Chapter 10

Findings and Recommendations

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Western forests are managed for many purposes, including wood products, recreation and wildlife habitat. By filtering rain and snowfall and delivering it to streams or aquifers, forests also produce the highest quality and most sustainable sources of fresh water on Earth, arguably their most important ecosystem service. The public values water produced from forests, and continues to rank water quality and quantity as primary concerns with forest management. Our extensive and diverse forests generally produce high quality water and supply the majority of state's community water systems. Forest practices designed to minimize impacts to water quality have improved significantly in recent decades. At the same time, demand for all forest ecosystem services continues to rise, against a backdrop of a changing climate and uncertain implications for water derived from forests. Together, these trends point to the importance of maintaining and expanding public awareness of current science knowledge regarding the complex relationships between forest hydrology and forest management.

10.1. Introduction, overview and purpose

With support from the Oregon Forest Resources Institute, our group at Oregon State University has spent the last two and a half years evaluating the effects of active forest management on source water quality for community water systems in Oregon. This evaluation included a science review focused on four topic areas: (1) water quantity; (2) sediment and turbidity; (3) forest chemicals; and (4) natural organic matter and disinfection byproducts. The 156 community water suppliers in Oregon who rely on surface water as their primary source were surveyed, and three representing different geographic regions (coast, interior valleys, and semiarid regions) had more in-depth case studies. Additionally, we examined about 65,000 Oregon forest operations notifications for the past four years, paying particular attention to use of forest chemicals, and reviewed incidents regarding chemical applications over the same time period.

In this chapter we pull from the preceding work to summarize our results, and in some cases provide recommendations for policymakers. In the interest of readability, we have chosen not to include citations of research to support each finding. For these citations and details, readers are referred to the chapters specific to each topic and section here.

10.2. Policy-related findings and recommendations

The Oregon Forest Practices Act is the state's primary regulatory framework for addressing the environmental impacts of forest operations on state and private forest lands. The act sets standards for all commercial activities involving the establishment, management or harvest of trees in the state. When passed in 1971, the Forest Practices Act was the first legislation of its kind in the U.S. The act's first rules were implemented in 1972 and emphasized best management practices, which have since been revised repeatedly in response to emerging environmental concerns and science findings.

The Safe Drinking Water Act was enacted in 1974 and expanded in 1996 to protect drinking water quality. The Safe Drinking Water Act focuses on all U.S. surface water or groundwater sources actually or potentially used for drinking, and requires the EPA to establish and enforce standards to protect tap water. The EPA's National Primary Drinking Water Regulations are legally enforceable standards, treatment techniques and water-testing schedules that apply to public water systems. The act allows individual states to set and enforce their own drinking water standards if the standards are at a minimum as stringent as the EPA's national standards. The Oregon Health Authority regulates the treatment and distribution of potable water under the federal Safe Drinking Water Act, while the state Department of Environmental Quality has regulatory authority under the federal Clean Water Act for point and nonpoint sources of pollution.

In the past, the Clean Water Act and Safe Drinking Water Act had mostly separate goals and functions. The Clean Water Act focused on environmental protection and maintaining "fishable/swimmable" waters, primarily by identifying and regulating sources of pollution in waterways. In contrast, the Safe Drinking Water Act focused on municipal water treatment standards and providing clean drinking water at the tap. Coordination across the Clean Water Act and Safe Drinking Water Act is motivated by potential synergisms among goals and outcomes of these policies, recognizing that preventing contamination is much more cost-effective at providing safe drinking water than removing contaminants or finding alternative water sources after the fact. In 1996, Congress significantly expanded the Safe Drinking Water Act to facilitate prevention of contamination through an increased focus on drinking water source protection by requiring states to develop EPA-approved programs to carry out Source Water Assessments for all public water systems in the state. The state environmental quality department provides reports, general information and technical assistance regarding surface water systems, while the Oregon Health Authority supplies these services for groundwater systems. Updated source water assessments with more detailed data, maps and technical information were completed for roughly 50% of these systems in 2016–2017.

Much of our understanding of the effects of active forest management, in particular water and sediment interactions, comes from paired watershed studies conducted from the 1960s to the 1990s. Funding for long-term, paired watershed studies has declined, so knowledge regarding effects of current practices is more limited. Long-term studies on relationships between forestry, sediment and water quality relationships are expensive and time-consuming, and thus relatively uncommon. However, major storms and associated peak flows are often a significant or even dominant driver of sediment movement, so whether one or more such storms occur during the duration of study can significantly affect results of studies that span only a few years.

- Most studies we reviewed were focused on the effects of forest management on water quality, but few were specific to drinking water quality. We were able to infer effects on source water quality in many cases, but the cause-and-effect linkages were not as direct as we would have preferred.
- Similarly, most of the studies were conducted in the upper parts of watersheds while raw water intakes are located at various and often substantial distances downstream. In addition to forest management, intervening land uses and contaminant sources may also affect water before it reaches an intake. The size of the source watershed, and its mixture of land uses and management actions, often confound the ability to isolate forest management effects.
- Research has identified general patterns for several aspects of forest management effects on water, but findings are often based primarily on a relatively small number of studies and locations. In many ways, how forestry may affect a particular source watershed represents a unique combination of size, geology, topography, ecology, land use history and variability in present and future climate.
- Over time, changes related to climate change are expected to result in significant increases in peak flow frequencies and magnitudes in the Pacific Northwest, especially in snow-dominated watersheds as more winter precipitation falls as rain. This suggests that any effects that forestry activities have on peak flows will intertwine with climate in increasingly complex ways.
- Harmful algal blooms of cyanobacteria (cyanoHABs) are a growing concern because they produce cyanotoxins that can cause sickness and death in humans, adversely affect taste and odor, and are predicted to increase as climate change progresses. Sources of phosphorus and nitrogen that exacerbate cyanoHABs from septic systems, fertilizers, agricultural runoff and urban and forestry runoff are all likely to come under increasing scrutiny.
- Since 2013, Forest Practices Act rule compliance monitoring has been conducted by ODF for BMPs related to road construction and maintenance, timber

harvesting, some riparian management area measures, measures for small wetlands and rules for operations near waters of the state. Audits through 2016 indicate generally high compliance rates, e.g. 97% overall compliance for 2016.

- Nonetheless, existing Forest Practices Act rules are insufficient to protect some water quality attributes. Multiple studies have shown that existing riparian buffers do not meet the “protect cold water” standard. As we saw in the Forest Chemicals section, wooded buffer areas on nonfish-bearing streams can prevent or reduce pesticide drift. And, as of June 2019, the Forest Practices Act does not have any water quality-related landslide-prone area rules (although the rules related to landslide hazards to humans and infrastructure provide protection to some areas).

Policy-related recommendations:

Targeted research needed. Additional research is needed to evaluate the effects of all types of land uses, and particularly forest management, on source water quality. Understanding the connections, and cause-and-effect linkages, between land management activities and source water quality can be improved with targeted studies in the many areas outlined in this report.

Information preservation. Records retention policies constrained our ability to evaluate longer-term trends for both harvests and pesticide incidents. Most state records (in Oregon and elsewhere) are destroyed after five years. Retention of these records in state archives would enable researchers to conduct more robust analysis and prediction.

Cooperative planning. Drinking water protection plans provide a structure and venue for land managers and water utilities to cooperate on maintaining source water quality and quantity in the face of potential changes. The state and other entities (such as the Natural Resources Conservation Service) should continue to provide support and funding for local groups to prepare these plans. Oregon State University can play a supporting role by providing information through its Oregon Explorer web-based service, and expertise in modeling and analysis.

Rules revisions. The governor’s 2020 “Oregon Strategy” of state, timber industry and conservation groups will likely improve water quality to the benefit of community water sources within those areas covered by the agreement. If the Legislature fails to act according to the memo of understanding, the Board of Forestry should entertain rulemaking consistent with the agreement.

10.3. Findings and recommendations related to community water suppliers

In Oregon, 238 source watersheds feed into 157 water treatment plants, operated by 156 community water systems, that utilize surface water and shallow wells influenced by surface water to provide the raw water for almost 3 million Oregonians. About 75% of Oregon’s population obtains drinking water from large community water systems (serving 10,001–100,000 people) or very large systems (serving more than 100,000 people). However, about 80% of the 156 systems are smaller, with 29% serving fewer than 500 people (very small), 34% serving 501–3,300 people (small), and 17% serving 3,301–10,000 people (medium). Forty-one percent of survey respondents have drinking water primary source watersheds of 10 square miles or less in size. Almost two-thirds of the community water providers dependent on surface water serve small (35% of 156 total) or very small (29%) populations. Their small size limits the human, financial and infrastructure capacity of these providers. Compared to larger community water systems, smaller systems usually face higher costs per delivered unit of finished water, have smaller budgets, and operate with fewer staff. Some of the smallest systems are staffed by volunteers only. Fifty-eight percent of the Oregon community water systems that responded to our survey operate on a budget of $500,000 per year or less; 24% operate on a budget of $100,000 per year or less.

Our survey of community water systems showed that the top three general areas of concern among survey respondents were forest harvest and management, stormwater runoff, and ability of the watershed to meet supply demands. Water providers — especially those serving smaller communities — often feel they have little control over activities in their source watersheds that affect the quality of their water, including: water temperatures, nutrient levels, landslides, riparian buffer blowdown, wildfire risk and effects, forest chemicals, future water quantity, and sediment and turbidity. More than 70% felt they had no control at all over multiple issues. For every issue affecting their source watersheds listed in the survey, respondents' level of concern over the issue was greater than their perceived control over it, especially wildfire impacts, forest chemicals, floods and sediment, and water temperatures and quantity.

Respondents' key "lessons learned" via experiences managing source watersheds fell roughly into three categories: the importance of 1) maintaining lines of communication with forest landowners; 2) being proactive and prepared rather than reactive in the face of events and challenges, and 3) actively managing for forest health. Specifically:

- Water provider survey respondents stressed the importance of knowing and communicating regularly with landowners and their agents in source watersheds, including logging crews who were on the ground, to have real-time discussions about forest operations as they occur.
- Respondents stressed the importance of proactively preparing for a range of possible events and situations via regular examination of the source watershed, knowing who to call in the event of problems, practicing response scenarios, stocking supplies such as filter bags, updating assessments and plans and having all necessary documentation.
- Some respondents indicated that hands-on, fully engaged management for forest health, with proactive planning, inventory, monitoring and activities such as invasive species control and stand improvement, is necessary to maintain source water quality.
- Respondents indicated that their most important partners in managing their drinking water source watershed were private forestland owners (likely because they own many of the drinking water source areas for providers we surveyed) followed by watershed councils and Soil and Water Conservation Districts.

10.4. Water quantity findings and recommendations

Relationships between forest cover and type, forest management and the quantity and timing of water produced by forested watersheds have been studied for at least 100 years. Understanding of these relationships has been significantly enhanced by research, especially long-term, paired watershed studies. We reviewed evidence regarding changes in (a) annual flow, (b) peak flows and flooding, (c) low (base) flows, and (d) the timing of water delivery. Throughout, we noted the difficulty in trying to extrapolate from studies that typically took place in higher elevation, small watersheds to effects on downstream drinking water supplies. There is often considerable variability in results, with some studies finding large effects and others none at all. Effects that have been quantified at smaller scales may potentially "scale up" to larger watershed scales, but these larger scale effects are rarely studied and thus remain generally speculative. Lastly, conditions in many watersheds reflect the cumulative effects of actions conducted over the span of many decades of evolving forest management practices.

A substantial body of evidence has nevertheless accumulated, from an increasingly diverse array of research perspectives and methodologies:

- We know with considerable certainty that the percent area of the watershed harvested is the predominant factor affecting changes in stream flow volumes.
- Timber harvesting temporarily increases annual water production, especially in the first few years after harvest. These increases decline in following years as vegetation, including planted commercial timber species, establishes and starts growing vigorously.
- By volume, these changes often peak in the fall and early winter. By percentage, the largest changes in low flows often occur in late summer.

Peak flows and floods have implications for community water suppliers in terms of increased sediment transport, turbidity, mobilization of pollutants and potential damage to water treatment infrastructure. The generally accepted scientific understanding is that:

- Peak flow increases are most prominent for smaller, more frequent peak storm flow events, and these increases tend to decline as peak flow size and basin size increase.
- Snowpack changes related to climate change are likely to result in large increases in peak flow magnitudes in mountainous areas such as the Cascades and Blue Mountains due to a greater frequency and magnitude of extreme precipitation events, and a growing proportion of winter precipitation falling as rain instead of snow.

Seasonal low flows are of particular interest because they generally coincide in late summer with the period of greatest demand for drinking and irrigation water:

- Along with rising temperatures, dry years are increasing, low flows are declining and the annual low flow period is lengthening in duration.
- Stands of conifers established after clear-cut harvests can, once they are 15– 20 years old and growing quickly, significantly and persistently reduce summer low flows in comparison to the older stands they replaced.

In summary, evidence indicates that forest management can and probably does affect the volume and timing of water delivered from managed watersheds and, by extension, community water systems that are hydrologically connected downstream. The limitations on existing knowledge make it difficult to specify these effects for a particular area. However, linkages between water supplies and forest management (e.g., harvesting a significant percentage of the watershed) can be more readily established in smaller systems that are closer to the source watershed than in larger systems that are further away, with more intervening land uses. Finally, climate change and associated shifts in snowpack levels and timing, and in the frequency and severity of extreme weather events, will further complicate an already complex set of factors that influence the amount and timing of raw water provided in actively managed drinking water source watersheds.

10.5. Sediment and turbidity findings and recommendations

Linkages between active forest management and increased sediment loading in streams have been studied extensively and are well-established in broad terms. There is also an expanding body of evidence indicating that modern practices, such as improved road building methods and stream buffers, have significantly reduced sediment production from forest management activities and the chances that this sediment will enter waterways. But these effects and findings are highly variable due to the complexity of interactions among such factors as site-specific ecology, geology and geomorphology, management prescriptions and land use histories. Also, the specific sources of mobilized sediment within an actively managed area are often not clear. Considerable uncertainty remains in predicting precisely how a particular set of forest management actions will affect sediment production in specific cases. Further, there is a paucity of research focused on linkages between sediment inputs related to timber harvesting and associated activities in headwater areas of watersheds and increases in suspended sediment or turbidity in water withdrawn downstream for domestic uses.

A range of potential contributing factors may help explain the lack of research focused on forestry and drinking water linkages. As watershed size and distance from forest management activities increase, it becomes progressively more challenging to isolate and quantify the effects of particular actions. There are usually cumulative effects resulting from forest management in larger watersheds, partly due to variability in forestry activities (e.g., road building and use, harvesting, site preparation) and timing of their impacts on stream sediment, with some actions having immediate effects and others taking years to become apparent. Timber has been harvested for a century or more in many Oregon watersheds, historically without BMPs in place, with a legacy of sediment production and sediment transfer downstream in many watersheds. Over time, effects accumulate in complex patterns across forestlands managed through multiple harvests and rotations. Distinguishing effects of modern forest practices from those used earlier, and whether increased sediment and turbidity originates primarily from remobilized natural or anthropogenic sediments within streams, streambank erosion, or sources external to the waterway is difficult and complex. Climate variability, the generally episodic nature of sediment movement, and the outsize influence of stochastic events such as infrequent large storms can introduce additional uncertainty into research findings. Finally, in larger watersheds, forest management is often not the only land use or potential source of sediments.

For these reasons, it is difficult to make specific, firm conclusions regarding how, where and the extent to which sediment produced by active forest management in a headwater area affects water quality at a drinking water intake downstream. There is, however, an extensive body of evidence accumulated through forestry and sediment-focused research conducted in upper watersheds that is highly relevant to drinking water quality. Reasoned inferences can be drawn from this evidence base regarding effects on drinking water sources because hillslopes, headwaters and larger downstream waterways are all elements of fundamentally connected and integrated hydrological systems. Headwater streams comprise about 60% to 80% of total stream length in a typical river drainage and generate most of the streamflow in downstream areas, and these first- and second-order streams cumulatively contribute to and can profoundly affect water quality downstream.

Headwater streamflow is usually routed efficiently downstream, meaning that management-induced changes in streamflow parameters will accumulate downstream. Because turbidity and fine sediment can be readily transported downstream, changes in headwater inputs of these constituents may be directly linked to downstream conditions. In contrast, linkages between upstream inputs and downstream fluxes for coarse sediment and large woody debris are considerably weaker. It is also important to note the substantial variation in distances between actively managed forests and drinking water intakes across the range of different municipal water suppliers in Oregon. Studies that show forest management activities or forest roads increase sediment production and reduce stream water quality in headwaters can be more reliably extrapolated to drinking water quality effects where intakes are in relatively closer proximity to these management activities and have fewer intervening land uses.

In general, due primarily to the complex interplay of factors outlined above and difficulties in isolating and quantifying the sources and fates of mobilized sediment, we found little direct evidence that forestry activities and forest roads impact community drinking water in Oregon. But there is considerable indirect evidence that forestry can have such effects, and likely continues to have effects in certain cases, inferred from:

- Extensive findings regarding linkages between forestry activities and mass wasting in upper watersheds.
- Cumulative and legacy effects of harvesting, site preparation and forest roads dating from periods when BMPs were not as robust.
- Inevitable variability in BMP implementation and effectiveness.
- The ability of fine sediment to be carried considerable distances, especially during peak flow events.
- The inherent connectivity of hillslopes, headwaters and larger downstream waterways.
- The lack of provisions to protect small, non-fish-bearing, ephemeral and intermittent streams during harvesting, and lack of water quality protection provisions for operations in landslide-prone areas.

Key findings are:

- A large body of evidence links forest management activities to increases in sediment production. Most of this evidence comes from research conducted in smaller first- and second-order watersheds, mainly to avoid the confounding effects of other land uses.
- Most available evidence suggests that forest roads, skid trails, log landings and slash burning are more likely to increase sediment mobilization than timber harvesting itself. However, considerable knowledge gaps remain regarding the sources of increased sediment loads in streams in specific cases (e.g., roads, general harvest areas or sources within the stream channel). Soil tracers and sediment "fingerprinting" show promise as research tools to provide insight on the specific sources of sediment associated with forest management.
- In steep terrain, landslides and debris flows have been identified as the primary sources of sediment inputs into streams and have been consistently shown to significantly increase in response to forest harvesting and forest roads in such terrain.

It is generally accepted that modern best management practices — primarily improvements in road location, construction and use, and riparian management areas with buffers strips of forest vegetation along larger streams — have substantially reduced external sources of sediment into streams resulting from active forest management. However, forestry activities have occurred on a significant scale in Oregon for well over a century, mostly without modern BMPs, leaving a legacy of old forest roads in many watersheds and unknown but potentially significant amounts of historic "legacy" sediment stored in Oregon waterways.

- Oregon forest practices for activities in landslide-prone terrain and for protection of smaller, non-fish-bearing streams have not evolved to the same degree as for activities in other areas; scientific evidence regarding forest management effects on sediment and water quality must be interpreted in this context.
- There is growing recognition of the role and importance of forest harvesting effects on hydrologic regimes as drivers of sediment movement (e.g., the potential for increases in water yields and peak flows after harvesting to remobilize sediment stored in a stream, increasing suspended sediment and turbidity even in the absence of increased sediment inputs from sources external to the stream).
- Variability in research findings across different studies regarding sediment production from active forest management may be explained in some cases or to some degree by differences in geology (soil and rock type) and geomorphology (e.g., slope) and how these factors affect erodibility of sediments.
- The limited evidence available regarding larger, catchment-scale effects of forest operations and roads indicates that suspended sediment increases in the downstream direction as the size of the waterway increases.

In summary, the potential for forest operations to affect sediment mobilization and movement through drinking water source watersheds is higher for:

- Operations in steep, landslide-prone terrain.
- Areas with relatively more erodible soil and rock types.
- Areas with a significant areal extent of unbuffered small streams.
- Where previous operations have left significant amounts of bare mineral soil or sediment stored in streams.

Linkages between forest management and sediment production will increasingly be complicated (and potentially exacerbated) by predicted shifts in weather patterns associated with anthropogenic climate change, including increases in storm frequency and intensity, and in the proportion of winter precipitation falling as rainfall versus snowfall.

10.6. Findings and recommendations on forest chemicals

Chemicals play an integral role in the management of Oregon's forests. Based on an analysis of Oregon Department of Forestry FERNS data, there are over 7,400 activities that involve chemical applications on potentially 1 million acres of Oregon forest land annually, with the vast majority of these being herbicide applications to harvested units. Applications range from herbicide spraying for site preparation prior to replanting, and competing vegetation control afterwards, animal and rodent repellants to protect seedlings, fertilization to increase growth rates after thinning, and for maintenance of rights-of-way for both travel and utility corridors. With the exception of rights-of-way, a defining characteristic of these chemical applications is that they occur infrequently over the 30- to 80-year typical harvest cycle (Figure 6-1). And while the public perceives chemical use in forests as significant, pesticides applied to forest land represent only about from 2.8% (2007) to 4.2% (2008) of those used statewide, according to data reported through the Oregon Pesticide Use Reporting System that was defunded in 2009. Accordingly, it's relevant that only 3.5% of pesticide-related incidents from the more recent Oregon Department of Agriculture data involve forestry use of pesticides, and that about half of these are requests for staff to observe applications.

In comparison to other sectors of Oregon's economy that use pesticides, those typically applied in forestry are less toxic to humans, move fairly rapidly through soil and water, and don't accumulate. Most of these are herbicides that are not strongly absorbed (attached) to soil particles, are water soluble, have low volatility (i.e., evaporation and resuspension), and decay rapidly in both water and soil. This means that these herbicides don't tend to build up in the soil or bioaccumulate.

Contemporary best management practices, with a couple of additions, have the potential to protect areas off-site from the pesticide application if followed. Extensive research (and accompanying models) have allowed a better understanding of the importance of droplet size distributions on reducing pesticide drift, as has the development of adjuvants specifically tailored to mitigate drift. Helicopters have precise GPS and nozzle flow data loggers that accurately position the ship both in space and chemical delivery; some models can be preprogrammed to include flight plans that automatically buffer streams and sensitive areas. There is also substantial research from the agriculture community, and one paper reported here from forestry, on the value of wooded buffers to prevent drift into streams. Additions to the Forest Practice Act rules recently proposed through an industry-environmental collaborative process would extend buffers along non-fish streams, but if these were forested they would more effectively reduce spray drift into streams.

The evidence we examined demonstrates that while pesticides are commonly detected in surface waters, in almost all cases they are found in concentrations below levels that can be accurately measured. When quantifiable detections are found, as we've seen from the forestry use studies, they tend to be transient and most likely to occur either during application or in early season storms. In particular, unless live water is directly sprayed (a label violation for herbicides used in forest silviculture), most herbicide runoff occurs during the first winter storms. In one report, this constituted 70% to 90% of the pesticide loadings, a finding that was confirmed by two other studies.

A caveat here, again, is that the impact of forest chemicals on downstream raw source water supplies will depend on the size of the contributing watershed, the proportion annually subject to chemical applications, and other land uses in the basin. There are substantial knowledge gaps regarding the exact timing, locations, areas, amounts and formulations of forestry pesticides applied and also the effectiveness of BMPs for their use. These knowledge gaps can be at least partially addressed via more rigorous monitoring and reporting. If chemicals are to continue to be an acceptable tool in forest management from a public perspective, there is the need for investments in understanding their fates at the watershed/catchment scale. Also, most studies on the effects of silvicultural chemicals to investigate their safety prior to being authorized for public sale and use were conducted on the active ingredient only. In actual use, these chemicals are just about always mixed with other active ingredients and/or adjuvants. The effects of these "tank mixes" are often unknown.

Recommendations related to forest chemicals:

Pesticide use data needs to be reported. It is difficult for the stakeholders and the affected public to understand the impacts, positive and negative, of forest chemicals without good reporting data. This is part of a larger concern over pesticide use relating to air and water quality in Oregon. Data on pesticide and chemical use is not routinely reported, even at the aggregate level. While ODF FERNS provides information on where and possibly when forest chemicals will be used, it allows multiple chemicals to be listed over long periods of time, with no subsequent reporting on what was actually applied unless a complaint was filed. In 1999 the Oregon Legislature created the Pesticide Use

Reporting System (PURS), but it was never adequately funded and implemented. When its sunset provision was proposed for renewal during the 2019 Legislative Session in HB2980, there was broad support from across the political spectrum (Oregonians for Food and Shelter to the Farmworkers Union) for PURS to be extended and funded. This bill died in the Ways and Means Committee as the Legislature adjourned. A bill, HB4168, more specific to forestry was also introduced. HB4168 implements the aerial application procedures and reporting requirements identified in the Memorandum of Understanding for the "Oregon Strategy" drafted by the timber industry and the conservation community. This bill, too, died prior to passage in the House with adjournment; however, it was subsequently revived as SB 1602 and passed during the First Special Session in June, 2020. Nonetheless, this law does not require disclosure to the public about the amount and location of pesticides applied in forest management. The Board of Forestry and ODF could by administrative rule change its notification system to require reporting and disclosure of chemicals used in management operations.

Current water quality sampling efforts are insufficient. A corollary to the lack of pesticide use information is the relative sparseness of data on potential pesticide loadings in surface waters, particularly at the raw water intakes for public water supplies. Most current sampling at raw water intakes is not correlated with times of likely chemical pulses — i.e., the early winter storms. Moreover, it's clear from the silvicultural herbicide applications studies reviewed that detections and concentrations in receiving waters are highly variable even within a storm event. There is a similar constraint in the grab samples and automatic samplers that are commonly used: they provide detection and concentration information at point(s) of time, but not loads (i.e., the total mass of the substance transported in water over a given period of time) since stream discharge is usually not measured during the sampling. Sampling and analysis techniques developed and applied by the USGS, such as the polar organic chemical integrative sampler and the semipermeable membrane device, have the capability to accurately integrate pesticide concentrations over longer time periods and, in conjunction with streamflow, the ability to estimate loads. These devices could be particularly beneficial at raw water intakes where there is concern over pesticide loadings and the quantity of water flowing into the intake is known.

Study designs need improvement. The majority of studies focused on assessing the impact of pesticides on water quality can be loosely characterized as "reconnaissance" or "case studies" because of their study design and limited replicability. Most of the pesticide/herbicide peer-reviewed studies in the Pacific Northwest and other areas of the U.S. were conducted by industry or industry-supported organizations (such as the National Council for Air and Stream Improvement) and tend to be short-term and locally focused. They have the advantage of knowing exactly when and what was applied, have more site-specific sampling, but are limited because the applicators know that they are being studied, which may affect their behavior. In contrast, the Pesticide Stewardship Partnerships and USGS studies sampled over a longer period, but the PSP studies didn't have exact amounts and timing of application, and may have missed storm events. Meanwhile, the USGS studies used a sampling method that integrated pesticide concentrations over time but was still limited because of unknown application amounts and timing. Improved study designs would incorporate random, applicator- and landowner-blind sampling of pesticide applications. This approach is critical for developing replicable and reliable scientific results.

Pesticide fate modeling is a critical need. Inference based on downstream measurements includes complex interactions between pesticide and environment, as well as assumptions on their spatial and temporal distribution, which still require significant research. A useful tool to answer many management questions is modeling. Complex hydrological models, such as the Soil and Water Assessment Tool, could assist practitioners and regulators to understand the fate of silvicultural forest chemicals. The assessment tool has been used for over 50 pesticide fate studies worldwide for agricultural practices, but not for pesticide fates in forest applications. While such process-based models have their limitations, they can provide a structured approach to evaluating herbicide movements at the watershed scale.

Pesticide Stewardship Partnerships. The partnerships are good outreach tools but don't produce replicable science. The partnerships don't collect pesticide application data and locations within their partnership boundaries and their sampling regimes aren't designed and implemented to catch episodic events (application, early winter storms) generally recognized to be when the highest concentrations are likely to be found. Additionally, the lack of streamflow data in these studies limits their ability to evaluate "loads" versus point concentrations. The benefits of partnerships involving landowners, applicators, and agency personnel could be enhanced by better knowledge of pesticides applied, their timing, and better monitoring procedures as outlined above.

OSU research cooperatives provide a framework to support future studies. Creating credible science in an arena as complex as forest chemical use requires long-term and intensive studies across the ownership landscape. One model to achieve this is the research cooperatives in the College of Forestry at Oregon State University. Since 1982 there has been an industry-agency-university cooperative studying forest revegetation that has a substantial record of accomplishments over its almost 40-year history, presently called the Vegetation Management Research Cooperative (http://vmrc.forestry.oregonstate.edu/). The research cooperative has the partners and can bring the expertise needed to successfully conduct the type of herbicide transport and fate studies and modeling described here.

Wooded buffers prevent or reduce spray drift. Directly spraying into live water is a label violation for most herbicides used in forest management. However, some small streams can be hard to detect and therefore may be inadvertently sprayed during aerial applications, resulting in herbicide detections downstream. Both pesticide fate studies from coastal Oregon demonstrated that nonbuffered, small non-fish streams received spray during application. In contrast, another study demonstrated the efficacy of wooded buffers in capturing or deflecting fine spray drift. This finding is consistent with a number of studies on agricultural spray drift. The extension of wooded buffers to small non-fish (Type N) streams under the Forest Practice Act and its rules would protect these streams from drift, and reduce potential loadings downstream. Extension of spray exclusion zones along Type N streams is one of the proposals in the "Oregon Strategy" of state, timber industry and conservation groups (Governor's Office 2020). It is clear from the science that the effectiveness of these no-spray buffers would be improved if they were wooded.

10.7. Natural organic matter and disinfection byproducts findings and recommendations

The relationship between natural organic matter and disinfection byproducts is important because two disinfection byproducts — total haloacetic acids (HAA5) and total trihalomethanes (TTHM) — are regulated by the EPA under the Safe Drinking Water Act. These disinfection byproducts are created when carbon in water comes into contact with the chlorine disinfectant that is required to remain as residual throughout a water utility's distribution system until the water comes out the tap. The carbon can be from natural sources, can result from human activities, may be added during water treatment and may be formed through the disinfection process in the treatment plant.

The two regulated disinfection byproducts — total haloacetic acids and total trihalomethanes — are respectively the fourth- and fifth-most frequent contaminant alerts and exceedances in the Oregon Health Authority's database. Disinfection byproduct detections in finished drinking water show that in most cases the utility relies on surface water as its primary source, and these samples are often taken at the end of long pipe runs. Most detections are isolated events, but a subset of water utilities (17%) have clusters of detections with absences in intervening years, while a smaller set (5%) have chronic, annual detections of disinfection byproducts in their water systems. Most exceedances are within 150% of the maximum contaminant level.

Today, natural organic matter is the raw water constituent that most often influences the design, operation and performance of water treatment systems. In addition to its role in the formation of disinfection byproducts, natural organic matter can overwhelm activated carbon beds used in water treatment and reduce their ability to remove organic micropollutants. Natural organic matter also contributes significantly to the fouling of membranes in all membrane technologies used in water treatment, and can promote microbial fouling and regrowth in water distribution systems.

Operationally, natural organic matter is separated in two components: dissolved organic matter and particulate organic matter. A significant amount of fresh water dissolved organic matter is derived from terrestrial soil organic matter that underwent specific transformations that increased its affinity for an aqueous environment. The composition of fresh water dissolved organic matter is believed to depend on the transformation of plant and decomposed animal compounds into humic-like substances. Freshwater dissolved organic matter is an aggregation of spontaneous self-associated superstructures formed by plant-derived products of natural decay, such as lipids, amino sugars, sugars, terpene derivatives, aromatic condensed structures and lignin-derived compounds.

Concentrations of constituents increase as a function of stream discharge, with their export being dominated by short-lived, wintertime high-discharge events. Low flows contain primarily organic detritus from nonvegetation sources (e.g., algal cells) while particles with vegetation and soil-derived particulate organic matter dominated the high flows.

- Modeling indicates that many decades after harvesting, the metabolism of dissolved organic matter is still being affected. This is because carbon and nitrogen losses from the terrestrial system to waterways and the atmosphere increase due to reduced plant nitrogen uptake, increased soil organic matter decomposition, and high soil moisture.
- During and after harvesting, if slash is removed or burned, dissolved organic carbon and dissolved organic matter are reduced due to the diminished amount of coarse woody debris remaining.
- Evidence for the Pacific Northwest area indicates that the main export of natural organic matter and disinfection byproducts is triggered by the first major rain event occurring in the fall.
- Wildfires are increasing in frequency and severity in the United States, which is likely altering the chemistry and quantity of natural organic matter and disinfection byproducts traveling outside forested watersheds. Wildfires consume a large portion of organic matter from the detritus layer, which leads to lower yields of water extractable organic carbon and organic nitrogen. Therefore, wildfires

appear to trigger an overall reduction in water extractable terrestrial disinfection byproducts precursor yield from detritus.

- The last 15 years of bark beetle infestation had a significant impact on water quality as a result of increased organic carbon release and hydrologic shifts induced by the tree dieback. Water quality is impacted nearly one decade after bark beetle infestation, but significant increases in total organic carbon mobilization and disinfection byproducts precursors are limited to areas that experience massive tree mortality.

10.8. Fire risk findings and recommendations

The cause of recent wildfire catastrophes can be traced to multiple factors, including the expanding urban footprint, human ignitions, droughts and high-wind events. Wildfires remove litter, duff and vegetative cover leading to the creation or enhancement of hydrophobic soil layers, increasing surface runoff and erosion potential. Postfire changes in water chemistry and sediment transport can increase pollutant loads.

Growing awareness of the expanding scale of wildfire risk to communities and watersheds and water supplies in the U.S. has led to a wide range of research focused on fuel treatments to reduce postfire impacts to watersheds and drinking water. Researchers are using wildfire simulation models to test hypothetical treatment scenarios and estimate the potential reduction in risk, identified by metrics that quantify adverse impacts, including soil erosion and change in water yield.

Existing risk assessment technologies and frameworks do not explicitly examine the cross-boundary problem intrinsic to wildfire risk from large public wildlands. Wildfire risk concerns the estimation of expected loss, calculated as the product of the likelihood of a fire at a given intensity and the consequence(s). By contrast, wildfire exposure concerns the juxtaposition of threatened values in relation to predicted fire occurrence and intensity, without estimating potential loss. Methods used to assess wildfire exposure and transmission were summarized; then a detailed assessment of cross-boundary wildfire exposure in Oregon between major land tenures (private, public, state and federal) and drinking water source areas was provided. These latter results for each community water supply will be included in an accompanying online atlas.

Predicted area burned in 100 years was highest for public water supply areas in the eastern Cascades, southwest Oregon and eastern Oregon regions. Mean fire size, total annual area burned and the number of simulated fires that exposed public water supply areas also varied substantially across the regions, with the largest fires and the highest area burned occurring in southwestern Oregon. There was high variability among the major land tenures and their contribution to wildfire exposure within and among public water supply areas regions (Figure 8-11). The U.S. Forest Service was the leading contributor to area burned in all but the Coastal region, where private industrial lands were the largest contributor.

Firesheds represent the biophysical risk in and around public water supply areas and the sources of risk in terms of land ownership. A fireshed also represents the area surrounding each public water supply area that can ignite and transmit large wildfires that expose the public water supply area to risk. Fireshed boundaries are often magnitudes larger than the administrative boundary of the public water supply areas and can represent a mosaic of land tenures.

The juxtaposition of fire-prone forests in and around critical municipal watersheds intermixed with a high number of homes and infrastructure, and in close proximity to dense urban areas under a changing climate, creates a complex fuel management problem. Forest management has the potential to reduce fuels and restore ecological resiliency; however, the scale of the risk will require a coordinated, multiagency, multilandowner collaborative response. This will require coordinated and targeted fuel management and forest restoration activities that minimize the risk of fire exposure to public water supply areas, maximize landscape resilience to wildfire and allow for beneficial wildfire management.

Translating the findings in this report to prioritize fuel management activities is straightforward. Maps of fire transmission to public water supply areas can be used as priorities in scenario planning models to design and sequence project areas and treatment units within them. Including potential treatment costs and revenues associated with harvesting and fuels treatments into planning makes it possible to examine economic costs and benefits associated with forest management to protect water. The fireshed maps are also useful for identifying the scale of risk to public water supply areas and determining the relative contribution of risk from different landowners. Newer initiatives like shared stewardship recognize that the increasing scale of risk requires cross-boundary prioritization and action to treat at the appropriate scale. Assessments of cross-boundary risk can be integrated into this process and used as a management objective to target forest management where wildfires are predicted to spread across federal and state boundaries and expose drinking water sources or other highly valued resources.

10.9. Findings and recommendations from the community water systems case studies

We conducted three case studies to delve deeper into how managers of forested drinking water supply watersheds identify and address management concerns that have affected or could affect source water. This includes how they collaborate with other landowners and managers to identify, monitor and respond to these concerns. Water provider survey respondents were stratified by location (Coast, Dryside or Valley), primary landownerships in source watersheds and the size of systems. We then purposively chose three case studies, one from each geographic region. Cases were also selected to represent a range of relevant contexts and issues: 1) a public lands context with a proximate wildland-urban interface and extensive collaboration on source watershed management (Ashland); 2) a public lands context with less proximity, collaboration and public engagement (Baker City); and 3) a private industrial forestland context and a small system (Oceanside). Key takeaways from these studies are presented below.

From the Ashland case study:

- A multipartner effort like the Ashland Forest Restoration project is necessary to incorporate the diverse social, economic and ecological desires that the community of Ashland holds for the management of its watershed. This is particularly essential in the public lands ownership context, where the Forest Service must consider diverse public values in its decisions. Development of scientifically sound monitoring and robust community plans helps address questions and foster adaptation.
- Activities necessary to reduce hazardous fuels and wildfire risk can be costly in areas with steep slopes and complex forest types. The Ashland Forest Restoration project's strengths and ability to seek multiple authorities and programs to accomplish this work within and adjacent to the watershed expands outcomes beyond what the Forest Service alone could fund or accomplish.

- The City of Ashland has been proactive in articulating its interest in the watershed and using formalized structures and tools (memos of understanding, community alternative, Master Stewardship Agreement, ratepayer fee) to participate in active forest management. Its investment in forestry staff and the fire department provides the human capacity necessary to be part of collaborative efforts.

From the Baker City case study:

- Regular, such as quarterly, communication between the Forest Service and a municipality with source watersheds on national forest land assists in maintenance of relationships and proactive capacity for identifying issues and opportunities. Field tours and opportunities to view the watershed and potential management issues together in person help increase mutual understanding of conditions, challenges and opportunities. This helps keep drinking water source protection issues on the table when both partners are also busy with other responsibilities and projects.
- There can be city and community frustration with the time and other requirements of the NEPA process for management actions on federal land. Increased experience and exposure can help build mutual understanding through the process. Written documentation of agreements and meetings can assist in the creation of agreements and institutional memory, which is important in a context with the frequent personnel turnover that can occur in both the Forest Service and city management.
- Municipalities and other partners may aid federal partners in managing source watersheds by building political support and obtaining grant funding from sources not accessible to federal agencies.

From the Oceanside case study:

- More consistent and proactive communication between the water district and private industrial timberland owners has enhanced cooperation. Communication has historically been intermittent as it has been solely based around issues with quarry operations or planned forest operations. Opportunities to learn more about each other's goals and processes may have increased mutual understanding. Foresters have toured the Oceanside treatment plant, and water district commissioners and the watermaster have toured proposed forest operations.
- One industrial timberland owner's use of a process communication checklist is intended to help ensure that the water district and other water providers are notified beyond what is required by Oregon's Forest Practices Act.
- In small rural landscapes with a limited number of landowners, individuals particularly matter. The interests and actions of the water district staff and board and company foresters have made cooperation possible.

Although the case studies were conducted in three different contexts, there were common lessons learned from each case as well as common themes across cases that may offer broader insights.

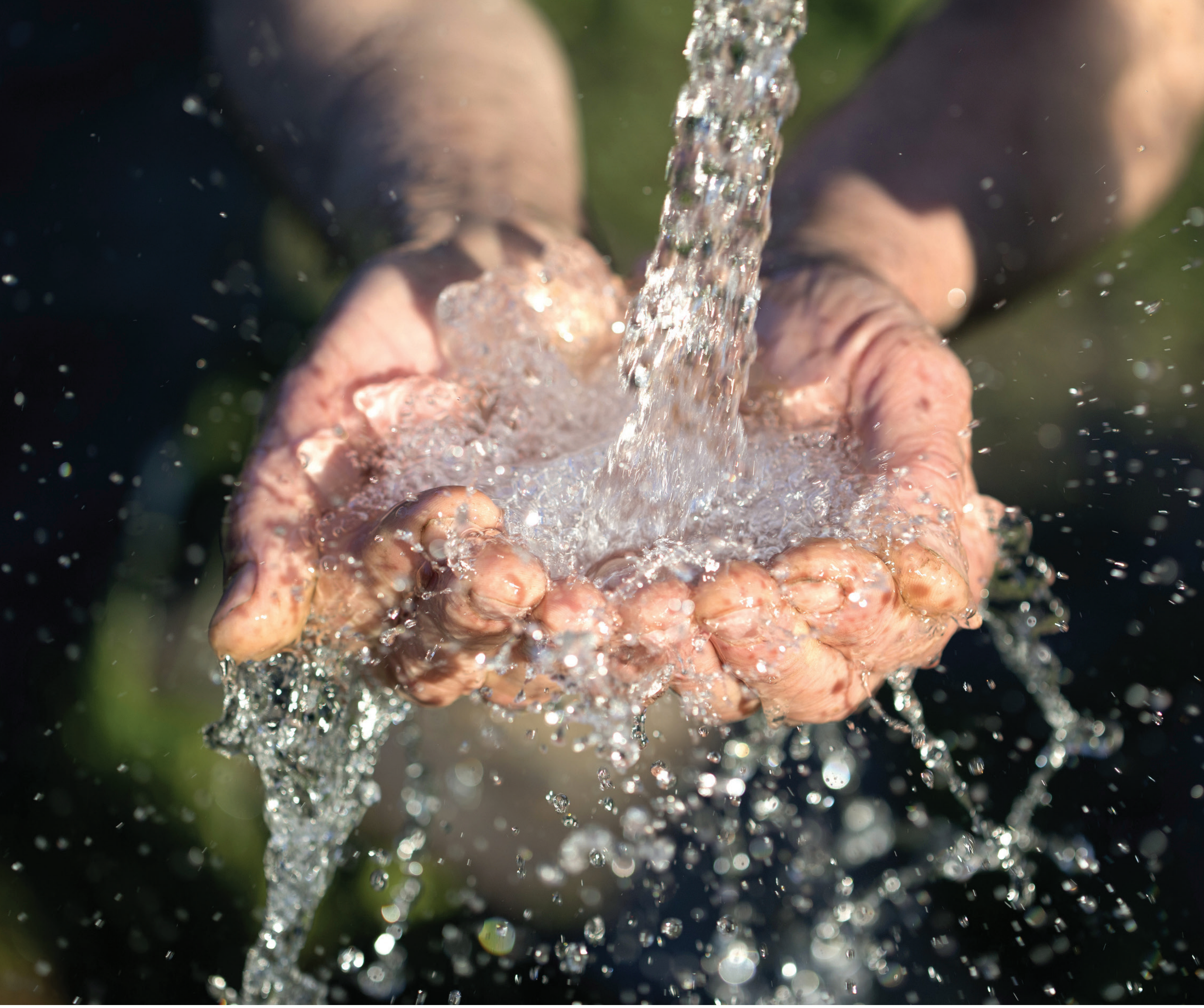
Landownership frames the opportunities and challenges for managing source watersheds. The laws and regulations that govern different types of forestland ownerships set the stage for what management activities are permitted, how they are to be conducted and any public involvement. For example, Oregon's Forest Practices Act provides standards for the establishment, management, and/or harvest of trees on private industrial and nonindustrial forest lands. Public lands managed by federal agencies such as the U.S. Forest Service or the Bureau of Land Management are subject to an array of laws and policies, as well as land use designations and requirements for public participation in management decisions. Drinking water providers who seek to interact and collaborate with their source forestland managers must do so with understanding of these existing frameworks, and the time and effort that it may take to engage.

Regular communication provides a foundation for relationships. Regular communication between drinking water providers and source watershed land managers may assist the maintenance of relationships and proactive capacity for identifying issues and opportunities. This helps keep drinking water source protection issues on the table when both partners are also busy with other responsibilities and projects. Field tours and opportunities to view the watershed and potential management issues together in person may help increase mutual understanding of conditions, challenges and opportunities. The scope and scale of this communication may necessarily vary by context. For example, it may be more informal and involve far fewer parties in areas where source watersheds are spatially small and systems serve smaller populations. Regardless, the need for both land managers and drinking water providers to be intentional and proactive about communication with each other remains. Written documentation of agreements and meetings can assist in the creation of agreements and institutional memory, which is important when there is personnel turnover with any organization.

Specific projects offer opportunities to collaborate. Planning forest management activities, a source water protection plan, or a monitoring effort can offer concrete ways for drinking water providers to engage with their watershed's land managers. Depending on the ownership of the source watershed, providers may be able to provide project design input, develop community plans, or create monitoring protocols. This may involve additional partners such as local nonprofits, government agencies and community leadership. The opportunity to participate directly may improve understanding of source watershed conditions and needs, particularly though monitoring that could address uncertainties with scientific information. It can also bring leveraged funds from other sources that help support monitoring or management activities.

10.10. Final thoughts

The body of work here, and that found in the supporting chapters, represents a substantial contribution towards understanding the effects of active forest management on drinking water source quality. The project's steering committee provided important perspectives and clarified priorities during our formative stage. The committee also provided substantive reviews and comments as we crafted this report. Throughout, we have made every effort to be careful and critical in our reviews. We do not realistically expect that this report will resolve the many debates over forest management. However, we do hope that it will provide a common reference on current science and the policy context. If that is the case, then we will be satisfied.



Tracing the roots of the watershed

FORESTS PRODUCE ECONOMIC BENEFITS such as timber, forest products and jobs. They also provide wildlife habitat, recreation, carbon storage and clean water. In fact, most of Oregon's drinking water is sourced from our forests. But logging, forest road building, using herbicides and other activities related to growing and harvesting timber can impact the quality and quantity of water. Oregon State University scientists examine these links in this comprehensive look at watershed health.

Oregon State University Extension Service

Oregon Forest Resources Institute

ISBN-13: 978-0-578-95066-2