FOREST HYDROLOGY - KEY LESSONS LEARNED[1]

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Abstract--Nine general lessons learned over the last 75 years are: (1) Forest vegetation creates conditions which make forest watersheds respond differently to storms and floods than nonforested watersheds. Forest practices that recognize and manage for these important watershed conditions will avoid major disruptions to hydrologic processes. (2) Not all the watershed is created equal. Forest practices can be designed to address hydrologically more important locations in a watershed. (3) Forest management can either disrupt or maintain basic hydrologic functions depending on whether appropriate practices are chosen and the skill of their implementation. (4) Both management practices and assessments of forest practice performance will fail if they do not recognize the natural variability of forest watersheds and natural disturbances. (5) Realistic expectations for management impacts must include the limits on our ability to read watersheds and prescribe control practices and the effectiveness of those practices. (6) We continue to improve our measurement capabilities, allowing us to measure ever smaller changes in water quality and discharge. The most important question is whether this is a functional change that affects the uses and health of the stream system. (7) Watershed analysis and watershed management strategies provide opportunities for achieving hydrologic goals that might not be addressed through assessments made only on-site. (8) In watershed analysis, rigid assessments and blanket prescriptions will not work. (9) Ongoing monitoring of forest management performance is needed to document successes or to refine practices and watershed management approaches. Without better information, there will continue to be skepticism about how effectively we are managing forest watersheds.

I WHERE HAVE WE BEEN?

Forest watersheds have long been considered important for supply of high quality water and for providing important habitat for fish. Yet despite this broad understanding of forests and water, major impacts to watersheds have occurred throughout the United States and the Northwest. Large wood was removed, streambed gravels flushed out, and channels straightened as a result of practices like splash dams and log drives to transport logs to mills and stream cleanups to remove perceived fish barriers. Fine sediments have accumulated in many Western streams due to past abusive logging practices (such as jammer logging in erosive granitic soils in Idaho where 30 percent of the harvest area was put into roads) that greatly accelerated erosion. While it may be hard today to imagine these practices, consider that contemporary industrial operations were designed to select rivers with large enough discharge so that industrial waste would be adequately diluted. Just 30 years ago the Willamette River had oxygen levels so low that salmon would not move upstream, and dairy barns were built over streams to allow them to be cleaned easily. The consequence of these past forest management activities is a legacy of large stream impacts which can still be detected today.

II WHY DO FOREST WATERSHEDS OPERATE DIFFERENTLY?

Forest watersheds function differently than urban or agricultural watersheds. The presence of perennial, large vegetation, both alive and dead, is one of the major reasons. Trees and understory vegetation create tremendous surface area for interception and evapotranspiration. Probably more importantly, dead plant material on the soil surface and incorporated in the soil results in rapid infiltration and reduces the potential for surface erosion. Also, the decay of roots and other processes create macropores in the soil, causing subsurface delivery of water to channels. We can also say that current forest management impacts are generally much "lighter" than for other land-uses, causing less hydrologic modification to watersheds. For example, urban watersheds are extensively plumbed with large proportions of impermeable surfaces and extensive networks of stormwater drains. This causes increases in both amount and rate of runoff.

These differences in how watersheds function can be seen in how hydrology is taught to engineers and forest hydrologists. Engineers learn the infiltration method of computing net storm precipitation to predict stream runoff (1). That is, runoff is the excess of precipitation over the infiltration rate for the soil. But forest hydrologists learn that most forest soils have infiltration rates that exceed anticipated storm intensities; yet obviously stream runoff does occur in forests. Instead of using "net storm precipitation" to explain forest stream runoff, it is explained by return flow, and the variable source area concept. Water that infiltrates into forest soils is carried downslope in macropores and can return to the surface as streamflow. Watersheds do not have uniform soil and geomorphic characteristics. Shallow-depth sites and channel depressions, where upslope waters concentrate, provide areas of surface flow. As storm events increase in intensity or duration the source area contributing to surface flow and the actual size of the stream network within the watershed increases. This expansion and contraction of the stream and source area network throughout storms is referred to as the variable source area concept.

For foresters, an understanding of where the stream network and source areas will expand, provides an opportunity to avoid activities that disturb soil and deliver sediment to the stream channel.

III APPLYING HYDROLOGIC PRINCIPLES TO DECISIONS

By recognizing how forest watersheds operate, management practices can be adjusted to minimize disturbance. The recognition of critical locations is part of developing appropriate practices. In the Six

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Rivers National Forest, Furbish and Rice found that areas with slopes greater than 58 percent and adjacent to streams had landslide rates 20 times those of non-steepland sites (2). If we are to make both environmentally sound and economically practical choices, then we need to recognize that practices to minimize erosion, provide shade to streams, or provide sources of large woody debris can and should be tailored to site conditions within the watershed.

IV EFFECTIVENESS OF FOREST PRACTICES IN PROTECTING WATER QUALITY

In numerous studies throughout the United States, it has been shown that if state Best Management Practices (BMPs) are used, water quality will usually be protected. A qualitative review of the Washington Forest Practice Rules by an interdisciplinary team in 1980 found that almost no water quality impacts occurred for operations where the rules were followed. Where rules were not followed, water quality impacts occurred 69 percent of the time (3). Adams, in a 1992 study of BMPs in South Carolina, using a benthic macroinvertebrate and a stream habitat assessment, found that "water quality was adequately protected where silvicultural BMPs were implemented during harvesting operations..."(4). He further found that "...lack of compliance [with BMPs] was generally caused by a failure of landowners to identify and adequately protect sensitive sites."

A demonstration of the effectiveness of properly tailored management practices to minimize impacts from forest operations is provided by a study of landslides by MacMillan Bloedel of their holdings on Vancouver Island, British Columbia (5). The landslide inventory found an increase in the frequency of failures for clearcut steep slopes compared to moderate slopes. However, road failures on steep slopes were less frequent than on moderate slopes. This apparently resulted from more cautious road location and construction on steep terrain than for moderate slopes. A landslide inventory in the Waldport Ranger District of Oregon found that the relative number of landslides from roads in recent years had decreased. The reduction in landslides from roads was at least partly a result of "... improved road-building techniques, [and] better enforcement of contract specifications..." (6).

Effectiveness is not only dependant on if you apply appropriate practices but also who and how the practices are applied. Rice found that operator performance was an important source of variation in logging-related erosion (7).

Unfortunately, many impacts observed in forest watershed today are a result of past practices. A study of landslides in the Upper Deschutes River Basin found "most of the problems occurred in roads from 16-45 years of age when construction standards were much lower than today. The majority of problems occurred because of steep cut slopes and blocked culverts" (8). In the Tolt Watershed, the assessment team found that riparian harvesting in the past had caused current stream channel erosion.

V NATURAL DISTURBANCES AND WATERSHED VARIABILITY

Both management practices and assessments of forest practice performance are doomed to failure if they do not recognize the natural variability of forest watersheds and the dynamics caused by natural disturbances.

Management decisions must recognize that "average" events will not determine the performance of a practice. There is a 20 percent chance that a culvert designed for 50-year flood will experience a flood of that magnitude or greater over an 11 year period. Large floods usually are the dominant sediment producing events, particularly for headwater systems. So safeguards need to be developed to anticipate possible failures. For example, if a stream culvert becomes clogged with debris or the flow capacity is exceeded then the stream can be diverted down the road, potentially causing serious erosion. Roads can be designed to avoid "diversion potential" by dipping both approaches into the crossing. In the event of a culvert failure only the crossing fill is lost (9).

Assessments of watershed performance must also recognize natural disturbances and variability. Fine sediments in small Idaho streams have been traced to the 1910 wildfire. Major modifications to forest streams in the Northwest, both in managed and unmanaged watersheds, occurred during the December 1964 and January 1965 storms. The 1962 Columbus Day storm, which blew down 3 billion board feet of timber and the 1933 Tillamook Burn which burned 200,000 acres of forest in 20 hours are examples of the types of disturbances that forest watersheds can and historically have experienced (9). Ongoing assessments must be put into the context of the recent hydrologic history to judge performance. Retrospective assessments, like landslide inventories or stream channel condition inventories, need to recognize natural disturbances as a part of the history of forest watersheds.

VI EXPECTATIONS FOR WATERSHED PERFORMANCE

Although we would like to avoid all impacts from management there are limits to what is technically and economically feasible. A study of erosion on 344 miles of logging roads in northwest California found that about 40 percent of erosion was natural (would have occurred even without the road), 24 percent was avoidable using conventional engineering methods, and 36 percent was unavoidable given the decision to construct the road (10). This erosion distribution is not presented as typical. The point is that with improved management methods and improvements in our ability to assess watershed conditions, we will continue to shift the unavoidable erosion toward avoidable. But there will always be some error in our ability to read landscapes or a point where marginal improvements in erosion control are not economically or institutionally justifiable. The critical role of forest watershed specialists is to provide the information to decision makers about the expectations of management options so that decisions can be made against watershed goals.

VII REALISTIC MANAGEMENT GOALS

Coupled with the need for information on the expected performance of management practices is the establishment of realistic goals to allow for design of appropriate watershed practices. An unpublished project by the TFW Water Quality Steering Committee raises this issue for forest chemicals. Monitoring of streams near forest spray operations showed that water quality criteria or recommendations were not exceeded but some chemical was detected in all cases. It must now be decided whether any detected chemical should be a violation of forest practice rules and label instructions. As we get increasingly sophisticated in our measurement capabilities and with unlimited funds we can always measure smaller and smaller changes in management effects. The most important question, which the management goal should address, is whether this is a functional change that affects the uses and health of the stream system.

VIII THE ROLE OF WATERSHED ANALYSIS

Mike Truax of Simpson Timber Company recently posed the question, "What Cumulative Watershed Effects are likely to occur from a series of forest practices in a watershed which can't be addressed on a project-specific basis." Members of the NCASI Cumulative Effects Subcommittee identified a number of responses. First, foresters and watershed specialists will not always be successful in developing the right prescriptions so there is a potential for impacts to accumulate and be transported downstream. Second, assessments of impacts have often been made in channels near the operation where changes in sediment and flow are greatest, but downslope channels may respond differently if they are unconfined so these assessments are suspect. Third, some watershed processes may not be addressed effectively by on-site practices. If watershed leaf-area-index determines the potential for increased peak discharge due to rain-on-snow then a basin-wide rather than site-specific view is needed. So there are limits to what on-site assessments can achieve.

Probably more importantly, watershed analysis makes us look at the system as a whole and forces us to continue to review and test our assumptions about how the system is working.

There is tremendous activity nationally and regionally on various watershed assessment and management approaches. These include proposals for "comprehensive, holistic" watershed management and the development of Total Maximum Daily Loads (TMDLs) for water-quality limited streams. One possible outcome is the development of blanket prescriptions such as 200 foot no-cut zones around all streams or application of load models that do not consider the entire watershed story. The Washington Watershed Analysis Process provides for preemptive cumulative effects assessments that recognize the legacy of past practices, the locations of hydrologic hazards in the basin and the high risk sites in the basin. It establishes watershed goals, and provides a process for developing tailored management prescriptions. One assessment or management approach is not appropriate for all basins. A blanket prescription will always fail in some sites because it is either too restrictive and expensive to carry out or it is not protective enough for a difficult site.

IX NEED TO MONITOR PERFORMANCE

One unfortunate outcome of several years of nonpoint source control programs and forest practice acts throughout the United States is that, while there is general agreement among professional forest hydrologists that practices have dramatically improved, the amount of well designed monitoring and testing of current practices is limited. This has resulted in skepticism by the public and agencies about the effectiveness of the forest practice rules and forest watershed protection, often caused by observations about past practices. Management programs, especially for private forest regulation programs, while improving the prescriptions and BMPs being applied, have failed to generate research and monitoring information to document improvements.

There are certainly examples of attempts to address this shortcoming. These include the Timber/Fish/Wildlife monitoring and research program, effectiveness monitoring efforts by the Oregon Department of Forestry, and the California Department of Forestry and Fire Protection, and a national project to develop BMP effectiveness assessment protocol. Individual companies throughout the Northwest are also testing the effectiveness of their operations and practices. But, the rate at which questions are being asked and new approaches proposed is greater than the level of information being generated. A systematic and intensified program is needed if we are ever to gain on the technical questions being posed about forest management, hydrology, and stream quality.

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APPENDIX A
PARADIGMS OF FOREST HYDROLOGY

RUNOFF

There is a lack of direct surface runoff from forests. Peak flows from forests are relatively low compared to other land-uses.

Removing vegetation reduces interception and evapotranspiration and increases water yields.

For rain-generated floods, as magnitude of the flood increases, the role of forest management decreases.

Harvesting can increase snowpack accumulation, depending on the configuration of the opening, by reducing canopy interception and melt/sublimation.

Harvesting is believed to increase rain-on-snow events by increasing snowpack accumulation and exposing the pack to warm winds.

Radiation snowmelt can be delayed by using cutting patterns that provide shade to the snowpack.

Increases in water yield decrease with time.

EROSION AND SEDIMENTATION

Trees provide minimal protection to surface erosion; their main role is to provide litter to cover the soil and reduce raindrop impact energy.

Surface erosion is usually limited to areas with exposed mineral soil or other disturbed sites (highly compacted surfaces).

Dry ravel is accelerated on steep slopes following wildfires and hot prescribed burns. Most dry ravel occurs immediately.

Channels store large amounts of sediments. Disturbances to channels or removal of riparian vegetation root-strength and stable large-woody debris will accelerate the removal of stored channel sediments.

Shallow-rapid landslides generally only occur on slopes greater than 60 percent.

Landslide frequency is dependent on the soils, vegetation, geomorphology, and climate at the site.

Forest management can increase landslide frequency. Loss of root strength, changes in site hydrology, soil disturbance, and changes in slope configuration (roads) all can contribute to landslides. The relative importance of these factors can only be determined for the specific site.

Channel gradient, channel roughness, stored mobile materials, and angle of channel intersections all determine the potential for debris torrents and length of run.

Deep seated landslides are most influenced by changes in water inputs, not root strength.

Erosion materials must be transported to the channel to become sediment. Sediment problems can be managed by either avoiding erosion or interrupting transport.

Erosion, both surface and mass wasting, and the potential for delivery depend on the specific site conditions.

Most surface erosion occurs in the first several years and the rate rapidly decreases with time.

CHANNELS

Channel and stream conditions reflect the sediment, water, wood, energy, and vegetation inputs to the system.

Physical response of channels to inputs varies. The most responsive channels are unconfined and low-gradient. The least responsive channels are confined and high-gradient.

STREAM TEMPERATURE

Small streams, where shade from riparian vegetation is maintained, will not have large increases in the summer or decreases in winter from expected temperatures due to management.

Lowland and southern streams are naturally warmer than northern and high elevation streams.

Tributaries can provide thermal refuges and local cooling of rivers but all waters are in equilibrium with their environment and will equilibrate with the air temperature.

Groundwater inflows tend to cool stream temperatures in summer.

WATER QUALITY

Phosphorus and nitrogen are the most important nutrients for eutrophication of streams and lakes.

Phosphorus is mostly attached to particles and is best managed through erosion control practices; especially surface erosion control.

Nitrogen is found in both soluble inorganic (ie: nitrate) and organic forms in forest streams. Riparian vegetation is important for cycling of nitrogen. Wet, anaerobic, carbon rich riparian soils are important sites for denitrification which reduces total nitrogen delivered to streams. Certain forest species such as alder can elevate nitrate concentrations in streams because of symbiotic nitrogen fixation (especially if they are in the riparian zone). Harvesting and slash burning can accelerate the loss of nitrate, at least in part by increasing mineralization.

Aerial forest fertilization with urea and other nitrogen-containing fertilizers can cause short term increases in stream nitrogen species, especially if there is direct application to the stream channel.

Forest herbicides and insecticides vary in their toxicity and potential for contamination of streams. Concentrations are generally best controlled by avoiding direct applications to streams, by minimizing the rate of application, and by employing appropriate drift control methods.

Dissolved oxygen in surface waters is not a problem if fresh slash is kept out of the stream and shade is maintained.