the watershed has also contributed to increasing levels of total dissolved solids and other contaminants from urban runoff in the water supply. To address potential impacts from increased urbanization, the utility provides input on urban planning. Sweetwater Authority developed erosion and sedimentation prevention strategies because of concerns about poor water quality, urban runoff and degradation, and wildfire impacts.

The Sweetwater Reservoir is losing capacity due to siltation. The watershed is large and sediment barriers and BMPs, such as hydroseeding, may not sufficiently protect the reservoir. The Sweetwater Reservoir is protected from poor quality runoff (related to urbanization) on the north side by the Urban Runoff Diversion System (URDS). The system consists of four ponds, a pump station, a conveyance system, and associated appurtenances. During dry weather, low-level flows are intercepted and diverted into the holding ponds. From there, the water can be conveyed to the URDS pump station, where it is pumped around the reservoir into the lower Sweetwater alluvial basin. During wet weather, the first flush of the winter storms are intercepted, diverted, and conveyed around the reservoir in a similar manner. The utility estimates tons of salt are diverted (based on diverted water conductivity) from the reservoir on a monthly basis. Water quality has improved within the holding ponds.

Sweetwater Authority budgets approximately $125,000 each year for operations and maintenance costs.

APPENDIX B
ON-LINE RESOURCES FOR ASSESSING VULNERABILITY

WILDFIRE

On-line resources are available to assist watershed managers in assessing the current vulnerability of their watersheds to fire. The National Interagency Coordination Center is the focal point for providing information on current fire status and fire danger in the U.S., including Puerto Rico (http://www.nifc.gov/nicc/index.htm). The Canadian Wildland Fire Information Center is the focal point for information on fires and fire danger across Canada (http://cwfis.cfs.nrcan.gc.ca/en/index_e.php).

The National Interagency Coordination Center has developed a wide variety of on-line resources that provide "outlooks" of future fire weather and fire danger for the U.S., including Alaska. This internet site: http://www.nifc.gov/nicc/predictive/outlooks/outlooks.htm is a Web "portal" with links to daily, weekly, and seasonal outlooks for different regions.

For example, a watershed manager who wants a broad understanding of upcoming fire danger may be interested in a national outlook that gives brief descriptions of the fire outlook for nine regions in the U.S., found at: http://www.nifc.gov/nicc/predictive/outlooks/monthly_seasonal_outlook.pdf. This Web product is a short document (approximately six pages) that is issued monthly and provides a three-month outlook of fire danger.

There are also regional workshops held every year in advance of the fire season that give outlooks of the upcoming fire season for different regions. A workshop for the Eastern, Southern, and Southwest areas is typically held in January. A workshop for the Western and Alaska regions is typically held in April. The summary reports from these workshops provide a good overview of the upcoming fire season danger, which can be accessed from this Web site: http://www.nifc.gov/nicc/predictive/outlooks/outlooks.htm, under the heading National Seasonal Assessment Workshop reports.

For watershed managers interested in short-term outlooks of fire danger, there are Web pages that give the seven-day fire danger during the fire season for different regions. These Web pages can be accessed through the "outlooks portal" at http://www.nifc.gov/nicc/predictive/outlooks/outlooks.htm, under the heading Geographic Area Outlooks and then 7-day fire danger. This Web page can be useful for watershed managers because the regional map provides information on fuel dryness and on significant weather triggers. There also is a brief discussion of fire potential for the area. In some cases, the regional map is interactive and watershed units within the regional map can be clicked with a mouse to obtain more detailed information. The "outlooks portal" referenced above also provides daily, monthly, and seasonal outlooks that could be useful depending on the needs of the watershed manager.

For information about fires that are currently burning, the National Interagency Fire Center provides a daily update of wildfire (referred to as "wildland fire"), available at: http://www.nifc.gov/fire_info/nfn.htm. This Web site provides an overview of current wildland fires in the U.S., with contact information to obtain more details about a specific fire. Maps of current fire activity are available as well. A map that is updated daily and shows large fire incidents (defined as 100 acres or more in timber or 300 acres or more in grass/sage) can be found at: http://activefiremaps.fs.fed.us/lg_fire2.php.

The Canadian Wildland Fire Information Center provides information on fire danger in Canada at: http://cwfis.cfs.nrcan.gc.ca/en/index_e.php. This page provides links to maps of fire danger that are updated daily (under the heading of Fire Weather). Also on this page are links to maps of daily hotspots that show where fires are occurring and maps of fire behavior that show the intensity of a fire. There is also a map of large fires for Canada, similar to the one available for the U.S., which can be found at: http://activefiremaps.fs.fed.us/canada/.

STORMS

The National Oceanic and Atmospheric Administration (NOAA) maintains a Web site with national hazard assessment maps for temperature/wind, precipitation, and soil conditions/wildfire in the U.S. at: http://www.cpc.ncep.noaa.gov/products/predictions/threats/threats.php. The maps are updated weekly and give 7–10 day hazard forecasts. There is a separate map for each hazard and a compilation map that combines all hazards on one map (the smaller maps can be enlarged by clicking on them). The national weather service hazard map at: http://www.weather.gov/ gives hazardous weather warnings at a finer geographic scale than the NOAA national hazard assessment maps. Listed hazards include tropical storm warning, storm warning, gale warning, small craft advisory, dense fog advisory, frost advisory, and extreme fire danger. The Web site also provides special weather statements, marine weather statements, hazardous weather outlooks, and a short-term forecast. At the top of the map is a pull-down menu allowing the viewer to choose a state; the individual state pages give a list of current hazardous weather warnings by county and are updated approximately every two minutes.

The National Weather Service flood map (http://www.weather.gov/ahps/) shows 3,709 active stream gauges in the U.S. (as of September 27, 2007), color-coded based on the level of current flooding. By clicking on the icon for a specific gauge, the viewer is taken to a page with a map of the area immediately surrounding that gauge. A pull-down menu at the top of the map allows the viewer to filter the displayed gauges by locations with a hydrograph only or locations with a hydrograph and probability forecasting.

The Web page for the National Hurricane Center (http://www.nhc.noaa.gov/) gives information about current tropical depressions, tropical storms, and hurricanes, including wind speed probabilities, three- and five-day warnings, Mariner's 1-2-3 Rule, and wind history. Each storm or depression has a forecast and listed public advisories. The main page gives information about the tropical weather outlook and includes an experimental graphical outlook, a tropical weather discussion, and forecasts and analyses.

The Northeast States Emergency Consortium has compiled a list of links to real-time hazard maps for the U.S. (http://www.nesec.org/hazard_maps.cfm). Links from the main page include maps of earthquakes, hurricanes, floods, tsunamis, wildfires, droughts, rain and snow, extreme weather, tornadoes, lightning, air quality, and other hazards (worldwide). Many of the maps on this page are described in other sections of this document; this Web page maintains an updated list and links to the important hazard maps.

The U.S. Geological Survey (USGS) has Web pages listing seismic hazards in the U.S. The main page of the Earthquake Hazards Program (http://earthquake.usgs.gov/eqcenter/recenteqsus/) identifies locations with recent seismic activity (within the last week, day, and hour). It gives probabilistic data on a map of the U.S., showing the risk to seismic activity across the country (http://earthquake.usgs.gov/research/hazmaps/products_data/48_States/index.php). On the left side of the Conterminous States Probabilistic Maps and Data pages is a link called Seismic Hazard Maps (http://earthquake.usgs.gov/research/hazmaps/products_data/index.php), which provides further links to hazard maps for the conterminous U.S., Alaska, Hawaii, and Puerto Rico; urban hazard maps for a selection of urban locations; foreign maps; and other seismic hazard maps.

The Meteorological Service of Canada maintains a comprehensive Web site for climate and weather warnings and data (http://www.weatheroffice.gc.ca/warnings/warnings_e.html). The active links on the left side of the page include weather warnings, several weather forecasts (five day, marine weather, and seasonal), weather maps, imagery, hurricane information, sea ice information, air quality forecasts, and past weather. Many of the pages include information as both maps and text (usually a table).

Environment Canada maintains a Web site with hurricane tracking information (http://www.weatheroffice.gc.ca/hurricane/track_e.html). This site may be reached from the Meteorological Service of Canada page. It has updated satellite imagery and warnings for tropical weather patterns. This Web site (http://atlas.nrcan.gc.ca/site/english/maps/environment#naturalhazards), maintained by Natural Resources Canada, provides a number of maps on environmental issues, including natural hazards (floods, volcanoes, and landslides).

INSECT PESTS AND PATHOGENS

The USDA Forest Service maintains current analyses on forest risks from insects and disease (http://www.fs.fed.us/foresthealth/technology/nidrm.shtml). The Forest Service has produced maps showing the geographic location and range of risks to vegetation loss from insects and diseases. As discussed above, high risk is defined as "the expectation that 25% or more of the standing live volume of trees greater than 1" in diameter will die over the next 15 years" from insects or disease. A variety of maps show this risk in a variety of ways including by state and watershed. As of November 10, 2008, the maps were current for 2006. Each map is provided in PDF format and can be downloaded and saved. Also, a detailed on-line mapping service from the Forest Service provides county-level information on forest threats in 12 southeastern states (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia) (http://www.fs.fed.us/r8/foresthealth/atlas/index.shtml). Similar county-level information does not yet seem to be available for other regions.

The Canadian Forest Service maintains a site with current information about insect and disease risks (http://cfs.nrcan.gc.ca/?lang = en). For example, on October 2, 2007, the top three news stories on their Web site were related to spruce budworm, tree vaccinations against pathogens, and white pine blister rust. Under the General Information tab at the top of the page, the viewer can navigate to other pages of general interest. For example, the page http://cfs.nrcan.gc.ca/general/entomology has links to additional Web sites and fact sheets about individual insect pathogens of concern in Canadian forests. The page http://cfs.nrcan.gc.ca/general/pathology contains similar information about tree diseases (cankers, blights, fungi, etc.). Under the Forest Research tab at the top of the main page, there is a link to a page containing additional information about pathology, including a general description, links to publications (in a box on the right side of the page), and links related to pathology. Information is provided in the form of fact sheets, which include photos and descriptions useful in identifying pests, and scientific articles. The Canadian Forest Service does not provide information maps showing the regional or national risks from insects and disease.

INVASIVE SPECIES

A large number of Web sites are devoted the problem of invasive species. However, unlike the resources available for fires or storms, there does not seem to be a single systematic location to find comprehensive regional, state, or watershed assessments of current and future invasive species threats. Instead, the availability of information appears to vary greatly by location. The National Biological Information Infrastructure is a program managed by the USGS. As part of this program, the USGS manages a Web site known as the Invasive Species Information Node (http://invasivespecies.nbii.gov/index.html). This Web site has links to aquatic, terrestrial, regional, and state maps of invasive species. The regional section links to existing regional information, where it is available. For example, this section includes a link to a map of susceptibility to cheatgrass invasion in the Pacific Northwest (http://www.icbemp.gov/cgi-bin/vmap.pl?img=disturbance%2Fimg%2F928x2.gif). The state maps section links to a Web site (http://ceris.purdue.edu/napis/maps/stsurvey.html) that lists invasive species by state, with maps available for individual invasive species. These lists focus on agricultural pests, however, and are not comprehensive of all invasive species.

The NASA Office of Earth Science and the USGS are working to develop a National Invasive Species Forecasting System for Department of Interior lands and adjacent sites (http://bp.gsfc.nasa.gov/index.html), but the system is still in its infancy, with information available for three test sites: Rocky Mountain National Park, the Cerro Grande wildfire site in New Mexico, and the Grand Staircase-Escalante National Monument in Utah.

DROUGHT

The NOAA Drought Information Center (http://www.drought.gov/portal/server.pt) contains links to different types of information about drought conditions in the U.S. Links from the Drought Information Center page include the NOAA drought assessment (including graphics), animated indicator maps for six- and 12-week forecasts, a seasonal drought outlook, a hazards assessment (extreme weather), a drought calculator, a current monthly state of the climate report, U.S. soil moisture monitoring, U.S. statewide and regional moisture status, a monthly standardized precipitation index, the Palmer drought severity index (updated weekly), Palmer regional drought information, and the crop moisture index. Additionally, the site has links to historic information about drought including general information and historic climate data, extreme climate events, and hazard mapping.

Another comprehensive drought Web site is the U.S. Drought Monitor site (http://www.drought.unl.edu/dm/index.html), which is a combined effort of NOAA, the USDA, and the National Drought Mitigation Center at the University of Nebraska-Lincoln. The Drought Monitor site has maps with forecasts of drought and current conditions for the entire U.S.

The Canadian Ministry of Agriculture and Agri-food Canada maintains a comprehensive Web site covering drought concerns for Canada (http://www.agr.gc.ca/pfra/drought/index_e.htm). The site focuses on drought effects on agriculture. Links on the left side of the page contain information about current conditions, historical maps, climate profiles, and agriculturally oriented resources such as drought management information, federal programs, and the crop condition assessment program. Clicking on the current conditions maps link leads to the page http://www.agr.gc.ca/pfra/drought/mapscc_e.htm, which opens a page containing links to national and regional precipitation, temperature, and drought index maps that may be viewed on the Web or as

Adobe Acrobat (PDF) files. The maps are updated according to their period of record (from seven days to a year). The current condition maps are likely the most relevant resources for watershed managers concerned about Canadian drought conditions. The Canadian Forest Service also has a fact sheet about drought at: http://cfs.nrcan.gc.ca/factsheets/drought-secheresse/cat.misc.

LOGGING

The vulnerability of a particular watershed to logging depends on logging plans and practices in an area. The best information for assessing vulnerability is likely to be local forest planning documents; however, on-line maps and resources to assess logging impacts are available for certain areas. The USDA Forest Service and the California Department of Forestry and Fire Protection maintain a Web site with maps that track changes to land and vegetation cover throughout the State of California (http://frap.cdf.ca.gov/projects/land_cover/monitoring/index.html). An index at the top of the page allows the viewer to navigate through the site, looking at maps by region.

The Klamath Resource Information System (KRIS) Web site (http://www.krisweb.com/index.htm) provides links to compiled information about fisheries and water quality in Northern California, especially as it relates to logging activity. A list of KRIS projects is along the left side of the page and clicking on the links takes the viewer to each specific project page. The compiled information provides a comprehensive evaluation of factors affecting water quality and the health of the fisheries in each project area.

The USDA Forest Service Forest Inventory and Analysis Web site (http://fia.fs.fed.us/) contains information about the forest inventory program. A map toward the bottom middle of the page allows the viewer to click on a region to visit the regional site, where further information about the forest inventory is available. By clicking on the Program Features link at the top left side of the page (http://fia.fs.fed.us/program-features/), the viewer can access information about how the inventory is conducted. From this page, additional links are available on the left side of the page and the viewer can find more information about the basic forest inventory, forest health indicators, timber products output studies, the national woodland owner survey, and the National Assessment Resources Planning Act.

AGRICULTURE AND GRAZING

The National Agricultural Statistics Service within the USDA maintains a comprehensive Web site with information on crops and animal production (http://www.nass.usda.gov). Maps are available that show planted acreage by county across the U.S. for a variety of crops. Maps of total crop acreage are available for selected states as well.

URBANIZATION

The USGS maintains a site devoted to examining and describing land use changes throughout the U.S. (http://edc2.usgs.gov/LT/index.php). The site has information about the types of land conversion and the potential forces driving those changes. Tabs across the top of the page allow the viewer to learn more about land use trends, and view preliminary results and a listing of publications, links, and contact information.

When the map is accessed on-line, the viewer can click on selected ecoregions to see photos and a more detailed analysis of land-use change. As of October 2, 2007, six of the 82 ecoregions in the U.S. had this additional information available.

A separate document detailing the land use changes in the Eastern U.S. is also available (http://edc2.usgs.gov/LT/coverpage.php). This publication has detailed information about land use changes in the Eastern U.S. by ecoregion and includes graphics and detailed analyses of land uses and changes for each ecosystem in the East.

Natural Resources Canada maintains a list of maps available from their Web site (http://ess.nrcan.gc.ca/mapcar/index_e.php), including maps that are relevant to understanding the impacts of urbanization. By clicking on the first link, Atlas of Canada, and then clicking on the Environment heading, the Land Cover Map can be accessed (http://atlas.nrcan.gc.ca/site/english/maps/environment/land/landcover), which shows Canada divided into 31 land-cover categories, including forest, shrub lands, tundra/grasslands, developed lands, and water. In the people and society maps section, the change in population in Canada between 1996 and 2001 can be seen (http://atlas.nrcan.gc.ca/site/english/maps/peopleandsociety/population/population2001/change2001). Other maps of interest to an analysis of urbanization include the population distribution as of 1996, population density by ecoregion, the percentage of the land committed to productive forests, and the road density map. These maps may be found by exploring the environment and people and society sections of the Atlas of Canada Web site.

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ABBREVIATIONS

ACE	U.S. Army Corps of Engineers
AFOs	animal feeding operations
ALDS	Automated Lightning Detection Systems
AWSD	Asheville Water Services Department
AWWA	American Water Works Association
AwwaRF	Awwa Research Foundation
BAER	Burned Area Emergency Rehabilitation
BMPs	best management practices
BOD	biological oxygen demand
DBP	disinfection by-product
EBMUD	East Bay Municipal Water District
EDC	endocrine-disrupting compound
°F	degrees Fahrenheit
FMU	Fire Management Unit
FOLKS	Friends of Lake Keowee
GIS	geographic information systems
HAA5	haloacetic acids
IPM	integrated pest management
JWC	Joint Water Commission
km^2	square kilometer
KRIS	Klamath Resource Information System
L	liter
LT2ESWTR	Long-Term 2 Enhanced Surface Water Treatment Rule
m	meter
m^3	cubic meter
MGD	million gallons per day
mg/L	milligrams per liter
mi^2	square mile
mL	milliliter
mm	millimeter
MWRA	Massachusetts Water Resources Authority

NLT	Natural Lands Trust
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
OWASA	Orange Water and Sewer Authority
PAH	polycyclic aromatic hydrocarbon
PAM	polyacrylamides
pH	potential of hydrogen
PPCP	pharmaceuticals and personal care product
ppm	parts per million
SAN	Schuylkill Action Network
SDWA	Safe Drinking Water Act
SFMN	Strategic Fuel Modification Network
THM	trihalomethane
TMDL	total maximum daily load
TOC	total organic carbon
TSS	total suspended solids
URDS	Urban Runoff Diversion System
U.S.	United States
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
UV	ultraviolet
VLAWMO	Vadnais Lake Area Water Management Organization
WAP	Watershed Agricultural Program
WSPAM	water soluble polyacrylamides
WTP	water treatment plant

Note: This file has Adobe Acrobat bookmarks. Clicking on the tab for bookmarks (at left) will enable the user to skip to each section of the bibliography.

Searchable, Annotated Bibliography

For easier reference, the sections in this annotated bibliography follow:

1. Agriculture and Grazing

Northeast

Agouridis, C.T., S.R. Workman, R.C. Warner, and G.D. Jennings. 2005. Livestock grazing management impacts on stream water quality: A review. *Journal of the American Water Resources Association* 41(3):591-606.

Abstract: Controlling agricultural nonpoint source pollution from livestock grazing is a necessary step to improving the water quality of the nation's streams. The goal of enhanced stream water quality will most likely result from the implementation of an integrated system of best management practices (BMPs) linked with stream hydraulic and geomorphic characteristics. However, a grazing BMP system is often developed with the concept that BMPs will function independently from interactions among controls, climatic regions, and the multifaceted functions exhibited by streams. This paper examines the peer-reviewed literature pertaining to grazing BMPs commonly implemented in the southern humid region of the United States to ascertain effects of BMPs on stream water quality. Results indicate that the most extensive BMP research efforts occurred in the western and midwestern United States. While numerous studies documented the negative impacts of grazing on stream health, few actually examined the success of BMPs for mitigating these effects. Even fewer studies provided the necessary information to enable the reader to determine the efficacy of a comprehensive systems approach integrating multiple BMPs with pre-BMP and post-BMP geomorphic conditions. Perhaps grazing BMP research should begin incorporating geomorphic information about the streams with the goal of achieving sustainable stream water quality.

Keywords: grazing; non-point source; Northeast; Southeast; water quality

Chowdhury, S. and K. Ganesh. 2006. The impact of landuse on surface water quality in Queens County, New York. *Journal of Environmental Hydrology* 14:Paper 15.

Abstract: Community water supplies throughout the United States are under increasing threat of contamination from agricultural and urban use of fertilizers and pesticides. Water samples were collected and analyzed in the field from six ponds and lakes from Queens County, New York. The concentrations of dissolved oxygen, chlorine, phosphate, ammonia, and nitrate were determined. Several types of land use around these waterbodies were identified. The present analyses indicate that a relationship exists between the agrochemicals (nitrate, phosphate, and ammonia) found in the water and the land use in Queens County.

Keywords: agriculture; drinking water quality; land use; nonpoint source; Northeast; water quality; watershed management

Foster, D., E. Boose, and J. Aber. 1998. Regionalization studies at Harvard Forest LTER. In *Perspectives on the Land-Use History of North America: A Context for Understanding Our Changing Environment*. T. D. Sisk (ed.), U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR 1998-0003 (Revised September 1999). Available: http://biology.usgs.gov/luhna/harvardforest.html.

Abstract: Ecological patterns are different at the regional, subregional, and landscape scales. This article describes the major ecological factors affecting New England at these various scales including major species and natural and human disturbance regimes.

Keywords: agriculture; fire; logging; Northeast

Jones, R.C. and B.H. Holmes. 1985. Effects of land use practices on water resources in Virginia. Virginia Water Resources Research Center Bulletin 144. Virginia Polytechnic Institute & State University.

Abstract: This study reviews the relationship between land use and water resources in Virginia. It examines three major land uses in the state-agriculture, urban, and forestry activities. For each land use, the relevant literature and state management programs are reviewed. In addition, the report outlines research needs in each area.

Agricultural activities affect the receiving waters of Virginia through increased loads of sediment, nutrients, pesticides, and pathogens. In general, pollutant loads are greatest from more intensive agricultural activities. Sediments and particulate nutrient losses may require other strategies. Urban land uses have the potential to increase sediment, nutrient, and heavy metal loads. Forestry practices may damage receiving waters through sediment loadings and alteration in stream habitat due to removal of riparian vegetation.

Recommended future research includes documentation and refinement of the effectiveness of existing best management practices (BMPs), investigation of the effectiveness of urban sediment BMP enforcement, determination of the significance of pathogen indicator organisms in urban and agricultural runoff, evaluation of the long-term cost of BMP structures, demonstration of agricultural and forestry BMPs, and exploration of the pollutant delivery problem in watersheds.

Keywords: agriculture; land use; nonpoint source; Northeast; nutrient load; urban

Lyon, S.W., M.R. McHale, M.T. Walter, and T.S. Steenhuis. 2006. The impact of runoff generation mechanisms on the location of critical source areas. *Journal of the American Water Resources Association* 42(3):793-804.

Abstract: Identifying phosphorous (P) source areas and transport pathways is a key step in decreasing P loading to natural water systems. This study compared the effects of two modeled runoff generation processes – saturation excess and infiltration excess – on total phosphorous (TP) and soluble reactive phosphorous (SRP) concentrations in 10 catchment streams of a Catskill Mountain watershed in southeastern New York. The spatial distribution of runoff from forested land and agricultural land was generated for both runoff processes; results of both distributions were consistent with Soil Conservation Service-Curve Number theory. These spatial runoff distributions were then used to simulate stream concentrations of TP and SRP through a simple equation derived from an observed relation between P concentration and land use; empirical results indicate that TP and SRP concentrations increased with increasing percentage of agricultural land. Simulated TP and SRP stream concentrations predicted for the 10 catchments were strongly affected by the assumed runoff mechanism. The modeled TP and SRP concentrations produced by saturation excess distribution averaged 31% higher and 42% higher, respectively, than those produced by the infiltration excess distribution. Misrepresenting the primary runoff mechanism could not only produce erroneous concentrations, it could fail to correctly locate critical source areas for implementation of best management practices. Thus, identification of the primary runoff mechanism is critical in the selection of appropriate models in the mitigation of nonpoint source pollution. Correct representation of runoff processes is also critical in the future development of biogeochemical transport models, especially those that address nutrient fluxes.

Keywords: agriculture; best management practices; development; land use; management; nonpoint source; Northeast; phosphorous; runoff; water quality; water resources; watershed

Stout, W.L., S.L. Fales, L.D. Muller, R.R. Schnabel, and S.R. Weaver. 2000. Water quality implications of nitrate leaching from intensively grazed pasture swards in the northeast US. *Agriculture Ecosystems & Environment* 77:203-210.

Abstract: High density animal production systems, such as management intensive grazing (MIG), can have a negative effect on water quality. Learning to manage such systems to minimize water quality impacts is essential for the environmental and economic sustainability of these types of animal production systems. Management intensive grazing is a grazing system in which animals at a high stocking density are rotated through several paddocks at short time intervals (12-24 hours) so that animal performance is maximized. Although MIG has the potential to increase dairy farm profitability in the northeast United States, recent work in this region has shown that a substantial amount of nitrogen applied as fertilizer is leached below the root zone of orchardgrass (*Dactylis glomerata* L., (cv.) "Pennlate") managed as an intensive pasture. How much N is leached from other forage species managed as intensive pasture under the climatic conditions of the northeast United States is not known. A field study was conducted using large drainage lysimeters to measure nitrate nitrogen (NO_3^--N) leaching loss from six pasture swards: orchardgrass + N, orchardgrass+alfalfa (*Medicago sativa* L., (cv.) Alfagraze), orchardgrass + Ladino type white clover (*Trifolium repens* L.), Ryegrass (*Lolium perenne* L, (cv.) Citadel) + N, ryegrass + alfalfa, and ryegrass + white clover. The study site was located in central Pennsylvania on a Hagerstown silt loam soil (fine, mixed, mesic Typic Hapludalf). Nitrate-N leaching losses were most consistent under N fertilized swards where the amount of N could be adjusted for yearly weather conditions. In a drought year, NO_3^--N leaching increased dramatically in swards containing alfalfa or white clover. Sward type and stocking density need to be taken into consideration when developing an animal production system that will be both environmentally and economically sustainable.

Keywords: drought; grazing; land use; management; management intensive grazing (MIG); nitrate; Northeast; water quality

Southeast

Agouridis, C.T., S.R. Workman, R.C. Warner, and G.D. Jennings. 2005. Livestock grazing management impacts on stream water quality: A review. *Journal of the American Water Resources Association* 41(3):591-606.

Abstract: Controlling agricultural nonpoint source pollution from livestock grazing is a necessary step to improving the water quality of the nation's streams. The goal of enhanced stream water quality will most likely result from the implementation of an integrated system of best management practices (BMPs) linked with stream hydraulic and geomorphic characteristics. However, a grazing BMP system is often developed with the concept that BMPs will function independently from interactions among controls, climatic regions, and the multifaceted functions exhibited by streams. This paper examines the peer-reviewed literature pertaining to grazing BMPs commonly implemented in the southern humid region of the United States to ascertain effects of BMPs on stream water quality. Results indicate that the most extensive BMP research efforts occurred in the western and midwestern United States. While numerous studies documented the negative impacts of grazing on stream health, few actually examined the success of BMPs for mitigating these effects. Even fewer studies provided the necessary information to enable the reader to determine the efficacy of a comprehensive systems approach integrating multiple BMPs with pre-BMP and post-BMP geomorphic conditions. Perhaps grazing BMP research should begin incorporating geomorphic information about the streams with the goal of achieving sustainable stream water quality.

Keywords: grazing; non-point source; Northeast; Southeast; water quality

Braatz, D.A. 2001. Effectiveness of agricultural BMP's in reducing stormflow sediment in Tellico Creek, Macon County, North Carolina. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X065-X-72. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf.

Abstract: Tellico Creek is a tributary of the Little Tennessee River, in the southern Appalachian Mountains in western North Carolina. Headwater reaches, starting at the Appalachian Trail, consist of stream types A and A+; lower reaches in this study's area, are B3a channels. The region is largely forested, with limited agriculture. Water quality is generally very good: specific conductance is low (7 to 20 micromhos per centimeter); total alkalinity is low (2.0 to 4.6 milligrams $CaCO_3$ per liter); and nutrient concentrations are low. Total suspended solids (TSS) have been monitored at up to eight sites in the 1,591 hectare (6.05 square miles) Tellico Creek study area since 1990, as part of Duke Power Company's erosion control assessment program for transmission lines. Construction activity such as clearing tower sites and building or upgrading access roads in this area of high rainfall and rugged terrain poses significant potential

for erosion and for sedimentation impacts to surface waters. North Carolina's Division of Water Quality has identified sedimentation as the biggest threat to mountain streams.

An earlier study documented the successful use of construction best management practices (BMPs), and the subsequent reduction of stormflow sediment concentrations. BMPs to improve and stabilize roads (such as installing culverts and broad-based dips, maintaining silt fences to reduce off-site sediment, promptly seeding disturbed areas, and respecting vegetated buffer zones along the creek), all contributed to the successful completion of the transmission line project. However, lower reaches of the creek, including a major aquaculture operation, remained subject to sediment concentrations exceeding 10,000 milligrams per liter after the initial program. A small family farm was identified as the source of 90% of the stormflow TSS. The current study focuses on that farm, and on three sampling sites: Upper Tellico and Sugar Cove creeks (the main stream and a major tributary, both just above the farm), and Lower Tellico (just below the farm, and also below the confluence of Tellico and Sugar Cove creeks). A cooperative program between stakeholders was initiated in 1994 to address the agricultural impact to the stream. The study objective was to eliminate the 90% of stormflow TSS estimated to originate on the agricultural property, so that the quantity of sediment leaving the farm would be no greater than the quantity of sediment entering the farm from upstream.

Keywords: agriculture; development; road construction; Southeast; vegetation change; water quality

Kirkman, L.K., R.F. Lide, G. Wein, and R.R. Sharitz. 1996. Vegetation changes and land-use legacies of depression wetlands of the western coastal plain of South Carolina: 1951-1992. *Wetlands* 16(4):564-576.

Abstract: The authors examined historical patterns of land use of depression wetlands (Carolina bay and bay-like wetlands) to determine if a relationship between vegetative successional changes over a 41-year period and previous human disturbances (primarily agricultural) could be established. Land cover was interpreted from 1951 (black and white) and 1992 (false color infrared) aerial photography of the Savannah River site (a 780 square kilometer federal nuclear facility in which wetlands have been relatively undisturbed since 1951). Patterns of change from one land cover to another were detected by constructing a series of frequency tables. About one-fourth of the 299 wetlands identified were either pasture or cultivated in 1951, and the majority had been ditched for drainage. Agriculturally disturbed wetlands primarily became mixed hardwood/pine or were converted to pine plantations by 1992; however, no successional differences between wetlands that were cultivated versus pasture were detectable. The type of land use of many of the depression wetlands prior to 1951 probably was determined by physical characteristics of the wetlands (e.g., topographic position, size, and hydrologic features). Thus, in many cases, separation of recovery trajectories from other successional pathways, initial hydrogeomorphic differences, and/or continued human influences is not possible in this study. However, from this change-detection study, the authors recognize that many of the currently protected depression wetlands at the Savannah River site were disturbed by agricultural practices or were impacted by hydrologic alterations prior to 1951, implying considerable resilience in the recovery toward a functioning wetland condition if hydrologic regimes are restored. A significant finding of this study is the relative stability of herb-dominated bays, which indicates that this vegetation type is not necessarily a successional continuum toward an eventual hardwood forest, at least in the temporal scale of the study. Thus, the authors suggest that management prescriptions for the restoration/conservation of herb-dominated wetlands should incorporate concepts of temporal stability within a framework of cyclical hydrologic and vegetation changes.

Keywords: agriculture; land use change; Southeast; vegetation change

Mallin, M.A., M.H. Posey, G.C. Shank, M.R. McIver, S.H. Ensign, and T.D. Alphin. 1999. Hurricane effects on water quality and benthos in the Cape Fear watershed: natural and anthropogenic impacts. *Ecological Applications* 9(1):350-362.

Abstract: In the summer of 1996, southeastern North Carolina, was struck by two hurricanes, with the second (Hurricane Fran) doing considerably more damage than the first (Hurricane Bertha). The Cape Fear watershed, the largest in North Carolina, suffered from severe water quality problems for weeks following Hurricane Fran, including a massive fish kill in the Northeast Cape Fear River. Post-hurricane flooding caused inputs of riparian swamp water to river channels, and sewage treatment plant and pump station power failures caused diversions of millions of liters of raw and partially treated human waste into rivers. Additionally, several swine waste lagoons were breached, overtopped, or inundated, discharging large quantities of concentrated organic waste into the system, particularly into the Northeast Cape Fear River. Dissolved oxygen (DO) decreased to 2 milligram per liter in the mainstem Cape Fear River, and fell to zero in the Northeast Cape Fear River for > 3 weeks. Biochemical oxygen demand in the Northeast Cape Fear River was sixfold greater than in the other tributaries, probably as a result of anthropogenically derived inputs. The Cape Fear Estuary also suffered from hypoxia for several weeks. Following Hurricane Fran, ammonium levels in the Northeast Cape Fear River displayed a distinct increase, and total phosphorus reached its highest concentration in 27 years. The benthic community, which is dominated by opportunistic species typical of oligohaline to mesohaline estuarine areas, showed a mixed response. There was a significant decline in total benthic abundances immediately after Hurricane Fran at an oligohaline station in the Northeast Cape Fear River, with recovery occurring in 3 months. An oligohaline station in the mainstem Cape Fear River, which had relatively rapid DO recovery, did not display significant declines. A mesohaline station 5 kilometers below the confluence of these rivers showed broad and long-lasting benthic declines, but benthic declines were less severe in the lowest reaches of the estuary sampled. The natural hurricane effect of swamp water flooding into river basins led to reduced dissolved oxygen levels and increased light attenuation. However, environmental damage was considerably increased by anthropogenic practices, including the lack of backup generating systems for waste treatment systems and subsequent sewage diversions into rivers, as well as accidents occurring at swine waste lagoons sited on river floodplains.

Keywords: agriculture; hurricane; Southeast; water quality

McGregor, K., J. Schreiber, R. Cullum, and J. Johnson. 2001. Return of two grassed watersheds to crop production. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X-81-X-88. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf.

Abstract: Two watersheds at Holly Springs, Mississippi, were returned to row crop production in 1994, thus simulating the similar return of Conservation Reserve Program land to row crop production. Runoff and sediment yield were very low before and after the return of the two grassed watersheds to row crop production. One watershed, WS-1 (1.3 hectares, ha), had predominantly Lexington silt loam soils on slopes of 5 to 10% and Memphis silt loam soils on other parts of the watershed. The other watershed, DB-1 (1.8 ha), had Memphis silt loam and Loring silt loam soils on slopes of 2.5% and Providence silt loam soils on slopes of about 7.5%. The DB-1 watershed also contained shallow fragipan soils. No-till crops were planted between 6.1-meter wide fescue grassed buffer strips in the spring of 1994 on both watersheds. Continuous cotton (*Gossypium hirsutum*) was grown on the DB-1 watershed for four years, but the watershed then was returned to grass because of the development of rills and small gullies. A corn (*Zea mays*)-cotton rotation was grown on the WS-1 watershed. The combination of no-till, cotton-corn rotation, and grassed buffer strips provided good erosion control on the WS-1 watershed. Results from this study will be useful to conservationists and farmers considering returning idle-land to row crop production.

Keywords: agriculture; erosion; Southeast; vegetation change

Schoonover, J.E., G.E. Lockaby, and B.S. Helms. 2006. Impacts of land cover on stream hydrology in the West Georgia Piedmont, USA. *Journal of Environmental Quality* 35:2123-2131.

Abstract: The southeastern United States is experiencing rapid urban development. Consequently, Georgia's streams are experiencing hydrologic alterations from extensive development and from other land use activities such as livestock grazing and silviculture. A study was performed to assess stream hydrology within 18 watersheds ranging from 500 to 2,500 hectares. Study streams were first, second, or third order and hydrology was continuously monitored from July 29, 2003 to September 23, 2004 using in situ pressure transducers. Rating curves between stream stage (i.e., water depth) and discharge were developed for each stream by correlating biweekly discharge measurements and stage data. Dependent variables were calculated from discharge data and placed into four categories: flow frequency (i.e., the number of times a predetermined discharge threshold is exceeded), flow magnitude (i.e., maximum and minimum flows), flow duration (i.e., the amount of time discharge was above or below a predetermined threshold), and flow predictability and flashiness. Fine resolution data (i.e., 15-minute interval) were also compared to daily discharge data to determine if resolution affected how streams were classified hydrologically. Urban watersheds experienced flashy discharges during storm events, whereas pastoral and forested watersheds showed less flashy hydrographs. Also, in comparison to all other flow variables, flow frequency measures were

most strongly correlated to land cover. Furthermore, the stream hydrology was explained similarly with both the 15-minute and daily data resolutions.

Keywords: development; flow; grazing; land cover; land use; Southeast; storm; urban; vegetation change; watershed

Zhang, Y.-K. and K.E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940's: Effect of land use change. *Journal of Hydrology* 324(1-4):412-422.

Abstract: A trend of increasing streamflow has been observed in the Mississippi River (MR) basin since the 1940s as a result of increased precipitation. This study shows that increasing MR flow is mainly a result of land use change and accompanying agricultural activities that occurred in the MR basin during the last 60 years. Agricultural land use change in the MR basin has affected the basin-scale hydrology: more precipitation is being routed into streams as baseflow than stormflow since the 1940s. The authors explain that the conversion of perennial vegetation to seasonal row crops, especially soybeans, in the basin since the 1940s may have reduced evapotranspiration, increased groundwater recharge, and thus increased baseflow and streamflow. This explanation is supported with a data analysis of the annually and monthly flow rates at various river stations in the MR basin. Results from this study will help to direct efforts in managing land use and in reducing nutrient levels in MR and other major rivers since nutrient concentrations and loads carried by stormwater and baseflow are different.

Keywords: agriculture; land use change; North Central; nutrient load; South Central; Southeast; streamflow

North Central

Queen, L.P., K.N. Brooks, and W.L. Wold. 1995. Assessing cumulative effects in the Nemadji river basin, Minnesota. In *Watershed Management: Planning for 21st Century*. T. J. Ward (ed.) American Society of Civil Engineers, New York, pp. 239-248.

Abstract: The Nemadji River in northeastern Minnesota contributes an estimated 525,000 metric tons of sediment per year to Lake Superior. A portion of the Nemadji Basin is composed of highly erodible red clays that are susceptible to soil mass movement. The red clay area was studied in the late 1970s through a joint interagency project that concluded that natural levels of erosion-sedimentation in the red clay area have been intensified by human activity. The cumulative effects of logging, burning, clearing for agriculture, and road construction are increased runoff, higher peak streamflows, rapid channel scouring, increased soil mass movement, and stream bank undercutting. This study uses a Geographic Information System to analyze watershed characteristics of subwatersheds within the Nemadji Basin. Bivariate analyses indicated that the frequency of slump occurrence was inversely related to the total forested area. The results of this investigation indicate that the percent of nonforested area is related to a greater frequency of soil slumps, and that management should be aimed at increasing and maintaining forest cover in the watershed.

Keywords: agriculture; development; erosion; fire; logging; mudslide; North Central; risk reduction; runoff; sediment control; vegetation change; watershed management

Schilling, K.E. and J. Spooner. 2006. Effects of watershed-scale land use change on stream nitrate concentrations. *Journal of Environmental Quality* 35:2132-2145.

Abstract: The Walnut Creek Watershed Monitoring Project was conducted from 1995 through 2005 to evaluate the response of stream nitrate concentrations to changing land use patterns in paired 5,000-hectare Iowa watersheds. A large portion of the Walnut Creek watershed is being converted from row crop agriculture to native prairie and savanna by the U.S. Fish and Wildlife Service at the Neal Smith National Wildlife Refuge. Before restoration, land use in both Walnut Creek (treatment) and Squaw Creek (control) watersheds consisted of 70% row crops. Between 1990 and 2005, row crop area decreased 25.4% in Walnut Creek due to prairie restoration, but increased 9.2% in Squaw Creek due to Conservation Reserve Program (CRP) grassland conversion back to row crop. Nitrate concentrations ranged between 0.5 and 14 milligrams per liter (mg/L) at the Walnut Creek outlet and 2.1 to 15 mg/L at the downstream Squaw Creek outlet. Nitrate concentrations decreased 1.2 mg/L over 10 years in the Walnut Creek watershed but increased 1.9 mg/L over 10 years in Squaw Creek. Changes in nitrate were easier to detect and more pronounced in monitored subbasins, decreasing 1.2 to 3.4 mg/L in three Walnut Creek subbasins, but increasing up to 8.0 and 11.6 mg/L in 10 years in two Squaw Creek subbasins. Converting row crop lands to grass reduced stream nitrate levels over time in Walnut Creek, but stream nitrate rapidly increased in Squaw Creek when CRP grasslands were converted back to row crop. Study results highlight the close association of stream nitrate to land use change and emphasize that grasslands or other perennial vegetation placed in agricultural settings should be part of a long-term solution to water quality problems.

Keywords: agriculture; land use; nitrate; nonpoint source; North Central; phosphorous; water quality; watershed

Zhang, Y.-K. and K.E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940's: Effect of land use change. *Journal of Hydrology* 324(1-4):412-422.

Abstract: A trend of increasing streamflow has been observed in the Mississippi River (MR) basin since the 1940s as a result of increased precipitation. This study shows that increasing MR flow is mainly a result of land use change and accompanying agricultural activities that occurred in the MR basin during the last 60 years. Agricultural land use change in the MR basin has affected the basin-scale hydrology: more precipitation is being routed into streams as baseflow than stormflow since the 1940s. The authors explain that the conversion of perennial vegetation to seasonal row crops, especially soybeans, in the basin since the 1940s may have reduced evapotranspiration, increased groundwater recharge, and thus increased baseflow and streamflow. This explanation is supported with a data analysis of the annually and monthly flow rates at various river stations in the MR basin. Results from this study will help to direct efforts in managing land use and in reducing nutrient levels in MR and other major rivers since nutrient concentrations and loads carried by stormwater and baseflow are different.

Keywords: agriculture; land use change; North Central; nutrient load; South Central; Southeast; streamflow

South Central

Edwards, D.R., T.C. Daniel, H.D. Scott, J.F. Murdoch, M.J. Habiger, and H.M. Burks. 1996. Stream quality impacts of best management practices in a northwestern Arkansas Basin. *Water Resources Bulletin* 32(3):499-509.

Abstract: A variety of management options are used to minimize losses of nitrogen (N), phosphorous (P), and other potential pollutants from agricultural source areas. There is little information available, however, to indicate the effectiveness of these options (sometimes referred to as Best Management Practices, or BMPs) on basin scales. The objective of this study is to assess the water quality effectiveness of BMPs implemented in the 2,340 hectare Lincoln Lake basin in Northwest Arkansas. Land use in the basin was primarily forest (34%) and pasture (56%), with much of the pasture being regularly treated with animal manures. The BMPs were oriented toward minimizing the impact of confined animal operations in the basin and included nutrient management, dead bird composter construction, and other practices. Streamflow samples (representing primarily base flow conditions) were collected biweekly from five sites within the basin from September 1991 through April 1994 and analyzed for nitrate N, ammonia N (NH_3-N), total Kjeldahl N (TKN), ortho-P (PO_4^--P), total P (TP), chemical oxygen demand (COD), and total suspended solids (TSS). Mean concentrations of PO_4^--P, TP, and TSS were highest for subbasins with the highest proportions of pasture land use. Concentrations of NH_3-N, TKN, and COD decreased significantly with time (35-75% per year) for all subbasins, while concentration of other parameters were generally stable. The declines in analysis parameter concentrations are attributed to the implementation of BMPs in the basin since (1) the results are consistent with what would be expected for the particular BMPs implemented and (2) no other known activities in the basin would have caused the declines in analysis parameter concentrations.

Keywords: agriculture; best management practices; land use; nonpoint source; South Central; water quality; water resources management

McIntyre, S.C. 1993. Reservoir sedimentation rates linked to long-term changes in agricultural land use. *Water Resources Bulletin* 29(3):487-495.

Abstract: Long-term land use and reservoir sedimentation were quantified and linked in a small agricultural reservoir-watershed system without having historical data. Land use was determined from a time sequence of aerial photographs, and reservoir sedimentation was determined from cores with 137Ca dating techniques. They were linked by relating sediment deposition to potential sediment production, which was determined by the Universal Soil Loss Equation and the SCS Pottawatomie Company, Oklahoma estimates for cullied land. Sediment cores were collected from Tecumesh Lake, a 55-hectare (ha) reservoir with a 1,189-ha agricultural watershed, constructed in 1934 in central Oklahoma. Reservoir sediment deposition decreased

from an average of 5,933 milligrams per year (mg/yr) from 1934 to 1954, to 3,179 mg/yr from 1962 to 1987. Potential sediment production decreased from an average of 29,892 to 11,122 and then to 3,5933 mg/yr for the same time periods as above, respectively. Reductions in deposition and sediment production corresponded to reductions in cultivated and abandoned cropland which became perennial pasture. Together, cultivated and abandoned cropland accounted for 59% of the watershed in 1937, 24% in 1954, and 10% in 1962. Roadway erosion, stream bank erosion, stored stream channel sediment, and long-term precipitation were considered, but none seemed to play a significant role in changing sediment deposition rates. Instead, the dominant factor was the conversion of fields to perennial pastures. The effect of conservation measures on reservoir sedimentation can now be quantified for many reservoirs where historical data are not available.

Keywords: agriculture; land use; reservoirs; sedimentation; South Central; watershed

Zhang, Y.-K. and K.E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940's: Effect of land use change. *Journal of Hydrology* 324(1-4):412-422.

Abstract: A trend of increasing streamflow has been observed in the Mississippi River (MR) basin since the 1940s as a result of increased precipitation. This study shows that increasing MR flow is mainly a result of land use change and accompanying agricultural activities that occurred in the MR basin during the last 60 years. Agricultural land use change in the MR basin has affected the basin-scale hydrology: more precipitation is being routed into streams as baseflow than stormflow since the 1940s. The authors explain that the conversion of perennial vegetation to seasonal row crops, especially soybeans, in the basin since the 1940s may have reduced evapotranspiration, increased groundwater recharge, and thus increased baseflow and streamflow. This explanation is supported with a data analysis of the annually and monthly flow rates at various river stations in the MR basin. Results from this study will help to direct efforts in managing land use and in reducing nutrient levels in MR and other major rivers since nutrient concentrations and loads carried by stormwater and baseflow are different.

Keywords: agriculture; land use change; North Central; nutrient load; South Central; Southeast; streamflow

Northwest

Emmerich, W.E. and R.K. Heitschmidt. 2002. Drought and grazing II: Effects on runoff and water quality. *Journal of Range Management* 55:229-234.

Abstract: Understanding the interacting effects of drought and grazing on runoff, erosion, and nutrient transport is essential for improved rangeland management. Research was conducted at the Fort Keogh Livestock and Range Research Laboratory located near Miles City, Montana using 12 non-weighing lysimeters for 3 years. During years 1 and 3, no drought treatment was imposed. For year 2, one-half of the lysimeters were covered to implement a drought treatment. The 3 grazing treatments were ungrazed, grazed during but not after drought, and grazed during and after drought. Runoff, sediment yield, and an array of nutrients in the runoff water were measured from the lysimeters. First year base line data with no grazing or drought treatments applied indicated no significant differences among lysimeters.

Below normal precipitation occurred during year 2, resulting in no runoff from the drought treatment and negated the "nondrought" control. This prevented a direct assessment of the interaction among the drought and grazing treatments for this year. The drought treatment did produce significant reductions in water, sediment, and nutrient yield. No grazing impacts were observed during year 2. The third year with more normal precipitation, there was a trend toward increased runoff, sediment, and nutrient yield from the second year drought treatment lysimeters. In the third year, both grazing treatments showed significantly greater runoff, sediment, and nutrient yield than the ungrazed treatment. Runoff and sediment yield tended to increase from the combination of drought and grazing treatments. The observed increases in runoff and sediment and reduced water quality from the drought and grazing treatments were measured against controls and when compared to the natural variability and water quality standards, they were concluded to be minimal.

Keywords: drought; grazing; Northwest; nutrient; sediment; water quality

Heitschmidt, R.K., K.D. Klement, and M.R. Haferkamp. 2005. Interactive effects of drought and grazing on northern Great Plains rangelands. *Rangeland Ecology and Management* 58:11-19.

Abstract: Drought is common in rangeland environments and an understanding of its impacts on the structure and function of rangeland ecosystems is paramount for developing effective management strategies. This research was the second of a series of studies investigating the impacts of varying seasonal droughts on northern Great Plains rangelands. Research was conducted on native rangeland during the 1998 through 2001 growing seasons. Study plots were twelve 5 × 10 meters nonweighing lysimeters. An automated rainout shelter was used to establish drought conditions on 6 lysimeters during April, May, and June of 1998 and 1999. Single-day, flash grazing events were imposed at the beginning of May, June, and July. Grazing treatments were (1) graze during the two years of drought and the year after; (2) graze during the two years of drought and rest the year after; and (3) rest all years. Results showed that the intense spring drought reduced soil water content in the upper 30 centimeters of the soil profile and subsequently reduced total herbage production 20% to 40%; cool-season perennial grasses were the primary contributor to the reduction and cool-season annual grasses were secondary. Periodic grazing during drought had minimal impact on herbage production, whereas impacts on nondrought plots ranged from moderate enhancement to moderate suppression, with effects varying depending on functional group. Results also showed that substantial recovery occurred during the 1st postdrought year, with near full recovery realized within two years.

Keywords: drought; grazing; Northwest

Pierson Jr., F.B., K.E. Spaeth, and D.H. Carlson. 2001. Fire effects on sediment and runoff in steep rangeland watersheds. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X-33-X-40. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf.

Abstract: Fire is a natural component of the Intermountain sagebrush-steppe ecosystem with a return period of 25 to 100 years, depending on community type and natural fuel load and distribution. However, fuel and land management activities in the past century have placed wildland values such as soil and water quality at greater risk from wildfire. Increased soil erosion over natural levels following wildfire can lead to the loss of soil productivity. Additionally, higher runoff rates from severely burned landscapes can lead to flooding, sedimentation, and increased risk to human life and property. This increased risk of runoff and erosion following wildfire continues to generate concern at the expanding urban-wildland interface throughout the western United States.

While the hydrological consequences of fire have been widely examined in forest ecosystems, few studies have examined wildfire impacts on rangeland hydrology and erosion. Most of these studies have shown an increase in runoff and erosion rates the first year following fire, with recovery to pre-fire rates generally within five years. Timing and extent of recovery is highly dependent on slope and vegetation type. Many rangeland plant communities have naturally occurring hydrophobicity, but litter and vegetative cover protect the soil and enhance infiltration. Fire removes this protective covering, exposing the soil to erosion by raindrop impact and overland flow. Fire can also vaporize some of the organic compounds on the soil surface and distill the rest downwards, creating concentrated hydrophobic layers within the upper soil. The degree and longevity of hydrophobicity is dependent on compounds present and intensity and duration of fire. Fire can also reduce the organic matter content in the upper layers, thus reducing infiltration.

Major unknowns associated with rangeland wildfire are effects on vegetation and soil conditions affecting hydrologic processes, including infiltration, surface runoff, erosion, sediment production and transport, flooding, and the effectiveness of mitigation practices. The U.S. Department of Agriculture Agricultural Research Service Northwest Watershed Research Center (NWRC) has been investigating the impact of fire on rangeland hydrology and erosion in the mountains above Boise, Idaho (Boise Front) and in the Pine Forest Range near Denio, Nevada. The objective of the NWRC investigations are to quantify fire impacts on infiltration capacity, runoff, and erosion following fire; gain insight into the processes involved; and determine how long the fire effects persist.

Keywords: erosion; fire; grazing; Northwest; sediment; vegetation change; water quality; water quantity; watershed

Southwest

Gary, H.L., S.R. Johnson, and S.L. Ponce. 1983. Cattle grazing impact on surface water quality in a Colorado Front Range stream. *Journal of Soil and Water Conservation* 38:124-128.

Abstract: Cattle grazing in pastures bisected by a small perennial stream in central Colorado had only minor effects on water quality during two years of study. Suspended solids and nitrate nitrogen did not increase significantly, and ammonia nitrogen increased significantly only once under moderate rates of grazing. Indicator bacteria densities in the stream water were significantly higher when at least 150 cattle were grazing. After removal of cattle or when 40 head of cattle were grazing, bacterial counts dropped to levels similar to those in adjacent, ungrazed pasture. About 5% of the total manure produced by cattle contributed to pollution and/or enrichment of the stream.

Keywords: ammonia; bacterial pathogens; grazing; land use; nitrate; phosphorous; Southwest; suspended solids; water quality

Kent, R., K. Belitz, A.J. Altmann, M.T. Wright, and G.O. Mendez. 2005. Occurrence and Distribution of Pesticides in Surface Water of the Santa Ana Basin, California, 1998-2001. U.S. Geological Survey Scientific Investigations Report 2005-5203.

Abstract: A study of the occurrence and distribution of pesticide compounds in surface water of the highly urbanized Santa Ana Basin, California, was done as part of the U.S. Geological Survey's National Water-Quality Assessment Program. One-hundred and forty-eight samples were collected from 23 sites, and analyzed for pesticide compounds during the study period from November 1998 to September 2001. Sixty-six different pesticide compounds were detected at varying frequencies and concentrations, and one or more pesticides were detected in 92% of the samples. All pesticide concentrations were below maximum levels permitted in drinking water. However, two compounds-diazinon and diuron-exceeded nonenforceable drinking water health advisory levels in at least one stream sample, and five compounds exceeded guidelines to protect aquatic life-carbaryl, chlorpyrifos, diazinon, lindane, and malathion. Twenty-two pesticide compounds were detected in at least 25% of the samples collected from any one fixed site. These are identified as "major" pesticide compounds and are emphasized in this report.

The degree to which pesticides were used in the basin, as well as their physical-chemical properties, are important explanatory factors in stream pesticide occurrence, and most pesticides probably enter streams with urban runoff. Stormflow substantially increases urban runoff, and storm effects on stream pesticide concentrations sometimes persist for several days or weeks after the storm. Water sources other than urban runoff also deliver pesticide compounds to surface water in the basin. For example, atrazine may enter streams in gaining reaches where groundwater carries high loads as a result of historical use in the basin. Also, the data suggest that lindane, and perhaps bromacil, are present in treated wastewater, the predominant source of water to streams in the Santa Ana Basin.

Keywords: agriculture; pesticides; Southwest; urbanization; water quality

Klamt, R.R. 2000. The Garcia experience: a sediment TMDL case study. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 29-34. Water Resources Center Report No. 98.

Abstract: Salmon and steelhead play a significant role in California north coastal economy, philosophy, and politics. Author Mark Twain is credited with saying that in the West, whisky is for drinking and water is to fight over. More recently on the north coast, the fight has focused on salmon and land use. Continued concern for the anadromous fisheries has turned attention from the water itself to the riparian zone and hill slopes of the steep erosive coastal mountains of northern California.

The Garcia River is a coastal tributary located about 100 miles north of San Francisco Bay. It is forested with commercial conifers and hardwoods and supports farming and cattle and sheep ranching. Historic waves of logging activity at different levels of regard for the land and water resources coupled with erosive soils on steep slopes and high winter rainfall resulted in significant erosion and sedimentation. Concern over declining anadromous salmonid populations brought attention to sediment impacts in the Garcia River watershed. That focus and threat of a lawsuit prompted the development of a sediment reduction strategy (TMDL) that addresses habitat and channel structure in the waterways by requiring landowners to submit erosion control plans. In May 1998 the North Coast Regional Water Quality Control Board adopted a TMDL and implementation plan with the assistance of the U.S. Environmental Protection Agency. Controllable sediment discharges are prohibited, and reductions of sediment delivery to streams from roads, timber harvest, and agriculture are required on a 40-year time table. Instream numeric targets that describe the desired future conditions of the riparian area, stream channel and fish habitat are used as goals to measure the success of the reductions over time. The development of the TMDL and, especially, the implementation plan were contentious and involved numerous public workshops and hearings over a 2-year period. However, landowner response and attitude and, subsequently, the nature of land use activities is slowly changing. Landowner inventories and monitoring will provide a physical assessment of watershed recovery. The response of the fisheries will tell the ultimate story.

Keywords: case study; development; erosion; grazing; land management; land use; logging; sediment; Southwest; vegetation; water quality; water resources; watershed

Lewis, D.J., E.R. Atwill, M.S. Lennox, L. Hou, B. Karle, and K.W. Tate. 2005. Linking on-farm dairy management practices to storm-flow fecal coliform loading for California coastal watersheds. *Environmental Monitoring and Assessment* 107(1-3):407-425.

Abstract: How and where to improve water quality within an agricultural watershed requires data at a spatial scale that corresponds with individual management decision units on an agricultural operation. This is particularly true in the context of water quality regulations, such as Total Maximum Daily Loads, that identify agriculture as one source of nonpoint source pollution through larger tributary watershed scales and above and below water quality investigations. A systems approach study of 10 coastal dairies and ranches to document fecal coliform concentration and loading to surface waters at the management decision unit scale was conducted. Water quality samples were collected on a storm event basis from loading units that included manure management systems; gutters; storm drains; pastures; and corrals and lots. In addition, in-stream samples were collected above and below the dairy facilities and from a control watershed, managed for light grazing and without a dairy facility or human residence and corresponding septic system. Samples were analyzed for fecal coliform concentration by membrane filtration. Instantaneous discharge was measured for each collected sample. Storm runoff was also calculated using the curve number method. Results for a representative dairy as well as the entire 10 dairy dataset are presented. Fecal coliform concentrations demonstrate high variability both within and between loading units. Fecal coliform concentrations for pastures range from 206 to 2,288,888 colony forming units (cfu)/100 milliliters (mL) and for lots from 1,933 to 166,105,000 cfu/100 mL. Mean concentrations for pastures and lots are 121,298 (standard error, SE = 62,222) and 3,155,584 (SE = 1,902,713) cfu/100 mL, respectively. Fecal coliform load from units of concentrated animals and manure are significantly more than units such as pastures while storm flow amounts were significantly less. Compared with results from earlier tributary scale studies in the watershed, this system's approach has generated water quality data that are beneficial for management decisions because of its scale and representation of current management activities. These results are facilitating on-farm changes through the cooperative efforts of dairy managers, regulatory agency staff, and sources of technical and financial assistance.

Keywords: agriculture; E. coli; fecal coliform; land use; management; nonpoint source; Southwest; watershed

United States

Ernst, C. and K. Hart. 2005. Path to Protection: Ten Strategies for Successful Source Water Protection. The Trust for Public Land.

Abstract: Over the past five years, the U.S. Environmental Protection Agency's (EPA's) Office of Ground Water and Drinking Water funded five national nonprofit organizations to launch source water demonstration projects in communities around the country. The purpose of the projects was to build on state Source Water Assessment Programs to move communities from planning to implementing protection for drinking water sources. Successful pilot projects could then be replicated by state and local governments and water suppliers around the country. In order to glean the lessons learned and identify best practices, the Trust for Public Land (TPL) led a joint review of the five grantees' source protection demonstration projects during the spring and summer of 2004. The five grantees were the Clean Water Network/Clean Water Fund/Campaign for Safe and Affordable Drinking Water, the Groundwater Foundation, the Environmental Finance Center Network, the National Rural Water Association, and TPL (in partnership with the University of Massachusetts and the U.S. Department of Agriculture

[USDA] Forest Service). Each of EPA's grantees took a different approach to advance source water protection through its pilot project.

The partnership of Clean Water Network/Clean Water Fund/Campaign for Safe and Affordable Drinking Water worked with hundreds of voluntary and nonprofit watershed associations around the country to help them advocate more effectively for source protection as part of a larger goal to achieve fishable and swimmable water.

The Groundwater Foundation supported suppliers working to advance new tools for wellhead and groundwater protection.

The Environmental Finance Center Network helped local stakeholders develop and implement source water protection plans for sources that are shared by many water systems.

The National Rural Water Association hired technicians around the country to assist small rural communities design and implement source water plans.

The Trust for Public Land (in partnership with the University of Massachusetts and the USDA Forest Service) worked with local communities in multijurisdictional watersheds to integrate land conservation and forest management into comprehensive source water protection efforts. This report summarizes findings based on experiences of the five pilot projects and proposes 10 strategies that will help put more state and local governments on the path to protection. Each strategy includes a case study of a state or local entity that has successfully implemented some or all of the action steps included in that strategy. (Note: The case studies are independent of the pilot projects of the five grantees.)

Keywords: agriculture; case study; drinking water; management; source protection; source water protection; United States; watershed

Lubowski, R.N., M. Vesterby, S. Bucholtz, A. Baez, and M.J. Roberts. 2006. Major Uses of Land in the United States, 2002. Economic Information Bulletin No. 14. USDA Economic Research Service.

Abstract: This publication presents the results of the 2002 inventory of U.S. major land uses, drawing on data from the Census, public land management and conservation agencies, and other sources. The data are synthesized by state to calculate the use of several broad classes and subclasses of agricultural and nonagricultural land over time. The United States has a total land area of nearly 2.3 billion acres. Major uses in 2002 were forest-use land, 651 million acres (28.8%); grassland pasture and range land, 587 million acres (25.9%); cropland, 442 million acres (19.5%); special uses (primarily parks and wildlife areas), 297 million acres (13.1%); miscellaneous other uses, 228 million acres (10.1%); and urban land, 60 million acres (2.6%). National and regional trends in land use are discussed in comparison with earlier major land-use estimates.

Keywords: agriculture; development; land use; United States; urbanization

O'Keefe, T.C., J.M. Helfield, and R.J. Naiman. 2007. Agents of Watershed Change. Training module from U.S. EPA's Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: This training module provides an overview of natural and human-made change processes and the ways in which they affect the structure and function of watersheds. The module has four primary sections: an introduction to the role of change in the watershed, descriptions of specific natural agents of change and their ecological effects, descriptions of specific human made agents of change and their ecological effects, and a discussion of the watershed processes most vulnerable to change.

Change is a natural, essential feature of watersheds. Being able to identify different change processes, understand the differences between natural and human influences on watershed change, and recognize a change of concern are all critical for effective watershed management. Watershed change, however, can be very complicated to understand and manage when many human and natural causes of change interact as they often do.

After completing this training, the participant should know the major changes affecting watersheds and understand that watersheds are dynamic systems. Some background in watershed ecology is helpful for understanding the material presented here and can be obtained from the module, *Introduction to Watershed Ecology,* at http://www.epa.gov/watertrain/ecology.

Keywords: agriculture; climate change; drought; erosion; fire; flood; logging; United States; urbanization; water resources management; watershed change; watershed management; windstorm

Robbins, R.W., J.L. Glicker, D.M. Bloem, and B.M. Niss. 1991. Effective Watershed Management for Surface Water Supplies. Prepared for American Water Works Association Research Foundation (AwwaRF), Denver, CO.

Abstract: The purpose of this report is to assist water utility managers and local governments in developing effective watershed protection programs for their surface water supplies. The emphasis is on practical, effective solutions and techniques that have been implemented by water utilities and other agencies in protecting water supplies. The basis for much of this work is a national survey of water utilities and state regulatory agencies and 24 case studies of successful watershed protection programs.

Keywords: agriculture; case study; management; United States; water supply; watershed

Rosen, B.H. 2000. Waterborne Pathogens in Agricultural Watersheds. WSSI Technical Note 2. USDA Watershed Science Institute. February.

Abstract: This technical note provides an introduction to waterborne pathogens, the disease-causing organisms that contaminate water. Key organisms of concern are described in detail, including *Escherichia coli* 0157:H7, *Cryptosporidium parvum,* and *Giardia* spp. Indicator bacteria that are normally monitored for water quality are described. Information on viability of

organisms in an agricultural setting is presented, along with relevant management practices for controlling waterborne pathogens at their source, thereby reducing the overall pathogen loading within a watershed. The topic of harmful algal blooms is also addressed, although these organisms do not fall neatly into the category of pathogen. Because the potential exists for contamination of water with pathogens from agriculture, this technical note represents a proactive approach for reducing this source in watersheds.

Keywords: agriculture; grazing; land use; management; United States; water quality; waterborne pathogens; watershed

2. Utility Case Studies

Northeast

Adkins, J. Date unknown. Prioritizing Land Protection to Protect Source Water in the Schuylkill River (Presentation). Presented by Partnership for the Delaware Estuary & Schuylkill Action Network Watershed Land Protection Collaborative.

Abstract: This is a presentation of restoration and source water protection projects in the Delaware Estuary completed by the Schuylkill Action Network Watershed Land Protection Collaborative. A model was developed in support of the organization's actions.

Keywords: case study; drinking water quality; Northeast; watershed management

Fairfax County Water Authority. 2002. Fairfax County Water Authority Source Water Assessment Program Final Report. Fairfax County, VA. January.

Abstract: The Fairfax County Water Authority (FCWA) draws surface water from two primary sources: the Potomac River and the Occoquan Reservoir. The treatment facilities associated with each source are located at opposite ends of Fairfax County and feed an interconnected distribution system. The James J. Corbalis, Jr. Treatment Plant, located at the northern tip of the FCWA service area, draws water from the Potomac River. The Occoquan Reservoir, on the southern border of Fairfax County, supplies the Occoquan and Lorton treatment plants located near the Town of Occoquan.

The FCWA Source Water Assessment Program (SWAP) is comprised of a contaminant inventory, a windshield survey, a Best Management Practice (BMP) inventory, and a susceptibility analysis.

Through the contaminant inventory, information on potential sources of contamination in the assessment area was collected in a Geographical Information System (GIS) or database. The data collected included existing data obtained from other agencies and new data generated by FCWA. As required by the Virginia Department of Health SWAP, a windshield survey was conducted on the Zone 1 area for each intake. The windshield survey consisted of visually identifying potential sources of contamination in the field and obtaining location and property owner information for each site.

The Authority worked closely with County stormwater management departments to develop a BMP database useful for water quality purposes. As part of this process, Authority employees reviewed existing datasets, stormwater management plans, files, and fact sheets and entered available information in a GIS and database. A susceptibility analysis was conducted to determine the risk associated with various contaminant sources. As part of this effort, buffer distances and stream distances from each intake were determined for each contaminant site. The sources were ranked based on combined buffer and stream distance and the type of facility.

Keywords: case study; Northeast; source water assessment program; source water assessment plan; water quality; water supply; watershed management

Fairfax Water. 2007. Annual Report on Water Quality 2007. Fairfax, VA. June.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; Northeast; water quality

Massachusetts Department of Conservation and Recreation. 2007. Quabbin Reservoir Watershed System: Land Management Plan 2007-2017. Division of Water Supply Protection. September.

Abstract: The Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management produces Land Management Plans for each of the watersheds under its care and control – Quabbin Reservoir, Ware River, Wachusett Reservoir, and the Sudbury Reservoir – on a rotating 10-year schedule. This *2007-2017 Quabbin Land Management Plan* provides principles from the current state of the science of watershed and natural resources management, agency goals for the 10-year period, and specific objectives for accomplishing these in the areas of Land Protection, Forest Management, Wildlife Management, Management and Protection of Biodiversity, and Cultural Resources Protection. The plan builds on advancements in science and management techniques, the agency's own experience over six decades of managing the watershed and its resources, and accumulated input from advisory groups and the general, concerned public. It is designed as an adaptive plan, utilizing annual reviews to build immediately on new information and changes in the science that supports management decisions, and to revise objectives, as necessary, within the 10-year time frame of the plan.

Keywords: case study; Northeast; water quality; watershed management

Massachusetts Executive Office of Environmental Affairs. 2004. Forest Certification Information Sheet for the Commonwealth of Massachusetts. May 18.

Abstract: This document provides information about the process by which Massachusetts state lands are certified as "green." Included is a description of certification, a discussion of the significance, the goals of green certification, standards, a description of the process, and discussions of the ecological and financial/socioeconomic/legal implications of green forest certification.

Keywords: case study; forest certification; Northeast

McCormick, J., R.R. Grant Jr., and R. Patrick. 1970. Two Studies of Tinicum Marsh, Delaware and Philadelphia Counties, Pennsylvania. The Conservation Foundation, Washington, DC.

Abstract: Tinicum Marsh, the last tidal marsh in Pennsylvania, is part of a set of demonstrations initiated by The Conservation Foundation with assistance from a Ford Foundation Grant. The projects are designed to develop and demonstrate means of resolving conflicts between preservation and development. The purpose of the Tinicum study is to determine if ecological functions can be maintained, with minimum losses, as development reaches the marsh. Relevant questions address issues relating to the diminished functioning of a highly polluted marsh, which are the positive functions worth preserving, and how these functions can be enhanced as development encroaches. Two technical reports address these questions and provide a base of information for subsequent studies. The first study addresses the natural features of Tinicum marsh, with particular emphasis on the vegetation. The second study addresses Tinicum marsh as a water purifier.

Keywords: case study; development; Northeast; pollution; water quality

Mehaffey, M.H., M.S. Nash, T.G. Wade, D.W. Ebert, K.B. Jones, and A. Rager. 2005. Linking land cover and water quality in New York City's water supply watersheds. *Environmental Monitoring and Assessment* 107(1-3):29-44.

Abstract: The Catskill/Delaware reservoirs supply 90% of New York City's drinking water. The City has implemented a series of watershed protection measures, including land acquisition, aimed at preserving water quality in the Catskill/Delaware watersheds. The objective of this study was to examine how relationships between landscape and surface water measurements change between years. Thirty-two drainage areas delineated from surface water sample points (total nitrogen, total phosphorus, and fecal coliform bacteria concentrations) were used in step-wise regression analyses to test landscape and surface-water quality relationships. Two measurements of land use, percent agriculture and percent urban development, were positively related to water quality and consistently present in all regression models. Together these two land uses explained 25 to 75% of the regression model variation. However, the contribution of agriculture to water quality condition showed a decreasing trend with time as overall agricultural land cover decreased. Results from this study demonstrate that relationships between land cover and surface water concentrations of total nitrogen, total phosphorus, and fecal coliform bacteria counts over a large area can be evaluated using a relatively simple geographic information system method. Land managers may find this method useful for targeting resources in relation to a particular water quality concern, focusing best management efforts, and maximizing benefits to water quality with minimal costs.

Keywords: case study; development; drinking water; fecal coliform; land cover; land use; management; Northeast; reservoirs; total nitrogen; total phosphorus; urban; water quality; watershed

National Research Council. 2000. Watershed Management for Potable Water Supply: Assessing the New York City Strategy. National Academies Press, Washington, DC. Available: http://www.nap.edu/openbook/0309067774/html.

Abstract: January 21, 1997, marked an important event in the history of American water management: the signing of the mammoth New York City Watershed Memorandum of Agreement (MOA), which provides a legal framework for protecting the drinking water supply of nine million people. The culmination of years of negotiation between upstate and downstate interests, the MOA commits New York City to a long-term watershed management program that combines land acquisition, new watershed rules and regulations, and financial assistance to watershed communities to promote environmental quality and their local economies. Most important for New York City, the agreement currently satisfies provisions of the U.S. Environmental Protection Agency's Surface Water Treatment Rule that will allow the City to avoid filtering its upstate Catskill/Delaware water supply until at least 2002.

Immediately following the signing of the MOA, the National Research Council (NRC) was asked by the New York City Comptroller's Office to provide a scientific evaluation of the watershed management program. The goal of the NRC study was to determine whether the MOA is based on sound science and to recommend improvements to strengthen watershed management for this large unfiltered supply. This report is intended to inform New York City and other public water suppliers that are trying to maintain the purity of their existing water sources through proactive watershed management (regardless of whether they presently utilize filtration).

Keywords: case study; drinking water treatment; Northeast; prevention; water quality; watershed management

Newport News Waterworks. 2007. Water Quality Report 2007. Newport News, VA.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; Northeast; water quality

Newport News Waterworks. Date Unknown. Your Water Utility: Newport News Waterworks. Newport News, VA.

Abstract: If you live on the Virginia Peninsula, your water probably comes from Newport News Waterworks. Newport News Waterworks is a regional water utility that provides drinking water to more than 400,000 customers in the Cities of Newport News, Hampton, and Poquoson, and in parts of York and James City counties. On an average day, Newport News Waterworks treats and delivers between 45 and 50 million gallons of water to its customers. Their employees work every day of the year to keep the treatment plants running and the water flowing in the pipes.

Keywords: case study; drinking water treatment; Northeast; water quality; watershed management

New York City Department of Environmental Protection. 2006. New York City 2006 Drinking Water Supply and Quality Report.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; drinking water treatment; Northeast; water quality

New York Department of Environmental Protection. 2008. NYC Water Supply Watersheds (Web Page). Available: http://www.nyc.gov/html/dep/html/watershed_protection/home.html.

Abstract: This website provides information for New York Water customers about the watershed serving the City. Topics include watershed protection and other related topics.

Keywords: case study; Northeast; watershed management

Philadelphia Water Department. 2002. Philadelphia Water Department – Belmont & Queen Lane Treatment Plants (PWSID # 1510001) Source Water Assessment Report. Prepared for the Pennsylvania Department of Environmental Protection. January 2.

Abstract: The source water assessment report for the Philadelphia Water Department includes a general description of the Schuylkill River Watershed, the Belmont Water Treatment Plant, and the Queen Lake Intake.

Keywords: case study; Northeast; source water assessment plan; source water assessment programs; watershed management

Philadelphia Water Department. 2006. The Schuylkill River Watershed Source Water Protection Plan. Prepared for the Pennsylvania Department of Environmental Protection. January.

Abstract: This Source Water Protection Plan clearly identifies actual and potential sources of contamination to the raw water supplying the Philadelphia Water Department's (PWD's) water treatment plants and outlines targeted protection and cleanup projects to address these sources. The plan serves as the first step for long-term sustainable planning for the future of the communities in the watershed, and it provides a comprehensive framework for implementing a watershed-wide effort to improve source water quality. The plan incorporates the following seven objectives that will allow PWD to ensure the integrity and affordability of the region's water supply for generations to come.

1. Establish the Schuylkill Action Network as a permanent watershed-wide organization charged with identifying problems and prioritizing projects and funding sources to bring about real improvement in water quality throughout the Schuylkill River watershed.

2. Create a long-term, sustainable fund to support restoration, protection, and education projects in the Schuylkill River watershed.

3. Increase awareness of the Schuylkill River watershed's regional importance as a drinking water source.

4. Initiate changes in policies and decision-making that balance and integrate the priorities of both the Safe Drinking Water Act and the Clean Water Act.

5. Establish the Early Warning System as a regional information sharing resource and promote its capabilities for water quality monitoring and improving emergency communication.

6. Reduce point source impacts to water quality.

7. Reduce nonpoint source impacts to water quality.

Keywords: case study; drinking water quality; Northeast; source water protection plan; watershed management

Philadelphia Water Department. 2007. Annual Drinking Water Quality Report 2006. April.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; drinking water treatment; Northeast; water quality

Philadelphia Water Department. 2007. The Delaware River Watershed Source Water Protection Plan. Prepared for the Pennsylvania Department of Environmental Protection. June.

Abstract: The purpose of the Delaware River Protection Plan is to design a source water protection strategy to counter current and future water supply concerns of the Philadelphia Water Department and drinking water utilities that share the Delaware River as a resource.

The Baxter Water Treatment Plant, one of three drinking water facilities in Philadelphia, is supplied by the Delaware River. The Delaware River watershed extends 8,000 square miles through Pennsylvania, New Jersey, and New York. The Delaware River Source Water Protection Plan uses critical water quality, land cover, and population analyses as well as point and nonpoint source pollution modeling to characterize the water supply. The source water quality and quantity characterization, incorporated with the results from the 2002 Source Water Assessment, provide the technical foundation for a Delaware River source water protection strategy.

The Baxter Water Treatment Plant provides over 190 million gallons of safe and high quality drinking water per day to the citizens of Philadelphia and surrounding communities. The plant uses dual media filtration and chlorine disinfection technologies to provide high quality drinking water year-round. The Baxter Water Treatment Plant has an exceptional performance record and has never violated Safe Drinking Water Act regulations. The Baxter Water Treatment Plant owes its exceptional record to the hard work of dedicated Philadelphia Water Department staff and the quality source water supplied from the Delaware River.

The Philadelphia Water Department uses source water assessment and protection planning to maintain the integrity of the Delaware River as a drinking water supply.

Keywords: case study; drinking water quality; Northeast; source water protection plan; watershed management

Poor, P.J., K.L. Pessagno, and R.W. Paul. 2007. Exploring the hedonic value of ambient water quality: a local watershed-based study. *Ecological Economics* 60(4):797-806.

Abstract: Nonpoint source water pollution of local watersheds can result from various sources but is tied most closely to runoff from impervious surfaces associated with development activities such as roadways, parking lots, and large commercial structures. This research investigates the value of ambient water quality as measured by data from 22 monitoring stations located throughout a local watershed in Maryland: the St. Mary’s River watershed. A hedonic property value model is used to investigate the marginal implicit values of the following water quality variables: total suspended solids (TSS) and dissolved inorganic nitrogen. The econometric results indicate that the marginal implicit prices associated with a one milligram per liter change in TSS and dissolved inorganic nitrogen are $-1,086 and $-17,642, respectively.

Keywords: case study; development; Northeast; water quality

U.S. EPA Region 2. 2006. Region 2 Water: New York City Water Supply. Available: http://www.epa.gov/region02/water/nycshed/supply.htm.

Abstract: This document provides a description of the New York City water supply and watershed.

Keywords: case study; Northeast; watershed

Southeast

City of Asheville. 2007. City of Asheville 2007 Annual Water Quality Report. Asheville Water Resources Department, North Carolina.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; North Carolina; Southeast

Greenville Water System. 2007. Water Quality Report for 2007. Greenville, SC.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; Southeast; water quality

Orange Water & Sewer Authority. 2006. Water Quality: 2005 Report Card. Raleigh, NC. May.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; drinking water quality; Southeast

South Carolina Department of Health and Environmental Control. 2004. Watershed Water Quality Assessment: Saluda River Basin. October.

Abstract: In 1993, the South Carolina Department of Health and Environmental Control (SCDHEC) published the first in a series of five watershed management documents. The first in that series, Watershed Water Quality Management Strategy: Savannah- Salkehatchie Basin communicated SCDHEC's innovative watershed approach, summarizing water programs and water quality in the basins. The approach continues to evolve and improve. The watershed documents facilitate broader participation in the water quality management process. Through these publications, SCDHEC shares water quality information with internal and external partners, providing a common foundation for water quality improvement efforts at the local watershed or large-scale, often interstate, river basin level.

Water quality data from the Saluda River Basin was collected from 1997 to 2001, and assessed during this third five-year watershed management cycle. This updated atlas provides summary information on a watershed basis, as well as geographical presentations of all permitted watershed activities. A waterbody index and facility indices allow the reader to locate information on specific waters and facilities of interest.

A brief summary of the water quality assessments included in the body of this document is provided following the Table of Contents. This summary lists all waters within the Saluda River Basin that fully support recreational and aquatic life uses, followed by those waters not supporting uses. In addition, the summaries list changes in use support status; those that have improved or degraded over the five years since the last strategy was written. More comprehensive information can be found in the individual watershed sections. The information will be updated in five years.

Keywords: case study; source water assessment plan; source water assessment programs; Southeast; water quality; watershed management

North Central

St. Paul Regional Water Services. 2007. Water Quality Report 2007. St. Paul, MN.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; drinking water quality; North Central

St. Paul Regional Water Services and Minnesota Department of Health. 2001. City of St. Paul Source Water Assessment. September.

Abstract: The requirements of the Safe Drinking Water Act addressed are intended to provide St. Paul drinking water customers with (1) a general description of the area which supplies water to the St. Paul Regional Water Service (SPRWS); (2) an overview of why this water supply is susceptible to potential contaminants; (3) a description of the contaminants of concern which may impact the users of the public water supply; and (4) to the extent practical, the origins of the contaminants of concern. Because SPRWS relies on surface water and groundwater, each part of the assessment has a section devoted to each.

Keywords: case study; drinking water quality; North Central; source water assessment plan; watershed management

South Central

Northwest

Bakke, P.D. and M.R. Pyles. 1997. Predictive model for nitrate load in the Bull Run Watershed, Oregon. *Journal of the American Water Resources Association* 33(4):897-906.

Abstract: Predictive models for nitrate in four streams in the Bull Run Watershed in the Cascade Mountains of Oregon were developed from a record of 17 years of nitrate samples. The models are time series regression models written in terms of Log (nitrate load). The independent variables are the logarithm of 14-day mean daily stream discharge, the current day's precipitation, the logarithm of the previous day's precipitation, the total precipitation for the previous seven days, a hydrograph position variable that indicates rising or falling limb, and average maximum air temperature for the preceding 14 days. The models describe annual cycle and seasonable trends and variations in nitrate load, but are unable to describe large day-to-day variations like those associated with hydrograph peaks.

Keywords: case study; management; Northwest; water quality; watershed

Bend Water Division. Date Unknown. Source Water Assessment, City of Bend Water Division. Bend, OR.

Abstract: The Bridge Creek watershed provides, on the average over the past three years, about 50% of the City of Bend's drinking water supplies. The percentage of water from this source varies from year to year depending on weather, snow pack, maintenance activities, spring storm events, and community demands. The actual drainage boundary of the watershed is 3,200 acres while the designated legal boundary is 7,700 acres. The Bridge Creek watershed is an unfiltered source that complies with all state and federal regulations for source water quality, treatment techniques, and source water monitoring.

Keywords: case study; Northwest; water quality; water treatment; watershed management

Bloem, D.M., R.H. Hawkins, and R.W. Robbins. 1995. Detection of land use effects in the flows of the Bull Run river, Oregon. In *Watershed Management: Planning for the 21st century*. T. J. Ward (ed.) American Society of Civil Engineers, New York, pp. 429-437.

Abstract: Streamflow records for the Bull Run River, Oregon, from 1920 to 1992, were analyzed to determine if the watershed yield had changed over time. An increase in annual water yield of about 7% [55 cubic feet per second (cfs)] was detected to have occurred beginning in 1960. This date corresponds to the time when the streamflow gauge was moved, and to the beginning of a period of road construction and timber harvest. Data from a nearby reference gauge were used to remove the effects of climatic variation. After accounting for effects of gauge relocation, and changes in impervious road area, reservoir interception, and fog drip, the remaining increase of 1.5 to 2% (11-15 cfs) was attributed to silvicultural effects. All monthly yields showed post-1960 increases from some combination of larger drainage area and changes in watershed land use, although in some months this increase was overshadowed by a decrease in yield from climatic effects.

Keywords: case study; logging; Northwest; road construction; streamflow; water quantity; water yield; watershed management

City of Calgary. 2007. 2006 Water Quality Report. Calgary, Alberta, Canada.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; Canada; case study; Northwest; water quality

City of Hillsboro. 2006. Annual Water Quality Report. Hillsboro, OR.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; Northwest; water quality

Fend, J.F., J. Thornton, D. Rittenhouse, F. Pierson, C.R. Mickelson, and C.W. Slaughter. 2000. The science & politics of the 1996 Boise front fire – what have we learned from the 8th street fire rehabilitation. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 115-119. Water Resources Center Report No. 98.

Abstract: The 8th Street fire intensely burned 15,300 acres of highly erodible granitic soils immediately above Boise, the capitol city of Idaho in August 1996. Immediately downslope from burned watersheds were 12 schools, three hospitals, 65 child care facilities, 25 long-term care centers, and numerous public buildings, including the Federal building, City Hall, and the State Capitol. Agency managers, public officials, and local citizens expressed concern about the potential for devastating debris torrents and flash flooding; many remembered the flooding that occurred in 1959 in downtown Boise after a thunderstorm moved over a recently burned watershed just to the south of the 1996 8th Street Fire area.

This presentation discusses the process that was implemented locally to manage the recovery of the burned watershed while protecting the lives and properties at risk in town. “Best science” was utilized in preparing the recovery alternatives and actions considered. Public opinion concerning the recovery methods and the impacts to the aesthetics of the watershed landscape had to be dealt with through many hours of public meetings and workshops. The presentation shares lessons learned concerning collaboration on a multi-million dollar landscape rehabilitation plan covering 12 different agency jurisdictions. Followup monitoring and research continue to make this backyard outdoor laboratory a learning tool for the public and for science.

Keywords: case study; erosion; fire; Northwest; rehabilitation; urban; vegetation change; watershed; watershed management

Harr, R.D. 1980. Streamflow After Patch Logging in Small Drainages Within the Bull Run Municipal Watershed, Oregon. Research Paper PNW-268. USDA Forest Service Pacific Northwest Forest and Range Experiment Station.

Abstract: Three experimental watersheds in the City of Portland's Bull Run Municipal Watershed were used to determine the effects of patch logging on timing and quantity of streamflow. Annual water yields and size of instantaneous peak flows were not significantly changed, but low flow decreased significantly after logging of two small watersheds in small, clearcut patches totaling 25% of each watershed's area.

Keywords: case study; logging; Northwest; streamflow; vegetation change; water yield

Harr, R.D. 1982. Fog drip in the Bull Run Municipal Watershed, Oregon. *Water Resources Bulletin* 18(5):785-789.

Abstract: Net precipitation under old growth Douglas fir forest in the Bull Run Municipal Watershed (Portland, Oregon) totaled 1,739 millimeters during a 40-week period, 387 mm more than in adjacent clearcut areas. Expressing data on a full water year basis and adjusting gross precipitation for losses due to rainfall interception suggest fog drip could have added 882 mm of water to total precipitation during a year when precipitation measured 2,160 mm in a rain gauge in a nearby clearing. Standard rain gauges installed in open areas where fog is common may be collecting up to 30% less precipitation than would be collected in the forest. Long-term forest management (i.e., timber harvest) in the watershed could reduce annual water yield and, more importantly, summer streamflow by reducing fog drip.

Keywords: case study; fog drip; logging; Northwest; water quantity

Harr, R.D. and R.L. Fredriksen. 1988. Water quality after logging small watersheds within the Bull Run Watershed, Oregon. *Journal of the American Water Resources Association* 24(5):1103-1111.

Abstract: Road building, clearcutting 25% of the watershed, and slash disposal by broadcast burning or by natural decomposition caused changes in water quality of two small streams in the Bull Run Watershed in Oregon, which supplies water to the Portland, Oregon, metropolitan area. Concentrations of suspended sediment increased slightly, primarily owing to the construction of a permanent logging road that crossed streams. Changes in nutrient cycling occurred due to logging and slash disposal in both watersheds where cutting was done. Nitrate-nitrogen (NO_3^--N) concentrations, which increased most where logging residue was left to decompose naturally, increased more than sixfold and commonly exceeded 100 micrograms per liter (µg/L) during the October-June high-flow season for seven years after logging. Where logging slash was broadcast burned, NO_3^--N concentrations increased roughly fourfold, but rarely exceeded 50 µg/L, and increases had mostly disappeared six years after slash burning. Changes in outflows of cations and other anions were not apparent. Annual maximum stream temperatures increased 2-3°C after logging, but temperature increases had mostly disappeared within three years as vegetation regrowth shaded the streams.

Keywords: anion; case study; cation; development; erosion; logging; nitrate; Northwest; sediment; water quality; water quantity; water yield

Ingwersen, J.B. 1985. Fog drip, water yield, and timber harvesting in the Bull Run Municipal Watershed, Oregon. *Journal of the American Water Resources Association* 21(3):469-473.

Abstract: Analysis of recent streamflow data from other Fox Creek Experimental Watersheds in the Bull Run Municipal Watershed, Oregon, indicates a significant recovery from the impacts on summer water yield due to a loss of fog drip upon timber harvesting. Measurable impacts and their associated recovery are notable only during the months of June and July. Recovery begins about five or six years following harvest, possibly due to renewed fog drip from prolific revegetation. Watershed positioning with respect to prevailing weather systems and the extent of burning or removal of slash and residual vegetation during logging appear to be important factors in predicting the impact of fog drip reduction associated with the planned harvest. Apparently, once the temporary reduction in summer yield is offset by renewed fog drip, the expected increase in yield due to decreased evapotranspiration can be observed. Redistribution of fog drip may be a major factor in the measurements of local interception and water yield.

Keywords: case study; fog drip; logging; Northwest; water quality; water quantity; water yield

Keppeler, E.T. 1998. The summer flow and water yield response to timber harvest. In *Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story*, May 6, 1998. pp. 35-43. USDA Forest Service General Technical Report PSW-GTR-168. June. Available: http://www.fs.fed.us/psw/publications/documents/psw_gtr168/.

Abstract: Continuous measurement of streamflow at the Caspar Creek watersheds has led to several analyses of the effects of two harvest methods (selection and clearcut) on summer flows and annual yield. Although all Caspar Creek analyses have indicated an increase in runoff after timber removal, the magnitude and duration of the response depend on the nature and extent of the logging and site preparation, climatic conditions, as well as the definition of the hydrologic parameter at issue. Regression analysis using a calibration period of 1963 to 1971 was used to compare annual yield, summer flow volume, and minimum streamflow between the South Fork (SFC) and the North Fork (NFC) of Caspar Creek for a 35-year period. Selection/tractor logging of the SFC increased annual yield by a maximum of 2,053 cubic meters per hectare per year ($m^3ha^{-1}yr^{-1}$) during the seventh water year after harvest, began. Increased yields were observed beginning the second post-harvest year and averaged 15% or 932 $m^3ha^{-1}yr^{-1}$. Following clearcut logging of 50% of the NFC watershed, annual yield increased by as much as 1,032 $m^3ha^{-1}yr^{-1}$ eight years after logging and averaged 15% or 608 $m^3ha^{-1}yr^{-1}$ beginning in the second postharvest year. Streamflow changes due to logging are most evident during the long, dry summer season typical of northwestern California. During this prolonged recession, zones of deep perennial saturation maintain streamflow (baseflow). Statistically significant summer flow enhancements were evident on the SFC for seven years after logging. Subsequently, SFC summer yields fell at or below pretreatment predictions. Although summer flow increases amounted to relatively minor changes in minimum discharge averaging only 0.25 liters per second per square kilometer (L $s^{-1}km^{-2}$) on SFC and 0.40 L $s^{-1}km^{-2}$ on NFC, these enhancements are quite substantial in comparison to pretreatment summer low flows. Minimum discharge increases averaged 38% after the SFC selection logging and 148% after the NFC harvest and site preparation. NFC flow enhancements persist through hydrologic year 1997 with no recovery trend, as yet. After logging, reduced interception and evapotranspiration allow for additional water to be stored in the soil and routed to streams as summer baseflow. At Caspar Creek, enhanced soil moisture in the rooting zone followed timber harvest in the NFC clearcut units. Previously intermittent stream reaches and soil pipes became perennial. The larger increases in minimum flows observed on the NFC are probably due to wetter soils in the clearcut units where little vegetation exists to use this enhanced moisture. On the selectively cut SFC, mature residual forest vegetation more readily exploited this additional soil moisture. Fog plays an important role in the regional ecology by moderating evapotranspiration. However, Caspar Creek data indicate that any possible postlogging loss of fog drip did not result in a net reduction in streamflow. Moisture savings due to reduced evapotranspiration appear to override any fog precipitation losses at this site.

Keywords: case study; erosion; logging; Northwest; runoff; sediment; streamflow; water quantity

Lewis, J., S.R. Mori, E.T. Keppeler, and R.R. Ziemer. 2000. Impacts of logging on storm peak flows, flow volumes and suspended sediment loads in Caspar Creek, California. In *Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas*. M. S. Wigmosta and S. J. Burges (eds.) American Geophysical Union, Washington, DC, pp. 85-125.

Abstract: Models are fit to 11 years of storm peak flows, flow volumes, and suspended sediment loads on a network of 14 stream gauging stations in the North Fork Caspar Creek, a 473-hectare coastal watershed bearing a second-growth forest of redwood and Douglas-fir. For the first four years of monitoring, the watershed was in a relatively undisturbed state, having last been logged prior to 1904, with only a county road traversing the ridge tops. Nearly half the watershed was clear-cut over a period of three years, and yarded primarily using uphill skyline cable systems to spur roads constructed high on the slopes. Three tributaries were maintained as controls and left undisturbed. Four years of data were collected after logging was completed. Exploratory analysis and model fitting permit characterization and quantification of the effects of watershed disturbances, watershed area, antecedent wetness, and time since disturbance on storm runoff and suspended sediment. Model interpretations provide insight into the nature of certain types of cumulative watershed effects.

Keywords: case study; erosion; logging; Northwest; sediment; streamflow; water quantity; watershed management

Mickelson, C.R. 2000. Partnerships, public information, emergency preparedness and projects. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 101-104. Water Resources Center Report No. 98.

Abstract: Immediately following a major fire in the foothills above Boise, Idaho, in August 1996, cooperative actions by local, state, and federal government agencies allowed for prompt pre-emergency planning and implementation of pre-emptive actions to cope with possible flooding and sediment deposition in Boise.

Keywords: case study; erosion; fire; management; Northwest; sediment; storm; vegetation change; water quantity; watershed

Oregon Department of Environmental Quality and Oregon Department of Human Services. 2003. Source Water Assessment Summary Brochure, Joint Water Commission PWS #4100379 and Hillsboro-Cherry Grove PWS # 4100985.

Abstract: The Source Water Assessment was recently completed by the Department of Environmental Quality and the Oregon Department of Human Services to identify the surface areas (and/or subsurface areas) that supply water to the Hillsboro Utilities Commission, Beaverton, Forest Grove, and Tualatin Valley Water District Joint Water Commission and Hillsboro-Cherry Grove's public water system intakes and to inventory the potential contaminant sources that may impact the water supply.

Keywords: case study; Northwest; source water assessment plan; source water assessment programs; water quality; watershed management

Pierson, F.B. 2000. Hydrologic impacts of fire on the Boise front. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 105-113. Water Resources Center Report No. 98.

Abstract: The Eighth Street fire had a significant impact on the infiltration capacity and soil erodibility across the Boise Front. South-facing slopes had the lowest infiltration and showed the highest rates of erosion following the fire. Two years following the fire, ground cover had not yet sufficiently recovered to fully protect either the north or south slopes from increased runoff and accelerated erosion. Presented results are consistent with observations made following the September 1997, thunderstorm where the south-facing slopes had the highest concentration of rills and suffered significant soil loss.

Keywords: case study; erosion; fire; Northwest; runoff; sediment; storm; vegetation change; watershed

Sinton, D.S., J.A. Jones, J.L. Ohmann, and F.J. Swanson. 2000. Windthrow disturbance, forest composition, and structure in the Bull Run Basin, Oregon. *Ecology* 81(9):2539-2556.

Abstract: This study examined relationships among forest landscape dynamics, environmental factors (climate and landforms), and disturbance history in forests dominated by Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and Pacific silver fir (*Abies amabilis*) in the Bull Run Basin in northwestern Oregon and evaluated the findings in a broader geographic context. Three sets of analyses were conducted: mapping of historical windthrow disturbance patches in the 265-square kilometers Bull Run Basin over the past century and analysis of their relationships with meteorological conditions, landforms, and vegetation; comparison of forest structure and species composition as a function of mapped windthrow and wildfire disturbance history in 34 1-hectare vegetation survey plots in Bull Run; and canonical correspondence analysis of environmental factors and forest overstory species composition in 1,637 vegetation plots in the Mount Hood and Willamette National Forests. Nearly 10% of the Bull Run Basin has been affected by windthrow since 1890, but only 2% was affected prior to the onset of forest harvest in 1958. Most of the mapped windthrow occurred in areas with 500- to 700-year-old canopy dominants and no mapped disturbance by fire in the past 500 years. Most mapped windthrow occurred during three events in 1931, 1973, and 1983 that were characterized by extreme high speed east winds from the Columbia River Gorge. Forest harvest modified the effects of climate, landforms, and vegetation on windthrow disturbance, reducing the importance of topographic exposure to east and northeast winds, and creating a strong influence of recent clearcut edges, which accounted for 80% of windthrow in the 1983 event. Shade-tolerant overstory species (western hemlock and Pacific silver fir) are abundant in present-day forest stands affected by windthrow as well as by fire in the past century. In the western Cascade Range, Douglas-fir and western hemlock decline and Pacific silver fir increases with elevation (summer moisture stress declines but temperature variability increases), but this transition occurs at lower elevations in the Bull Run, perhaps because of the interaction between regional climate processes and disturbance along the Columbia Gorge. Complex landscape dynamics result from these contingent interactions among climate, landform and stand conditions, and disturbance.

Keywords: case study; disturbance; forest composition; land cover; Northwest; storm; vegetation change; windthrow

Southwest

Alexander, B. 2004. Forest fire impacts on drinking water supplies. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: A major fire in a drinking water watershed can impact water quantity and quality. Sediments and other contaminants such as heavy metals and nutrients can be significantly elevated in rivers and streams following a catastrophic fire, making it difficult for utilities to effectively provide safe, clean drinking water to their customers. The Bobcat fire in the Loveland, Colorado watershed in 2000 is an example for utilities serving a large urban population. The biggest threat to water quality in the West is from fire-related contaminants, not industrial chemicals or hazardous waste spills. The U.S. Environmental Protection Agency drinking water quality guidelines are not always consistent with appropriate forest management practices for managing forest fires and maintaining forest health. In order to prepare for and prevent severe impacts to drinking water resulting from forest fires, watershed managers need to employ best management practices to manage both issues simultaneously.

Keywords: Bobcat fire; case study; fire; prevention; response strategy; Southwest; water quality; water quantity; watershed management

Cafferata, P.H. and T.E. Spittler. 1998. Logging impacts of the 1970's vs. the 1990's in the Caspar Creek watershed. In *Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story*, May 6, 1998. pp. 103-115. USDA Forest Service General Technical Report PSW-GTR-168. June. Available: http://www.fs.fed.us/psw/publications/documents/psw_gtr168/.

Abstract: The Caspar Creek watershed study provides resource professionals with information regarding the impacts of timber operations conducted under varying forest practices on sensitive aquatic habitats. In the South Fork watershed, roads were constructed near watercourse channels in the 1960s, and the watershed was selectively logged using tractors during the early 1970s. Subwatersheds in the North Fork were clearcut from 1985 to 1991 using predominantly cable yarding and roads located high on ridges. Numerous landslides were documented after road construction and logging in the South Fork owing to inadequate road, skid trail, and landing design, placement, and construction. In contrast, the size and number of landslides after timber operations in the North Fork to date have been similar in logged and unlogged units. Considerably more hillslope erosion and sediment yield have also been documented after logging operations in the South Fork, when compared to the North Fork. An analysis of the storm events associated with documented landslides showed that high 3-day or 10-day precipitation totals in combination with moderately high 1-day amounts have been more important than very high 1-day totals alone in triggering debris sliding at Caspar Creek. Storm sequences meeting the criteria required for causing documented landslides were found to have occurred in all phases of the 36-year study, with the greatest number occurring in water year 1998. Numerous large landslides associated with the road system in the South Fork occurred in early 1998, indicating that "legacy" roads continue to be significant sources of sediment decades after they were constructed.

Keywords: case study; development; erosion; landslide; logging; Southwest; water quantity; watershed

Dahlgren, R.A. 1998. Effects of forest harvest on stream-water quality and nitrogen cycling in the Caspar Creek Watershed. In *Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story*, May 6, 1998. pp. 45-53. USDA Forest Service General Technical Report PSW-GTR-168. June. Available: http://www.fs.fed.us/psw/publications/documents/psw_gtr168/.

Abstract: The effects of forest harvest on stream-water quality and nitrogen cycling were examined for a redwood/Douglas-fir ecosystem in the North Fork, Caspar Creek experimental watershed in northern California. Stream-water samples were collected from treated (e.g., clearcut) and reference (e.g., noncut) watersheds, and from various locations downstream from the treated watersheds to determine how far the impacts of these practices extended. Additionally, a detailed nutrient cycling study was performed in a clearcut and reference watershed to gain insights into changes in nitrogen cycling after harvesting activities. Stream-water nitrate concentrations were higher in clearcut watersheds, especially during high stream discharge associated with storm events. Elevated concentrations of nitrate were due to increased leaching from the soil as mineralization (i.e., release of nutrients from organic matter) was enhanced and nutrient uptake by vegetation was greatly reduced after harvest. The elevated nitrate concentration in stream water from clearcut watersheds decreased in the higher-order downstream segments. This decrease is believed to be primarily due to dilution, although in-stream immobilization may also be important. Although elevated nitrate concentrations in stream water from the clearcut watershed might suggest a large nitrogen loss after clearcutting, conversion to a flux indicates a maximum loss of only 1.8 (kilograms of nitrogen per hectare per year, kg N ha^{-1} yr^{-1}); fluxes decreased to < 0.4 kg N ha^{-1} yr^{-1} three years after the harvest. Nitrogen fluxes from the reference watershed over the same period were < 0.1 kg N ha^{-1} yr^{-1}. The increased nitrogen flux was due to both higher nitrate concentrations and an increased water flux from the clearcut watershed. In contrast to many forest ecosystems that show large nutrient losses in stream water after harvest, this redwood/Douglas-fir ecosystem shows relatively small losses. The rapid regrowth of redwood stump sprouts, which use the vast rooting system from the previous tree, is capable of immobilizing nutrients in its biomass, thereby attenuating nutrient losses by leaching. Rapid regeneration also provides soil cover that appreciably reduces the erosion potential after harvest. Removal of nitrogen, primarily in the harvested biomass, results in an appreciable loss of nitrogen from the ecosystem. These data suggest that nitrogen fixation by Ceanothus may be an important nitrogen input that is necessary to maintain the long-term productivity and sustainability of these ecosystems.

Keywords: case study; erosion; logging; management; sediment; Southwest; streamflow; water quality

Dale, D. 2006. Wildfires and erosion: control from the air. *American Reconstruction* (October):A10-A14.

Abstract: The year 2002 was a bad one for wildfires. Over 7 million acres were burned, at a cost of over a billion dollars to fight them. What about the after effects? Apart from the environmental and property damage, one of the most feared aspects of a wildfire is the erosion on the denuded landscape. Nowhere was that more threatening than at the site of the Hayman

Fire in heavily sloped Colorado. This is the story of one company's participation in controlling erosion after the Hayman fire. By using special slurry mixes and airmailing them via helicopter, HydroGrass Technologies, Inc. was able to help prevent much damage to the watershed. Not only that, the company learned a lot about using erosion control products such as polyacrylamides in its bonding mixes.

Keywords: case study; erosion; fire; prevention; response strategy; Southwest; watershed management

East Bay Municipal Utility District. 2007. 2006 Annual Water Quality Report. Oakland, CA.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; Southwest; water quality

Ekarius, C. 2004. Forests, fires and watersheds: Stories and lessons learned on the land – the Hayman experience. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: This presentation details some of the actions taken after the Hayman Fire and the lessons learned that can help improve response strategies for the future. The lessons identified were dedication to *real* rehabilitation after fires; engaging local partners and ensuring that funding, technical, and moral support are provided; the need to translate science so that nonacademic, knowledgeable lay people such as managers and resource teams can use it effectively.

Keywords: case study; fire; Hayman fire; response actions; Southwest

Fornwalt, P. 2004. Ponderosa pine forests: Lessons from the ashes. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: This presentation is primarily a visual analysis of the historic and modern forest structure around Cheesman Reservoir. The goal is to define restoration activities that will reduce the severity of fires and return the local ecosystems to a structure and function similar to that which existed before fire suppression. The author identified the following restoration activities: restore landscape diversity by creating openings (15-25% or more of area); sharply reduce forest density, especially the smaller trees; reduce the amount of Douglas fir; retain and restore old growth; use prescribed fire to limit new growth.

Keywords: case study; Cheesman Reservoir; fire; Hayman fire; Southwest; vegetation change

Graham, R. 2004. Hayman Fire case study: Summary. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: In 2002 much of the Front Range of the Rocky Mountains in Colorado was rich in dry vegetation as a result of fire exclusion and the droughty conditions that prevailed in recent years. These dry and heavy fuel loadings were continuous along the South Platte River corridor located between Denver and Colorado Springs on the Front Range. These topographic and fuel conditions combined with a dry and windy weather system centered over eastern Washington to produce ideal burning conditions resulting in a wildfire run in 1 day of over 60,000 acres and finally impacting over 138 acres. The Hayman Fire case study, involving more than 60 scientists and professionals from throughout the United States, examined how the fire behaved, the effects of fuel treatments on burn severity, the emissions produced, the ecological (e.g., soil, vegetation, animals) effects, the home destruction, postfire rehabilitation activities, and the social and economic issues surrounding the Hayman Fire. The Hayman Fire case study revealed much about wildfires and their interactions with both the social and natural environments. As the largest fire in Colorado history it had a profound impacts both locally and nationally. The findings of this study will inform both private and public decisions on the management of natural resources and how individuals, communities, and organizations can prepare for wildfire events.

Keywords: case study; fire; Hayman fire; response strategy; Southwest

Kenney, D.S., R.A. Klein, and M.P. Clark. 2004. Use and effectiveness of municipal water restrictions during drought in Colorado. *Journal of the American Water Resources Association* (February):77-87.

Abstract: Drought conditions in the summer of 2002 prompted several cities along Colorado's Front Range to enact restrictions on outdoor water use, focusing primarily on limiting the frequency of lawn watering. The different approaches utilized by eight water providers were tracked to determine the level of water savings achieved, measured as a comparison of 2002 usage to 2000 to 2001 average usage, and also based on a statistical estimate of 2002 "expected use" that accounts for the impact of drought conditions on demand. Mandatory restrictions were shown to be an effective tool for drought coping. During periods of mandatory restrictions, savings measured in expected use per capita ranged from 18 to 56%, compared to just 4 to 12% savings during periods of voluntary restrictions. As anticipated, providers with the most stringent restrictions achieved the greatest savings.

Keywords: case study; costs; drought; management; prevention; Southwest; urban

Kent, B., K. Gebert, S. McCaffrey, W. Martin, D. Calkin, E. Schuster, I. Martin, H.W. Bender, G. Alward, Y. Kumagai, P.J. Cohn, M. Carroll, D. Williams, and C. Ekarius. 2003. Social and economic issues of the Hayman Fire. In *Hayman Fire Case Study*. R.T. Graham (ed.) USDA Forest Service Rocky Mountain Research Station, Fort Collins, CO, pp. 315-396. USDA Forest Service General Technical Report RMRS-GTR-114.

Abstract: On June 26, 2002, U.S. Representative Mark Udall wrote the U.S. Forest Service Chief, requesting that the Forest Service conduct an analysis of the Hayman Fire. In response to the Congressman's letter, five teams were established in August 2002 to analyze various aspects of the Hayman Fire experience. This report describes the Hayman Fire analysis work conducted by the social/economic team and presents their findings.

Keywords: case study; economic consequences; fire; Hayman fire; social consequences; Southwest

Klamt, R.R. 2000. The Garcia experience: a sediment TMDL case study. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 29-34. Water Resources Center Report No. 98.

Abstract: Salmon and steelhead play a significant role in California north coastal economy, philosophy, and politics. Author Mark Twain is credited with saying that in the West, whisky is for drinking and water is to fight over. More recently on the north coast, the fight has focused on salmon and land use. Continued concern for the anadromous fisheries has turned attention from the water itself to the riparian zone and hill slopes of the steep erosive coastal mountains of northern California.

The Garcia River is a coastal tributary located about 100 miles north of San Francisco Bay. It is forested with commercial conifers and hardwoods and supports farming and cattle and sheep ranching. Historic waves of logging activity at different levels of regard for the land and water resources coupled with erosive soils on steep slopes and high winter rainfall resulted in significant erosion and sedimentation. Concern over declining anadromous salmonid populations brought attention to sediment impacts in the Garcia River watershed. That focus and threat of a lawsuit prompted the development of a sediment reduction strategy (TMDL) that addresses habitat and channel structure in the waterways by requiring landowners to submit erosion control plans. In May 1998 the North Coast Regional Water Quality Control Board adopted a TMDL and implementation plan with the assistance of the U.S. Environmental Protection Agency. Controllable sediment discharges are prohibited, and reductions of sediment delivery to streams from roads, timber harvest, and agriculture are required on a 40-year time table. Instream numeric targets that describe the desired future conditions of the riparian area, stream channel and fish habitat are used as goals to measure the success of the reductions over time. The development of the TMDL and, especially, the implementation plan were contentious and involved numerous public workshops and hearings over a 2-year period. However, landowner response and attitude and, subsequently, the nature of land use activities is slowly changing. Landowner inventories and monitoring will provide a physical assessment of watershed recovery. The response of the fisheries will tell the ultimate story.

Keywords: case study; development; erosion; grazing; land management; land use; logging; sediment; Southwest; vegetation; water quality; water resources; watershed

Lewis, J. 1998. Evaluating the impacts of logging activities on erosion and suspended sediment transport in the Caspar Creek watersheds. In *Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story*, May 6, 1998. pp. 55-69. USDA Forest Service General Technical Report PSW-GTR-168. June. Available: http://www.fs.fed.us/psw/publications/documents/psw_gtr168/.

Abstract: Suspended sediment has been sampled at both the North and South Fork weirs of Caspar Creek in northwestern California since 1963, and at 13 tributary locations in the North Fork since 1986. The North Fork gauging station (NFC) was used as a control to evaluate the effects of logging in the South Fork in the 1970s on annual sediment loads. In the most conservative treatment of the data, suspended loads increased by 212% over the total predicted for a 6-year period commencing with the onset of logging. When the roles of the watersheds were reversed and the same analysis repeated to evaluate harvesting in the North Fork under California Forest Practice Rules in the 1990s, no significant increase was found at NFC in either annual suspended or bed load. With the advent of automatic pumping samplers, the authors were able to sample sediment concentration much more frequently in the 1980s. This allowed storm event loads from control watersheds in the North Fork to be used in a new regression analysis for NFC. According to this more sensitive analysis, for the 7-year period commencing with the onset of logging, the sum of the suspended storm loads at NFC was 89% higher than that predicted for the undisturbed condition. The much greater increase after logging in the South Fork is too great to be explained by differences in sampling methods and in water years, and appears to be the result of differences in road alignment, yarding methods, and stream protection zones. Similar analyses of storm event loads for each of the treated subwatersheds in the North Fork suggested increased suspended loads in all but one of the tributaries, but effects were relatively small or absent at the main stem locations. Of watersheds with less than 50% cut, only one showed a highly significant increase. The greater increase in sediment at NFC, compared to other main-stem stations, is largely explained by a 3,600-cubic meter landslide that occurred in 1995 in a subwatershed that drains into the main stem just above the NFC. Differences among tributary responses can be explained in terms of channel conditions. Analysis of an aggregated model simultaneously fit to all of the data shows that sediment load increases are correlated with flow increases after logging. Field evidence suggests that the increased flows, accompanied by soil disruption and intense burning, accelerated erosion of unbuffered stream banks and channel headward expansion. Windthrow along buffered streams also appears to be important as a source of both woody debris and sediment. All roads in the North Fork are located on upper slopes and do not appear to be a significant source of sediment reaching the channels. The aggregated model permitted evaluation of certain types of cumulative effects. Effects of multiple disturbances on suspended loads were approximately additive and, with one exception, downstream changes

were no greater than would have been expected from the proportion of area disturbed. A tendency for main-stem channels to yield higher unit-area suspended loads was also detected, but after logging this was no longer the case in the North Fork of Caspar Creek.

Keywords: case study; erosion; landslide; logging; sediment; Southwest; streamflow

Marin Municipal Water District. 2005. Watershed Sanitary Survey Update 2005. December.

Abstract: The Marin Municipal Water District (MMWD) is a purveyor of drinking water obtained from seven reservoirs in Marin County. As a drinking water supply agency that draws from a surface water supply, MMWD was required under the California Surface Water Treatment Rule to conduct a watershed sanitary survey (WSS) in 1995 and to conduct updates to the WSS every five years thereafter. This document is the second update to the 1995 WSS and fulfilled MMWD's requirement to complete an updated WSS by January 1, 2006. The focus of the 1995 WSS was to recommend measures that a water purveyor can implement to preserve and improve the quality of their surface water supplies. The focus of the WSS update is to identify the changes to the information provided in the original WSS and subsequent updates.

This WSS update addresses MMWD's seven local surface water reservoirs that are located in two major watersheds, the Mount Tamalpais Watershed and the Soulajule/Nicasio Watershed. MMWD also treats water that is supplied by the Sonoma County Water Agency (SCWA) from the Russian River; SCWA is addressing the WSS update requirements for the Russian River supply in a separate study.

Pursuant to the recommendation of Department of Health Services staff, this WSS update is intended to be a short update report to the 2000 WSS update and is intended to provide information on the changes that have occurred since 2000 to the various aspects of the original WSS.

Keywords: case study; source water assessment and protection; source water assessment plan; Southwest; water quality; watershed management; watershed sanitary survey

Marin Municipal Water District. 2007. 2007 Annual Water Quality Report. Corte Madera, CA.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; Southwest; water quality

Meixner, T. and P.M. Wohlgemuth. 2003. Climate variability, fire, vegetation recovery, and watershed hydrology. In *First Interagency Conference on Research in the Watersheds*, October 27-30, 2003. Renard, K.G., McElroy, S.A., Gburek, W.J., Canfield, H.E., and Scott, R.L.(eds.). USDA Agricultural Research Service pp. 651-656.

Abstract: The San Dimas Experimental Forest was established in 1934. A large database of fire history, and streamflow exists for several locations within the forest. San Dimas was selected as a perfect example of the hydrology, geology, and ecology of the mountains of southern California. As such, the long-term dataset provides the best examples available of rainfall-runoff relationships in a mountainous Mediterranean climate. One of the most important ecological processes operating at San Dimas is the frequent stand replacing fires that occur approximately every 40 years. The effect of fire on streamflow is a pertinent topic considering the current national discussion about changes in fire policy in the western United States. The datasets at San Dimas provide an opportunity to investigate what the short- and long-term impacts of fire are on water resources in chaparral ecosystems. In particular, the fires of 1938 and 1960 provide an opportunity to investigate the effect of fire on streamflow response. Immediately after the fires, the well-known fire-flood response of chaparral watersheds is noted with extremely large flood peaks possibly due to the combined effects of removal of vegetation and litter by fire as well as the presence of hydrophobic soils. However, longer-term impacts of fire are noticeable, lasting as long as 20 years and are most likely related to aggrading vegetation coverage and the linked increase in evapotranspiration. Around 1960, several watersheds were converted to annual and perennial grasslands from their native chaparral, which increased streamflow to the present day and offers insight into the importance of deeply rooted vegetation on summer streamflow in seasonally dry climates.

Keywords: case study; fire; Southwest; streamflow; vegetation change; watershed

National Association of Conservation Districts. Date Unknown. Special Report: Out Front on the Front Range. Available: http://www.nacdnet.org/special/DistrictFireWork.pdf.

Abstract: Shortly after Colorado's Hayman Fire scorched nearly 138,000 acres in the summer of 2002, the National Association of Conservation Districts (NACD) set out to learn about the economic and environmental consequences of fire. A visit to the Colorado Rocky Mountains Front Range in September 2003 by NACD's Urban, Community and Coastal Resources Committee is the occasion for this fire followup report. "Out Front on the Front Range" reviews the successes and challenges faced by fire-tested conservation partners. Their messages are straightforward and positive, intended to show what worked, what didn't, and what can be done to improve their actions. A lot is at stake as the NACD seeks to evolve and improve their work in fire-prone regions of the West and elsewhere in America. A broad consensus agrees that there will be more, bigger fires in the future. But a lot has been learned about fire in recent years, and the pace of work to mitigate wildfire impacts and to better manage forested lands has increased dramatically.

Keywords: case study; fire; response strategy; Southwest

Robichaud, P., L. MacDonald, J. Freeouf, D. Neary, D. Martin, and L. Ashman. 2003. Postfire rehabilitation of the Hayman Fire. In *Hayman Fire Case Study*. R.T. Graham (ed.). USDA Forest Service Rocky Mountain Research Station, Fort Collins, CO, pp. 293-314. General Technical Report RMRS-GTR-114.

Abstract: The Burned Area Emergency Rehabilitation (BAER) team was asked to analyze and comment on the existing knowledge and science related to postfire rehabilitation treatments, with particular emphasis on the known effectiveness of these treatments. The general effects of fire on western forested landscapes are well documented and have been thoroughly discussed in other chapters of this report. However, postfire erosion and rehabilitation treatment effectiveness have not been studied extensively. The first part of this report describes the postfire conditions, as identified by the BAER team, and the subsequent BAER team recommendations for rehabilitation treatment. The next sections describe the different treatments, where they were applied on the Hayman Fire burn area, and the current knowledge of treatment effectiveness. The recommendations for monitoring treatment effectiveness will answer the specific question, “What types of monitoring protocol and reports should Forest Service and other jurisdictions put in place to continue to learn from this fire?” and outline a general process for monitoring postfire rehabilitation efforts. This is followed by a description of the sites currently established within the Hayman Fire burned area to evaluate the effectiveness of various rehabilitation treatments. The need to establish control sites (burned but not treated) to provide a basis for comparison and monitor natural recovery is also discussed. The final section identifies the knowledge gaps that need to be addressed to guide the selection of postfire rehabilitation treatments on future fires in the Colorado Front Range and similar environments.

Keywords: case study; erosion; fire; runoff; sediment control; Southwest

Roessing, M.E., A.E. Camp, M.L. Tyrrell, and D.C. Morton. 2003. Wildfire and Watersheds: A Summary of a Forum and Workshop Examining the Environmental, Social, and Economic Impacts of Wildfire, M.L. Tyrrell (series ed.). A Yale Forest Forum Series Publication, Volume 6, Number 2.

Abstract: The Global Institute of Sustainable Forestry at the Yale School of Forestry and Environmental Studies held a forum examining the environmental, social, and economic impacts of wildfire. Between 2000 and 2002, several major fires throughout the continental United States attracted national attention and debate surrounding issues of wildfire and fire suppression strategies. Information about the costs and impacts of fire is limited to the cost of fire suppression, the number of acres burned, and the cost of property lost to fire. This document summarizes two forums that addressed the indirect costs of wildfires and the societal and environmental impacts from a wildfire. The forums focused on the 2002 Hayman Fire in Colorado, which was the biggest fire in Colorado history, burning 137,760 acres between Denver and Colorado Springs, affecting thousands of people, burning 133 residences, and impacting the water supplies for both cities. The most severely burned area (measured as the percentage of overstory trees killed) was adjacent to Cheeseman Reservoir, Denver’s drinking water source.

The title of the workshop was “Developing Strategies to Collect and Utilize Critical Wildfire Impact Information.”

Keywords: case study; costs; development; erosion; fire; Southwest; vegetation change; water quality; watershed

Salt Lake City Department of Public Utilities. 2005. 2005 Consumer Confidence Report. Salt Lake City, UT.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; drinking water quality; Southwest

San Francisco Planning Department. 2000. Alameda Watershed Management Plan: Final Environmental Impact Report.

Abstract: The purpose of the Management Plan is to provide a policy framework for the San Francisco Public Utilities Commission (SFPUC) to make consistent decisions about the activities, practices, and procedures that are appropriate on the Watershed lands. To aid the SFPUC in their decision-making, the Management Plan provides a comprehensive set of goals, policies, and management actions that address all Watershed activities and reflect the unique qualities of the Watershed.

Keywords: case study; Southwest; water quality; water treatment; watershed management

San Francisco Public Utilities Commission and Bay Area Water Users Association. 2000. Water Supply Master Plan: A Water Resource Strategy for the SFPUC System. April.

Abstract: Over 2.3 million people in San Francisco, San Mateo, Santa Clara and Alameda counties currently rely entirely, or in part, on water supplied by the San Francisco Public Utilities Commission (SFPUC) system. The SFPUC system is supplied by surface water and groundwater sources in the Bay area and is supplemented by water from the Tuolumne River watershed. The water supplied by the SFPUC system is of excellent quality and reasonable cost and is a positive factor in attracting businesses and industry to the Bay area, such as biotechnology businesses, computer and software companies, and research institutions. The SFPUC system is critical to the economy of San Francisco and the entire San Francisco Bay area. Characterized by rapid industrial growth, year-round tourism and a thriving high technology and biotechnology sector, the Bay area economy relies on SFPUC water supplies for industry, hotels, convention centers, restaurants, office buildings, and other commercial uses, as well as residential use for continued economic prosperity. The SFPUC system is owned and operated by the City and County of San Francisco through the SFPUC. The system provides retail water service to the residents and institutions within the City limits, as well as a number of residential and commercial accounts in

the Bay area and the Sierra Nevada foothills. The system provides wholesale water service to 29 customer agencies in the Bay area.

Keywords: case study; Southwest; urbanization; water quality; water treatment; watershed management

San Francisco Public Utilities Commission. 2006. Annual Water Quality Report. San Francisco, CA.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; case study; drinking water quality; Southwest

USDA Forest Service. 2006. Hayman Fire & BAER Information: Burned Area Emergency Rehabilitation (BAER). Available: http://www.fs.fed.us/r2/psicc/hayres/baer/index.htm.

Abstract: After a fire, some or all of the ground cover (called "duff," includes needles, decomposed wood, and leaves) will be burned away, exposing the soil to the direct impact of rain. In addition, and depending on the severity of the fire ("high" being the worst), the soil itself may become somewhat "hydrophobic," i.e., it will repel water, rather than absorbing it. These conditions can set the stage for soil erosion when rain occurs.

Also, keep in mind that a forest fire typically does not burn at the same intensity everywhere, depending on terrain and fuels. Usually, fire severity will be classified as low, moderate, or high. Generally, high intensity burned areas have priority for treatment, as they tend to be more hydrophobic, have the least duff, and have the greatest potential for erosion.

Keywords: case study; erosion; fire; response strategy; sediment; Southwest

Westerhoff, P., D. Gill, and S. Lohman. 2005. Effects of forest fires on reservoir water quality. In *American Water Works Association 2005 Source Water Protection Symposium*, January 23-26, Palm Beach Gardens, FL.

Abstract: The objective of this research was to determine the long-term effects of catastrophic forest fires on drinking water quality. The watersheds burned by the Rodeo-Chediski fire in Arizona and the Hayman fire in Colorado were the focus of this research. Both fires occurred in watersheds that serve as a drinking water source for a major metropolitan area. Concentration data and mass loading analyses were conducted utilizing pre- and post-fire water quality data. The results of the Rodeo-Chediski fire and the Hayman fire analysis were compared. In addition, an unburned watershed in Arizona was analyzed and served as the reference watershed.

The short- and long-term impacts on stream water that serves as a drinking water source were determined. Short-term effects consisted of elevated nutrient and particulate concentrations in the burned watersheds during subsequent storm events. The post-fire storm events also elevated the metal concentrations in runoff water. However, the maximum contaminant level set by the U.S. Environmental Protection Agency for the metals analyzed was not exceeded. Long-term effects will originate from the mobilized particulate fraction settling to the stream or lake bottom. The organic material adsorbed to the particulates will be slowly dissolved, diffusing into the water. The dissolved organics will serve as an energy source for microorganisms that have the ability to cause taste and odor problems in drinking water. The long-term effects are aesthetic and do not pose a human health risk.

Keywords: case study; drinking water quality; drought; fire; Southwest

Wohlgemuth, P.M. 2003. Post-fire erosion control research on the San Dimas Experimental Forest: past and present. In *First Interagency Conference on Research in the Watersheds*, October 27-30, 2003. Renard, K.G., McElroy, S.A., Gburek, W.J., Canfield, H.E., and Scott, R.L.(eds.). USDA Agricultural Research Service pp. 645-650.

Abstract: The San Dimas Experimental Forest (SDEF) was established in the early 1930s to document and quantify wildland hydrology in the semiarid chaparral-covered steeplands of southern California. Concomitantly, the nearly 70 years of accumulated watershed research in this fire-prone ecosystem has produced invaluable information on post-fire erosion and the effectiveness and consequences of post-fire erosion control treatments. On average, first-year, post-fire watershed sediment yield is 35 times greater than comparable unburned annual levels. This accelerated erosion can cause site degradation and threaten life, property, and infrastructure at the adjacent wildland/urban interface. To mitigate the undesirable consequences of post-fire accelerated erosion, land managers have developed a program of hillslope and stream channel emergency rehabilitation treatments as erosion control measures. The SDEF has been the site on which many of these erosion control practices, both past and present, have been tested. In the 1960s, some labor-intensive treatments were shown to have no effect on reducing post-fire erosion. At the same time, more radical ground-disturbing treatments that were marginally effective in the short-term have persisted on the landscape and altered the subsequent sediment fluxes through these watersheds. In September 2002, virtually the entire SDEF burned in the Williams Fire. This allowed the implementation of a new series of emergency rehabilitation treatments for which the effects and consequences are largely unknown. Preliminary results suggest that an aerial application of polyacrylamide did nothing to reduce post-fire sediment yield, but that prefabricated wooden channel checks may be an effective post-fire rehabilitation tool.

Keywords: case study; erosion; fire; sediment; Southwest

United States

Burby, R.J., E.J. Kaiser, T.L. Miller, and D.H. Moreau. 1983. *Drinking Water Supplies: Protection Through Watershed Management.* Ann Arbor Science Publishers. Ann Arbor, MI.

Abstract: This volume describes a new methodology for devising programs to protect surface water supply sources. Urbanization of water supply watersheds is creating an increasingly serious hazard to public health. In the past, protection of water supply sources relied on the concept of source isolation through purchase of the surrounding area. This practice is no longer practical – on economic, legal, or political grounds – particularly in areas where urban development pressures are accelerating. As a result, water supply systems and local governments must devise watershed management strategies that incorporate a variety of measures and institutional arrangements to protect raw water supplies from contamination.

Keywords: case study; drinking water quality; United States; urbanization; watershed management

Ernst, C. and K. Hart. 2005. Path to Protection: Ten Strategies for Successful Source Water Protection. The Trust for Public Land.

Abstract: Over the past five years, the U.S. Environmental Protection Agency's (EPA's) Office of Ground Water and Drinking Water funded five national nonprofit organizations to launch source water demonstration projects in communities around the country. The purpose of the projects was to build on state Source Water Assessment Programs to move communities from planning to implementing protection for drinking water sources. Successful pilot projects could then be replicated by state and local governments and water suppliers around the country. In order to glean the lessons learned and identify best practices, the Trust for Public Land (TPL) led a joint review of the five grantees' source protection demonstration projects during the spring and summer of 2004. The five grantees were the Clean Water Network/Clean Water Fund/Campaign for Safe and Affordable Drinking Water, the Groundwater Foundation, the Environmental Finance Center Network, the National Rural Water Association, and TPL (in partnership with the University of Massachusetts and the U.S. Department of Agriculture [USDA] Forest Service). Each of EPA's grantees took a different approach to advance source water protection through its pilot project.

The partnership of Clean Water Network/Clean Water Fund/Campaign for Safe and Affordable Drinking Water worked with hundreds of voluntary and nonprofit watershed associations around the country to help them advocate more effectively for source protection as part of a larger goal to achieve fishable and swimmable water.

The Groundwater Foundation supported suppliers working to advance new tools for wellhead and groundwater protection.

The Environmental Finance Center Network helped local stakeholders develop and implement source water protection plans for sources that are shared by many water systems.

The National Rural Water Association hired technicians around the country to assist small rural communities design and implement source water plans.

The Trust for Public Land (in partnership with the University of Massachusetts and the USDA Forest Service) worked with local communities in multijurisdictional watersheds to integrate land conservation and forest management into comprehensive source water protection efforts. This report summarizes findings based on experiences of the five pilot projects and proposes 10 strategies that will help put more state and local governments on the path to protection. Each strategy includes a case study of a state or local entity that has successfully implemented some or all of the action steps included in that strategy. (Note: The case studies are independent of the pilot projects of the five grantees.)

Keywords: agriculture; case study; drinking water; management; source protection; source water protection; United States; watershed

Frederick, K.D. 1991. Economic consequences of climate variability on water in the west. In *Managing Water Resources in the West Under Conditions of Climate Uncertainty: Proceedings of a Colloquium held 14-16 November 1990, Scottsdale, Arizona*. National Academy Press, Washington, DC, pp. 217-238.

Abstract: The economic impacts of hydrologic extremes and variability on specific regions depend on the nature of the economy, the slack in the existing water-supply system, and society's ability to anticipate and adapt to hydrologic change. Demand management and water marketing are potentially important tools for responding to drought and long-term reductions in supply.

A case study of the Missouri River basin illustrates the possible impacts of a general warming on the availability of water within one of the West's principal river basins and indicates how management changes and a reallocation of supplies would help the region adapt to a sizable reduction in streamflow.

Hydrologic extremes have long posed risks to settlements in the western United States. A five-year drought in the twelfth century may have caused the prehistoric Anasazi people to abandon the Colorado plateau. Twice within the last century prolonged drought forced tens of thousands of desperate families to flee the semiarid plains in search of more promising economic opportunities. And currently, a multiyear drought extending from southern California to the Missouri River basin is exacting a toll on a variety of water users.

The temporary transformation of the Trinity River in Texas from a small river to a mile-wide flood in the spring of 1990 provided a recent reminder of what can happen when too much water arrives within too short a time. Even though California has about six million acre-feet of flood control storage and 6,000 miles of levees, floods may pose a bigger problem to the state than earthquakes. Floods have consistently been the nation's most deadly atmospheric hazard in recent decades; they accounted for 61% of all presidential disaster declarations in the decade starting in April 1974.

Keywords: California; case study; climate change; Colorado; drought; flood; impacts; management; streamflow; United States; water resources; water supply

Hopper, K. and C. Ernst. 2005. *Source Protection Handbook: Using Land Conservation to Protect Drinking Water Supplies.* The Trust for Public Land and the American Water Works Association

Abstract: From source to tap, there are numerous points to capture and safeguard clean water or treat contaminated water. The most fundamental approach begins at the source – the lakes, rivers, streams, reservoirs, and groundwater that provide drinking water. By preserving the land that drains to these sources, the vast majority of contaminants are prevented from entering drinking water in the first place. This is a critical component of source protection and the focus of this handbook. Land conservation emphasizes the permanent preservation of land around both groundwater sources (aquifer recharge areas and wellheads) and surface water sources (land that buffers streams, rivers, and lakes). It is an extremely effective tool that can protect public health, prevent increased treatment costs, ensure consumer confidence, and maintain real estate values in areas where water supplies are protected.

Treatment, through filtration and disinfection, is the next barrier against contaminated water. Should pollutants enter water supplies, treatment removes most contaminants. Even in the most pristine watersheds, natural pollutants such as animal waste and organic matter can impair water quality, making treatment essential to the delivery of clean, safe drinking water.

The final barrier is infrastructure. From treatment plants, water travels into canals, pipes, wells, holding tanks, and finally consumer operated spigots. Contamination can occur through the corrosion of pipes and solder material (copper, lead, asbestos), the growth of bacteria in pipes, and untreated water that enters through a break in the distribution system itself. Sound and up-to-date distribution systems help prevent such contamination and disruption of service.

Keywords: costs; drinking water; filtration; land use; reservoirs; source protection; United States; water quality; water supply; watershed

Robbins, R.W., J.L. Glicker, D.M. Bloem, and B.M. Niss. 1991. Effective Watershed Management for Surface Water Supplies. Prepared for American Water Works Association Research Foundation (AwwaRF), Denver, CO.

Abstract: The purpose of this report is to assist water utility managers and local governments in developing effective watershed protection programs for their surface water supplies. The emphasis is on practical, effective solutions and techniques that have been implemented by water utilities and other agencies in protecting water supplies. The basis for much of this work is a national survey of water utilities and state regulatory agencies and 24 case studies of successful watershed protection programs.

Keywords: agriculture; case study; management; United States; water supply; watershed

Canada

City of Calgary. 2007. 2006 Water Quality Report. Calgary, Alberta, Canada.

Abstract: This report provides information to customers about source water, treatment processes, and major contaminants present in source waters. The report is required by the EPA as an annual update to utility customers. Information about contaminant and metals concentrations in source and treated waters is presented.

Keywords: annual water quality report; Canada; case study; Northwest; water quality

3. Climate Change

Northeast

Association of Metropolitan Water Agencies. 2008. Climate Change Case Studies: New York City, New York. Available: http://www.amwa.net/cs/climatechange/newyorkcity.

Abstract: New York City's heightened awareness of climate change issues over the past four years has led to extensive discussions about how regional changes in temperature, precipitation, sea level, and frequency of extreme weather events will impact the City's water supply, drainage, and wastewater management systems. Under the leadership of Commissioner Emily Lloyd, the subject of climate change is institutionalized at New York City's Department of Environmental Protection. Climate change impacts could be significant – new climate and sea level extremes could be experienced that the systems are not designed to accommodate. The City's existing awareness of system vulnerabilities, from observing the effects of past climate variability and extreme weather events, has guided the City's initial assessment of how climate change could impact the City and its water systems.

Keywords: climate change; drinking water quality; drinking water treatment; Northeast; watershed management

Claessens, L., C. Hopkinson, E. Rastetter, and J. Vallino. 2006. Effect of historical changes in land use and climate on the water budget of an urbanizing watershed. *Water Resources Research* 42:W03426

Abstract: The effects of historical (1931-1998) changes in both land use and climate on the water budget of a rapidly urbanizing watershed, the Ipswich River Basin (IRB) in northeastern Massachusetts were assessed. Water diversions and extremely low flow during summer are major issues in the IRB. This study centers on a detailed analysis of diversions and a combined empirical/modeling treatment of evapotranspiration (ET) response to changes in climate and land use. A detailed accounting of diversions showed that net diversions increased due to increases in water withdrawals (primarily groundwater pumping) and export of sewage. Net diversions constitute a major component of runoff (20% of streamflow). Using a combination of empirical analysis and physically based modeling, an increase in precipitation (2.7 millimeter per year, mm/yr) and changes in other climate variables to an increase in ET (1.7 mm/yr). Simulations with a physically based water-balance model showed that the increase in ET could be attributed entirely to a change in climate, while the effect of land use change was negligible. The land use change effect was different from ET and runoff trends commonly associated with urbanization. These and other findings were generalized to predict future streamflow using climate change scenarios. This study could serve as a framework for studying suburban watersheds, being the first study of a suburban watershed that addresses long-term effects of changes in both land use and climate, and accounts for diversions and other unique aspects of suburban hydrology.

Keywords: climate change; development; land use; Northeast; runoff; streamflow; urban; water quality

Cruise, J.F., A.S. Limaye, and N. Al-Abed. 1999. Assessment of impacts of climate change on water quality in the southeastern United States. *Journal of the American Water Works Association* 35(6):1539-1550.

Abstract: An assessment of current and future water quality conditions in the southeastern United States has been conducted using the U.S. Environmental Protection Agency BASINS GIS/database system. The analysis has been conducted for dissolved oxygen, total nitrate nitrogen, and pH. Future streamflow conditions have been predicted for the region based on the UK Hadley Center climate model. Thus far, the analyses have been conducted at a fairly coarse spatial scale due to time and resource limitations. Two hydrologic modeling techniques have been employed in future streamflow prediction: a regional stochastic approach and the application of a physically based soil moisture model. The regional model has been applied to the entire area while the physically based model is being used at selected locations to enhance and support the stochastic model. The results of the study reveal that few basins in the Southeast exhibit high nitrogen levels. These basins are located in regions of intense agricultural activity or in proximity to the Gulf Coast. In many of these areas, streamflow is projected to decline over the next 30-50 years, thus exacerbating these water quality problems.

Keywords: climate change; Northeast; Southeast; water quality

Southeast

Cruise, J.F., A.S. Limaye, and N. Al-Abed. 1999. Assessment of impacts of climate change on water quality in the southeastern United States. *Journal of the American Water Works Association* 35(6):1539-1550.

Abstract: An assessment of current and future water quality conditions in the southeastern United States has been conducted using the U.S. Environmental Protection Agency BASINS GIS/database system. The analysis has been conducted for dissolved oxygen, total nitrate nitrogen, and pH. Future streamflow conditions have been predicted for the region based on the UK Hadley Center climate model. Thus far, the analyses have been conducted at a fairly coarse spatial scale due to time and resource limitations. Two hydrologic modeling techniques have been employed in future streamflow prediction: a regional stochastic approach and the application of a physically based soil moisture model. The regional model has been applied to the entire area while the physically based model is being used at selected locations to enhance and support the stochastic model. The results of the study reveal that few basins in the Southeast exhibit high nitrogen levels. These basins are located in regions of intense agricultural activity or in proximity to the Gulf Coast. In many of these areas, streamflow is projected to decline over the next 30-50 years, thus exacerbating these water quality problems.

Keywords: climate change; Northeast; Southeast; water quality

Sun, G., S.G. McNulty, D.M. Amatya, R.W. Skaggs, L.W. Swift Jr., J.P. Shepard, and H. Riekerk. 2002. A comparison of the watershed hydrology of coastal forested wetlands and the mountainous uplands in the Southern US. *Journal of Hydrology* 263:92-104.

Abstract: Hydrology plays a critical role in wetland development and ecosystem structure and functions. Hydrologic responses to forest management and climate change are diverse in the southern United States due to topographic and climatic differences. This paper presents a comparison study on long-term hydrologic characteristics (long-term seasonal runoff patterns, water balances, storm flow patterns) of three watersheds in the southern United States. These three watersheds represent three types of forest ecosystems commonly found in the lower Atlantic coastal plain and the Appalachian upland mountains. Compared to the warm, flat, and shallow groundwater dominated pine flatwoods on the coast, the inland upland watershed was found to have significantly higher water yield. The precipitation/Hamon's potential evapotranspiration ratio was 1.9 for upland vs. 1.4 and 0.9 for wetlands, and the runoff/precipitation ratio was 0.53 ± 0.091 for upland vs. 0.30 ± 0.079 and 0.13 ± 0.094 for wetlands. Streamflow from flatwoods watersheds generally are discontinuous most of the years while the upland watershed showed continuous flows in most years. Stormflow peaks in a cypress-pine flatwoods system were smaller than that in the upland watershed for most cases, but exceptions occurred under extreme wet conditions. This study concludes that climate is the most important factor in determining the watershed water balances in the southern United States. Topography affects streamflow patterns and stormflow peaks and volume, and is the key to wetland development in the southern United States.

Keywords: climate change; development; management; runoff; Southeast; streamflow; watershed; wetlands

Northwest

Association of Metropolitan Water Agencies. 2008. Climate Change Case Studies: Portland, Oregon. Available: http://www.amwa.net/cs/climatechange/portland.

Abstract: This is a two-paragraph description of the steps Portland's water utility has taken to address climate change issues in their watershed.

Keywords: climate change; drinking water quality; Northwest; watershed management

Association of Metropolitan Water Agencies. 2008. Climate Change Case Studies: Seattle, Washington. Available: http://www.amwa.net/cs/climatechange/seattle.

Abstract: This website provides a short description of the actions Seattle Public Utilities has taken to address climate change issues in their watershed.

Keywords: climate change; drinking water treatment; Northwest; watershed management

Clark, R. 2007. Restoring Mixed Conifer Ecosystems to Pre-Fire Suppression Conditions in Crater Lake National Park. Fire Science Brief, Issue 3. Joint Fire Science Program.

Abstract: Mixed-conifer forests dominated by ponderosa pine trees prevail across the western United States. Once sustained by frequent, low-intensity fires, these ecosystems have changed dramatically as a result of 100 years of fire suppression resulting in an accumulation of fuels and shade-tolerant species. Researchers are finding that reintroducing fire to these systems may be more complicated than once thought. The forests at Crater Lake National Park are a kind of microcosm for the wide-ranging mixed conifer forests across the West. Early efforts to restore fire at Crater Lake showed that older ponderosa pines were at risk of mortality via increases in bark beetle attacks. In attempts to understand how fire affects tree vulnerability, researchers have gained a new, albeit early, understanding of how pine resin response to prescribed fire may begin to help managers with forest restoration management goals and decisions. The research at Crater Lake offers a deeper, more detailed understanding of how to restore mixed-conifer forests to pre-fire suppression conditions.

Key findings include:

- In the mixed-conifer forest at Crater Lake, fall burns were more effective at removing fuels and reducing wildfire risk than spring burns.
- In the old growth ponderosa pine stands at Crater Lake, entire age class cohorts of ponderosa pines were absent as a result of an era of fire suppression.
- Older ponderosa pines were at greater risk of mortality after fire treatments, largely as a result of their increased vulnerability to beetle attack.
- Resin response increased in burned trees as compared to control trees, but resin response was not correlated with beetle susceptibility.

Keywords: climate change; fire; insect pest; Northwest

Meyer, G.A., J.L. Pierce, S.H. Wood, and A.J.T. Jull. 2001. Fire, storms, and erosional events in the Idaho batholith. *Hydrological Processes* 15:3025-3038.

Abstract: In late December 1996, the South Fork Payette River basin in west-central Idaho experienced a prolonged storm that culminated on January 1, 1997, with intense rain on melting snow that triggered slide failures, producing debris flows and sediment-charged floods. Failures occurred in saturated, cohesionless, grussy colluvium derived from weathered Idaho batholith granitic rocks. Many failures along the South Fork Payette River originated in ponderosa pine forests burned in the 1989 stand-replacing Lowman fire. An example is the 0.49 square kilometers (km^2) Jughead Creek basin, where a single large colluvial failure produced almost 40% of the total volume eroded from the basin and generated a massive and rapid debris flow. Failures also occurred in steep, unburned, and unforested drainages such as Hopkins Creek. In this south-facing 0.58 km^2 basin, 15 colluvial hollows failed, but no single failure produced more

than 10% of the total eroded volume. Sediment transport in Hopkins Creek occurred by prolonged sediment-charged sheetflooding. Despite vegetation differences, sediment yields from the geomorphically similar Hopkins Creek (~42,000 megagrams per square kilometer, Mg km^2) and Jughead Creek (~44,000 Mg km^2) basins were quite similar. These 1997 erosion events are equivalent to several thousand years of sediment yield at low rates (2.7-30 Mg km^2 per year) measured by short-term sediment trapping and gauging in Idaho batholith watersheds. If similar large events were solely responsible for sediment export, recurrence intervals (RIs) of several hundred years would account for higher sediment yields averaged over ~104 year from Idaho batholith watersheds. Dating of small fire-induced sheetflooding events in an early Holocene tributary junction fan of Jughead Creek indicates that frequent small sedimentation events (RI ~ = 33-80 years) occurred between 7,400 and 6,600 calendar year before present, with an average yield not greatly exceeding 16 Mg km^2 per year. Compared with the Holocene average, erosion rates during that 800-year period were unusually low, suggesting that sediment yields have not been constant over time, and that climatic variations and related fire regime changes may exert a strong influence on the probability of major erosional events.

Keywords: climate change; erosion; fire; Northwest; sediment; storm; vegetation change; water yield

National Research Council. 1991. *Managing Water Resources in the West Under Conditions of Climate Uncertainty*. National Academy Press, Washington, DC, Prepared by the Committee on Climate Uncertainty and Water Resources Management.

Abstract: The question of whether the Earth's climate is changing in some significant, human-induced way remains a matter of much debate. But the fact that climate is variable over time is well known. These two elements of climatic uncertainty affect water resources planning and management in the American West.

Natural variability in hydrologic processes is all-pervasive. Many techniques have been developed to describe components of this variability. Additional tools and strategies are needed to manage water effectively given inherent supply variability and competing demands. With added and improved capabilities and strategies, society will be better prepared to deal with the uncertainties presented by potential climate change.

Keywords: climate change; Northwest; Southwest; United States; water resources management

Swanson, F.J., R.P. Neilson, and G.E. Grant. 1992. Some emerging issues in watershed management: Landscape patterns, species conservation, and climate change. In *New Perspectives for Watershed Management: Balancing Long-Term Sustainability with Cumulative Environmental Change. Seattle, WA, November 27-29, 1990.*, pp. 307-323. EPA/600/A-92/256.

Abstract: Emerging issues in watershed management include the need to assess the effects of management activities on a time scale of several cutting rotations (> 100 years) and on spatial scales that encompass influences from beyond watershed boundaries. Long-range analysis indicates that today's activities will have strong, long-lasting effects, though the ecological consequences may not be visible when the analysis horizon spans only a few decades. Land use decisions within watersheds are increasingly influenced by broader social, economic, and biological factors (e.g., wildlife management plans, such as the Northern Spotted Owl Conservation Strategy). Global climate change poses an even greater potential for altering watershed management. Consequently, improved social and technical tools are needed for planning management of multiple resources in an increasingly uncertain world.

Keywords: climate change; landscape; management; Northwest; watershed

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940-943.

Abstract: Western U.S. forest wildfire activity is widely thought to have increased in recent decades, yet neither the extent of recent changes nor the degree to which climate may be driving regional changes in wildfire has been systematically documented. Much of the public and scientific discussion of changes in western U.S. wildfire has focused instead on the effects of 19th and 20th century land-use history. This compilation of a comprehensive database of large wildfires in the western U.S. forests since 1970 is compared with hydroclimatic and land-surface data. Results show large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.

Keywords: climate change; fire; Northwest; Southwest

Southwest

Association of Metropolitan Water Agencies. 2008. Climate Change Case Studies: Denver, Colorado. Available: http://www.amwa.net/cs/climatechange/denver.

Abstract: This website provides a short description of the actions Denver Water has taken to address climate change issues in their watershed.

Keywords: climate change; drinking water quality; Southwest; water management

National Research Council. 1991. *Managing Water Resources in the West Under Conditions of Climate Uncertainty*. National Academy Press, Washington, DC, Prepared by the Committee on Climate Uncertainty and Water Resources Management.

Abstract: The question of whether the Earth's climate is changing in some significant, human-induced way remains a matter of much debate. But the fact that climate is variable over time is well known. These two elements of climatic uncertainty affect water resources planning and management in the American West.

Natural variability in hydrologic processes is all-pervasive. Many techniques have been developed to describe components of this variability. Additional tools and strategies are needed to manage water effectively given inherent supply variability and competing demands. With added and improved capabilities and strategies, society will be better prepared to deal with the uncertainties presented by potential climate change.

"Managing Water Resources in the West Under Conditions of Climate Uncertainty," a colloquium held November 14-16, 1990, in Scottsdale, Arizona, was organized by the Water Science and Technology Board at the request of the U.S. Bureau of Reclamation. The colloquium was held to examine the scientific basis for predictions of climate change, the implications of climate uncertainty for water resources management, and the management options available for responding to climate variability and potential climate change. Bureau of Reclamation Commissioner Dennis Underwood, noting the importance of climate variability to his agency's operations in the West, took a personal interest in the colloquium and spoke with participants about his goals for the Bureau of Reclamation as it increases its emphasis on resource management issues.

Keywords: climate change; Northwest; Southwest; United States; water resources management

Stohlgren, T.J., T.N. Chase, R.A. Pielke Sr., T.G.F. Kittel, and J.S. Baron. 1998. Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. *Global Change Biology* 4(5):495-504.

Abstract: Evidence is presented that land use practices in the plains of Colorado influence regional climate and vegetation in adjacent natural areas in the Rocky Mountains in predictable ways. Mesoscale climate model simulations using the Colorado State University Regional Atmospheric Modeling System (RAMS) projected that modifications to natural vegetation in the plains, primarily due to agriculture and urbanization, could produce lower summer temperatures in the mountains. The authors corroborated the RAMS simulations with three independent sets of data: (1) climate records from 16 weather stations, which showed significant trends of decreasing July temperatures in recent decades; (2) the distribution of seedlings of five dominant conifer species in Rocky Mountain National Park, Colorado, which suggested that cooler, wetter conditions occurred over roughly the same time period; and (3) increased stream flow, normalized for changes in precipitation, during the summer months in four river basins, which also indicates cooler summer temperatures and lower transpiration at landscape scales. Combined, the mesoscale atmospheric/land-surface model, short-term trends in regional temperatures, forest distribution changes, and hydrology data indicate that the effects of land use practices on regional climate may overshadow larger-scale temperature changes commonly associated with observed increases in carbon dioxide and other greenhouse gases.

Keywords: climate change; land use; Southwest; streamflow; vegetation change

Swetman, T.W. and J.L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American southwest. *Journal of Climate* 11:3128-3147.

Abstract: Ecological responses to climatic variability in the Southwest include regionally synchronized fires, insect outbreaks, and pulses in tree demography (births and deaths). Multicentury, tree-ring reconstructions of drought, disturbance history, and tree demography reveal climatic effects across scales, from annual to decadal, and from local [< 102 square kilometers (km^2) to mesoscale (104-106 km^2)]. Climate-disturbance relations are more variable and complex than previously assumed. During the past three centuries, mesoscale outbreaks of the western spruce budworm (*Choristoneura occidentalis*) were associated with wet, not dry episodes, contrary to conventional wisdom. Regional fires occur during extreme droughts but, in some ecosystems, antecedent wet conditions play a secondary role by regulating accumulation of fuels. Interdecadal changes in fire-climate associations parallel other evidence for shifts in the frequency or amplitude of the Southern Oscillation (SO) during the past three centuries. High interannual, fire-climate correlations (r = 0.7 to 0.9) during specific decades (i.e., circa 1740-1780 and 1830-1860) reflect periods of high amplitude in the SO and rapid switching from extreme wet to dry years in the Southwest, thereby entraining fire occurrence across the region. Weak correlations from 1780 to 1830 correspond with a decrease in SO frequency or amplitude inferred from independent tree-ring width, ice core, and coral isotope reconstructions.

Episodic dry and wet episodes have altered age structures and species composition of woodland and conifer forests. The scarcity of old, living conifers established before circa 1600 suggests that the extreme drought of 1575-1595 had pervasive effects on tree populations. The most extreme drought of the past 400 years occurred in the mid-twentieth century (1942-1957). This drought resulted in broadscale plant dieoffs in shrublands, woodlands, and forests and accelerated shrub invasion of grasslands. Drought conditions were broken by the post-1976 shift to the negative SO phase and wetter cool seasons in the Southwest. The post-1976 period shows up as an unprecedented surge in tree-ring growth within millennia-length chronologies. This unusual episode may have produced a pulse in tree recruitment and improved rangeland conditions (e.g., higher grass production), though additional study is needed to disentangle the interacting roles of land use and climate. The 1950s drought and the post-1976 wet period and their aftermaths offer natural experiments to study long-term ecosystem response to interdecadal climate variability.

Keywords: climate change; Southwest; vegetation change

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940-943.

Abstract: Western U.S. forest wildfire activity is widely thought to have increased in recent decades, yet neither the extent of recent changes nor the degree to which climate may be driving regional changes in wildfire has been systematically documented. Much of the public and scientific discussion of changes in western U.S. wildfire has focused instead on the effects of 19th and 20th century land-use history. This compilation of a comprehensive database of large

wildfires in the western U.S. forests since 1970 is compared with hydroclimatic and land-surface data. Results show large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.

Keywords: climate change; fire; Northwest; Southwest

United States

Association of Metropolitan Water Agencies. 2008. Climate Change Case Studies. Available: http://www.amwa.net/.

Abstract: Across the country, Association of Metropolitan Water Agencies member utilities are studying and preparing for the potential impacts of climate change on their community's drinking water supplies. Cities that have instituted plans to address climate change in their watersheds include Tucson, Arizona; San Francisco, California; Santa Clara County, California; Denver, Colorado; Miami, Florida; Las Vegas, Nevada; Albuquerque, New Mexico; New York City, New York; Portland, Oregon; and Seattle, Washington.

Keywords: climate change; drinking water quality; United States; watershed management

Cromwell, J.E., J.B. Smith, and R.S. Raucher. 2007. Implications of Climate Change for Urban Water Utilities. Prepared by Stratus Consulting for the Association of Metropolitan Water Agencies, Washington, DC. December.

Abstract: There are many parts to the climate change story that come together to produce a picture of potentially significant implications for urban water utilities. This can create an information overload that, coupled with uncertainties, presents a barrier to understanding and to developing responses. This paper is designed to help move past this initial barrier in order to draw an effective focus on implications and responses. The story is broken into its main elements and considered in logical sequence without tangential details that are documented sufficiently in the scientific literature. The intent is to provide an essential understanding and then turn to consideration of the issues involved in developing suitable water sector responses to climate change.

A general description of climate change processes and effects follows the introduction. Impacts of these climatic changes on water suppliers are then identified and described, including regional differences. Responses to climate change are then discussed, both in terms of "adaptation strategies" to reduce or avoid impacts of climate change, and in terms of "mitigation strategies" that utilities may adopt to reduce the contribution of water utility operations to the production of greenhouse gas emissions.

Keywords: climate change; drinking water quality; drinking water treatment; United States; watershed management

Curriero, F.C., J.A. Patz, J.B. Rose, and S. Lele. 2001. The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. *American Journal of Public Health* 91(8):1194-1199.

Abstract: Rainfall and runoff have been implicated in site-specific waterborne disease outbreaks because upward trends in heavy precipitation in the United States are projected to increase with climate change; this study sought to quantify the relationship between precipitation and disease outbreaks. The U.S. Environmental Protection Agency waterborne disease database, totaling 548 reports of outbreaks from 1948 through 1994, and precipitation data of the National Climatic Data Center were used to analyze the relationship between precipitation and waterborne diseases. Analyses were at the watershed level, stratified by groundwater and surface water contamination and controlled for effects due to season and hydrologic region. A Monte Carlo version of the Fisher exact test was used to test for statistical significance. Fifty-one percent of waterborne disease outbreaks were preceded by precipitation events above the 90th percentile ($P = 0.002$), and 68% by events above the 80th percentile ($P = 0.001$). Outbreaks due to surface water contamination showed the strongest association with extreme precipitation during the month of the outbreak; a 2-month lag applied to groundwater contamination events. The statistically significant association found between rainfall and disease in the United States is important for water managers, public health officials, and risk assessors of future climate change.

Keywords: climate; climate change; flood; runoff; United States; water quality; waterborne pathogens; watershed

Frederick, K.D. 1991. Economic consequences of climate variability on water in the west. In *Managing Water Resources in the West Under Conditions of Climate Uncertainty: Proceedings of a Colloquium held 14-16 November 1990, Scottsdale, Arizona*. National Academy Press, Washington, DC, pp. 217-238.

Abstract: The economic impacts of hydrologic extremes and variability on specific regions depend on the nature of the economy, the slack in the existing water-supply system, and society's ability to anticipate and adapt to hydrologic change. Demand management and water marketing are potentially important tools for responding to drought and long-term reductions in supply.

A case study of the Missouri River basin illustrates the possible impacts of a general warming on the availability of water within one of the West's principal river basins and indicates how management changes and a reallocation of supplies would help the region adapt to a sizable reduction in streamflow.

Hydrologic extremes have long posed risks to settlements in the western United States. A five-year drought in the twelfth century may have caused the prehistoric Anasazi people to abandon the Colorado plateau. Twice within the last century prolonged drought forced tens of thousands

of desperate families to flee the semiarid plains in search of more promising economic opportunities. And currently, a multiyear drought extending from southern California to the Missouri River basin is exacting a toll on a variety of water users.

The temporary transformation of the Trinity River in Texas from a small river to a mile-wide flood in the spring of 1990 provided a recent reminder of what can happen when too much water arrives within too short a time. Even though California has about six million acre-feet of flood control storage and 6,000 miles of levees, floods may pose a bigger problem to the state than earthquakes. Floods have consistently been the nation's most deadly atmospheric hazard in recent decades; they accounted for 61% of all presidential disaster declarations in the decade starting in April 1974.

Keywords: California; case study; climate change; Colorado; drought; flood; impacts; management; streamflow; United States; water resources; water supply

Hurd, B.H., N. Leary, R. Jones, and J.B. Smith. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association* 35(6):1399-1409.

Abstract: Changes in global climate may alter hydrologic conditions and have a variety of effects on human settlements and ecological systems. The effects include changes in water supply and quality for domestic, irrigation, recreational, commercial, and industrial uses; in instream flows that support aquatic ecosystems, recreation uses, hydropower, navigation, and wastewater assimilation; in wetland extent and productivity that support fish, wildlife, and wastewater assimilation; and in the frequency and severity of floods. Watersheds where water resources are stressed under current climate are most likely to be vulnerable to changes in mean climate and extreme events. This study identified key aspects of water supply and use that could be adversely affected by climate change, developed measures and criteria useful for assessing the vulnerability of regional water resources and water dependent resources to climate change, developed a regional database of water sensitive variables consistent with the vulnerability measures, applied the criteria in a regional study of the vulnerability measures, and applied the criteria in a regional study of the vulnerability of U.S. water resources. Key findings highlight the vulnerability of consumptive uses in the western and, in particular, the southwestern United States. However, southern U.S. watersheds are relatively more vulnerable to changes in water quality, flooding, and other instream uses.

Keywords: climate change; flood; flow; United States; water quality; water resources; water supply; watershed

Jentsch, A., J. Kreyling, and C. Beierkuhnlein. 2007. A new generation of climate-change experiments: events, not trends. *Frontiers in Ecology and the Environment* 5(7):365-374.

Abstract: Intensification of weather extremes is currently emerging as one of the most important facets of climate change. Research on extreme events ("event-focused" in contrast to "trend-focused") has increased in recent years and, in 2004, accounted for one-fifth of the experimental

climate change studies published. Numerous examples, ranging from microbiology and soil science to biogeography, demonstrate how extreme weather events can accelerate shifts in species composition and distribution, thereby facilitating changes in ecosystem functioning. However, assessing the importance of extreme events for ecological processes poses a major challenge because of the very nature of such events: their effects are out of proportion to their short duration. The authors propose that extreme events can be characterized by statistical extremity, timing, and abruptness relative to the life cycles of the organisms affected. To test system response to changing magnitude and frequency of weather events, controlled experiments are useful tools. Those experiments provide essential insights for science and for societies that must develop coping strategies for such events. Future research needs for climate-change experiments in ecology are discussed. For illustration, an experimental plan showing how to meet the challenge posed by changes in the frequency or magnitude of extreme events is described.

Keywords: climate change; drought; extreme events; storm; United States

National Research Council. 1991. *Managing Water Resources in the West Under Conditions of Climate Uncertainty.* National Academy Press, Washington, DC, Prepared by the Committee on Climate Uncertainty and Water Resources Management.

Abstract: The question of whether the Earth's climate is changing in some significant, human-induced way remains a matter of much debate. But the fact that climate is variable over time is well known. These two elements of climatic uncertainty affect water resources planning and management in the American West.

Natural variability in hydrologic processes is all-pervasive. Many techniques have been developed to describe components of this variability. Additional tools and strategies are needed to manage water effectively given inherent supply variability and competing demands. With added and improved capabilities and strategies, society will be better prepared to deal with the uncertainties presented by potential climate change.

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Keywords: climate change; Northwest; Southwest; United States; water resources management

O'Keefe, T.C., J.M. Helfield, and R.J. Naiman. 2007. Agents of Watershed Change. Training module from U.S. EPA's Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: This training module provides an overview of natural and human-made change processes and the ways in which they affect the structure and function of watersheds. The module has four primary sections: an introduction to the role of change in the watershed, descriptions of specific natural agents of change and their ecological effects, descriptions of specific human made agents of change and their ecological effects, and a discussion of the watershed processes most vulnerable to change.

Change is a natural, essential feature of watersheds. Being able to identify different change processes, understand the differences between natural and human influences on watershed change, and recognize a change of concern are all critical for effective watershed management. Watershed change, however, can be very complicated to understand and manage when many human and natural causes of change interact as they often do.

After completing this training, the participant should know the major changes affecting watersheds and understand that watersheds are dynamic systems. Some background in watershed ecology is helpful for understanding the material presented here and can be obtained from the module, *Introduction to Watershed Ecology,* at http://www.epa.gov/watertrain/ecology.

Keywords: agriculture; climate change; drought; erosion; fire; flood; logging; United States; urbanization; water resources management; watershed change; watershed management; windstorm

4. Drought

Northeast

Stout, W.L., S.L. Fales, L.D. Muller, R.R. Schnabel, and S.R. Weaver. 2000. Water quality implications of nitrate leaching from intensively grazed pasture swards in the northeast US. *Agriculture Ecosystems & Environment* 77:203-210.

Abstract: High density animal production systems, such as management intensive grazing (MIG), can have a negative effect on water quality. Learning to manage such systems to minimize water quality impacts is essential for the environmental and economic sustainability of these types of animal production systems. Management intensive grazing is a grazing system in which animals at a high stocking density are rotated through several paddocks at short time intervals (12-24 hours) so that animal performance is maximized. Although MIG has the potential to increase dairy farm profitability in the northeast United States, recent work in this region has shown that a substantial amount of nitrogen applied as fertilizer is leached below the root zone of orchardgrass [*Dactylis glomerata* L. (cv.) “Pennlate”] managed as an intensive pasture. How much N is leached from other forage species managed as intensive pasture under the climatic conditions of the northeast United States is not known. A field study was conducted using large drainage lysimeters to measure nitrate nitrogen (NO_3^--N) leaching loss from six pasture swards: orchardgrass + N, orchardgrass+alfalfa [*Medicago sativa* L. (cv.) Alfagraze], orchardgrass + Ladino type white clover (*Trifolium repens* L.), Ryegrass [*Lolium perenne* L, (cv.) Citadel] + N, ryegrass + alfalfa, and ryegrass + white clover. The study site was located in central Pennsylvania on a Hagerstown silt loam soil (fine, mixed, mesic Typic Hapludalf). Nitrate-N leaching losses were most consistent under N fertilized swards where the amount of N could be adjusted for yearly weather conditions. In a drought year, NO_3^--N leaching increased dramatically in swards containing alfalfa or white clover. Sward type and stocking density need to be taken into consideration when developing an animal production system that will be both environmentally and economically sustainable.

Keywords: drought; grazing; land use; management; management intensive grazing (MIG); nitrate; Northeast; water quality

North Central

Fowler, K.K. 1992. Description and Effects of 1988 Drought on Ground-Water Levels, Streamflow, and Reservoir Levels in Indiana. USGS Water-Resources Investigations Report 91-4100.

Abstract: Documentation of the 1988 drought in Indiana was undertaken to aid water management agencies and planners concerned with periods of below-normal precipitation and their effect on commercial, agricultural, and residential water uses. Precipitation, temperature, Palmer Drought Severity Indices, and ground- and surface-water levels from water years 1988

and 1989 were compared to the historical record to evaluate severity, extent, and duration of the 1988 drought in Indiana.

Three types of drought – climatological, hydrologic, and agricultural – occurred in most of Indiana during water years 1988 and 1989. The drought began toward the end of calendar year 1987 as annual precipitation decreased to 4.6 inches below the long-term mean. By the end of September 1988, statewide precipitation deficits had increased to almost 8 inches below normal. High temperatures during the summer months increased the stress on crops, livestock, and people. Northwest Indiana experienced the second warmest June-August on record. Palmer Drought Severity Indices indicated that a moderate-to-severe drought had occurred in Indiana during most of 1988.

Groundwater levels were affected substantially in many areas of the State. Record low-water levels were observed at 12 of the 20 monitoring wells included in this report. A 90-day groundwater emergency was declared in parts of northwestern Indiana. Streamflow throughout the State was affected to varying degrees by the drought. Annual mean discharge in some rivers was only slightly less than the mean annual discharge, while others flowed at less than half that value. The effects of low streamflows were felt by many as electric power plants reduced or ceased production and public-water utilities requested conservation measures by their customers. Major reservoirs in the State approached or reached record low levels, causing water supplies as well as recreational activities to be diminished.

Most major crops produced in Indiana were affected by the dry conditions. Average yields in 1988 ranged from 50 to 86% of 1987 yields.

Keywords: drought; management; North Central; reservoirs; streamflow; water supply

Muchmore, C.B. and B. Dziegielewski. 1983. Impact of drought on quality of potential water supply sources in the Sangamon River Basin. *Water Resources Bulletin* 19(1):37-46.

Abstract: The analysis of streamflow and several water quality parameters in six Illinois rivers showed both deterioration and improvement in quality indicators during the 1976-1977 drought. The adverse impacts were an increase of ammonia and manganese concentrations and, to a lesser degree, increased concentrations of phenol and specific conductance. At the worst point during the drought, the 12-month moving average of monthly ammonia concentration in the Sangamon River was about 620% higher than the antecedent value. On the other hand, average concentrations of nitrites and nitrates, total iron, and the number of coliform bacteria significantly decreased. This positive response suggests that streams which are considered unsuitable for municipal supply due to high levels of these quality indicators may be used as emergency sources during droughts.

Keywords: drought; North Central; water quality; water supply

Northwest

Emmerich, W.E. and R.K. Heitschmidt. 2002. Drought and grazing II: effects on runoff and water quality. *Journal of Range Management* 55:229-234.

Abstract: Understanding the interacting effects of drought and grazing on runoff, erosion, and nutrient transport is essential for improved rangeland management. Research was conducted at the Fort Keogh Livestock and Range Research Laboratory located near Miles City, Montana using 12 non-weighing lysimeters for 3 years. During years 1 and 3, no drought treatment was imposed. For year 2, one-half of the lysimeters were covered to implement a drought treatment. The 3 grazing treatments were ungrazed, grazed during but not after drought, and grazed during and after drought. Runoff, sediment yield, and an array of nutrients in the runoff water were measured from the lysimeters. First year base line data with no grazing or drought treatments applied indicated no significant differences among lysimeters.

Below normal precipitation occurred during year 2, resulting in no runoff from the drought treatment and negated the “nondrought” control. This prevented a direct assessment of the interaction among the drought and grazing treatments for this year. The drought treatment did produce significant reductions in water, sediment, and nutrient yield. No grazing impacts were observed during year 2. The third year with more normal precipitation, there was a trend toward increased runoff, sediment, and nutrient yield from the second year drought treatment lysimeters. In the third year, both grazing treatments showed significantly greater runoff, sediment, and nutrient yield than the ungrazed treatment. Runoff and sediment yield tended to increase from the combination of drought and grazing treatments. The observed increases in runoff and sediment and reduced water quality from the drought and grazing treatments were measured against controls and when compared to the natural variability and water quality standards, they were concluded to be minimal.

Keywords: drought; grazing; Northwest; nutrient; sediment; water quality

Heitschmidt, R.K., K.D. Klement, and M.R. Haferkamp. 2005. Interactive effects of drought and grazing on northern Great Plains rangelands. *Rangeland Ecology and Management* 58:11-19.

Abstract: Drought is common in rangeland environments and an understanding of its impacts on the structure and function of rangeland ecosystems is paramount for developing effective management strategies. This research was the second of a series of studies investigating the impacts of varying seasonal droughts on northern Great Plains rangelands. Research was conducted on native rangeland during the 1998 through 2001 growing seasons. Study plots were twelve 5 × 10 meters nonweighing lysimeters. An automated rainout shelter was used to establish drought conditions on 6 lysimeters during April, May, and June of 1998 and 1999. Single-day, flash grazing events were imposed at the beginning of May, June, and July. Grazing treatments were (1) graze during the two years of drought and the year after; (2) graze during the two years of drought and rest the year after; and (3) rest all years. Results showed that the intense

spring drought reduced soil water content in the upper 30 centimeters of the soil profile and subsequently reduced total herbage production 20% to 40%; cool-season perennial grasses were the primary contributor to the reduction and cool-season annual grasses were secondary. Periodic grazing during drought had minimal impact on herbage production, whereas impacts on nondrought plots ranged from moderate enhancement to moderate suppression, with effects varying depending on functional group. Results also showed that substantial recovery occurred during the 1st postdrought year, with near full recovery realized within two years.

Keywords: drought; grazing; Northwest

Southwest

Kenney, D.S., R.A. Klein, and M.P. Clark. 2004. Use and effectiveness of municipal water restrictions during drought in Colorado. *Journal of the American Water Resources Association* (February):77-87.

Abstract: Drought conditions in the summer of 2002 prompted several cities along Colorado's Front Range to enact restrictions on outdoor water use, focusing primarily on limiting the frequency of lawn watering. The different approaches utilized by eight water providers were tracked to determine the level of water savings achieved, measured as a comparison of 2002 usage to 2000 to 2001 average usage, and also based on a statistical estimate of 2002 "expected use" that accounts for the impact of drought conditions on demand. Mandatory restrictions were shown to be an effective tool for drought coping. During periods of mandatory restrictions, savings measured in expected use per capita ranged from 18 to 56%, compared to just 4 to 12% savings during periods of voluntary restrictions. As anticipated, providers with the most stringent restrictions achieved the greatest savings.

Keywords: case study; costs; drought; management; prevention; Southwest; urban

Sprague, L.A. 2005. Drought effects on water quality in the South Platte River Basin, Colorado. *Journal of the American Water Resources Association* (February):11-24.

Abstract: Twenty-three stream sites representing a range of forested, agricultural, and urban land uses were sampled in the South Platte River Basin of Colorado from July through September 2002 to characterize water quality during drought conditions. With a few exceptions, dissolved orthophosphate concentrations were similar to seasonal historical levels in all land use areas during the drought. At some agricultural sites, decreased dilution of irrigation return flow may have contributed to higher concentrations of some nutrient species, increased primary productivity, and higher dissolved oxygen concentrations. At some urban sites, decreased dilution of base flow and wastewater treatment plant effluent may have contributed to higher dissolved nitrite-plus-nitrate concentrations, increased primary productivity, and higher dissolved oxygen concentrations. Total pesticide concentrations in urban and agricultural areas were not consistently higher or lower during the drought. At most forested sites, decreased dilution of groundwater-derived calcium bicarbonate type base flow likely led to elevated pH and specific-conductance values. Water temperatures at many of the forested sites also were higher, contributing to lower dissolved oxygen concentrations during the drought.

Keywords: drought; flow; land use; nonpoint source; Southwest; urban; water quality

Westerhoff, P., D. Gill, and S. Lohman. 2005. Effects of forest fires on reservoir water quality. In *American Water Works Association 2005 Source Water Protection Symposium*, January 23-26, Palm Beach Gardens, FL.

Abstract: The objective of this research was to determine the long-term effects of catastrophic forest fires on drinking water quality. The watersheds burned by the Rodeo-Chediski fire in Arizona and the Hayman fire in Colorado were the focus of this research. Both fires occurred in watersheds that serve as a drinking water source for a major metropolitan area. Concentration data and mass loading analyses were conducted utilizing pre- and post-fire water quality data. The results of the Rodeo-Chediski fire and the Hayman fire analysis were compared. In addition, an unburned watershed in Arizona was analyzed and served as the reference watershed.

The short- and long-term impacts on stream water that serves as a drinking water source were determined. Short-term effects consisted of elevated nutrient and particulate concentrations in the burned watersheds during subsequent storm events. The post-fire storm events also elevated the metal concentrations in runoff water. However, the maximum contaminant level set by the U.S. Environmental Protection Agency for the metals analyzed was not exceeded. Long-term effects will originate from the mobilized particulate fraction settling to the stream or lake bottom. The organic material adsorbed to the particulates will be slowly dissolved, diffusing into the water. The dissolved organics will serve as an energy source for microorganisms that have the ability to cause taste and odor problems in drinking water. The long-term effects are aesthetic and do not pose a human health risk.

Keywords: case study; drinking water quality; drought; fire; Southwest

United States

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Hydrologic extremes have long posed risks to settlements in the western United States. A five-year drought in the twelfth century may have caused the prehistoric Anasazi people to abandon the Colorado plateau. Twice within the last century prolonged drought forced tens of thousands of desperate families to flee the semiarid plains in search of more promising economic opportunities. And currently, a multiyear drought extending from southern California to the Missouri River basin is exacting a toll on a variety of water users.

The temporary transformation of the Trinity River in Texas from a small river to a mile-wide flood in the spring of 1990 provided a recent reminder of what can happen when too much water arrives within too short a time. Even though California has about six million acre-feet of flood control storage and 6,000 miles of levees, floods may pose a bigger problem to the state than earthquakes. Floods have consistently been the nation's most deadly atmospheric hazard in recent decades; they accounted for 61% of all presidential disaster declarations in the decade starting in April 1974.

Keywords: California; case study; climate change; Colorado; drought; flood; impacts; management; streamflow; United States; water resources; water supply

Jentsch, A., J. Kreyling, and C. Beierkuhnlein. 2007. A new generation of climate-change experiments: events, not trends. *Frontiers in Ecology and the Environment* 5(7):365-374.

Abstract: Intensification of weather extremes is currently emerging as one of the most important facets of climate change. Research on extreme events ("event-focused" in contrast to "trend-focused") has increased in recent years and, in 2004, accounted for one-fifth of the experimental climate change studies published. Numerous examples, ranging from microbiology and soil science to biogeography, demonstrate how extreme weather events can accelerate shifts in species composition and distribution, thereby facilitating changes in ecosystem functioning. However, assessing the importance of extreme events for ecological processes poses a major challenge because of the very nature of such events: their effects are out of proportion to their short duration. The authors propose that extreme events can be characterized by statistical extremity, timing, and abruptness relative to the life cycles of the organisms affected. To test system response to changing magnitude and frequency of weather events, controlled experiments are useful tools. Those experiments provide essential insights for science and for societies that must develop coping strategies for such events. Future research needs for climate-change experiments in ecology are discussed. For illustration, an experimental plan showing how to meet the challenge posed by changes in the frequency or magnitude of extreme events is described.

Keywords: climate change; drought; extreme events; storm; United States

O'Keefe, T.C., J.M. Helfield, and R.J. Naiman. 2007. Agents of Watershed Change. Training module from U.S. EPA's Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: This training module provides an overview of natural and human-made change processes and the ways in which they affect the structure and function of watersheds. The module has four primary sections: an introduction to the role of change in the watershed, descriptions of specific natural agents of change and their ecological effects, descriptions of specific human made agents of change and their ecological effects, and a discussion of the watershed processes most vulnerable to change.

Change is a natural, essential feature of watersheds. Being able to identify different change processes, understand the differences between natural and human influences on watershed change, and recognize a change of concern are all critical for effective watershed management. Watershed change, however, can be very complicated to understand and manage when many human and natural causes of change interact as they often do.

After completing this training, the participant should know the major changes affecting watersheds and understand that watersheds are dynamic systems. Some background in watershed ecology is helpful for understanding the material presented here and can be obtained from the module, *Introduction to Watershed Ecology,* at http://www.epa.gov/watertrain/ecology.

Keywords: agriculture; climate change; drought; erosion; fire; flood; logging; United States; urbanization; water resources management; watershed change; watershed management; windstorm

Canada

Hogg, E.H. and R.W. Wein. 2005. Impacts of drought on forest growth and regeneration following fire in southeastern Yukon, Canada. *Canadian Journal of Forest Research* 35(9):2141-2150.

Abstract: The valleys of southwestern Yukon have a continental climate with average annual precipitation of < 300 millimeters. In 1958, fires burned large areas of mature mixed wood forests dominated by white spruce [*Picea glauca* (Moench) Voss] in the valleys near Whitehorse. Since then, the burned areas have shown poor regeneration of spruce, but have been colonized by scattered clones of trembling aspen (*Populus tremuloides* Michx.) interspersed by grassland. The objective of the study was to examine the influence of climatic variation on forest growth and regeneration in the 1958 burn and the adjacent unburned forests. Tree-ring analysis was conducted on 50 aspen and 54 white spruce in 12 mature stands where these species were codominant, and on 147 regenerating aspen in the 1958 Takhini burn. The mature stands were uneven-aged and the patterns of growth variation for the aspen and spruce between 1944 and 2000 were similar. Growth of both species was most strongly related to variation in precipitation.

The regenerating aspen had a wide age-class distribution (1959-2000) and their growth was also positively related to precipitation. The results indicate that these forests have been slow to regenerate after fire, and are vulnerable if the climate becomes drier under future global change.

Keywords: Canada; drought; fire; vegetation change; Yukon

5. Exotic or Invasive Species

South Central

Hart, C.R. 2003. Saltcedar Biology and Management. L-5440. Texas Cooperative Extension, Texas A&M University.

Abstract: More than 500,000 acres in Texas are infested with saltcedar, a small tree that poses major problems along rivers in the western half of the state. Saltcedar reduces the diversity of plant and animal life, uses tremendous amounts of water, and causes flooding and fire hazards. It has choked out native vegetation, creating a monoculture in most locations along major rivers and their tributaries in western Texas.

It is an increasing problem in central and coastal areas of the state as well. A native of Europe and Asia, saltcedar was introduced in the United States as an ornamental in the early 1800s. It was sold by nurseries throughout the 1800s, and in the early 1900s many people began planting the trees along waterways and stream banks for erosion control.

Although the plant clearly excelled in its intended purpose of stabilizing stream banks, the negatives quickly outweighed the positives. By the 1920s, its potential problems were becoming increasingly clear, as it rapidly spread from one watershed to the next. Saltcedar is now found across the western half of Texas and throughout the U.S. Southwest. One of the major factors contributing to the spread of saltcedar has been the construction of dams and controlled river flows that have provided conditions conducive to its spread.

Keywords: invasive species; South Central; vegetation change; water quality

Northwest

Dukes, J.S. and H.A. Mooney. 2004. Disruption of ecosystem processes in western North America by invasive species. *Revista Chilena de Historia Natural* 77:411-437.

Abstract: Many ecosystems of western North America have been dramatically changed by non-native species. This study reviews ecological impacts of 56 plant, animal, fungus, and protist species that were brought to this region by humans. Characteristics of invasive species that can lead to major ecosystem impacts are discussed, and how invasive species alter many different attributes of ecosystems is explored. Specifically, examples of invasive species that affect geomorphology, fire regimes, hydrology, microclimate, atmospheric composition, nutrient cycling, and productivity are included. Finally, the direct consequences of biological invasions for some native species are reviewed. The examples illustrate how, as invasive species have become dominant across large areas of western North America's grassland, shrubland, dune, riparian, and estuarine ecosystems, the properties and functioning of these systems have changed. To date, some systems in this region, such as its forests, remain relatively unaffected by

invasive species. However, recent attacks of forest pathogens highlight the potential vulnerability of these ecosystems.

Keywords: exotic species; Northwest; Southwest; vegetation change

Southwest

Dukes, J.S. and H.A. Mooney. 2004. Disruption of ecosystem processes in western North America by invasive species. *Revista Chilena de Historia Natural* 77:411-437.

Abstract: Many ecosystems of western North America have been dramatically changed by non-native species. This study reviews ecological impacts of 56 plant, animal, fungus, and protist species that were brought to this region by humans. Characteristics of invasive species that can lead to major ecosystem impacts are discussed, and how invasive species alter many different attributes of ecosystems is explored. Specifically, examples of invasive species that affect geomorphology, fire regimes, hydrology, microclimate, atmospheric composition, nutrient cycling, and productivity are included. Finally, the direct consequences of biological invasions for some native species are reviewed. The examples illustrate how, as invasive species have become dominant across large areas of western North America's grassland, shrubland, dune, riparian, and estuarine ecosystems, the properties and functioning of these systems have changed. To date, some systems in this region, such as its forests, remain relatively unaffected by invasive species. However, recent attacks of forest pathogens highlight the potential vulnerability of these ecosystems.

Keywords: exotic species; Northwest; Southwest; vegetation change

Ziska, L.H., J.B. Reeves III, and R.R. Blank. 2005. The impact of recent increases in atmospheric CO_2 on biomass production and vegetative retention of cheatgrass (*Bromus tectorum*): implications for fire disturbance. *Global Change Biology* 11:1325-1332.

Abstract: Cheatgrass (*Bromus tectorum*) is a recognized, invasive annual weed of the western United States that reduces fire return times from decades to less than 5 years. To determine the interaction between rising carbon dioxide (CO_2) concentration and fuel load, the authors characterized potential changes in biomass accumulation, the C : N ratio, and the digestibility of three cheatgrass populations from different elevations to recent and near-term projections in atmospheric CO_2. The experimental CO_2 values [270, 320, 370, 420 micromoles per mole (μmol mol^{-1})] corresponded roughly to the CO_2 concentrations that existed at the beginning of the 19th century, that during the 1960s, the current CO_2, and the near-term CO_2 projection for 2020, respectively. From 25 until 87 days after sowing, aboveground biomass for these different populations increased 1.5-2.7 g (grams) per plant for every 10 μmol mol^{-1} increase above the 270 μmol mol^{-1} preindustrial baseline. CO_2 sensitivity among populations varied with elevational origin with populations from the lowest elevation showing the greatest productivity. Among all populations, the indigestible portion of aboveground plant material (acid detergent fiber, mostly cellulose and lignin) increased with increasing CO_2. In addition, the ratio of C : N increased with leaf age, with CO_2 and was highest for the lower elevational population. These CO_2-induced qualitative changes could, in turn, result in potential decreases in herbivory and decomposition with subsequent effects on the aboveground retention of cheatgrass biomass. Overall, these data suggest that increasing atmospheric (CO_2) above preambient levels may have contributed significantly to cheatgrass productivity and fuel load with subsequent effects on fire frequency and intensity.

Keywords: fire; invasive species; nutrient load; Southwest; vegetation change

United States

Lovett, G.M., C.D. Canham, M.A. Arthur, K.C. Weathers, and R.D. Fitzhugh. 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. *Bioscience* 56(5):395-405.

Abstract: The forests of eastern North America have been subjected to repeated introductions of exotic insect pests and pathogens over the last century, and several new pests are currently invading, or threatening to invade, the region. These pests and pathogens can have major short- and long-term impacts on forest ecosystem processes such as productivity, nutrient cycling, and support of consumer food webs. Six key features are identified of the biology of exotic animal pests and the ecology of their hosts that are critical to predict the general nature and severity of those impacts. Using three examples of introduced pests and pathogens in eastern forest ecosystems, a conceptual framework for assessing potential ecosystem-scale effects is provided.

Keywords: exotic species; insect pest; United States

6. Insect Pests and Pathogens

Northeast

Bergeron, Y. and A. Leduc. 1998. Relationships between change in fire frequency and mortality due to spruce budworm outbreak in the southeastern Canadian boreal forest. *Journal of Vegetation Science* 9(4):493-500.

Abstract: A simple empirical model estimates mortality due to the spruce budworm (*Choristorneura fumiferana*) outbreak in relation to fire frequency and site characteristics. The occurrence of a spruce budworm outbreak around Lake Duparquet in northwestern Quebec permitted a reconstruction of the stand composition before the outbreak, and also of the mortality of *Abies balsamea* due to the outbreak. The basal area of *A. balsamea* increases with the amount of time since fire in all site types but with increasing values for (1) rock and shallow till, (2) till and mesic clay, and (3) hydric clay. Mortality (measured as percentage loss of basal area due to the outbreak) increases with time since fire but did not vary with site type. The increasing abundance of *A. balsamea* with time since fire is mainly responsible for this increase in mortality. Mortality for a specific basal area is, however, lower for the more recently burned stands suggesting a significant residual effect of time since fire. A landscape model integrating mortality due to the outbreak for stands of different age indicated that both absolute and relative losses of basal area increased with the length of the fire cycles. According to this model, changes in fire cycle could explain a large portion of the spatio-temporal variations observed in outbreak mortality in the southeastern boreal forest of Canada.

Keywords: Canada; fire; insect pest; Northeast; vegetation change

Eshleman, K.N., D.A. Fiscus, N.M. Castro, J.R. Webb, and A.T. Herlihy. 2004. Regionalization of disturbance-induced nitrogen leakage from mid-Appalachian forests using a linear systems model. *Hydrological Processes* 18:2713-2725.

Abstract: The "leakage" of nitrate-nitrogen (nitrate-N) to surface waters is a common (but not universal) response of forest ecosystems to both human-induced and natural disturbances. There are several reported examples of the transient leakage of nitrate-N to surface waters from eastern U.S. forests that have sustained outbreaks of defoliating insects, such as the introduced gypsy moth (*Lymantria dispar*) larva. Previous research has suggested that annual nitrate-N leakage from disturbed forests can be modeled using an empirically derived unit nitrogen export response function (UNERF) model. The model represents annual nitrate-N export as a linear deterministic process in both space and time and is analogous to a unit hydrograph. The goal of the present study was to verify and apply a regionalized, lithology-based UNERF model that references the geographic distribution of bedrock class and the timing and extent of gypsy moth defoliation of forests in the non-glaciated highlands of the Chesapeake Bay watershed. Despite an inability to verify the model for most individual watersheds within the study area, the model was able to reproduce the statistical distribution of annual nitrate-N export to streams that comprised the target population. During water year 1991 (the year following peak defoliation) the model results indicated that regional annual nitrate-N export had transiently increased by nearly 1,500% from a baseline rate of about 0.1 kilograms per hectare (kg ha^{-1}) to a peak value approaching 1.5 kg ha 1. The study concludes that natural vegetation disturbance is an important mechanism by which dissolved nitrogen is leaked from forested lands to small streams, rivers, and Chesapeake Bay. The present study also illustrates how simple, empirically derived linear systems approaches like the UNERF model can be successfully applied to problems where regionalization is a primary goal.

Keywords: insect pest; nitrate; Northeast; nutrient

Eshleman, K.N., R.P. Morgan, J.R. Webb, F.A. Deviney, and J.N. Galloway. 1998. Temporal patterns of nitrogen leakage from Mid-Appalachian forested watersheds: role of insect defoliation. *Water Resources Research* 34(8):2005-2016.

Abstract: Fluxes of dissolved nitrogen (N) as nitrate from forested watersheds in the mid-Appalachian region have important water quality ramifications for small acid-sensitive streams and for downstream receiving waters such as Chesapeake Bay. Previous studies of N leakage have suggested that annual dissolved N fluxes from small watersheds can vary by several orders of magnitude and may be increasing as second-growth forests gradually become N-saturated from the accrual of atmospheric N loadings. In this study, the authors examined the temporal (intra-annual and inter-annual) variability in dissolved nitrate fluxes from five small (area < 15 square kilometers) forested watersheds in the mid-Appalachian region from 1988 to 1995. At all sites, nitrate concentrations were observed to increase dramatically during stormflow events, with nitric acid contributing significantly to depressions in pH and acid neutralizing capacity; annual nitrate fluxes were dominated by high discharge periods. Inter-annually, the fluxes at each site varied by 1-2 orders of magnitude, but the patterns of N leakage displayed considerable synchrony with outbreaks of gypsy moth caterpillar defoliation that began in the late 1980s and early 1990s in this region. N leakage from forested watersheds apparently lagged the initial defoliation by several months to perhaps a year or more. Defoliation outbreaks by the gypsy moth caterpillar (or other herbivorous pests) thus provide an alternative explanation of N leakage from forest ecosystems. Poorly documented insect defoliations – rather than pre-mature N saturation of intact forest ecosystems – need to be considered as a possible explanation of N leakage from forested watersheds in the mid-Appalachian region and elsewhere.

Keywords: insect pest; Northeast; nutrient load; water quality

McCullough, D.G., R.A. Werner, and D. Neumann. 1998. Fire and insects in northern and boreal forest ecosystems of North America. *Annual Review of Entomology* 43:107-127.

Abstract: Fire and insects are natural disturbance agents in many forest ecosystems, often interacting to affect succession, nutrient cycling, and forest species composition. The authors review literature pertaining to effects of fire-insect interactions on ecological succession, use of prescribed fire for insect pest control, and effects of fire on insect diversity from northern and boreal forests in North America. Fire suppression policies implemented in the early 1900s have resulted in profound changes in forest species composition and structure. Associated with these changes was an increased vulnerability of forest stands to damage during outbreaks of defoliating insects. Information about the roles that both fire and insects play in many northern forests is needed to increase the understanding of the ecology of these systems and to develop sound management policies.

Keywords: fire; insect pest; Northeast; vegetation change

Yorks, T.E., D.J. Leopold, and D.J. Raynal. 2003. Effects of *Tsuga canadensis* mortality on soil water chemistry and understory vegetation: possible consequences of an invasive insect herbivore. *Canadian Journal of Forest Research* 33:1525-1537.

Abstract: Soil water chemistry and vegetation were monitored for almost one year before and four years after treatment in two healthy *Tsuga canadensis* (L.) Carrier (eastern hemlock) stands and two *T. canadensis* stands subjected to a girdling treatment. The girdling treatment was applied to simulate infestation and mortality by the introduced pest *Adelges tsugae* Annand. The girdling of *T. canadensis* trees resulted in elevated concentrations of nitrate iron (NO_3^-) and most cations in soil water within two to three months, and concentrations of several ions remained high relative to control stands for the duration of the study (e.g., 473-2,272 μ equivalents NO_3^-/Liter, 22-126 ~~μequivalents~~μ equivalents NH_4^+/Liter). Maximum mean annual weighted ion concentrations and fluxes (e.g., 236 ~~μequivalents~~μ equivalents NO_3^-/Liter and 18 kilograms NO_3^--N/hectare, respectively) were observed two to three years after girdling and were comparable to values reported in the literature regarding clear-cutting effects on stream water ion concentrations and losses.

Keywords: insect pest; Northeast; nutrient; nutrient leaching; water quality

Southeast

Johnson, D.W., G.S. Henderson, and W.F. Harris. 1987. Changes in aboveground biomass and nutrient content on Walker Branch Watershed from 1967 to 1983. In *Paper presented at the Sixth Central Hardwood Forest Conference, Knoxville, TN, February 24-26, 1987* pp. 487-495.

Abstract: The increment of forest biomass and nutrient content on Walker Branch Watershed, Tennessee, from 1967 to 1983 was interrupted by two insect outbreaks. An outbreak of the southern pine beetle in the early 1970s and an outbreak of the hickory borer in the late 1970s to early 1980s killed a number of shortleaf pine (*Pinus echinata*) and hickory (*Carya* spp.), respectively. Yellow-poplar (*Liriodendron tulipifera*) growth increased over this 16-year period, especially in response to the mortality of shortleaf pine. The net result of these events was little change in total biomass but a substantial shift in species composition (from pine to yellow-poplar) in the pine forest type over this period. No species has yet responded to the mortality of hickory.

Due to the shift in species composition in the pine type, calcium and magnesium accumulation rates in biomass increased but foliage biomass decreased over the inventory period. There was little change in foliage biomass or nutrient content in other forest types, despite hickory mortality, since mortality occurred primarily among large trees having low foliage-to-woody-biomass ratios.

The insect attacks, combined with apparently natural self-thinning, caused a large increase in standing dead biomass and in nutrient return via tree fall. This increased rate of return will substantially alter forest floor nutrient content and availability, especially with regard to calcium (where the calcium content of standing dead currently equals forest floor calcium content) and nitrogen (where inputs of woody litter will substantially alter carbon and nitrogen ratios).

Keywords: insect pest; Southeast; vegetation change

Kloeppel, B.D., L. Mazzarelli, W.T. Swank, J.M. Vose, T.R. Wentworth, and K.J. Elliott. 2004. Vegetation and forest floor responses to southern pine beetle impacts in a white pine ecosystem. In *Ecological Society of American 89th Annual Meeting Abstracts*, August 1-6, 2004, Portland, OR. pp. 273-274.

Abstract: The native southern pine beetle (SPB, *Dendroctonus frontalis* Zimmermann), along with its fungal symbiote (*Ophiostoma minus* Hedgcock), is one of the most destructive insects of pines in the southern United States, Mexico, and Central America. In the year 2000, two watersheds at Coweeta Hydrologic Lab near Otto, North Carolina, became infested by SPB. This infestation presented an opportunity to investigate two primary objectives: (1) characterize the impact of SPB outbreak on forest gap conditions including light, soil moisture, and temperature; and (2) qualify and quantify the impact of SPB outbreak on herb and seedling diversity and density and forest floor biomass and decomposition. Twenty permanent 0.08 hectare (~20 by 40 meters) plots were established in watershed 1 by Wayne Swank et al. in 1967 using a stratified random sampling design. Four beetle-impacted plots were selected for the study. Each beetle infested plot was paired with one of the permanent, non-beetle infested plots of similar elevation and basal area. Tree mortality due to SPB impacts increased dramatically. In 2001, two of the beetle plots had 1 and 18% of their total basal area killed by beetles. By 2003, tree mortality due to SPB occurred in all plots ranging from 16 to 57% of total basal area. Nitrogen (N) content (litter mass N concentration) of fresh litter was significantly higher in beetle plots than in non-beetle plots. Herb layer species results showed that there was significantly more Virginia creeper [*Parthenocissus quinquefolia* (L.) Planch.] and violet species (*Viola* spp.) in non-beetle plots than in beetle plots, and there was significantly more lowbush blueberry (*Vaccinium vacillans* Torr.) in beetle plots than in non-beetle plots. Diversity and evenness of tree seedlings and herb layer species in all years tended to be greater in non-beetle plots than in beetle plots, though no significant differences were found.

Keywords: disease; insect pest; Southeast

Leuschner, W.A., D.G. Shore, and D.W. Smith. 1979. Estimating the southern pine beetle's hydrologic impact. *Bulletin of the Entomological Society of America* 25:147-150.

Abstract: Decisions concerning institution or expansion of forest pest control programs should be based on all relevant effects of the pest. The southern pine beetle (*Dendroctonus frontalis* Zimm.) is a forest pest and the forest's watershed values could be affected by it. This study's objectives were to develop a methodology for estimating the physical impacts of *D. frontalis* infestations on forest-produced water and to place a value on that impact within the benefit-cost framework.

Keywords: costs; insect pest; Southeast; water yield

Swank, W.T., J.B. Wade, D.A. Crossley Jr., and R.L. Todd. 1981. Insect defoliation enhances nitrate export from forest ecosystems. *Oecologia* 51:297-299.

Abstract: Chronic defoliation by the fall cankerworm, *Alsophila pometaria* (Harris), accompanied substantial increases in the stream export of nitrate nitrogen (NO_3^--N) from three mixed hardwood forests in the southern Appalachians. These integrated results clearly demonstrate a measurable effect of insect consumers on ecosystem processes, and provide support for the regulatory importance of insects on a landscape scale.

Keywords: insect pest; nutrient; Southeast; vegetation change

Northwest

Clark, R. 2007. Restoring Mixed Conifer Ecosystems to Pre-Fire Suppression Conditions in Crater Lake National Park. Fire Science Brief, Issue 3. Joint Fire Science Program.

Abstract: Mixed-conifer forests dominated by ponderosa pine trees prevail across the western United States. Once sustained by frequent, low-intensity fires, these ecosystems have changed dramatically as a result of 100 years of fire suppression resulting in an accumulation of fuels and shade-tolerant species. Researchers are finding that reintroducing fire to these systems may be more complicated than once thought. The forests at Crater Lake National Park are a kind of microcosm for the wide-ranging mixed conifer forests across the West. Early efforts to restore fire at Crater Lake showed that older ponderosa pines were at risk of mortality via increases in bark beetle attacks. In attempts to understand how fire affects tree vulnerability, researchers have gained a new, albeit early, understanding of how pine resin response to prescribed fire may begin to help managers with forest restoration management goals and decisions. The research at Crater Lake offers a deeper, more detailed understanding of how to restore mixed-conifer forests to pre-fire suppression conditions.

Key findings include:

- In the mixed-conifer forest at Crater Lake, fall burns were more effective at removing fuels and reducing wildfire risk than spring burns
- In the old growth ponderosa pine stands at Crater Lake, entire age class cohorts of ponderosa pines were absent as a result of an era of fire suppression
- Older ponderosa pines were at greater risk of mortality after fire treatments, largely as a result of their increased vulnerability to beetle attack
- Resin response increased in burned trees as compared to control trees, but resin response was not correlated with beetle susceptibility.

Keywords: climate change; fire; insect pest; Northwest

Potts, D.F. 1984. Hydrologic impacts of a large-scale mountain pine beetle (*Dendroctonus ponderosae* Hopkins) epidemic. *Water Resources Bulletin* 20(3):373-377.

Abstract: The Jack Creek watershed, a 133 square kilometers (51.5 square miles) drainage in southwestern Montana, was impacted by a mountain pine beetle (*Dendroctonus ponderosae* Hopkins) epidemic in 1975-1977, which killed an estimated 35% of its total timber. Analysis of U.S. Geological Survey streamflow data for four years prior to and five years after mortality suggest a 15% post-epidemic increase in annual water yield, a two- to three-week advance in the annual hydrograph, a 10% increase in low flows, and little increase of peak runoff.

Keywords: insect pest; Northwest; water yield; watershed

Southwest

Anacker, B. L., N. E. Rank, D. Huberli, M. Garbelotto, S. Gordon, T. Harnik, R. Whitkus, and R. Meentemeyer. 2008. Susceptibility to *Phytophthora ramorum* in a key infectious host: landscape variation in host genotype, host phenotype, and environmental factors. *New Phytologist* 177:756-766.

Abstract: Sudden oak death is an emerging forest disease caused by the invasive pathogen *Phytophthora ramorum*. Genetic and environmental factors affecting susceptibility to *P. ramorum* in the key inoculum-producing host tree *Umbellularia californica* (bay laurel) were examined across a heterogeneous landscape in California, USA. Laboratory susceptibility trials were conducted on detached leaves and assessed field disease levels for 97 host trees from 12 225-m2 plots. Genotype and phenotype characteristics were assessed for each tree. Effects of plot-level environmental conditions (understory microclimate, amount of solar radiation and topographic moisture potential) on disease expression were also evaluated. Susceptibility varied significantly among *U. californica* trees, with a fivefold difference in leaf lesion size. Lesion size was positively related to leaf area, but not to other phenotypic traits or to field disease level.

Genetic diversity was structured at three spatial scales, but primarily among individuals within plots. Lesion size was significantly related to amplified fragment length polymorphism (AFLP) markers, but local environment explained most variation in field disease level. Thus, substantial genetic variation in susceptibility to *P. ramorum* occurs in its principal foliar host *U. californica*, but local environment mediates expression of susceptibility in nature.

Keywords: disease; insect pest; invasive species; Southwest; sudden oak death

Howe, E. and W.L. Baker. 2003. Landscape heterogeneity and disturbance interactions in a subalpine watershed in northern Colorado, USA. *Annals of the Association of American Geographers* 93(4):797-813.

Abstract: Three major disturbances affect subalpine forests in the Rocky Mountains: blowdown, insect outbreaks, and fire. These disturbances may influence one another temporally and spatially, creating a mosaic of disturbance patches. In 1997, a severe windstorm blew down trees on over 10,000 hectares of subalpine forest in northern Colorado. This study attempted to determine if previous disturbances influenced the spatial pattern of blowdown in a representative part of the blowdown in the Middle Fork Elk River watershed. Dendrochronological evidence and a geographic information system were used to reconstruct the disturbance history, and the relationship between disturbance history (i.e., patch age) and the 1997 blowdown were examined. The fire regime varies temporally and spatially, with an area-weighted mean fire interval/fire rotation of 108 to 195 years. Stand-replacing fires appear to have had the most impact on the fire regime, but evidence of nonstand-replacing fires was also found. South-facing, lower-elevation slopes were the settings most likely to burn. Low severity spruce-beetle disturbance found in the mid-1700s and mid- to late 1800s is possibly related to regional outbreaks. Sheep-grazing and fire suppression may have influenced tree-regeneration and fire-frequency patterns. Each disturbance event occurred with varying severity across the landscape, influenced, in part, by the patterns of severity of previous disturbances. Patch age contributed to the pattern of the 1997 blowdown, but the relationship is complicated. The vegetation mosaic influenced spatial patterns of blowdown, resulting in new complexity and maintaining landscape heterogeneity.

Keywords: blowdown; fire; insect pest; Southwest; vegetation change

Kulakowski, D. and T.T. Veblen. 2007. Effect of prior disturbances on the extent and severity of wildfire in Colorado subalpine forests. *Ecology* 88(3):759-769.

Abstract: Disturbances are important in creating spatial heterogeneity of vegetation patterns that in turn may affect the spread and severity of subsequent disturbances. Between 1997 and 2002, extensive areas of subalpine forests in northwestern Colorado were affected by a blowdown of trees, bark beetle outbreaks, and salvage logging. Some of these stands were also affected by severe fires in the late 19th century. During a severe drought in 2002, fires affected extensive areas of these subalpine forests. The authors evaluated and modeled the extent and severity of the 2002 fires in relation to these disturbances that occurred over the five years prior to the fires and

in relation to late 19th century stand-replacing fires. Occurrence of disturbances prior to 2002 was reconstructed using a combination of tree-ring methods, aerial photograph interpretation, field surveys, and geographic information systems (GIS). The extent and severity of the 2002 fires were based on the normalized difference burn ratio derived from satellite imagery. GIS and classification trees were used to analyze the effects of prefire conditions on the 2002 fires. Previous disturbance history had a significant influence on the severity of the 2002 fires. Stands that were severely blown down (> 66% trees down) in 1997 burned less severely than older stands. In contrast, prefire disturbances were poor predictors of fire extent, except that young (~120 year old) postfire stands burned less severely than older stands. Salvage logging and bark beetle outbreaks that followed the 1997 blowdown (within the blowdown as well as in the adjacent forest that was not blown down) did not appear to affect fire extent or severity. Conclusions regarding the influence of the beetle outbreaks on fire extent and severity are limited, however, by spatial and temporal limitations associated with aerial detection surveys of beetle activity. Thus, fire extent in these forests is largely independent of prefire disturbance history and vegetation conditions. In contrast, fire severity, even during extreme fire weather and in conjunction with a multiyear drought, is influenced by prefire stand conditions, including the history of previous disturbances.

Keywords: blowdown; fire; insect pest; land use; logging; Southwest

Meentemeyer, R. K., N. E. Rank, B. L. Anacker, D. M. Rizzo, and J. H. Cushman. 2008. Influence of land-cover change on the spread of an invasive forest pathogen. *Ecological Applications* 18(1):159-171.

Abstract: Human-caused changes in land use and land cover have dramatically altered ecosystems worldwide and may facilitate the spread of infectious diseases. To address this issue, we examined the influence of land-cover changes between 1942 and 2000 on the establishment of an invasive pathogen, Phytophthora ramorum, which causes the forest disease known as Sudden Oak Death. We assessed effects of land-cover change, forest structure, and understory microclimate on measures of inoculum load and disease prevalence in 102 15 × 15 m plots within a 275-km^2 region in northern California. Within a 150 m radius area around each plot, we mapped types of land cover (oak woodland, chaparral, grassland, vineyard, and development) in 1942 and 2000 using detailed aerial photos. During this 58-year period, oak woodlands significantly increased in area by 25%, while grassland and chaparral decreased by 34% and 51%, respectively. Analysis of covariance revealed that vegetation type in 1942 and woodland expansion were significant predictors of pathogen inoculum load in bay laurel (*Umbellularia californica*), the primary inoculum-producing host for P. ramorum in mixed evergreen forests. Path analysis showed that woodland expansion resulted in larger forests with higher densities of the primary host trees (*U. californica, Quercus agrifolia, Q. kelloggii*) and cooler understory temperatures. Together, the positive effects of woodland size and negative effects of understory temperature explained significant variation in inoculum load and disease prevalence in bay laurel; host stem density had additional positive effects on inoculum load. We conclude that enlargement of woodlands and closure of canopy gaps, likely due largely to years of fire suppression, facilitated establishment of *P. ramorum* by increasing the area occupied by inoculum-production foliar hosts and enhancing forest microclimate conditions. Epidemiological studies that incorporate land-use change are rare but may increase understanding of disease dynamics and improve our ability to manage invasive forest pathogens.

Keywords: disease; insect pest; invasive species; land use; Southwest; sudden oak death

Waring, K. M. and K. L. O'Hara. 2008. Redwood/tanoak stand development and response to tanoak mortality caused by *Phytophthora ramorum*. *Forest Ecology and Management* 255:2650-2658.

Abstract: Coast redwood (*Sequoia sempervirens*) and tanoak (*Lithocarpus densiflorus*) form mixed-evergreen forests along the northern California coast. In the mid-1990s, an introduced pathogen (*Phytophthora ramorum*) began causing extensive mortality of tanoak in these forests. This research reconstructed stand development patterns occurring in stands with and without the pathogen, measured stand responses to tanoak mortality, and developed projections of future stand development and structure in the presence of *P. ramorum*. Redwood forms an upper canopy layer while tanoak forms a multicohort lower canopy, resulting in distinct vertical stratification patterns. Individual redwood tree response patterns to tanoak mortality included crown expansion, increased basal sprouting, and increased basal area growth. Future stand structures will likely have greater proportions of redwood relative to tanoak.

Keywords: disease; insect pest; invasive species; Southwest; sudden oak death

Wickland, A. C., C. E. Jensen, and D. M. Rizzo. 2008. Geographic distribution, disease symptoms and pathogenicity of *Phytophthora nemorosa* and *Phytophthora pseudosyringae* in California, USA. *Forest Pathology* 38(4):288-298.

Abstract: During the course of surveys for Phytophthora ramorum in coastal forests of California and Oregon, *P. nemorosa* and *P. pseudosyringae* were frequently isolated from foliage and stems of the same hosts as P. ramorum. Both species ranged from central California to Oregon within 50 km of the Pacific Ocean. Both were also found in the Sierra Nevada Mountains. Phytophthora nemorosa was primarily found infecting trees in coast redwood forests and was most often isolated from bay laurel leaves (*Umbellularia californica*), bleeding cankers on the main bole of tanoak (*Lithocarpus densiflorus*), and leaf and small stem tissue of redwood (*Sequoia sempervirens*). Phytophthora pseudosyringae was primarily isolated from hosts found in coast live oak woodlands. Bay laurel was the most common host while infection of coast live oak (*Quercus agrifolia*) stems was less frequent. Inoculation studies confirmed the pathogenicity of *P. nemorosa* and *P. pseudosyringae* on their most common hosts.

Keywords: disease; insect pest; Southwest

United States

Lovett, G.M., C.D. Canham, M.A. Arthur, K.C. Weathers, and R.D. Fitzhugh. 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. *Bioscience* 56(5):395-405.

Abstract: The forests of eastern North America have been subjected to repeated introductions of exotic insect pests and pathogens over the last century, and several new pests are currently invading, or threatening to invade, the region. These pests and pathogens can have major short- and long-term impacts on forest ecosystem processes such as productivity, nutrient cycling, and support of consumer food webs. Six key features are identified of the biology of exotic animal pests and the ecology of their hosts that are critical to predict the general nature and severity of those impacts. Using three examples of introduced pests and pathogens in eastern forest ecosystems, a conceptual framework for assessing potential ecosystem-scale effects is provided.

Keywords: exotic species; insect pest; United States

Williams, D.W. and R.A. Birdsey. 2003. Historical Patterns of Spruce Budworm Defoliation and Bark Beetle Outbreaks in North American Conifer Forests: An Atlas and Description of Digital Maps. General Technical Report NE-308. USDA Forest Service Northeastern Research Station.

Abstract: This atlas provides maps of historical defoliation by the eastern and western spruce budworms and historical outbreaks of the mountain and southern pine beetles during the past half century. The maps encompass various regions of the conterminous United States and eastern Canada. The publication also serves as documentation for an extended set of digital maps, which are available online. The digital maps are useful for investigating spatial dynamics of insect populations and for providing pest disturbance inputs to spatially explicit forest simulation models.

Keywords: insect pest; United States; vegetation change

Canada

Bergeron, Y. and A. Leduc. 1998. Relationships between change in fire frequency and mortality due to spruce budworm outbreak in the southeastern Canadian boreal forest. *Journal of Vegetation Science* 9(4):493-500.

Abstract: A simple empirical model estimates mortality due to the spruce budworm (*Choristorneura fumiferana*) outbreak in relation to fire frequency and site characteristics. The occurrence of a spruce budworm outbreak around Lake Duparquet in northwestern Quebec permitted a reconstruction of the stand composition before the outbreak, and also of the mortality of *Abies balsamea* due to the outbreak. The basal area of *A. balsamea* increases with the amount of time since fire in all site types but with increasing values for (1) rock and shallow till, (2) till and mesic clay, and (3) hydric clay. Mortality (measured as percentage loss of basal area due to

the outbreak) increases with time since fire but did not vary with site type. The increasing abundance of *A. balsamea* with time since fire is mainly responsible for this increase in mortality. Mortality for a specific basal area is, however, lower for the more recently burned stands suggesting a significant residual effect of time since fire. A landscape model integrating mortality due to the outbreak for stands of different age indicated that both absolute and relative losses of basal area increased with the length of the fire cycles. According to this model, changes in fire cycle could explain a large portion of the spatio-temporal variations observed in outbreak mortality in the southeastern boreal forest of Canada.

Keywords: Canada; fire; insect pest; Northeast; vegetation change

Cheng, J.D. 1989. Streamflow changes after clear-cut logging of a pine beetle-infested watershed in southern British Columbia, Canada. *Water Resources Research* 25(3):449-456.

Abstract: The paired watershed technique was used to assess the streamflow changes of Camp Creek in interior British Columbia after clear-cut logging occurred over 30% of its 33.9 square kilometers (km^2) watershed. Existing hydrometric data for Camp Creek and those of an adjacent control, Graeta Creek, were analyzed for both the 1917-1976 prelogging and 1978-1983 postlogging periods. Postlogging Camp Creek streamflow changes are characterized by increases in annual and monthly water yields and annual peak flows, as well as earlier annual peak flow and half flow volume occurrence dates. The direction and magnitude of these postlogging streamflow increases are clear and consistent. The results are in good agreement with the findings of most previous studies conducted on watersheds which generally have been smaller than 2.5 km^2. This study provides strong evidence that changes in streamflow from a large forested watershed can be significant if a sizeable portion of its drainage area is clear-cut. Possible causes for streamflow changes are discussed.

Keywords: Canada; insect pest; logging; water quantity; watershed

7. Fire

Northeast

Bergeron, Y. and A. Leduc. 1998. Relationships between change in fire frequency and mortality due to spruce budworm outbreak in the southeastern Canadian boreal forest. *Journal of Vegetation Science* 9(4):493-500.

Abstract: A simple empirical model estimates mortality due to the spruce budworm (*Choristorneura fumiferana*) outbreak in relation to fire frequency and site characteristics. The occurrence of a spruce budworm outbreak around Lake Duparquet in northwestern Quebec permitted a reconstruction of the stand composition before the outbreak, and also of the mortality of *Abies balsamea* due to the outbreak. The basal area of *A. balsamea* increases with the amount of time since fire in all site types but with increasing values for (1) rock and shallow till, (2) till and mesic clay, and (3) hydric clay. Mortality (measured as percentage loss of basal area due to the outbreak) increases with time since fire but did not vary with site type. The increasing abundance of *A. balsamea* with time since fire is mainly responsible for this increase in mortality. Mortality for a specific basal area is, however, lower for the more recently burned stands suggesting a significant residual effect of time since fire. A landscape model integrating mortality due to the outbreak for stands of different age indicated that both absolute and relative losses of basal area increased with the length of the fire cycles. According to this model, changes in fire cycle could explain a large portion of the spatio-temporal variations observed in outbreak mortality in the southeastern boreal forest of Canada.

Keywords: Canada; fire; insect pest; Northeast; vegetation change

Foster, D., E. Boose, and J. Aber. 1998. Regionalization studies at Harvard Forest LTER. In *Perspectives on the Land-Use History of North America: A Context for Understanding Our Changing Environment*. T. D. Sisk (ed.), U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR 1998-0003 (Revised September 1999). Available: http://biology.usgs.gov/luhna/harvardforest.html.

Abstract: Ecological patterns are different at the regional, subregional, and landscape scales. This article describes the major ecological factors affecting New England at these various scales including major species and natural and human disturbance regimes.

Keywords: agriculture; fire; logging; Northeast

Goodale, C.L., J.D. Aber, and W.H. McDowell. 2000. The long-term effects of disturbance on organic and inorganic nitrogen export in the White Mountains, New Hampshire. *Ecosystems* 3:433-450.

Abstract: Traditional biogeochemical theories suggest that ecosystem nitrogen retention is controlled by biotic N limitation, that stream N losses should increase with successional age, and

that increasing N deposition will accelerate this process. These theories ignore the role of dissolved organic nitrogen (DON) as a mechanism of N loss. The authors examined patterns of organic and inorganic N export from sets of old growth and historically (80-110 years ago) logged and burned watersheds in the northeastern United States, a region of moderate, elevated N deposition. Stream nitrate concentrations were strongly seasonal, and mean (± Standard Deviation) nitrate export from old-growth watersheds 1.4 (± 0.6) kilograms nitrogen per hectare per year (kg N ha^{-1} y^{-1}) was four times greater than from disturbed watersheds 0.3 (± 0.3) kg N ha^{-1} y^{-1}, suggesting that biotic control over nitrate loss can persist for a century. DON loss averaged 0.7 (± 0.2) kg N ha^{-1} y^{-1} and accounted for 28-87% of total dissolved N (TDN) export. DON concentrations did not vary seasonally or with successional status, but correlated with dissolved organic carbon (DOC), which varied inversely with hardwood forest cover. The patterns of DON loss did not follow expected differences in biotic N demand but instead were consistent with expected differences in DOC production and sorption. Despite decades of moderate N deposition, TDN export was low, and even old-growth forests retained at least 65% of N inputs. The reasons for this high N retention are unclear: if due to a large capacity for N storage or biological removal, N saturation may require several decades to occur; if due to interannual climate variability, large losses of nitrate may occur much sooner.

Keywords: fire; logging; Northeast; vegetation change; water quality

Johnson, E.A. 1992. *Fire and Vegetation Dynamics: Studies from the North American Boreal Forest.* Cambridge University Press.

Abstract: This book attempts to couple four characteristics of fire behavior in the boreal forest to their effects on boreal forest populations. The first section discusses major aspects of the vegetation dynamics of the North American boreal forest and fire behavior. The second section discusses fire and its relationship to vegetation, especially in boreal forests. The third section describes the relationships between specific physical processes of fire and the population processes of recruitment and mortality. The final section discusses the combination of fire behavior and its effects on population recruitment and mortality.

Keywords: boreal forest; fire; North Central; Northeast; vegetation change

McCullough, D.G., R.A. Werner, and D. Neumann. 1998. Fire and insects in northern and boreal forest ecosystems of North America. *Annual Review of Entomology* 43:107-127.

Abstract: Fire and insects are natural disturbance agents in many forest ecosystems, often interacting to affect succession, nutrient cycling, and forest species composition. The authors review literature pertaining to effects of fire-insect interactions on ecological succession, use of prescribed fire for insect pest control, and effects of fire on insect diversity from northern and boreal forests in North America. Fire suppression policies implemented in the early 1900s have resulted in profound changes in forest species composition and structure. Associated with these changes was an increased vulnerability of forest stands to damage during outbreaks of defoliating insects. Information about the roles that both fire and insects play in many northern forests is needed to increase the understanding of the ecology of these systems and to develop sound management policies.

Keywords: fire; insect pest; Northeast; vegetation change

Southeast

Glitzenstein, J.S., D.R. Streng, and D.D. Wade. 2003. Fire frequency effects on longleaf pine (*Pinus palustris* P. Miller) vegetation in South Carolina. *Natural Areas Journal* 23(1):22-37.

Abstract: Southeastern U.S. habitats dominated by longleaf pine (*Pinus palustris* P. Miller) have declined precipitously in area and extent. Conservation of diverse ground-layer vegetation in these endangered habitats depends on prescribed fire. While the need for prescribed fire is now generally accepted, there is disagreement concerning the most appropriate fire regime. One of the more important variables is frequency of fire. Several hypothetical relationships between fire frequency and vascular plant richness and composition are suggested by the existing literature. Results of two long-term prescribed fire studies support the hypothesis that burning as frequently as fuels permit is optimal for maintaining the largest number of native ground-layer plant species. However, fire frequency effects on species composition differed between the two studies. Increasing fire frequency in South Carolina ultisol flatwoods and wet savannas was associated with a distinct shift from woody to herbaceous-dominated communities. Herbs, particularly bunchgrasses and perennial fobs, dominated annual- and biennial-burn treatment plots, whereas triennial- and quadrennial-burn plots were shrub-dominated. In contrast, annual and biennial fires did not produce herbaceous dominated ground-layer vegetation in North Florida spodosol flatwoods. Reduced dominance of saw palmetto and somewhat increased importance of forbs and grasses, particularly rhizomatous grasses, distinguished the annually burned plots. However, biennial- and quadrennial-burn plots were similar in composition and did not differ significantly in species richness at the largest spatial scale.

Keywords: fire; fire regime; Southeast

North Central

Driscoll, D.G., J.M. Carter, and D.O. Ohlen. 2004. Hydrologic Effects of the 1988 Galena Fire, Black Hills Area, South Dakota. U.S. Geological Survey Water-Resources Investigations Report 03-4323.

Abstract: The Galena Fire burned about 16,788 acres of primarily ponderosa pine forest during July 5-8, 1988, in the Black Hills area of South Dakota. The fire burned primarily within the Grace Coolidge Creek drainage basin and almost entirely within the boundaries of Custer State Park. A U.S. Geological Survey gauging station with streamflow records dating back to 1977 was located along Grace Coolidge Creek within the burned area. About one-half of the gauging station's 26.8 square-mile drainage area was burned. The drainage basin for Bear Gulch, which is a tributary to Grace Coolidge Creek, was burned particularly severely, with complete

deforestation occurring in nearly the entirety of the area upstream from a gauging station that was installed in 1989.

A study to evaluate the effects of the Galena Fire on streamflow, geomorphology, and water quality was initiated in 1988. The geomorphologic and water-quality components of the study were completed by 1990 and are summarized in this report. A data-collection network consisting of streamflow- and precipitation-gauging stations was operated through water year 1998 for the evaluation of effects on streamflow characteristics, including both annual-yield and peak-flow characteristics, which are the main focus of this report.

Moderately burned areas did not experience a substantial increase in the rate of surface erosion; however, severely burned areas underwent surficial erosion nearly twice that of the unburned areas. The sediment production rate of Bear Gulch estimated 8 to 14 months after the fire was 870 cubic feet per acre (44 tons per acre). Substantial degradation of stream channels within the severely burned headwater areas of Bear Gulch was documented. Farther downstream, channel aggradation resulted from deposition of sediments transported from the headwater areas.

The most notable water-quality effect was on concentrations of suspended sediment, which were orders of magnitude higher for Bear Gulch than for the unburned control area. The effects on several other water-quality constituents, such as organic carbon and nitrogen and phosphorus nutrient constituents, probably were influenced by the large concentrations of suspended matter that were documented in initial post-fire, stormflow events. The first post-fire stormflow produced the highest measured concentrations of specific conductance, nitrogen, phosphorus, organic carbon, calcium, magnesium, potassium, manganese, and sulfate in the burned areas. For most constituents sampled, differences in concentrations between burned and unburned areas were no longer discernible within about one year following the Galena Fire.

The effects of the Galena Fire on annual-yield characteristics of Grace Coolidge Creek were evaluated primarily from comparisons with long-term streamflow records for Battle Creek, which is hydrogeologically similar and is located immediately to the north. Annual yield for Grace Coolidge Creek increased by about 20% as a result of the fire. This estimate was based on relations between annual yield for Grace Coolidge Creek and Battle Creek for pre- and post-burn periods. Many of the post-burn data points are well beyond the range of the pre-burn data, which is a source of uncertainty for this estimate.

Substantial increases in peak-flow characteristics for severely burned drainages were visually apparent from numerous post-fire field observations. Various analyses of streamflow data indicated substantial increases in peak-flow response for burned drainage areas; however, quantification of effects was particularly difficult because peak-flow response diminished quickly and returned to a generally pre-burn condition by about 1991. Field observations of vegetation and analysis of remotely sensed data indicated that establishment of grasses and forbs occurred within a similar timeframe. Comparison of pre-fire peak flows to post-1991 peak flows indicates that these grasses and forbs were equally effective in suppressing peak flows as the predominantly ponderosa pine forest was prior to the Galena Fire.

Numerous peak-flow events with small recurrence intervals occurred within burned areas through 1990. Peak-flow events for Bear Gulch during this period were about one to two orders of magnitude larger than corresponding peaks for a small control drainage located along Grace Coolidge Creek upstream from the burn area. The small peaks do not provide quantitative information applicable to estimation of peak-flow magnitudes for larger events, however. Peak-flow events for Bear Gulch that occurred during 1991-1998 were generally similar to those for the control drainage. A short-term increase in peak-flow potential also was documented for the longer-term gauging station located along Grace Coolidge Creek; however, peak-flow response was less pronounced than for Bear Gulch, which had nearly complete deforestation within a much smaller drainage area.

Keywords: erosion; fire; flow; nitrogen; North Central; sediment; streamflow; vegetation; water quality; water quantity

Johnson, E.A. 1992. *Fire and Vegetation Dynamics: Studies from the North American Boreal Forest.* Cambridge University Press.

Abstract: This book attempts to couple four characteristics of fire behavior in the boreal forest to their effects on boreal forest populations. The first section discusses major aspects of the vegetation dynamics of the North American boreal forest and fire behavior. The second section discusses fire and its relationship to vegetation, especially in boreal forests. The third section describes the relationships between specific physical processes of fire and the population processes of recruitment and mortality. The final section discusses the combination of fire behavior and its effects on population recruitment and mortality.

Keywords: boreal forest; fire; North Central; Northeast; vegetation change

McColl, J.G. and D.F. Grigal. 1975. Forest fire: effects on phosphorus movement to lakes. *Science* 188:1109-1111.

Abstract: After a wildfire in the virgin forest of a lake-watershed region in northeastern Minnesota, the phosphorus concentration in the runoff was elevated for two years and decreased in the third year. However, there was no increase in the phosphorus concentrations of the lake and its input stream. This indicates that, under similar circumstances, controlled burning will not damage streams or lakes by elevating phosphorus levels.

Keywords: fire; North Central; water quality

Nelson, J.C., L. DeHaan, R.E. Sparks, and L. Robinson. 1998. Presettlement and contemporary vegetation patterns along two navigation reaches of the upper Mississippi River. In *Perspectives on the Land-Use History of North America: A Context for Understanding Our Changing Environment*. T. D. Sisk (ed.), U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR 1998-0003 (Revised September 1999). Available: http://biology.usgs.gov/luhna/chap7.html.

Abstract: Restoration efforts within large floodplain-river ecosystems should rely heavily upon knowledge of these systems prior to large-scale alterations by humans. Unfortunately, most large rivers in the north temperate zone were modified centuries ago – long before any ecological investigations. In many parts of the United States, though, historical records exist that contain quantifiable data about the "natural" conditions of a region. This study reconstructs presettlement vegetation patterns along two navigation reaches of the upper Mississippi River using data recorded in 1816 by surveyors from the U.S. General Land Office. Contrary to many previous studies that indicate forest as the dominant community type along the floodplains of the upper Mississippi River, these results indicate that prairie was a dominant community type. Savannas, open woodlands, and closed forests were also important features. While flood regime has long been regarded as the master variable influencing productivity and biodiversity within large floodplain-river ecosystems, the authors propose that fire also played an important role in maintaining some plant communities on the floodplains of the upper Mississippi River.

Keywords: fire; fire return interval; land use change; North Central; South Central; vegetation change

Queen, L.P., K.N. Brooks, and W.L. Wold. 1995. Assessing cumulative effects in the Nemadji river basin, Minnesota. In *Watershed Management: Planning for 21st Century*. T.J. Ward (ed.) American Society of Civil Engineers, New York, pp. 239-248.

Abstract: The Nemadji River in northeastern Minnesota contributes an estimated 525,000 metric tons of sediment per year to Lake Superior. A portion of the Nemadji Basin is composed of highly erodible red clays that are susceptible to soil mass movement. The red clay area was studied in the late 1970s through a joint interagency project that concluded that natural levels of erosion-sedimentation in the red clay area have been intensified by human activity. The cumulative effects of logging, burning, clearing for agriculture, and road construction are increased runoff, higher peak streamflows, rapid channel scouring, increased soil mass movement, and stream bank undercutting. This study uses a Geographic Information System to analyze watershed characteristics of subwatersheds within the Nemadji Basin. Bivariate analyses indicated that the frequency of slump occurrence was inversely related to the total forested area. The results of this investigation indicate that the percent of nonforested area is related to a greater frequency of soil slumps, and that management should be aimed at increasing and maintaining forest cover in the watershed.

Keywords: development; erosion; fire; logging; mudslide; North Central; risk reduction; runoff; sediment control; vegetation change; watershed management

South Central

Nelson, J.C., L. DeHaan, R.E. Sparks, and L. Robinson. 1998. Presettlement and contemporary vegetation patterns along two navigation reaches of the upper Mississippi River. In *Perspectives on the Land-Use History of North America: A Context for Understanding Our Changing Environment*. T. D. Sisk (ed.), U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR 1998-0003 (Revised September 1999). Available: http://biology.usgs.gov/luhna/chap7.html.

Abstract: Restoration efforts within large floodplain-river ecosystems should rely heavily upon knowledge of these systems prior to large-scale alterations by humans. Unfortunately, most large rivers in the north temperate zone were modified centuries ago – long before any ecological investigations. In many parts of the United States, though, historical records exist that contain quantifiable data about the "natural" conditions of a region. This study reconstructs presettlement vegetation patterns along two navigation reaches of the upper Mississippi River using data recorded in 1816 by surveyors from the U.S. General Land Office. Contrary to many previous studies that indicate forest as the dominant community type along the floodplains of the upper Mississippi River, these results indicate that prairie was a dominant community type. Savannas, open woodlands, and closed forests were also important features. While flood regime has long been regarded as the master variable influencing productivity and biodiversity within large floodplain-river ecosystems, the authors propose that fire also played an important role in maintaining some plant communities on the floodplains of the upper Mississippi River.

Keywords: fire; fire return interval; land use change; North Central; South Central; vegetation change

Northwest

Agee, J.K. 1993. *Fire Ecology of Pacific Northwest Forests.* Island Press, Washington, DC.

Abstract: This book began as a source book for natural area managers interested in restoring or maintaining fire in the natural areas of the Pacific Northwest. It grew to encompass a broader charge: to provide a natural baseline that wildland managers, or those interested in wildland management, could use in understanding the effects of natural or altered fire regimes in the western United States. This ecological perspective about fire is not a prescriptive guide, since prescriptions must include management objectives. This management emphasis is on the role of fire in natural areas, but such information is also useful in fire applications for other management purposes.

The structure of most virgin forests in the American West today reflects a past disturbance history that includes fire. Although media reports of the 1988 Yellowstone fires treated the scene as an ecological catastrophe, these forests were born of fire in the 1700s and are now being reborn in the 1990s. Knowledge of the natural and often inevitable disturbances likely to affect forests, including fire, is essential to any forest management plan, whether the objective is timber production, wildlife conservation, or wilderness management. Creating desirable forest stand structures in the future for these objectives may not require simulation of past fire activity. Such efforts, however, will be successful only if we understand the processes responsible for desirable structures we see today before undertaking future stand manipulation.

Keywords: fire; Northwest; Southwest; watershed management

Clark, R. 2007. Restoring Mixed Conifer Ecosystems to Pre-Fire Suppression Conditions in Crater Lake National Park. Fire Science Brief, Issue 3. Joint Fire Science Program.

Abstract: Mixed-conifer forests dominated by ponderosa pine trees prevail across the western United States. Once sustained by frequent, low-intensity fires, these ecosystems have changed dramatically as a result of 100 years of fire suppression resulting in an accumulation of fuels and shade-tolerant species. Researchers are finding that reintroducing fire to these systems may be more complicated than once thought. The forests at Crater Lake National Park are a kind of microcosm for the wide-ranging mixed conifer forests across the West. Early efforts to restore fire at Crater Lake showed that older ponderosa pines were at risk of mortality via increases in bark beetle attacks. In attempts to understand how fire affects tree vulnerability, researchers have gained a new, albeit early, understanding of how pine resin response to prescribed fire may begin to help managers with forest restoration management goals and decisions. The research at Crater Lake offers a deeper, more detailed understanding of how to restore mixed-conifer forests to pre-fire suppression conditions.

Key findings include:

In the mixed-conifer forest at Crater Lake, fall burns were more effective at removing fuels and reducing wildfire risk than spring burns.

- In the old growth ponderosa pine stands at Crater Lake, entire age class cohorts of ponderosa pines were absent as a result of an era of fire suppression.

- Older ponderosa pines were at greater risk of mortality after fire treatments, largely as a result of their increased vulnerability to beetle attack.

- Resin response increased in burned trees as compared to control trees, but resin response was not correlated with beetle susceptibility.

Keywords: climate change; fire; insect pest; Northwest

Fend, J.F., J. Thornton, D. Rittenhouse, F. Pierson, C.R. Mickelson, and C.W. Slaughter. 2000. The science & politics of the 1996 Boise front fire – what have we learned from the 8th street fire rehabilitation. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 115-119. Water Resources Center Report No. 98.

Abstract: The 8th Street fire intensely burned 15,300 acres of highly erodible granitic soils immediately above Boise, the capitol city of Idaho in August 1996. Immediately downslope from burned watersheds were 12 schools, three hospitals, 65 child care facilities, 25 long-term care centers, and numerous public buildings, including the Federal building, City Hall, and the State Capitol. Agency managers, public officials, and local citizens expressed concern about the potential for devastating debris torrents and flash flooding; many remembered the flooding that occurred in 1959 in downtown Boise after a thunderstorm moved over a recently burned watershed just to the south of the 1996 8th Street Fire area.

This presentation discusses the process that was implemented locally to manage the recovery of the burned watershed while protecting the lives and properties at risk in town. “Best science” was utilized in preparing the recovery alternatives and actions considered. Public opinion concerning the recovery methods and the impacts to the aesthetics of the watershed landscape had to be dealt with through many hours of public meetings and workshops. The presentation shares lessons learned concerning collaboration on a multi-million dollar landscape rehabilitation plan covering 12 different agency jurisdictions. Followup monitoring and research continue to make this backyard outdoor laboratory a learning tool for the public and for science.

Keywords: case study; erosion; fire; Northwest; rehabilitation; urban; vegetation change; watershed; watershed management

Megahan, W.F. 2000. Cumulative watershed effects research needs for forested watersheds in the 21st century. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 61-68. Water Resources Center Report No. 98.

Abstract: Key cumulative effects research needs dealing with forest watersheds include natural variability in watershed characteristics and in downstream responses, sediment routing, and effects of disturbance on streamflow. Important information needs relating to natural variability include better descriptions of spatial variability and a broader perspective on temporal variability. Large regional differences in landslide types and streamflow rates are used to illustrate the need for studies of spatial variability. Justification for increased research on temporal variability is based on recent studies documenting long-term (thousands of years) sediment supplies from mountain watersheds in Idaho averaging about an order of magnitude greater than present day (tens of years) sediment data indicate. Additional studies in western Oregon show that mountain channels exhibit a natural succession from energy limited (aggraded) to supply limited (degraded) conditions, with accompanying changes in aquatic habitat conditions. Important components of sediment routing research include delivery of landslide material to channels, downslope sediment from roads to channels, and downstream routing of bedload sediments in channels. Evaluation of the effects of disturbance on streamflow should include the effects of forest management and wildfire on all levels of streamflow, and the accompanying erosional and sedimentation response of channels and aquatic ecosystems. Physically based, distributed models need to be developed and improved to predict the effects of disturbance on streamflow and channel changes.

Keywords: fire; flood; Northwest; sediment; streamflow; urban; vegetation change; watershed management

Megahan, W.F. and D.C. Molitor. 1975. Erosion effects of wildfire and logging in Idaho. In *Watershed Management Symposium*, August 1975, Logan, UT. American Society of Civil Engineers Irrigation and Drainage Division, New York, pp. 423-444.

Abstract: Erosion was evaluated on clearcut and unlogged study watersheds that had been subjected to wildfire. Soils found on the study watersheds exhibited the high erodibility characteristics of the granitic soils found in the Idaho batholith. Erosion data were collected by rill surveys, erosion pins, splash pans, and sediment collection troughs. Additional data to record vegetation responses and soil water repellency were collected using a grid sampling technique. Considerable erosion occurred as the results of overland flow and raindrop splash on the clearcut watershed. There was no evidence of erosion from overland flow on the unlogged watershed, but there was slight splash erosion. Canopy cover effects and litter production from the fire-killed trees were probably an important factor regulation erosion on the unlogged areas. Greater fuel loading and the consequent more intense burn on the clearcut area also probably had an effect by reducing soil surface protection, influencing vegetation responses, and increasing soil water repellency.

Keywords: erosion; fire; logging; Northwest; sediment; stormflow

Meyer, G.A., J.L. Pierce, S.H. Wood, and A.J.T. Jull. 2001. Fire, storms, and erosional events in the Idaho batholith. *Hydrological Processes* 15:3025-3038.

Abstract: In late December 1996, the South Fork Payette River basin in west-central Idaho experienced a prolonged storm that culminated on January 1, 1997, with intense rain on melting snow that triggered slide failures, producing debris flows and sediment-charged floods. Failures occurred in saturated, cohesionless, grussy colluvium derived from weathered Idaho batholith granitic rocks. Many failures along the South Fork Payette River originated in ponderosa pine forests burned in the 1989 stand-replacing Lowman fire. An example is the 0.49 square kilometers (km^2) Jughead Creek basin, where a single large colluvial failure produced almost 40% of the total volume eroded from the basin and generated a massive and rapid debris flow. Failures also occurred in steep, unburned, and unforested drainages such as Hopkins Creek. In this south-facing 0.58 km^2 basin, 15 colluvial hollows failed, but no single failure produced more

than 10% of the total eroded volume. Sediment transport in Hopkins Creek occurred by prolonged sediment-charged sheetflooding. Despite vegetation differences, sediment yields from the geomorphically similar Hopkins Creek (~42,000 megagrams per square kilometer, Mg km^2) and Jughead Creek (~44,000 Mg km^2) basins were quite similar. These 1997 erosion events are equivalent to several thousand years of sediment yield at low rates (2.7-30 Mg km^2 per year) measured by short-term sediment trapping and gauging in Idaho batholith watersheds. If similar large events were solely responsible for sediment export, recurrence intervals (RIs) of several hundred years would account for higher sediment yields averaged over ~104 year from Idaho batholith watersheds. Dating of small fire-induced sheetflooding events in an early Holocene tributary junction fan of Jughead Creek indicates that frequent small sedimentation events (RI ~ = 33-80 years) occurred between 7,400 and 6,600 calendar year before present, with an average yield not greatly exceeding 16 Mg km^2 per year. Compared with the Holocene average, erosion rates during that 800-year period were unusually low, suggesting that sediment yields have not been constant over time, and that climatic variations and related fire regime changes may exert a strong influence on the probability of major erosional events.

Keywords: climate change; erosion; fire; Northwest; sediment; storm; vegetation change; water yield

Mickelson, C.R. 2000. Partnerships, public information, emergency preparedness and projects. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 101-104. Water Resources Center Report No. 98.

Abstract: Immediately following a major fire in the foothills above Boise, Idaho, in August 1996, cooperative actions by local, state, and federal government agencies allowed for prompt pre-emergency planning and implementation of pre-emptive actions to cope with possible flooding and sediment deposition in Boise.

Keywords: case study; erosion; fire; management; Northwest; sediment; storm; vegetation change; water quantity; watershed

Pierson Jr., F.B., K.E. Spaeth, and D.H. Carlson. 2001. Fire effects on sediment and runoff in steep rangeland watersheds. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X-33-X-40. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf.

Abstract: Fire is a natural component of the Intermountain sagebrush-steppe ecosystem with a return period of 25 to 100 years, depending on community type and natural fuel load and distribution. However, fuel and land management activities in the past century have placed wildland values such as soil and water quality at greater risk from wildfire. Increased soil erosion over natural levels following wildfire can lead to the loss of soil productivity. Additionally, higher runoff rates from severely burned landscapes can lead to flooding, sedimentation, and increased risk to human life and property. This increased risk of runoff and erosion following wildfire continues to generate concern at the expanding urban-wildland interface throughout the western United States.

While the hydrological consequences of fire have been widely examined in forest ecosystems, few studies have examined wildfire impacts on rangeland hydrology and erosion. Most of these studies have shown an increase in runoff and erosion rates the first year following fire, with recovery to pre-fire rates generally within five years. Timing and extent of recovery is highly dependent on slope and vegetation type. Many rangeland plant communities have naturally occurring hydrophobicity, but litter and vegetative cover protect the soil and enhance infiltration. Fire removes this protective covering, exposing the soil to erosion by raindrop impact and overland flow. Fire can also vaporize some of the organic compounds on the soil surface and distill the rest downwards, creating concentrated hydrophobic layers within the upper soil. The degree and longevity of hydrophobicity is dependent on compounds present and intensity and duration of fire. Fire can also reduce the organic matter content in the upper layers, thus reducing infiltration.

Major unknowns associated with rangeland wildfire are effects on vegetation and soil conditions affecting hydrologic processes, including infiltration, surface runoff, erosion, sediment production and transport, flooding, and the effectiveness of mitigation practices. The U.S. Department of Agriculture Agricultural Research Service Northwest Watershed Research Center (NWRC) has been investigating the impact of fire on rangeland hydrology and erosion in the mountains above Boise, Idaho (Boise Front) and in the Pine Forest Range near Denio, Nevada. The objective of the NWRC investigations are to quantify fire impacts on infiltration capacity, runoff, and erosion following fire; gain insight into the processes involved; and determine how long the fire effects persist.

Keywords: erosion; fire; grazing; Northwest; sediment; vegetation change; water quality; water quantity; watershed

Pierson, F.B. 2000. Hydrologic impacts of fire on the Boise front. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 105-113. Water Resources Center Report No. 98.

Abstract: The Eighth Street fire had a significant impact on the infiltration capacity and soil erodibility across the Boise Front. South-facing slopes had the lowest infiltration and showed the highest rates of erosion following the fire. Two years following the fire, ground cover had not yet sufficiently recovered to fully protect either the north or south slopes from increased runoff and accelerated erosion. Presented results are consistent with observations made following the September 1997, thunderstorm where the south-facing slopes had the highest concentration of rills and suffered significant soil loss.

Keywords: case study; erosion; fire; Northwest; runoff; sediment; storm; vegetation change; watershed

Potts, D.F., D.L. Peterson, and H.R. Zuuring. 1989. Estimating Postfire Water Production in the Pacific Northwest. Research Paper PSW-197. Pacific Southwest Forest and Range Experiment Station, USDA Forest Service. Berkeley, CA.

Abstract: Two hydrologic models were adapted to estimate postfire changes in water yield in Pacific Northwest watersheds. The Water Resources Evaluation of Non-Point Silvicultural Sources (WRENSS) version of the simulation model PROSPER is used for hydrologic regimes dominated by rainfall; it calculates water available for streamflow on the basis of seasonal precipitation and leaf area index. The WRENSS version of the simulation model WATBAL is used for hydrologic regimes dominated by snowfall; it calculates water available for streamflow based on seasonal precipitation, energy aspect, and cover density. The PROSPER and WATBAL models estimated large postfire increases in water available for streamflow only for fires that have removed more than 50% of the leaf area cover density, respectively. Guidelines for selecting appropriate models, and tables and figures for calculating postfire water yield are presented. This simulation approach should be useful for estimating long-term effects of fire on water production within the framework of land management planning.

Keywords: fire; Northwest; streamflow; water yield; watershed management

Robichaud, P.R. 2005. Measurement of post-fire hillslope erosion to evaluate and model rehabilitation treatment effectiveness and recovery. *International Journal of Wildland Fire* 14:475-485.

Abstract: The increasing size and severity of wildfires in the western United States has caused a corresponding increase in post-fire emergency erosion control activities. Hillslope treatments, such as broadcast seeding, mulching and installed barriers, are applied to reduce runoff and erosion, as well as downslope sedimentation. However, there are few data to determine if these post-fire treatments are practical and effective. Direct measurement of hillslope erosion, particularly in the remote settings where wildfires occur, is time consuming and costly. Rainfall simulation, sediment fences, and paired catchment studies have been adapted for measuring post-fire erosion in the mountainous forest regions of the western United States. The use of paired catchments to measure hillslope erosion and evaluate treatment effectiveness is illustrated by an ongoing experiment of six contour-felled log erosion barrier research sites. Deciding which type of treatments to use, as well as the locations and timing of application, requires treatment cost and effectiveness to be weighed against potential damage from unmitigated erosion. To assist in this process, a web-based Erosion Risk Management Tool has been developed that incorporates variability in rainfall, burn severity and soil properties, as well as treatment options, to provide probabilistic erosion estimates for four years after a fire.

Keywords: development; erosion; fire; hillslope treatment; management; Northwest; runoff; sediment; sediment control; Southwest; United States

Robichaud, P.R. and W.J. Elliot. 2006. Protection from erosion following wildfire. In *Presented at the 2006 ASABE Annual International Meeting*, 9-12 July, 2006, Portland, OR. American Society of Agricultural and Biological Engineers. Paper No. 068009.

Abstract: Erosion in the first year after a wildfire can be up to three orders of magnitude greater than the erosion from undisturbed forests. To mitigate potential postfire erosion, various erosion control treatments are applied on highly erodible areas with downstream resources in need of protection. Because postfire erosion rates generally decline by an order of magnitude for each year of recovery, effective erosion mitigation treatments are most needed during the first year or two after a fire. Postfire treatments include broadcast seeding, scarification and trenching, physical erosion barriers such as contour-felled logs and straw wattles, and mulching with wheat straw, wood straw, and hydromulch. This paper summarizes data from more than seven years of studies to evaluate the effectiveness of postfire erosion mitigation treatments at the hillslope and small watershed-scale in the western United States. Results suggest that some mitigation treatments may help reduce erosion for some, but not all, rainfall events. Generally, mulching is more effective than seeding, scarifying, or erosion barriers. For small rainfall events, reduction in first year erosion rates have been measured for engineered wood straw and straw mulch (60 to 80%), contour-felled log erosion barriers (50 to 70%), and hydromulch (19%). Grass seeding treatments have little effect on first year erosion reduction. For intense rain events (I10 greater than 40 millimeters per hour) there was little difference between treated and nontreated areas.

Keywords: erosion; fire; Northwest; sediment control; Southwest

Robichaud, P.R., F.B. Pierson, W.J. Elliot, and P.M. Wohlgemuth. 2005. Risk Assessment of Fuel Management Practices on Hillslope Erosion Processes (Phase I) 98-1-4-12. Final Report. July 1.

Abstract: After wildfires, the use of rapid response field protocols allowed measurements of postfire soil infiltration, soil erodibility, and hillslope erosion rates, while long-term measurements provided data on postfire rehabilitation treatment effectiveness and general recovery rates. These data were used to expand and validate the current suite of web-based erosion prediction tools, and to develop a conceptually different erosion risk management tool, ERMiT.

ERMiT's probabilistic analysis not only accounts for the variability in climate, soil properties, and spatial burn severity at the hillslope scale, but also provides the probabilistic output needed for postfire risk analysis. The custom interface is designed for use by hydrologists and soil scientists and is available to the public, along with other erosion prediction tools developed by the authors, on the Internet.

Keywords: erosion; fire; management; Northwest; rehabilitation; sediment control; Southwest

Ryan, S.E., M.K. Dixon, K.A. Dwire, and W.W. Emmett. 2003. Historical and on-going hydrologic and sediment transport research at Little Granite Creek near Bondurant, Wyoming. In *First Interagency Conference on Research in the Watersheds*, October 27-30, 2003. Renard, K.G., McElroy, S.A., Gburek, W.J., Canfield, H.E., and Scott, R.L.(eds.). USDA Agricultural Research Service pp. 657-662.

Abstract: Measurements of sediment flux and flow were made during the course of 13 runoff seasons in a small watershed near Bondurant, Wyoming. Begun in 1982 through the combined efforts of the U.S. Geological Survey and the U.S. Forest Service (USFS), the database from Little Granite Creek represents one of the most comprehensive sources of information on stream transport processes available for an individual site. In August 2000, a wildfire burned portions of the watershed, creating an opportunity to monitor the impacts of fire on stream processes and water quality. Scientists from the USFS, Rocky Mountain Research Station, initiated studies in 2001 to assess the magnitude of increased runoff and sedimentation generated by spring snowmelt and summer thunderstorms following wildfire. Additional work was initiated in 2002 on the post-fire dynamics of organic matter (i.e., dissolved, fine, and coarse), the status of aquatic macroinvertebrates and fish, and the reestablishment of vegetation in the riparian corridor. In this paper, the authors describe the monitoring effort in the Little Granite watershed and present preliminary results from the first year after burning. Such data are useful for planning future Burned Area Emergency Rehabilitation efforts, validating erosion models (such as Water Erosion Protection Project), and evaluating long-term sensitivity of aquatic systems to wildfire.

Keywords: fire; Northwest; sedimentation; watershed

Schultz, S., R. Lincoln, J. Cauhorn, and C. Montagne. 1992. Quantification of erosion from a fire and subsequent rainfall event in the northern Rocky Mountains. In *Proceedings of the Montana Academy of Sciences: 52nd Annual Meeting*, March 27-28, 1992, Montana State University. pp. 143-151.

Abstract: Soil erosion events occurred after a wildfire and rainstorm in the Gates of the Mountains Wilderness area north of Helena, Montana, in August 1984. Erosion of hydrophobic soils occurred on about 1,500 hectares (ha) (3,800 acres, ac) of the 11,000 ha (27,000 ac) fire. Measurements made after the fire at three eroded sites document topsoil losses averaging 871 megagrams per hectare (Mg ha^{-1}) to 389 tons per acre ($t.a.^{-1}$) with values ranging from 280 Mg ha^{-1} (130 $t.a.^{-1}$) to 3,500 Mg ha^{-1} (1,600 $t.a.^{-1}$). Erosion events such as these may be a dominant geomorphological factor in this area.

Erosion following wildfire has long been a major concern of forest managers. Sediment yields help determine effects of fires on drainages. But there are few areas from which fire regime and related sediment yield data are available, which follow. A study compared sediment yield rates following fire to “baseflow” sediment rates under well-established vegetation, and estimated rates for southern California the first year following fire to be about 30 times the “baseflow” rate. Estimates for steep, unstable terrain in western Oregon indicate that accelerated erosion

following wildfire contributes 25 to 30% of long-term total sediment yield in small, steep watersheds. Another study showed increased erosion rates in the San Gabriel Mountains following fire on a burned watershed to be 28 times the average annual rate. Sediment records and charcoal deposition in a small northeastern Minnesota lake showed a 35% increase in varve thickness for about 15 years following fire. Another study estimated that almost 70% of long-term sediment yield occurs in the first year after a fire.

While increased erosion following fire has been verified by many studies, few references are available that have directly measured the amount of soil lost from steep slopes after fire. Annual soil losses of up to 253 Mg ha^{-1} (113 $t.a.^{-1}$) on woodland plots in the Sierra Nevada foothills were measured. In the first year following a 1942 fire in central Arizona, soil losses of 72 to 370 Mg ha^{-1} (32 to 165 $t.a.^{-1}$) were noted.

Recent research recommends prioritizing studies that analyze interrelationships between fire and geomorphology and the quantitative relationships between fire and soil. An opportunity to do this occurred in 1984. A forest fire occurred in the Beaver Creek drainage and Gates of the Mountains Wilderness area between August 27 and 30. The fire area is located in the Big Belt Range of the Northern Rocky Mountains near Helena, Montana. This fire, which became known as the North Hills fire, burned 11,000 ha (27,000 ac) before cooler temperatures and light rain stopped further advance. On August 31, 32.5 millimeters (1.28 inches) of precipitation fell on the burned area within 20 minutes (Forest Service weather gauge on hogback Mountain, 12 miles northwest of the fire area). This precipitation event initiated sheet, rill, and gully erosion. Side drainages were scoured by sediment-laden runoff. As flows reached main drainages, debris torrents formed, transporting mature trees and large boulders, and causing debris fans to form at mouths of several drainages. Stream bottoms were covered with a muddy mixture of ash and calcareous soil that dried into a cement-like consistency when the waters receded. The purpose of the study was to quantify the erosion that took place.

Keywords: erosion; fire; Northwest; sediment

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940-943.

Abstract: Western U.S. forest wildfire activity is widely thought to have increased in recent decades, yet neither the extent of recent changes nor the degree to which climate may be driving regional changes in wildfire has been systematically documented. Much of the public and scientific discussion of changes in western U.S. wildfire has focused instead on the effects of 19th and 20th century land-use history. This compilation of a comprehensive database of large wildfires in the western U.S. forests since 1970 is compared with hydroclimatic and land-surface data. Results show large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.

Keywords: climate change; fire; Northwest; Southwest

Zelt, R.B. 2001. Channel characteristics and large organic debris in adjacent burned and unburned watersheds a decade after wildfire. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X-57-X-66. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf.

Abstract: Wildfire can affect not only vegetation communities but also hydrologic and geomorphic processes. Its geomorphic importance relates to the sensitivity of landscapes to fire-caused changes in vegetation and soils, and consequent changes in hydrology. Increased overland flow and soil erosion may result when vegetation is removed. Reduced transpiration increases soil moisture levels, and increased exposure to sun and wind can alter the magnitude and timing of snowmelt runoff. Changes in burned watersheds impact stream channels through altered hydrology, sediment inputs, or riparian disruption that produce effects on channel erosion, sediment storage and transport, and aquatic life. Debris torrents may dramatically alter stream channels and sediment loads. Many fire-caused changes have immediate and short-term effects. Delayed or long-term effects are due to such processes as root decay of fire-killed trees, loading of stream channels with large organic debris (LOD), or fluvial adjustments of channels to increased runoff. Current understanding of fire effects on channel characteristics and LOD is limited by the large variability in effects due to the number of affected processes and controls. Due to this variability, the magnitude and duration of fire effects cannot be predicted reliably.

The 1988 wildfire season climaxed in early September as the Clover-Mist Fire burned beyond the eastern boundary of Yellowstone National Park and consumed most of the vegetation in Jones Creek watershed, a headwater drainage of the North Fork Shoshone River in Shoshone National Forest. However, less than 8% of Crow Creek watershed was burned, despite being adjacent to Jones Creek. The wilderness watersheds of Crow and Jones creeks provide a rare opportunity to compare fluvial processes in a severely burned watershed with those in an undisturbed adjacent watershed having very similar physical characteristics, without the confounding influences of activities such as timber harvest, roads, or mining.

This paper reports preliminary results from a case study of channel conditions during the postfire recovery of Jones Creek, in contrast with Crow Creek. The study focuses on channel characteristics (including width, substrate, and pool characteristics) and differences in LOD loading and characteristics that may be attributed to severe wildfire disturbance. However, observed differences between the streams cannot establish fire as the causal agent because no pre-fire data exist. Specific research hypotheses include (1) Jones Creek is wider and has more fine sediment stored within its channel than Crow Creek; and (2) following a decade of presumably accelerated input of burned LOD, debris loading is larger in Jones Creek than in Crow Creek.

Keywords: fire; Northwest; sediment; vegetation change; water quality; water quantity

Southwest

Agee, J.K. 1993. *Fire Ecology of Pacific Northwest Forests.* Island Press, Washington, DC.

Abstract: This book began as a source book for natural area managers interested in restoring or maintaining fire in the natural areas of the Pacific Northwest. It grew to encompass a broader charge: to provide a natural baseline that wildland managers, or those interested in wildland management, could use in understanding the effects of natural or altered fire regimes in the western United States. This ecological perspective about fire is not a prescriptive guide, since prescriptions must include management objectives. This management emphasis is on the role of fire in natural areas, but such information is also useful in fire applications for other management purposes.

The structure of most virgin forests in the American West today reflects a past disturbance history that includes fire. Although media reports of the 1988 Yellowstone fires treated the scene as an ecological catastrophe, these forests were born of fire in the 1700s and are now being reborn in the 1990s. Knowledge of the natural and often inevitable disturbances likely to affect forests, including fire, is essential to any forest management plan, whether the objective is timber production, wildlife conservation, or wilderness management. Creating desirable forest stand structures in the future for these objectives may not require simulation of past fire activity. Such efforts, however, will be successful only if we understand the processes responsible for desirable structures we see today before undertaking future stand manipulation.

Keywords: fire; Northwest; Southwest; watershed management

Alexander, B. 2004. Forest fire impacts on drinking water supplies. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: A major fire in a drinking water watershed can impact water quantity and quality. Sediments and other contaminants such as heavy metals and nutrients can be significantly elevated in rivers and streams following a catastrophic fire, making it difficult for utilities to effectively provide safe, clean drinking water to their customers. The Bobcat fire in the Loveland, Colorado watershed in 2000 is an example for utilities serving a large urban population. The biggest threat to water quality in the West is from fire-related contaminants, not industrial chemicals or hazardous waste spills. The U.S. Environmental Protection Agency drinking water quality guidelines are not always consistent with appropriate forest management practices for managing forest fires and maintaining forest health. In order to prepare for and prevent severe impacts to drinking water resulting from forest fires, watershed managers need to employ best management practices to manage both issues simultaneously.

Keywords: Bobcat Fire; case study; fire; prevention; response strategy; Southwest; water quality; water quantity; watershed management

Baker Jr., M.B. 1990. Hydrologic and water quality effects of fire. In *Effects of Fire Management of Southwestern Natural Resources: Proceedings of the Symposium*, November 15-17, 1988, Tucson, AZ. Krammes, J.S.(ed.). pp. 31-42. USDA Forest Service General Technical Report RM-191.

Abstract: Prescribed burns usually have minimal hydrologic impacts on watersheds because the surface vegetation, litter, and forest floor are only partially burned. Wildfire can, however, have a pronounced effect on basic hydrologic processes, leading to increased sensitivity of the site to eroding forces and to reduced land stability. Fire often causes increased overland flow and greater peak and total discharge, factors responsible for transporting sediment from the site. Fire also causes rapid mineralization and mobilization of nutrients. Because of the natural variability found in forest and range environments in the Southwest, the wide range of impacts that land managers face in this area, is quite broad.

Keywords: erosion; fire; mudslide; Southwest; streamflow; water quality; water quantity; water yield

Benavides-Solorio, J.D.D. 2003. Post-Fire Runoff and Erosion at the Plot and Hillslope Scale, Colorado Front Range. Ph.D. Dissertation, Colorado State University, Fort Collins.

Abstract: Forest ecosystems in the Colorado Front Range are at very high risk for large increases in runoff and erosion after wildfires. This research was proposed because there is very limited data on post-fire runoff and erosion rates and the factors that control these rates. This research focused on two different scales: (1) runoff and erosion rates from small plots subjected to high-intensity artificial rainfall, and (2) sediment production rates at the hillslope scale from prescribed and wild fires of different ages. The results will help predict the effect of future fires and design more effective rehabilitation treatments.

On the small plots, 70-85 millimeter of mean rainfall was applied in 60 minutes, and runoff/rainfall ratios generally exceeded 45%. The high rainfall rate meant that runoff/rainfall ratios were only slightly higher from plots burned at high severity than from low severity/unburned plots. Mean runoff/rainfall ratios in recently-burned, high-severity plots decreased by 15-30% from the first to second year after burning, but were still high relative to runoff rates from simulations on the 1994 Hourglass wildfire. Post-fire soil water repellency was the main control on runoff/rainfall ratios.

Mean sediment yields from rainfall simulations on high severity sites in the Bobcat wildfire were 1,280 grams per square meter (g m^{-2}) in 2000 and 1,230 g m^{-2} in 2001. Sediment yields from high severity sites in the Lower Flowers prescribed fire decreased from 850 g m^{-2} in 2000 to 350 g m^{-2} in 2001. High severity plots yielded 16-33 times more sediment than low severity and unburned plots. Simulations on high severity plots in the 1994 Hourglass wildfire yielded only slightly more sediment than unburned plots, indicating that recovery was nearly complete after six years. Univariate and multivariate analyses showed that percent bare soil was the dominant

control on sediment yields, although percent silt and the runoff/rainfall ratio were significant factors for high severity sites.

At the hillslope scale, sediment production rates exceeded 10 megagrams per hectare per year (Mg ha^{-1} yr^{-1}) from sites burned at high severity in a recent wildfire, and only 0.1-4 Mg ha^{-1} yr^{-1} from high severity sites in recent prescribed fires. High severity sites in the Bobcat wildfire produced 75 times more sediment than moderate severity sites. Summer rainstorms generated at least 73% of the sediment at all sites. Sediment production rates from swales or small drainages were 2-3 times higher than planar hillslopes.

Keywords: erosion; fire; sediment; Southwest

Bolin, S.B. and T.J. Ward. 1987. Recovery of a New Mexico drainage basin from a forest fire. In *Forest Hydrology and Watershed Management, Proceedings of the Vancouver Symposium* Swanson, R.H., Bernier, P.Y., and Woodard, P.D. (eds.). pp. 191-198. IAHS Publication No. 167.

Abstract: New Mexico is a semiarid state with essentially all surface water originating as runoff from forested drainage basins. When these basins are disturbed by natural or man-made events, a vital part of the state's water resource is affected. In 1977, a fire burned approximately 60% of a 45.33 square kilometers forested basin in northern New Mexico. Following the fire, water discharge was high and erratic. Peak flow was 100 times greater than the pre-fire levels. Suspended sediment concentrations immediately following the fire were as high as 98,800 milligrams per liter (mg/L). Two years after the fire, peak sediment concentrations dropped to less than 600 mg/L. In the first two years after the fire, an estimated 23,290 tons of sediment were removed from the basin compared to 10 tons over the next two years. Analyses showed that the sediment yield began as a transport-limited phenomena, but eventually returned to a more typical supply-limited situation.

Keywords: fire; sediment; Southwest; water quality

Buehrer, J. 2007. Vast tinderbox threatens Colorado's watersheds. *Mainstream* 51(3):1,7.

Abstract: Seven Front Range Colorado water providers met with representatives of the Colorado State Forest Service, the U.S. Forest Service, the U.S. Geological Survey, the National Park Service, other related entities, American Water Works Association, and Awwa Research Foundation at an August 15 workshop hosted by AWWA in Denver.

At the half-day meeting on protecting Front Range forest watersheds from high-severity wildfires, forestry experts and water utility managers with first-hands experience spoke about the link between forest fires and drinking water quality.

Keywords: erosion; fire; sediment; Southwest; water quality

Caldwell, C.A., C.M. Canavan, and N.S. Bloom. 2000. Potential effects of forest fire and storm flow on total mercury and methylmercury in sediments of an arid-lands reservoir. *Science of the Total Environment* 260:125-133.

Abstract: A study was conducted from July 1995 to June 1996 to examine the spatial and temporal changes of mercury concentrations in sediments of an arid-lands reservoir. Prior to the first sample collection in July, a forest fire burned 2,930 hectares (ha) of mixed conifer and ponderosa pine in the watershed of Caballo Reservoir in south-central New Mexico. The fire was eventually extinguished by summer rains and storm runoff resulting in the mobilization and transport of charred vegetative material into an intermittent tributary (Palomas Creek) that drains the watershed into Caballo Reservoir. Concentrations of total mercury (THg), monomethylmercury (MMHg), and total organic carbon in surficial sediments revealed fire, followed by storm runoff, enhanced the transport of mercury and organic matter to the reservoir. Concentrations of THg in sediments increased from 7.5 nanograms per gram (ng/g) in July to 46.1 ng/g by November 1995 at one site (Palomas) nearest the outflow of Palomas Creek. No other spatial or temporal trends were observed for THg at other sites throughout the remainder of the study. Concentrations of MMHg in sediments at the Palomas site increased from 0.428 ng/g in July to 12.46 ng/g by October 1995 compared to concentrations in sediments at the remaining sites which ranged from 0.11 to 1.50 ng/g throughout the study. The ratio of MMHg to THg (a gross index of methylation activity) was greatest in sediments from the Palomas site (5.4-33.8%) that remained elevated throughout the study. Fire and subsequent late-summer rains may have had a twofold effect on mercury concentrations in Caballo Reservoir. The storm-driven runoff following the forest fire carried mercury complexed to organic matter which resulted in elevated levels of mercury as well as providing a carbon source for microbial methylation processes in sediment.

Keywords: fire; mercury; New Mexico; organic carbon; runoff; sediment; Southwest; storm; water quality; water quantity; watershed

Campbell, R.E., M.B. Baker Jr., P.F. Folliott, R.R. Larson, and C.C. Avery. 1977. Wildfire Effects on a Ponderosa Pine Ecosystem: An Arizona Case Study. Research Paper RM-191. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Abstract: A wildfire of variable severity swept through 717 acres (290 hectares) of ponderosa pine forest in north-central Arizona in May 1972. Where the fire was intense it killed 90% of the small trees and 50% of the sawtimber, burned 2.6 inches (6.5 centimeters) of forest floor to the mineral soil, and induced a water-repellent layer in the sandier soils. The reduced infiltration rates, which greatly increased water yield from severely burned areas during unusually heavy fall rains, caused soils to erode and removed some nutrients which had been mineralized by the fire. Water yields have declined each year toward prefire levels. The soluble nutrients that leached into the surface soil during fall rains were subsequently removed by a record snowmelt. Successional changes provided up to 1,650 pounds per acre (1,850 kilograms per hectare) of herbage production compared to about 515 pounds per acre (577 kilograms per hectare) in unburned forest.

Keywords: erosion; fire; sediment; Southwest; streamflow; water quality

Colorado State Forest Service. 2007. About Wildfire. Available: http://csfs.colostate.edu/wildfire.htm.

Abstract: Fire ecology is the study of wildland fires and their relationships to living and non-living things in the environment. Fire is a vital part of a healthy forest, especially in the West. Many species, such as lodgepole pine, are partially dependent on fire to spread their seeds. Fire was used by the Native Americans to clear land, expose enemies, and hunt game. By the 1900s, however, damages to personal property, farmland, livestock, wildlife, and threats to human life resulted in Americans fearing and suppressing wildfire, whether natural or human caused. The Colorado State Forest Service report on wildfire describes the important factors related to fire and fire management including fuel; current management; the wildland urban interface; wildfire protection and suppression; the history of wildland fire policy; historical wildfire statistics in Colorado; home, forest, and property protection; prescribed burns; and post-fire rehabilitation and restoration.

Keywords: fire; prevention; response strategy; Southwest

Crouch, R.L., H.J. Timmenga, T.R. Barber, and P.C. Fuchsman. 2006. Post-fire surface water quality: comparison of fire retardant versus wildfire-related effects. *Chemosphere* 62:874-889.

Abstract: An understanding of the environmental effects of the use of wildland fire retardant is needed to provide informed decision-making regarding forest management. The authors compiled data from all post-fire surface water monitoring programs where the fire retardant constituents ammonia, phosphorus, and cyanide were measured, and data were available in the public domain. For streams near four major wildfires, this study evaluated whether these chemicals originated primarily from fire or from retardant use. Measured concentrations in streams was compared where chemical wildland fire retardant was applied with concentrations in streams draining areas where retardant was not used. Correlations with calcium provided an additional line of evidence, because calcium concentrations in ash are much higher than in retardant. Ammonia, phosphorus, and total cyanide were found in streams in burned areas where retardant was not used, at concentrations similar to those found in areas where retardant was applied. Concentrations of weak acid dissociable cyanide were generally not detected or very low, whether or not wildland fire retardant was used in the watershed. These results indicate that the application of wildland fire retardant had minimal effects on proximate surface water quality. Cyanide concentrations in post-fire stormwater runoff were not affected by the presence of ferrocyanide in the retardant formulas and were due to pyrogenic sources.

Keywords: Canada; fire; fire retardant; Southwest; water quality

Dale, D. 2006. Wildfires and erosion: control from the air. *American Reconstruction* (October):A10-A14.

Abstract: The year 2002 was a bad one for wildfires. Over 7 million acres were burned, at a cost of over a billion dollars to fight them. What about the after effects? Apart from the environmental and property damage, one of the most feared aspects of a wildfire is the erosion on the denuded landscape. Nowhere was that more threatening than at the site of the Hayman Fire in heavily sloped Colorado. This is the story of one company's participation in controlling erosion after the Hayman fire. By using special slurry mixes and airmailing them via helicopter, HydroGrass Technologies, Inc. was able to help prevent much damage to the watershed. Not only that, the company learned a lot about using erosion control products such as polyacrylamides in its bonding mixes.

Keywords: case study; erosion; fire; prevention; response strategy; Southwest; watershed management

DeBano, L.F., P.F. Folliott, and M.B. Baker Jr. 1996. Fire severity effects on water resources. In *Effects of Fire on Madrean Province Ecosystems: A Symposium Proceedings*. P.F. Folliott, L.F. DeBano, M.B. Baker Jr., G.J. Gottfried, G. Solis-Garza, C.B. Edminster, D.G. Neary, L.S. Allen, and R.H. Hamre (eds.), pp. 77-84. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. Gen. Tech. Rep. RM-GTR-289.

Abstract: Fire plays an important role in southwestern ecosystems. The use of fire, however, must be carefully planned and implemented to gain the desired response without damaging the water resources. Recognizing the differences between fire effects during prescribed burns and wildfires is necessary to adequately assess fire effects. This paper summarizes the basic hydrologic processes affected by fire, offers a conceptual model for relating watershed responses to fire severity, and presents generalized data for selected hydrologic responses of a ponderosa pine forest to fire in the Madrean Archipelago Province.

Keywords: fire; sediment; Southwest; streamflow; watershed

Ekarius, C. 2004. Forests, fires and watersheds: Stories and lessons learned on the land – the Hayman experience. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: This presentation details some of the actions taken after the Hayman Fire and the lessons learned that can help improve response strategies for the future. The lessons identified were dedication to *real* rehabilitation after fires; engaging local partners and ensuring that funding, technical, and moral support are provided; the need to translate science so that nonacademic, knowledgeable lay people such as managers and resource teams can use it effectively.

Keywords: case study; fire; Hayman fire; response actions; Southwest

Fornwalt, P. 2004. Ponderosa pine forests: Lessons from the ashes. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: This presentation is primarily a visual analysis of the historic and modern forest structure around Cheesman Reservoir. The goal is to define restoration activities that will reduce the severity of fires and return the local ecosystems to a structure and function similar to that which existed before fire suppression. The author identified the following restoration activities: restore landscape diversity by creating openings (15-25% or more of area); sharply reduce forest density, especially the smaller trees; reduce the amount of Douglas fir; retain and restore old growth; use prescribed fire to limit new growth.

Keywords: case study; Cheesman Reservoir; fire; Hayman fire; Southwest; vegetation change

Graham, R. 2004. Hayman Fire case study: Summary. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: In 2002 much of the Front Range of the Rocky Mountains in Colorado was rich in dry vegetation as a result of fire exclusion and the droughty conditions that prevailed in recent years. These dry and heavy fuel loadings were continuous along the South Platte River corridor located between Denver and Colorado Springs on the Front Range. These topographic and fuel conditions combined with a dry and windy weather system centered over eastern Washington to produce ideal burning conditions resulting in a wildfire run in 1 day of over 60,000 acres and finally impacting over 138 acres. The Hayman Fire case study, involving more than 60 scientists and professionals from throughout the United States, examined how the fire behaved, the effects of fuel treatments on burn severity, the emissions produced, the ecological (e.g., soil, vegetation, animals) effects, the home destruction, postfire rehabilitation activities, and the social and economic issues surrounding the Hayman Fire. The Hayman Fire case study revealed much about wildfires and their interactions with both the social and natural environments. As the largest fire in Colorado history it had a profound impacts both locally and nationally. The findings of this study will inform both private and public decisions on the management of natural resources and how individuals, communities, and organizations can prepare for wildfire events.

Keywords: case study; fire; Hayman fire; response strategy; Southwest

Hastings, B.K., F.M. Smith, and B.F. Jacobs. 2003. Rapidly eroding pinon-juniper woodlands in New Mexico: response to slash treatment. *Journal of Environmental Quality* 32:1290-1298.

Abstract: The pinion (*Pinus edulis* Engle.)-juniper [*Juniperus monosperma* (Engelm.) Sarg.] woodlands of Bandelier National Monument are experiencing accelerated erosion. Earlier studies suggest that causes of these rapidly eroding woodlands are related to an unprecedented rapid transition of ponderosa pine (*Pinus ponderosa* C. Lawson) savanna to pinion-juniper woodlands as a result of cumulative historical effects of overgrazing, fire suppression, and severe drought. To study the effectiveness of slash treatment in reducing accelerated erosion, the authors used

sediment check dams to quantify sediment yield from 12 paired microwatersheds (300-1,100 square meters) within an existing paired watershed study. Six of the 12 microwatersheds were located in a 41-hectare (ha) (treatment) watershed with scattered slash treatment, whereas six microwatersheds were located in an adjacent 35-ha untreated (control) watershed. The primary purpose of this research was to quantify the rates of sediment yield between the treated and control microwatersheds. Sediment yield was measured from 15 individual storms during the months of June-September (2000 and 2001). In response to slash treatment, mean seasonal sediment yield for 2000 equaled 2.99 megagrams per hectare (Mg/ha)in the control vs. 0.03 Mg/ha in the treatment, and 2.07 Mg/ha in the control vs. 0.07 Mg/ha in the treatment in 2001. The practice of slash treatment demonstrates efficacy in reducing erosion in degraded pinion-juniper woodlands by encouraging herbaceous recovery. The data show that slash treatment increases total ground cover (slash and herbaceous growth) beyond a potential erosion threshold. Restored pinion-juniper woodlands, as the result of slash treatment, provide a forest structure similar to pre-grazing and pre-fire suppression conditions and decreases catastrophic fire hazard.

Keywords: erosion; fire; management; Southwest; vegetation change

Hendricks, B.A. and J.M. Johnson. 1944. Effects of fire on steep mountain slopes in central Arizona. *Journal of Forestry* 42(8):568-571.

Abstract: Southwestern mountain slopes have high value as multiple-use lands. The immediate and damaging effects of a forest fire on the Sierra Ancha Experimental Forest demonstrate the need for preserving the plant cover on slopes of this character in order to protect soil resources and watershed values. Heavy soil-erosion losses were recorded on the burned area during the summer period immediately following the fire, although no outstanding or exceptional rains occurred.

Keywords: erosion; fire; Southwest; water quality

Howe, E. and W.L. Baker. 2003. Landscape heterogeneity and disturbance interactions in a subalpine watershed in northern Colorado, USA. *Annals of the Association of American Geographers* 93(4):797-813.

Abstract: Three major disturbances affect subalpine forests in the Rocky Mountains: blowdown, insect outbreaks, and fire. These disturbances may influence one another temporally and spatially, creating a mosaic of disturbance patches. In 1997, a severe windstorm blew down trees on over 10,000 hectares of subalpine forest in northern Colorado. This study attempted to determine if previous disturbances influenced the spatial pattern of blowdown in a representative part of the blowdown in the Middle Fork Elk River watershed. Dendrochronological evidence and a geographic information system were used to reconstruct the disturbance history, and the relationship between disturbance history (i.e., patch age) and the 1997 blowdown were examined. The fire regime varies temporally and spatially, with an area-weighted mean fire interval/fire rotation of 108 to 195 years. Stand-replacing fires appear to have had the most impact on the fire regime, but evidence of nonstand-replacing fires was also found. South-facing, lower-elevation slopes were the settings most likely to burn. Low severity spruce-beetle disturbance found in the mid-1700s and mid- to late 1800s is possibly related to regional outbreaks. Sheep-grazing and fire suppression may have influenced tree-regeneration and fire-frequency patterns. Each disturbance event occurred with varying severity across the landscape, influenced, in part, by the patterns of severity of previous disturbances. Patch age contributed to the pattern of the 1997 blowdown, but the relationship is complicated. The vegetation mosaic influenced spatial patterns of blowdown, resulting in new complexity and maintaining landscape heterogeneity.

Keywords: blowdown; fire; insect pest; Southwest; vegetation change

Kent, B., K. Gebert, S. McCaffrey, W. Martin, D. Calkin, E. Schuster, I. Martin, H.W. Bender, G. Alward, Y. Kumagai, P.J. Cohn, M. Carroll, D. Williams, and C. Ekarius. 2003. Social and economic issues of the Hayman Fire. In *Hayman Fire Case Study*. R.T. Graham (ed.) USDA Forest Service Rocky Mountain Research Station, Fort Collins, CO, pp. 315-396. USDA Forest Service General Technical Report RMRS-GTR-114.

Abstract: On June 26, 2002, U.S. Representative Mark Udall wrote the U.S. Forest Service Chief, requesting that the Forest Service conduct an analysis of the Hayman Fire. In response to the Congressman's letter, five teams were established in August 2002 to analyze various aspects of the Hayman Fire experience. This report describes the Hayman Fire analysis work conducted by the social/economic team and presents their findings.

Keywords: case study; economic consequences; fire; Hayman fire; social consequences; Southwest

Kilfore, B.M. and D. Taylor. 1979. Fire history of a sequoia-mixed conifer forest. *Ecology* 60(1):129-142.

Abstract: Data on the years in which fires burned, on fire frequency, and on the intensity and areal extent of fires were gathered from 935 scars on 220 stumps of mixed conifer forest species in an 1,800 hectare (ha) study area in Sierra Nevada, California. Before 1875, fires scarred clusters of living trees every 9 years on west-facing slopes at Redwood Mountain and every 16 years on east-facing slopes. Mean fire-free intervals between 1700 and 1875 varied by habitat phase from 5 years in ponderosa pine on a dry ridge to 15-18 years in more moist sites with white fir. For most 1-ha sites, the maximum time without fire was 14-28 years.

From 1700 to 1875, fires of various sizes were found every 2-3 years somewhere in a given drainage (not necessarily the same site) and every 5-9 years in 3 to 16-ha sites. This compares with fires every 8-18 years in 1-ha clusters and every 11-39 years on individual trees. Scar records of pre-1700 fires suggest intervals fairly comparable to those from 1700 to 1875. Evidence of fires diminished greatly after Indian burning was eliminated in the early 1870s, and such fire records became almost nonexistent after 1900, when fire suppression became more effective.

Most of the pre-1875 fires were small and of low intensity. Even the larger fires were usually confined to 1 slope or 1 drainage area. The short mean intervals between fires suggest that pre-1875 mixed conifer forests did not usually have heavy accumulations of litter or dense thickets of understory trees. Instead, small-acreage, low-intensity surface fires must have consumed accumulated litter at frequent intervals and at the same time killed most of the conifer regeneration which had become established since previous fires. Such frequent fires would have led to an intricate mosaic of age classes and vegetation subtypes which, in turn, ensured that a subsequent fire would not burn large areas with great intensity. Intense fires which moved from crown to crown were absent in the study area for the past 400 to 2,000 years. If frequency of lightning ignition of fires over the past 50 years is typical, ignitions by Indians must have augmented lightning-caused fires to yield the pre-1865 frequency of fires in the Sierra mixed conifer forest. Since 1900, the lack of frequent, low-intensity fires has resulted in a major increase in understory forest and fuels.

Keywords: fire; fire frequency; Southwest; suppression

Kulakowski, D. and T.T. Veblen. 2007. Effect of prior disturbances on the extent and severity of wildfire in Colorado subalpine forests. *Ecology* 88(3):759-769.

Abstract: Disturbances are important in creating spatial heterogeneity of vegetation patterns that in turn may affect the spread and severity of subsequent disturbances. Between 1997 and 2002, extensive areas of subalpine forests in northwestern Colorado were affected by a blowdown of trees, bark beetle outbreaks, and salvage logging. Some of these stands were also affected by severe fires in the late 19th century. During a severe drought in 2002, fires affected extensive areas of these subalpine forests. The authors evaluated and modeled the extent and severity of the 2002 fires in relation to these disturbances that occurred over the five years prior to the fires and in relation to late 19th century stand-replacing fires. Occurrence of disturbances prior to 2002 was reconstructed using a combination of tree-ring methods, aerial photograph interpretation, field surveys, and geographic information systems (GIS). The extent and severity of the 2002 fires were based on the normalized difference burn ratio derived from satellite imagery. GIS and classification trees were used to analyze the effects of prefire conditions on the 2002 fires. Previous disturbance history had a significant influence on the severity of the 2002 fires. Stands that were severely blown down (> 66% trees down) in 1997 burned less severely than older stands. In contrast, prefire disturbances were poor predictors of fire extent, except that young (~120 year old) postfire stands burned less severely than older stands. Salvage logging and bark beetle outbreaks that followed the 1997 blowdown (within the blowdown as well as in the adjacent forest that was not blown down) did not appear to affect fire extent or severity. Conclusions regarding the influence of the beetle outbreaks on fire extent and severity are limited, however, by spatial and temporal limitations associated with aerial detection surveys of beetle activity. Thus, fire extent in these forests is largely independent of prefire disturbance history and vegetation conditions. In contrast, fire severity, even during extreme fire weather and in conjunction with a multiyear drought, is influenced by prefire stand conditions, including the history of previous disturbances.

Keywords: blowdown; fire; insect pest; land use; logging; Southwest

Meixner, T. and P.M. Wohlgemuth. 2003. Climate variability, fire, vegetation recovery, and watershed hydrology. In *First Interagency Conference on Research in the Watersheds*, October 27-30, 2003. Renard, K.G., McElroy, S.A., Gburek, W.J., Canfield, H.E., and Scott, R.L.(eds.). USDA Agricultural Research Service pp. 651-656.

Abstract: The San Dimas Experimental Forest was established in 1934. A large database of fire history, and streamflow exists for several locations within the forest. San Dimas was selected as a perfect example of the hydrology, geology, and ecology of the mountains of southern California. As such, the long-term dataset provides the best examples available of rainfall-runoff relationships in a mountainous Mediterranean climate. One of the most important ecological processes operating at San Dimas is the frequent stand replacing fires that occur approximately every 40 years. The effect of fire on streamflow is a pertinent topic considering the current national discussion about changes in fire policy in the western United States. The datasets at San Dimas provide an opportunity to investigate what the short- and long-term impacts of fire are on water resources in chaparral ecosystems. In particular, the fires of 1938 and 1960 provide an opportunity to investigate the effect of fire on streamflow response. Immediately after the fires, the well-known fire-flood response of chaparral watersheds is noted with extremely large flood peaks possibly due to the combined effects of removal of vegetation and litter by fire as well as the presence of hydrophobic soils. However, longer-term impacts of fire are noticeable, lasting as long as 20 years and are most likely related to aggrading vegetation coverage and the linked increase in evapotranspiration. Around 1960, several watersheds were converted to annual and perennial grasslands from their native chaparral, which increased streamflow to the present day and offers insight into the importance of deeply rooted vegetation on summer streamflow in seasonally dry climates.

Keywords: case study; fire; Southwest; streamflow; vegetation change; watershed

Meyer, V.F., E.F. Redente, K.A. Barbarick, and R. Brobst. 2001. Biosolids applications affect runoff water quality following forest fire. *Journal of Environmental Quality* 30:1528-1532.

Abstract: Soil erosion and nutrient losses are great concerns following forest wildfires. Biosolids application might enhance revegetation efforts while reducing soil erodibility. Consequently, this study applied Denver Metro Wastewater District composted biosolids at rates of 0, 40, and 80 megagrams per hectare (Mg ha^{-1}) to a severely burned, previously forested site near Buffalo Creek, CO to increase plant cover and growth. Soils were classified as Ustorthents, Ustochrepts, and Haploborols. Simulated rainfall was applied for 30 minutes at a rate of 100 millimeters per hectare to 3- by 10-meter paired plots. Biosolids application rates did not significantly affect mean total runoff ($p < 0.05$). Sediment concentrations were significantly greater ($p < 0.05$) from the control plots compared with the plots that had received the 80 Mg biosolids ha^{-1} rate. Biosolids application rate had mixed effects on water-quality constituents; however, concentrations of all runoff constituents for all treatment rates were below levels recommended

for drinking water standards, except lead. Biosolids application to this site increased plant cover, which should provide erosion control.

Keywords: erosion; fire; sediment; sediment control; Southwest; water quality

Moody, J.A. 2001. Sediment transport regimes after a wildfire in steep mountainous terrain. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X-41-X-48. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf. *Abstract*: Intense rains after a wildfire created catastrophic erosion and deposition in a mountainous watershed. The result was a slug of sediment filling the main channel and parts of many tributaries up to 4 meters thick. This changed a supply-limited system to a transport-limited system. During the four years after the wildfire, three different transport regimes were identified. These regimes were not persistent enough to transport sediment as a wave but changed frequently, thus altering the morphology of the sediment slug.

Keywords: erosion; fire; sediment; Southwest

Murphy, J.D., D.W. Johnson, W.W. Miller, R.F. Walker, E.F. Carroll, and R.R. Blank. 2006. Wildfire effects on soil nutrients and leaching in a Tahoe Basin watershed. *Journal of Environmental Quality* 35:479-489.

Abstract: A wildfire burned through a previously sampled research site, allowing pre- and post-burn measurements of the forest floor, soils, and soil leaching near Lake Tahoe, Nevada. Fire and post-fire erosion caused large and statistically significant (p less than or equal to 0.05) losses of carbon, nitrogen, phosphorus, sulfur, calcium, and magnesium from the forest floor. There were no statistically significant effects on mineral soils aside from a decrease in total nitrogen in the surface (A11) horizon, an increase in pH in the A11 horizon, and increases in water-extractable sulfate ion in the A11 and A12 horizons. Burning caused consistent but insignificant increases in exchangeable calcium ion in most horizons, but no consistent or statistically significant effects on exchangeable potassium ion or magnesium ion, or on Bray-, bicarbonate-, or water-extractable phosphorus concentrations. Before the burn, there were no significant differences in leaching, but during the first winter after the fire, soil solution concentrations of ammonium ion, nitrate ion, ortho-P, and (especially) sulfate ion were elevated in the burned area, and resin lysimeters showed significant increases in the leaching of ammonium ion and mineral N. The leaching losses of mineral N were much smaller than the losses from the forest floor and A11 horizons, however. The authors concluded that the major short-term effects of wildfire were on leaching whereas the major long-term effect was the loss of N from the forest floor and soil during the fire.

Keywords: erosion; fire; Southwest; water quality

National Association of Conservation Districts. Date Unknown. Special Report: Out Front on the Front Range. Available: http://www.nacdnet.org/special/DistrictFireWork.pdf.

Abstract: Shortly after Colorado's Hayman Fire scorched nearly 138,000 acres in the summer of 2002, the National Association of Conservation Districts (NACD) set out to learn about the economic and environmental consequences of fire. A visit to the Colorado Rocky Mountains Front Range in September 2003 by NACD's Urban, Community and Coastal Resources Committee is the occasion for this fire followup report. "Out Front on the Front Range" reviews the successes and challenges faced by fire-tested conservation partners. Their messages are straightforward and positive, intended to show what worked, what didn't, and what can be done to improve their actions. A lot is at stake as the NACD seeks to evolve and improve their work in fire-prone regions of the West and elsewhere in America. A broad consensus agrees that there will be more, bigger fires in the future. But a lot has been learned about fire in recent years, and the pace of work to mitigate wildfire impacts and to better manage forested lands has increased dramatically.

Keywords: case study; fire; response strategy; Southwest

Pierson, F.B., P.R. Robichaud, and K.E. Spaeth. 2001. Spatial and temporal effects of wildfire on the hydrology of a steep rangeland watershed. *Hydrological Processes* 15:2905-2916.

Abstract: Wildfire is a major ecological process and management issue on western rangelands. The impacts of wildfire on hydrologic processes such as infiltration, runoff, and erosion are not well understood. Small-plot rainfall simulation methods were applied in a rangeland wildfire setting to determine post-fire hydrologic response. Infiltration and interrill erosion processes were measured immediately post-fire and one year following the 1999 34,400-hectare Denio fire in northwestern Nevada. Plot-scale spatial and temporal variabilities in fire impacts were compared with adjacent unburned areas. An index of water repellency was derived and used to quantify the influence of water-repellent soil conditions on infiltration. Results indicate the impact of the fire on infiltration was localized primarily on coppice microsites directly under shrubs characterized by high surface litter accumulations. Coppice microsites had very uniform fire induced soil water repellency with 29 of 30 plots exhibiting at least a 10% reduction in initial infiltration with an average 28% reduction. Cumulative erosion was nearly four times higher on burned coppices compared with unburned coppices. The impact of the fire on infiltration and erosion was reduced, but still evident, one year after the fire. Significant temporal variability in infiltration between years was observed on both the burned and unburned areas, complicating the interpretation of fire impacts and hydrologic recovery following wildfire.

Keywords: erosion; fire; runoff; Southwest

Plumlee, G.S., D.A. Martin, T. Hoefen, R. Kokaly, P. Hageman, A. Eckberg, G.P. Meeker, M. Adams, M. Anthony, and P.J. Lamothe. 2007. Preliminary Analytical Results for Ash and Burned Soils from the October 2007 Southern California Wildfires. U.S. Geological Survey Open-File Report 2007-1407.

Abstract: The U.S. Geological Survey (USGS) collected ash and burned soils from about 28 sites in southern California wildfire areas (Harris, Witch, Ammo, Santiago, Canyon and Grass Valley) from November 2 through 9, 2007. USGS researchers are applying a wide variety of analytical methods to these samples, with the goal of helping identify characteristics of the ash and soils from wildland and suburban burned areas that may be of concern for their potential to adversely affect water quality, human health, endangered species, and debris-flow or flooding hazards. These studies are part of the Southern California Multi-Hazards Demonstration Project, and preliminary findings are presented here.

Keywords: erosion; fire; Southwest; water quality

Robichaud, P.R. 2005. Measurement of post-fire hillslope erosion to evaluate and model rehabilitation treatment effectiveness and recovery. *International Journal of Wildland Fire* 14:475-485.

Abstract: The increasing size and severity of wildfires in the western United States has caused a corresponding increase in post-fire emergency erosion control activities. Hillslope treatments, such as broadcast seeding, mulching and installed barriers, are applied to reduce runoff and erosion, as well as downslope sedimentation. However, there are few data to determine if these post-fire treatments are practical and effective. Direct measurement of hillslope erosion, particularly in the remote settings where wildfires occur, is time consuming and costly. Rainfall simulation, sediment fences, and paired catchment studies have been adapted for measuring post-fire erosion in the mountainous forest regions of the western United States. The use of paired catchments to measure hillslope erosion and evaluate treatment effectiveness is illustrated by an ongoing experiment of six contour-felled log erosion barrier research sites. Deciding which type of treatments to use, as well as the locations and timing of application, requires treatment cost and effectiveness to be weighed against potential damage from unmitigated erosion. To assist in this process, a web-based Erosion Risk Management Tool has been developed that incorporates variability in rainfall, burn severity and soil properties, as well as treatment options, to provide probabilistic erosion estimates for four years after a fire.

Keywords: development; erosion; fire; hillslope treatment; management; Northwest; runoff; sediment; sediment control; Southwest; United States

Robichaud, P.R. and W.J. Elliot. 2006. Protection from erosion following wildfire. In *Presented at the 2006 ASABE Annual International Meeting*, 9-12 July, 2006, Portland, OR. American Society of Agricultural and Biological Engineers. Paper No. 068009.

Abstract: Erosion in the first year after a wildfire can be up to three orders of magnitude greater than the erosion from undisturbed forests. To mitigate potential postfire erosion, various erosion control treatments are applied on highly erodible areas with downstream resources in need of protection. Because postfire erosion rates generally decline by an order of magnitude for each year of recovery, effective erosion mitigation treatments are most needed during the first year or two after a fire. Postfire treatments include broadcast seeding, scarification and trenching, physical erosion barriers such as contour-felled logs and straw wattles, and mulching with wheat straw, wood straw, and hydromulch. This paper summarizes data from more than seven years of studies to evaluate the effectiveness of postfire erosion mitigation treatments at the hillslope and small watershed-scale in the western United States. Results suggest that some mitigation treatments may help reduce erosion for some, but not all, rainfall events. Generally, mulching is more effective than seeding, scarifying, or erosion barriers. For small rainfall events, reduction in first year erosion rates have been measured for engineered wood straw and straw mulch (60 to 80%), contour-felled log erosion barriers (50 to 70%), and hydromulch (19%). Grass seeding treatments have little effect on first year erosion reduction. For intense rain events (I10 greater than 40 millimeters per hour) there was little difference between treated and nontreated areas.

Keywords: erosion; fire; Northwest; sediment control; Southwest

Robichaud, P.R., F.B. Pierson, W.J. Elliot, and P.M. Wohlgemuth. 2005. Risk Assessment of Fuel Management Practices on Hillslope Erosion Processes (Phase I) 98-1-4-12. Final Report. July 1.

Abstract: After wildfires, the use of rapid response field protocols allowed measurements of postfire soil infiltration, soil erodibility, and hillslope erosion rates, while long-term measurements provided data on postfire rehabilitation treatment effectiveness and general recovery rates. These data were used to expand and validate the current suite of web-based erosion prediction tools, and to develop a conceptually different erosion risk management tool, ERMiT.

ERMiT's probabilistic analysis not only accounts for the variability in climate, soil properties, and spatial burn severity at the hillslope scale, but also provides the probabilistic output needed for postfire risk analysis. The custom interface is designed for use by hydrologists and soil scientists and is available to the public, along with other erosion prediction tools developed by the authors, on the Internet.

Keywords: erosion; fire; management; Northwest; rehabilitation; sediment control; Southwest

Robichaud, P., L. MacDonald, J. Freeouf, D. Neary, D. Martin, and L. Ashman. 2003. Postfire rehabilitation of the Hayman Fire. In *Hayman Fire Case Study*. R.T. Graham (ed.) USDA Forest Service Rocky Mountain Research Station, Fort Collins, CO, pp. 293-314. General Technical Report RMRS-GTR-114.

Abstract: The Burned Area Emergency Rehabilitation (BAER) team was asked to analyze and comment on the existing knowledge and science related to postfire rehabilitation treatments, with particular emphasis on the known effectiveness of these treatments. The general effects of fire on western forested landscapes are well documented and have been thoroughly discussed in other chapters of this report. However, postfire erosion and rehabilitation treatment effectiveness have not been studied extensively. The first part of this report describes the postfire conditions, as identified by the BAER team, and the subsequent BAER team recommendations for rehabilitation treatment. The next sections describe the different treatments, where they were applied on the Hayman Fire burn area, and the current knowledge of treatment effectiveness. The recommendations for monitoring treatment effectiveness will answer the specific question, "What types of monitoring protocol and reports should Forest Service and other jurisdictions put in place to continue to learn from this fire?" and outline a general process for monitoring postfire rehabilitation efforts. This is followed by a description of the sites currently established within the Hayman Fire burned area to evaluate the effectiveness of various rehabilitation treatments. The need to establish control sites (burned but not treated) to provide a basis for comparison and monitor natural recovery is also discussed. The final section identifies the knowledge gaps that need to be addressed to guide the selection of postfire rehabilitation treatments on future fires in the Colorado Front Range and similar environments.

Keywords: case study; erosion; fire; runoff; sediment control; Southwest

Roessing, M.E., A.E. Camp, M.L. Tyrrell, and D.C. Morton (eds.). 2003. Wildfire and Watersheds: A Summary of a Forum and Workshop Examining the Environmental, Social, and Economic Impacts of Wildfire. A Yale Forest Forum Series Publication, Volume 6, Number 2.

Abstract: The Global Institute of Sustainable Forestry at the Yale School of Forestry and Environmental Studies held a forum examining the environmental, social, and economic impacts of wildfire. Between 2000 and 2002, several major fires throughout the continental United States attracted national attention and debate surrounding issues of wildfire and fire suppression strategies. Information about the costs and impacts of fire is limited to the cost of fire suppression, the number of acres burned, and the cost of property lost to fire. This document summarizes two forums that addressed the indirect costs of wildfires and the societal and environmental impacts from a wildfire. The forums focused on the 2002 Hayman Fire in Colorado, which was the biggest fire in Colorado history, burning 137,760 acres between Denver and Colorado Springs, affecting thousands of people, burning 133 residences, and impacting the water supplies for both cities. The most severely burned area (measured as the percentage of overstory trees killed) was adjacent to Cheeseman Reservoir, Denver's drinking water source. The title of the workshop was "Developing Strategies to Collect and Utilize Critical Wildfire Impact Information."

Keywords: case study; costs; development; erosion; fire; Southwest; vegetation change; water quality; watershed

Stephens, S.L., T. Meixner, M. Poth, B. McGurk, and D. Payne. 2004. Prescribed fire, soils, and stream water chemistry in a watershed in the Lake Tahoe Basin, California. *International Journal of Wildland Fire* 13:27-35.

Abstract: Before Euro-American settlement, fire was a common process in the forests of the Lake Tahoe Basin. The combination of drought, fire suppression, and past harvesting has been recommended but there is incomplete understanding of the ecological effects of fuels treatments, especially with regard to how treatments will affect the flow of nutrients in Lake Tahoe. Nitrogen and phosphorous are the most important nutrients affecting algal growth, and thus lake clarity. Existing data demonstrate a long-term shift from a co-limitation by both nitrogen and phosphorous to phosphorous limitation. Two high-consumption, moderate-intensity prescribed fires were conducted to determine their effects on soil and stream water chemistry. Stream water calcium concentrations increased in burned watersheds whereas soluble reactive phosphorous concentrations were not significantly different. Prescribed fires released calcium and raised soil pH and this may have resulted in the incorporation of phosphorous into insoluble forms. Stream monitoring data indicate water quality effects last for ~3 months. Prescribed fires did not significantly increase the amount of soluble reactive phosphorous in stream waters. However, additional research is needed to determine if prescribed fire increases erosion or movement of particulate phosphorus, particularly in areas with steep slopes.

Keywords: fire; nutrient; phosphorous; Southwest; vegetation change; water quality

USDA Forest Service. 2006. Hayman Fire & BAER Information: Burned Area Emergency Rehabilitation (BAER). Available: http://www.fs.fed.us/r2/psicc/hayres/baer/index.htm.

Abstract: After a fire, some or all of the ground cover (called "duff," includes needles, decomposed wood, and leaves) will be burned away, exposing the soil to the direct impact of rain. In addition, and depending on the severity of the fire ("high" being the worst), the soil itself may become somewhat "hydrophobic," i.e., it will repel water, rather than absorbing it. These conditions can set the stage for soil erosion when rain occurs.

Also, keep in mind that a forest fire typically does not burn at the same intensity everywhere, depending on terrain and fuels. Usually, fire severity will be classified as low, moderate, or high. Generally, high intensity burned areas have priority for treatment, as they tend to be more hydrophobic, have the least duff, and have the greatest potential for erosion.

Keywords: case study; erosion; fire; response strategy; sediment; Southwest

USGS. 1998. USGS Wildland Fire Research. USGS Fact Sheet 125-98.

Abstract: Wildland fire is a serious and growing hazard over much of the United States, posing a great threat to life and property, particularly when it moves from forest or rangeland into developed areas. However, wildland fire is also a natural process, and its suppression is now recognized to have created a larger fire hazard, as live and dead vegetation accumulate in areas where fire has been excluded. In addition, the absence of fire has altered or disrupted the cycle of

natural plant succession and wildlife habitat in many areas. Consequently, U.S. land management agencies are committed to finding ways, such as prescribed burning to reintroduce fire into natural ecosystems, while recognizing that fire fighting and suppression are still important. The U.S. Geological Survey conducts fire-related research to meet the varied needs of the fire management community and to understand the role of fire in the landscape; this research includes fire management support, studies of postfire effects, and a wide range of studies on fire history and ecology.

Keywords: erosion; fire; manganese; Southwest; vegetation change; water quality; water yield

Veenhuis, J.E. 2002. Effects of Wildfire on the Hydrology of Capulin and Rito de los Frijoles Canyons, Bandelier National Monument, New Mexico. U.S. Geological Survey Water-Resources Investigations Report 02-4152.

Abstract: In June 1977, the La Mesa wildfire burned 15,270 acres in and around Frijoles Canyon in Bandelier National Monument and the adjacent Santa Fe National Forest, New Mexico. The Dome wildfire in April 1996 in Bandelier National Monument burned 16,516 acres in Capulin Canyon and the surrounding Dome Wilderness area. Both watersheds are characterized by abundant and extensive archeological sites that could be affected by increased runoff and accelerated rates of erosion, which typically occur after a wildfire. The U.S. Geological Survey, in cooperation with the National Park Service, monitored the wildfires' effects on streamflow in both canyons.

The magnitude of large stormflows increased dramatically after these wildfires; peak flows at the most downstream streamflow-gauging station in Frijoles and Capulin canyons increased to about 160 times the maximum recorded flood prior to the fire. Maximum peak flow was 3,030 cubic feet per second at the gauging station in Frijoles Canyon (drainage area equals 18.1 square miles) and 3,630 cubic feet per second at the most downstream crest-stage gauge in Capulin Canyon (drainage area equals 14.1 square miles). The pre-fire maximum peak flow recorded in these two canyons was 19 and an estimated 25 cubic feet per second, respectively. As vegetation reestablished itself during the second year, the post-fire annual maximum peak flow decreased to about 10 to 15 times the pre-fire annual maximum peak flow. During the third year, maximum annual peak flows decreased to about three to five times the pre-fire maximum peak flow. In the 22 years since the La Mesa wildfire, flood magnitudes have not completely returned to pre-fire size.

Post-fire flood magnitudes in Frijoles and Capulin canyons do not exceed the maximum floods per drainage area for physiographic regions 5 and 6 in New Mexico. For a burned watershed, however, the peak flows that occur after a wildfire are several orders of magnitude larger than normal forested watershed peak flows.

The frequency of larger stormflows also increased in response to the effects of the wildfires in both canyons. In Frijoles Canyon, the number of peak stormflows greater than the pre-fire maximum flow of 19 cubic feet per second was 15 in 1977, 9 in 1978, and 5 in 1979, which is about the magnitude of the maximum pre-fire peak flow in both canyons. Again the hydrologic effects of a wildfire seem to be more pronounced for the three years following the date of the fire. Likewise, larger peak flows occurred more frequently in Capulin Canyon for the first three years after the 1996 wildfire.

Median suspended-sediment concentrations in samples collected in Frijoles Canyon in 1977 were 1,330 milligrams per liter; median concentrations were 16 milligrams per liter after the watershed stabilized in 1993-1995. The annual load calculated from regression equations for load compared to flow for the first year after the wildfire was 220 times the annual load for the post-recovery period.

To convey the increased frequency and magnitude of average flows in Capulin Canyon after the 1996 Dome wildfire, the stream channel in Capulin Canyon increased in flow capacity by widening and downcutting. As Capulin Canyon peak flows have decreased in both magnitude and frequency with vegetative recovery, the stream channel also has slowly begun to readjust. The channel at the most downstream crest-stage gauge, which has the shallowest initial valley slope, is showing the first signs of aggradation.

Keywords: erosion; fire; flood; runoff; sediment; Southwest; streamflow; suspended sediment; vegetation change; watershed

Westerhoff, P., D. Gill, and S. Lohman. 2005. Effects of forest fires on reservoir water quality. In *American Water Works Association 2005 Source Water Protection Symposium*, January 23-26, Palm Beach Gardens, FL.

Abstract: The objective of this research was to determine the long-term effects of catastrophic forest fires on drinking water quality. The watersheds burned by the Rodeo-Chediski fire in Arizona and the Hayman fire in Colorado were the focus of this research. Both fires occurred in watersheds that serve as a drinking water source for a major metropolitan area. Concentration data and mass loading analyses were conducted utilizing pre- and post-fire water quality data. The results of the Rodeo-Chediski fire and the Hayman fire analysis were compared. In addition, an unburned watershed in Arizona was analyzed and served as the reference watershed.

The short- and long-term impacts on stream water that serves as a drinking water source were determined. Short-term effects consisted of elevated nutrient and particulate concentrations in the burned watersheds during subsequent storm events. The post-fire storm events also elevated the metal concentrations in runoff water. However, the maximum contaminant level set by the U.S. Environmental Protection Agency for the metals analyzed was not exceeded. Long-term effects will originate from the mobilized particulate fraction settling to the stream or lake bottom. The organic material adsorbed to the particulates will be slowly dissolved, diffusing into the water. The dissolved organics will serve as an energy source for microorganisms that have the ability to cause taste and odor problems in drinking water. The long-term effects are aesthetic and do not pose a human health risk.

Keywords: case study; drinking water quality; drought; fire; Southwest

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313:940-943.

Abstract: Western U.S. forest wildfire activity is widely thought to have increased in recent decades, yet neither the extent of recent changes nor the degree to which climate may be driving regional changes in wildfire has been systematically documented. Much of the public and scientific discussion of changes in western U.S. wildfire has focused instead on the effects of 19th and 20th century land-use history. This compilation of a comprehensive database of large wildfires in the western U.S. forests since 1970 is compared with hydroclimatic and land-surface data. Results show large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.

Keywords: climate change; fire; Northwest; Southwest

Wohlgemuth, P.M. 2001. Prescribed fire as a sediment management tool in southern California chaparral watersheds. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X-49-X-56. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf.

Abstract: Land managers in southern California have speculated that prescribed burning could reduce the soil erosion generated by catastrophic wildfires. A unique opportunity to test this notion arose when a wildfire swept over a field experiment measuring hillslope erosion from a prior prescribed burn. Results indicate that (1) fire severity may directly affect erosion response, (2) postfire hillslope erosion levels may return to normal within three years, and (3) prescribed fire may reduce the erosion produced by subsequent wildfires. These results suggest that prescribed fire may be an effective sediment management tool in southern California chaparral brushfields.

Keywords: erosion; fire; sediment; Southwest; vegetation change

Wohlgemuth, P.M. 2003. Post-fire erosion control research on the San Dimas Experimental Forest: past and present. In *First Interagency Conference on Research in the Watersheds*, October 27-30, 2003. Renard, K.G., McElroy, S.A., Gburek, W.J., Canfield, H.E., and Scott, R.L.(eds.). USDA Agricultural Research Service pp. 645-650.

Abstract: The San Dimas Experimental Forest (SDEF) was established in the early 1930s to document and quantify wildland hydrology in the semiarid chaparral-covered steeplands of southern California. Concomitantly, the nearly 70 years of accumulated watershed research in this fire-prone ecosystem has produced invaluable information on post-fire erosion and the effectiveness and consequences of post-fire erosion control treatments. On average, first-year, post-fire watershed sediment yield is 35 times greater than comparable unburned annual levels. This accelerated erosion can cause site degradation and threaten life, property, and infrastructure

at the adjacent wildland/urban interface. To mitigate the undesirable consequences of post-fire accelerated erosion, land managers have developed a program of hillslope and stream channel emergency rehabilitation treatments as erosion control measures. The SDEF has been the site on which many of these erosion control practices, both past and present, have been tested. In the 1960s, some labor-intensive treatments were shown to have no effect on reducing post-fire erosion. At the same time, more radical ground-disturbing treatments that were marginally effective in the short-term have persisted on the landscape and altered the subsequent sediment fluxes through these watersheds. In September 2002, virtually the entire SDEF burned in the Williams Fire. This allowed the implementation of a new series of emergency rehabilitation treatments for which the effects and consequences are largely unknown. Preliminary results suggest that an aerial application of polyacrylamide did nothing to reduce post-fire sediment yield, but that prefabricated wooden channel checks may be an effective post-fire rehabilitation tool.

Keywords: case study; erosion; fire; sediment; Southwest

Ziska, L.H., J.B. Reeves III, and R.R. Blank. 2005. The impact of recent increases in atmospheric CO_2 on biomass production and vegetative retention of cheatgrass (*Bromus tectorum*): implications for fire disturbance. *Global Change Biology* 11:1325-1332.

Abstract: Cheatgrass (*Bromus tectorum*) is a recognized, invasive annual weed of the western United States that reduces fire return times from decades to less than 5 years. To determine the interaction between rising carbon dioxide (CO_2) concentration and fuel load, the authors characterized potential changes in biomass accumulation, the C : N ratio, and the digestibility of three cheatgrass populations from different elevations to recent and near-term projections in atmospheric CO_2. The experimental CO_2 values [270, 320, 370, 420 micromoles per mole ($\mu mol\ mol^{-1}$)] corresponded roughly to the CO_2 concentrations that existed at the beginning of the 19th century, that during the 1960s, the current CO_2, and the near-term CO_2 projection for 2020, respectively. From 25 until 87 days after sowing, aboveground biomass for these different populations increased 1.5-2.7 g (grams) per plant for every 10 $\mu mol\ mol^{-1}$ increase above the 270 $\mu mol\ mol^{-1}$ preindustrial baseline. CO_2 sensitivity among populations varied with elevational origin with populations from the lowest elevation showing the greatest productivity. Among all populations, the indigestible portion of aboveground plant material (acid detergent fiber, mostly cellulose and lignin) increased with increasing CO_2. In addition, the ratio of C : N increased with leaf age, with CO_2 and was highest for the lower elevational population. These CO_2-induced qualitative changes could, in turn, result in potential decreases in herbivory and decomposition with subsequent effects on the aboveground retention of cheatgrass biomass. Overall, these data suggest that increasing atmospheric (CO_2) above preambient levels may have contributed significantly to cheatgrass productivity and fuel load with subsequent effects on fire frequency and intensity.

Keywords: fire; invasive species; nutrient load; Southwest; vegetation change

United States

McMichael, C.E. and A.S. Hope. 2007. Predicting streamflow response to fire-induced landcover change: implications of parameter uncertainty in the MIKE SHE model. *Journal of Environmental Management* 84(3):245-256.

Abstract: Fire is a primary agent of landcover transformation in California semi-arid shrubland watersheds; however, few studies have examined the impacts of fire and post-fire succession on streamflow dynamics in these basins. While it may seem intuitive that larger fires will have a greater impact on streamflow response than smaller fires in these watersheds, the nature of these relationships has not been determined. The effects of fire size on seasonal and annual streamflow responses were investigated for a medium-sized basin in central California using a modified version of the MIKE SHE model which had been previously calibrated and tested for this watershed using the Generalized Likelihood Uncertainty Estimation (GLUE) methodology. Model simulations were made for two contrasting periods, wet and dry, in order to assess whether fire size effects varied with weather regime. Results indicated that seasonal and annual streamflow responses increased nearly linearly with fire size in a given year under both regimes. Annual flow responses were generally higher in wetter years for both weather regimes, however, a clear trend was confounded by the effect of stand age. These results expand the understanding of the effects of fire size on hydrologic response in chaparral watersheds, but it is important to note that the majority of model predictions were largely indistinguishable from the predictive uncertainty associated with the calibrated model – a key finding that highlights the importance of analyzing hydrologic predictions for altered landcover conditions in the context of model uncertainty. Future work is needed to examine how alternative decisions (e.g., different likelihood measures) may influence GLUE-based MIKE SHE streamflow predictions following different size fires, and how the effect of fire size on streamflow varies with other factors such as fire location.

Keywords: erosion; fire; streamflow; United States; vegetation change; water quantity

Moody, J.A. and D.A. Martin. 2001. Post-fire, rainfall intensity-peak discharge relations for three mountainous watersheds. *Hydrological Processes* 15(15):2981-2993.

Abstract: Wildfire alters the hydrologic response of watersheds, including the peak discharges resulting from subsequent rainfall. Improving predictions of the magnitude of flooding that follows wildfire is needed because of the increase in human population at risk in the wildland-urban interface. Because this wildland-urban interface is typically in mountainous terrain, the authors investigated rainfall-runoff relations by measuring the maximum 30 minute rainfall intensity and the unit-area peak discharge (peak discharge divided by the area burned) in three mountainous watersheds (17-26.8 square kilometers) after a wildfire.

The authors found rainfall-runoff relations that relate the unit-area peak discharges to the maximum 30 minute rainfall intensities by a power law. These rainfall-runoff relations appear to have a threshold value for the maximum 30 minute rainfall intensity (around 10 millimeters per

hour) such that, above this threshold, the magnitude of the flood peaks increases more rapidly with increases in intensity. This rainfall intensity could be used to set threshold limits in rain gauges that are part of an early-warning flood system after wildfire. The maximum unit-area peak discharges from these three burned watersheds ranged from 3.2 to 50 cubic meters per second per square kilometer. These values could provide initial estimates of the upper limits of runoff that can be used to predict floods after wildfires in mountainous terrain.

Keywords: development; erosion; fire; United States; vegetation change; water quality; water yield

Neary, D.G. and G.J. Gottfried. 2000. Post-wildfire peak flood flows: causes and effects. In *Proceedings: 2000 National Convention of the Society of American Foresters*, November 16-20, Washington DC. pp. 459-463.

Abstract: Next to the destruction of forest vegetation during a wildfire, the most destructive post-wildfire impact comes from flood peak flows. These flows can severely affect stream physical conditions, aquatic habitat, aquatic biota, cultural resources, and human health and safety. Flood flows in forest, woodland, and rangeland watersheds after wildfires can increase dramatically due to vegetation and forest floor combustion, high fire severity, development of water repellant layers in the soil, and accelerated development of post-fire thunderstorms. Increases in flood peak flows of 11 to 44,670%, well beyond observed ranges of variability in managed watersheds, have been measured after wildfires. These flows need to be understood in order to safely manage watershed resources and recreational uses of riparian areas in a post-fire environment.

Keywords: erosion; fire; sediment; streamflow; United States; watershed management

O'Keefe, T.C., J.M. Helfield, and R.J. Naiman. 2007. Agents of Watershed Change. Training module from U.S. EPA's Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: This training module provides an overview of natural and human-made change processes and the ways in which they affect the structure and function of watersheds. The module has four primary sections: an introduction to the role of change in the watershed, descriptions of specific natural agents of change and their ecological effects, descriptions of specific human made agents of change and their ecological effects, and a discussion of the watershed processes most vulnerable to change.

Change is a natural, essential feature of watersheds. Being able to identify different change processes, understand the differences between natural and human influences on watershed change, and recognize a change of concern are all critical for effective watershed management. Watershed change, however, can be very complicated to understand and manage when many human and natural causes of change interact as they often do.

After completing this training, the participant should know the major changes affecting watersheds and understand that watersheds are dynamic systems. Some background in watershed ecology is helpful for understanding the material presented here and can be obtained from the module, *Introduction to Watershed Ecology,* at http://www.epa.gov/watertrain/ecology.

Keywords: agriculture; climate change; drought; erosion; fire; flood; logging; United States; Urbanization; Water resources management; watershed change; watershed management; windstorm

Ravi, S., P. D'Odorico, B. Herbert, T. Zobeck, and T.M. Over. 2006. Enhancement of wind erosion by fire-induced water repellency. *Water Resources Research* 42:W11422

Abstract: The occurrence of fire and the subsequent increase in wind erosion are known to affect vegetation dynamics in dryland landscapes. Fires act as a disturbance on shrubs and trees and expose the soil surface to the erosive action of wind, thereby affecting the loss and redistribution of soil nutrients. Despite the relevance of wind erosion and fires to the dynamics of arid ecosystems, the interactions between these two processes remain poorly understood. The authors have investigated how a representative water repellent organic compound released by burning biomass and absorbed in the soil may enhance soil erodibility. To this end, this study carried out a series of wind tunnel experiments, laboratory tests, and theoretical analyses to assess the effects of fire-induced water repellency on the soil susceptibility to wind erosion. The experiments were carried out using clean, well-sorted sand which was artificially coated with palmitic acid, a common water repellency inducing fatty acid found in most plants. The results indicate that fire-induced water repellency enhances soil erodibility, causing a drop in wind erosion threshold velocity. The results are explained by the effect of water repellent compounds on soil-water contact angle and on the strength of interparticle wet-bonding forces.

Keywords: erosion; fire; United States; vegetation change; water repellency; wind

Robichaud, P.R. 2000. Forest fire effects on hillslope erosion: what we know. *Watershed Management Council Networker* 9(1)

Abstract: Increased awareness of the role of fire in healthy ecosystems has focused attention on some of the effects of fires, wild and prescribed, on watershed condition and health. Precipitation events after forest fires may cause high sediment inputs, destruction of aquatic habitat, and downstream flooding, all which may be part of the natural ecosystem response. However, if the fires are more severe due to past fire suppression activities, then the fire effects may be greater than natural. Fire and erosion are both natural processes that have been impacted by forest management activities such as fire suppression, logging, and road building during the last century. Management activities may contribute to increased streamflows and increased sediment supplies to streams and rivers. Additional sediment places streams and rivers at a higher risk for degradation. Sediment adversely affects spawning and rearing sites for anadromous and resident fish species, mobilizes in-stream sediment, and destroys aquatic habitat. Therefore, various management and mitigation strategies are often devised to reduce the threat of increased

sediment. This paper reviews the effects of fire on hillslope erosion and the associated risks on watershed health.

Fire is a natural and important part of the disturbance regime for forested terrestrial and aquatic systems, especially in the western United States. However, much uncertainty exists in quantifying fire effects on ecosystem components such as watershed condition and health.

Keywords: erosion; fire; sediment; United States; water quality; water yield

Robichaud, P.R. 2005. Measurement of post-fire hillslope erosion to evaluate and model rehabilitation treatment effectiveness and recovery. *International Journal of Wildland Fire* 14:475-485.

Abstract: The increasing size and severity of wildfires in the western United States has caused a corresponding increase in post-fire emergency erosion control activities. Hillslope treatments, such as broadcast seeding, mulching and installed barriers, are applied to reduce runoff and erosion, as well as downslope sedimentation. However, there are few data to determine if these post-fire treatments are practical and effective. Direct measurement of hillslope erosion, particularly in the remote settings where wildfires occur, is time consuming and costly. Rainfall simulation, sediment fences, and paired catchment studies have been adapted for measuring post-fire erosion in the mountainous forest regions of the western United States. The use of paired catchments to measure hillslope erosion and evaluate treatment effectiveness is illustrated by an ongoing experiment of six contour-felled log erosion barrier research sites. Deciding which type of treatments to use, as well as the locations and timing of application, requires treatment cost and effectiveness to be weighed against potential damage from unmitigated erosion. To assist in this process, a web-based Erosion Risk Management Tool has been developed that incorporates variability in rainfall, burn severity and soil properties, as well as treatment options, to provide probabilistic erosion estimates for four years after a fire.

Keywords: development; erosion; fire; hillslope treatment; management; Northwest; runoff; sediment; sediment control; Southwest; United States

Rosenberger, A. 2004. Evaluating watershed vulnerability: A fishes' perspective on fire. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: Fire and fire management practices may threaten fish populations by affecting habitat characteristics, food supply, and changing the chemical environment. This presentation identifies management techniques that may impact fish before, during, and after fire.

Keywords: fire; management; United States; water quality

USDA Agricultural Research Service. 2003. First Interagency Conference on Research in the Watersheds. October 27-30, 2003. Available: http://www.tucson.ars.ag.gov/icrw/proceedings.htm.

Abstract: This report comprises *Abstract*s and papers presented at the First Interagency Conference on Research in the Watersheds, October 27-30, 2003, in Benson, Arizona. This report represents state-of-the-art research in watersheds. The content includes reviews of watershed research programs conducted by the U.S. Department of Agriculture's Agricultural Research Service and Forest Service, the U.S. Geological Survey, the U.S. Bureau of Land Management, the U.S. Environmental Protection Agency, and the National Science Foundation Consortium of Universities for the Advancement of Hydrological Sciences, Inc., and recent research on watershed-scale topics such as hydrology, erosion, economic, instrumentation, ecology, sociology and fire.

Keywords: costs; erosion; fire; hydrology; United States; water quality; water quantity; watershed

U.S. Department of the Interior and USDA Forest Service. 2005. Interagency Burned Area Emergency Response Handbook: For the Emergency Stabilization of Federal and Tribal Trust Lands. Version 4.0. July. Available: http://www.nps.gov/policy/DOrders/DraftHandbook.htm#_Toc106685090.

Abstract: The purpose of the Interagency Burned Area Emergency Response Handbook (Handbook) is to provide general operational guidance for the Department of Agriculture and the Department of the Interior emergency stabilization activities. It is designed to provide agency administrators and emergency stabilization specialists with sufficient information to understand emergency stabilization policy, standards, and procedures; assess wildfire damage and develop a cost effective Burned Area Emergency Response Plan/Report; and assess and report accomplishments.

It consolidates and provides an interagency interpretation of emergency stabilization policies, procedures, objectives, and standards where there is departmental and agency agreement. Individual agency policy and procedure manual guidance can be more but not less restrictive than that presented in this Handbook.

Keywords: fire; response strategy; United States; water quality

Canada

Bergeron, Y. and A. Leduc. 1998. Relationships between change in fire frequency and mortality due to spruce budworm outbreak in the southeastern Canadian boreal forest. *Journal of Vegetation Science* 9(4):493-500.

Abstract: A simple empirical model estimates mortality due to the spruce budworm (*Choristorneura fumiferana*) outbreak in relation to fire frequency and site characteristics. The

occurrence of a spruce budworm outbreak around Lake Duparquet in northwestern Quebec permitted a reconstruction of the stand composition before the outbreak, and also of the mortality of *Abies balsamea* due to the outbreak. The basal area of *A. balsamea* increases with the amount of time since fire in all site types but with increasing values for (1) rock and shallow till, (2) till and mesic clay, and (3) hydric clay. Mortality (measured as percentage loss of basal area due to the outbreak) increases with time since fire but did not vary with site type. The increasing abundance of *A. balsamea* with time since fire is mainly responsible for this increase in mortality. Mortality for a specific basal area is, however, lower for the more recently burned stands suggesting a significant residual effect of time since fire. A landscape model integrating mortality due to the outbreak for stands of different age indicated that both absolute and relative losses of basal area increased with the length of the fire cycles. According to this model, changes in fire cycle could explain a large portion of the spatio-temporal variations observed in outbreak mortality in the southeastern boreal forest of Canada.

Keywords: Canada; fire; insect pest; Northeast; vegetation change

Bladon, K. D., U. Silins, M. J. Wagner, M. Stone, M. B. Emelko, C. A. Mendoza, K. J. Devito, and S. Boon. 2008. Wildfire impacts on nitrogen concentration and production from headwater streams in southern Alberta's Rocky Mountains. *Canadian Journal of Forest Research* 38:2359-2371.

Abstract: The objective of this study was to examine initial effects of the 2003 Lost Creek wildfire (southwestern Rocky Mountains of Alberta) on concentrations and production (yield and total export) of several nitrogen (N) forms, and to explore initial recovery of these effects within the first 3 years after the fire. During the first postfire year, nitrate (NO_3^-), dissolved organic nitrogen (DON), and total nitrogen (TN) concentrations in severely burned watershed streams were 6.5, 4.1, and 5.3 times greater, respectively, than those in reference streams. Weaker effects were evident for concentrations of ammonium (NH4+; 1.5 times) and total particulate nitrogen (TPN; 3.0 times). A rapid decline in mean watershed concentrations and production of NO_3^-, DON, total dissolved nitrogen (TDN), and TN was observed from burned watersheds over the three seasons after the fire. However, elevated NO3-, TDN, and TN concentrations and production were still evident during the snowmelt freshet and following precipitation events after 3 years. Effects of the burn were strongly influenced by the regional flow regime, with the most elevated N concentrations and production occurring during higher discharge periods (snowmelt freshet and storm flows).

Keywords: Canada; fire; water quality; water quantity

Crouch, R.L., H.J. Timmenga, T.R. Barber, and P.C. Fuchsman. 2006. Post-fire surface water quality: comparison of fire retardant versus wildfire-related effects. *Chemosphere* 62:874-889.

Abstract: An understanding of the environmental effects of the use of wildland fire retardant is needed to provide informed decision-making regarding forest management. The authors

compiled data from all post-fire surface water monitoring programs where the fire retardant constituents ammonia, phosphorus, and cyanide were measured, and data were available in the public domain. For streams near four major wildfires, this study evaluated whether these chemicals originated primarily from fire or from retardant use. Measured concentrations in streams was compared where chemical wildland fire retardant was applied with concentrations in streams draining areas where retardant was not used. Correlations with calcium provided an additional line of evidence, because calcium concentrations in ash are much higher than in retardant. Ammonia, phosphorus, and total cyanide were found in streams in burned areas where retardant was not used, at concentrations similar to those found in areas where retardant was applied. Concentrations of weak acid dissociable cyanide were generally not detected or very low, whether or not wildland fire retardant was used in the watershed. These results indicate that the application of wildland fire retardant had minimal effects on proximate surface water quality. Cyanide concentrations in post-fire stormwater runoff were not affected by the presence of ferrocyanide in the retardant formulas and were due to pyrogenic sources.

Keywords: Canada; fire; fire retardant; Southwest; water quality

Hogg, E.H. and R.W. Wein. 2005. Impacts of drought on forest growth and regeneration following fire in southeastern Yukon, Canada. *Canadian Journal of Forest Research* 35(9):2141-2150.

Abstract: The valleys of southwestern Yukon have a continental climate with average annual precipitation of < 300 millimeters. In 1958, fires burned large areas of mature mixed wood forests dominated by white spruce [*Picea glauca* (Moench) Voss] in the valleys near Whitehorse. Since then, the burned areas have shown poor regeneration of spruce, but have been colonized by scattered clones of trembling aspen (*Populus tremuloides* Michx.) interspersed by grassland. The objective of the study was to examine the influence of climatic variation on forest growth and regeneration in the 1958 burn and the adjacent unburned forests. Tree-ring analysis was conducted on 50 aspen and 54 white spruce in 12 mature stands where these species were codominant, and on 147 regenerating aspen in the 1958 Takhini burn. The mature stands were uneven-aged and the patterns of growth variation for the aspen and spruce between 1944 and 2000 were similar. Growth of both species was most strongly related to variation in precipitation. The regenerating aspen had a wide age-class distribution (1959-2000) and their growth was also positively related to precipitation. The results indicate that these forests have been slow to regenerate after fire, and are vulnerable if the climate becomes drier under future global change.

Keywords: Canada; drought; fire; vegetation change; Yukon

Timoney, K.P. 2003. The changing disturbance regime of the boreal forest of the Canadian prairie provinces. *Forestry Chronicle* 79(3):502-516.

Abstract: The subhumid boreal forest of western Canada is different today from what it was 25 years ago. Before the 1950s, the main human impacts on this forest were agricultural expansion, escaped settlement fires, and high-grade logging. The latter half of the 20th century

saw increased human stresses placed on the ecosystems, against a background of insect outbreaks and high forest fire activity. In the prairie provinces, current annual area burned is greater and more variable than it was in the 1970s. Over the past 25 years, the area disturbed by insects (primarily forest tent caterpillar) and disease has declined, but both the area and timber volume logged have risen. The boreal forest (particularly its southern half) is being converted to a fragmented landscape dominated by young aspen, shrub, grass, plantations, exotic species, industrial infrastructure, and agricultural fields. The current disturbance level has increased to the point that forest land and volume losses now exceed forest accruals in some regions; average forest age and biomass have been declining since about 1970. Relative to past decades, the present subhumid boreal forest region of Canada is warmer, and more fragmented and dissected; it supports less old growth, less old white spruce, and more young aspen and recently disturbed areas; it has simplified and truncated age-class structures; and it has a greater prevalence of non-native plants. Future stresses may include *in situ* tar sands development, groundwater depletion or degradation, and water diversions. Should present trends continue, declining forest productivity and predictability, and spread of exotic species are likely, as is replacement of coniferous forest by deciduous forest in some regions. Stressed aquatic systems may undergo major changes in biotic composition, productivity, and physical characteristics. Without a rapid decrease in the rate of disturbances, the establishment of a more complete protected areas network, and the adoption of ecosystem-centered management, the subhumid boreal ecosystem will continue to be degraded.

Keywords: Canada; fire; logging

8. Logging

Northeast

Bormann, F.H., G.E. Likens, D.W. Fisher, and R.S. Pierce. 1968. Nutrient loss accelerated by clear-cutting of a forest. *Science* 159:882-884.

Abstract: The forest of a small watershed-ecosystem was cut in order to determine the effects of removal of vegetation on nutrient cycles. Relative to undisturbed ecosystems, the cut ecosystem exhibited accelerated loss of nutrients: nitrogen lost during the first year after cutting was equivalent to the amount annually turned over in an undisturbed system, and losses of cations were 3 to 20 times greater than from comparable undisturbed systems. Possible causes of the pattern of nutrient loss from the cut ecosystem are discussed.

Keywords: logging; Northeast; water quality

Foster, D., E. Boose, and J. Aber. 1998. Regionalization studies at Harvard Forest LTER. In *Perspectives on the Land-Use History of North America: A Context for Understanding Our Changing Environment*. T. D. Sisk (ed.), U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR 1998-0003 (Revised September 1999). Available: http://biology.usgs.gov/luhna/harvardforest.html.

Abstract: Ecological patterns are different at the regional, subregional, and landscape scales. This article describes the major ecological factors affecting New England at these various scales including major species and natural and human disturbance regimes.

Keywords: agriculture; fire; logging; Northeast

Goodale, C.L., J.D. Aber, and W.H. McDowell. 2000. The long-term effects of disturbance on organic and inorganic nitrogen export in the White Mountains, New Hampshire. *Ecosystems* 3:433-450.

Abstract: Traditional biogeochemical theories suggest that ecosystem nitrogen retention is controlled by biotic N limitation, that stream N losses should increase with successional age, and that increasing N deposition will accelerate this process. These theories ignore the role of dissolved organic nitrogen (DON) as a mechanism of N loss. The authors examined patterns of organic and inorganic N export from sets of old growth and historically (80-110 years ago) logged and burned watersheds in the northeastern United States, a region of moderate, elevated N deposition. Stream nitrate concentrations were strongly seasonal, and mean (± Standard Deviation) nitrate export from old-growth watersheds 1.4 (± 0.6) kilograms nitrogen per hectare per year (kg N ha^{-1} y^{-1}) was four times greater than from disturbed watersheds 0.3 (± 0.3) kg N ha^{-1} y^{-1}, suggesting that biotic control over nitrate loss can persist for a century. DON loss averaged 0.7 (± 0.2) kg N ha^{-1} y^{-1} and accounted for 28-87% of total dissolved N (TDN) export. DON concentrations did not vary seasonally or with successional status, but correlated with dissolved organic carbon (DOC), which varied inversely with hardwood forest cover. The patterns of DON loss did not follow expected differences in biotic N demand but instead were consistent with expected differences in DOC production and sorption. Despite decades of moderate N deposition, TDN export was low, and even old-growth forests retained at least 65% of N inputs. The reasons for this high N retention are unclear: if due to a large capacity for N storage or biological removal, N saturation may require several decades to occur; if due to interannual climate variability, large losses of nitrate may occur much sooner.

Keywords: fire; logging; Northeast; vegetation change; water quality

Grace III, J.M. 2005. Forest operations and water quality in the south. *Transactions of the ASAE* 48(2):871-880.

Abstract: Southern forests, which rely on intensive management practices, are some of the most productive forests in the United States. Intensive forest management utilizes forest operations, such as site preparation, fertilization, thinning, and harvesting, to increase site productivity and reduce rotation time. These operations are essential to meet the ever-increasing demands for timber products. Forest managers utilize forest operations as tools in an attempt to manage the nation's forestlands for multiple uses while maintaining or improving resource quality. Forest operations can influence nonpoint-source (NPS) pollution by disturbing natural processes that maintain water quality. In recent years, NPS pollution has been identified as the nation's largest source of water quality problems. Forest management activities have been identified as activities that influence NPS pollution in the South. Results of watershed-scale studies that investigated the effects of forest operations on water quality in the 13 southern states are highly variable. However, taken collectively, the results indicate that forest operations have little impact on the quality of water draining from forests in the South. Based on this review, best management practices (BMPs) show the potential to protect water quality following forest operations; however, accurate assessments of the overall effectiveness of BMPs are not possible because the benefits of BMPs on different scales are relatively unknown.

Keywords: erosion; logging; Northeast; sediment; South Central; Southeast; water quality; watershed management

Hobbie, J.E. and G.E. Likens. 1973. Output of phosphorus, dissolved organic carbon, and fine particulate carbon from Hubbard Brook watersheds. *Limnology and Oceanography* 18(5):734-742.

Abstract: The output of phosphorus, dissolved organic carbon (DOC), and fine particulate organic carbon (FPOC) was measured in two watersheds of the Hubbard Brook Experimental Forest, New Hampshire. One watershed had a cover of birch, beech, and maple; the other had been denuded of trees and regrowth was prevented by herbicide application for three years. Concentrations of DOC and dissolved plus fine particulate P changed little with changes in flow. Concentrations of FPOC, however, were strongly dependent on flow and most of the FPOC was exported during a few periods of high runoff. Deforestation caused higher runoff (by 26%), but

also greatly increased erosion. Thus, DOC and FPOC output was similar in the two watersheds while the loss of large particulate phosphorus, mostly as inorganic bedload, increased 12 times in the treated watershed. With a rainwater input of 100 grams phosphorous per hectare (g P ha^{-1}), there was an annual net gain of 87 g P in the undisturbed watershed and a net loss of 104 g P in the disturbed watershed. In view of the large amounts of phosphorus cycling in the natural forest (e.g., some 1,900 g P ha^{-1} in annual leaf fall alone), this ecosystem is strongly conserving phosphorus.

Keywords: logging; Northeast; water quality

Hornbeck, J.W. and C.W. Martin. 1986. Protecting forest streams during whole-tree harvesting. *Northern Journal of Applied Forestry* 3:97-100.

Abstract: Whole-tree harvesting has the potential to cause different responses in quality of forest streams than those resulting from bole-only harvests. This study sampled turbidity, temperature, and chemistry of streams draining watersheds that were whole-tree harvested in Maine, New Hampshire, and Connecticut. Changes in stream quality can be expected as a result of whole-tree harvesting, but commonsense precautions suggested at the end of this paper can keep the changes within acceptable limits.

Keywords: logging; Northeast; water quality

Hornbeck, J.W., R.S. Rierce, and C.A. Federer. 1970. Streamflow changes after forest clearing in New England. *Water Resources Research* 6(4):1124-1132.

Abstract: Clearing a hardwood forest cover and preventing regrowth with herbicides on a 39-acre watershed in central New England increased annual water yield an average 12.2 area-inches for the first two water years after treatment. Most of this increase occurred during the critical low flow months of June through September, and the amount was governed in large part by rainfall in this period. There was a small advance of snowmelt runoff and a consistent increase in growing season high flow values. These data agree with others showing that sizeable streamflow increases can result from forest clearing in the uplands of the eastern United States.

Keywords: logging; management; Northeast; streamflow; water quantity; water yield

Kochenderfer, J.N., P.J. Edwards, and F. Wood. 1997. Hydrologic impacts of logging an Appalachian watershed using West Virginia's best management practices. *Northern Journal of Applied Forestry* 14(4):207-218.

Abstract: A 39-hectare gauged watershed located in north-central West Virginia near Parsons was cut to a 35.5 centimeter stump diameter and logged using wheeled skidders to evaluate the effectiveness of West Virginia's best management practices (BMPs). Roads initially occupied 10.6% of the watershed, but this percentage is decreasing as much of the original road prism reverts to forest. Reducing basal area by 44% in stems 2.54 centimeters diameter breast height – 4.5 feet above ground and larger had a negligible effect on maximum growing season stream

temperatures, apparently because the stream remained shaded by residual trees and understory shrubs growing along it. Both growing season peakflows and total stormflow had small but significant increases due to treatment. Dormant season stormflows did not increase significantly. Although mean monthly exports of suspended sediment doubled the first year when the area was being logged, they remained within the range reported for carefully managed areas in the East. Sediment exports returned to pretreatment levels by the third post-treatment year. Long-term projections of current exports rates indicate that sediment exports from harvesting operations (three entries) during a 100-year rotation will account for less than 5% of the total sediment exported from the study watershed. Nitrate exports increased significantly during most of the monitored post-treatment years, but fertilizer applied to the roads during grass seeding is believed to have contributed to this increase. Actual concentration values remained low, with maximum concentrations well below standards for potable water. Calcium concentrations also increased during most years, but road liming during seeding probably was responsible for most of this increase. The BMPs used in this study were effective in minimizing adverse impacts to soil and water resources.

Keywords: deforestation; logging; Northeast; sedimentation; water quality; water quantity

Patric, J.H. 1978. Harvesting effects on soil and water in the eastern hardwood forest. *Southern Journal of Applied Forestry* 2(3):66-73.

Abstract: For the eastern United States, there is overwhelming evidence that neither the productivity of forest soil nor the quality of forest water are substantially lessened during or after responsibly managed harvest of wood products. Carelessness, however, damages both resources. The key is forest roads; they cause little adverse effect on soil or water given proper location, drainage, traffic control, and maintenance. The public must better understand that it bears much of the cost for these measures.

Keywords: logging; management; Northeast; Southeast; water quality; water resources

Patric, J.H. 1980. Effects of wood products harvest on forest soil and water relations. *Journal of Environmental Quality* 9(1):73-80.

Abstract: The effects of silvicultural treatments on streamflow have been evaluated for 20 years on a 34.7 hectare (ha) forested catchment on the Fernow Experimental Forest, near Parsons, in north-central West Virginia. Selection harvest of 13, 8, and 6% of the basal area in 1958, 1963, and 1968, respectively, had negligible effect on any measured property of water. In 1969-1970, 31.7 ha were harvested by clearcutting, leaving a 3.0-ha protective strip of lightly cut forest extending about 20 meters along both sides of the stream channel. This treatment had no effect on stormflow or stream temperature, but water yield increased 253 millimeters (mm) (38%) during the first year after cutting. Concentrations of sediment, nitrate, calcium, magnesium, potassium, and sodium in streamflow increased slightly. These effects on water quality were held to low levels by the protective strip and prudent management of logging roads. Subsequent cutting of the protective strip and clearing the stream channel in 1972 increased water yield

40 mm (9%) and raised stream temperature as much as 7.8°C. Luxuriant regrowth over the entire watershed reduced all effects on water within two years after each treatment, and no effect from any treatment was measurable after 1977.

Keywords: logging; Northeast; streamflow; water quality; water quantity

Schaberg, R.H. and R.C. Abt. 2004. Vulnerability of Mid-Atlantic forested watersheds to timber harvest disturbance. *Environmental Monitoring and Assessment* 94(1-3):101-113.

Abstract: Forested watersheds of the Mid-Atlantic region are an important economic resource. They are also critical for maintaining water quality, sustaining important ecological services, and providing habitat to many animal and plant species of conservation concern. These forests are vulnerable to disturbance and fragmentation from changing patterns of land use in the Mid-Atlantic region, and from harvests of commercially mature and relatively inexpensive timber. The U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (FIA) compiles data on forest condition by state and county. This report transforms these FIA data to a U.S. Geological Survey 6-digit hydrologic unit code watershed base, and projected trends in timber growth, inventory, and harvest to 2025 using a timber economics forecasting model. The authors consider forest sustainability from the perspective of timber production, and from the perspective of landscape stability important to conservation values. Simulation data are combined with FIA planted pine acreage data to form a more complete picture of forest extent, composition, and silvicultural practice. Early recognition of prevailing economic trends that encourage the fragmentation of mature forests due to increasing timber harvests may provide managers and policymakers with a planning tool to mitigate undesirable impacts.

Keywords: land use; logging; Northeast; Southeast; water quality; watershed

Southeast

Grace III, J.M. 2004. Soil erosion following forest operations in the southern Piedmont of central Alabama. *Journal of Soil and Water Conservation* 59(4):160-166.

Abstract: In recent years, nonpoint source pollution (NPS) has been recognized as one of the major threats to the nation's water quality. Clearly, forest operations such as harvesting and site preparation have the potential to have degrading impacts on forest water quality. However, there exists a gap in the understanding of the nature and extent of NPS pollution problems related to forest operations. The study presented here was performed in Lee County, Alabama, to investigate the impact of clear-cut harvesting and mechanical site preparation on a 20-year-old loblolly pine (*Pinus taeda* L.) plantation on sediment and runoff yield. Sediment and runoff yield responses on treated areas were compared to that of undisturbed areas. Impacts were evaluated by monitoring isolated small plots, 2 meters (m) (6.6 feet, ft) by 5.5 m (18 ft), over a two-year period following the harvest prescription. Sediment yield from the control treatment was 0.11 tons per hectare (t/ha) (0.30 tons per acre, t/ac) over the study period. Sediment yield increases of 0.11 t/ha (0.30 t/ac) and 1.3 t/ha (3.5 t/ac) were observed from clear cut harvest/site preparation/plant treatment and clear cut harvest/plant treatment, respectively. However, erosion

losses from the most erosive treatment, clear cut harvest/plant, was still very low at less than 1 t/ha/yr. Runoff yield results were similar to those observed with sediment yields from treatments in the investigation. Differences in the two treatments were likely due to the differences in surface roughness, which affect infiltration and surface flow velocity.

Keywords: erosion; logging; sediment; sediment control; Southeast; water quality; water quantity

Grace III, J.M. 2005. Forest operations and water quality in the south. *Transactions of the ASAE* 48(2):871-880.

Abstract: Southern forests, which rely on intensive management practices, are some of the most productive forests in the United States. Intensive forest management utilizes forest operations, such as site preparation, fertilization, thinning, and harvesting, to increase site productivity and reduce rotation time. These operations are essential to meet the ever-increasing demands for timber products. Forest managers utilize forest operations as tools in an attempt to manage the nation's forestlands for multiple uses while maintaining or improving resource quality. Forest operations can influence nonpoint-source (NPS) pollution by disturbing natural processes that maintain water quality. In recent years, NPS pollution has been identified as the nation's largest source of water quality problems. Forest management activities have been identified as activities that influence NPS pollution in the South. Results of watershed-scale studies that investigated the effects of forest operations on water quality in the 13 southern states are highly variable. However, taken collectively, the results indicate that forest operations have little impact on the quality of water draining from forests in the South. Based on this review, best management practices (BMPs) show the potential to protect water quality following forest operations; however, accurate assessments of the overall effectiveness of BMPs are not possible because the benefits of BMPs on different scales are relatively unknown.

Keywords: erosion; logging; Northeast; sediment; South Central; Southeast; water quality; watershed management

Patric, J.H. 1978. Harvesting effects on soil and water in the eastern hardwood forest. *Southern Journal of Applied Forestry* 2(3):66-73.

Abstract: For the eastern United States, there is overwhelming evidence that neither the productivity of forest soil nor the quality of forest water are substantially lessened during or after responsibly managed harvest of wood products. Carelessness, however, damages both resources. The key is forest roads; they cause little adverse effect on soil or water given proper location, drainage, traffic control, and maintenance. The public must better understand that it bears much of the cost for these measures.

Keywords: logging; management; Northeast; Southeast; water quality; water resources

Rummer, B. 1999. Water quality effects of forest roads in bottomland hardwood stands. In *Presented at the 1999 ASAE/CSAE-SCGR Annual International Meeting*, July 18-21, 1999, Toronto, Canada. ASAE, St. Joseph, MI. Paper No. 99-5051.

Abstract: Management of bottomland hardwood sites requires adequate access to support forest operations. A study conducted in a bottomland forest in central Georgia has evaluated the effect of forest road design on sediment movement and water quality. Five years of measurement indicate that a conventional crowned road design is a net sink for sediment, primarily due to settling in ditches. An alternative road design with a flat cross-section was a net source of sediment. Overall, the contribution of sediment from bottomland forest roads is minor in a major river floodplain.

Keywords: erosion; logging; road construction; sediment control; Southeast; water quality

Schaberg, R.H. and R.C. Abt. 2004. Vulnerability of Mid-Atlantic forested watersheds to timber harvest disturbance. *Environmental Monitoring and Assessment* 94(1-3):101-113.

Abstract: Forested watersheds of the Mid-Atlantic region are an important economic resource. They are also critical for maintaining water quality, sustaining important ecological services, and providing habitat to many animal and plant species of conservation concern. These forests are vulnerable to disturbance and fragmentation from changing patterns of land use in the Mid-Atlantic region, and from harvests of commercially mature and relatively inexpensive timber. The U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (FIA) compiles data on forest condition by state and county. This report transforms these FIA data to a U.S. Geological Survey 6-digit hydrologic unit code watershed base, and projected trends in timber growth, inventory, and harvest to 2025 using a timber economics forecasting model. The authors consider forest sustainability from the perspective of timber production, and from the perspective of landscape stability important to conservation values. Simulation data are combined with FIA planted pine acreage data to form a more complete picture of forest extent, composition, and silvicultural practice. Early recognition of prevailing economic trends that encourage the fragmentation of mature forests due to increasing timber harvests may provide managers and policymakers with a planning tool to mitigate undesirable impacts.

Keywords: land use; logging; Northeast; Southeast; water quality; watershed

North Central

Person, M. 1991. Ratings for Potential Water Quality Impairment from Logging Activities in Forested Watersheds. Evaluation of Forest Water Quality Concern Area, Menominee River Basin. Sponsored by The Upper Peninsula Resource Conservation and Development Council and Michigan DNR River Partners Program. September.

Abstract: There is a changing and growing concern for the quality of all water resources within the United States. The water quality efforts which once primarily addressed point source pollutants are shifting to more localized efforts focusing on more diffuse nonpoint source pollution. While these efforts most often target areas of agriculture and urban run-off, the logging industry is beginning to receive its share of scrutiny in regard to its potential nonpoint impacts.

As environmentalists and the logging industries battle over these issues, public natural resource agencies are finding themselves in the middle of the controversy. This has sparked much debate over public policy in regard to logging. However, one thing is agreed: there is a great need to better understand and quantify water quality impacts from logging practices.

Recent environmental legislation is making it increasingly harder for logging companies throughout the western United States to operate effectively. Yet, an environmentally conscious society is pushing for further environmental regulation.

In Michigan, the logging controversy is evolving although it is relatively new. The Michigan Department of Natural Resources (MDNR) has begun implementing a nonregulatory and educational approach to these logging concerns. Some of Michigan's forest product industries have begun considering ways to become more accountable before Michigan takes a regulatory approach similar to many western states.

Providing quantifiable data to validate water quality problems resulting from logging is a first step to encourage a self-regulatory approach. It is important to also provide a concise and comprehensive educational program and provide standards for basing best management decisions on. MDNR is in the process of implementing both aspects, which should be encouraged and supported.

The procedure outlined and used in developing this report can be utilized to identify environmentally sensitive water quality concern areas in regard to forest land. The results of the study will be used to generally indicate the areas and types of water quality concerns on forest lands within five major drainage areas in Michigan. These watersheds have been identified as study areas as part of the U.S. Department of Agriculture sponsored Menominee River Basin Study. Hopefully, the results of this evaluation will provide a foundation for groups seeking funding to further study water quality impacts of forest management.

Keywords: logging; management; North Central; water quality

Queen, L.P., K.N. Brooks, and W.L. Wold. 1995. Assessing cumulative effects in the Nemadji river basin, Minnesota. In *Watershed Management: Planning for 21st Century*. T. J. Ward (ed.) American Society of Civil Engineers, New York, pp. 239-248.

Abstract: The Nemadji River in northeastern Minnesota contributes an estimated 525,000 metric tons of sediment per year to Lake Superior. A portion of the Nemadji Basin is composed of highly erodible red clays that are susceptible to soil mass movement. The red clay area was studied in the late 1970s through a joint interagency project that concluded that natural levels of erosion-sedimentation in the red clay area have been intensified by human activity. The cumulative effects of logging, burning, clearing for agriculture, and road construction are

increased runoff, higher peak streamflows, rapid channel scouring, increased soil mass movement, and stream bank undercutting. This study uses a Geographic Information System to analyze watershed characteristics of subwatersheds within the Nemadji Basin. Bivariate analyses indicated that the frequency of slump occurrence was inversely related to the total forested area. The results of this investigation indicate that the percent of nonforested area is related to a greater frequency of soil slumps, and that management should be aimed at increasing and maintaining forest cover in the watershed.

Keywords: development; erosion; fire; logging; mudslide; North Central; risk reduction; runoff; sediment control; vegetation change; watershed management

South Central

Grace III, J.M. 2005. Forest operations and water quality in the south. *Transactions of the ASAE* 48(2):871-880.

Abstract: Southern forests, which rely on intensive management practices, are some of the most productive forests in the United States. Intensive forest management utilizes forest operations, such as site preparation, fertilization, thinning, and harvesting, to increase site productivity and reduce rotation time. These operations are essential to meet the ever-increasing demands for timber products. Forest managers utilize forest operations as tools in an attempt to manage the nation's forestlands for multiple uses while maintaining or improving resource quality. Forest operations can influence nonpoint-source (NPS) pollution by disturbing natural processes that maintain water quality. In recent years, NPS pollution has been identified as the nation's largest source of water quality problems. Forest management activities have been identified as activities that influence NPS pollution in the South. Results of watershed-scale studies that investigated the effects of forest operations on water quality in the 13 southern states are highly variable. However, taken collectively, the results indicate that forest operations have little impact on the quality of water draining from forests in the South. Based on this review, best management practices (BMPs) show the potential to protect water quality following forest operations; however, accurate assessments of the overall effectiveness of BMPs are not possible because the benefits of BMPs on different scales are relatively unknown.

Keywords: erosion; logging; Northeast; sediment; South Central; Southeast; water quality; watershed management

Northwest

Bloem, D.M., R.H. Hawkins, and R.W. Robbins. 1995. Detection of land use effects in the flows of the Bull Run river, Oregon. In *Watershed Management: Planning for the 21st century*. T. J. Ward (ed.). American Society of Civil Engineers, New York, pp. 429-437.

Abstract: Streamflow records for the Bull Run River, Oregon, from 1920 to 1992, were analyzed to determine if the watershed yield had changed over time. An increase in annual water yield of about 7% [55 cubic feet per second (cfs)] was detected to have occurred beginning in 1960. This date corresponds to the time when the streamflow gauge was moved, and to the beginning of a period of road construction and timber harvest. Data from a nearby reference gauge were used to remove the effects of climatic variation. After accounting for effects of gauge relocation, and changes in impervious road area, reservoir interception, and fog drip, the remaining increase of 1.5 to 2% (11-15 cfs) was attributed to silvicultural effects. All monthly yields showed post-1960 increases from some combination of larger drainage area and changes in watershed land use, although in some months this increase was overshadowed by a decrease in yield from climatic effects.

Keywords: case study; logging; Northwest; road construction; Streamflow; water quantity; water yield; watershed management

Harr, R.D. 1980. Streamflow After Patch Logging in Small Drainages Within the Bull Run Municipal Watershed, Oregon. Research Paper PNW-268. USDA Forest Service Pacific Northwest Forest and Range Experiment Station.

Abstract: Three experimental watersheds in the City of Portland's Bull Run Municipal Watershed were used to determine the effects of patch logging on timing and quantity of streamflow. Annual water yields and size of instantaneous peak flows were not significantly changed, but low flow decreased significantly after logging of two small watersheds in small, clearcut patches totaling 25% of each watershed's area.

Keywords: case study; logging; Northwest; streamflow; vegetation change; water yield

Harr, R.D. 1982. Fog drip in the Bull Run Municipal Watershed, Oregon. *Water Resources Bulletin* 18(5):785-789.

Abstract: Net precipitation under old growth Douglas fir forest in the Bull Run Municipal Watershed (Portland, Oregon) totaled 1,739 millimeters during a 40-week period, 387 mm more than in adjacent clearcut areas. Expressing data on a full water year basis and adjusting gross precipitation for losses due to rainfall interception suggest fog drip could have added 882 mm of water to total precipitation during a year when precipitation measured 2,160 mm in a rain gauge in a nearby clearing. Standard rain gauges installed in open areas where fog is common may be collecting up to 30% less precipitation than would be collected in the forest. Long-term forest management (i.e., timber harvest) in the watershed could reduce annual water yield and, more importantly, summer streamflow by reducing fog drip.

Keywords: case study; fog drip; logging; Northwest; water quantity

Harr, R.D. 1986. Effects of clearcutting on rain-on-snow runoff in western Oregon: a new look at old studies. *Water Resources Research* 22(7):1095-1100.

Abstract: Results of updating and reanalyzing streamflow data from studies in two experimental watersheds in western Oregon suggest that clearcut logging has altered snow accumulation and snowmelt enough to have increased the size of peak flows caused by snowmelt during rainfall. In a 96-hectare (ha) clearcut watershed in the transient snow zone, peak flows with return periods of roughly 3-8 years were higher than predicted by prelogging data. In a similarly clearcut 10-ha watershed, sizes of peak flows caused by melting of relatively deep snowpacks during rainfall were also higher after logging. Higher peak flows indicate a higher rate of water delivery to soils, which, in turn, suggests increased potential for both hillslope and channel erosion.

Keywords: erosion; logging; Northwest; snowmelt; water quantity; water yield

Harr, R.D. and R.L. Fredriksen. 1988. Water quality after logging small watersheds within the Bull Run Watershed, Oregon. *Journal of the American Water Resources Association* 24(5):1103-1111.

Abstract: Road building, clearcutting 25% of the watershed, and slash disposal by broadcast burning or by natural decomposition caused changes in water quality of two small streams in the Bull Run Watershed in Oregon, which supplies water to the Portland, Oregon, metropolitan area. Concentrations of suspended sediment increased slightly, primarily owing to the construction of a permanent logging road that crossed streams. Changes in nutrient cycling occurred due to logging and slash disposal in both watersheds where cutting was done. Nitrate-nitrogen (NO_3^--N) concentrations, which increased most where logging residue was left to decompose naturally, increased more than sixfold and commonly exceeded 100 micrograms per liter (µg/L) during the October-June high-flow season for seven years after logging. Where logging slash was broadcast burned, NO_3^--N concentrations increased roughly fourfold, but rarely exceeded 50 µg/L, and increases had mostly disappeared six years after slash burning. Changes in outflows of cations and other anions were not apparent. Annual maximum stream temperatures increased 2-3°C after logging, but temperature increases had mostly disappeared within three years as vegetation regrowth shaded the streams.

Keywords: anion; case study; cation; development; erosion; logging; nitrate; Northwest; sediment; water quality; water quantity; water yield

Hicks, B.J., R.L. Beschta, and R.D. Harr. 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. *Journal of the American Water Resources Association* 27(2):217-226.

Abstract: The long-term effect of logging on low summer stream-flow was investigated with a dataset of 36 years. Hydrologic records were analyzed for the period 1953 and 1988 from Watershed (WS) 1 (clearcut logged and burned), WS 2 (unlogged control), and WS 3 (25% patch-cut logged and burned) in the H. J. Andrews Experimental Forest, western Cascade Range, Oregon. These records spanned 9-10 years before logging, and 21-25 years after logging and burning. Streamflows in August were the lowest of any month, and were unaffected by occasional heavy rains that occurred at the beginning of summer. August streamflows increased in WS 1 compared to WS 2 by 159% following logging in WS 1, but this increase lasted for only eight years following the start of logging in 1962. Water yield in August for 1970-1988 observed from WS 1 was 25% less than predicted from the control (WS 2, ANOVA, $p = 0.032$).

Water yield in August increased by 59% after 25% of the area of WS 3 was patch-cut logged and burned in 1963. In contrast to WS 1, however, water yields from WS 3 in August were consistently greater than predicted for 16 years following the start of logging, through to 1978. For the 10 years 1979 to 1988, water yield observed in August from WS 3 was not different than predicted from control (WS 2, analysis of variance (ANOVA), p value = 0.175).

The contrasting responses of WS 1 and 3 to logging are thought to be the result of differences in riparian vegetation caused by different geomorphic conditions. A relatively wide valley floor in WS 1 allowed the development of hardwoods in the riparian zone following logging, but the narrow valley of WS 3 and limited sediment deposits prevented establishment of riparian hardwoods.

Low streamflows during summer have implications for salmonid survival.

Reduced streamflow reduces the amount of rearing habitat, thus increasing competition. Combined with high water temperatures, reduced streamflow can lead directly to salmonid mortality by driving salmonids from riffles and glides, and trapping them in drying pools. Low streamflow also increases oxygen depletion caused by leaves from riparian red alders.

Keywords: logging; Northwest; streamflow; vegetation change; water quantity; water yield

Ingwersen, J.B. 1985. Fog drip, water yield, and timber harvesting in the Bull Run Municipal Watershed, Oregon. *Journal of the American Water Resources Association* 21(3):469-473.

Abstract: Analysis of recent streamflow data from other Fox Creek Experimental Watersheds in the Bull Run Municipal Watershed, Oregon, indicates a significant recovery from the impacts on summer water yield due to a loss of fog drip upon timber harvesting. Measurable impacts and their associated recovery are notable only during the months of June and July. Recovery begins about five or six years following harvest, possibly due to renewed fog drip from prolific revegetation. Watershed positioning with respect to prevailing weather systems and the extent of burning or removal of slash and residual vegetation during logging appear to be important factors in predicting the impact of fog drip reduction associated with the planned harvest. Apparently, once the temporary reduction in summer yield is offset by renewed fog drip, the expected increase in yield due to decreased evapotranspiration can be observed. Redistribution of fog drip may be a major factor in the measurements of local interception and water yield.

Keywords: case study; fog drip; logging; Northwest; water quality; water quantity; water yield

Jones, J.A. 2000. Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon. *Water Resources Research* 36(9):2621-2642.

Abstract: The magnitude, seasonality, and duration of peak discharge responses to forest removal and regrowth and roads in 10 pairs of experimental basins in the western Cascade Range of Oregon are consistent with fundamental water balance and routing concepts in hydrology.

Hypothesized effects of forestry treatments on evapotranspiration, cloud water interception, snowpack dynamics, and subsurface flow interception vary predictably by season, geographic setting, amount of forest canopy removal, stage of canopy regrowth, and arrangement of roads in the basin. Post-treatment responses of selected subpopulations of matched peak discharge events were examined over 10- to 34-year post-treatment periods in treated-control basin pairs in a range of geographic settings. Changes in evapotranspiration associated with forest canopy removal and regrowth apparently accounted for significant increases (31-116%) in peak discharges during the first post-harvest decade of 8 to 10 treated basins, but the vents that were affected were small (< 0.22- or 0.28-year return periods) and occurred in the fall (September-November), when soils are in the moisture deficit, rather than spring (March-May), when soils are in moisture surplus. For a given amount of forest canopy removal, initial increases in small, fall events were greater in drier basins than wetter basins, and increases tended to disappear as forest canopies regrew. Changes in cloud water interception apparently offset changes in evapotranspiration in two partially cut basins. Changes in snowpack dynamics apparently accounted for significant increases (25-31%) in winter rain-on-snow events, but other types of winter events did not change, in four of the five basins at the H.J. Andrews Experimental Forest. Changes in subsurface flow interception apparently accounted for significant increases (13-36%) in large (> 1-year return period) events in seven of the eight basins with roads, and, controlling geographic location, the magnitude of increases was related to the density of midslope roads.

Keywords: development; logging; Northwest; streamflow; watershed

Jones, J.A. and G.E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. *Water Resources Research* 32(4):959-974.

Abstract: This study quantified long-term changes in streamflows associated with clear-cutting and road construction and examined alternative hydrologic mechanisms to explain stream hydrograph changes in the Cascades Range, western Oregon. Differences in paired peak discharges for 150 to 375 storm events for five basin pairs were examined, using 34-year records from two pairs of 60 to 101 hectares experimental basins in the H.J. Andrews Experimental Forest, and 50 to 55 year records from three pairs of adjacent basins ranging from 60 to 600 square kilometers. Forest harvesting has increased peak discharges by as much as 50% in small basins and 100% in large basins over the past 50 years. These increases are attributable to changes both in flow routing due to roads and in water balance due to treatment effects and vegetation succession.

Keywords: development; logging; Northwest; streamflow

Keppeler, E.T. 1998. The summer flow and water yield response to timber harvest. In *Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story*, May 6, 1998. pp. 35-43. USDA Forest Service General Technical Report PSW-GTR-168. June. Available: http://www.fs.fed.us/psw/publications/documents/psw_gtr168/.

Abstract: Continuous measurement of streamflow at the Caspar Creek watersheds has led to several analyses of the effects of two harvest methods (selection and clearcut) on summer flows and annual yield. Although all Caspar Creek analyses have indicated an increase in runoff after timber removal, the magnitude and duration of the response depend on the nature and extent of the logging and site preparation, climatic conditions, as well as the definition of the hydrologic parameter at issue. Regression analysis using a calibration period of 1963 to 1971 was used to compare annual yield, summer flow volume, and minimum streamflow between the South Fork (SFC) and the North Fork (NFC) of Caspar Creek for a 35-year period. Selection/tractor logging of the SFC increased annual yield by a maximum of 2,053 cubic meters per hectare per year ($m^3ha^{-1}yr^{-1}$) during the seventh water year after harvest, began. Increased yields were observed beginning the second post-harvest year and averaged 15% or 932 $m^3ha^{-1}yr^{-1}$. Following clearcut logging of 50% of the NFC watershed, annual yield increased by as much as 1,032 $m^3ha^{-1}yr^{-1}$ eight years after logging and averaged 15% or 608 $m^3ha^{-1}yr^{-1}$ beginning in the second postharvest year. Streamflow changes due to logging are most evident during the long, dry summer season typical of northwestern California. During this prolonged recession, zones of deep perennial saturation maintain streamflow (baseflow). Statistically significant summer flow enhancements were evident on the SFC for seven years after logging. Subsequently, SFC summer yields fell at or below pretreatment predictions. Although summer flow increases amounted to relatively minor changes in minimum discharge averaging only 0.25 liters per second per square kilometer ($L\ s^{-1}km^{-2}$) on SFC and 0.40 $L\ s^{-1}km^{-2}$ on NFC, these enhancements are quite substantial in comparison to pretreatment summer low flows. Minimum discharge increases averaged 38% after the SFC selection logging and 148% after the NFC harvest and site preparation. NFC flow enhancements persist through hydrologic year 1997 with no recovery trend, as yet. After logging, reduced interception and evapotranspiration allow for additional water to be stored in the soil and routed to streams as summer baseflow. At Caspar Creek, enhanced soil moisture in the rooting zone followed timber harvest in the NFC clearcut units. Previously intermittent stream reaches and soil pipes became perennial. The larger increases in minimum flows observed on the NFC are probably due to wetter soils in the clearcut units where little vegetation exists to use this enhanced moisture. On the selectively cut SFC, mature residual forest vegetation more readily exploited this additional soil moisture. Fog plays an important role in the regional ecology by moderating evapotranspiration. However, Caspar Creek data indicate that any possible postlogging loss of fog drip did not result in a net reduction in streamflow. Moisture savings due to reduced evapotranspiration appear to override any fog precipitation losses at this site.

Keywords: case study; erosion; logging; Northwest; runoff; sediment; streamflow; water quantity

Lewis, J., S.R. Mori, E.T. Keppeler, and R.R. Ziemer. 2000. Impacts of logging on storm peak flows, flow volumes and suspended sediment loads in Caspar Creek, California. In *Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas*. M. S. Wigmosta and S. J. Burges (eds.). American Geophysical Union, Washington, DC, pp. 85-125.

Abstract: Models are fit to 11 years of storm peak flows, flow volumes, and suspended sediment loads on a network of 14 stream gauging stations in the North Fork Caspar Creek, a 473-hectare coastal watershed bearing a second-growth forest of redwood and Douglas-fir. For the first four years of monitoring, the watershed was in a relatively undisturbed state, having last been logged prior to 1904, with only a county road traversing the ridge tops. Nearly half the watershed was clear-cut over a period of three years, and yarded primarily using uphill skyline cable systems to spur roads constructed high on the slopes. Three tributaries were maintained as controls and left undisturbed. Four years of data were collected after logging was completed. Exploratory analysis and model fitting permit characterization and quantification of the effects of watershed disturbances, watershed area, antecedent wetness, and time since disturbance on storm runoff and suspended sediment. Model interpretations provide insight into the nature of certain types of cumulative watershed effects.

Keywords: case study; erosion; logging; Northwest; sediment; streamflow; water quantity; watershed management

Megahan, W.F. and D.C. Molitor. 1975. Erosion effects of wildfire and logging in Idaho. In *Watershed Management Symposium*, August 1975, Logan, UT. American Society of Civil Engineers Irrigation and Drainage Division, New York, pp. 423-444.

Abstract: Erosion was evaluated on clearcut and unlogged study watersheds that had been subjected to wildfire. Soils found on the study watersheds exhibited the high erodibility characteristics of the granitic soils found in the Idaho batholith. Erosion data were collected by rill surveys, erosion pins, splash pans, and sediment collection troughs. Additional data to record vegetation responses and soil water repellency were collected using a grid sampling technique. Considerable erosion occurred as the results of overland flow and raindrop splash on the clearcut watershed. There was no evidence of erosion from overland flow on the unlogged watershed, but there was slight splash erosion. Canopy cover effects and litter production from the fire-killed trees were probably an important factor regulation erosion on the unlogged areas. Greater fuel loading and the consequent more intense burn on the clearcut area also probably had an effect by reducing soil surface protection, influencing vegetation responses, and increasing soil water repellency.

Keywords: erosion; fire; logging; Northwest; sediment; stormflow

Moore, R.D. and S.M. Wondzell. 2005. Physical hydrology and the effects of forest harvesting in the Pacific Northwest: a review. *Journal of the American Water Resources Association* 41(4):763-784.

Abstract: The Pacific Northwest encompasses a range of hydrologic regimes that can be broadly characterized as either coastal (where rain and rain on snow are dominant) or interior (where snowmelt is dominant). Forest harvesting generally increases the fraction of precipitation that is available to become streamflow, increases rates of snowmelt, and modifies the runoff pathways by which water flows to the stream channel. Harvesting may potentially decrease the magnitude of hyporheic exchange flow through increases in fine sediment and clogging of bed materials and through changes in channel morphology, although the ecological consequences of these changes are unclear. In small headwater catchments, forest harvesting generally increases annual runoff and peak flows and reduces the severity of low flows, but exceptions have been observed for each effect. Low flows appear to be more sensitive to transpiration from vegetation in the riparian zone than in the rest of the catchment. Although it appears that harvesting increased only the more frequent, geomorphologically benign peak flows in several studies, in others the treatment effect increased with return period. Recovery to pre-harvest conditions appeared to occur within about 10 to 20 years in some coastal catchments, but may take many decades in mountainous, snow-dominated catchments.

Keywords: logging; Northwest; rehabilitation; streamflow

Noble, E.L. and L. Lundeen. 1971. Analysis of rehabilitation treatment alternatives for sediment control. In *Symposium on Forest Land Uses and Stream Environment*, October 19-21 1971, Corvallis, OR. pp. 86-96. Oregon State University School of Forestry and Department of Fisheries and Wildlife Continuing Education Publications.

Abstract: The aquatic environment of the South Fork Salmon River has been severely damaged in recent years by excessive rates of sediment production. A special study was conducted to determine the source and extent of the damage, and measures required to reduce future sediment production to a “tolerable” level. Linear programming was used as an aid to select from 190 possible treatment alternatives and minimize treatment costs at various levels of sediment reduction. The desired level of sediment could be reached at a cost of $5 million. Debris basins to trap sediment moving in the channel were the most effective and economical type of treatment, while control of sediment production from roads and timber harvest on steep, fragile lands would have been very costly.

Keywords: development; logging; Northwest; sedimentation; water quality

Rashin, E.B., C.J. Clishe, A.T. Loch, and J.M. Bell. 2006. Effectiveness of timber harvest practices for controlling sediment related water quality impacts. *Journal of the American Water Resources Association* (October):1307-1327.

Abstract: Timber harvest best management practices (BMPs) in Washington State were evaluated to determine their effectiveness at achieving water quality standards pertaining to sediment-related effects. A weight-of-evidence approach was used to determine BMP effectiveness based on assessment of erosion with sediment delivery to streams, physical disturbance of stream channels, and aquatic habitat conditions during the first two years following harvest. Stream buffers were effective at preventing chronic sediment delivery to streams and physical disturbance of stream channels. Practices for ground-based harvest and cable yarding in the vicinity of small streams without buffers were ineffective or only partially effective at preventing water quality impacts. The primary operational factors influencing BMP effectiveness were the proximity of ground disturbing activities to streams; the presence or absence of designated stream buffers; the use of special timber falling and yarding practices intended to minimize physical disturbance of stream channels; and the timing of harvest to occur during snow cover or frozen ground conditions. Important site factors included the density of small streams at harvest sites and the steepness of inner stream valley slopes. Recommendations are given for practices that provide a high confidence of achieving water quality standards by preventing chronic sediment delivery and avoiding direct stream channel disturbance.

Keywords: erosion; logging; Northwest; sediment; sediment control; water quality

Southwest

Barrett, J.C. and W.J. Conroy. 2001. Evaluation of timber harvest impacts on water quality. In *AWRA Annual Spring Specialty Conference: Water Quality Monitoring and Modeling*, April 30-May 2, 2001, San Antonio, TX. Warwick, J.J. (ed.). American Water Resources Association, Middleburg, VA, pp. 205-210.

Abstract: The Pacific Lumber Company in 1999 signed a Habitat Conservation Plan that commits it to conduct watershed analysis studies, monitoring, and research to determine how its timber harvesting practices impact water quality, and how best to reduce those impacts. The watershed analysis assesses impacts to water quality by evaluating sediment inputs to streams and the ability of riparian forest stands to protect beneficial uses of water. Studies to date have documented that surface erosion from roads is the primary impact to water quality in low-relief portions of the ownership, whereas mass wasting processes are the predominant impact in high-relief areas. Research efforts have focused on the calibration and use of the U.S. Forest Service Water Erosion Potential Project model to estimate sediment volumes generated by timber harvest operations. The work includes the evaluation of the effectiveness of hillslope management strategies and riparian buffers in preventing sediment delivery to streams.

Keywords: erosion; logging; prevention; road construction; sediment control; Southwest; water quality

Cafferata, P.H. and T.E. Spittler. 1998. Logging impacts of the 1970's vs. the 1990's in the Caspar Creek watershed. In *Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story*, May 6, 1998. pp. 103-115. USDA Forest Service General Technical Report PSW-GTR-168. June. Available: http://www.fs.fed.us/psw/publications/documents/psw_gtr168/.

Abstract: The Caspar Creek watershed study provides resource professionals with information regarding the impacts of timber operations conducted under varying forest practices on sensitive aquatic habitats. In the South Fork watershed, roads were constructed near watercourse channels in the 1960's, and the watershed was selectively logged using tractors during the early 1970's. Subwatersheds in the North Fork were clearcut from 1985 to 1991 using predominantly cable yarding and roads located high on ridges. Numerous landslides were documented after road construction and logging in the South Fork owing to inadequate road, skid trail, and landing design, placement, and construction. In contrast, the size and number of landslides after timber operations in the North Fork to date have been similar in logged and unlogged units. Considerably more hillslope erosion and sediment yield have also been documented after logging operations in the South Fork, when compared to the North Fork. An analysis of the storm events associated with documented landslides showed that high 3-day or 10-day precipitation totals in combination with moderately high 1-day amounts have been more important than very high 1-day totals alone in triggering debris sliding at Caspar Creek. Storm sequences meeting the criteria required for causing documented landslides were found to have occurred in all phases of the 36-year study, with the greatest number occurring in water year 1998. Numerous large landslides associated with the road system in the South Fork occurred in early 1998, indicating that "legacy" roads continue to be significant sources of sediment decades after they were constructed.

Keywords: case study; development; erosion; landslide; logging; Southwest; water quantity; watershed

Coats, R. and L. Collins. 1984. Streamside landsliding and channel change in a suburban forested watershed: effects of an extreme event. In *Symposium on Effects of Forest Land Use on Erosion and Slope Stability*, 7-11 May, 1984, Honolulu, HI. O'Loughlin, C.L. and Pearce, A.J. (eds.). pp. 165-175.

Abstract: A continuing controversy in the management of steep and unstable forested land is the relative importance of land disturbance and extreme climatic events in triggering mass wasting and channel change. In California, this controversy has been brought into sharp focus in recent years by increasing concern for water quality and anadromous fisheries. Conflicts are especially acute where suburban growth impinges on productive forest land in areas of high rainfall and unstable terrain. New forest residents often express concern about geomorphic and aesthetic effects of logging, yet residential development itself is not without effects on the stream environment.

Large and infrequent storms provide a unique learning opportunity. For the land manager and land use planner, they are a severe test of the efficacy of forest practice regulation and land use controls. For the geomorphologist, they provide valuable lessons in geomorphic effectiveness and landscape evolution. This paper reports on the effects of the January 1982 storm in Zayante Creek Basin and the lower San Lorenzo River in Santa Cruz County, California.

Keywords: development; erosion; landslide; logging; Southwest; storm; water quality

Dahlgren, R.A. 1998. Effects of forest harvest on stream-water quality and nitrogen cycling in the Caspar Creek Watershed. In *Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story*, May 6, 1998. pp. 45-53. USDA Forest Service General Technical Report PSW-GTR-168. June. Available: http://www.fs.fed.us/psw/publications/documents/psw_gtr168/.

Abstract: The effects of forest harvest on stream-water quality and nitrogen cycling were examined for a redwood/Douglas-fir ecosystem in the North Fork, Caspar Creek experimental watershed in northern California. Stream-water samples were collected from treated (e.g., clearcut) and reference (e.g., noncut) watersheds, and from various locations downstream from the treated watersheds to determine how far the impacts of these practices extended. Additionally, a detailed nutrient cycling study was performed in a clearcut and reference watershed to gain insights into changes in nitrogen cycling after harvesting activities. Stream-water nitrate concentrations were higher in clearcut watersheds, especially during high stream discharge associated with storm events. Elevated concentrations of nitrate were due to increased leaching from the soil as mineralization (i.e., release of nutrients from organic matter) was enhanced and nutrient uptake by vegetation was greatly reduced after harvest. The elevated nitrate concentration in stream water from clearcut watersheds decreased in the higher-order downstream segments. This decrease is believed to be primarily due to dilution, although in-stream immobilization may also be important. Although elevated nitrate concentrations in stream water from the clearcut watershed might suggest a large nitrogen loss after clearcutting, conversion to a flux indicates a maximum loss of only 1.8 (kilograms of nitrogen per hectare per year, kg N ha^{-1} yr^{-1}); fluxes decreased to < 0.4 kg N ha^{-1} yr^{-1} three years after the harvest. Nitrogen fluxes from the reference watershed over the same period were < 0.1 kg N ha^{-1} yr^{-1}. The increased nitrogen flux was due to both higher nitrate concentrations and an increased water flux from the clearcut watershed. In contrast to many forest ecosystems that show large nutrient losses in stream water after harvest, this redwood/Douglas-fir ecosystem shows relatively small losses. The rapid regrowth of redwood stump sprouts, which use the vast rooting system from the previous tree, is capable of immobilizing nutrients in its biomass, thereby attenuating nutrient losses by leaching. Rapid regeneration also provides soil cover that appreciably reduces the erosion potential after harvest. Removal of nitrogen, primarily in the harvested biomass, results in an appreciable loss of nitrogen from the ecosystem. These data suggest that nitrogen fixation by Ceanothus may be an important nitrogen input that is necessary to maintain the long-term productivity and sustainability of these ecosystems.

Keywords: case study; erosion; logging; management; sediment; Southwest; streamflow; water quality

Klamt, R.R. 2000. The Garcia experience: a sediment TMDL case study. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 29-34. Water Resources Center Report No. 98.

Abstract: Salmon and steelhead play a significant role in California north coastal economy, philosophy, and politics. Author Mark Twain is credited with saying that in the West, whisky is for drinking and water is to fight over. More recently on the north coast, the fight has focused on salmon and land use. Continued concern for the anadromous fisheries has turned attention from the water itself to the riparian zone and hill slopes of the steep erosive coastal mountains of northern California.

The Garcia River is a coastal tributary located about 100 miles north of San Francisco Bay. It is forested with commercial conifers and hardwoods and supports farming and cattle and sheep ranching. Historic waves of logging activity at different levels of regard for the land and water resources coupled with erosive soils on steep slopes and high winter rainfall resulted in significant erosion and sedimentation. Concern over declining anadromous salmonid populations brought attention to sediment impacts in the Garcia River watershed. That focus and threat of a lawsuit prompted the development of a sediment reduction strategy (TMDL) that addresses habitat and channel structure in the waterways by requiring landowners to submit erosion control plans. In May 1998 the North Coast Regional Water Quality Control Board adopted a TMDL and implementation plan with the assistance of the U.S. Environmental Protection Agency. Controllable sediment discharges are prohibited, and reductions of sediment delivery to streams from roads, timber harvest, and agriculture are required on a 40-year time table. Instream numeric targets that describe the desired future conditions of the riparian area, stream channel and fish habitat are used as goals to measure the success of the reductions over time. The development of the TMDL and, especially, the implementation plan were contentious and involved numerous public workshops and hearings over a 2-year period. However, landowner response and attitude and, subsequently, the nature of land use activities is slowly changing. Landowner inventories and monitoring will provide a physical assessment of watershed recovery. The response of the fisheries will tell the ultimate story.

Keywords: case study; development; erosion; grazing; land management; land use; logging; sediment; Southwest; vegetation; water quality; water resources; watershed

Kulakowski, D. and T.T. Veblen. 2007. Effect of prior disturbances on the extent and severity of wildfire in Colorado subalpine forests. *Ecology* 88(3):759-769.

Abstract: Disturbances are important in creating spatial heterogeneity of vegetation patterns that in turn may affect the spread and severity of subsequent disturbances. Between 1997 and 2002, extensive areas of subalpine forests in northwestern Colorado were affected by a blowdown of trees, bark beetle outbreaks, and salvage logging. Some of these stands were also affected by severe fires in the late 19th century. During a severe drought in 2002, fires affected extensive

areas of these subalpine forests. The authors evaluated and modeled the extent and severity of the 2002 fires in relation to these disturbances that occurred over the five years prior to the fires and in relation to late 19th century stand-replacing fires. Occurrence of disturbances prior to 2002 was reconstructed using a combination of tree-ring methods, aerial photograph interpretation, field surveys, and geographic information systems (GIS). The extent and severity of the 2002 fires were based on the normalized difference burn ratio derived from satellite imagery. GIS and classification trees were used to analyze the effects of prefire conditions on the 2002 fires. Previous disturbance history had a significant influence on the severity of the 2002 fires. Stands that were severely blown down (> 66% trees down) in 1997 burned less severely than older stands. In contrast, prefire disturbances were poor predictors of fire extent, except that young (~120 year old) postfire stands burned less severely than older stands. Salvage logging and bark beetle outbreaks that followed the 1997 blowdown (within the blowdown as well as in the adjacent forest that was not blown down) did not appear to affect fire extent or severity. Conclusions regarding the influence of the beetle outbreaks on fire extent and severity are limited, however, by spatial and temporal limitations associated with aerial detection surveys of beetle activity. Thus, fire extent in these forests is largely independent of prefire disturbance history and vegetation conditions. In contrast, fire severity, even during extreme fire weather and in conjunction with a multiyear drought, is influenced by prefire stand conditions, including the history of previous disturbances.

Keywords: blowdown; fire; insect pest; land use; logging; Southwest

Lewis, J. 1998. Evaluating the impacts of logging activities on erosion and suspended sediment transport in the Caspar Creek watersheds. In *Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story*, May 6, 1998. pp. 55-69. USDA Forest Service General Technical Report PSW-GTR-168. June. Available: http://www.fs.fed.us/psw/publications/documents/psw_gtr168/.

Abstract: Suspended sediment has been sampled at both the North and South Fork weirs of Caspar Creek in northwestern California since 1963, and at 13 tributary locations in the North Fork since 1986. The North Fork gauging station (NFC) was used as a control to evaluate the effects of logging in the South Fork in the 1970s on annual sediment loads. In the most conservative treatment of the data, suspended loads increased by 212% over the total predicted for a 6-year period commencing with the onset of logging. When the roles of the watersheds were reversed and the same analysis repeated to evaluate harvesting in the North Fork under California Forest Practice Rules in the 1990s, no significant increase was found at NFC in either annual suspended or bed load. With the advent of automatic pumping samplers, the authors were able to sample sediment concentration much more frequently in the 1980s. This allowed storm event loads from control watersheds in the North Fork to be used in a new regression analysis for NFC. According to this more sensitive analysis, for the 7-year period commencing with the onset of logging, the sum of the suspended storm loads at NFC was 89% higher than that predicted for the undisturbed condition. The much greater increase after logging in the South Fork is too great to be explained by differences in sampling methods and in water years, and appears to be the result of differences in road alignment, yarding methods, and stream protection zones. Similar

analyses of storm event loads for each of the treated subwatersheds in the North Fork suggested increased suspended loads in all but one of the tributaries, but effects were relatively small or absent at the main stem locations. Of watersheds with less than 50% cut, only one showed a highly significant increase. The greater increase in sediment at NFC, compared to other main-stem stations, is largely explained by a 3,600-cubic meter landslide that occurred in 1995 in a subwatershed that drains into the main stem just above the NFC. Differences among tributary responses can be explained in terms of channel conditions. Analysis of an aggregated model simultaneously fit to all of the data shows that sediment load increases are correlated with flow increases after logging. Field evidence suggests that the increased flows, accompanied by soil disruption and intense burning, accelerated erosion of unbuffered stream banks and channel headward expansion. Windthrow along buffered streams also appears to be important as a source of both woody debris and sediment. All roads in the North Fork are located on upper slopes and do not appear to be a significant source of sediment reaching the channels. The aggregated model permitted evaluation of certain types of cumulative effects. Effects of multiple disturbances on suspended loads were approximately additive and, with one exception, downstream changes were no greater than would have been expected from the proportion of area disturbed. A tendency for main-stem channels to yield higher unit-area suspended loads was also detected, but after logging this was no longer the case in the North Fork of Caspar Creek.

Keywords: case study; erosion; landslide; logging; sediment; Southwest; streamflow

Lopes, V.L. and P.F. Folliott. 1995. Effects of forest harvesting practices on streamflow-sediment relationships for southwestern ponderosa pine watersheds. In *Watershed Management: Planning for the 21st Century*. T. J. Ward (ed.) American Society of Civil Engineers, New York, pp. 64-72.

Abstract: Streamflow was measured and suspended sediment concentrations sampled on three ponderosa pine forest watersheds as part of an environmental monitoring program in northern-central Arizona. One watershed was completely cleared of forest overstory (clear-cut), another was partially cleared (strip-cut), and a third remained in uncut conditions as a control. Data obtained eight years after the watersheds treatments were used to evaluate forest harvesting practices on streamflow-suspended sediment relationships for the watersheds. The dataset obtained for each watershed was partitioned by streamflow-generation mechanisms and hydrograph stage in developing sediment rating curves. The clear-cut watershed produced the highest observed suspended sediment concentrations. Higher suspended sediment concentrations were observed during the rising-stage than for similar flows on the falling-stage. This occurred for both frontal rainfall events in the winter with insignificant snow accumulation on the ground and snowmelt runoff events. Greater scatter about the sediment rating curves was found for the harvested watersheds.

Keywords: erosion; logging; sediment; sediment control; Southwest; streamflow; watershed management

United States

Adams, D.M., R.W. Haynes, and A.J. Daigneault. 2006. Estimated Timber Harvest by U.S. Region and Ownership, 1950-2002. General Technical Report PNW-GTR-659. USDA Forest Service Pacific Northwest Research Station.

Abstract: This publication provides estimates of total softwood and hardwood harvests by region and owner for the United States from 1950 to 2002. These data are generally not available in a consistent fashion and have to be estimated from state-level data, forest resource inventory statistics, and production of forest products. This publication describes the estimation process and documents the various assumptions. These estimates have been used for the past three decades in the periodic USDA Forest Service timber assessments.

Keywords: logging; United States

O'Keefe, T.C., J.M. Helfield, and R.J. Naiman. 2007. Agents of Watershed Change. Training module from U.S. EPA's Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: This training module provides an overview of natural and human-made change processes and the ways in which they affect the structure and function of watersheds. The module has four primary sections: an introduction to the role of change in the watershed, descriptions of specific natural agents of change and their ecological effects, descriptions of specific human made agents of change and their ecological effects, and a discussion of the watershed processes most vulnerable to change.

Change is a natural, essential feature of watersheds. Being able to identify different change processes, understand the differences between natural and human influences on watershed change, and recognize a change of concern are all critical for effective watershed management. Watershed change, however, can be very complicated to understand and manage when many human and natural causes of change interact as they often do.

After completing this training, the participant should know the major changes affecting watersheds and understand that watersheds are dynamic systems. Some background in watershed ecology is helpful for understanding the material presented here and can be obtained from the module, *Introduction to Watershed Ecology,* at http://www.epa.gov/watertrain/ecology.

Keywords: agriculture; climate change; drought; erosion; fire; flood; logging; United States; urbanization; water resources management; watershed change; watershed management; windstorm

Vitousek, P.M. and J.M. Melillo. 1979. Nitrate losses from disturbed forests: patterns and mechanisms. *Forest Science* 25(4):605-619.

Abstract: Losses of nitrate in drainage water from disturbed forest ecosystems vary over a wide range. High losses of nitrate to streamwater or groundwater have been observed in a few sites, while in others only small increases in losses have occurred. A limited set of mechanisms could be responsible for such differences. Before disturbance, annual nitrogen mineralization and plant nitrogen uptake vary widely among temperate forests, with higher rates observed in deciduous forests. Destructive disturbance increases nitrogen mineralization and (at least briefly) reduces plant uptake. The nitrogen mineralized in excess of plant uptake could be lost to streamwater or groundwater, lost to the atmosphere through ammonia volatilization or denitrification, or retained within the disturbed system through nitrogen immobilization by decomposers, clay fixation of ammonium, lags in nitrification, nitrate reduction to ammonium, nitrate adsorption on soil colloids, a lack of water for nitrate transport, or (once plant regrowth is established) plant nitrogen uptake. Systematic studies of these mechanisms will allow the development of a more thorough understanding of the nitrogen cycle in disturbed ecosystems. Such an understanding should in turn permit the prediction of nitrate losses from disturbed forests.

Keywords: logging; United States; water quality

Canada

Caissie, D., S. Jolicieur, M. Bouchard, and E. Poncet. 2002. Comparison of streamflow between pre and post timber harvesting in Catamaran Brook (Canada). *Journal of Hydrology* 258:232-248.

Abstract: The forest industry plays a major role in the economy of eastern Canada. The recreational fishery also represents an important source of revenue for this area. Therefore, there is concern over the potential economic effects and ecological impacts from logging operations on aquatic habitats. This study deals with the comparison of streamflow between pre- and post-timber harvesting at Catamaran Brook (New Brunswick, Canada) to identify any potential changes to the hydrological regime. Studies were carried out on two subbasins of Catamaran Brook, namely the Middle Reach (mid-basin) and the Upper Tributary 1. The harvested area at the Middle Reach represented 2.3% of this subbasin while 23.4% of Upper Tributary 1 was harvested. It was noted that during both the calibration and timber harvesting phases, meteorological conditions (e.g., precipitation, runoff) contributed to relatively high natural variability. When studying changes on an annual and seasonal basis for the basin cut at 2.3% (e.g., the Middle Reach) and using a control basin for comparison, no changes were detected to the annual water yield, seasonal runoff and streamflow timing between the calibration and timber harvesting phases. On a summer rainfall event basis, no changes were detected at the Middle Reach and the Upper Tributary 1 when studying relations between peak flows and precipitation ($p < 0.05$) at the Upper Tributary 1 when comparing the calibration and timber harvesting phases. Peak flows showed higher values following timber harvesting. No significant changes were observed between peak flows and precipitation at the Middle Reach.

When comparative studies were carried out on peak flow and storm flow between subbasins (using the Middle Reach as control for treatments vs. the most affected site, i.e., the Upper Tributary 1), significant changes were detected in peak flow ($p < 0.05$) between the calibration and timber harvesting phases at the Upper Tributary 1 only. Increased peak flows were observed at the Upper Tributary 1 compared to the Middle Reach following timber harvesting. It was concluded that for timber harvesting at Catamaran Brook, changes could only be detected on a summer storm event basis for the most affected site (Upper Tributary 1) and for peak flow only.

Keywords: Canada; logging; streamflow; water quantity; watershed management

Cheng, J.D. 1989. Streamflow changes after clear-cut logging of a pine beetle-infested watershed in southern British Columbia, Canada. *Water Resources Research* 25(3):449-456.

Abstract: The paired watershed technique was used to assess the streamflow changes of Camp Creek in interior British Columbia after clear-cut logging occurred over 30% of its 33.9 square kilometers (km^2) watershed. Existing hydrometric data for Camp Creek and those of an adjacent control, Graeta Creek, were analyzed for both the 1917-1976 prelogging and 1978-1983 postlogging periods. Postlogging Camp Creek streamflow changes are characterized by increases in annual and monthly water yields and annual peak flows, as well as earlier annual peak flow and half flow volume occurrence dates. The direction and magnitude of these postlogging streamflow increases are clear and consistent. The results are in good agreement with the findings of most previous studies conducted on watersheds which generally have been smaller than 2.5 km^2. This study provides strong evidence that changes in streamflow from a large forested watershed can be significant if a sizeable portion of its drainage area is clear-cut. Possible causes for streamflow changes are discussed.

Keywords: Canada; insect pest; logging; water quantity; watershed

Hale, D.L. 2001. Will a System of Partial Cutting, in a Monoculture, Mature Lodgepole Pine (*Pinus contorta* Dougl. Var. *latifolia* Engelm.) Forest, in an East Kootenay Community Watershed, Contribute to the Optimization and Protection of Raw Potable Water Quality? MS, Royal Roads University.

Abstract: A study was conducted on the Mark Creek Community Watershed, the main raw, potable water source of the City of Kimberley, located in southeastern British Columbia. The purpose of the study was to contribute to the awareness of, and management of, both natural and anthropogenic risks to raw potable water quality, by investigating ecological elements important for the protection of aquatic ecosystems and raw drinking water.

The investigation, principally a literature review, assessed potential logging methods (specifically partial cutting and clearcutting) in forest stands dominated by lodgepole pine. Natural disturbance factors inherent to lodgepole pine forests in interior British Columbia, and potential impacts on water quality parameters (principally turbidity, pathogens, water quantity and stream temperature) were also considered.

Site visits and interviews with land management professionals were conducted during the literature review, to gain familiarity with examples of partial cutting and clearcutting systems in lodgepole pine forest types, throughout East Kootenay region. Applicable concepts and principles were related to the management of the Mark Creek Community Watershed. Some fieldwork was carried out in the study watershed to gather semi-quantitative information on forest stand attributes in two forest types in or near proposed cut-block locations.

Very little work was found relating to partial cutting, or clearcutting, to biological or ecological parameters potentially important for the management of risks to drinking water quality. A system of partial cutting was only recommended for limited areas in the Mark Creek Community Watershed, including some riparian areas, and stands requiring mountain pine beetle management, where windthrow risks are determined to be acceptable. A clear need was identified for further research, and for a long-term water quality monitoring program that applies locally relevant indicators of drinking water quality and ecosystem health to Community Watershed management.

Keywords: Canada; drinking water quality; insect pest; logging; watershed management; windthrow

Jordan, P. 2006. The use of sediment budget concepts to assess the impact on watersheds of forestry operations in the southern interior of British Columbia. *Geomorphology* 79:27-44.

Abstract: Sediment budget concepts can be applied to the assessment of the impacts of forest resource development on the sediment regime of streams. In British Columbia, these impacts are of concern because of the extent of commercially valuable forests. Increases in sediment yield from forestry operations can affect water quality, fish habitat, and channel stability. To address these concerns, the BC Ministry of Forests conducted several sediment budget studies from about 1992 to 2002. This paper reports the results of two studies, focusing on the water quality of streams used for community water supply. The studies address several questions: How sensitive are the streams to an increase in sediment supply? Are development-related sediment sources significant compared to natural sources? What forest practices are responsible for increasing or minimizing sediment impacts? How can the impact of forestry operations on water quality be monitored? The studies used a paired watershed approach, with discharge, turbidity, sediment yield, and solute yield measured on watersheds undergoing logging and road building, and on similar undeveloped watersheds. The studies concluded that erosion from forest roads can be a significant source of suspended sediment, but sediment from logging operations is usually negligible. The risk of landslides is an important factor in the sediment budgets, but is difficult to quantify. Differences in geology and groundwater regime can influence the sensitivity of watersheds to sediment impacts.

Keywords: Canada; erosion; logging; mudslide; public water supply; road construction; sediment; sediment control; water quality

Timoney, K.P. 2003. The changing disturbance regime of the boreal forest of the Canadian prairie provinces. *Forestry Chronicle* 79(3):502-516.

Abstract: The subhumid boreal forest of western Canada is different today from what it was 25 years ago. Before the 1950s, the main human impacts on this forest were agricultural expansion, escaped settlement fires, and high-grade logging. The latter half of the 20th century

saw increased human stresses placed on the ecosystems, against a background of insect outbreaks and high forest fire activity. In the prairie provinces, current annual area burned is greater and more variable than it was in the 1970s. Over the past 25 years, the area disturbed by insects (primarily forest tent caterpillar) and disease has declined, but both the area and timber volume logged have risen. The boreal forest (particularly its southern half) is being converted to a fragmented landscape dominated by young aspen, shrub, grass, plantations, exotic species, industrial infrastructure, and agricultural fields. The current disturbance level has increased to the point that forest land and volume losses now exceed forest accruals in some regions; average forest age and biomass have been declining since about 1970. Relative to past decades, the present subhumid boreal forest region of Canada is warmer, and more fragmented and dissected; it supports less old growth, less old white spruce, and more young aspen and recently disturbed areas; it has simplified and truncated age-class structures; and it has a greater prevalence of non-native plants. Future stresses may include *in situ* tar sands development, groundwater depletion or degradation, and water diversions. Should present trends continue, declining forest productivity and predictability, and spread of exotic species are likely, as is replacement of coniferous forest by deciduous forest in some regions. Stressed aquatic systems may undergo major changes in biotic composition, productivity, and physical characteristics. Without a rapid decrease in the rate of disturbances, the establishment of a more complete protected areas network, and the adoption of ecosystem-centered management, the subhumid boreal ecosystem will continue to be degraded.

Keywords: Canada; fire; logging

9. Storm or Flood

Northeast

Cowell, C.M. and J.M. Dyer. 2002. Vegetation development in a modified riparian environment: human imprints on an Allegheny river wilderness. *Annals of the Association of American Geographers* 92(2):189-202.

Abstract: This review explores the ecological and silvicultural impacts of ice storms on forests in the southern United States. Different environmental factors like weather conditions, topography, vegetation, stand density, and management practices influence the degree of glaze damage a particular forest may experience. Additionally, the frequent contradictions in the relationships between these factors and the resulting damage suggests a complexity that makes each ice storm unique and difficult to predict. The authors recommend a series of silvicultural responses to ice storms, including density management, planting species selection, post-event evaluation, salvage, stand rehabilitation, and long-term monitoring of forest health.

Keywords: dam construction; development; flood; Northeast; vegetation change

Southeast

Balthis, W.L., J.L. Hyland, and D.W. Bearden. 2006. Ecosystem responses to extreme natural events: impacts of three sequential hurricanes in fall 1999 on sediment quality and condition of benthic fauna in the Neuse River Estuary, North Carolina. *Environmental Monitoring and Assessment* 119(1-3):367-389.

Abstract: A study was conducted in November 1999 to assess the sediment quality and condition of benthic fauna in the Neuse River Estuary, North Carolina, following the passage of three Atlantic hurricanes during the prior two months. Samples for analysis of macroinfauna (> 0.5 millimeter sieve size), chemical contamination of sediments, and other abiotic environmental variables (salinity, dissolved oxygen, pH, depth, sediment granulometry) were collected at 20 sites from the mouth of the Neuse River at Pamlico Sound to approximately 90 kilometers upstream. Results were compared to those obtained from the same area in July 1998 using similar protocols. Depressed salinity, caused by extreme rainfall and associated high freshwater flow, persisted throughout much of the estuary, which had experienced periods of water-column stratification and hypoxia of underlying waters. Fifteen of the 20 sites, representing 299 square kilometers (76% of the survey area), also showed signs of benthic stress based on a multi-metric benthic index of biotic integrity. Benthic impacts included reductions in the abundance, diversity, and numbers of species and shifts in taxonomic composition, with a notable increase in dominance of the opportunistic polychaete *Mediomastus ambiseta* as other former dominant species declined. There was no significant increase in the extent of chemical contamination compared to pre-hurricane conditions. Storm-related reductions in dissolved oxygen and salinity were the more likely causes of the observed benthic impacts, though it was

not possible, based on these results, to separate storm effects from seasonal changes in the benthos and annual episodes of summer anoxia and hypoxia.

Keywords: flood; hurricane; land cover change; sediment; Southeast; water quality

Bolstad, P.V. and W.T. Swank. 1997. Cumulative impacts of land use on water quality in a southern Appalachian watershed. *Journal of the American Water Resources Association* 33(3):519-533.

Abstract: Water quality variables were sampled over 109 weeks along Coweeta Creek, a fifth-order stream located in the Appalachian Mountains of western North Carolina. The purpose of this study was to observe any changes in water quality over a range of flow conditions, with concomitant downstream changes in the mix of land uses. Variables sampled include pH, HCO_3^{2-}, conductivity, NO_3^--N, NH_4^+-N, PO_4^{3-}-P, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, SiO_2, turbidity, temperature, dissolved oxygen, total and fecal coliform, and fecal streptococcus. Landcover/landuse was interpreted from 1:20,000 aerial photographs and entered in a geographic information system, along with information on total and paved road length, building location and density, catchment boundaries, hydrography, and slope. Linear regressions were performed to relate basin and near-stream landscape variables to water quality.

Consistent, cumulative, downstream changes in water quality variables were observed along Coweeta Creek, concomitant with downstream, human-caused changes in landuse. Furthermore, larger downstream changes in water quality variables were observed during stormflow when compared to baseflow, suggesting cumulative impacts due to landscape alteration under study conditions were much greater during storm events. Although most water quality regulations, legislation, and sampling are promulgated for baseflow conditions, this work indicates they should also consider the cumulative impacts of physical, chemical, and biological water quality during stormflow.

Keywords: ammonia; development; fecal coliform; land cover; land use; nitrate; nonpoint source; Southeast; storm; water quality

Davis III, S.E., J.E. Cable, D.L. Childers, C. Coronado-Molina, J.W. Day Jr., C.D. Hittle, C.J. Madden, E. Reyes, D. Rudnick, and F. Sklar. 2004. Importance of storm events in controlling ecosystem structure and function in a Florida Gulf Coast estuary. *Journal of Coastal Research* 20(4):1198-1208.

Abstract: From August 1995 to February 2001, this study investigated the ecological effects of intra- and inter-annual variability in freshwater flow through Taylor Creek in southeastern Everglades National Park. Continuous monitoring and intensive sampling studies overlapped with an array of pulsed weather events that impacted physical, chemical, and biological attributes of this region. The effects were quantified for three events representing a range of characteristics (duration, amount of precipitation, storm intensity, and wind direction) on the hydraulic connectivity, nutrient and sediment dynamics, and vegetation structure of the southeast Everglades estuarine ecotone. These events included a strong winter storm in November 1996, Tropical Storm Harvey in September 1999, and Hurricane Irene in October 1999. Continuous hydrologic and daily water sample data were used to examine the effects of these events on the physical forcing and quality of water in Taylor Creek. A high resolution, flow-through sampling and mapping approach was used to characterize water quality in the adjacent bay. To understand the effects of these events on vegetation communities, mangrove litter production and estimated seagrass cover in the bay at monthly intervals were measured. Quantified sediment deposition associated with Hurricane Irene's flood surge along the Buttonwood Ridge was also quantified. These three events resulted in dramatic changes in surface water movement and chemistry in Taylor Creek and adjacent regions of Florida Bay as well as increased mangrove litterfall and flood surge scouring of seagrass beds. Up to 5 centimeters of bay-derived mud was deposited along the ridge adjacent to the creek in this single pulsed event. These short-term events can account for a substantial proportion of the annual flux of freshwater and materials between the mangrove zone and Florida Bay. The findings shed light on the capacity of these storm events, especially when in succession, to have far reaching and long-lasting effects on coastal ecosystems such as the estuarine ecotone of the southeast Everglades.

Keywords: nutrient; sediment; Southeast; storm; streamflow

Schoonover, J.E., G.E. Lockaby, and B.S. Helms. 2006. Impacts of land cover on stream hydrology in the West Georgia Piedmont, USA. *Journal of Environmental Quality* 35:2123-2131.

Abstract: The southeastern United States is experiencing rapid urban development. Consequently, Georgia's streams are experiencing hydrologic alterations from extensive development and from other land use activities such as livestock grazing and silviculture. A study was performed to assess stream hydrology within 18 watersheds ranging from 500 to 2,500 hectares. Study streams were first, second, or third order and hydrology was continuously monitored from July 29, 2003 to September 23, 2004 using in situ pressure transducers. Rating curves between stream stage (i.e., water depth) and discharge were developed for each stream by correlating biweekly discharge measurements and stage data. Dependent variables were calculated from discharge data and placed into four categories: flow frequency (i.e., the number of times a predetermined discharge threshold is exceeded), flow magnitude (i.e., maximum and minimum flows), flow duration (i.e., the amount of time discharge was above or below a predetermined threshold), and flow predictability and flashiness. Fine resolution data (i.e., 15-minute interval) were also compared to daily discharge data to determine if resolution affected how streams were classified hydrologically. Urban watersheds experienced flashy discharges during storm events, whereas pastoral and forested watersheds showed less flashy hydrographs. Also, in comparison to all other flow variables, flow frequency measures were most strongly correlated to land cover. Furthermore, the stream hydrology was explained similarly with both the 15-minute and daily data resolutions.

Keywords: development; flow; grazing; land cover; land use; Southeast; storm; urban; vegetation change; watershed

Van Metre, P.C., A.J. Horowitz, B.J. Mahler, W.T. Foreman, C.C. Fuller, M.R. Burkhardt, K.A. Elrick, E.T. Furlong, S.C. Skrobialowski, J.J. Smith, J.T. Wilson, and S.D. Zaugg. 2006. Effects of Hurricanes Katrina and Rita on the chemistry of bottom sediments in Lake Pontchartrain, Louisiana, USA. *Environmental Science and Technology* 40(22):6894-6902.

Abstract: The effects of Hurricanes Katrina and Rita and the subsequent unwatering of New Orleans, Louisiana, on the sediment chemistry of Lake Pontchartrain were evaluated by chemical analysis of samples of street mud and suspended and bottom sediments. The highest concentrations of urban-related elements and compounds (e.g., lead, zinc, polycyclic aromatic hydrocarbons, and chlordane) in bottom sediments exceeded median concentrations in U.S. urban lakes and sediment-quality guidelines. The extent of the elevated concentrations was limited, however, to within a few hundred meters of the mouth of the 17th Street Canal, similar to results of historical assessments. Chemical and radionuclide analysis of pre- and post-Hurricane Rita samples indicate that remobilization of near-shore sediment by lake currents and storms is an ongoing process. The effects of Hurricanes Katrina and Rita on the sediment chemistry of Lake Pontchartrain are limited spatially and are most likely transitory.

Keywords: hurricane; sediment; sediment quality; Southeast; storm; urban; urban pollution

Williams, E.S. and W.R. Wise. 2006. Hydrologic impacts of alternative approaches to storm water management and land development. *Journal of the American Water Resources Association* 42(2):443-455.

Abstract: Low Impact Development (LID) and other land development methods have been presented as alternatives to conventional stormwater management and site design. Low impact development encourages land preservation and the use of distributed, infiltration-based stormwater management systems to minimize impacts on hydrology. Such systems can include shallow retention areas, akin to natural depression storage. Other approaches to land development may emphasize land preservation only. Herein, an analysis of four development alternatives is presented. The first is traditional development with conventional pipe/pond stormwater management and half-acre lots. The second alternative is cluster development, in which implementation of the local cluster development ordinance was assumed, resulting in quarter-acre lots with a pipe/pond stormwater management system and open space preservation. The “partial” LID option used the same lot layout as the traditional option, with a stormwater management system emphasizing shallow depression storage. The “full” LID used the cluster site plan and the depression storage-based stormwater management system. The alternatives were compared to the hydrologic response of existing site conditions. The analysis used two design storms and a continuous rainfall record. The combination of land preservation and infiltration-based stormwater management yielded the hydrologic response closest to existing conditions, although ponds were required to control peak flows for the design storms.

Keywords: development; flow; management; Southeast; storm

North Central

Johnson, W.C. 1992. Dams and riparian forests: case study from the upper Missouri River. *Rivers* 3(4):229-242.

Abstract: This research examined the effects of altered flow and meandering rate of the Missouri River in central North Dakota on the compositional dynamics of floodplain forests. This was accomplished by estimating the rates of river erosion and deposition during predam and postdam periods from historical maps and aerial photographs. Future changes in forest composition were simulated using a simple mathematical model based on measured rates of forest succession and river meandering for pre- and post-dam periods. Simulations indicated a future decline in the areal extent of pioneer forests (cottonwood, willow) due to river regulation. Later successional species (primarily green ash) will dominate the future forests. Experimentation is needed in order to regenerate pioneer forests to maintain current levels of species diversity on the floodplain.

Keywords: dam construction; flood; forest; North Central; vegetation change

Northwest

Bradley, J.B., T.R. Grindeland, and H.R. Hadley. 2001. Sediment supply from Mount St. Helens: twenty years later. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X-9-X-16. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf.

Abstract: The May 18, 1980 eruption of Mount St. Helens deposited a debris avalanche of over 3.8 billion cubic yards of silt, sand, gravel, and debris in the upper 17 miles of the North Fork Toutle River valley and another 50 to 60 million cubic yards in the upper portion of the South Fork Toutle River valley. The eruption devastated approximately 150 square miles of evergreen forests, lakes, and wildlife within this area. Mudflows, triggered by the eruption, carried large volumes of sediment from the debris avalanche into the Toutle-Cowlitz-Columbia River system. The resulting sediment deposition caused widespread flooding along the Toutle and Cowlitz rivers and blockage of the Columbia River Navigation Channel.

Sediment continues to erode from the debris avalanche and is transported down the North Fork Toutle River. The majority of this material now deposits behind the Sediment Retention Structure, which was completed in 1989. A period of about 20 years has elapsed during which hydrologic recovery of effected watershed areas and watercourses may have partially occurred. A reassessment of the eruption-influenced sediment transport conditions was conducted to quantify the extent of hydrologic recovery and estimate the future supply of sediment to downstream areas. A comparison was made of sediment yield estimates developed for the current study and those developed shortly after the eruption.

Keywords: flood; mudslide; Northwest; sediment; vegetation change; volcano

LaHusen, R.G. 1994. Variations in Turbidity in Streams of the Bull Run Watershed, Oregon, Water Years 1989-90. U.S. Geological Survey Water-Resources Investigations Report 93-4045.

Abstract: In this study, turbidity is used to help explain spatial and temporal patterns of erosion and sediment transport. Automated turbidity sampling in streams in the Bull Run watershed during water years 1989 and 1990, showed turbidity levels, in general, are remarkably low, with levels below 1 nephelometric turbidity unit (NTU) about 90% of the time. However, ephemeral increases in turbidity in streams of the Bull Run watershed occur in direct response to storms. Turbidity is caused by abundant organic particles as well as by materials eroded from unconsolidated geologic materials located along roads, streams channels, or stream banks. Seasonal and within-storm decreases in turbidity are attributed to depletion of accumulated particle supplies. During winter storms, erosion caused by rainfall intensities greater than 0.25 inches in three hours is sufficient to increase stream turbidities from less than 1 NTU to as much as 100 NTUs. Large-scale storms or floods cause persistent effects because mass erosion or scour of channel armor increases available sediment supply. Spatial variability in turbidity is evident only during storms when erosion and sediment-transport processes are active. Parts of the Rhododendron Formation are particularly prone to channel and mass erosion during large storms. Eroding glacial deposits in sections of Log Creek affected by a 1964 dam-break flood also cause high stream turbidity relative to other streams in the watershed. Analysis of characteristics of magnetic minerals in sediment sources and deposits was unproductive as a means to identify source areas of suspended sediment because high concentrations of magnetite in all samples of the volcanic rocks masked differences of less magnetic minerals in the samples.

Keywords: erosion; management; Northwest; runoff; sediment; storm; water quality

Megahan, W.F. 2000. Cumulative watershed effects research needs for forested watersheds in the 21st century. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 61-68. Water Resources Center Report No. 98.

Abstract: Key cumulative effects research needs dealing with forest watersheds include natural variability in watershed characteristics and in downstream responses, sediment routing, and effects of disturbance on streamflow. Important information needs relating to natural variability include better descriptions of spatial variability and a broader perspective on temporal variability. Large regional differences in landslide types and streamflow rates are used to illustrate the need for studies of spatial variability. Justification for increased research on temporal variability is based on recent studies documenting long-term (thousands of years) sediment supplies from mountain watersheds in Idaho averaging about an order of magnitude greater than present day (tens of years) sediment data indicate. Additional studies in western Oregon show that mountain channels exhibit a natural succession from energy limited (aggraded) to supply limited (degraded) conditions, with accompanying changes in aquatic habitat conditions. Important components of sediment routing research include delivery of landslide material to channels, downslope sediment from roads to channels, and downstream routing of

bedload sediments in channels. Evaluation of the effects of disturbance on streamflow should include the effects of forest management and wildfire on all levels of streamflow, and the accompanying erosional and sedimentation response of channels and aquatic ecosystems. Physically based, distributed models need to be developed and improved to predict the effects of disturbance on streamflow and channel changes.

Keywords: fire; flood; Northwest; sediment; streamflow; urban; vegetation change; watershed management

Meyer, G.A., J.L. Pierce, S.H. Wood, and A.J.T. Jull. 2001. Fire, storms, and erosional events in the Idaho batholith. *Hydrological Processes* 15:3025-3038.

Abstract: In late December 1996, the South Fork Payette River basin in west-central Idaho experienced a prolonged storm that culminated on January 1, 1997, with intense rain on melting snow that triggered slide failures, producing debris flows and sediment-charged floods. Failures occurred in saturated, cohesionless, grussy colluvium derived from weathered Idaho batholith granitic rocks. Many failures along the South Fork Payette River originated in ponderosa pine forests burned in the 1989 stand-replacing Lowman fire. An example is the 0.49 square kilometers (km^2) Jughead Creek basin, where a single large colluvial failure produced almost 40% of the total volume eroded from the basin and generated a massive and rapid debris flow. Failures also occurred in steep, unburned, and unforested drainages such as Hopkins Creek. In this south-facing 0.58 km^2 basin, 15 colluvial hollows failed, but no single failure produced more than 10% of the total eroded volume. Sediment transport in Hopkins Creek occurred by prolonged sediment-charged sheetflooding. Despite vegetation differences, sediment yields from the geomorphically similar Hopkins Creek (~42,000 megagrams per square kilometer, Mg km^2) and Jughead Creek (~44,000 Mg km^2) basins were quite similar. These 1997 erosion events are equivalent to several thousand years of sediment yield at low rates (2.7-30 Mg km^2 per year) measured by short-term sediment trapping and gauging in Idaho batholith watersheds. If similar large events were solely responsible for sediment export, recurrence intervals (RIs) of several hundred years would account for higher sediment yields averaged over ~104 year from Idaho batholith watersheds. Dating of small fire-induced sheetflooding events in an early Holocene tributary junction fan of Jughead Creek indicates that frequent small sedimentation events (RI ~ = 33-80 years) occurred between 7,400 and 6,600 calendar year before present, with an average yield not greatly exceeding 16 Mg km^2 per year. Compared with the Holocene average, erosion rates during that 800-year period were unusually low, suggesting that sediment yields have not been constant over time, and that climatic variations and related fire regime changes may exert a strong influence on the probability of major erosional events.

Keywords: climate change; erosion; fire; Northwest; sediment; storm; vegetation change; water yield

Mickelson, C.R. 2000. Partnerships, public information, emergency preparedness and projects. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter,

C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 101-104. Water Resources Center Report No. 98.

Abstract: Immediately following a major fire in the foothills above Boise, Idaho, in August 1996, cooperative actions by local, state, and federal government agencies allowed for prompt pre-emergency planning and implementation of pre-emptive actions to cope with possible flooding and sediment deposition in Boise.

Keywords: case study; erosion; fire; management; Northwest; sediment; storm; vegetation change; water quantity; watershed

Pierson, F.B. 2000. Hydrologic impacts of fire on the Boise front. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 105-113. Water Resources Center Report No. 98.

Abstract: The Eighth Street fire had a significant impact on the infiltration capacity and soil erodibility across the Boise Front. South-facing slopes had the lowest infiltration and showed the highest rates of erosion following the fire. Two years following the fire, ground cover had not yet sufficiently recovered to fully protect either the north or south slopes from increased runoff and accelerated erosion. Presented results are consistent with observations made following the September 1997, thunderstorm where the south-facing slopes had the highest concentration of rills and suffered significant soil loss.

Keywords: case study; erosion; fire; Northwest; runoff; sediment; storm; vegetation change; watershed

Sinton, D.S., J.A. Jones, J.L. Ohmann, and F.J. Swanson. 2000. Windthrow disturbance, forest composition, and structure in the Bull Run Basin, Oregon. *Ecology* 81(9):2539-2556.

Abstract: This study examined relationships among forest landscape dynamics, environmental factors (climate and landforms), and disturbance history in forests dominated by Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and Pacific silver fir (*Abies amabilis*) in the Bull Run Basin in northwestern Oregon and evaluated the findings in a broader geographic context. Three sets of analyses were conducted: mapping of historical windthrow disturbance patches in the 265-square kilometers Bull Run Basin over the past century and analysis of their relationships with meteorological conditions, landforms, and vegetation; comparison of forest structure and species composition as a function of mapped windthrow and wildfire disturbance history in 34 1-hectare vegetation survey plots in Bull Run; and canonical correspondence analysis of environmental factors and forest overstory species composition in 1,637 vegetation plots in the Mount Hood and Willamette National Forests. Nearly 10% of the Bull Run Basin has been affected by windthrow since 1890, but only 2% was affected prior to the onset of forest harvest in 1958. Most of the mapped windthrow occurred in areas with 500- to 700-year-old canopy dominants and no mapped disturbance by fire in the past 500 years. Most

mapped windthrow occurred during three events in 1931, 1973, and 1983 that were characterized by extreme high speed east winds from the Columbia River Gorge. Forest harvest modified the effects of climate, landforms, and vegetation on windthrow disturbance, reducing the importance of topographic exposure to east and northeast winds, and creating a strong influence of recent clearcut edges, which accounted for 80% of windthrow in the 1983 event. Shade-tolerant overstory species (western hemlock and Pacific silver fir) are abundant in present-day forest stands affected by windthrow as well as by fire in the past century. In the western Cascade Range, Douglas-fir and western hemlock decline and Pacific silver fir increases with elevation (summer moisture stress declines but temperature variability increases), but this transition occurs at lower elevations in the Bull Run, perhaps because of the interaction between regional climate processes and disturbance along the Columbia Gorge. Complex landscape dynamics result from these contingent interactions among climate, landform and stand conditions, and disturbance.

Keywords: case study; disturbance; forest composition; land cover; Northwest; storm; vegetation change; windthrow

Southwest

Caldwell, C.A., C.M. Canavan, and N.S. Bloom. 2000. Potential effects of forest fire and storm flow on total mercury and methylmercury in sediments of an arid-lands reservoir. *Science of the Total Environment* 260:125-133.

Abstract: A study was conducted from July 1995 to June 1996 to examine the spatial and temporal changes of mercury concentrations in sediments of an arid-lands reservoir. Prior to the first sample collection in July, a forest fire burned 2,930 hectares (ha) of mixed conifer and ponderosa pine in the watershed of Caballo Reservoir in south-central New Mexico. The fire was eventually extinguished by summer rains and storm runoff resulting in the mobilization and transport of charred vegetative material into an intermittent tributary (Palomas Creek) that drains the watershed into Caballo Reservoir. Concentrations of total mercury (THg), monomethylmercury (MMHg), and total organic carbon in surficial sediments revealed fire, followed by storm runoff, enhanced the transport of mercury and organic matter to the reservoir. Concentrations of THg in sediments increased from 7.5 nanograms per gram (ng/g) in July to 46.1 ng/g by November 1995 at one site (Palomas) nearest the outflow of Palomas Creek. No other spatial or temporal trends were observed for THg at other sites throughout the remainder of the study. Concentrations of MMHg in sediments at the Palomas site increased from 0.428 ng/g in July to 12.46 ng/g by October 1995 compared to concentrations in sediments at the remaining sites which ranged from 0.11 to 1.50 ng/g throughout the study. The ratio of MMHg to THg (a gross index of methylation activity) was greatest in sediments from the Palomas site (5.4-33.8%) that remained elevated throughout the study. Fire and subsequent late-summer rains may have had a twofold effect on mercury concentrations in Caballo Reservoir. The storm-driven runoff following the forest fire carried mercury complexed to organic matter which resulted in elevated levels of mercury as well as providing a carbon source for microbial methylation processes in sediment.

Keywords: fire; mercury; New Mexico; organic carbon; runoff; sediment; Southwest; storm; water quality; water quantity; watershed

Coats, R. and L. Collins. 1984. Streamside landsliding and channel change in a suburban forested watershed: effects of an extreme event. In *Symposium on Effects of Forest Land Use on Erosion and Slope Stability*, 7-11 May, 1984, Honolulu, HI. O'Loughlin, C.L. and Pearce, A.J. (eds.). pp. 165-175.

Abstract: A continuing controversy in the management of steep and unstable forested land is the relative importance of land disturbance and extreme climatic events in triggering mass wasting and channel change. In California, this controversy has been brought into sharp focus in recent years by increasing concern for water quality and anadromous fisheries. Conflicts are especially acute where suburban growth impinges on productive forest land in areas of high rainfall and unstable terrain. New forest residents often express concern about geomorphic and aesthetic effects of logging, yet residential development itself is not without effects on the stream environment.

Large and infrequent storms provide a unique learning opportunity. For the land manager and land use planner, they are a severe test of the efficacy of forest practice regulation and land use controls. For the geomorphologist, they provide valuable lessons in geomorphic effectiveness and landscape evolution. This paper reports on the effects of the January 1982 storm in Zayante Creek Basin and the lower San Lorenzo River in Santa Cruz County, California.

Keywords: development; erosion; landslide; logging; Southwest; storm; water quality

Veenhuis, J.E. 2002. Effects of Wildfire on the Hydrology of Capulin and Rito de los Frijoles Canyons, Bandelier National Monument, New Mexico. U.S. Geological Survey Water-Resources Investigations Report 02-4152.

Abstract: In June 1977, the La Mesa wildfire burned 15,270 acres in and around Frijoles Canyon in Bandelier National Monument and the adjacent Santa Fe National Forest, New Mexico. The Dome wildfire in April 1996 in Bandelier National Monument burned 16,516 acres in Capulin Canyon and the surrounding Dome Wilderness area. Both watersheds are characterized by abundant and extensive archeological sites that could be affected by increased runoff and accelerated rates of erosion, which typically occur after a wildfire. The U.S. Geological Survey, in cooperation with the National Park Service, monitored the wildfires' effects on streamflow in both canyons.

The magnitude of large stormflows increased dramatically after these wildfires; peak flows at the most downstream streamflow-gauging station in Frijoles and Capulin canyons increased to about 160 times the maximum recorded flood prior to the fire. Maximum peak flow was 3,030 cubic feet per second at the gauging station in Frijoles Canyon (drainage area equals 18.1 square miles) and 3,630 cubic feet per second at the most downstream crest-stage gauge in Capulin Canyon (drainage area equals 14.1 square miles). The pre-fire maximum peak flow recorded in these two canyons was 19 and an estimated 25 cubic feet per second, respectively. As vegetation reestablished itself during the second year, the post-fire annual maximum peak flow decreased to about 10 to 15 times the pre-fire annual maximum peak flow. During the third year, maximum annual peak flows decreased to about three to five times the pre-fire maximum peak flow. In the 22 years since the La Mesa wildfire, flood magnitudes have not completely returned to pre-fire size.

Post-fire flood magnitudes in Frijoles and Capulin canyons do not exceed the maximum floods per drainage area for physiographic regions 5 and 6 in New Mexico. For a burned watershed, however, the peak flows that occur after a wildfire are several orders of magnitude larger than normal forested watershed peak flows.

The frequency of larger stormflows also increased in response to the effects of the wildfires in both canyons. In Frijoles Canyon, the number of peak stormflows greater than the pre-fire maximum flow of 19 cubic feet per second was 15 in 1977, 9 in 1978, and 5 in 1979, which is about the magnitude of the maximum pre-fire peak flow in both canyons. Again the hydrologic effects of a wildfire seem to be more pronounced for the three years following the date of the fire. Likewise, larger peak flows occurred more frequently in Capulin Canyon for the first three years after the 1996 wildfire.

Median suspended-sediment concentrations in samples collected in Frijoles Canyon in 1977 were 1,330 milligrams per liter; median concentrations were 16 milligrams per liter after the watershed stabilized in 1993-1995. The annual load calculated from regression equations for load compared to flow for the first year after the wildfire was 220 times the annual load for the post-recovery period.

To convey the increased frequency and magnitude of average flows in Capulin Canyon after the 1996 Dome wildfire, the stream channel in Capulin Canyon increased in flow capacity by widening and downcutting. As Capulin Canyon peak flows have decreased in both magnitude and frequency with vegetative recovery, the stream channel also has slowly begun to readjust. The channel at the most downstream crest-stage gauge, which has the shallowest initial valley slope, is showing the first signs of aggradation.

Keywords: erosion; fire; flood; runoff; sediment; Southwest; streamflow; suspended sediment; vegetation change; watershed

United States

Curriero, F.C., J.A. Patz, J.B. Rose, and S. Lele. 2001. The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948-1994. *American Journal of Public Health* 91(8):1194-1199.

Abstract: Rainfall and runoff have been implicated in site-specific waterborne disease outbreaks because upward trends in heavy precipitation in the United States are projected to increase with climate change; this study sought to quantify the relationship between precipitation and disease outbreaks. The U.S. Environmental Protection Agency waterborne disease database, totaling

548 reports of outbreaks from 1948 through 1994, and precipitation data of the National Climatic Data Center were used to analyze the relationship between precipitation and waterborne diseases. Analyses were at the watershed level, stratified by groundwater and surface water contamination and controlled for effects due to season and hydrologic region. A Monte Carlo version of the Fisher exact test was used to test for statistical significance. Fifty-one percent of waterborne disease outbreaks were preceded by precipitation events above the 90th percentile ($P = 0.002$), and 68% by events above the 80th percentile ($P = 0.001$). Outbreaks due to surface water contamination showed the strongest association with extreme precipitation during the month of the outbreak; a 2-month lag applied to groundwater contamination events. The statistically significant association found between rainfall and disease in the United States is important for water managers, public health officials, and risk assessors of future climate change.

Keywords: climate; climate change; flood; runoff; United States; water quality; waterborne pathogens; watershed

Frederick, K.D. 1991. Economic consequences of climate variability on water in the west. In *Managing Water Resources in the West Under Conditions of Climate Uncertainty: Proceedings of a Colloquium held 14-16 November 1990, Scottsdale, Arizona*. National Academy Press, Washington, DC, pp. 217-238.

Abstract: The economic impacts of hydrologic extremes and variability on specific regions depend on the nature of the economy, the slack in the existing water-supply system, and society’s ability to anticipate and adapt to hydrologic change. Demand management and water marketing are potentially important tools for responding to drought and long-term reductions in supply.

A case study of the Missouri River basin illustrates the possible impacts of a general warming on the availability of water within one of the West’s principal river basins and indicates how management changes and a reallocation of supplies would help the region adapt to a sizable reduction in streamflow.

Hydrologic extremes have long posed risks to settlements in the western United States. A five-year drought in the twelfth century may have caused the prehistoric Anasazi people to abandon the Colorado plateau. Twice within the last century prolonged drought forced tens of thousands of desperate families to flee the semiarid plains in search of more promising economic opportunities. And currently, a multiyear drought extending from southern California to the Missouri River basin is exacting a toll on a variety of water users.

The temporary transformation of the Trinity River in Texas from a small river to a mile-wide flood in the spring of 1990 provided a recent reminder of what can happen when too much water arrives within too short a time. Even though California has about six million acre-feet of flood control storage and 6,000 miles of levees, floods may pose a bigger problem to the state than earthquakes. Floods have consistently been the nation’s most deadly atmospheric hazard in recent decades; they accounted for 61% of all presidential disaster declarations in the decade starting in April 1974.

Keywords: California; case study; climate change; Colorado; drought; flood; impacts; management; streamflow; United States; water resources; water supply

Hurd, B.H., N. Leary, R. Jones, and J.B. Smith. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association* 35(6):1399-1409.

Abstract: Changes in global climate may alter hydrologic conditions and have a variety of effects on human settlements and ecological systems. The effects include changes in water supply and quality for domestic, irrigation, recreational, commercial, and industrial uses; in instream flows that support aquatic ecosystems, recreation uses, hydropower, navigation, and wastewater assimilation; in wetland extent and productivity that support fish, wildlife, and wastewater assimilation; and in the frequency and severity of floods. Watersheds where water resources are stressed under current climate are most likely to be vulnerable to changes in mean climate and extreme events. This study identified key aspects of water supply and use that could be adversely affected by climate change, developed measures and criteria useful for assessing the vulnerability of regional water resources and water dependent resources to climate change, developed a regional database of water sensitive variables consistent with the vulnerability measures, applied the criteria in a regional study of the vulnerability measures, and applied the criteria in a regional study of the vulnerability of U.S. water resources. Key findings highlight the vulnerability of consumptive uses in the western and, in particular, the southwestern United States. However, southern U.S. watersheds are relatively more vulnerable to changes in water quality, flooding, and other instream uses.

Keywords: climate change; flood; flow; United States; water quality; water resources; water supply; watershed

Jentsch, A., J. Kreyling, and C. Beierkuhnlein. 2007. A new generation of climate-change experiments: events, not trends. *Frontiers in Ecology and the Environment* 5(7):365-374.

Abstract: Intensification of weather extremes is currently emerging as one of the most important facets of climate change. Research on extreme events (“event-focused” in contrast to “trend-focused”) has increased in recent years and, in 2004, accounted for one-fifth of the experimental climate change studies published. Numerous examples, ranging from microbiology and soil science to biogeography, demonstrate how extreme weather events can accelerate shifts in species composition and distribution, thereby facilitating changes in ecosystem functioning. However, assessing the importance of extreme events for ecological processes poses a major challenge because of the very nature of such events: their effects are out of proportion to their short duration. The authors propose that extreme events can be characterized by statistical extremity, timing, and abruptness relative to the life cycles of the organisms affected. To test system response to changing magnitude and frequency of weather events, controlled experiments

are useful tools. Those experiments provide essential insights for science and for societies that must develop coping strategies for such events. Future research needs for climate-change experiments in ecology are discussed. For illustration, an experimental plan showing how to meet the challenge posed by changes in the frequency or magnitude of extreme events is described.

Keywords: climate change; drought; extreme events; storm; United States

O'Keefe, T.C., J.M. Helfield, and R.J. Naiman. 2007. Agents of Watershed Change. Training module from U.S. EPA's Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: This training module provides an overview of natural and human-made change processes and the ways in which they affect the structure and function of watersheds. The module has four primary sections: an introduction to the role of change in the watershed, descriptions of specific natural agents of change and their ecological effects, descriptions of specific human made agents of change and their ecological effects, and a discussion of the watershed processes most vulnerable to change.

Change is a natural, essential feature of watersheds. Being able to identify different change processes, understand the differences between natural and human influences on watershed change, and recognize a change of concern are all critical for effective watershed management. Watershed change, however, can be very complicated to understand and manage when many human and natural causes of change interact as they often do.

After completing this training, the participant should know the major changes affecting watersheds and understand that watersheds are dynamic systems. Some background in watershed ecology is helpful for understanding the material presented here and can be obtained from the module, *Introduction to Watershed Ecology,* at http://www.epa.gov/watertrain/ecology.

Keywords: agriculture; climate change; drought; erosion; fire; flood; logging; United States; urbanization; water resources management; watershed change; watershed management; windstorm

10. Treatment

Northeast

Cruise, J.F., A.S. Limaye, and N. Al-Abed. 1999. Assessment of impacts of climate change on water quality in the southeastern United States. *Journal of the American Water Works Association* 35(6):1539-1550.

Abstract: An assessment of current and future water quality conditions in the southeastern United States has been conducted using the U.S. Environmental Protection Agency BASINS GIS/database system. The analysis has been conducted for dissolved oxygen, total nitrate nitrogen, and pH. Future streamflow conditions have been predicted for the region based on the UK Hadley Center climate model. Thus far, the analyses have been conducted at a fairly coarse spatial scale due to time and resource limitations. Two hydrologic modeling techniques have been employed in future streamflow prediction: a regional stochastic approach and the application of a physically based soil moisture model. The regional model has been applied to the entire area while the physically based model is being used at selected locations to enhance and support the stochastic model. The results of the study reveal that few basins in the Southeast exhibit high nitrogen levels. These basins are located in regions of intense agricultural activity or in proximity to the Gulf Coast. In many of these areas, streamflow is projected to decline over the next 30-50 years, thus exacerbating these water quality problems.

Keywords: climate change; Northeast; Southeast; water quality

Fairfax County Water Authority. 2002. Fairfax County Water Authority Source Water Assessment Program Final Report. Fairfax County, VA. January.

Abstract: The Fairfax County Water Authority (FCWA) draws surface water from two primary sources: the Potomac River and the Occoquan Reservoir. The treatment facilities associated with each source are located at opposite ends of Fairfax County and feed an interconnected distribution system. The James J. Corbalis, Jr. Treatment Plant, located at the northern tip of the FCWA service area, draws water from the Potomac River. The Occoquan Reservoir, on the southern border of Fairfax County, supplies the Occoquan and Lorton treatment plants located near the Town of Occoquan.

The FCWA Source Water Assessment Program (SWAP) is comprised of a contaminant inventory, a windshield survey, a Best Management Practice (BMP) inventory, and a susceptibility analysis.

Through the contaminant inventory, information on potential sources of contamination in the assessment area was collected in a Geographical Information System (GIS) or database. The data collected included existing data obtained from other agencies and new data generated by FCWA. As required by the Virginia Department of Health SWAP, a windshield survey was conducted on the Zone 1 area for each intake. The windshield survey consisted of visually identifying potential

sources of contamination in the field and obtaining location and property owner information for each site.

The Authority worked closely with County stormwater management departments to develop a BMP database useful for water quality purposes. As part of this process, Authority employees reviewed existing datasets, stormwater management plans, files, and fact sheets and entered available information in a GIS and database. A susceptibility analysis was conducted to determine the risk associated with various contaminant sources. As part of this effort, buffer distances and stream distances from each intake were determined for each contaminant site. The sources were ranked based on combined buffer and stream distance and the type of facility.

Keywords: case study; Northeast; source water assessment program; source water assessment plan; water quality; water supply; watershed management

Long, S.C. and J.D. Plummer. 2004. Assessing land use impacts on water quality using microbial source tracking. *Journal of the American Water Resources Association* (December):1433-1448.

Abstract: A renewed emphasis on source water protection and watershed management has resulted from recent amendments and initiatives under the Safe Drinking Water Act and the Clean Water Act. Knowledge of the impact of land use choices on source water quality is critical for efforts to properly manage activities within a watershed. This study evaluated qualitative relationships between land use and source water quality and the quantitative impact of season and rainfall events on water quality parameters. High levels of specific conductance tended to be associated with dense residential development, while organic carbon was elevated at several forested sites. Turbidity was generally higher in more urbanized areas. Sources tracking indicators were detected in samples where land use types would predict their presence. Coliform levels were statistically different at the 95% confidence levels for winter versus summer conditions and dry versus wet weather conditions. Other water quality parameters that varied with season were organic carbon, turbidity, dissolved oxygen, and specific conductance. These results indicate that land use management can be effective for mitigating impacts to a waterbody; however, year-round, comprehensive data are necessary to thoroughly evaluate the water quality at a particular site.

Keywords: development; drinking water; fecal coliform; land use; nonpoint source; Northeast; source water protection; urban; water quality; watershed management

Massachusetts Department of Conservation and Recreation. 2007. Quabbin Reservoir Watershed System: Land Management Plan 2007-2017. Division of Water Supply Protection. September.

Abstract: The Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management produces Land Management Plans for each of the watersheds under its care and control – Quabbin Reservoir, Ware River, Wachusett Reservoir, and the Sudbury Reservoir – on a rotating 10-year schedule. This *2007-2017 Quabbin Land*

Management Plan provides principles from the current state of the science of watershed and natural resources management, agency goals for the 10-year period, and specific objectives for accomplishing these in the areas of Land Protection, Forest Management, Wildlife Management, Management and Protection of Biodiversity, and Cultural Resources Protection. The plan builds on advancements in science and management techniques, the agency's own experience over six decades of managing the watershed and its resources, and accumulated input from advisory groups and the general, concerned public. It is designed as an adaptive plan, utilizing annual reviews to build immediately on new information and changes in the science that supports management decisions, and to revise objectives, as necessary, within the 10-year time frame of the plan.

Keywords: case study; Northeast; water quality; watershed management

Massachusetts Department of Environmental Protection. 2002. Source Water Assessment and Protection (SWAP) Report, Massachusetts Water Resources Authority (MWRA), Quabbin Reservoir, Ware River and Wachusett Reservoir. June.

Abstract: This Source Water Assessment and Protection (SWAP) report is a planning tool to support local and state efforts to improve water supply protection. By identifying land uses within water supply protection areas that may be potential sources of contamination, the assessment helps focus protection efforts on appropriate best management practices and drinking water source protection measures. The Massachusetts Water Resources Authority (MWRA) and the Metropolitan District Commission (MDC) meet the Department of Environmental Protection's (DEP's) annual review of "Measures of Success" for implementation of Watershed Protection Plans and disinfection treatment processes. MWRA and MDC have implemented DEP-approved Watershed Protection Plans to protect source water reservoirs since 1991. The findings contained in this report document conditions as of June 2002. For updates on watershed programs, please visit www.mwra.com, www.state.ma.us/mdc/water.htm, or call MWRA at 617-242-5323.

Keywords: Northeast; source water assessment and protection; source water protection report; water quality; watershed management

Mehaffey, M.H., M.S. Nash, T.G. Wade, D.W. Ebert, K.B. Jones, and A. Rager. 2005. Linking land cover and water quality in New York City's water supply watersheds. *Environmental Monitoring and Assessment* 107(1-3):29-44.

Abstract: The Catskill/Delaware reservoirs supply 90% of New York City's drinking water. The City has implemented a series of watershed protection measures, including land acquisition, aimed at preserving water quality in the Catskill/Delaware watersheds. The objective of this study was to examine how relationships between landscape and surface water measurements change between years. Thirty-two drainage areas delineated from surface water sample points (total nitrogen, total phosphorus, and fecal coliform bacteria concentrations) were used in step-wise regression analyses to test landscape and surface-water quality relationships. Two measurements of land use, percent agriculture and percent urban development, were positively related to water quality and consistently present in all regression models. Together these two land uses explained 25 to 75% of the regression model variation. However, the contribution of agriculture to water quality condition showed a decreasing trend with time as overall agricultural land cover decreased. Results from this study demonstrate that relationships between land cover and surface water concentrations of total nitrogen, total phosphorus, and fecal coliform bacteria counts over a large area can be evaluated using a relatively simple geographic information system method. Land managers may find this method useful for targeting resources in relation to a particular water quality concern, focusing best management efforts, and maximizing benefits to water quality with minimal costs.

Keywords: case study; development; drinking water; fecal coliform; land cover; land use; management; Northeast; reservoirs; total nitrogen; total phosphorus; urban; water quality; watershed

National Research Council. 2000. Watershed Management for Potable Water Supply: Assessing the New York City Strategy. National Academies Press, Washington, DC. Available: http://www.nap.edu/openbook/0309067774/html.

Abstract: January 21, 1997, marked an important event in the history of American water management: the signing of the mammoth New York City Watershed Memorandum of Agreement (MOA), which provides a legal framework for protecting the drinking water supply of nine million people. The culmination of years of negotiation between upstate and downstate interests, the MOA commits New York City to a long-term watershed management program that combines land acquisition, new watershed rules and regulations, and financial assistance to watershed communities to promote environmental quality and their local economies. Most important for New York City, the agreement currently satisfies provisions of the U.S. Environmental Protection Agency's Surface Water Treatment Rule that will allow the City to avoid filtering its upstate Catskill/Delaware water supply until at least 2002.

Immediately following the signing of the MOA, the National Research Council (NRC) was asked by the New York City Comptroller's Office to provide a scientific evaluation of the watershed management program. The goal of the NRC study was to determine whether the MOA is based on sound science and to recommend improvements to strengthen watershed management for this large unfiltered supply. This report is intended to inform New York City and other public water suppliers that are trying to maintain the purity of their existing water sources through proactive watershed management (regardless of whether they presently utilize filtration).

Keywords: case study; drinking water treatment; Northeast; prevention; water quality; watershed management

Philadelphia Water Department. 2006. The Schuylkill River Watershed Source Water Protection Plan. Prepared for the Pennsylvania Department of Environmental Protection. January.

Abstract: This Source Water Protection Plan clearly identifies actual and potential sources of contamination to the raw water supplying the Philadelphia Water Department's (PWD's) water treatment plants and outlines targeted protection and cleanup projects to address these sources. The plan serves as the first step for long-term sustainable planning for the future of the communities in the watershed, and it provides a comprehensive framework for implementing a watershed-wide effort to improve source water quality. The plan incorporates the following seven objectives that will allow PWD to ensure the integrity and affordability of the region's water supply for generations to come.

1. Establish the Schuylkill Action Network as a permanent watershed-wide organization charged with identifying problems and prioritizing projects and funding sources to bring about real improvement in water quality throughout the Schuylkill River watershed.

2. Create a long-term, sustainable fund to support restoration, protection, and education projects in the Schuylkill River watershed.

3. Increase awareness of the Schuylkill River watershed's regional importance as a drinking water source.

4. Initiate changes in policies and decision-making that balance and integrate the priorities of both the Safe Drinking Water Act and the Clean Water Act

5. Establish the Early Warning System as a regional information sharing resource and promote its capabilities for water quality monitoring and improving emergency communication.

6. Reduce point source impacts to water quality.

7. Reduce nonpoint source impacts to water quality.

Keywords: case study; drinking water quality; Northeast; source water protection plan; watershed management

Philadelphia Water Department. 2007. The Delaware River Watershed Source Water Protection Plan. Prepared for the Pennsylvania Department of Environmental Protection. June.

Abstract: The purpose of the Delaware River Protection Plan is to design a source water protection strategy to counter current and future water supply concerns of the Philadelphia Water Department and drinking water utilities that share the Delaware River as a resource.

The Baxter Water Treatment Plant, one of three drinking water facilities in Philadelphia, is supplied by the Delaware River. The Delaware River watershed extends 8,000 square miles through Pennsylvania, New Jersey, and New York. The Delaware River Source Water Protection Plan uses critical water quality, land cover, and population analyses as well as point and nonpoint source pollution modeling to characterize the water supply. The source water quality and quantity characterization, incorporated with the results from the 2002 Source Water Assessment, provide the technical foundation for a Delaware River source water protection strategy.

The Baxter Water Treatment Plant provides over 190 million gallons of safe and high quality drinking water per day to the citizens of Philadelphia and surrounding communities. The plant uses dual media filtration and chlorine disinfection technologies to provide high quality drinking water year-round. The Baxter Water Treatment Plant has an exceptional performance record and has never violated Safe Drinking Water Act regulations. The Baxter Water Treatment Plant owes its exceptional record to the hard work of dedicated Philadelphia Water Department staff and the quality source water supplied from the Delaware River.

The Philadelphia Water Department uses source water assessment and protection planning to maintain the integrity of the Delaware River as a drinking water supply.

Keywords: case study; drinking water quality; Northeast; source water protection plan; watershed management

U.S. EPA Region 2. 2006. Region 2 Water: Filtration Avoidance. Available: http://www.epa.gov/region02/water/nycshed/filtad.htm.

Abstract: For a drinking water system to qualify for filtration avoidance under the Surface Water Treatment Rule the system cannot be the source of a waterborne disease outbreak, must meet source water quality limits for coliform and turbidity, and meet coliform and total trihalomethane maximum contaminant levels. Disinfectant residual levels and redundant disinfection capability must also be maintained. Filtration avoidance also requires that a watershed control program be implemented to minimize microbial contamination of the source water. This program must characterize the watershed's hydrology, physical features, land use, source water quality, and operational capabilities. It must also identify, monitor, and control manmade and naturally occurring activities that are detrimental to water quality. The watershed control program must also be able to control activities through land ownership or written agreements.

Keywords: Northeast; water quality; watershed management

Southeast

South Carolina Department of Health and Environmental Control. 2004. Watershed Water Quality Assessment: Saluda River Basin. October.

Abstract: In 1993, the South Carolina Department of Health and Environmental Control (SCDHEC) published the first in a series of five watershed management documents. The first in that series, Watershed Water Quality Management Strategy: Savannah- Salkehatchie Basin communicated SCDHEC's innovative watershed approach, summarizing water programs and water quality in the basins. The approach continues to evolve and improve. The watershed documents facilitate broader participation in the water quality management process. Through these publications, SCDHEC shares water quality information with internal and external partners, providing a common foundation for water quality improvement efforts at the local watershed or large-scale, often interstate, river basin level.

Water quality data from the Saluda River Basin was collected from 1997 to 2001, and assessed during this third five-year watershed management cycle. This updated atlas provides summary information on a watershed basis, as well as geographical presentations of all permitted watershed activities. A waterbody index and facility indices allow the reader to locate information on specific waters and facilities of interest.

A brief summary of the water quality assessments included in the body of this document is provided following the Table of Contents. This summary lists all waters within the Saluda River Basin that fully support recreational and aquatic life uses, followed by those waters not supporting uses. In addition, the summaries list changes in use support status; those that have improved or degraded over the five years since the last strategy was written. More comprehensive information can be found in the individual watershed sections. The information will be updated in five years.

Keywords: case study; source water assessment plan; source water assessment programs; Southeast; water quality; watershed management

North Central

MacKenzie, W.R., N.J. Hoxie, M.E. Proctor, M.S. Gradus, K.A. Blair, D.E. Petersen, J.J. Kazmierczak, D.G. Addiss, K.R. Fox, J.B. Rose, and J.P. Davis. 1994. A massive outbreak in Milwaukee of *Cryptosporidium* infection transmitted through the public water supply. *New England Journal of Medicine* 331(3):161-167.

Abstract: Early in the spring of 1993 there was a widespread outbreak of acute watery diarrhea among the residents of Milwaukee. This study investigated the two Milwaukee water-treatment plants, gathered data from clinical laboratories on the results of tests for enteric pathogens, and examined ice made during the time of the outbreak for cryptosporidium oocysts. The authors surveyed residents with confirmed cryptosporidium infection and a sample of those with acute watery diarrhea consistent with cryptosporidium infection. To estimate the magnitude of the

outbreak, the authors also conducted a survey using randomly selected telephone numbers in Milwaukee and four surrounding counties.

There were marked increases in the turbidity of treated water at the City's southern water-treatment plant from March 23 until April 9, when the plant was shut down. Cryptosporidium oocysts were identified in water from ice made in southern Milwaukee during these weeks. The rates of isolation of other enteric pathogens remained stable, but there was more than a 100-fold increase in the rate of isolation of cryptosporidium. The median duration of illness was nine days (range, 1 to 55). The median maximal number of stools per day was 12 (range, 1 to 90). Among 285 people surveyed who had laboratory-confirmed cryptosporidiosis, the clinical manifestations included watery diarrhea (in 93%), abdominal cramps (in 84%), fever (in 57%), and vomiting (in 48%). The authors estimate that 403,000 people had watery diarrhea attributable to this outbreak.

This massive outbreak of watery diarrhea was caused by cryptosporidium oocysts that passed through the filtration system of one of the City's water-treatment plants. Water-quality standards and the testing of patients for cryptosporidium were inadequate to detect this outbreak.

Keywords: cryptosporidium; drinking water treatment; filtration; North Central; water quality

Muchmore, C.B. and B. Dziegielewski. 1983. Impact of drought on quality of potential water supply sources in the Sangamon River Basin. *Water Resources Bulletin* 19(1):37-46.

Abstract: The analysis of streamflow and several water quality parameters in six Illinois rivers showed both deterioration and improvement in quality indicators during the 1976-1977 drought. The adverse impacts were an increase of ammonia and manganese concentrations and, to a lesser degree, increased concentrations of phenol and specific conductance. At the worst point during the drought, the 12-month moving average of monthly ammonia concentration in the Sangamon River was about 620% higher than the antecedent value. On the other hand, average concentrations of nitrites and nitrates, total iron, and the number of coliform bacteria significantly decreased. This positive response suggests that streams which are considered unsuitable for municipal supply due to high levels of these quality indicators may be used as emergency sources during droughts.

Keywords: drought; North Central; water quality; water supply

St. Paul Regional Water Services and Minnesota Department of Health. 2001. City of St. Paul Source Water Assessment. September.

Abstract: The requirements of the Safe Drinking Water Act addressed are intended to provide St. Paul drinking water customers with (1) a general description of the area which supplies water to the St. Paul Regional Water Service (SPRWS); (2) an overview of why this water supply is susceptible to potential contaminants; (3) a description of the contaminants of concern which may impact the users of the public water supply; and (4) to the extent practical, the origins of the contaminants of concern. Because SPRWS relies on surface water and groundwater, each part of the assessment has a section devoted to each.

Keywords: case study; drinking water quality; North Central; source water assessment plan; watershed management

Northwest

Bend Water Division. Date Unknown. Source Water Assessment, City of Bend Water Division. Bend, OR.

Abstract: The Bridge Creek watershed provides, on the average over the past three years, about 50% of the City of Bend's drinking water supplies. The percentage of water from this source varies from year to year depending on weather, snow pack, maintenance activities, spring storm events, and community demands. The actual drainage boundary of the watershed is 3,200 acres while the designated legal boundary is 7,700 acres. The Bridge Creek watershed is an unfiltered source that complies with all state and federal regulations for source water quality, treatment techniques, and source water monitoring.

Keywords: case study; Northwest; water quality; water treatment; watershed management

Herbert, E. 2007. Forest management by west coast water utilities: protecting the source? *Journal of the American Water Works Association* 99(2):91-106.

Abstract: Most water utilities nationwide that depend on surface water draw water from watersheds over which they have little or no control. Therefore, water utility managers view land acquisition as one of the most effective ways to protect water quality. Because land acquisition can be costly, land trusts are increasingly using conservation easements to protect forest land. This article summarizes the key findings of a research project that analyzed forest management policies and practices of 45 West Coast public water utilities that own forested land in their source watersheds. The research includes three types of quantitative analysis and six case studies.

The primary research question driving this study was, "What is the variation in forest management policies and practices among West Coast public water utilities that own forest land, and what factors account for this variation?" If water utilities seek to buy land or acquire conservation easements in their forested watersheds to protect source water quality, then it is vital to consider how they manage this land once it is purchased. Public water utilities undeniably set an example for other land managers in terms of the importance of source water protection. Conservation easements to protect source watersheds therefore must be designed to protect forests from damaging forest practices as well as from conversion to other land uses.

Keywords: land use; management; Northwest; source water protection; Southwest; water quality; watershed

LaHusen, R.G. 1994. Variations in Turbidity in Streams of the Bull Run Watershed, Oregon, Water Years 1989-90. U.S. Geological Survey Water-Resources Investigations Report 93-4045.

Abstract: In this study, turbidity is used to help explain spatial and temporal patterns of erosion and sediment transport. Automated turbidity sampling in streams in the Bull Run watershed during water years 1989 and 1990, showed turbidity levels, in general, are remarkably low, with levels below 1 nephelometric turbidity unit (NTU) about 90% of the time. However, ephemeral increases in turbidity in streams of the Bull Run watershed occur in direct response to storms. Turbidity is caused by abundant organic particles as well as by materials eroded from unconsolidated geologic materials located along roads, streams channels, or stream banks. Seasonal and within-storm decreases in turbidity are attributed to depletion of accumulated particle supplies. During winter storms, erosion caused by rainfall intensities greater than 0.25 inches in three hours is sufficient to increase stream turbidities from less than 1 NTU to as much as 100 NTUs. Large-scale storms or floods cause persistent effects because mass erosion or scour of channel armor increases available sediment supply. Spatial variability in turbidity is evident only during storms when erosion and sediment-transport processes are active. Parts of the Rhododendron Formation are particularly prone to channel and mass erosion during large storms. Eroding glacial deposits in sections of Log Creek affected by a 1964 dam-break flood also cause high stream turbidity relative to other streams in the watershed. Analysis of characteristics of magnetic minerals in sediment sources and deposits was unproductive as a means to identify source areas of suspended sediment because high concentrations of magnetite in all samples of the volcanic rocks masked differences of less magnetic minerals in the samples.

Keywords: erosion; management; Northwest; runoff; sediment; storm; water quality

Oregon Department of Environmental Quality and Oregon Department of Human Services. 2003. Source Water Assessment Summary Brochure, Joint Water Commission PWS #4100379 and Hillsboro-Cherry Grove PWS # 4100985.

Abstract: The Source Water Assessment was recently completed by the Department of Environmental Quality and the Oregon Department of Human Services to identify the surface areas (and/or subsurface areas) that supply water to the Hillsboro Utilities Commission, Beaverton, Forest Grove, and Tualatin Valley Water District Joint Water Commission and Hillsboro-Cherry Grove's public water system intakes and to inventory the potential contaminant sources that may impact the water supply.

Keywords: case study; Northwest; source water assessment plan; Source Water Assessment Programs; water quality; watershed management

Seierstad, A., R. Willis, and S. Mengistu. 1994. Watershed use impacts on total and fecal coliform concentrations. In *Proceedings 1993 Water Quality Technology Conference; Part II* AWWA pp. 1701-1711.

Abstract: Prevailing wisdom tells us that restricting a watershed's uses and entry will result in improved water quality. However, there are few studies that have made water quality

comparisons between watersheds which are similar except with regard to their allowed uses and entry policies.

This study made comparisons between the Bull Run watershed and the Little North Santiam River watershed in Oregon. Both watersheds are used for drinking water production; the Bull Run watershed is used by the City of Portland, Oregon; and the Little North Santiam watershed is used by the City of Salem, Oregon. These watersheds are located on the western slopes of the Cascade Mountains in Oregon. They are in relatively close proximity and subject to similar weather patterns; the Bull Run watershed is about 45 miles due north of the Little North Santiam watershed. These watersheds were known to be similar in many ways, and were believed to have potential for use in a comparative water quality study such as this.

Keywords: drinking water; fecal coliform; nonpoint source; Northwest; water quality; watershed

Southwest

Alexander, B. 2004. Forest fire impacts on drinking water supplies. In *Wildland Fire Impacts on Watersheds: Understanding, Planning, and Response*, October 21-23, 2003, Englewood, CO. Geological Society of America, Boulder, CO.

Abstract: A major fire in a drinking water watershed can impact water quantity and quality. Sediments and other contaminants such as heavy metals and nutrients can be significantly elevated in rivers and streams following a catastrophic fire, making it difficult for utilities to effectively provide safe, clean drinking water to their customers. The Bobcat fire in the Loveland, Colorado watershed in 2000 is an example for utilities serving a large urban population. The biggest threat to water quality in the West is from fire-related contaminants, not industrial chemicals or hazardous waste spills. The U.S. Environmental Protection Agency drinking water quality guidelines are not always consistent with appropriate forest management practices for managing forest fires and maintaining forest health. In order to prepare for and prevent severe impacts to drinking water resulting from forest fires, watershed managers need to employ best management practices to manage both issues simultaneously.

Keywords: Bobcat fire; case study; fire; prevention; response strategy; Southwest; water quality; water quantity; watershed management

Buehrer, J. 2007. Vast tinderbox threatens Colorado’s watersheds. *Mainstream* 51(3):1,7.

Abstract: Seven Front Range Colorado water providers met with representatives of the Colorado State Forest Service, the U.S. Forest Service, the U.S. Geological Survey, the National Park Service, other related entities, American Water Works Association, and Awwa Research Foundation at an August 15 workshop hosted by AWWA in Denver.

At the half-day meeting on protecting Front Range forest watersheds from high-severity wildfires, forestry experts and water utility managers with first-hands experience spoke about the link between forest fires and drinking water quality.

Keywords: erosion; fire; sediment; Southwest; water quality

Gary, H.L., S.R. Johnson, and S.L. Ponce. 1983. Cattle grazing impact on surface water quality in a Colorado Front Range stream. *Journal of Soil and Water Conservation* 38:124-128.

Abstract: Cattle grazing in pastures bisected by a small perennial stream in central Colorado had only minor effects on water quality during two years of study. Suspended solids and nitrate nitrogen did not increase significantly, and ammonia nitrogen increased significantly only once under moderate rates of grazing. Indicator bacteria densities in the stream water were significantly higher when at least 150 cattle were grazing. After removal of cattle or when 40 head of cattle were grazing, bacterial counts dropped to levels similar to those in adjacent, ungrazed pasture. About 5% of the total manure produced by cattle contributed to pollution and/or enrichment of the stream.

Keywords: ammonia; bacterial pathogens; grazing; land use; nitrate; phosphorous; Southwest; suspended solids; water quality

Herbert, E. 2007. Forest management by west coast water utilities: protecting the source? *Journal of the American Water Works Association* 99(2):91-106.

Abstract: Most water utilities nationwide that depend on surface water draw water from watersheds over which they have little or no control. Therefore, water utility managers view land acquisition as one of the most effective ways to protect water quality. Because land acquisition can be costly, land trusts are increasingly using conservation easements to protect forest land. This article summarizes the key findings of a research project that analyzed forest management policies and practices of 45 West Coast public water utilities that own forested land in their source watersheds. The research includes three types of quantitative analysis and six case studies.

The primary research question driving this study was, “What is the variation in forest management policies and practices among West Coast public water utilities that own forest land, and what factors account for this variation?” If water utilities seek to buy land or acquire conservation easements in their forested watersheds to protect source water quality, then it is vital to consider how they manage this land once it is purchased. Public water utilities undeniably set an example for other land managers in terms of the importance of source water protection. Conservation easements to protect source watersheds therefore must be designed to protect forests from damaging forest practices as well as from conversion to other land uses.

Keywords: land use; management; Northwest; source water protection; Southwest; water quality; watershed

Kent, R., K. Belitz, A.J. Altmann, M.T. Wright, and G.O. Mendez. 2005. Occurrence and Distribution of Pesticides in Surface Water of the Santa Ana Basin, California, 1998-2001. U.S. Geological Survey Scientific Investigations Report 2005-5203.

Abstract: A study of the occurrence and distribution of pesticide compounds in surface water of the highly urbanized Santa Ana Basin, California, was done as part of the U.S. Geological Survey's National Water-Quality Assessment Program. One-hundred and forty-eight samples were collected from 23 sites, and analyzed for pesticide compounds during the study period from November 1998 to September 2001. Sixty-six different pesticide compounds were detected at varying frequencies and concentrations, and one or more pesticides were detected in 92% of the samples. All pesticide concentrations were below maximum levels permitted in drinking water. However, two compounds-diazinon and diuron-exceeded nonenforceable drinking water health advisory levels in at least one stream sample, and five compounds exceeded guidelines to protect aquatic life-carbaryl, chlorpyrifos, diazinon, lindane, and malathion. Twenty-two pesticide compounds were detected in at least 25% of the samples collected from any one fixed site. These are identified as "major" pesticide compounds and are emphasized in this report.

The degree to which pesticides were used in the basin, as well as their physical-chemical properties, are important explanatory factors in stream pesticide occurrence, and most pesticides probably enter streams with urban runoff. Stormflow substantially increases urban runoff, and storm effects on stream pesticide concentrations sometimes persist for several days or weeks after the storm. Water sources other than urban runoff also deliver pesticide compounds to surface water in the basin. For example, atrazine may enter streams in gaining reaches where groundwater carries high loads as a result of historical use in the basin. Also, the data suggest that lindane, and perhaps bromacil, are present in treated wastewater, the predominant source of water to streams in the Santa Ana Basin.

Keywords: agriculture; pesticides; Southwest; urbanization; water quality

Marin Municipal Water District. 2005. Watershed Sanitary Survey Update 2005. December.

Abstract: The Marin Municipal Water District (MMWD) is a purveyor of drinking water obtained from seven reservoirs in Marin County. As a drinking water supply agency that draws from a surface water supply, MMWD was required under the California Surface Water Treatment Rule to conduct a watershed sanitary survey (WSS) in 1995 and to conduct updates to the WSS every five years thereafter. This document is the second update to the 1995 WSS and fulfilled MMWD's requirement to complete an updated WSS by January 1, 2006. The focus of the 1995 WSS was to recommend measures that a water purveyor can implement to preserve and improve the quality of their surface water supplies. The focus of the WSS update is to identify the changes to the information provided in the original WSS and subsequent updates.

This WSS update addresses MMWD's seven local surface water reservoirs that are located in two major watersheds, the Mount Tamalpais Watershed and the Soulajule/Nicasio Watershed. MMWD also treats water that is supplied by the Sonoma County Water Agency (SCWA) from

the Russian River; SCWA is addressing the WSS update requirements for the Russian River supply in a separate study.

Pursuant to the recommendation of Department of Health Services staff, this WSS update is intended to be a short update report to the 2000 WSS update and is intended to provide information on the changes that have occurred since 2000 to the various aspects of the original WSS.

Keywords: case study; source water assessment and protection; source water assessment plan; Southwest; water quality; watershed management; watershed sanitary survey

San Francisco Planning Department. 2000. Alameda Watershed Management Plan: Final Environmental Impact Report.

Abstract: The purpose of the Management Plan is to provide a policy framework for the San Francisco Public Utilities Commission (SFPUC) to make consistent decisions about the activities, practices, and procedures that are appropriate on the Watershed lands. To aid the SFPUC in their decision-making, the Management Plan provides a comprehensive set of goals, policies, and management actions that address all Watershed activities and reflect the unique qualities of the Watershed.

Keywords: case study; Southwest; water quality; water treatment; watershed management

San Francisco Public Utilities Commission and Bay Area Water Users Association. 2000. Water Supply Master Plan: A Water Resource Strategy for the SFPUC System. April.

Abstract: Over 2.3 million people in San Francisco, San Mateo, Santa Clara and Alameda counties currently rely entirely, or in part, on water supplied by the San Francisco Public Utilities Commission (SFPUC) system. The SFPUC system is supplied by surface water and groundwater sources in the Bay area and is supplemented by water from the Tuolumne River watershed. The water supplied by the SFPUC system is of excellent quality and reasonable cost and is a positive factor in attracting businesses and industry to the Bay area, such as biotechnology businesses, computer and software companies, and research institutions. The SFPUC system is critical to the economy of San Francisco and the entire San Francisco Bay area. Characterized by rapid industrial growth, year-round tourism and a thriving high technology and biotechnology sector, the Bay area economy relies on SFPUC water supplies for industry, hotels, convention centers, restaurants, office buildings, and other commercial uses, as well as residential use for continued economic prosperity. The SFPUC system is owned and operated by the City and County of San Francisco through the SFPUC. The system provides retail water service to the residents and institutions within the City limits, as well as a number of residential and commercial accounts in the Bay area and the Sierra Nevada foothills. The system provides wholesale water service to 29 customer agencies in the Bay area.

Keywords: case study; Southwest; urbanization; water quality; water treatment; watershed management

Sprague, L.A. 2005. Drought effects on water quality in the South Platte River Basin, Colorado. *Journal of the American Water Resources Association* (February):11-24.

Abstract: Twenty-three stream sites representing a range of forested, agricultural, and urban land uses were sampled in the South Platte River Basin of Colorado from July through September 2002 to characterize water quality during drought conditions. With a few exceptions, dissolved orthophosphate concentrations were similar to seasonal historical levels in all land use areas during the drought. At some agricultural sites, decreased dilution of irrigation return flow may have contributed to higher concentrations of some nutrient species, increased primary productivity, and higher dissolved oxygen concentrations. At some urban sites, decreased dilution of base flow and wastewater treatment plant effluent may have contributed to higher dissolved nitrite-plus-nitrate concentrations, increased primary productivity, and higher dissolved oxygen concentrations. Total pesticide concentrations in urban and agricultural areas were not consistently higher or lower during the drought. At most forested sites, decreased dilution of groundwater-derived calcium bicarbonate type base flow likely led to elevated pH and specific-conductance values. Water temperatures at many of the forested sites also were higher, contributing to lower dissolved oxygen concentrations during the drought.

Keywords: drought; flow; land use; nonpoint source; Southwest; urban; water quality

Westerhoff, P., D. Gill, and S. Lohman. 2005. Effects of forest fires on reservoir water quality. In *American Water Works Association 2005 Source Water Protection Symposium*, January 23-26, Palm Beach Gardens, FL.

Abstract: The objective of this research was to determine the long-term effects of catastrophic forest fires on drinking water quality. The watersheds burned by the Rodeo-Chediski fire in Arizona and the Hayman fire in Colorado were the focus of this research. Both fires occurred in watersheds that serve as a drinking water source for a major metropolitan area. Concentration data and mass loading analyses were conducted utilizing pre- and post-fire water quality data. The results of the Rodeo-Chediski fire and the Hayman fire analysis were compared. In addition, an unburned watershed in Arizona was analyzed and served as the reference watershed.

The short- and long-term impacts on stream water that serves as a drinking water source were determined. Short-term effects consisted of elevated nutrient and particulate concentrations in the burned watersheds during subsequent storm events. The post-fire storm events also elevated the metal concentrations in runoff water. However, the maximum contaminant level set by the U.S. Environmental Protection Agency for the metals analyzed was not exceeded. Long-term effects will originate from the mobilized particulate fraction settling to the stream or lake bottom. The organic material adsorbed to the particulates will be slowly dissolved, diffusing into the water. The dissolved organics will serve as an energy source for microorganisms that have the ability to cause taste and odor problems in drinking water. The long-term effects are aesthetic and do not pose a human health risk.

Keywords: case study; drinking water quality; drought; fire; Southwest

United States

Association of Metropolitan Water Agencies. 2008. Climate Change Case Studies. Available: http://www.amwa.net/.

Abstract: Across the country, Association of Metropolitan Water Agencies member utilities are studying and preparing for the potential impacts of climate change on their community's drinking water supplies. Cities that have instituted plans to address climate change in their watersheds include Tucson, Arizona; San Francisco, California; Santa Clara County, California; Denver, Colorado; Miami, Florida; Las Vegas, Nevada; Albuquerque, New Mexico; New York City, New York; Portland, Oregon; and Seattle, Washington.

Keywords: climate change; drinking water quality; United States; watershed management

Cromwell, J.E., J.B. Smith, and R.S. Raucher. 2007. Implications of Climate Change for Urban Water Utilities. Prepared by Stratus Consulting for the Association of Metropolitan Water Agencies, Washington, DC. December.

Abstract: There are many parts to the climate change story that come together to produce a picture of potentially significant implications for urban water utilities. This can create an information overload that, coupled with uncertainties, presents a barrier to understanding and to developing responses. This paper is designed to help move past this initial barrier in order to draw an effective focus on implications and responses. The story is broken into its main elements and considered in logical sequence without tangential details that are documented sufficiently in the scientific literature. The intent is to provide an essential understanding and then turn to consideration of the issues involved in developing suitable water sector responses to climate change.

A general description of climate change processes and effects follows the introduction. Impacts of these climatic changes on water suppliers are then identified and described, including regional differences. Responses to climate change are then discussed, both in terms of "adaptation strategies" to reduce or avoid impacts of climate change, and in terms of "mitigation strategies" that utilities may adopt to reduce the contribution of water utility operations to the production of greenhouse gas emissions.

Keywords: climate change; drinking water quality; drinking water treatment; United States; watershed management

Dissmeyer, G.E. (ed.). 2000. Drinking Water from Forests and Grasslands: A Synthesis of the Scientific Literature. General Technical Report SRS-39. USDA Forest Service Southern Research Station.

Abstract: The Safe Drinking Water Act Amendments of 1996 required every state to perform source water assessments of all public drinking water sources and make the results public by 2003. Forests and grasslands serve as sources of many public drinking water supplies, and managers of these lands are expected to participate in preparing assessments and to work with the public to ensure safe drinking water. To help managers of forests and grasslands meet this requirement, this report reviews the current scientific literature about the potential of common land-use practices to introduce contaminants that pose risks to human health into public drinking water sources. Potential audiences for this report include managers of national forests, grasslands, and other public and private lands with similar uses. Operators of public drinking water utilities and citizens' groups concerned with drinking water may also find this report useful.

Safe drinking water is essential to protect public health. Modern drinking water treatment can reduce most contaminants in source water to acceptable levels before it is delivered to consumers, but costs increase significantly when more rigorous treatment is needed to cleanse contaminated source water. Managing land to prevent source water contamination may be more cost-effective and may better protect human health than treating water after it has been contaminated.

Water from forests and grasslands is usually cleaner than water from urban and agricultural areas. Nevertheless, many common practices on forests and grasslands can contaminate drinking water sources. Soil disturbing activities such as road construction and maintenance, forest harvesting, and intermixed urban and wildland uses can introduce sediment into drinking water sources. Disease organisms may enter source waters from (1) recreation and other human activities that lack developed sanitary facilities, (2) malfunctioning sewage disposal facilities, and (3) wild and domestic animals concentrated near source waters. Nutrients may enter source water from fertilizer and from atmospheric deposition of nitrogen compounds. Toxic chemicals may reach source water from pest control; from extraction of minerals, oil, and gas; from accidental chemical spills along highways and utility corridors; and from leaking underground storage tanks.

Gaps exist in the scientific understanding of the effects of many land-use practices on drinking water sources. For example, pathogens in wild animal populations and their transmission to source water are poorly known. Risk of contamination from recreation that occurs in areas without developed sanitary facilities is largely unstudied. Effects of multiple land uses that overlap in time and space across large watersheds are difficult to predict with current knowledge. Managers should consider uncertainties due to these unknowns in land-use decisions until research fills these knowledge gaps.

Source water assessments for forest and grassland watersheds are not likely to be fundamentally different from those in areas with other land uses. Scientific information will need to be applied locally on a case-by-case basis to consider which natural and human activities have a reasonable potential to introduce contaminants that are likely to reach a drinking water intake. Assessments will need to integrate across conventional disciplinary boundaries to assess the overall degree of risk to drinking water sources. Scientists, land managers, and the public will need to cooperate to translate the basic information in this report into meaningful source water assessments.

Keywords: costs; sediment; source water; United States; water quality

Ernst, C. and K. Hart. 2005. Path to Protection: Ten Strategies for Successful Source Water Protection. The Trust for Public Land.

Abstract: Over the past five years, the U.S. Environmental Protection Agency's (EPA's) Office of Ground Water and Drinking Water funded five national nonprofit organizations to launch source water demonstration projects in communities around the country. The purpose of the projects was to build on state Source Water Assessment Programs to move communities from planning to implementing protection for drinking water sources. Successful pilot projects could then be replicated by state and local governments and water suppliers around the country. In order to glean the lessons learned and identify best practices, the Trust for Public Land (TPL) led a joint review of the five grantees' source protection demonstration projects during the spring and summer of 2004. The five grantees were the Clean Water Network/Clean Water Fund/Campaign for Safe and Affordable Drinking Water, the Groundwater Foundation, the Environmental Finance Center Network, the National Rural Water Association, and TPL (in partnership with the University of Massachusetts and the U.S. Department of Agriculture [USDA] Forest Service). Each of EPA's grantees took a different approach to advance source water protection through its pilot project.

The partnership of Clean Water Network/Clean Water Fund/Campaign for Safe and Affordable Drinking Water worked with hundreds of voluntary and nonprofit watershed associations around the country to help them advocate more effectively for source protection as part of a larger goal to achieve fishable and swimmable water.

The Groundwater Foundation supported suppliers working to advance new tools for wellhead and groundwater protection.

The Environmental Finance Center Network helped local stakeholders develop and implement source water protection plans for sources that are shared by many water systems.

The National Rural Water Association hired technicians around the country to assist small rural communities design and implement source water plans.

The Trust for Public Land (in partnership with the University of Massachusetts and the USDA Forest Service) worked with local communities in multijurisdictional watersheds to integrate land conservation and forest management into comprehensive source water protection efforts. This report summarizes findings based on experiences of the five pilot projects and proposes 10 strategies that will help put more state and local governments on the path to protection. Each strategy includes a case study of a state or local entity that has successfully implemented some or all of the action steps included in that strategy. (Note: The case studies are independent of the pilot projects of the five grantees.)

Keywords: agriculture; case study; drinking water; management; source protection; source water protection; United States; watershed

Hurd, B.H., N. Leary, R. Jones, and J.B. Smith. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association* 35(6):1399-1409.

Abstract: Changes in global climate may alter hydrologic conditions and have a variety of effects on human settlements and ecological systems. The effects include changes in water supply and quality for domestic, irrigation, recreational, commercial, and industrial uses; in instream flows that support aquatic ecosystems, recreation uses, hydropower, navigation, and wastewater assimilation; in wetland extent and productivity that support fish, wildlife, and wastewater assimilation; and in the frequency and severity of floods. Watersheds where water resources are stressed under current climate are most likely to be vulnerable to changes in mean climate and extreme events. This study identified key aspects of water supply and use that could be adversely affected by climate change, developed measures and criteria useful for assessing the vulnerability of regional water resources and water dependent resources to climate change, developed a regional database of water sensitive variables consistent with the vulnerability measures, applied the criteria in a regional study of the vulnerability measures, and applied the criteria in a regional study of the vulnerability of U.S. water resources. Key findings highlight the vulnerability of consumptive uses in the western and, in particular, the southwestern United States. However, southern U.S. watersheds are relatively more vulnerable to changes in water quality, flooding, and other instream uses.

Keywords: climate change; flood; flow; United States; water quality; water resources; water supply; watershed

Pyke, G.W., W.C. Becker, R. Head, and C.R. O'Melia. 2003. Impacts of Major Point and NonPoint Sources on Raw Water Treatability. Jointly sponsored by Awwa Research Foundation and Water Environment Research Foundation. Denver, Colorado.

Abstract: Point and nonpoint source pollution of surface waters have a negative impact not only on the health of aquatic ecosystems but also on the drinking water treatment plants that rely on surface waters. Sediment, nutrients, pesticides, pathogens, and other pollutants in source waters can decrease treatability, increase treatment costs, and ultimately increase risks to public health. Utility managers typically respond to deteriorating raw water quality by increasing chemical dosages, modifying existing processes, or adding additional processes. As an alternative or supplement to changes at the treatment plant, managers may also consider promoting best management practices (BMPs) in the watershed to preserve or improve raw water quality. Given limited resources, however, managers need guidance on allocating resources between increased treatment at the plant and promotion of BMPs in the watershed.

Keywords: atrazine; cryptosporidium; total organic carbon; total phosphorus; total suspended solids; United States; urbanization; water quality; water treatment

Rosen, B.H. 2000. Waterborne Pathogens in Agricultural Watersheds. WSSI Technical Note 2. USDA Watershed Science Institute. February.

Abstract: This technical note provides an introduction to waterborne pathogens, the disease-causing organisms that contaminate water. Key organisms of concern are described in detail, including *Escherichia coli* 0157:H7, *Cryptosporidium parvum,* and *Giardia* spp. Indicator bacteria that are normally monitored for water quality are described. Information on viability of organisms in an agricultural setting is presented, along with relevant management practices for controlling waterborne pathogens at their source, thereby reducing the overall pathogen loading within a watershed. The topic of harmful algal blooms is also addressed, although these organisms do not fall neatly into the category of pathogen. Because the potential exists for contamination of water with pathogens from agriculture, this technical note represents a proactive approach for reducing this source in watersheds.

Keywords: agriculture; grazing; land use; management; United States; water quality; waterborne pathogens; watershed

Schmitt, C. 2002. Source Water Protection: Linking Surface Water Quality to the Watershed: Problems, Sources, and Solutions. Prepared by: Senator George J. Mitchell Center for Environmental & Watershed Research, University of Maine; Maine Water Utilities Association; Drinking Water Program, Maine Department of Human Services.

Abstract: The purpose of this Source Water Protection Guide is to help community water systems safeguard their surface water supplies. This guide was produced as part of Maine's Source Water Assessment Program (SWAP) in order to help surface water systems move from source water assessment to source water protection. This guide is intended to help small utilities manage and minimize risks identified by SWAP by focusing on the watershed causes of specific water quality problems.

Keywords: source water protection; United States; water quality; water supply; watershed

Hopper, K. and C. Ernst. 2005. *Source Protection Handbook: Using Land Conservation to Protect Drinking Water Supplies.* The Trust for Public Land and the American Water Works Association

Abstract: From source to tap, there are numerous points to capture and safeguard clean water or treat contaminated water. The most fundamental approach begins at the source – the lakes, rivers, streams, reservoirs, and groundwater that provide drinking water. By preserving the land that drains to these sources, the vast majority of contaminants are prevented from entering drinking water in the first place. This is a critical component of source protection and the focus of this handbook. Land conservation emphasizes the permanent preservation of land around both groundwater sources (aquifer recharge areas and wellheads) and surface water sources (land that buffers streams, rivers, and lakes). It is an extremely effective tool that can protect public health, prevent increased treatment costs, ensure consumer confidence, and maintain real estate values in areas where water supplies are protected.

Treatment, through filtration and disinfection, is the next barrier against contaminated water. Should pollutants enter water supplies, treatment removes most contaminants. Even in the most pristine watersheds, natural pollutants such as animal waste and organic matter can impair water quality, making treatment essential to the delivery of clean, safe drinking water.

The final barrier is infrastructure. From treatment plants, water travels into canals, pipes, wells, holding tanks, and finally consumer operated spigots. Contamination can occur through the corrosion of pipes and solder material (copper, lead, asbestos), the growth of bacteria in pipes, and untreated water that enters through a break in the distribution system itself. Sound and up-to-date distribution systems help prevent such contamination and disruption of service.

Keywords: costs; drinking water; filtration; land use; reservoirs; source protection; United States; water quality; water supply; watershed

USDA Agricultural Research Service. 2003. First Interagency Conference on Research in the Watersheds. October 27-30, 2003. Available: http://www.tucson.ars.ag.gov/icrw/proceedings.htm.

Abstract: This report comprises *Abstract*s and papers presented at the First Interagency Conference on Research in the Watersheds, October 27-30, 2003, in Benson, Arizona. This report represents state-of-the-art research in watersheds. The content includes reviews of watershed research programs conducted by the U.S. Department of Agriculture's Agricultural Research Service and Forest Service, the U.S. Geological Survey, the U.S. Bureau of Land Management, the U.S. Environmental Protection Agency, and the National Science Foundation Consortium of Universities for the Advancement of Hydrological Sciences, Inc., and recent research on watershed-scale topics such as hydrology, erosion, economic, instrumentation, ecology, sociology and fire.

Keywords: costs; erosion; fire; hydrology; United States; water quality; water quantity; watershed

U.S. EPA. 1999. Protecting Sources of Drinking Water: Selected Case Studies in Watershed Management. EPA 816-R-98-019.

Abstract: This document presents case studies of 17 drinking water systems committed to extensive efforts to incorporate source water management and protection as an integral part of their business of providing safe drinking water to their customers. The authors provide snapshots of lessons learned in implementing four aspects of source water protection: partnerships, watershed assessment, watershed land use management, and land acquisition.

Though diverse in their watershed management experiences, there is a common thread among all of the water systems: the importance of cross-program coordination. The coordination of a drinking water utility's goals with local watershed management initiatives aimed at aquatic ecosystem restoration and protection can boost the effectiveness of program implementation for both priorities.

Keywords: United States; water quality; watershed management

U.S. EPA. 2003. Watershed Analysis and Management (WAM) Guide for States and Communities. EPA 841-B-03-007.

Abstract: Using a watershed approach provides a unique and effective way to assess the environment, identify problems, establish priorities for preservation or restoration, and implement solutions. The Watershed Analysis and Management (WAM) Program is an effort to guide communities in the successful application of a watershed approach and led to the development in 2002 of this Guide. The U.S. Environmental Protection Agency's Office of Wetlands, Oceans, and Watersheds (OWOW) and the American Indian Environmental Office (AIEO) collaborated in 1997 on a joint project to develop a comprehensive WAM methodology. The initial WAM approach was based on watershed planning efforts in the Pacific Northwest, including the Washington State watershed analysis methodology for state and private forest lands and the Northwest Forest Plan watershed analysis guide for federal ownership. The concept was to extend existing capabilities to address a nationwide range of ecological environments, project objectives, and watershed management issues at the state, community, and tribal levels. With substantial support from the AIEO, a more comprehensive approach was undertaken to include the additional issues of tribal cultural and community values. The first product, *Watershed Analysis and Management (WAM) Guide for Tribes*, was developed with a system development grant from OWOW to the Pacific Watershed Institute, concurrent with pilot applications of the approach, through AIEO grants, by tribes representing different ecological environments, objectives, and community issues.

Keywords: development; management; United States; water quality; watershed

U.S. EPA. 2005. Handbook for Developing Watershed Plans to Restore and Protect Our Waters. EPA 841-B-05-005. October.

Abstract: This handbook provides information on developing and implementing watershed plans that help to restore and protect water quality. Experience over the past decade has shown that effective watershed management includes active participation from stakeholders, analysis and quantification of the specific causes and sources of water quality problems, identification of measurable water quality goals, and specific actions needed to solve those problems.

Keywords: management; United States; water quality; watershed management

U.S. EPA. 2005. EPA's Targeted Watershed Grants 2005 Annual Report. EPA 840-R-06-001. December.

Abstract: The 34 watersheds funded in 2003 and 2004 under the U.S. Environmental Protection Agency's Targeted Watersheds Grant Program are spread out across the United States and include large and relatively small watersheds. While a few of the watersheds are in urban areas, most are in rural and agricultural areas, flowing through deserts, forests, mountains, coastal areas, and a bayou. Although they differ in size and scope, all of the watershed partnerships reflect the unique custom and cultural values of the region.

Keywords: costs; United States; water quality; watershed management

U.S. EPA. 2006. EPA Watershed Tools. May. Available: http://www.epa.gov/owow/watershed/watershedtools606.pdf.

Abstract: This document is a fact sheet with links and descriptions for databases, publications, and other resources useful in watershed management and protection.

Keywords: United States; water quality; watershed; watershed management

11. Urbanization

Northeast

Chowdhury, S. and K. Ganesh. 2006. The impact of landuse on surface water quality in Queens County, New York. *Journal of Environmental Hydrology* 14:Paper 15.

Abstract: Community water supplies throughout the United States are under increasing threat of contamination from agricultural and urban use of fertilizers and pesticides. Water samples were collected and analyzed in the field from six ponds and lakes from Queens County, New York. The concentrations of dissolved oxygen, chlorine, phosphate, ammonia, and nitrate were determined. Several types of land use around these waterbodies were identified. The present analyses indicate that a relationship exists between the agrochemicals (nitrate, phosphate, and ammonia) found in the water and the land use in Queens County.

Keywords: drinking water quality; land use; nonpoint source; Northeast; water quality; watershed management

Claessens, L., C. Hopkinson, E. Rastetter, and J. Vallino. 2006. Effect of historical changes in land use and climate on the water budget of an urbanizing watershed. *Water Resources Research* 42:W03426

Abstract: The effects of historical (1931-1998) changes in both land use and climate on the water budget of a rapidly urbanizing watershed, the Ipswich River Basin (IRB) in northeastern Massachusetts were assessed. Water diversions and extremely low flow during summer are major issues in the IRB. This study centers on a detailed analysis of diversions and a combined empirical/modeling treatment of evapotranspiration (ET) response to changes in climate and land use. A detailed accounting of diversions showed that net diversions increased due to increases in water withdrawals (primarily groundwater pumping) and export of sewage. Net diversions constitute a major component of runoff (20% of streamflow). Using a combination of empirical analysis and physically based modeling, an increase in precipitation (2.7 millimeter per year, mm/yr) and changes in other climate variables to an increase in ET (1.7 mm/yr). Simulations with a physically based water-balance model showed that the increase in ET could be attributed entirely to a change in climate, while the effect of land use change was negligible. The land use change effect was different from ET and runoff trends commonly associated with urbanization. These and other findings were generalized to predict future streamflow using climate change scenarios. This study could serve as a framework for studying suburban watersheds, being the first study of a suburban watershed that addresses long-term effects of changes in both land use and climate, and accounts for diversions and other unique aspects of suburban hydrology.

Keywords: climate change; development; land use; Northeast; runoff; streamflow; urban; water quality

Jones, R.C. and B.H. Holmes. 1985. Effects of land use practices on water resources in Virginia. Virginia Water Resources Research Center Bulletin 144. Virginia Polytechnic Institute & State University.

Abstract: This study reviews the relationship between land use and water resources in Virginia. It examines three major land uses in the state-agriculture, urban, and forestry activities. For each land use, the relevant literature and state management programs are reviewed. In addition, the report outlines research needs in each area.

Agricultural activities affect the receiving waters of Virginia through increased loads of sediment, nutrients, pesticides, and pathogens. In general, pollutant loads are greatest from more intensive agricultural activities. Sediments and particulate nutrient losses may require other strategies. Urban land uses have the potential to increase sediment, nutrient, and heavy metal loads. Forestry practices may damage receiving waters through sediment loadings and alteration in stream habitat due to removal of riparian vegetation.

Recommended future research includes documentation and refinement of the effectiveness of existing best management practices (BMPs), investigation of the effectiveness of urban sediment BMP enforcement, determination of the significance of pathogen indicator organisms in urban and agricultural runoff, evaluation of the long-term cost of BMP structures, demonstration of agricultural and forestry BMPs, and exploration of the pollutant delivery problem in watersheds.

Keywords: agriculture; land use; nonpoint source; Northeast; nutrient load; urban

Long, S.C. and J.D. Plummer. 2004. Assessing land use impacts on water quality using microbial source tracking. *Journal of the American Water Resources Association* (December):1433-1448.

Abstract: A renewed emphasis on source water protection and watershed management has resulted from recent amendments and initiatives under the Safe Drinking Water Act and the Clean Water Act. Knowledge of the impact of land use choices on source water quality is critical for efforts to properly manage activities within a watershed. This study evaluated qualitative relationships between land use and source water quality and the quantitative impact of season and rainfall events on water quality parameters. High levels of specific conductance tended to be associated with dense residential development, while organic carbon was elevated at several forested sites. Turbidity was generally higher in more urbanized areas. Sources tracking indicators were detected in samples where land use types would predict their presence. Coliform levels were statistically different at the 95% confidence levels for winter versus summer conditions and dry versus wet weather conditions. Other water quality parameters that varied with season were organic carbon, turbidity, dissolved oxygen, and specific conductance. These results indicate that land use management can be effective for mitigating impacts to a waterbody; however, year-round, comprehensive data are necessary to thoroughly evaluate the water quality at a particular site.

Keywords: development; drinking water; fecal coliform; land use; nonpoint source; Northeast; source water protection; urban; water quality; watershed management

McCormick, J., R.R. Grant Jr., and R. Patrick. 1970. Two Studies of Tinicum Marsh, Delaware and Philadelphia Counties, Pennsylvania. The Conservation Foundation, Washington, DC.

Abstract: Tinicum Marsh, the last tidal marsh in Pennsylvania, is part of a set of demonstrations initiated by The Conservation Foundation with assistance from a Ford Foundation Grant. The projects are designed to develop and demonstrate means of resolving conflicts between preservation and development. The purpose of the Tinicum study is to determine if ecological functions can be maintained, with minimum losses, as development reaches the marsh. Relevant questions address issues relating to the diminished functioning of a highly polluted marsh, which are the positive functions worth preserving, and how these functions can be enhanced as development encroaches. Two technical reports address these questions and provide a base of information for subsequent studies. The first study addresses the natural features of Tinicum marsh, with particular emphasis on the vegetation. The second study addresses Tinicum marsh as a water purifier.

Keywords: case study; development; Northeast; pollution; water quality

Mehaffey, M.H., M.S. Nash, T.G. Wade, D.W. Ebert, K.B. Jones, and A. Rager. 2005. Linking land cover and water quality in New York City's water supply watersheds. *Environmental Monitoring and Assessment* 107(1-3):29-44.

Abstract: The Catskill/Delaware reservoirs supply 90% of New York City's drinking water. The City has implemented a series of watershed protection measures, including land acquisition, aimed at preserving water quality in the Catskill/Delaware watersheds. The objective of this study was to examine how relationships between landscape and surface water measurements change between years. Thirty-two drainage areas delineated from surface water sample points (total nitrogen, total phosphorus, and fecal coliform bacteria concentrations) were used in step-wise regression analyses to test landscape and surface-water quality relationships. Two measurements of land use, percent agriculture and percent urban development, were positively related to water quality and consistently present in all regression models. Together these two land uses explained 25 to 75% of the regression model variation. However, the contribution of agriculture to water quality condition showed a decreasing trend with time as overall agricultural land cover decreased. Results from this study demonstrate that relationships between land cover and surface water concentrations of total nitrogen, total phosphorus, and fecal coliform bacteria counts over a large area can be evaluated using a relatively simple geographic information system method. Land managers may find this method useful for targeting resources in relation to a particular water quality concern, focusing best management efforts, and maximizing benefits to water quality with minimal costs.

Keywords: case study; development; drinking water; fecal coliform; land cover; land use; management; Northeast; reservoirs; total nitrogen; total phosphorus; urban; water quality; watershed

Poor, P.J., K.L. Pessagno, and R.W. Paul. 2007. Exploring the hedonic value of ambient water quality: a local watershed-based study. *Ecological Economics* 60(4):797-806.

Abstract: Nonpoint source water pollution of local watersheds can result from various sources but is tied most closely to runoff from impervious surfaces associated with development activities such as roadways, parking lots, and large commercial structures. This research investigates the value of ambient water quality as measured by data from 22 monitoring stations located throughout a local watershed in Maryland: the St. Mary's River watershed. A hedonic property value model is used to investigate the marginal implicit values of the following water quality variables: total suspended solids (TSS) and dissolved inorganic nitrogen. The econometric results indicate that the marginal implicit prices associated with a one milligram per liter change in TSS and dissolved inorganic nitrogen are $-1,086 and $-17,642, respectively.

Keywords: case study; development; Northeast; water quality

Southeast

Atasoy, M., R.B. Palmquist, and D.J. Phaneuf. 2006. Estimating the effects of urban residential development on water quality using microdata. *Journal of Environmental Management* 79(4):399-408.

Abstract: This study examines the impact on water quality of urbanization using disaggregate data from Wake County, North Carolina. A unique panel dataset tracing the conversion of individual residentially zoned land parcels to relate the density of residential development and the change in residential land use to three measures of water quality is used. A spatial econometrics model, relates spatially and temporally referenced monitoring station readings to measures of residential land use while controlling for other factors affecting water quality. Both the density of residential land use and the rate of land conversion have negative impacts on water quality. The impacts of these nonpoint sources are found to be larger in magnitude than those from urban point sources.

Keywords: development; land use; nonpoint source; Southeast; total nitrogen; total phosphorus; total suspended solids; urban; water quality

Bolstad, P.V. and W.T. Swank. 1997. Cumulative impacts of landuse on water quality in a southern Appalachian watershed. *Journal of the American Water Resources Association* 33(3):519-533.

Abstract: Water quality variables were sampled over 109 weeks along Coweeta Creek, a fifth-order stream located in the Appalachian Mountains of western North Carolina. The purpose of this study was to observe any changes in water quality over a range of flow conditions, with

concomitant downstream changes in the mix of land uses. Variables sampled include pH, HCO_3^{2-}, conductivity, NO_3^--N, NH_4^+-N, PO_4^{3-}-P, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, SiO_2, turbidity, temperature, dissolved oxygen, total and fecal coliform, and fecal streptococcus. Landcover/landuse was interpreted from 1:20,000 aerial photographs and entered in a geographic information system, along with information on total and paved road length, building location and density, catchment boundaries, hydrography, and slope. Linear regressions were performed to relate basin and near-stream landscape variables to water quality.

Consistent, cumulative, downstream changes in water quality variables were observed along Coweeta Creek, concomitant with downstream, human-caused changes in landuse. Furthermore, larger downstream changes in water quality variables were observed during stormflow when compared to baseflow, suggesting cumulative impacts due to landscape alteration under study conditions were much greater during storm events. Although most water quality regulations, legislation, and sampling are promulgated for baseflow conditions, this work indicates they should also consider the cumulative impacts of physical, chemical, and biological water quality during stormflow.

Keywords: ammonia; development; fecal coliform; land cover; land use; nitrate; nonpoint source; Southeast; storm; water quality

Evett, J.B. 1995. Effects of urbanization on low streamflows in North Carolina. In *Integrated Water Resources Planning for the 21st Century: Proceedings of the 22nd Annual Conference, Cambridge, Massachusetts, May 7-11, 1995*. M. F. Domenica (ed.) American Society of Civil Engineers, New York, pp. 149-152.

Abstract: Historical low-streamflow data were analyzed for a number of gauging stations on streams in and around various urban areas in North Carolina in an attempt to find and document effects of urbanization on low streamflows. Records for streams within each urban area were compared with streams outside the area by two statistical methods. It was concluded from the study that there is some support for the premise that urbanization causes a decrease in streamflows over time, but statistically the results are inconclusive. It appears that most small streams in North Carolina – both urban and rural – are experiencing decreasing flows over time.

Keywords: development; flow; Southeast; Streamflow; urban; water supply

Lehrter, J.C. 2006. Effects of land use and land cover, stream discharge, and interannual climate on the magnitude and timing of nitrogen, phosphorus, and organic carbon concentrations in three coastal plain watersheds. *Water Environment Research* 78(12):2356-2368.

Abstract: In-stream nitrogen, phosphorus, organic carbon, and suspended sediment concentrations were measured in 18 subbasins over two annual cycles to assess how land use and land cover (LULC) and stream discharge regulate water quality variables. The LULC was a primary driver of in-stream constituent concentrations and nutrient speciation owing to differences in dominant sources and input pathways associated with agricultural, urban, and forested land uses. Stream discharge was shown to be a major factor that dictated not only the magnitude of constituent concentrations, but also the chemical form. In high discharge agricultural subbasins, where nitrate was the dominant nitrogen form, there was a negative correlation between discharge and nitrate concentration indicating groundwater inputs as the dominant pathway. In urban settings, however, nitrate was positively correlated with discharge, and, in forested subwatersheds, where dissolved organic nitrogen (DON) was the dominant nitrogen form, there was a positive correlation between discharge and DON, indicating wash off from the watershed as the dominant input pathway. Similarly, phosphorus concentrations were strongly regulated by LULC, discharge, and seasonality. This comparative study highlights that different mechanisms regulate different forms of nitrogen, phosphorus, and carbon, and thus field programs or water quality models used for regulatory purposes must assess these nutrient forms to accurately apply management plans for nutrient reductions.

Keywords: land cover; land use; nitrogen; nonpoint source; organic carbon; phosphorous; Southeast; suspended sediment; water quality; watershed management

Schoonover, J.E., G.E. Lockaby, and B.S. Helms. 2006. Impacts of land cover on stream hydrology in the West Georgia Piedmont, USA. *Journal of Environmental Quality* 35:2123-2131.

Abstract: The southeastern United States is experiencing rapid urban development. Consequently, Georgia's streams are experiencing hydrologic alterations from extensive development and from other land use activities such as livestock grazing and silviculture. A study was performed to assess stream hydrology within 18 watersheds ranging from 500 to 2,500 hectares. Study streams were first, second, or third order and hydrology was continuously monitored from July 29, 2003 to September 23, 2004 using in situ pressure transducers. Rating curves between stream stage (i.e., water depth) and discharge were developed for each stream by correlating biweekly discharge measurements and stage data. Dependent variables were calculated from discharge data and placed into four categories: flow frequency (i.e., the number of times a predetermined discharge threshold is exceeded), flow magnitude (i.e., maximum and minimum flows), flow duration (i.e., the amount of time discharge was above or below a predetermined threshold), and flow predictability and flashiness. Fine resolution data (i.e., 15-minute interval) were also compared to daily discharge data to determine if resolution affected how streams were classified hydrologically. Urban watersheds experienced flashy discharges during storm events, whereas pastoral and forested watersheds showed less flashy hydrographs. Also, in comparison to all other flow variables, flow frequency measures were most strongly correlated to land cover. Furthermore, the stream hydrology was explained similarly with both the 15-minute and daily data resolutions.

Keywords: development; flow; grazing; land cover; land use; Southeast; storm; urban; vegetation change; watershed

Van Metre, P.C., A.J. Horowitz, B.J. Mahler, W.T. Foreman, C.C. Fuller, M.R. Burkhardt, K.A. Elrick, E.T. Furlong, S.C. Skrobialowski, J.J. Smith, J.T. Wilson, and S.D. Zaugg. 2006. Effects of Hurricanes Katrina and Rita on the chemistry of bottom sediments in Lake Pontchartrain, Louisiana, USA. *Environmental Science and Technology* 40(22):6894-6902.

Abstract: The effects of Hurricanes Katrina and Rita and the subsequent unwatering of New Orleans, Louisiana, on the sediment chemistry of Lake Pontchartrain were evaluated by chemical analysis of samples of street mud and suspended and bottom sediments. The highest concentrations of urban-related elements and compounds (e.g., lead, zinc, polycyclic aromatic hydrocarbons, and chlordane) in bottom sediments exceeded median concentrations in U.S. urban lakes and sediment-quality guidelines. The extent of the elevated concentrations was limited, however, to within a few hundred meters of the mouth of the 17th Street Canal, similar to results of historical assessments. Chemical and radionuclide analysis of pre- and post-Hurricane Rita samples indicate that remobilization of near-shore sediment by lake currents and storms is an ongoing process. The effects of Hurricanes Katrina and Rita on the sediment chemistry of Lake Pontchartrain are limited spatially and are most likely transitory.

Keywords: hurricane; sediment; sediment quality; Southeast; storm; urban; urban pollution

Williams, E.S. and W.R. Wise. 2006. Hydrologic impacts of alternative approaches to storm water management and land development. *Journal of the American Water Resources Association* 42(2):443-455.

Abstract: Low Impact Development (LID) and other land development methods have been presented as alternatives to conventional stormwater management and site design. Low impact development encourages land preservation and the use of distributed, infiltration-based stormwater management systems to minimize impacts on hydrology. Such systems can include shallow retention areas, akin to natural depression storage. Other approaches to land development may emphasize land preservation only. Herein, an analysis of four development alternatives is presented. The first is traditional development with conventional pipe/pond stormwater management and half-acre lots. The second alternative is cluster development, in which implementation of the local cluster development ordinance was assumed, resulting in quarter-acre lots with a pipe/pond stormwater management system and open space preservation. The "partial" LID option used the same lot layout as the traditional option, with a stormwater management system emphasizing shallow depression storage. The "full" LID used the cluster site plan and the depression storage-based stormwater management system. The alternatives were compared to the hydrologic response of existing site conditions. The analysis used two design storms and a continuous rainfall record. The combination of land preservation and infiltration-based stormwater management yielded the hydrologic response closest to existing conditions, although ponds were required to control peak flows for the design storms.

Keywords: development; flow; management; Southeast; storm

North Central

Bhaduri, B., M. Grove, C. Lowry, and J. Harbor. 1997. Assessing long-term hydrologic effects of land use change. *Journal of the American Water Works Association* 89(11):94-106.

Abstract: Many communities are seeking to understand how future development may affect a watershed, and they are using this information to develop long-term watershed management plans that protect their water supply. As part of the work on the Cuppy-McClure watershed in Indiana, a land use-runoff estimation technique was developed based on the local long-term climate record. The technique, which uses the core of the U.S. Department of Agriculture’s curve number method, produces results that can be easily understood and used by managers, planners, and developers. The technique can estimate the effect of development on watershed hydrology, and it can quickly provide sensitivity analyses of alternative proposed land uses. Analysis of Cuppy-McClure identified six subbasins that dominate the cumulative effects of proposed land uses that should be the focus of watershed management.

Keywords: development; land use; North Central; water supply; watershed management; wetlands

South Central

Jones, J.R. and M.F. Knowlton. 2005. Suspended solids in Missouri reservoirs in relation to catchment features and internal processes. *Water Research* 39(15):3629-3635.

Abstract: Mean total suspended solids (TSS), in 135 Missouri reservoirs range from 1.2 to 47 milligrams per liter (mg/L). The volatile suspended solids (VSS) and nonvolatile suspended solids (NVSS) fractions range from 0.6 to 9.6 mg/L and 0.5 to 37 mg/L, respectively. Percent NVSS is the larger fraction and declines through summer as %VSS increases. Suspended solids (particularly VSS) correlate with metrics of lake trophic state and are positively related with the proportion of cropland (%C, $r = 0.69$ to 0.74) in their catchments, negatively related with forest cover ($r = 0.54$ to 0.56), and weakly related with grassland ($r < 0.31$). Regressions including %C with dam height (representing morphometry) and flushing rate (representing hydrology), explain 70% of cross-system variation in TSS and 67% in VSS. Dam height and %C explain 57% of variation in NVSS. Residual analysis shows statewide models underpredict suspended solids in urban reservoirs. Effects of catchment features on summer TSS largely reflect internal plankton growth mediated by influent nutrients (affecting VSS) over direct sediment input (affecting NVSS).

Keywords: land cover; nitrogen; phosphorous; reservoirs; South Central; total suspended solids; urban

Northwest

Noble, E.L. and L. Lundeen. 1971. Analysis of rehabilitation treatment alternatives for sediment control. In *Symposium on Forest Land Uses and Stream Environment*, October 19-21 1971, Corvallis, OR. pp. 86-96. Oregon State University School of Forestry and Department of Fisheries and Wildlife Continuing Education Publications.

Abstract: The aquatic environment of the South Fork Salmon River has been severely damaged in recent years by excessive rates of sediment production. A special study was conducted to determine the source and extent of the damage, and measures required to reduce future sediment production to a “tolerable” level. Linear programming was used as an aid to select from 190 possible treatment alternatives and minimize treatment costs at various levels of sediment reduction. The desired level of sediment could be reached at a cost of $5 million. Debris basins to trap sediment moving in the channel were the most effective and economical type of treatment, while control of sediment production from roads and timber harvest on steep, fragile lands would have been very costly.

Keywords: development; logging; Northwest; sedimentation; water quality

Southwest

Ahearn, D.S., R.W. Sheibley, R.A. Dahlgren, M. Anderson, J. Johnson, and K.W. Tate. 2005. Land use and land cover influence on water quality in the last free-flowing river draining the western Sierra Nevada, California. *Journal of Hydrology* 313(3-4):234-247.

Abstract: Land use and land cover across 28 subbasins within the Cosumnes Watershed, California (1,989 square kilometers) were correlated to nitrate-N and total suspended solids (TSS) loading between water years 1999 and 2001. The impact of human development on stream water quality were evident in both agricultural area and population density predicted TSS loading in a linear mixed effects model. In contrast to the TSS model, the nitrate-N loading model was more complex with agriculture, grassland, and the presence or absence of wastewater treatment plants (WWTPs) all contributing. The lack of correlation between population density and nitrate-N loading indicates that human habitation of the landscape does not impact stream nitrate levels until a WWTP is built within the subbasin. During dry water years the models predict a linear reduction in TSS loading, but the correlations to agriculture and population density remain positive. In contrast, nitrate is positively correlated to grasslands during average water years and negatively correlated during dry water years. Analysis of constituent fluxes from the upper watershed versus the lower watershed indicates that silica is derived primarily from the uplands and that during dry water years the upper watershed is an important source of dissolved organic carbon and nitrate. The lower watershed contributes the majority of the sediment and nutrients during both dry and average water years, the one caveat being that during dry years the lower basin becomes a nitrate sink.

Keywords: development; dissolved organic carbon; land cover; land use; nitrate; non-point source; Southwest; total suspended solids; urbanization; water quality

Coats, R. and L. Collins. 1984. Streamside landsliding and channel change in a suburban forested watershed: effects of an extreme event. In *Symposium on Effects of Forest Land Use on Erosion and Slope Stability*, 7-11 May, 1984, Honolulu, HI. O'Loughlin, C.L. and Pearce, A.J. (eds.). pp. 165-175.

Abstract: A continuing controversy in the management of steep and unstable forested land is the relative importance of land disturbance and extreme climatic events in triggering mass wasting and channel change. In California, this controversy has been brought into sharp focus in recent years by increasing concern for water quality and anadromous fisheries. Conflicts are especially acute where suburban growth impinges on productive forest land in areas of high rainfall and unstable terrain. New forest residents often express concern about geomorphic and aesthetic effects of logging, yet residential development itself is not without effects on the stream environment.

Large and infrequent storms provide a unique learning opportunity. For the land manager and land use planner, they are a severe test of the efficacy of forest practice regulation and land use controls. For the geomorphologist, they provide valuable lessons in geomorphic effectiveness and landscape evolution. This paper reports on the effects of the January 1982 storm in Zayante Creek Basin and the lower San Lorenzo River in Santa Cruz County, California.

Keywords: development; erosion; landslide; logging; Southwest; storm; water quality

Kenney, D.S., R.A. Klein, and M.P. Clark. 2004. Use and effectiveness of municipal water restrictions during drought in Colorado. *Journal of the American Water Resources Association* (February):77-87.

Abstract: Drought conditions in the summer of 2002 prompted several cities along Colorado's Front Range to enact restrictions on outdoor water use, focusing primarily on limiting the frequency of lawn watering. The different approaches utilized by eight water providers were tracked to determine the level of water savings achieved, measured as a comparison of 2002 usage to 2000 to 2001 average usage, and also based on a statistical estimate of 2002 "expected use" that accounts for the impact of drought conditions on demand. Mandatory restrictions were shown to be an effective tool for drought coping. During periods of mandatory restrictions, savings measured in expected use per capita ranged from 18 to 56%, compared to just 4 to 12% savings during periods of voluntary restrictions. As anticipated, providers with the most stringent restrictions achieved the greatest savings.

Keywords: case study; costs; drought; management; prevention; Southwest; urban

Sprague, L.A. 2005. Drought effects on water quality in the South Platte River Basin, Colorado. *Journal of the American Water Resources Association* (February):11-24.

Abstract: Twenty-three stream sites representing a range of forested, agricultural, and urban land uses were sampled in the South Platte River Basin of Colorado from July through September 2002 to characterize water quality during drought conditions. With a few exceptions, dissolved

orthophosphate concentrations were similar to seasonal historical levels in all land use areas during the drought. At some agricultural sites, decreased dilution of irrigation return flow may have contributed to higher concentrations of some nutrient species, increased primary productivity, and higher dissolved oxygen concentrations. At some urban sites, decreased dilution of base flow and wastewater treatment plant effluent may have contributed to higher dissolved nitrite-plus-nitrate concentrations, increased primary productivity, and higher dissolved oxygen concentrations. Total pesticide concentrations in urban and agricultural areas were not consistently higher or lower during the drought. At most forested sites, decreased dilution of groundwater-derived calcium bicarbonate type base flow likely led to elevated pH and specific-conductance values. Water temperatures at many of the forested sites also were higher, contributing to lower dissolved oxygen concentrations during the drought.

Keywords: drought; flow; land use; nonpoint source; Southwest; urban; water quality

Stohlgren, T.J., T.N. Chase, R.A. Pielke Sr., T.G.F. Kittel, and J.S. Baron. 1998. Evidence that local land use practices influence regional climate, vegetation, and stream flow patterns in adjacent natural areas. *Global Change Biology* 4(5):495-504.

Abstract: Evidence is presented that land use practices in the plains of Colorado influence regional climate and vegetation in adjacent natural areas in the Rocky Mountains in predictable ways. Mesoscale climate model simulations using the Colorado State University Regional Atmospheric Modeling System (RAMS) projected that modifications to natural vegetation in the plains, primarily due to agriculture and urbanization, could produce lower summer temperatures in the mountains. The authors corroborated the RAMS simulations with three independent sets of data: (1) climate records from 16 weather stations, which showed significant trends of decreasing July temperatures in recent decades; (2) the distribution of seedlings of five dominant conifer species in Rocky Mountain National Park, Colorado, which suggested that cooler, wetter conditions occurred over roughly the same time period; and (3) increased stream flow, normalized for changes in precipitation, during the summer months in four river basins, which also indicates cooler summer temperatures and lower transpiration at landscape scales. Combined, the mesoscale atmospheric/land-surface model, short-term trends in regional temperatures, forest distribution changes, and hydrology data indicate that the effects of land use practices on regional climate may overshadow larger-scale temperature changes commonly associated with observed increases in carbon dioxide and other greenhouse gases.

Keywords: climate change; land use; Southwest; Streamflow; vegetation change

United States

Burby, R.J., E.J. Kaiser, T.L. Miller, and D.H. Moreau. 1983. *Drinking Water Supplies: Protection Through Watershed Management.* Ann Arbor Science Publishers. Ann Arbor, MI.

Abstract: This volume describes a new methodology for devising programs to protect surface water supply sources. Urbanization of water supply watersheds is creating an increasingly serious hazard to public health. In the past, protection of water supply sources relied on the concept of source isolation through purchase of the surrounding area. This practice is no longer practical – on economic, legal, or political grounds – particularly in areas where urban development pressures are accelerating. As a result, water supply systems and local governments must devise watershed management strategies that incorporate a variety of measures and institutional arrangements to protect raw water supplies from contamination.

Keywords: case study; drinking water quality; United States; urbanization; watershed management

Lubowski, R.N., M. Vesterby, S. Bucholtz, A. Baez, and M.J. Roberts. 2006. Major Uses of Land in the United States, 2002. Economic Information Bulletin No. 14. USDA Economic Research Service.

Abstract: This publication presents the results of the 2002 inventory of U.S. major land uses, drawing on data from the Census, public land management and conservation agencies, and other sources. The data are synthesized by state to calculate the use of several broad classes and subclasses of agricultural and nonagricultural land over time. The United States has a total land area of nearly 2.3 billion acres. Major uses in 2002 were forest-use land, 651 million acres (28.8%); grassland pasture and range land, 587 million acres (25.9%); cropland, 442 million acres (19.5%); special uses (primarily parks and wildlife areas), 297 million acres (13.1%); miscellaneous other uses, 228 million acres (10.1%); and urban land, 60 million acres (2.6%). National and regional trends in land use are discussed in comparison with earlier major land-use estimates.

Keywords: agriculture; development; land use; United States; urbanization

Moody, J.A. and D.A. Martin. 2001. Post-fire, rainfall intensity-peak discharge relations for three mountainous watersheds. *Hydrological Processes* 15(15):2981-2993.

Abstract: Wildfire alters the hydrologic response of watersheds, including the peak discharges resulting from subsequent rainfall. Improving predictions of the magnitude of flooding that follows wildfire is needed because of the increase in human population at risk in the wildland-urban interface. Because this wildland-urban interface is typically in mountainous terrain, the authors investigated rainfall-runoff relations by measuring the maximum 30 minute rainfall intensity and the unit-area peak discharge (peak discharge divided by the area burned) in three mountainous watersheds (17-26.8 square kilometers) after a wildfire.

The authors found rainfall-runoff relations that relate the unit-area peak discharges to the maximum 30 minute rainfall intensities by a power law. These rainfall-runoff relations appear to have a threshold value for the maximum 30 minute rainfall intensity (around 10 millimeters per hour) such that, above this threshold, the magnitude of the flood peaks increases more rapidly with increases in intensity. This rainfall intensity could be used to set threshold limits in rain gauges that are part of an early-warning flood system after wildfire. The maximum unit-area peak discharges from these three burned watersheds ranged from 3.2 to 50 cubic meters per second per square kilometer. These values could provide initial estimates of the upper limits of runoff that can be used to predict floods after wildfires in mountainous terrain.

Keywords: development; erosion; fire; United States; vegetation change; water quality; water yield

Poff, N.L., B.P. Bledsoe, and C.O. Cuhaciyan. 2006. Hydrologic variation with land use across the contiguous United States: Geomorphic and ecological consequences for stream ecosystems. *Geomorphology* 79:264-285.

Abstract: Using daily discharge data from the U.S. Geological Survey (USGS), the authors analyzed how hydrologic regimes vary with land use in four large hydrologic regions that span a gradient of natural land cover and precipitation across the continental United States. In each region, small streams (contributing area < 282 square kilometers) that have continuous daily streamflow data were identified. Using a national database, the composition of land cover of the watersheds in terms of aggregate measures of agriculture, urbanization, and least disturbed ("natural") were characterized. Hydrologic alteration using 10 ecologically-relevant hydrologic metrics that describe magnitude, frequency, and duration of flow for 158 watersheds within the Southeast (SE), Central (CE), Pacific Northwest (NW), and Southwest (SW) hydrologic regions of the United States were calculated. Within each watershed, percent cover was calculated for agriculture, urbanized land, and least disturbed land to elucidate how components of the natural flow regime inherent to a hydrologic region is modified by different types and proportions of land cover. How dams in these regions altered the hydrologic regimes of the 43 streams that have pre- and post-dam daily streamflow data was evaluated. In an analysis of flow alteration along gradients of increasing proportion of the three land cover types, many regional differences in hydrologic responses were found. In response to increasing urban land cover, peak flows increased (SE and CE), minimum flows increased (CE) or decreased (NW), duration of near-bankfull flows declined (SE and NW) and flow variability increased (SE, CE, and NW). Responses to increasing agricultural land cover were less pronounced, as minimum flows decreased (CE), near-bankfull flow durations increased (SE and SW), and flow variability declined (CE). In a second analysis for three of the regions, the differences between least disturbed watersheds and those having either N15% urban and N25% agricultural land cover were compared. Relative to natural land cover in each region, urbanization either increased (SE and NW) or decreased (SW) peak flows, decreased minimum flows (SE, NW, and SW), decreased durations of near-bankfull flows (SE, NW, and SW), and increased flow variability (SE, NW, and SW). Agriculture had similar effects except in the SE, where near-bankfull flow durations increased. Overall, urbanization appeared to induce greater hydrologic responses than similar proportions of agricultural land cover in watersheds. Finally, the effects of dams on hydrologic variation were largely consistent across regions, with a decrease in peak flows, an increase in minimum flows, an increase in near bankfull flow durations, and a decrease in flow variability. This analysis was used to evaluate the relative degree to which land use has altered flow regimes across regions in the United States with naturally varying climate and natural land cover, and the geomorphic and ecological implications of such flow modification discussed. The article ends with a consideration of what elements will ultimately be required to conduct a more comprehensive national assessment of the hydrologic responses of streams to land cover types and dams. These include improved tools for modeling hydrologic metrics in ungauged watersheds, incorporation of high-resolution geospatial data to map geomorphic and hydrologic drivers of stream response to different types of land cover, and analysis of scale dependence in the distribution of land-use impacts, including mixed land uses. Finally, ecological and geomorphic responses to human alteration of land cover will have to be calibrated to the regional hydroclimatological, geologic, and historical context in which the streams occur, in order to determine the degree to which stream responses are region-specific versus geographically independent and broadly transferable.

Keywords: development; hydrology; land use change; streamflow; United States

Sisk, T.D. 1998. *Perspectives on the Land-Use History of North America: A Context for Understanding Our Changing Environment.*, U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR 1998-0003 (Revised September 1999). Available: http://biology.usgs.gov/luhna/index.html.

Abstract: The Earth is a dynamic planet. As the authors come to appreciate its history and the long-term trends that have shaped the present, the authors realize that continuous change characterizes the planet, from the movement of continents to changes in the chemical composition of the atmosphere. Perhaps nowhere is change more obvious that on the planet's surface, where human land use shapes landscapes, alters ecosystems, and influences the diversity of life they support. Yet an appreciation of changing land cover and land use poses a host of questions that are difficult to answer: What types of changes are occurring now, and how fast are they occurring? How do these changes compare with those in the past, and what does it all mean for future environmental quality and the habitability of the planet?

This web site addresses some of these questions for several regions of North America. More importantly, it strives to convey the importance of a historical context for understanding ongoing changes in land cover and land use. Each section has been written by researchers for the non-specialist and reviewed independently by peer scientists. The contributors hope that the long-term perspective presented here will provide a context for assessing environmental conditions, interpreting current trends, and making more informed policy and management decisions for the future.

Keywords: development; land use change; United States

U.S. EPA. 2003. Watershed Analysis and Management (WAM) Guide for States and Communities. EPA 841-B-03-007.

Abstract: Using a watershed approach provides a unique and effective way to assess the environment, identify problems, establish priorities for preservation or restoration, and implement solutions. The Watershed Analysis and Management (WAM) Program is an effort to guide communities in the successful application of a watershed approach and led to the development in 2002 of this Guide. The U.S. Environmental Protection Agency's Office of

Wetlands, Oceans, and Watersheds (OWOW) and the American Indian Environmental Office (AIEO) collaborated in 1997 on a joint project to develop a comprehensive WAM methodology. The initial WAM approach was based on watershed planning efforts in the Pacific Northwest, including the Washington State watershed analysis methodology for state and private forest lands and the Northwest Forest Plan watershed analysis guide for federal ownership. The concept was to extend existing capabilities to address a nationwide range of ecological environments, project objectives, and watershed management issues at the state, community, and tribal levels. With substantial support from the AIEO, a more comprehensive approach was undertaken to include the additional issues of tribal cultural and community values. The first product, *Watershed Analysis and Management (WAM) Guide for Tribes*, was developed with a system development grant from OWOW to the Pacific Watershed Institute, concurrent with pilot applications of the approach, through AIEO grants, by tribes representing different ecological environments, objectives, and community issues.

Keywords: development; management; United States; water quality; watershed

U.S. EPA. 2007. Making the Connection: Smart Growth and Water Resource Protection. Training module from U.S. EPA's Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: Changes in land use are linked to impacts on water resources. This module illustrates how historical trends in growth patterns and activities on land have become the most significant challenge for preserving water quality and meeting future water resource goals. Factors such as traffic congestion, air quality, and public health figure prominently in discussions on urban growth and development today. This module focuses on the connections between smart growth approaches and Clean Water Act programs. It also includes tools, resources, and case studies illustrating how land use decisions made at the local and state levels can help protect and restore water resources by using innovative approaches that meet economic, environmental, and social goals.

Keywords: development; United States; watershed management

12. Watershed Management

Northeast

Adkins, J. Date Unknown. Prioritizing Land Protection to Protect Source Water in the Schuylkill River (Presentation). Presented by Partnership for the Delaware Estuary & Schuylkill Action Network Watershed Land Protection Collaborative.

Abstract: This is a presentation of restoration and source water protection projects in the Delaware Estuary completed by the Schuylkill Action Network Watershed Land Protection Collaborative. A model was developed in support of the organization's actions.

Keywords: case study; drinking water quality; Northeast; watershed management

Bent, G.C. 2001. Effects of basin and land use characteristics on suspended-sediment yield in the Housatonic River Basin, Western Massachusetts. In *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, March 25-29, 2001, Reno, NV. pp. X-1-X-8. Available: http://pubs.usgs.gov/misc_reports/FISC_1947-2006/pdf/1st-7thFISCs-CD/MENU.pdf.

Abstract: Suspended-sediment yield was measured for six subbasins and estimated for two subbasins with different basin and land-use characteristics in the Housatonic River Basin in western Massachusetts from April 1994 through March 1996. Measured yields ranged from 21 to 147 tons per year per square mile, and estimated yields were 82 and 395 tons per year per square mile. Five dams and associated reservoirs, although relatively small in size (each less than 0.20 square miles in surface area), decreased yield in one subbasin by trapping sediment. Suspended-sediment yields were moderately related to the combined percent areas of forested wetlands, nonforested wetlands, waterbodies (-0.50 correlation coefficient), and the percent area of sand and gravel (0.64 correlation coefficient). Yields were highly related to the percent areas of floodplain alluvium (0.89 correlation coefficient), agricultural and open land (0.86 correlation coefficient), and soils with a high soil-erodibility factor (0.93 correlation coefficient). The five soils in the basin with a high soil-erodibility factor are all silt-loam soils and have a soil erodibility factor of 0.49. The causative effects of the silt-loam soils, floodplain alluvium, and agricultural and open land on suspended sediment yields cannot be clearly discerned because they are interrelated, inasmuch as that the silt-loam soils are related to the areas of floodplain alluvium and of agricultural and open land, and the area of floodplain alluvium is also related to the area of agricultural and open land.

Keywords: land cover; Northeast; sediment; water quality

Fairfax County Water Authority. 2002. Fairfax County Water Authority Source Water Assessment Program Final Report. Fairfax County, VA. January.

Abstract: The Fairfax County Water Authority (FCWA) draws surface water from two primary sources: the Potomac River and the Occoquan Reservoir. The treatment facilities associated with each source are located at opposite ends of Fairfax County and feed an interconnected distribution system. The James J. Corbalis, Jr. Treatment Plant, located at the northern tip of the FCWA service area, draws water from the Potomac River. The Occoquan Reservoir, on the southern border of Fairfax County, supplies the Occoquan and Lorton treatment plants located near the Town of Occoquan.

The FCWA Source Water Assessment Program (SWAP) is comprised of a contaminant inventory, a windshield survey, a Best Management Practice (BMP) inventory, and a susceptibility analysis.

Through the contaminant inventory, information on potential sources of contamination in the assessment area was collected in a Geographical Information System (GIS) or database. The data collected included existing data obtained from other agencies and new data generated by FCWA. As required by the Virginia Department of Health SWAP, a windshield survey was conducted on the Zone 1 area for each intake. The windshield survey consisted of visually identifying potential sources of contamination in the field and obtaining location and property owner information for each site.

The Authority worked closely with County stormwater management departments to develop a BMP database useful for water quality purposes. As part of this process, Authority employees reviewed existing datasets, stormwater management plans, files, and fact sheets and entered available information in a GIS and database. A susceptibility analysis was conducted to determine the risk associated with various contaminant sources. As part of this effort, buffer distances and stream distances from each intake were determined for each contaminant site. The sources were ranked based on combined buffer and stream distance and the type of facility.

Keywords: case study; Northeast; source water assessment program; source water assessment plan; water quality; water supply; watershed management

Long, S.C. and J.D. Plummer. 2004. Assessing land use impacts on water quality using microbial source tracking. *Journal of the American Water Resources Association* (December):1433-1448.

Abstract: A renewed emphasis on source water protection and watershed management has resulted from recent amendments and initiatives under the Safe Drinking Water Act and the Clean Water Act. Knowledge of the impact of land use choices on source water quality is critical for efforts to properly manage activities within a watershed. This study evaluated qualitative relationships between land use and source water quality and the quantitative impact of season and rainfall events on water quality parameters. High levels of specific conductance tended to be associated with dense residential development, while organic carbon was elevated at several forested sites. Turbidity was generally higher in more urbanized areas. Sources tracking indicators were detected in samples where land use types would predict their presence. Coliform levels were statistically different at the 95% confidence levels for winter versus summer conditions and dry versus wet weather conditions. Other water quality parameters that varied with season were organic carbon, turbidity, dissolved oxygen, and specific conductance. These results indicate that land use management can be effective for mitigating impacts to a waterbody; however, year-round, comprehensive data are necessary to thoroughly evaluate the water quality at a particular site.

Keywords: development; drinking water; fecal coliform; land use; nonpoint source; Northeast; source water protection; urban; water quality; watershed management

Lyon, S.W., M.R. McHale, M.T. Walter, and T.S. Steenhuis. 2006. The impact of runoff generation mechanisms on the location of critical source areas. *Journal of the American Water Resources Association* 42(3):793-804.

Abstract: Identifying phosphorous (P) source areas and transport pathways is a key step in decreasing P loading to natural water systems. This study compared the effects of two modeled runoff generation processes – saturation excess and infiltration excess – on total phosphorous (TP) and soluble reactive phosphorous (SRP) concentrations in 10 catchment streams of a Catskill Mountain watershed in southeastern New York. The spatial distribution of runoff from forested land and agricultural land was generated for both runoff processes; results of both distributions were consistent with Soil Conservation Service-Curve Number theory. These spatial runoff distributions were then used to simulate stream concentrations of TP and SRP through a simple equation derived from an observed relation between P concentration and land use; empirical results indicate that TP and SRP concentrations increased with increasing percentage of agricultural land. Simulated TP and SRP stream concentrations predicted for the 10 catchments were strongly affected by the assumed runoff mechanism. The modeled TP and SRP concentrations produced by saturation excess distribution averaged 31% higher and 42% higher, respectively, than those produced by the infiltration excess distribution. Misrepresenting the primary runoff mechanism could not only produce erroneous concentrations, it could fail to correctly locate critical source areas for implementation of best management practices. Thus, identification of the primary runoff mechanism is critical in the selection of appropriate models in the mitigation of nonpoint source pollution. Correct representation of runoff processes is also critical in the future development of biogeochemical transport models, especially those that address nutrient fluxes.

Keywords: best management practices; development; land use; management; nonpoint source; Northeast; phosphorous; runoff; water quality; water resources; watershed

Massachusetts Department of Conservation and Recreation. 2007. Quabbin Reservoir Watershed System: Land Management Plan 2007-2017. Division of Water Supply Protection. September.

Abstract: The Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management produces Land Management Plans for each of the watersheds under its care and control – Quabbin Reservoir, Ware River, Wachusett Reservoir, and the Sudbury Reservoir – on a rotating 10-year schedule. This *2007-2017 Quabbin Land*

Management Plan provides principles from the current state of the science of watershed and natural resources management, agency goals for the 10-year period, and specific objectives for accomplishing these in the areas of Land Protection, Forest Management, Wildlife Management, Management and Protection of Biodiversity, and Cultural Resources Protection. The plan builds on advancements in science and management techniques, the agency's own experience over six decades of managing the watershed and its resources, and accumulated input from advisory groups and the general, concerned public. It is designed as an adaptive plan, utilizing annual reviews to build immediately on new information and changes in the science that supports management decisions, and to revise objectives, as necessary, within the 10-year time frame of the plan.

Keywords: case study; Northeast; water quality; watershed management

Massachusetts Department of Environmental Protection. 2002. Source Water Assessment and Protection (SWAP) Report, Massachusetts Water Resources Authority (MWRA), Quabbin Reservoir, Ware River and Wachusett Reservoir. June.

Abstract: This Source Water Assessment and Protection (SWAP) report is a planning tool to support local and state efforts to improve water supply protection. By identifying land uses within water supply protection areas that may be potential sources of contamination, the assessment helps focus protection efforts on appropriate best management practices and drinking water source protection measures. The Massachusetts Water Resources Authority (MWRA) and the Metropolitan District Commission (MDC) meet the Department of Environmental Protection's (DEP's) annual review of "Measures of Success" for implementation of Watershed Protection Plans and disinfection treatment processes. MWRA and MDC have implemented DEP-approved Watershed Protection Plans to protect source water reservoirs since 1991. The findings contained in this report document conditions as of June 2002. For updates on watershed programs, please visit www.mwra.com, www.state.ma.us/mdc/water.htm, or call MWRA at 617-242-5323.

Keywords: Northeast; source water assessment and protection; source water protection report; water quality; watershed management

Mehaffey, M.H., M.S. Nash, T.G. Wade, D.W. Ebert, K.B. Jones, and A. Rager. 2005. Linking land cover and water quality in New York City's water supply watersheds. *Environmental Monitoring and Assessment* 107(1-3):29-44.

Abstract: The Catskill/Delaware reservoirs supply 90% of New York City's drinking water. The City has implemented a series of watershed protection measures, including land acquisition, aimed at preserving water quality in the Catskill/Delaware watersheds. The objective of this study was to examine how relationships between landscape and surface water measurements change between years. Thirty-two drainage areas delineated from surface water sample points (total nitrogen, total phosphorus, and fecal coliform bacteria concentrations) were used in step-wise regression analyses to test landscape and surface-water quality relationships. Two measurements of land use, percent agriculture and percent urban development, were positively related to water quality and consistently present in all regression models. Together these two land uses explained 25 to 75% of the regression model variation. However, the contribution of agriculture to water quality condition showed a decreasing trend with time as overall agricultural land cover decreased. Results from this study demonstrate that relationships between land cover and surface water concentrations of total nitrogen, total phosphorus, and fecal coliform bacteria counts over a large area can be evaluated using a relatively simple geographic information system method. Land managers may find this method useful for targeting resources in relation to a particular water quality concern, focusing best management efforts, and maximizing benefits to water quality with minimal costs.

Keywords: case study; development; drinking water; fecal coliform; land cover; land use; management; Northeast; reservoirs; total nitrogen; total phosphorus; urban; water quality; watershed

National Research Council. 2000. Watershed Management for Potable Water Supply: Assessing the New York City Strategy. National Academies Press, Washington, DC. Available: http://www.nap.edu/openbook/0309067774/html.

Abstract: January 21, 1997, marked an important event in the history of American water management: the signing of the mammoth New York City Watershed Memorandum of Agreement (MOA), which provides a legal framework for protecting the drinking water supply of nine million people. The culmination of years of negotiation between upstate and downstate interests, the MOA commits New York City to a long-term watershed management program that combines land acquisition, new watershed rules and regulations, and financial assistance to watershed communities to promote environmental quality and their local economies. Most important for New York City, the agreement currently satisfies provisions of the U.S. Environmental Protection Agency's Surface Water Treatment Rule that will allow the City to avoid filtering its upstate Catskill/Delaware water supply until at least 2002.

Immediately following the signing of the MOA, the National Research Council (NRC) was asked by the New York City Comptroller's Office to provide a scientific evaluation of the watershed management program. The goal of the NRC study was to determine whether the MOA is based on sound science and to recommend improvements to strengthen watershed management for this large unfiltered supply. This report is intended to inform New York City and other public water suppliers that are trying to maintain the purity of their existing water sources through proactive watershed management (regardless of whether they presently utilize filtration).

Keywords: case study; drinking water treatment; Northeast; prevention; water quality; watershed management

Philadelphia Water Department. 2007. The Delaware River Watershed Source Water Protection Plan. Prepared for the Pennsylvania Department of Environmental Protection. June.

Abstract: The purpose of the Delaware River Protection Plan is to design a source water protection strategy to counter current and future water supply concerns of the Philadelphia Water Department and drinking water utilities that share the Delaware River as a resource.

The Baxter Water Treatment Plant, one of three drinking water facilities in Philadelphia, is supplied by the Delaware River. The Delaware River watershed extends 8,000 square miles through Pennsylvania, New Jersey, and New York. The Delaware River Source Water Protection Plan uses critical water quality, land cover, and population analyses as well as point and nonpoint source pollution modeling to characterize the water supply. The source water quality and quantity characterization, incorporated with the results from the 2002 Source Water Assessment, provide the technical foundation for a Delaware River source water protection strategy.

The Baxter Water Treatment Plant provides over 190 million gallons of safe and high quality drinking water per day to the citizens of Philadelphia and surrounding communities. The plant uses dual media filtration and chlorine disinfection technologies to provide high quality drinking water year-round. The Baxter Water Treatment Plant has an exceptional performance record and has never violated Safe Drinking Water Act regulations. The Baxter Water Treatment Plant owes its exceptional record to the hard work of dedicated Philadelphia Water Department staff and the quality source water supplied from the Delaware River.

The Philadelphia Water Department uses source water assessment and protection planning to maintain the integrity of the Delaware River as a drinking water supply.

Keywords: case study; drinking water quality; Northeast; source water protection plan; watershed management

U.S. EPA Region 2. 2006. Region 2 Water: Filtration Avoidance. Available: http://www.epa.gov/region02/water/nycshed/filtad.htm.

Abstract: For a drinking water system to qualify for filtration avoidance under the Surface Water Treatment Rule the system cannot be the source of a waterborne disease outbreak, must meet source water quality limits for coliform and turbidity, and meet coliform and total trihalomethane maximum contaminant levels. Disinfectant residual levels and redundant disinfection capability must also be maintained. Filtration avoidance also requires that a watershed control program be implemented to minimize microbial contamination of the source water. This program must characterize the watershed's hydrology, physical features, land use, source water quality, and operational capabilities. It must also identify, monitor, and control manmade and naturally occurring activities that are detrimental to water quality. The watershed control program must also be able to control activities through land ownership or written agreements.

Keywords: Northeast; water quality; watershed management

Southeast

Lehrter, J.C. 2006. Effects of land use and land cover, stream discharge, and interannual climate on the magnitude and timing of nitrogen, phosphorus, and organic carbon concentrations in three coastal plain watersheds. *Water Environment Research* 78(12):2356-2368.

Abstract: In-stream nitrogen, phosphorus, organic carbon, and suspended sediment concentrations were measured in 18 subbasins over two annual cycles to assess how land use and land cover (LULC) and stream discharge regulate water quality variables. The LULC was a primary driver of in-stream constituent concentrations and nutrient speciation owing to differences in dominant sources and input pathways associated with agricultural, urban, and forested land uses. Stream discharge was shown to be a major factor that dictated not only the magnitude of constituent concentrations, but also the chemical form. In high discharge agricultural subbasins, where nitrate was the dominant nitrogen form, there was a negative correlation between discharge and nitrate concentration indicating groundwater inputs as the dominant pathway. In urban settings, however, nitrate was positively correlated with discharge, and, in forested subwatersheds, where dissolved organic nitrogen (DON) was the dominant nitrogen form, there was a positive correlation between discharge and DON, indicating wash off from the watershed as the dominant input pathway. Similarly, phosphorus concentrations were strongly regulated by LULC, discharge, and seasonality. This comparative study highlights that different mechanisms regulate different forms of nitrogen, phosphorus, and carbon, and thus field programs or water quality models used for regulatory purposes must assess these nutrient forms to accurately apply management plans for nutrient reductions.

Keywords: land cover; land use; nitrogen; nonpoint source; organic carbon; phosphorous; Southeast; suspended sediment; water quality; watershed management

South Carolina Department of Health and Environmental Control. 2004. Watershed Water Quality Assessment: Saluda River Basin. October.

Abstract: In 1993, the South Carolina Department of Health and Environmental Control (SCDHEC) published the first in a series of five watershed management documents. The first in that series, Watershed Water Quality Management Strategy: Savannah- Salkehatchie Basin communicated SCDHEC's innovative watershed approach, summarizing water programs and water quality in the basins. The approach continues to evolve and improve. The watershed documents facilitate broader participation in the water quality management process. Through these publications, SCDHEC shares water quality information with internal and external partners, providing a common foundation for water quality improvement efforts at the local watershed or large-scale, often interstate, river basin level.

Water quality data from the Saluda River Basin was collected from 1997 to 2001, and assessed during this third five-year watershed management cycle. This updated atlas provides summary information on a watershed basis, as well as geographical presentations of all permitted

watershed activities. A waterbody index and facility indices allow the reader to locate information on specific waters and facilities of interest.

A brief summary of the water quality assessments included in the body of this document is provided following the Table of Contents. This summary lists all waters within the Saluda River Basin that fully support recreational and aquatic life uses, followed by those waters not supporting uses. In addition, the summaries list changes in use support status; those that have improved or degraded over the five years since the last strategy was written. More comprehensive information can be found in the individual watershed sections. The information will be updated in five years.

Keywords: case study; source water assessment plan; source water assessment programs; Southeast; water quality; watershed management

Sun, G., S.G. McNulty, D.M. Amatya, R.W. Skaggs, L.W. Swift Jr., J.P. Shepard, and H. Riekerk. 2002. A comparison of the watershed hydrology of coastal forested wetlands and the mountainous uplands in the Southern US. *Journal of Hydrology* 263:92-104.

Abstract: Hydrology plays a critical role in wetland development and ecosystem structure and functions. Hydrologic responses to forest management and climate change are diverse in the southern United States due to topographic and climatic differences. This paper presents a comparison study on long-term hydrologic characteristics (long-term seasonal runoff patterns, water balances, storm flow patterns) of three watersheds in the southern United States. These three watersheds represent three types of forest ecosystems commonly found in the lower Atlantic coastal plain and the Appalachian upland mountains. Compared to the warm, flat, and shallow groundwater dominated pine flatwoods on the coast, the inland upland watershed was found to have significantly higher water yield. The precipitation/Hamon's potential evapotranspiration ratio was 1.9 for upland vs. 1.4 and 0.9 for wetlands, and the runoff/precipitation ratio was 0.53 ± 0.091 for upland vs. 0.30 ± 0.079 and 0.13 ± 0.094 for wetlands. Streamflow from flatwoods watersheds generally are discontinuous most of the years while the upland watershed showed continuous flows in most years. Stormflow peaks in a cypress-pine flatwoods system were smaller than that in the upland watershed for most cases, but exceptions occurred under extreme wet conditions. This study concludes that climate is the most important factor in determining the watershed water balances in the southern United States. Topography affects streamflow patterns and stormflow peaks and volume, and is the key to wetland development in the southern United States.

Keywords: climate change; development; management; runoff; Southeast; streamflow; watershed; wetlands

Yeakley, J.A., D.C. Coleman, B.L. Haines, B.D. Kloeppel, J.L. Meyer, W.T. Swank, B.W. Argo, J.M. Deal, and S.F. Taylor. 2003. Hillslope nutrient dynamics following upland riparian vegetation disturbance. *Ecosystems* 6(2):154-167.

Abstract: The authors investigated the effects of removing near-stream *Rhododendron* and of the natural blowdown of canopy trees on nutrient export to streams in the southern Appalachians. Transects were instrumented on adjacent hillslopes in a first-order watershed at the Coweeta Hydrologic Laboratory (in Otto, North Carolina). Dissolved organic carbon (DOC), potassium ion (K^+), sodium ion (Na^+), calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}), nitrate-nitrogen (NO_3^--N), ammonium ion (NH_4^+-N), phosphate ion (PO_4^--P), and sulfate ion (SO_4^{2-}) were measured for two years prior to the disturbance. In August 1995, riparian *Rhododendron* on one hillslope was cut, removing 30% of total woody biomass. In October 1995, Hurricane Opal uprooted nine canopy trees on the other hillslope, downing 81% of the total woody biomass. Over the three years following the disturbance, soilwater concentrations of NO_3^--N (nitrate-nitrogen) tripled on the cut hillslope. There were also small changes in soilwater DOC, SO_4^{2-}, Ca^{2+}, and Mg^{2+}. However, no significant changes occurred in groundwater nutrient concentrations following *Rhododendron* removal. In contrast, soilwater NO_3^--N on the storm-affected hillslope showed persistent 500-fold increases, groundwater NO_3^--N increased four-fold, and streamwater NO_3^--N doubled. Significant changes also occurred in soilwater pH, DOC, SO_4^{2-}, Ca^{2+}, and Mg^{2+}. There were no significant changes in microbial immobilization of soil nutrients or water outflow on the storm-affected hillslope. The results suggest that *Rhododendron* thickets play a relatively minor role in controlling nutrient export to headwater streams. They further suggest that nutrient uptake by canopy trees is a key control on NO_3^--N export in upland riparian zones, and that disruption of the root-soil connection in canopy trees via uprooting promotes significant nutrient loss to streams.

Keywords: nutrient load; Southeast; vegetation change; water quality; watershed management

North Central

Bhaduri, B., M. Grove, C. Lowry, and J. Harbor. 1997. Assessing long-term hydrologic effects of land use change. *Journal of the American Water Works Association* 89(11):94-106.

Abstract: Many communities are seeking to understand how future development may affect a watershed, and they are using this information to develop long-term watershed management plans that protect their water supply. As part of the work on the Cuppy-McClure watershed in Indiana, a land use-runoff estimation technique was developed based on the local long-term climate record. The technique, which uses the core of the U.S. Department of Agriculture's curve number method, produces results that can be easily understood and used by managers, planners, and developers. The technique can estimate the effect of development on watershed hydrology, and it can quickly provide sensitivity analyses of alternative proposed land uses. Analysis of Cuppy-McClure identified six subbasins that dominate the cumulative effects of proposed land uses that should be the focus of watershed management.

Keywords: development; land use; North Central; water supply; watershed management; wetlands

Schilling, K.E. and J. Spooner. 2006. Effects of watershed-scale land use change on stream nitrate concentrations. *Journal of Environmental Quality* 35:2132-2145.

Abstract: The Walnut Creek Watershed Monitoring Project was conducted from 1995 through 2005 to evaluate the response of stream nitrate concentrations to changing land use patterns in paired 5,000-hectare Iowa watersheds. A large portion of the Walnut Creek watershed is being converted from row crop agriculture to native prairie and savanna by the U.S. Fish and Wildlife Service at the Neal Smith National Wildlife Refuge. Before restoration, land use in both Walnut Creek (treatment) and Squaw Creek (control) watersheds consisted of 70% row crops. Between 1990 and 2005, row crop area decreased 25.4% in Walnut Creek due to prairie restoration, but increased 9.2% in Squaw Creek due to Conservation Reserve Program (CRP) grassland conversion back to row crop. Nitrate concentrations ranged between 0.5 and 14 milligrams per liter (mg/L) at the Walnut Creek outlet and 2.1 to 15 mg/L at the downstream Squaw Creek outlet. Nitrate concentrations decreased 1.2 mg/L over 10 years in the Walnut Creek watershed but increased 1.9 mg/L over 10 years in Squaw Creek. Changes in nitrate were easier to detect and more pronounced in monitored subbasins, decreasing 1.2 to 3.4 mg/L in three Walnut Creek subbasins, but increasing up to 8.0 and 11.6 mg/L in 10 years in two Squaw Creek subbasins. Converting row crop lands to grass reduced stream nitrate levels over time in Walnut Creek, but stream nitrate rapidly increased in Squaw Creek when CRP grasslands were converted back to row crop. Study results highlight the close association of stream nitrate to land use change and emphasize that grasslands or other perennial vegetation placed in agricultural settings should be part of a long-term solution to water quality problems.

Keywords: land use; nitrate; nonpoint source; North Central; phosphorous; water quality; watershed

South Central

Edwards, D.R., T.C. Daniel, H.D. Scott, J.F. Murdoch, M.J. Habiger, and H.M. Burks. 1996. Stream quality impacts of best management practices in a northwestern Arkansas Basin. *Water Resources Bulletin* 32(3):499-509.

Abstract: A variety of management options are used to minimize losses of nitrogen (N), phosphorous (P), and other potential pollutants from agricultural source areas. There is little information available, however, to indicate the effectiveness of these options (sometimes referred to as Best Management Practices, or BMPs) on basin scales. The objective of this study is to assess the water quality effectiveness of BMPs implemented in the 2,340 hectare Lincoln Lake basin in Northwest Arkansas. Land use in the basin was primarily forest (34%) and pasture (56%), with much of the pasture being regularly treated with animal manures. The BMPs were oriented toward minimizing the impact of confined animal operations in the basin and included nutrient management, dead bird composter construction, and other practices. Streamflow

samples (representing primarily base flow conditions) were collected biweekly from five sites within the basin from September 1991 through April 1994 and analyzed for nitrate N, ammonia N (NH_3-N), total Kjeldahl N (TKN), ortho-P (PO_4^--P), total P (TP), chemical oxygen demand (COD), and total suspended solids (TSS). Mean concentrations of PO_4^--P, TP, and TSS were highest for subbasins with the highest proportions of pasture land use. Concentrations of NH_3-N, TKN, and COD decreased significantly with time (35-75% per year) for all subbasins, while concentration of other parameters were generally stable. The declines in analysis parameter concentrations are attributed to the implementation of BMPs in the basin since (1) the results are consistent with what would be expected for the particular BMPs implemented and (2) no other known activities in the basin would have caused the declines in analysis parameter concentrations.

Keywords: best management practices; land use; nonpoint source; South Central; water quality; Water resources management

Ernst, C., R. Gullick, and K. Nixon. 2004. Protecting the source: conserving forests to protect water. *Opflow* 30(5):1,4-7

Abstract: More than a century ago, many of America's fastest growing cities, such as Boston and New York, bought land in their source areas to provide lasting protection of water resources critical for sustaining their populations in the future. To this day, these cities, some of the largest in the country, have relatively clean source waters that require minimal treatment.

Advancements in science and technology have enabled water utilities to effectively treat most known contaminants from drinking water sources and to provide American citizens with some of the safest drinking water in the world. However, these advancements have contributed to a movement away from protecting and managing source areas and to the unfortunate notion that the quality of raw water supplies is less important.

Treatment alone, although critical to preventing disease, should not be the sole protection of drinking water. Multiple barriers to disease agents need to be maintained in order to provide the greatest protection to public health. A multiple-barrier approach to drinking water protection involves several consecutive and interrelated steps, including selection of high-quality source water(s), source water management and protection, appropriate treatment, distribution system management, and water quality monitoring.

Current research on the effects of urban and agricultural runoff in raw water sources on public health and recognition of the high costs and limitations of technological fixes has led water supply and watershed managers to revisit two principles that were taken for granted a century ago: (1) the public's water supply should be reasonably clean to begin with, and (2) forests and natural lands are critical to the quantity and quality of water supplies.

Water suppliers and municipalities can build effective partnerships to conserve forested land and protect their source water. A recent study shows the relationship between forests and clean water, and the resulting effects on treatment costs.

Keywords: costs; source protection; South Central; United States; vegetation change; watershed management

Koelliker, J.K., R.S. Govindaraju, and S.L. Lewis. 1995. Estimating yield from watersheds undergoing changes. In *Watershed Management: Planning for the 21st century*. T. J. Ward (ed.) American Society of Civil Engineers, New York, pp. 419-428.

Abstract: Effects of changes in three similar-sized watersheds, Council Grove, Marion, and El Dorado, of water supply reservoirs in east central Kansas since the drought of 1952-1957 were examined to estimate the effects on inflow for current and future conditions. A continuous simulation deterministic water budget model, POTYLDR, along with an adjustment factor to account for variability of inflow caused by precipitation nonuniformity over the watershed, were used to estimate monthly inflow to the reservoirs for the 1952-1957 period for development in the watersheds for conditions in the 1950s, 1992, and 2035. Council Grove has remained nearly unchanged, Marion has been affected by conservation treatment on agricultural land, and El Dorado has considerable watershed dam construction in it. Results show POTYLDR predicted water yield satisfactorily for the three watersheds. The addition of a factor to account for variability in precipitation nonuniformity improved predictions, especially during dry periods. Predicted decrease in yield for 1992 and 2035 conditions in percent compared to conditions during the 1950s are 0 and 0, 15 and 18, and 20 and 24, for Council Grove, Marion, and El Dorado, respectively.

Keywords: South Central; water quantity; water yield; watershed management

McIntyre, S.C. 1993. Reservoir sedimentation rates linked to long-term changes in agricultural land use. *Water Resources Bulletin* 29(3):487-495.

Abstract: Long-term land use and reservoir sedimentation were quantified and linked in a small agricultural reservoir-watershed system without having historical data. Land use was determined from a time sequence of aerial photographs, and reservoir sedimentation was determined from cores with 137Ca dating techniques. They were linked by relating sediment deposition to potential sediment production, which was determined by the Universal Soil Loss Equation and the SCS Pottawatomie Company, Oklahoma estimates for cullied land. Sediment cores were collected from Tecumesh Lake, a 55-hectare (ha) reservoir with a 1,189-ha agricultural watershed, constructed in 1934 in central Oklahoma. Reservoir sediment deposition decreased from an average of 5,933 milligrams per year (mg/yr) from 1934 to 1954, to 3,179 mg/yr from 1962 to 1987. Potential sediment production decreased from an average of 29,892 to 11,122 and then to 3,5933 mg/yr for the same time periods as above, respectively. Reductions in deposition and sediment production corresponded to reductions in cultivated and abandoned cropland which became perennial pasture. Together, cultivated and abandoned cropland accounted for 59% of the watershed in 1937, 24% in 1954, and 10% in 1962. Roadway erosion, stream bank erosion, stored stream channel sediment, and long-term precipitation were considered, but none seemed to play a significant role in changing sediment deposition rates. Instead, the dominant factor was

the conversion of fields to perennial pastures. The effect of conservation measures on reservoir sedimentation can now be quantified for many reservoirs where historical data are not available.

Keywords: land use; reservoirs; sedimentation; South Central; watershed

Northwest

Herbert, E. 2007. Forest management by west coast water utilities: protecting the source? *Journal of the American Water Works Association* 99(2):91-106.

Abstract: Most water utilities nationwide that depend on surface water draw water from watersheds over which they have little or no control. Therefore, water utility managers view land acquisition as one of the most effective ways to protect water quality. Because land acquisition can be costly, land trusts are increasingly using conservation easements to protect forest land. This article summarizes the key findings of a research project that analyzed forest management policies and practices of 45 West Coast public water utilities that own forested land in their source watersheds. The research includes three types of quantitative analysis and six case studies.

The primary research question driving this study was, “What is the variation in forest management policies and practices among West Coast public water utilities that own forest land, and what factors account for this variation?” If water utilities seek to buy land or acquire conservation easements in their forested watersheds to protect source water quality, then it is vital to consider how they manage this land once it is purchased. Public water utilities undeniably set an example for other land managers in terms of the importance of source water protection. Conservation easements to protect source watersheds therefore must be designed to protect forests from damaging forest practices as well as from conversion to other land uses.

Keywords: land use; management; Northwest; source water protection; Southwest; water quality; watershed

Megahan, W.F. 2000. Cumulative watershed effects research needs for forested watersheds in the 21st century. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 61-68. Water Resources Center Report No. 98.

Abstract: Key cumulative effects research needs dealing with forest watersheds include natural variability in watershed characteristics and in downstream responses, sediment routing, and effects of disturbance on streamflow. Important information needs relating to natural variability include better descriptions of spatial variability and a broader perspective on temporal variability. Large regional differences in landslide types and streamflow rates are used to illustrate the need for studies of spatial variability. Justification for increased research on temporal variability is based on recent studies documenting long-term (thousands of years) sediment supplies from mountain watersheds in Idaho averaging about an order of magnitude greater than present day (tens of years) sediment data indicate. Additional studies in western Oregon show that mountain channels exhibit a natural succession from energy limited (aggraded) to supply limited (degraded) conditions, with accompanying changes in aquatic habitat conditions. Important components of sediment routing research include delivery of landslide material to channels, downslope sediment from roads to channels, and downstream routing of bedload sediments in channels. Evaluation of the effects of disturbance on streamflow should include the effects of forest management and wildfire on all levels of streamflow, and the accompanying erosional and sedimentation response of channels and aquatic ecosystems. Physically based, distributed models need to be developed and improved to predict the effects of disturbance on streamflow and channel changes.

Keywords: fire; flood; Northwest; sediment; streamflow; urban; vegetation change; watershed management

National Research Council. 1991. *Managing Water Resources in the West Under Conditions of Climate Uncertainty.* National Academy Press, Washington, DC, Prepared by the Committee on Climate Uncertainty and Water Resources Management.

Abstract: The question of whether the Earth's climate is changing in some significant, human-induced way remains a matter of much debate. But the fact that climate is variable over time is well known. These two elements of climatic uncertainty affect water resources planning and management in the American West.

Natural variability in hydrologic processes is all-pervasive. Many techniques have been developed to describe components of this variability. Additional tools and strategies are needed to manage water effectively given inherent supply variability and competing demands. With added and improved capabilities and strategies, society will be better prepared to deal with the uncertainties presented by potential climate change.

"Managing Water Resources in the West Under Conditions of Climate Uncertainty," a colloquium held November 14-16, 1990, in Scottsdale, Arizona, was organized by the Water Science and Technology Board at the request of the U.S. Bureau of Reclamation. The colloquium was held to examine the scientific basis for predictions of climate change, the implications of climate uncertainty for water resources management, and the management options available for responding to climate variability and potential climate change. Bureau of Reclamation Commissioner Dennis Underwood, noting the importance of climate variability to his agency's operations in the West, took a personal interest in the colloquium and spoke with participants about his goals for the Bureau of Reclamation as it increases its emphasis on resource management issues.

Keywords: climate change; Northwest; Southwest; United States; water resources management

Oregon Department of Environmental Quality and Oregon Department of Human Services. 2003. Source Water Assessment Summary Brochure, Joint Water Commission PWS #4100379 and Hillsboro-Cherry Grove PWS # 4100985.

Abstract: The Source Water Assessment was recently completed by the Department of Environmental Quality and the Oregon Department of Human Services to identify the surface areas (and/or subsurface areas) that supply water to the Hillsboro Utilities Commission, Beaverton, Forest Grove, and Tualatin Valley Water District Joint Water Commission and Hillsboro-Cherry Grove's public water system intakes and to inventory the potential contaminant sources that may impact the water supply.

Keywords: case study; Northwest; source water assessment plan; source water assessment programs; water quality; watershed management

Seierstad, A., R. Willis, and S. Mengistu. 1994. Watershed use impacts on total and fecal coliform concentrations. In *Proceedings 1993 Water Quality Technology Conference; Part II* AWWA pp. 1701-1711.

Abstract: Prevailing wisdom tells us that restricting a watershed's uses and entry will result in improved water quality. However, there are few studies that have made water quality comparisons between watersheds which are similar except with regard to their allowed uses and entry policies.

This study made comparisons between the Bull Run watershed and the Little North Santiam River watershed in Oregon. Both watersheds are used for drinking water production; the Bull Run watershed is used by the City of Portland, Oregon; and the Little North Santiam watershed is used by the City of Salem, Oregon. These watersheds are located on the western slopes of the Cascade Mountains in Oregon. They are in relatively close proximity and subject to similar weather patterns; the Bull Run watershed is about 45 miles due north of the Little North Santiam watershed. These watersheds were known to be similar in many ways, and were believed to have potential for use in a comparative water quality study such as this.

Keywords: drinking water; fecal coliform; nonpoint source; Northwest; water quality; watershed

Stickel, L. 1998. The evolving relationship between federal land management and municipal supplies in the Willamette & Sandy Basins of Oregon. In *1998 Annual Conference Proceedings; American Water Works Association*, June 21-25,1998, Dallas, TX. AWWA pp. 85-99.

Abstract: Many watersheds, especially in the American West, are owned and managed by federal agencies while the water is used by municipal water providers. This relationship can create conflicts between the two managing groups. This paper examines the relationship between federal land managers and municipal water providers.

Keywords: land management; management; municipal water supply; Northwest; water quality; watershed

Swanson, F.J., R.P. Neilson, and G.E. Grant. 1992. Some emerging issues in watershed management: Landscape patterns, species conservation, and climate change. In *New Perspectives for Watershed Management: Balancing Long-Term Sustainability with Cumulative Environmental Change. Seattle, WA, November 27-29, 1990.*, pp. 307-323. EPA/600/A-92/256.

Abstract: Emerging issues in watershed management include the need to assess the effects of management activities on a time scale of several cutting rotations (> 100 years) and on spatial scales that encompass influences from beyond watershed boundaries. Long-range analysis indicates that today's activities will have strong, long-lasting effects, though the ecological consequences may not be visible when the analysis horizon spans only a few decades. Land use decisions within watersheds are increasingly influenced by broader social, economic, and biological factors (e.g., wildlife management plans, such as the Northern Spotted Owl Conservation Strategy). Global climate change poses an even greater potential for altering watershed management. Consequently, improved social and technical tools are needed for planning management of multiple resources in an increasingly uncertain world.

Keywords: climate change; landscape; management; Northwest; watershed

Tualatin River Flow Management Committee. 2005. Tualatin River Flow Management Committee Technical Reports: Annual Reports, 1992-2005. District 18 Watermaster's Office, Oregon Water Resources Department.

Abstract: Since its inception in 1987, the Tualatin River Flow Management Technical Committee has provided a mechanism for the coordination and management of flow in the Tualatin River. The members of the committee are technical staff with detailed knowledge of the specific characteristics of flow in this river. The committee meets monthly from February through November. Meetings focus mainly on the review of hydrographs and current status of the reservoirs. In addition, a variety of other water issues and any problems are discussed. Each member updates the committee on any changes that could impact the flow management of the Tualatin Basin.

The Tualatin River Flow Management Technical Committee Annual Report is a compilation of hydrographic data collected by the cooperating entities and prepared by Clean Water Services, Watershed Management Division, in cooperation with the Oregon Water Resources Department, District 18 Watermaster.

Keywords: Northwest; streamflow; watershed management

Southwest

Herbert, E. 2007. Forest management by west coast water utilities: protecting the source? *Journal of the American Water Works Association* 99(2):91-106.

Abstract: Most water utilities nationwide that depend on surface water draw water from watersheds over which they have little or no control. Therefore, water utility managers view land

acquisition as one of the most effective ways to protect water quality. Because land acquisition can be costly, land trusts are increasingly using conservation easements to protect forest land. This article summarizes the key findings of a research project that analyzed forest management policies and practices of 45 West Coast public water utilities that own forested land in their source watersheds. The research includes three types of quantitative analysis and six case studies.

The primary research question driving this study was, "What is the variation in forest management policies and practices among West Coast public water utilities that own forest land, and what factors account for this variation?" If water utilities seek to buy land or acquire conservation easements in their forested watersheds to protect source water quality, then it is vital to consider how they manage this land once it is purchased. Public water utilities undeniably set an example for other land managers in terms of the importance of source water protection. Conservation easements to protect source watersheds therefore must be designed to protect forests from damaging forest practices as well as from conversion to other land uses.

Keywords: land use; management; Northwest; source water protection; Southwest; water quality; watershed

Klamt, R.R. 2000. The Garcia experience: a sediment TMDL case study. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 29-34. Water Resources Center Report No. 98.

Abstract: Salmon and steelhead play a significant role in California north coastal economy, philosophy, and politics. Author Mark Twain is credited with saying that in the West, whisky is for drinking and water is to fight over. More recently on the north coast, the fight has focused on salmon and land use. Continued concern for the anadromous fisheries has turned attention from the water itself to the riparian zone and hill slopes of the steep erosive coastal mountains of northern California.

The Garcia River is a coastal tributary located about 100 miles north of San Francisco Bay. It is forested with commercial conifers and hardwoods and supports farming and cattle and sheep ranching. Historic waves of logging activity at different levels of regard for the land and water resources coupled with erosive soils on steep slopes and high winter rainfall resulted in significant erosion and sedimentation. Concern over declining anadromous salmonid populations brought attention to sediment impacts in the Garcia River watershed. That focus and threat of a lawsuit prompted the development of a sediment reduction strategy (TMDL) that addresses habitat and channel structure in the waterways by requiring landowners to submit erosion control plans. In May 1998 the North Coast Regional Water Quality Control Board adopted a TMDL and implementation plan with the assistance of the U.S. Environmental Protection Agency. Controllable sediment discharges are prohibited, and reductions of sediment delivery to streams from roads, timber harvest, and agriculture are required on a 40-year time table. Instream numeric targets that describe the desired future conditions of the riparian area, stream channel and fish habitat are used as goals to measure the success of the reductions over time. The development of the TMDL and, especially, the implementation plan were contentious and involved numerous public workshops and hearings over a 2-year period. However, landowner response and attitude and, subsequently, the nature of land use activities is slowly changing. Landowner inventories and monitoring will provide a physical assessment of watershed recovery. The response of the fisheries will tell the ultimate story.

Keywords: case study; development; erosion; grazing; land management; land use; logging; sediment; Southwest; vegetation; water quality; water resources; watershed

Marin Municipal Water District. 2005. Watershed Sanitary Survey Update 2005. December.

Abstract: The Marin Municipal Water District (MMWD) is a purveyor of drinking water obtained from seven reservoirs in Marin County. As a drinking water supply agency that draws from a surface water supply, MMWD was required under the California Surface Water Treatment Rule to conduct a watershed sanitary survey (WSS) in 1995 and to conduct updates to the WSS every five years thereafter. This document is the second update to the 1995 WSS and fulfilled MMWD's requirement to complete an updated WSS by January 1, 2006. The focus of the 1995 WSS was to recommend measures that a water purveyor can implement to preserve and improve the quality of their surface water supplies. The focus of the WSS update is to identify the changes to the information provided in the original WSS and subsequent updates.

This WSS update addresses MMWD's seven local surface water reservoirs that are located in two major watersheds, the Mount Tamalpais Watershed and the Soulajule/Nicasio Watershed. MMWD also treats water that is supplied by the Sonoma County Water Agency (SCWA) from the Russian River; SCWA is addressing the WSS update requirements for the Russian River supply in a separate study.

Pursuant to the recommendation of Department of Health Services staff, this WSS update is intended to be a short update report to the 2000 WSS update and is intended to provide information on the changes that have occurred since 2000 to the various aspects of the original WSS.

Keywords: case study; source water assessment and protection; source water assessment plan; Southwest; water quality; watershed management; watershed sanitary survey

Meixner, T. and P.M. Wohlgemuth. 2003. Climate variability, fire, vegetation recovery, and watershed hydrology. In *First Interagency Conference on Research in the Watersheds*, October 27-30, 2003. Renard, K.G., McElroy, S.A., Gburek, W.J., Canfield, H.E., and Scott, R.L.(eds.). USDA Agricultural Research Service pp. 651-656.

Abstract: The San Dimas Experimental Forest was established in 1934. A large database of fire history, and streamflow exists for several locations within the forest. San Dimas was selected as a perfect example of the hydrology, geology, and ecology of the mountains of southern

California. As such, the long-term dataset provides the best examples available of rainfall-runoff relationships in a mountainous Mediterranean climate. One of the most important ecological processes operating at San Dimas is the frequent stand replacing fires that occur approximately every 40 years. The effect of fire on streamflow is a pertinent topic considering the current national discussion about changes in fire policy in the western United States. The datasets at San Dimas provide an opportunity to investigate what the short- and long-term impacts of fire are on water resources in chaparral ecosystems. In particular, the fires of 1938 and 1960 provide an opportunity to investigate the effect of fire on streamflow response. Immediately after the fires, the well-known fire-flood response of chaparral watersheds is noted with extremely large flood peaks possibly due to the combined effects of removal of vegetation and litter by fire as well as the presence of hydrophobic soils. However, longer-term impacts of fire are noticeable, lasting as long as 20 years and are most likely related to aggrading vegetation coverage and the linked increase in evapotranspiration. Around 1960, several watersheds were converted to annual and perennial grasslands from their native chaparral, which increased streamflow to the present day and offers insight into the importance of deeply rooted vegetation on summer streamflow in seasonally dry climates.

Keywords: case study; fire; Southwest; streamflow; vegetation change; watershed

National Research Council. 1991. *Managing Water Resources in the West Under Conditions of Climate Uncertainty*. National Academy Press, Washington, DC, Prepared by the Committee on Climate Uncertainty and Water Resources Management.

Abstract: The question of whether the Earth's climate is changing in some significant, human-induced way remains a matter of much debate. But the fact that climate is variable over time is well known. These two elements of climatic uncertainty affect water resources planning and management in the American West.

Natural variability in hydrologic processes is all-pervasive. Many techniques have been developed to describe components of this variability. Additional tools and strategies are needed to manage water effectively given inherent supply variability and competing demands. With added and improved capabilities and strategies, society will be better prepared to deal with the uncertainties presented by potential climate change.

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Keywords: climate change; Northwest; Southwest; United States; Water resources management

San Francisco Planning Department. 2000. Alameda Watershed Management Plan: Final Environmental Impact Report.

Abstract: The purpose of the Management Plan is to provide a policy framework for the San Francisco Public Utilities Commission (SFPUC) to make consistent decisions about the activities, practices, and procedures that are appropriate on the Watershed lands. To aid the SFPUC in their decision-making, the Management Plan provides a comprehensive set of goals, policies, and management actions that address all Watershed activities and reflect the unique qualities of the Watershed.

Keywords: case study; Southwest; water quality; water treatment; watershed management

United States

Association of Metropolitan Water Agencies. 2008. Climate Change Case Studies. Available: http://www.amwa.net/.

Abstract: Across the country, Association of Metropolitan Water Agencies member utilities are studying and preparing for the potential impacts of climate change on their community's drinking water supplies. Cities that have instituted plans to address climate change in their watersheds include Tucson, Arizona; San Francisco, California; Santa Clara County, California; Denver, Colorado; Miami, Florida; Las Vegas, Nevada; Albuquerque, New Mexico; New York City, New York; Portland, Oregon; and Seattle, Washington.

Keywords: climate change; drinking water quality; United States; watershed management

Burby, R.J., E.J. Kaiser, T.L. Miller, and D.H. Moreau. 1983. *Drinking Water Supplies: Protection Through Watershed Management.* Ann Arbor Science Publishers. Ann Arbor, MI.

Abstract: This volume describes a new methodology for devising programs to protect surface water supply sources. Urbanization of water supply watersheds is creating an increasingly serious hazard to public health. In the past, protection of water supply sources relied on the concept of source isolation through purchase of the surrounding area. This practice is no longer practical – on economic, legal, or political grounds – particularly in areas where urban development pressures are accelerating. As a result, water supply systems and local governments must devise watershed management strategies that incorporate a variety of measures and institutional arrangements to protect raw water supplies from contamination.

Keywords: case study; drinking water quality; United States; urbanization; watershed management

Coats, R. 2000. Forest hydromythology: myths and misconceptions about forests, rainfall and streamflow. In *Western Watersheds: Science, Sense, Strategies. Proceedings of the Seventh Biennial Watershed Management Council Conference*, October 19-23, 1998, Boise, ID. Slaughter, C.W.(ed.). Centers for Water and Wildland Resources, University of California, Riverside, CA, pp. 93-98. Water Resources Center Report No. 98.

Abstract: Myths and misconceptions about basic relationships of forest hydrology are firmly imbedded in popular culture, and have played an important role in American history. The notion that rainfall could be enhanced by planting crops, orchards, and forests played an unfortunate role in the settlement of the arid West. The idea that timber harvest exacerbates flooding in large river basins played a more salutary role in the establishment of the Forest Reserve system. In efforts to develop simple indices and indicators of watershed health, foresters and hydrologists have sometimes promoted their own set of myths about forest hydrology. Generally the consequences of management programs based on mistaken ideas about watershed ecosystems have not been disastrous; an exception was the program to remove woody debris from streams in north coastal California. The history of misconceptions about forest hydrology suggests that (1) we should be very cautious in applying experience gained in one region to problems in another; (2) we should avoid the use of simple indices and formulas to solve complex management problems; (3) we should not embark on stream “improvement” programs without first analyzing the fluvial system from a geomorphic and ecological perspective; and (4) we should be wary of hydrologic dogma.

Keywords: land use; United States; watershed management

Cromwell, J.E., J.B. Smith, and R.S. Raucher. 2007. Implications of Climate Change for Urban Water Utilities. Prepared by Stratus Consulting for the Association of Metropolitan Water Agencies, Washington, DC. December.

Abstract: There are many parts to the climate change story that come together to produce a picture of potentially significant implications for urban water utilities. This can create an information overload that, coupled with uncertainties, presents a barrier to understanding and to developing responses. This paper is designed to help move past this initial barrier in order to draw an effective focus on implications and responses. The story is broken into its main elements and considered in logical sequence without tangential details that are documented sufficiently in the scientific literature. The intent is to provide an essential understanding and then turn to consideration of the issues involved in developing suitable water sector responses to climate change.

A general description of climate change processes and effects follows the introduction. Impacts of these climatic changes on water suppliers are then identified and described, including regional differences. Responses to climate change are then discussed, both in terms of “adaptation strategies” to reduce or avoid impacts of climate change, and in terms of “mitigation strategies” that utilities may adopt to reduce the contribution of water utility operations to the production of greenhouse gas emissions.

Keywords: climate change; drinking water quality; drinking water treatment; United States; watershed management

Ernst, C. and K. Hart. 2005. Path to Protection: Ten Strategies for Successful Source Water Protection. The Trust for Public Land.

Abstract: Over the past five years, the U.S. Environmental Protection Agency's (EPA's) Office of Ground Water and Drinking Water funded five national nonprofit organizations to launch source water demonstration projects in communities around the country. The purpose of the projects was to build on state Source Water Assessment Programs to move communities from planning to implementing protection for drinking water sources. Successful pilot projects could then be replicated by state and local governments and water suppliers around the country. In order to glean the lessons learned and identify best practices, the Trust for Public Land (TPL) led a joint review of the five grantees' source protection demonstration projects during the spring and summer of 2004. The five grantees were the Clean Water Network/Clean Water Fund/Campaign for Safe and Affordable Drinking Water, the Groundwater Foundation, the Environmental Finance Center Network, the National Rural Water Association, and TPL (in partnership with the University of Massachusetts and the U.S. Department of Agriculture [USDA] Forest Service). Each of EPA's grantees took a different approach to advance source water protection through its pilot project.

The partnership of Clean Water Network/Clean Water Fund/Campaign for Safe and Affordable Drinking Water worked with hundreds of voluntary and nonprofit watershed associations around the country to help them advocate more effectively for source protection as part of a larger goal to achieve fishable and swimmable water.

The Groundwater Foundation supported suppliers working to advance new tools for wellhead and groundwater protection.

The Environmental Finance Center Network helped local stakeholders develop and implement source water protection plans for sources that are shared by many water systems.

The National Rural Water Association hired technicians around the country to assist small rural communities design and implement source water plans.

The Trust for Public Land (in partnership with the University of Massachusetts and the USDA Forest Service) worked with local communities in multijurisdictional watersheds to integrate land conservation and forest management into comprehensive source water protection efforts. This report summarizes findings based on experiences of the five pilot projects and proposes 10 strategies that will help put more state and local governments on the path to protection. Each strategy includes a case study of a state or local entity that has successfully implemented some or all of the action steps included in that strategy. (Note: The case studies are independent of the pilot projects of the five grantees.)

Keywords: agriculture; case study; drinking water; management; source protection; source water protection; United States; watershed

Ernst, C., R. Gullick, and K. Nixon. 2004. Protecting the source: conserving forests to protect water. *Opflow* 30(5):1,4-7

Abstract: More than a century ago, many of America's fastest growing cities, such as Boston and New York, bought land in their source areas to provide lasting protection of water resources critical for sustaining their populations in the future. To this day, these cities, some of the largest in the country, have relatively clean source waters that require minimal treatment.

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Treatment alone, although critical to preventing disease, should not be the sole protection of drinking water. Multiple barriers to disease agents need to be maintained in order to provide the greatest protection to public health. A multiple-barrier approach to drinking water protection involves several consecutive and interrelated steps, including selection of high-quality source water(s), source water management and protection, appropriate treatment, distribution system management, and water quality monitoring.

Current research on the effects of urban and agricultural runoff in raw water sources on public health and recognition of the high costs and limitations of technological fixes has led water supply and watershed managers to revisit two principles that were taken for granted a century ago: (1) the public's water supply should be reasonably clean to begin with, and (2) forests and natural lands are critical to the quantity and quality of water supplies.

Water suppliers and municipalities can build effective partnerships to conserve forested land and protect their source water. A recent study shows the relationship between forests and clean water, and the resulting effects on treatment costs.

Keywords: costs; source protection; South Central; United States; vegetation change; watershed management

Hopper, K. and C. Ernst. 2005. *Source Protection Handbook: Using Land Conservation to Protect Drinking Water Supplies.* The Trust for Public Land and the American Water Works Association.

Abstract: From source to tap, there are numerous points to capture and safeguard clean water or treat contaminated water. The most fundamental approach begins at the source – the lakes, rivers, streams, reservoirs, and groundwater that provide drinking water. By preserving the land that drains to these sources, the vast majority of contaminants are prevented from entering drinking water in the first place. This is a critical component of source protection and the focus of this handbook. Land conservation emphasizes the permanent preservation of land around both groundwater sources (aquifer recharge areas and wellheads) and surface water sources (land that buffers streams, rivers, and lakes). It is an extremely effective tool that can protect public health, prevent increased treatment costs, ensure consumer confidence, and maintain real estate values in areas where water supplies are protected.

Treatment, through filtration and disinfection, is the next barrier against contaminated water. Should pollutants enter water supplies, treatment removes most contaminants. Even in the most pristine watersheds, natural pollutants such as animal waste and organic matter can impair water quality, making treatment essential to the delivery of clean, safe drinking water.

The final barrier is infrastructure. From treatment plants, water travels into canals, pipes, wells, holding tanks, and finally consumer operated spigots. Contamination can occur through the corrosion of pipes and solder material (copper, lead, asbestos), the growth of bacteria in pipes, and untreated water that enters through a break in the distribution system itself. Sound and up-to-date distribution systems help prevent such contamination and disruption of service.

Keywords: costs; drinking water; filtration; land use; reservoirs; source protection; United States; water quality; water supply; watershed

Hurd, B.H., N. Leary, R. Jones, and J.B. Smith. 1999. Relative regional vulnerability of water resources to climate change. *Journal of the American Water Resources Association* 35(6):1399-1409.

Abstract: Changes in global climate may alter hydrologic conditions and have a variety of effects on human settlements and ecological systems. The effects include changes in water supply and quality for domestic, irrigation, recreational, commercial, and industrial uses; in instream flows that support aquatic ecosystems, recreation uses, hydropower, navigation, and wastewater assimilation; in wetland extent and productivity that support fish, wildlife, and wastewater assimilation; and in the frequency and severity of floods. Watersheds where water resources are stressed under current climate are most likely to be vulnerable to changes in mean climate and extreme events. This study identified key aspects of water supply and use that could be adversely affected by climate change, developed measures and criteria useful for assessing the vulnerability of regional water resources and water dependent resources to climate change, developed a regional database of water sensitive variables consistent with the vulnerability measures, applied the criteria in a regional study of the vulnerability measures, and applied the criteria in a regional study of the vulnerability of U.S. water resources. Key findings highlight the vulnerability of consumptive uses in the western and, in particular, the southwestern United States. However, southern U.S. watersheds are relatively more vulnerable to changes in water quality, flooding, and other instream uses.

Keywords: climate change; flood; flow; United States; water quality; water resources; water supply; watershed

Megahan, W.F. and J. Hornbeck. 2000. Lessons learned in watershed management: A retrospective view. In *Land Stewardship in the 21st Century: The Contributions of Watershed Management*, March 13-16, 2000; Tucson, AZ. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO. RMRS-P-13.

Abstract: Forest watershed management research is mandated by over 100 years of legislation, from the Organic Act and Weeks Law enacted around the beginning of the 20th century, to a variety of environmental protection acts passed over the past several decades. Research results have come primarily from studies of a multitude of gauged watersheds selected to represent a variety of geographic locations, forest types, topography, and climate. These studies have shown the effects of forests and forest disturbances on water yield, peak and flood flows, snow accumulation and melt, soil erosion, and water quality including sedimentation and turbidity, chemicals and temperature. The resulting knowledge of hydrologic, nutrient and energy cycles and soil erosion has been incorporated into land and water management primarily through best management practices and an ever-increasing array of procedures including computer simulation models to help assess cumulative watershed effects. This paper reviews some important lessons learned from watershed management research across the nation and discusses management implications.

Keywords: erosion; sediment; sediment control; snowmelt; streamflow; United States; water quality; water yield; watershed management

National Research Council. 1991. *Managing Water Resources in the West Under Conditions of Climate Uncertainty.* National Academy Press, Washington, DC, Prepared by the Committee on Climate Uncertainty and Water Resources Management.

Abstract: The question of whether the Earth's climate is changing in some significant, human-induced way remains a matter of much debate. But the fact that climate is variable over time is well known. These two elements of climatic uncertainty affect water resources planning and management in the American West.

Natural variability in hydrologic processes is all-pervasive. Many techniques have been developed to describe components of this variability. Additional tools and strategies are needed to manage water effectively given inherent supply variability and competing demands. With added and improved capabilities and strategies, society will be better prepared to deal with the uncertainties presented by potential climate change.

"Managing Water Resources in the West Under Conditions of Climate Uncertainty," a colloquium held November 14-16, 1990, in Scottsdale, Arizona, was organized by the Water Science and Technology Board at the request of the U.S. Bureau of Reclamation. The colloquium was held to examine the scientific basis for predictions of climate change, the implications of climate uncertainty for water resources management, and the management options available for responding to climate variability and potential climate change. Bureau of Reclamation Commissioner Dennis Underwood, noting the importance of climate variability to

his agency's operations in the West, took a personal interest in the colloquium and spoke with participants about his goals for the Bureau of Reclamation as it increases its emphasis on resource management issues.

Keywords: climate change; Northwest; Southwest; United States; water resources management

Robbins, R.W., J.L. Glicker, D.M. Bloem, and B.M. Niss. 1991. Effective Watershed Management for Surface Water Supplies. Prepared for American Water Works Association Research Foundation (AwwaRF), Denver, CO.

Abstract: The purpose of this report is to assist water utility managers and local governments in developing effective watershed protection programs for their surface water supplies. The emphasis is on practical, effective solutions and techniques that have been implemented by water utilities and other agencies in protecting water supplies. The basis for much of this work is a national survey of water utilities and state regulatory agencies and 24 case studies of successful watershed protection programs.

Keywords: agriculture; case study; management; United States; water supply; watershed

Schmitt, C. 2002. Source Water Protection: Linking Surface Water Quality to the Watershed: Problems, Sources, and Solutions. Prepared by: Senator George J. Mitchell Center for Environmental & Watershed Research, University of Maine; Maine Water Utilities Association; Drinking Water Program, Maine Department of Human Services.

Abstract: The purpose of this Source Water Protection Guide is to help community water systems safeguard their surface water supplies. This guide was produced as part of Maine's Source Water Assessment Program (SWAP) in order to help surface water systems move from source water assessment to source water protection. This guide is intended to help small utilities manage and minimize risks identified by SWAP by focusing on the watershed causes of specific water quality problems.

Keywords: source water protection; United States; water quality; water supply; watershed

Tetra Tech. 1995. A Phase I Inventory of Current EPA Efforts to Protect Ecosystems. EPA 841-S-95-001. Prepared for U.S. EPA.

Abstract: This inventory includes summaries of projects that involve the U.S. Environmental Protection Agency (EPA) and its partners in place-based management and ecosystem protection (an approach intended to integrate environmental management with human needs, consider long-term ecosystem health, and highlight the positive correlations between economic prosperity and environmental well-being). The purpose of this document is to let readers throughout EPA and outside the Agency know of the increasing amount and variety of ecologically oriented activities in which EPA is participating and the many places at which these activities are occurring. The inventory was prepared under the direction of EPA's Ecosystem Protection Task Force.

Keywords: United States; watershed management

USDA Agricultural Research Service. 2003. First Interagency Conference on Research in the Watersheds. October 27-30, 2003. Available: http://www.tucson.ars.ag.gov/icrw/proceedings.htm.

Abstract: This report comprises *Abstract*s and papers presented at the First Interagency Conference on Research in the Watersheds, October 27-30, 2003, in Benson, Arizona. This report represents state-of-the-art research in watersheds. The content includes reviews of watershed research programs conducted by the U.S. Department of Agriculture's Agricultural Research Service and Forest Service, the U.S. Geological Survey, the U.S. Bureau of Land Management, the U.S. Environmental Protection Agency, and the National Science Foundation Consortium of Universities for the Advancement of Hydrological Sciences, Inc., and recent research on watershed-scale topics such as hydrology, erosion, economic, instrumentation, ecology, sociology and fire.

Keywords: costs; erosion; fire; hydrology; United States; water quality; water quantity; watershed

U.S. EPA. 1999. *Protecting Sources of Drinking Water: Selected Case Studies in Watershed Management.* EPA 816-R-98-019.

Abstract: This document presents case studies of 17 drinking water systems committed to extensive efforts to incorporate source water management and protection as an integral part of their business of providing safe drinking water to their customers. The authors provide snapshots of lessons learned in implementing four aspects of source water protection: partnerships, watershed assessment, watershed land use management, and land acquisition.

Though diverse in their watershed management experiences, there is a common thread among all of the water systems: the importance of cross-program coordination. The coordination of a drinking water utility's goals with local watershed management initiatives aimed at aquatic ecosystem restoration and protection can boost the effectiveness of program implementation for both priorities.

Keywords: United States; water quality; watershed management

U.S. EPA. 2000. Watershed Analysis and Management (WAM) Guide for Tribes. September. Available: http://www.epa.gov/owow/watershed/wacademy/wam/.

Abstract: The Watershed Approach provides a unique and effective way to assess the environment, identify problems, establish priorities for preservation or restoration, and implement solutions.

The U.S. Environmental Protection Agency's Office of Wetlands, Oceans, and Watersheds and the American Indian Environmental Office have collaborated on a joint project to develop a comprehensive Watershed Analysis and Management (WAM) methodology that addresses tribal and state watershed management issues. The objective is to produce a customer-tailored watershed analysis and management framework that includes geographic-specific analytical assessment methods and application techniques for addressing a wide range of environmental issues. The goal is to develop a well-defined process that recognizes the explicit objectives of multiple stakeholders and results in watershed management plans that reflect cultural values and consider economic impacts and critical environmental resources. Typical problems addressed by the WAM approach include the impact of timber operations on erosion, water quality, and fish habitat and the impacts of various land use plans on pollutant runoff.

Keywords: management; United States; watershed; watershed management

U.S. EPA. 2003. Annotated Bibliography of Source Water Protection Materials. EPA 816-C-03-003. June. Available: http://www.epa.gov/owow/watershed/wacademy/wam2003/index.html.

Abstract: This bibliography provides a comprehensive list of available materials on source water protection. The documents are organized by subject area. Within each subject area, materials are classified as technical materials, outreach materials, or programmatic guidance. Programmatic guidance provides direction and priorities for actions. Technical guidance provides detailed instruction on tools to assist program implementation. Outreach documents provide key information for stakeholders on program and technical information. For each, the title, type of document, publication date, authoring organization, and document number (if available), availability (as of May 2003), publication date, format (e.g., report or brochure), and key terms are presented. You can search by the subjects below or by keyword. Each entry has information on how to obtain the resource material.

Keywords: source water protection; United States; watershed

U.S. EPA. 2003. Watershed Analysis and Management (WAM) Guide for States and Communities. EPA 841-B-03-007.

Abstract: Using a watershed approach provides a unique and effective way to assess the environment, identify problems, establish priorities for preservation or restoration, and implement solutions. The Watershed Analysis and Management (WAM) Program is an effort to guide communities in the successful application of a watershed approach and led to the development in 2002 of this Guide. The U.S. Environmental Protection Agency's Office of Wetlands, Oceans, and Watersheds (OWOW) and the American Indian Environmental Office (AIEO) collaborated in 1997 on a joint project to develop a comprehensive WAM methodology. The initial WAM approach was based on watershed planning efforts in the Pacific Northwest, including the Washington State watershed analysis methodology for state and private forest lands and the Northwest Forest Plan watershed analysis guide for federal ownership. The concept was to extend existing capabilities to address a nationwide range of ecological environments, project objectives, and watershed management issues at the state, community, and tribal levels. With substantial support from the AIEO, a more comprehensive approach was undertaken to include

the additional issues of tribal cultural and community values. The first product, *Watershed Analysis and Management (WAM) Guide for Tribes*, was developed with a system development grant from OWOW to the Pacific Watershed Institute, concurrent with pilot applications of the approach, through AIEO grants, by tribes representing different ecological environments, objectives, and community issues.

Keywords: development; management; United States; water quality; watershed

U.S. EPA. 2005. EPA's Targeted Watershed Grants 2005 Annual Report. EPA 840-R-06-001. December.

Abstract: The 34 watersheds funded in 2003 and 2004 under the U.S. Environmental Protection Agency's Targeted Watersheds Grant Program are spread out across the United States and include large and relatively small watersheds. While a few of the watersheds are in urban areas, most are in rural and agricultural areas, flowing through deserts, forests, mountains, coastal areas, and a bayou. Although they differ in size and scope, all of the watershed partnerships reflect the unique custom and cultural values of the region.

Keywords: costs; United States; water quality; watershed management

U.S. EPA. 2005. Handbook for Developing Watershed Plans to Restore and Protect Our Waters. EPA 841-B-05-005. October.

Abstract: This handbook provides information on developing and implementing watershed plans that help to restore and protect water quality. Experience over the past decade has shown that effective watershed management includes active participation from stakeholders, analysis and quantification of the specific causes and sources of water quality problems, identification of measurable water quality goals, and specific actions needed to solve those problems.

Keywords: management; United States; water quality; watershed management

U.S. EPA. 2006. EPA Watershed Tools. May. Available: http://www.epa.gov/owow/watershed/watershedtools606.pdf.

Abstract: This document is a fact sheet with links and descriptions for databases, publications, and other resources useful in watershed management and protection.

Keywords: United States; water quality; watershed; watershed management

U.S. EPA. 2007. Making the Connection: Smart Growth and Water Resource Protection. Training module from U.S. EPA's Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: Changes in land use are linked to impacts on water resources. This module illustrates how historical trends in growth patterns and activities on land have become the most significant

challenge for preserving water quality and meeting future water resource goals. Factors such as traffic congestion, air quality, and public health figure prominently in discussions on urban growth and development today. This module focuses on the connections between smart growth approaches and Clean Water Act programs. It also includes tools, resources, and case studies illustrating how land use decisions made at the local and state levels can help protect and restore water resources by using innovative approaches that meet economic, environmental, and social goals.

Keywords: development; United States; watershed management

U.S. EPA. 2007. Watershed Academy Web. Available: http://www.epa.gov/watertrain/.

Abstract: Watershed Academy's Distance Learning Program – *Watershed Academy Web*. This Web site offers a variety of self-paced training modules that represent a basic and broad introduction to the watershed management field. The modules are organized by six themes. Modules vary in the time they to complete, from ½ hour to 2 hours.

Keywords: United States; watershed management

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