PROTECTING FOREST WATER QUALITY: PROGRESS AND MANAGEMENT IMPLICATIONS[1]

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Abstract: The effectiveness of Best Management Practices and forest practice rules in protecting water quality has been extensively researched. However, some people have a distorted image of forest management impacts on water quality because of a focus on historic practices and immediate responses. The Watersheds Research Cooperative addresses the impacts of ***contemporary*** forest management and has produced both expected findings and some surprises. Key management implications arising from these finding include:

- ***Oregon's Forest Practice rules and contemporary forest management practices are effective, reducing water quality impact to small changes;***
- ***these small water quality changes recover rapidly downstream and over time;***
- ***water quality criteria used to assess forest stream conditions can be unattainable and in some cases unproductive;***
- ***technology allows measurements of small changes that may be statistically but not ecologically significant; and***
- ***there is a law of diminishing returns for forest practice rules.***

INTRODUCTION

Forty years ago I came to study at Oregon State University, intrigued by research at the original Alsea Watershed Study testing practical solutions to reduce water quality impacts from timber management (Krygier and Hall 1971). Over my career I conducted, supported, and monitored research advancing forest management practices designed to protect water quality. I also studied how water quality varies in forest settings as a result of natural disturbances, weather, geology, vegetation, and other factors. The Watersheds Research Cooperative (WRC) (http://watershedsresearch.org/), with research at Hinkle Creek, the Alsea Watershed Study Revisited, and Trask Watershed, is contributing to our understanding of forest watersheds and the effectiveness of Oregon's Forest Practices Act (FPA) rules.

Partly from design and partly from serendipity, the three WRC studies address hydrology, water quality, and aquatic responses with different but complementary replication approaches. The first, Hinkle Creek, was designed to assess the effectiveness of Oregon's current FPA rules. It provides replication of managed and control watersheds for two reach types of concern: fish-bearing and non-fish-bearing streams. The study design also allows assessment of impacts at different watershed scales, from onsite impacts to downstream effects. The Alsea Watershed Study Revisited does not have the same replication of watersheds but instead replicates in time, directly comparing impacts of contemporary management with impacts that resulted from practices of the 1960s in the same watershed. The Trask Watershed looks at alternative riparian practices with replication of individual treatments along non-fish-bearing reaches, and also

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assesses how these impacts translate downstream. The conditions represented by these three watersheds reflect an important cross section of managed forests in Oregon.

WATER QUALITY FINDINGS

Forest Watershed Research

There are literally hundreds of forest research studies across the United States that have contributed to our understanding of forest water quality responses to forest management (Ice and Stednick 2004; NCASI 2012). The Alsea Watershed Study near Toledo OR was the first paired watershed study in the US to look at hydrology, water quality, fish, and fish habitat responses to alternative forest management practices simultaneously (Stednick 2008). The H.J. Andrews Experimental Forest has hosted key forest watershed research (Fredricksen et al. 1975), and both Oregon State University and the Oregon Department of Forestry have conducted important, sometimes groundbreaking, forest water quality research (e.g., Robison et al. 1999). However, no paired watershed study of contemporary forest practices had been conducted in Oregon since the Alsea Watershed Study was completed in 1973.

Distorted Perspective

Despite (or perhaps because of) this rich history of research, some people have a distorted view of how contemporary forest management affects water quality. Because no paired watershed research had been conducted in Oregon since the original Alsea Watershed Study, many believe the impacts observed then are inevitable consequences of forest management. This ignores the fact that the Oregon FPA was passed in large part to correct poor practices, and further changes have been made since the first rule package as new science has emerged. Forest practices in Oregon today are fundamentally different than they were in the 1960s. Key changes include recognition and protection of stream channels and riparian corridors, reduced soil disturbance during yarding and site preparation, and improved road construction and maintenance. Disconnecting of roads from streams is symbolic of this evolution in management practices.

Research showed that road segments draining directly to streams (direct delivery) can be an important source of suspended sediment (Bilby et al. 1989; Ketcheson and Megahan 1996; Furniss et al. 2000; Mills et al. 2007). Some early surveys found as much as 75% of the road network draining directly to streams. The forest community has been actively relocating and disconnecting legacy roads and constructing new roads to avoid these conditions. Martin (2009) reported on a survey of private forest roads covering more than 1000 miles of roads in eastern and western Washington. He found that 73% of the road network had low delivery potential (located on ridgelines, in shallow terrain, or without crossing defined channels). About half of the road system with high delivery potential was disconnected. Based on that survey, only about 12% of the road network was hydrologically connected with the stream. Mills et al. (2007) in Oregon and Dubé et al (2010) in Washington documented similar reductions in the length of the road network delivering directly to streams. It will be impossible to remove all direct delivery culverts and ditches, but the forest community is making progress and has other practices, such as special hardening of sensitive road segments, that reduce sediment impacts from roads.

Another distorting factor is a typically limited period of assessment. Almost invariably, forest watershed research is limited to a short period around management activities and does not account for the full management cycle of a forest (Hewlett 1979). This can leave the impression that impacts are perpetual. In addition, watershed scientists commonly use a control watershed that has not experienced recent disturbance to help assess the magnitude of any management impacts and account for weather patterns.[3] The choice of control watersheds without any recent disturbance tends to skew our perspective, because we know fire, insect outbreaks, windstorms, and other natural disturbances constantly shape forested watersheds (Ice and Schoenholtz 2002). Ironically, the United States Geological Survey's National Water Quality Assessment Program often chooses forested watersheds to serve as "least impaired" controls, yet these are sometime the same watersheds forest scientists are studying as "impacted."

Current Forest Practices Act rules effective

Compared to water quality impacts measured in benchmark studies at the Alsea Watersheds in coastal Oregon and H.J. Andrews Experimental Forest in the Oregon Cascades, impacts following the WRC harvests are small (Beschta and Jackson 2008; http://watershedsresearch.org/assets/reports/WRC_Skaugset_Hinkle%20Sediment_2013_S3.pdf). In the first benchmark studies suspended sediment loads increased 100 to 400% over expected values based on the paired watershed response. In the original Alsea Watershed Study the two treatment watersheds appear to have experienced increases in suspended sediment losses for different reasons: one as a result of severe channel disturbance and the other due to uncompacted sidecast road failures (landslides). Both issues were addressed in the Oregon FPA rules. Compared to these large impacts, sediment responses in WRC study basins harvested using contemporary practices are generally small. There appears to be no shift in suspended sediment concentrations for the treated watershed in the Alsea Watershed Study Revisited. Hinkle Creek increases in suspended sediment were in the range of 20 to 40%. Most of the increase is believed to have resulted from increased stream power due to elevated discharge, as no overt sediment delivery was observed. This is consistent with findings from other forest watershed studies across the US (NCASI 2012). In the Alto Watershed Project in Texas, sediment losses for contemporary forest practices with BMPs were 80 to 90% less than historic levels and were within the range of natural disturbance events (McBroom et al. 2008).

This story is repeated for stream temperature changes. Increases in temperature for harvests near fish-bearing streams were small compared to impacts we would have expected without FPA rules. In the Alsea Watershed Study Revisited we can look at water quality responses in the same watershed to compare effects with and without the Oregon FPA rules (Ice et al. 2011; http://watershedsresearch.org/assets/reports/WRC_Light_Alsea%20stream%20temps_2013_S2.pdf). The maximum temperature increase was about 1°F (7 day moving average of maximum daily water temperature) compared to as much as 18 to 25°F increases observed in the original study. There was also little temperature response in the harvests near fish-bearing reaches of Hinkle Creek.

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[3] This requires stationarity; the development of a predictable relationship between the control and treated watersheds. Some have criticized the control watersheds used, arguing that human impacts are commonly found on these "least impaired" watersheds. However, for water quality and hydrology some forest hydrologists and statisticians have pointed out that if there are residual "impacts" to a control watershed and it continues to recover, then the "impacts" measured on the treated watershed will be overestimated (Hewlett et al. 1969; Thomas 1990).

There were also some surprises. The consensus among forest hydrologists was that harvests along non-fish-bearing reaches in Hinkle Creek would produce large stream temperature increases, perhaps approaching those observed in the original Alsea Watershed Study. FPA rules do not require shade retention along these types of streams. Instead, water temperature responses were small and variable (Kibler 2007). In some cases streamwater temperatures actually *decreased* following logging. The small responses were a result of shade produced by low-hanging shrubs and slash in the riparian area. The decrease in water temperature was probably a result of increased streamflow from reduced evapotranspiration following harvesting. The headwater reach in the treatment watershed in the Alsea Watershed Study Revisited also showed little change in temperature, as waters remained very cold.

Recovery

Another finding was the rapid recovery of observed water quality changes. Changes in water quality resulting from forest management can diminish rapidly downstream and over time. All water parameters are non-conservative, meaning that they do not transport downstream without reductions. Suspended sediment particles can be trapped in long-term storage or dissolve. Watershed scientists use the term "delivery ratio" to reflect the change in sediment amount delivered downslope or downstream from an erosion site. Delivery ratios are always less than one, often reflecting a large reduction in sediment delivered. Forest streams often have features, such as deep gravel deposits, that allow for mixing and muting of temperature increases. Water temperature is constantly interacting with its environment to gain or lose heat. The Hinkle Creek study showed that temperature increases were not propagating far downstream. Nutrients may be taken up by aquatic or riparian plants. Forests also recover over time and provide the cover and forest floor conditions that provide high quality water resources. Even for severe disturbances such as the original Alsea Watershed Study, temperatures recovered to within the range of values observed in the 1959-1965 pre-treatment period (Hale 2007).

Unattainable Water Quality Criteria and Standards

One surprising finding was the consistent drop in dissolved oxygen (DO) concentrations observed in Needle Branch (Alsea Watershed Study) during the pre-treatment period (http://watershedsresearch.org/assets/reports/WRC_Ice_Dissolved%20Oxygen_2013_S2.pdf). This natural phenomenon appears to be a result of low summer and fall streamflows experienced in Needle Branch, which create reaches that go subsurface. Other researchers have found that low DO concentrations in streams can be used to identify "gaining" reaches with groundwater inputs (Werner et al. 2007). Low DO concentrations are normally associated with high stream temperatures and organic loads. Here we have a watershed without human disturbance for four decades, yielding cold water temperatures that consistently experiences low DO concentrations and violates Oregon's water quality criteria. Perhaps we should not have been too surprised with this, as we found that small headwater forest watersheds sometimes cannot meet state water quality criteria or standards. The control watershed in the Alsea Watershed Study, Flynn Creek, has one of the highest nitrate-N concentrations found in the Oregon Coast Range, even though it has not been managed since wildfires in the 1800s and it is a USDA Forest Service Research Natural Area. It also experiences high stream temperatures, approaching the state water quality criteria (Hale 2007), and has failed proposed macroinvertebrate indicators for sediment impairment (http://www.deq.state.or.us/wq/assessment/2010Report.htm). Similarly, pre-

treatment monitoring at Hinkle Creek found stream temperatures to be highly variable between adjacent sub-basins, with some streams exceeding state water quality criteria *before harvesting*.

Previous research showed that water quality criteria may not be attainable, even for least-impaired forest watersheds. A survey of nutrient data from small unmanaged forest watersheds in the USDA Forest Service Experimental Forest and Range network found that nutrient criteria proposed by EPA could not be attained for a significant number of sites (NCASI 2001; Ice and Binkley 2003). Additional surveys and investigations found that water quality criteria for unmanaged or least-impaired waterbodies could exceed water quality criteria for important water quality parameters such as sediment and turbidity (Markman 1990), temperature (Ice et al. 2004), and DO (Ice and Sugden 2003). An ongoing court case, *Barnum Timber Company versus EPA*, is addressing this issue as part of state listings of impaired waterbodies.

Technology

Advances in technology and statistical methods make it possible to detect very small changes that would have been undetected in the past. Water temperature used to be measured using bulky, wound thermographs that mechanically charted temperature. These required frequent servicing and downloading of the paper-charted temperature record. Today, a temperature probe costing $100 can record data for an entire summer and be quickly downloaded directly to a computer database. DO concentrations were historically measured using the Winkler titration method and later with polarographic probes. The probes needed constant stirring and frequent changes of the membranes and reactive solution to avoid “drift” in measurement calibration. Today, a luminescent DO probe can be deployed to collect data every 30 minutes for several days without servicing, and data can be quickly downloaded to a database. These advances have increased our ability to collect data in remote locations at numerous sites and over long periods. The scale of changes in water quality that can be detected needs to be compared to natural variations between basins and years, to assess whether changes that are statistically significant are also ecologically significant. For example, we looked at how suspended sediment loads varied for the three Alsea Watersheds during the 1959-1965 pre-treatment period. During this time all three watersheds were described as having old-growth forest stands. For this seven year period (before management activities) the annual suspended sediment loads varied around the median load by -52 to +830% for the control watershed, and minus 43-65% to + 267-560% for the two treated watersheds. The average suspended sediment loads (adjusted for watershed size) between the three watersheds during this period varied by ±45%. By using the paired watershed approach scientists were able to detect the 100 to 400% increases in the original study and we should be able to detect the smaller changes in our contemporary studies, but is it affecting aquatic communities that have developed in this type of variability? Maximum temperatures experienced annually during this same period varied by 1.7 to 2.8°C for the three watersheds and the difference in maximum annual water temperature observed between watersheds was 0.6°C.

Diminishing Returns

There is some debate about whether improvements in water quality protection under the current FPA rules are adequate. Scientists and the public generally agree about the value of FPA rules such as streamside management zones to provide shade, litter, large wood, and streambank stabilization. There is less recognition of the “law of diminishing returns,” where additional

investments in conservation offer diminishing benefits. This is clearly shown in graphs developed to display riparian functions, where benefits for shading, sediment removal, chemical removal, and fine and coarse organic inputs decrease rapidly away from the stream (NCASI 2000), but it is true for all conservation rules. One of the most exciting areas of investigation is optimization schemes. Agricultural research has recently explored methods to optimize investments to achieve water quality objectives, using models such as the Comprehensive Economic and Environmental Optimization Tool (CEEOT) (Osei et al. 2000). These approaches could result in returning the most water quality benefits to the public for a given investment by forest landowners. For example, a study recently tested whether there might be a net environmental benefit to expanding buffer protection on headwater streams with commensurate reductions in the area buffered along larger streams (Dr. Jami Nettles, Weyerhaeuser Company, pers. comm.).

Forest aquatic communities have developed in dynamic systems that vary between watersheds, annually, daily, and in response to disturbance events. Small temperature changes following contemporary timber harvests are often statistically but probably not ecologically significant, and increases diminish rapidly both downstream and over time. Shouldn't regulatory agencies and others consider whether the costs of further reductions in temperature increases might be better invested in other watershed restoration or protection activities such as road restoration or large wood additions?

MANAGEMENT IMPLICATIONS

Based on these findings, management implications include:

Oregon's Forest Practice rules are effective: Suspended sediment responses are reduced by 80 to 90% compared to historic impacts. Similarly, stream temperature increases are reduced to about 1°F or less with current riparian protection compared to increases of 18 to 24°F observed in the original Alsea Watershed Study. We were surprised that small non-fish-bearing streams with adjacent harvesting generally did not experience major stream temperature increases, but this appears to be a result of protection of the stream channel and especially avoiding hot prescribed fires in these areas.

Water quality impacts from forest management diminish downstream and over time: At Hinkle Creek stream temperatures in headwater streams recovered within a few hundred meters. At the Alsea Watershed Study Revisited temperatures had returned to within the pre-harvest range in about 7 to 10 years.

***Water quality criteria used to assess "effectiveness" are often unattainable*:** Most state water quality criteria were developed for large streams or rivers without considering the natural variability inherent to headwaters. During pre-treatment periods for these watershed studies we have found instances where water would not meet state water quality criteria.

Technology allows measurement of small changes in water quality: New instruments allow watershed scientists to detect small water quality changes but these changes may be within the range of natural conditions or may benefit some aquatic community components.

There is a law of diminishing returns for the effectiveness of rules: Small temperature changes following contemporary timber harvests are often statistically but probably not ecologically significant, and increases diminish rapidly both downstream and over time.

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