

Caspar Creek Phase II: Discovering How Watersheds Respond to Logging

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For the past three decades, researchers from the Pacific Southwest Research Station's Redwood Sciences Laboratory in Arcata, California, and the California Department of Forestry and Fire Protection (CDF), Jackson Demonstration State Forest near Fort Bragg, have been studying the effects of logging northern California watersheds. Their findings have identified the extent and nature of hydrologic, erosion, and sedimentation impacts of logging operations on watersheds in this area.

Cooperation between CDF and the Station dates from 1962. It has been a productive division of labors, with CDF supervising the construction and maintenance of research facilities and the logging of experimental watersheds, and the Station designing the experiments and analyzing the data. Together, they have jointly decided which studies to undertake and have co-authored several research reports.

Calibrating and treating the watershed

In 1962, the Station and CDF started a typical "paired watershed" experiment, in which researchers recorded changes in streamflow and sedimentation before and after roadbuilding and logging. Gaging stations were installed in both the 424-ha South Fork and 484-ha North Forks of Caspar Creek, located about five miles southeast of Fort Bragg. These sites were chosen because the two drainages have roughly comparable physical characteristics. The old-growth forest was logged during the late 19th century, and both watersheds now support stands of second-growth redwood, Douglas-fir, grand fir, hemlock, and several hardwood species. Winters are mild and wet. Annual rainfall is 1190 mm (47 in), with 90 percent falling from October to April. In the summer, coastal fog often clings to the watershed until late morning. Soil in the area is derived from hard, coarse-grained sandstone and shale that have been deeply shattered and moderately weathered.

After a five-year calibration period (1962-1966), logging roads were built into the South Fork drainage in 1967. The effects of roadbuilding were measured as local on-site erosion, suspended sediment loads in the stream, and sediment deposited in debris basins. Logging commenced in 1971, using selective cutting and tractor yarding procedures typical for that time, and ended in 1973. In all, 60 percent of the timber volume of the South Fork watershed was removed. The North Fork served as an untreated control. Except for a major landslide in the North Fork, Raymond M. Rice (now retired, formerly chief hydrologist with the Station) considers the results a paradigm for logging's effects on any Northern California watershed having similar climate, soil, and logging history.

Effects of roadbuilding and logging on sedimentation

Adjusting the data to account for the landslide, Rice and collaborators Forest B. Tilley (CDF) and Patricia A. Datzman (PSW) found that stream sediment increased 80 percent with roadbuilding and 275 percent with logging.

The researchers observed that most sediment was carried during relatively short periods of high flow. In fact, 81 percent of suspended sediment was transported by flows exceeding 1.23 cubic meters per second (45 cubic feet per second). Flows of this magnitude or greater occur only 1 percent of the time. Plotting sediment yield versus the top 25 percent of flow volume for the unlogged North Fork of Caspar Creek from 1967 to 1976 showed only slight increases in suspended sediment loads as stream power increased. But when sediment entered the stream because of ground disturbance by roadbuilding or logging, sediment discharge increased rapidly with stream power. In effect, the data suggest that sediment discharge switches from being mostly "supply dependent" during undisturbed years to being more "stream power dependent" during disturbance years. This indicates that sediment discharge is limited only by the ability of the stream to carry sediment as more sediment becomes available for transport.

The end result was that tractor logging and roadbuilding delivered more sediment to the Caspar Creek stream channels than was predicted on the basis of the calibration years.

Effects on streamflow

Another possible consequence of roadbuilding or logging is destabilization of the stream channel because of more or larger floods. Roadbuilding, even on a moderate scale, might be expected to increase peak stormflow by compacting road surfaces (which would reduce water infiltration), by intercepting groundwater flow, and by channeling water directly into the stream.

However, after reviewing Caspar Creek flow data, chief research hydrologist Robert R. Ziemer found no change in any of several storm flow parameters measured after the period of roadbuilding in the South Fork. The absence of flow effects in Ziemer's data may be explained by the fact that roads occupied only 5 percent of the area.

Selective timber cutting and tractor yarding were likewise found to have no major hydrologic consequences. By the conclusion of logging, about 15 percent of the watershed had been compacted by roads, landings, or skid trails. Streamflow peaks in the fall increased three-fold after logging in the South Fork, but these storms were small in magnitude. Storms occurring later in the rainy season--even large ones--were not associated with any change in peak streamflow above the predicted levels. Flood peaks were the same height, and flood volumes were not increased in the South Fork when compared to flows in the untreated North Fork.

These results suggest that logging had little effect on flow and that building skid trails and landings probably did not increase runoff. If they had, there should have been measurable increases in flow peaks throughout the year, not just in the fall.

Why did logging affect only fall storms? Ziemer theorizes that the forested watersheds are initially drier than logged watersheds (trees transpire and intercept water) and, therefore, the unlogged watershed has a greater capacity to absorb rainfall. But when soil in the unlogged watershed becomes as wet as that in the logged area, the two watersheds perform identically. This explanation is supported by an analysis of summer streamflow by hydrologist Elizabeth T. Keppeler and Ziemer. Summer streamflow increases were greatest the year after logging was completed and diminished each year thereafter.

In a separate review of the data from Caspar Creek, Kenneth Wright and co-workers Karen H. Sendek, Raymond Rice, and Robert B. Thomas found that hydrographs (plots of runoff with time) were shifted forward in time after the area was logged. They found that although peak flows did not change much throughout the year, the logged watershed did respond more quickly to rainfall.

Average lag times from rainfall peak to streamflow peak were decreased by 1.5 hours. Lag times associated with larger storms shortened by as much as 3 hours. Wright and co-workers attribute the increases in the timing of runoff during large storms to the building of skid trails, roads, and other compacted surfaces that are less pervious to water. Since the hydrographs were moved forward in time but were unchanged in shape, logging probably did not have an adverse effect on the channels within the watershed.

Wright and co-workers acknowledged, however, that an unwanted impact might occur downstream where tributaries from logged and unlogged watersheds, whose peak flows are normally unsynchronized, join. After logging, flow at the junction of the two streams could become synchronized and lead to increased flow effects. They noted that the opposite scenario is also a possibility: that synchronized effects downstream could become uncoupled and reduce peak flows in lower reaches of the basin.

It's just such complicated interactions between different watersheds and logging activities that researchers are addressing in the second Caspar Creek study.

Caspar Creek: 1985-Present

Forest practices change, and the definition of which effects need to be measured is also changing. This has led researchers to initiate new studies that, together with past efforts, will give forest managers and public policy makers an empirical basis on which to formulate sound logging practices.

For the second study, the roles of the two watersheds have been switched. Statistician Robert Thomas studied storm peaks and volumes, daily flows, and suspended sediment concentrations from 1963 to 1985 and concluded that the South Fork had returned to near-pretreatment conditions. Therefore, in Phase II, the now-stabilized South Fork is a control while, in the North Fork, separate subwatersheds have been clearcut, clearcut and burned, or left unlogged. About 45% of the timber has been removed from the North Fork study area.

Unlike the first study, the logged areas were clearcut because this had become the most common silvicultural practice in redwood stands in the 1970's and 1980's. Another difference was the predominant use of skyline yarding. Less than 20 percent of the logged area was harvested using tractors, and then only on gentler ridge-top slopes. This change resulted in much less ground disturbance and soil compaction than occurred when the South Fork was logged.

As in the first study, researchers are monitoring storm sediment discharge and streamflow parameters before, during, and after roadbuilding and logging. Logging operations were conducted between May 1989 and January 1992, after four calibration years. Monitoring will continue another four or five years after logging. This length of time is needed to measure a range of storm events before and after logging, and to study watershed recovery rates.

Study methods and equipment have been substantially improved since the 1967-1976 experiment. Thomas (now retired) developed a new sediment sampling technique that yields more accurate estimates of sediment discharge. Past procedures for measuring suspended sediment yields have been found to underestimate actual values by as much as 50 percent. Other improvements include the addition of stream gauging stations on 13 subwatersheds of the North Fork, each station controlled by a microprocessor.

Just as logging practices and measurement techniques have changed since the sixties, so too have definitions of effects that are of interest to the public and the subject of regulations. Additional requirements have been placed on forest activities by the National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), and Clean Water Act (PL92-500). The latter Act, passed in 1972, mandates the development of plans to reduce non-point source pollution from activities such as timber harvesting. NEPA and CEQA direct governmental agencies to consider cumulative effects of pollution when assessing environmental impacts. Also, California's Forest Practice Rules have been revised to keep pace with environmental law as it applies to forestry practices on state and private lands.

Cumulative effects

A cumulative effect is the incremental environmental impact of an action when added to other past, present, and reasonably foreseeable future actions. Of special concern are situations in which acceptable activities interact to produce something unacceptable.

Cumulative effects in forested watersheds may occur after activities like road construction, mining, or logging, each of which can contribute sediment to stream channels. For example, small, high-gradient streams subjected to these activities might transport sediment downstream to reaches with lower slope gradients and less stream power, where sediment deposits from multiple disturbances may combine to degrade fish habitat.

The study will identify, for various degrees of disturbance, the relationship between sediment yield per unit area and watershed position, indexed by the area upstream of each gauging station. If the slope of the relationship increases after logging, then synergistic cumulative effects are occurring. That is, upstream disturbances cause greater impacts than would be expected from summing the individual impacts. If the relationship is unchanged by logging, then the effects are additive, and cumulative effects can be assessed by summing the expected impacts of individual activities. If the slope of the relationship decreases after logging, then the impacts are offsetting or diminishing with distance from the source.

In addition to sediment changes after roadbuilding and logging, the cumulative effects analysis will examine changes in the timing, peak flow, and volume of storm runoff.

Companion Studies

Companion studies conducted by the Station and university scientists will provide linkages to hillslope processes, and changes in water chemistry and stream biota.

Subsurface flow

Before logging, a dense network of automated groundwater instruments was installed in a headwater drainage of the North Fork Caspar Creek. Researchers are monitoring the hillslope's response to timber removal and the effects on timing and movement of groundwater through the soil matrix, macropores, and soil pipes. Subsurface flow is the primary pathway for stormflow to streams in this region and directly impacts the timing of storm peaks.

Soil pipe flow

Trenches were dug across three swales in the North Fork Caspar Creek two years before logging, and naturally occurring soil pipes located between 0.5 and 2 meters in depth were instrumented by capturing the flow and sediment in containers. Two of the swales were subsequently logged, and one remained unlogged as a control. Data are recorded at 10-minute intervals by electronic data logger, and periodic sediment samples are collected by an automatic pumping sampler. Groundwater is concentrated by pipe networks and accounts for virtually all of the storm flow from each swale. It now appears that the soil pipes are enlarged by turbulent flow. This leads to eventual collapse of the pipe feature, which in turn creates headward eroding gullies.

Bed load transport

While suspended load is primarily a water quality concern, the bed load (that portion of the sediment transported in close contact with the channel bottom) is directly related to bed composition, channel stability, and aquatic habitat quality. In a lower reach of the North Fork, a bed-load monitoring station has been set up to automatically measure bed load accumulation in submerged traps (flush with the bed surface) at 5-minute

intervals. This type of data is available at very few streams worldwide, and the instrumentation demonstrates a useful new methodology. In addition, depositional volume computed from detailed surveys of the North Fork bed load delta (at the upper end of the weir pond) provides annual measurements of bed load yield.

Channel processes

All gauged stream channels are mapped in detail each year to document bank failures, recruitment and movement of logs, and other changes in channel configuration. Natural debris dams, or steps, are revisited each year to determine changes in woody debris and sediment storage. A GIS (Geographic Information System) database, incorporating annual surveys since 1984, has been developed to aid in the production of channel maps and analysis of spatial and temporal patterns in the channel's structure. This should help researchers understand channel processes and their response to logging.

Intensive turbidity and suspended sediment records

Intensive data on turbidity and suspended sediment are being collected for a subset of storms at one gauging station. For the selected storms, turbidity is measured at 10-minute intervals, sediment concentration is determined for a subset of intervals, and suspended sediment is estimated for the remaining intervals from the relationship between concentration and turbidity developed from that storm. Complete records of suspended sediment discharge such as this are rare and will provide valuable baseline data that can be used in computer simulations to help design future sampling strategies.

Fisheries

Fisheries research in Caspar Creek focuses on the effects of logging activities on fish habitat and how the fish respond to these changes. Fish habitat inventories in the North and South Fork Caspar Creek will allow comparison of habitat availability and condition before and after logging. Summer baseflows are being monitored to determine if logging-induced changes affect the quality of habitat. Annual assessment of the size composition of streambed substrate will detect changes in the sediment characteristics. Logging activities may also alter water temperatures through removal of streamside vegetation. Electronic data loggers in the North and South Fork provide a year-round record of air and water temperatures. The impacts of logging may be reflected in the condition of fish utilizing the creek. Fish from selected habitat units in the North and South Fork are sampled and measured each summer to obtain annual estimates of fish distribution and abundance. In addition, length and weight measurements from the sampled fish will detect changes in the physical condition of the fish.

Other monitoring and outside research

A network of five rain gauges records the time after each 0.01 inches of rainfall. A solar pyranometer provides 5-minute solar energy flux readings, which are useful in explaining changes in evapotranspiration and summer low flow responses. Two university research teams are studying nutrient cycling and the responses of stream insect populations to logging. Such measurements will provide a more complete understanding of watershed function and its alteration during and after logging.