Overview of the Caspar Creek Watershed Study[1]

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***Abstract**: The California Department of Forestry and Fire Protection (CDF) and the Pacific Southwest Research Station, Redwood Sciences Laboratory (PSW) have been conducting watershed research within the Caspar Creek watershed on the Jackson Demonstration State Forest, in northern California, since 1962. A concrete broad-crested weir with a 120° low-flow V-notch was constructed in both the 473-ha North Fork and 424-ha South Fork of Caspar Creek by the late fall of 1962. Both watersheds supported predominantly second-growth stands of coast redwood (*Sequoia sempervirens *(D. Don) Endl.) and Douglas-fir (*Pseudotsuga menziesii *(Mirb.) Franco) averaging 700 m^3 ha^{-1} of stem wood. The study has been conducted in two phases. The South Fork phase was designed as a traditional paired-watershed study and involved monitoring the impacts of road construction and selection harvesting by tractor on streamflow, suspended sediment, and bedload. Approximately one-third of the watershed was logged in each year from 1971 to 1973, starting with the most downstream area. Several publications have documented the results from (1) the calibration and roading activities (1962-1971) and (2) the logging activity and subsequent monitoring through 1976. Planning for the North Fork phase started in the early 1980's. This study phase was initiated in response to new federal legislation requiring the evaluation of cumulative watershed effects as a part of management activities. The principal objective was to test for cumulative watershed effects (CWE) resulting from timber harvesting and related activities.*

The North Fork became the treatment watershed and was divided into 13 sub-basins including three control watersheds to be left untreated. Ten Parshall flumes and three rated sections were installed in the watershed — one at the outflow of each of these sub-basins. A new sampling system called SALT was developed along with the necessary sampling software and hardware for implementation.

Total timber volume removal in North Fork was slightly less than in the South Fork (about 50 percent); however, harvesting activities were limited to eight discrete clearcut harvest blocks ranging from 9 to 60 ha, occupying 35-100 percent of individual subwatersheds in the CWE study area. These harvest units were logged using primarily skyline cable yarding techniques. Road and landing construction and tractor logging were limited to ridgetop and upper slope locations. Auxiliary studies examining summer low flow, soil pipe flow, bedload movement, geochemical response, and biological aquatic effects were also monitored during this period. Monitoring began in 1985 and harvesting was done over a 3-year period (1989-1992). Harvesting began in the upper third of the North Fork watershed to aid in detecting the existence of possible CWE's. Monitoring was maintained at all gaging stations through hydrologic year 1995. After 1995, a long-term monitoring plan was instituted. This plan uses a subset of the gaging stations (SF, NF, A, C, D, E, H, I) to monitor the possible long-term effects of timber harvesting on stream discharge, suspended sediment, and bedload.

This overview of the history, site characteristics, major events, equipment, and sampling systems used during the life of the Caspar Watershed Study will provide background for the following papers in these proceedings.

Historical Land Use in the Study Area

Considerable disturbance of the inner gorge and channel areas occurred in the Caspar drainage before management by the State of California and the implementation of this study. The 2,167-ha Caspar watershed, like most north coast watersheds, was subject to intensive land-use practices spanning decades during the early old-growth logging era.

The first European settlement in the area was before the 1860's. The watershed and neighboring village were named after a local trapper, Siegfried Caspar. In 1860, the Caspar Logging Company was founded, the owners having purchased most of the Caspar Creek watershed. A sawmill was built at the mouth of Caspar Creek, ultimately producing up to 25,000 board feet of lumber per day. Jacob Green Jackson, after whom Jackson State Forest is named, bought the mill in 1864 and soon after had three log crib dams built on Caspar Creek. They were constructed of log cribbing with a rock and soil core with a flume and spillway through the center. A triggering mechanism enabled the operator to open the spillway gate when the natural stream flow was judged high enough. The dams were built to provide additional stream discharge for river log drives, permitting logging operations to be expanded into the upper reaches of Caspar Creek. Thirty thousand logs or more were often tiered in the channel, waiting to be floated down to the mill during high winter flows. Log drives required a full reservoir and a storm capable of raising the water level of the stream by about 2 feet. Francis Jackson, a local historian who found remnants of many crib dam sites on the local streams, estimated from historical archives that an average of two log drives per winter took place in each of the North and South Fork drainages (Napolitano 1996).

Clearcut logging was used exclusively during this era. The felled areas were broadcast burned to remove obstructions before yarding the old-growth logs by oxen teams over skid trails to "roll away" landing type areas near the stream channels. Logs were then jack screwed into the creek to form log tiers that would be floated downstream during the winter high flows. These activities involved extensive excavation into inner-gorge slope areas. Years later, railroads were expanded into upper reaches of some watersheds, and semi-mechanized yarding of remote canyon tributaries was made possible using railway inclines (also called tramways) powered by steam donkeys. For example, one incline was built to yard logs from the Dollard-Eagle subwatershed over the ridge to the railway in Hare Creek. Most of the watershed had been logged by

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the late 1890's, and by 1906, a quiescent period followed as Caspar Lumber Company moved eastward in search of new timbered areas to harvest. Harvest activities did not begin again until the early 1960's, after the State took over management of the area.

Caspar Watershed Study Genesis

As the State started harvesting many of the second-growth stands in the historically logged areas, more information was needed on the effects of logging and road-building on sedimentation and aquatic habitat. The impetus for beginning a joint study with federal and state agency cooperators in 1960 was to answer such questions as: (1) What are the water and sediment production of north coast watersheds that have been undisturbed for many years?, (2) How are water yield, water quality, flood peaks, and stream sedimentation affected by current road-building and logging practices?, and (3) What changes take place in the channel after logging, and how do these changes affect fish and their habitat? (Anonymous 1963). Early participants besides the California Department of Forestry and Fire Protection (CDF), Jackson Demonstration State Forest, and the Pacific Southwest Forest and Range Experiment Station (PSW), Redwood Sciences Laboratory, included Humboldt State University, California Department of Fish and Game, and the University of California. Staff from the California Department of Water Resources, and U.S. Geological Survey also participated in an advisory capacity at the initial design stage of the study.

Methods

Location

The study is located in the Caspar Creek Experimental Watershed on the Jackson Demonstration State Forest (Preface, fig. 1, these proceedings). The watershed study encompasses 897 ha of the North and South Forks of Caspar Creek in northwestern California. The basins are located about 7 km from the Pacific Ocean at approximately 39°21'N, 123°44'W and have a general west-southwest orientation. The North and South Fork weirs are approximately 14 and 15 km, respectfully, southeast of Fort Bragg, California.

Topography and Soils

Topographic development consists of uplifted marine terraces that are deeply incised by coastal streams. About 35 percent of the basin's slopes are less than 17° and 7 percent are steeper than 35°. The hillslopes are steepest near the stream channel with inner-gorge slope gradients of 50 percent or more. A slope change typically occurs 100 m to 350 m upslope, becoming more gentle near the broad and rounded ridgetops. The elevation of the watershed ranges from 37 to 320 m.

The soils in the Caspar Creek study basins are well-drained clay-loams 1 to 2 m in depth, and are derived from Franciscan sandstone and weathered coarse-grained shale of the Cretaceous Age. They have high hydraulic conductivity, and subsurface stormflow is rapid, producing saturated areas of only limited extent and duration (Wosika 1981). Three soil complexes are dominant in the study area. The Vandamme, Irmulco-Tramway, and Dehaven-Hotel series occupy the upper, mid, and inner-gorge areas, respectively. The first two complexes account for approximately 90 percent of the area.

Climate

A Mediterranean climate is typical of low-elevation watersheds on the central North American Pacific coast. The fall and winter seasons are characterized by a westerly flow of moist air that typically results in low-intensity rainfall and prolonged cloudy periods with snow occurring rarely. In the spring, this weather pattern migrates northward, and rainfall becomes much less frequent. Summers are relatively dry, with cool coastal fog that typically can extend 16 km or more inland during the summer, often burning off to the coast by midday.

Temperatures are mild with muted annual extremes and narrow diurnal fluctuations due to the moderating effect of the Pacific Ocean. Average monthly air temperatures between 1990 and 1995 in December were 6.7 °C, with an average minimum of 4.7 °C. Average July temperature was 15.6 °C, with an average maximum of 22.3 °C (Ziemer 1996). The frost-free season ranges from 290 to 365 days. Mean annual precipitation from 1962 through 1997 was 1,190 mm, with a range from 305 to 2,007 mm. Ninety percent of the total annual precipitation falls between October and April. The frequent occurrence of summer coastal fog makes a small, but unknown, contribution to the total precipitation in the form of fog drip. Snowfall is rare at these low elevations in this region.

Vegetation

The forest vegetation of this coastal region is the product of favorable climatic and soil conditions. The area supports dense stands of second-growth Douglas-fir (*Pseudotsuga menzieii* (Mirb.) Franco), coast redwood (*Sequoia sempervirens* (D. Don) Endl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.). There are also minor components of hardwoods, including tanoak (*Lithocarpus densiflorus* (Fook. and Arn.) Rohn) and red alder (*Alnus rubrus* Bong.), and scattered Bishop pine (*Pinus muricata* D. Don). A few old-growth redwoods remain within the Caspar Creek watershed. The timber stands average 700 $m^3 ha^{-1}$ of stem wood.

Understory vegetation includes evergreen huckleberry (*Vaccinum ovatum* Pursh), Pacific rhododendron (*Rhododendron macrophyllum* D. Don), and sword fern (*Polystichum munitum* (Kaulf.) Presl.).

The South Fork Phase

Study Design

The initial South Fork study was designed as paired watersheds. Both watersheds are initially untreated until sufficient data have been accumulated to allow the variable(s) of interest to be predicted from the control watershed (Thomas 1980). One watershed was then logged and the other remained unlogged as a control. The South Fork was chosen to be the treated watershed because it had older and larger second-growth timber stands while the North Fork was designated to serve as the control (Preface, fig. 1, these proceedings).

Precipitation Monitoring System

Five standard manually-read rain gages were installed in both watersheds in 1961 (Tilley and Rice 1977). One weighing-type recording gage was placed near the confluence of the North and South Forks in fall 1962. A second recording gage was located near the North Fork weir in August 1964. These 8-inch recording gages could chart 7 days of rainfall data and were the primary system until 1989. The network was measured on a weekly basis through most of the South Fork study phase. Some gage locations were changed when the study transitioned into the North Fork Phase.

Streamflow, Suspended Sediment and Fisheries Monitoring System

Concrete broad-crested weirs with an inset 120° low-flow V-notch were constructed in both the North and South forks of Caspar Creek by November 1962 (Krammes and Burns 1973). Stream discharge data were collected throughout the South Fork phase (1962-1976) using A-35 stream recorders[3] mounted on stilling wells. Suspended sediment data were collected with fixed-stage samplers mounted on the weirs. The watersheds were calibrated from 1963 through 1967. From 1978 through 1982, sediment sampling instrumentation was upgraded to a PS-69 automatic pumping sampler installed at each weir. Flow-proportional frequency controllers were added later to increase the efficiency of the sampling and to reduce the processing workload. All of the automatic sampling was supplemented and calibrated using DH-48 manual grab-samplers to perform depth-integrated hand samples. Several different sampling algorithms were used through 1984 to trigger the sampler, including sediment proportional, flow and time modes. Since 1983, ISCO pumping samplers have been the primary sediment sampling instrument.

In cooperation with the California Department of Fish and Game (DFG), a fish ladder and control dams for fisheries research (Kabel and German 1967) were completed in November 1962 on the South Fork, but not finished on the North Fork until August 1963. A counting weir was also installed 2.5 km upstream from the ocean in November 1964, but it was severely damaged during the December 1964 storm and was never used for any extended fish monitoring. DFG monitored the fisheries until 1964 and then discontinued its participation. PSW contracted with University of California at Davis to study fish habitat by monitoring stream bottom fauna before and after road building and logging in the South Fork (Anonymous 1963).

[3] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Debris Basin Measurements and Maintenance

Debris settling basins behind the weirs have been surveyed annually since 1962 to account for deposited suspended sediment and bedload. During the summer low-flow period, permanently placed pins are used for a sag tape measurement of about two dozen transects in each weir pond. Measurements from the current year are compared to the previous year to obtain the volume of sediment deposited.

Periodically these basins are drained and the sediment excavated so that the gaging accuracy of the weir is not diminished. The basins are surveyed before and after excavation. During the fifth clean-out, in 1988, core samples were taken to determine the grain-size of the deposited debris. Debris removal was initially accomplished by building a truck ramp over the weir so that heavy equipment could excavate and remove the debris. Eventually, an access road was built to the back of each debris basin to provide better access for sediment removal.

Road Construction

In summer 1967, about 6.8 km of logging roads were constructed near the canyon bottom in the South Fork. Of these, about 6 km were within 61 m of the stream, of which 2.3 km directly impinged on the stream channel. About 5 percent of the watershed was occupied by main line and spur roads (Wright 1985). Fill slopes, landings, and major areas of soil exposed by road-building were fertilized and seeded with annual ryegrass in September 1967, immediately after completion of the road. The following 3 years were used to evaluate the effects of road construction on streamflow and sedimentation (Krammes and Burns 1973).

Timber Harvesting

After the road evaluation phase, harvesting began in the South Fork in March 1971 and ended in September 1973 (Preface, fig. 1, these proceedings). Single-tree and small-group-selection silviculture was used with ground-lead tractor log yarding. Most of the landings were located near the canyon bottom. The watershed was divided into three sale units of approximately equal size. Starting in the most downstream unit, harvesting progressed upstream, one unit each year. In the first sale (Watershed #1), 60 percent of the timber volume was harvested over 101 ha. The Watershed #2 timber sale removed about 70 percent, covering another 128 ha. The final sale, Watershed #3, harvested about 65 percent of the timber from 176 ha. In total, about 153,000 m^3 of timber were removed from the South Fork watershed (Tilley and Rice 1977). More than 15 percent of the watershed was compacted from skid trail, landing, and road construction. Skid trail construction accounted for more than half of that compaction, and road construction accounted for more than one-third (Wright 1985).

Landslide/Soil Erosion Surveys

CDF conducted a landslide survey in the South Fork during summer 1976. Soil displacements larger than about 50 m^3 ha^{-1} were measured. These data were compiled to estimate the soil displacement of mass movements occurring in the watershed in a post-logging state.

Similarly, PSW installed seven plots as part of a larger study to assess soil movement associated with various logging systems. The plot locations centered on existing landings, with additional transects to measure the cross-sectional area of rills, gullies, ruts, and cuts made for skid trails or roads.

The North Fork Phase

Conception and Planning

Planning for this phase of the study started in the late 1970's. Impetus for this study was to respond to new regulatory requirements, both at the federal and state levels, that significantly affected resource management activities. The National Environmental Policy Act (NEPA) and Public Law 92-500 mandated the consideration of "cumulative effects" as part of Environmental Impact Statements. The North Phase of the study was designed to quantitatively test the magnitude of cumulative watershed effects (CWE's) associated with suspended sediment, storm runoff volume, and streamflow peaks (Rice 1983).

Study Design

A system of 13 nested subwatersheds (Preface, fig. 2, these proceedings) was selected to quantitatively evaluate whether synergistic cumulative effects were occurring (*table 1*). These subwatersheds were selected on the basis of size and location to assist in tracing sediment through many sizes of watersheds. They ranged in size from 10 ha (BAN) to 384 ha (ARF). Eight are tributary non-nested subwatersheds. The DOL station gages a tributary containing one nested subwatershed (EAG). The remaining four are progressively larger nested mainstem gaged subwatersheds. The subwatersheds were named after people who lived and worked in the local area during the early logging era (with the exception of watershed Munn). The North Fork phase was designed to address the question: For any given intensity of storm and management impact, does watershed response increase with watershed area? Cumulative effects are discussed in a broader context by Reid (these proceedings).

Table 1*—Subwatershed names, areas, and treatment chronology.*

Watershed	Gaging station	Drainage area (ha)	Harvest units subwatersheds	Year(s) logged	Year(s) burned	Year(s) of herbicide application
Arfstein	**ARF**	384	B C G V E K J L	1989-91	1990-91	1993-96
Banker	**BAN**	10	B	1991		
Carlson	**CAR**	26	C	1991		
Dollard	**DOL**	77	E V	1990		
Eagle	**EAG**	27	E	1990-91	1991	1994-96
Flynn	**FLY**	217	G V E K J L	1989-90	1990-91	1993-96
Gibbs	**GIB**	20	G	1991	1991	1994, 96
Henningson	**HEN**	39				
Iverson	**IVE**	21				
Johnson	**JOH**	55	K	1989	1990	1993
Kjeldsen	**KJE**	15	K	1989		
Lansing	**LAN**	156	K J L	1989-90	1990	1993
Munn	**MUN**	16				
North Fork	**NFC**	473	All	1985-91	1990-91	1993-96

Precipitation, Solar Radiation, Air, and Water Temperature

Six rainfall monitoring sites were operated during this phase. Five of the sites had been monitored since 1962. An additional site was installed in 1987 on the northerly ridge of the North Fork watershed. Tipping-bucket rain gages replaced the recording weighing type gages in 1989 and provided greater resolution by electronically recording a measurement every 5 minutes. In 1990, the rain gages were improved again to allow instantaneous rainfall readings — that is, a data point is recorded at each tip of the bucket (0.01 inch of precipitation).

One solar radiometer, located on a regenerated south-facing clearcut unit in the middle fork of Caspar Creek near the Eagle subwatershed unit, has been operational for 10 years. Solar radiation was also monitored along the main stem of the North Fork in conjunction with the stream biology study (Bottorff and Knight 1996) to help assess the effects of logging on the stream community related to increased light. Eight solar radiometers were installed along a 100-m reach during a study of aquatic insects. At other sites, photographs of the effective canopy cover have been taken using a fisheye lens.

Air and water temperatures have been recorded at 0.5-hr or 1-hr intervals at 11 sites beginning in 1988.

Streamflow and Suspended Sediment Measurements

Parshall flumes were chosen as the primary gaging design to measure streamflow and sediment in the tributary watersheds. This design has the advantage of allowing sediment to pass through the gaging station unobstructed and is engineered so that little calibration is required to calculate streamflow from stage readings. The design of the floor and side-wall keeps most of the sediment in suspension so that it can be sampled using pumping samplers. The flumes were custom-sized to handle the expected range of discharge in each subwatershed. They were constructed from old-growth redwood lumber that was milled at the CDF/CDC Parlin Fork Conservation Camp and pre-fabricated at the CDF/CDC Chamberlain Creek Conservation Camp cabinet shop. The flume components were hand-carried to each designated gaging location, reassembled, and installed on site.

For those subwatersheds that were too large to feasibly construct and install an appropriately-sized Parshall flume, natural channel-bottom rated sections were installed. These consisted of parallel plywood sidewalls erected on each side of the channel and sized for the expected range of stream discharge. Discharge measurements were required at these stations to establish and periodically update the relationship between water height (stage) and discharge.

Four stream gages (ARF, FLY, IVE, and LAN) were operational by November 1983. Four more stations (DOL, EAG, GIB, and HEN) were fully operational by the following November. The four remaining stations (BAN, CAR, JOH, and KJE) were not operational until January 1985, because of delays in acquiring the necessary equipment. An additional control station (MUN) was completed in September 1985. Because of the scattered start-up times and the time required to install and troubleshoot new sampling technology, most of the analyses begin with hydrologic year 1986.

Sampling Development and Design

Critical to the success of obtaining unbiased estimates of suspended sediment loads at these remote sites were the development and implementation of a new sampling technology. In these small forested watersheds, high-discharge flows occur relatively infrequently, but carry a disproportionate part of the sediment. Traditional methods of sampling suspended sediment give biased estimates of total sediment yield and do not allow valid estimation of error (Thomas 1980). SALT (Selection At List Time) and related methods had been in use in forest sampling (e.g., 3P cruising) for many years, but research statistician Robert Thomas successfully modified the method for use in sampling suspended sediment loads (Thomas 1985).

SALT Sampling Hardware and Process

The initial station equipment (*fig. 1*) consisted of a 12-volt battery-powered system that included portable computer, interface circuit board, pressure transducer, ISCO pumping sampler, and a backup stage chart-recorder with an event marker (Eads 1987).

RSL (PSW Redwood Sciences Laboratory) also designed an interface circuit board that could convert input data from a stage-sensing device — the pressure transducer (*fig. 2*) — and also produce an output signal to the pumping sampler to collect a pumped sample. The electronic data storage and transfer functions eventually used a more powerful portable computer — the HP-71B — that the field crews carried with them. The data were archived on other media and sent via modem to the mainframe computer at the Redwood Sciences Laboratory.

Staffing requirements were high for equipment maintenance and data retrieval even with the sophisticated sampling schemes. During the full-scale monitoring period, up to 16 people might be involved in alternating 12-hour shifts during storm periods. The

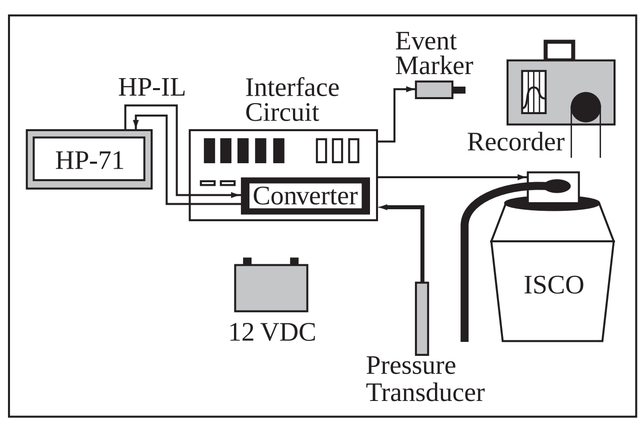

Figure 1 — Station equipment setup.

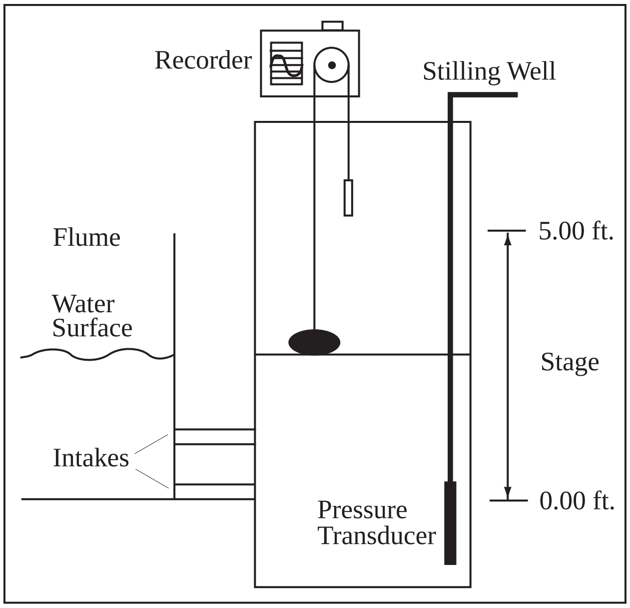

Figure 2 — Stage sensing device.

watershed was divided into sections and 3 to 4 two-person crews would cover their assigned stations, retrieving data from the computers and replacing the full sample bottles. Troubleshooting was an important function to ensure that the system was working properly. Corrosion of terminals, low voltages, and clogged intakes were some of the common problems that had to be dealt with immediately to minimize the loss of data during these important storm flow periods.

Long-Term Monitoring

The long-term monitoring phase of the study began in water year 1996 and ushered in a new sampling scheme that relies on real-time turbidity data to drive the sampling process. Experience has shown that the excellent relationship between suspended sediment and turbidity can reduce the sampling effort considerably (Lewis 1996). Results have shown that the relationship between sediment concentration and turbidity has been generally linear and has little scatter for a given station and storm. The current turbidity-based sampling system collects in-stream turbidity measurements every 10 min at eight stations. This approach has reduced the number of samples to about one-sixth of the number needed under a SALT sampling regime.

Harvesting Activities

The first harvest entry into the North Fork watershed occurred in spring 1985 (Preface, fig. 2, these proceedings). The Caspar West 85 timber sale was located in a subwatershed just upstream from the North Fork weir. About 64 ha, spread over two units, were harvested in this sale. More than 90 percent of the area was clearcut with the remaining area being selectively cut stream buffers. About 52 ha were cable logged and 12 ha were tractor logged near ridgetops. Nearly 2 km of new haul road were constructed near the ridgetop as part of this sale, primarily to provide cable-yarding access. This area was logged independently of the CWE timber sales. Initial information about this area had indicated that the soils were not similar to the rest of the watershed. However, later investigation indicated otherwise.

After about 4 years of pretreatment stream monitoring, harvesting activities began in the North Fork CWE study area (*table 1*). Felling began in spring 1989 on the Caspar East Timber Sale — the first of three timber sales planned as part of this study phase. The upper three units (J, L, and K) were logged as part of this sale. A steady progression of harvest-related activities allowed the completion of this first sale by spring 1990 (*table 1*). Two units of the sale (J and L) were broadcast burned in fall 1990 to reduce the fuel loading and to accommodate replanting.

To investigate the effects of burning on sedimentation, units E and G were burned in the fall/winter period after harvesting was completed. Units C and K were designated non-burn units.

The second sale in the series was the 79-ha Rice 1990. This sale covered the middle third of the North Fork watershed in three separate clearcut units (E, G, and V). Felling for road construction began in April 1990. An unexpectedly large amount of precipitation in late May (more than 12 inches) affected some of the new road construction in and between units E and V, although no significant off-site impacts were detected. A small portion of unit V was yarded downhill. This is an unusual practice and was the only place where this occurred.

Tramway 1991 was the final and most downstream sale in the series. The sale was named after the historic tramway mentioned earlier in this paper. Remnants of this railway incline were protected as a documented archeological feature and are still visible today. Two of the clearcut subwatersheds (G and C) shared a divide, technically producing a cut unit larger than that allowed under Forest Practice Rules. The experiment required implementation of this sale design, so ultimately the timber harvest was permitted through a CEQA process and the Board of Forestry declared the North Fork an official experimental watershed. This sale was done very quickly, having started in September 1991 and completed by January 1992.

Table 2 shows how the subwatersheds were affected by the harvesting activities. The largest subwatershed, ARF, just above the North Fork weir, for example, had just over one third of its area affected by cable yarding and less than 10 percent affected by tractor logging. About one percent of this watershed is in new roads, and the total bare area created by new roads, landings, and skid trails is about 3 percent. About one quarter of the watershed area above station ARF was burned.

Other Studies or Treatments

Organic Step Mapping Study

This study was initiated to determine the mobility and dynamics of organic steps and debris within the main-stem and tributaries of the North Fork. Results will be used to estimate the availability of sediment storage sites and the buffering capability of channels following management activities.

The main-stem channel system had been mapped in 1984 at a scale of 1:500, whereas the tributaries were mapped at 1:250. Bank characteristics, gravel bars, rock outcroppings, and live and dead organic material were mapped. Each organic step (debris dam) having a minimum height of one foot and storing a sediment volume of at least 5 cubic feet is mapped and assigned a number and condition rating. Channels have been remeasured annually during the summer low-flow period.

Large Event Survey

An important sediment contribution to the channel can be large erosion features that most often occur during storms. Erosion events exceeding 10 cubic yards were surveyed after most storms. A sketch is made of each landslide, and its location is identified on the detailed watershed map.

Subsurface Study

A study of subsurface drainage patterns before and after logging was initiated in a 0.81-ha portion of a swale in the K unit in 1987. Piezometers were installed to bedrock in multiple locations with depths varying from 1.5 to 8 m. Tensiometers were placed at 1.2 m and 1.5 m depths. The instruments were placed along five separate hillslope segments having straight, concave, and convex contours (Keppeler and others 1994).

***Table 2**—Percentage of each subwatershed affected by various treatments.*

Watershed	Gaging station	Cutarea (percent)	Cable (percent)	Tractor (percent)	Thinned (percent)	WLPZ (percent)	WLPZcut (percent)	NewRoad (percent)	NewLndg (percent)	Skid trails (percent)	Total Bare Gnd (percent)	Total burned (percent)
Arfstein	ARF	45.5	35.1	7.1	0.1	4.2	1.4	0.9	0.9	0.8	2.9	24.0
Banker	BAN	95.0	77.3	13.4	0	5.3	1.7	1.3	1.3	0.6	3.2	0
Carlson	CAR	95.7	82.1	9.2	0	5.6	1.7	0.9	1.9	1.5	4.4	0
Dollard	DOL	36.4	27.4	5.9	0.6	0.4	0	1.6	0.9	0.8	3.7	33.9
Eagle	EAG	99.9	79.0	15.4	1.8	1.1	0.1	2.6	2.3	2.3	8.5	97.8
Flynn	FLY	45.4	34.6	7.6	0	4.3	1.6	0.7	0.9	0.8	3.0	30.4
Gibbs	GIB	99.6	54.9	39.4	0	2.0	1.2	2.0	2.2	2.8	7.9	98.2
Henningson	HEN	0										
Iverson	IVE	0										
Johnson	JOH	30.2	26.4	1.3	0	1.3	0.5	1.0	1.0	0.1	2.1	0.1
Kjeldsen	KJE	97.1	85.2	3.9	0	4.4	1.6	3.1	3.4	0.4	6.9	0
Lansing	LAN	32.2	27.8	1.9	0	4.1	1.5	0.4	0.6	0.3	1.9	20.3
Munn	MUN	0										
North Fork	NFC	49.6	38.6	7.6	0.1	4.1	1.4	1.0	1.0	0.8	3.2	19.5

NOTE:

Cutarea	Cable + Tractor + Thinned + WLPZcut + NewRoad + NewLndg
Cable	clearcut and yarded by cable
Tractor	clearcut and yarded by tractor
Thinned	thinned viewshed areas (logged by tractor)
WLPZ	water and lake protection zone
WLPZcut	WLPZ times proportion of volume removed from WLPZ
NewRoad	road surfaces, cuts, and fills (excludes old main haul roads)
NewLndg	landing surfaces, cuts, and fills
Skid Trails	skid trail surfaces, cuts, and fills
Total Bare Gnd	NewRoad + NewLndg + Skid Trails + firelines
Total Burned	broadcast burns

Bedload Study

Quantitative information on bedload rates and patterns of movement is an important addition to the overall knowledge about sedimentation effects from harvest activities. One objective of this study was to refine and calibrate a bedload measurement technique for use in small to medium-sized forested catchments with flashy hydrographs (Albright and others 1987). The Birkbeck-type sampler consists of a cast concrete form (pit), 0.6 m on a side, with a removable top cover that is horizontally level with the stream bed. Removable metal boxes inside the concrete forms collect the bedload material that passes through a 0.1-m-wide slot. Four of these pits were installed at Station ARF. Bedload transport rates were initially monitored by a hydraulic system using a pressure transducer to sense pressure in a fluid-filled pillow and a data logger to record the pressure. Each pressure pillow and transducer were soon replaced by a load cell that produces a voltage that, when interrogated by the data logger, is proportional to the submerged weight of the box (Lewis 1991). Collected material was removed after each storm. A fixed I-beam was used for winching the full boxes from the concrete pits. A sump pump was used to empty the boxes during a storm. Some of this bedload material was sieved for grain-size analysis. For a measure of total annual bedload, detailed surveys of the bedload delta at the upper end of the North Fork debris basin were completed each year from 1989 to 1995.

Low Flow Study

Much of the summer low flow in the tributaries is subsurface through porous gravel. To measure summer low flow, slotted polyvinylchloride (PVC) pipes were buried in the streambed with a pressure transducer that was interrogated periodically by an HP-71B data logger (Keppeler 1986).

Aquatic Invertebrate Biological Studies

The objective of the North Fork Caspar Creek biological study was to determine whether logging treatments (1989-1991) within the drainage basin caused changes in three components of stream structure and function: (1) the benthic macroinvertebrate community; (2) leaf litter processing rates; and (3) the benthic algal community (Bottorff and Knight 1996).

Water Chemistry and Quality

The primary purpose of this research was to examine the effects of forest harvest and post-harvest management practices on biogeochemical processes. Results provide information to understand the complex interactions that occur in nutrient cycling processes at the ecosystem scale (Dahlgren 1998).

Aquatic Vertebrate Biological Studies

Since the mid-1980's, fisheries research has been examining the relationships between timber harvest, aquatic habitat, and vertebrate populations.

Aerial Photography

Two flights have been made over the Caspar watershed to produce large-scale (1:6000) color photographs of the study area. The first was completed in summer 1988 to document the watershed condition before harvest. The second flight was completed in summer 1992 to document the condition of the logged watershed. These aerial photos were used in timber sale planning and, later, in geomorphic mapping both the North and South Forks.

Vegetation Management Treatments

Although not part of the initial study design, several types of vegetation management treatments were applied to a number of units at various times. To reduce the competition from both native and exotic plant invaders, herbicide applications were used in units J, G, E, and V. The chemicals have all been applied with hand-operated backpack sprayers using either a directed-broadcast or a directed-spot treatment. A one percent formulation of Garlon 4 herbicide was used in these two types of application. Precommercial thinning has also been used, although, to date, only in units Y and Z as part of the 1985 Caspar West timber sale. The other cut units are planned to receive these treatments as needed to foster rapid regrowth of commercially-desirable forest vegetation.

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