JDSF Newsletter
Jackson Demonstration State Forest
State of California Dept. of Forestry P.O. Box 1185 Fort Bragg, CA. 95437
No. 41 April, 1991

FORT BRAGG RAINFALL - HOW DRY IS DRY ON THE NORTH COAST ?

Hugh Scanlon 1/

Drought! The word conjures up mental pictures of wilted crops and parched, arid soils. While the "Dust Bowl" image of drought may be accurate for some areas, other parts of California that enjoy relatively high average rainfall amounts respond differently. Traveling through the still-green forests of the Mendocino coast, it can be easy to forget that California is in its fifth year of drought. We may begin to wonder if the drought, although apparent in much of the State, is even occurring on the North Coast. Webster's defines drought as "1. dryness; absence of moisture esp. rain. 2. prolonged dry weather." By examining some rainfall statistics for Fort Bragg, we can get a better idea of whether this statewide drought is fiction or a serious reality on the Mendocino coast.

In some areas of the State, influences of the drought are easily seen. The Department of Forestry estimates that at least 10 million trees are dead statewide. These trees, weakened by drought stress, succumb to insects, pathogens, and other environmental factors. Ken Delfino, CDF's deputy director of Resource Management, announced that one-third of the trees in the inland wildlands south of Plumas County are dead or dying. While traveling through the inland forests, you can see the brown crowns of the dead pines and firs standing as a constant reminder of the State's serious drought condition.

On the North Coast, the water shortage is not as obvious. Here on Jackson Demonstration State Forest (JDSF), we have not observed an increase in insect attack or tree mortality. There has been a dramatic decrease in the number of salmon and steelhead making it up our coastal streams to spawn, but this is as much a function of rainfall timing as the quantity of annual rain. The lack of rainfall year after year has caused low fuel moistures late into the winter months. As each dry month advances, we become more concerned with the increased threat of wildfire to our wildland and timber resources. Since most of our precipitation arrives as seasonal rainfall, an examination of monthly rainfall totals and trends may help define the situation here on the Mendocino Coast.

Total Rainfall through 1990

At JDSF, we have rainfall data that has been collected in Fort Bragg since 1911. Annual rainfall totals are based on the sum of rainfall occurring during the hydrologic year which begins on July 1. The annual totals were averaged through the 1990 hydrologic year. Based on this data, the average annual, or "normal" rainfall for this area is 37.07 inches. The annual average (mean) is a statistic often used for comparison between years. For our data the median (where half of the observations are above and half are below this central value) rainfall was 35.82 inches. This reflects the fact that 44 out of the 80 years had totals that were below the average for rainfall. The lowest rainfall year was 1977 with 15.06 inches of precipitation, and the highest was 60.84 inches in 1941. Figure 1 illustrates the annual rainfall totals since 1911. The standard deviation (S.D.)for annual rainfall is 10.35. This statistic describes the distribution of observations around the mean. For a normal distribution, 68.3 % of the observations occur within 1 S.D. plus or minus of the mean, 95.4 % at 2 S.D.'s, and 99.7 % at 3 S.D.'s. For our

1/ Assistant Forester, Demonstrations & Experiments, Jackson Demonstration State Forest.

CALIFORNIA DEPARTMENT OF FORESTRY AND FIRE PROTECTION
Harold Walt, Director

Pete Wilson
Governor
State of California

Douglas P. Wheeler
Secretary of Resources
The Resources Agency

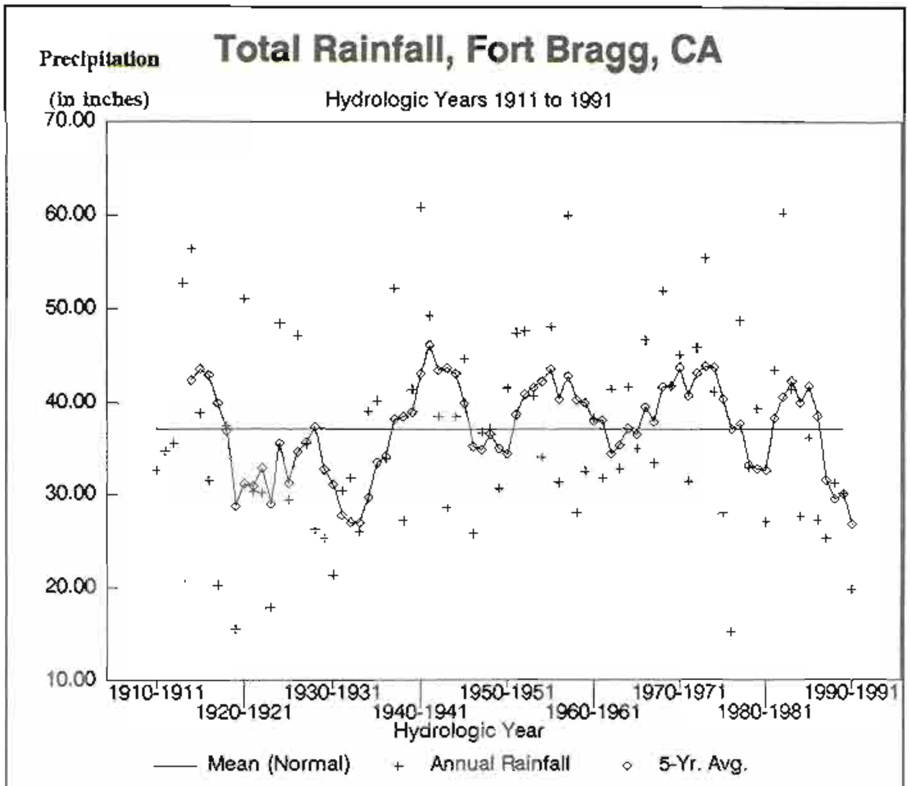

Figure 1. Total annual rainfall and rainfall averages for Fort Bragg.

data, 68.3 percent of annual rainfalls occur between 26.72 and 47.42 inches (1 S.D.). The distribution of rainfall years is shown in Figure 2.

Analysis of totals for the last five years indicates that, although all annual totals were below average, only one year's total (1988) was greater than one S.D. away from the mean. This is not particularly convincing evidence of a serious drought condition. Since drought is generally characterized by a long period of dry weather, we need to look at more than one-year's rainfall if we are to find more substantial evidence of drought.

For each hydrologic year, total annual rainfall was averaged over the preceding years for a 5-year period. Data for the current hydrologic year is not included in these calculations. The 5-year annual statistics yield a mean of 37.31 inches and a S.D. of 4.832 inches. The highest 5-year average was 1938-42 with 46.13 inches and the lowest was 1930-34 with 26.88 inches per year (Fig. 1). For the most recent seasons, the 1985-89 and 1986-90 averages ranked as the 6th driest with 29.46 inches and 8th driest with 29.97 inches respectively. In fact, the 5-year average for the last three completed rainfall years were all greater than one standard deviation below the mean. It is worthwhile to note that this period does not represent the longest dry spell in Fort Bragg's record. The 5-year averages for the 1928-32 to 1930-34 periods ranked third, second, and first as the driest. Through the 1989-90 season, we could characterize the most recent period as a significant dry spell, but this area has experienced drier weather.

In Fort Bragg's record, cycles of wet and dry weather are apparent. The plot of the 5-year running average (Fig. 1) shows our last major dry period during the years 1918-38. This was followed by several periods of moderately wet weather ending with our current dry spell. Periods of dry weather which have occurred prior to rainfall being measured have been estimated using dendrochronology (tree ring analysis). H.C. Fritts, and G.A. Gordon (1980) reported that big droughts in California occurred in the years from 1600-1625, 1665-1670, 1720-1730, 1760-1820, and 1865- 1885. In all of these intervals of dry weather, the annual rainfall fell below the level of the 1924-1938 dry period. By combining this information, a forty-year period between the end of the last and the beginning of the next dry spell is notable. With our current dry period having begun in 1985, we were on schedule for another dry cycle. Unfortunately, the length of these dry periods is unpredictable.

The 1990-91 Hydrologic Year

So far, we have looked at annual rainfall trends. The previous statistics are extracted from accumulated monthly rainfall totals for completed hydrologic years. We cannot yet close the book on rainfall for this year, but we can compare statistics through the month of April for each hydrologic year and project an annual total for this year. Perhaps this will give us a better idea of where we stand, and where we may be going.

JDSF has a particular interest in rainfall and tracks it closely. The Caspar Creek watershed study, which is investigating the potential cumulative effects of clearcutting, includes rainfall and stream gauging as part of the study analysis. Since the majority of sediment moves in streams during high flow periods, the sampling equipment is programmed to operate during these "storm events." Watershed storm events occur when the level of the North Fork rises and sustains above a 2 foot stage at the weir for a period of not less than 6 hours. Fewer storm events than expected has been one effect of the dry weather. While we anticipate six events per year, this year's rainfall has resulted in only one short-lived storm event on the Caspar Creek watershed study.

The media throughout the State have used a lot of different numbers to describe the extent of the drought. Here are some numbers for Fort Bragg so you can see how we compare to the rest of the State. Through the end of February, this

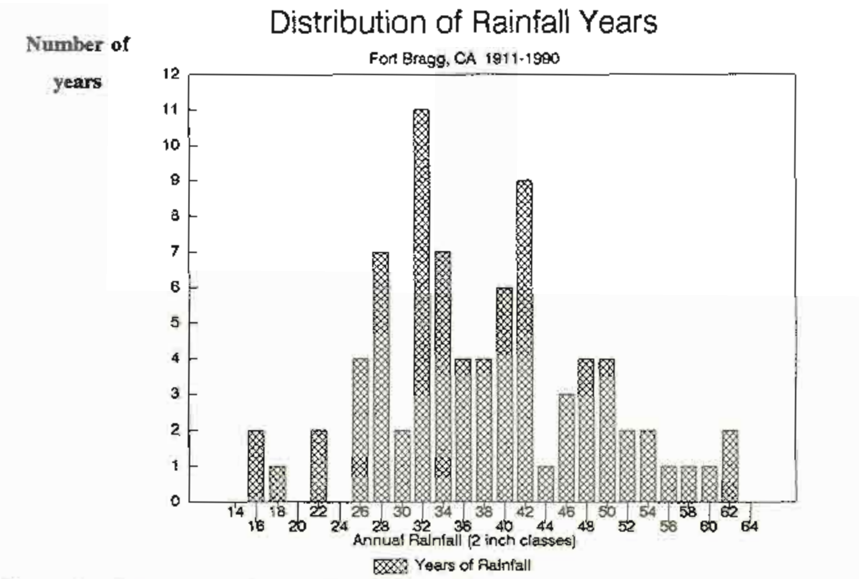

Figure 2. Freqyency of annual rainfall years by 2 inch class.

is the second driest year on record with 8.32 inches. Fortunately, we experienced the eighth wettest March which brought our year-to-date total to 16.85 inches. This was the third driest year on record through the end of March. April's showers were not quite as generous. By June 1, Fort Bragg had received only 18.85 inches of rain, leaving us with our fourth driest year-to-date. Figure 3 compares cumulative rainfall for the last three years to our average rainfall. Projecting the annual total, based on historic monthly averages for the remainder of the year, Fort Bragg would record the current hydrologic year as its fourth driest with a total 19.41 inches. Without major unseasonal rainfall before the hydrologic year ends, we are on course for another relatively dry season.

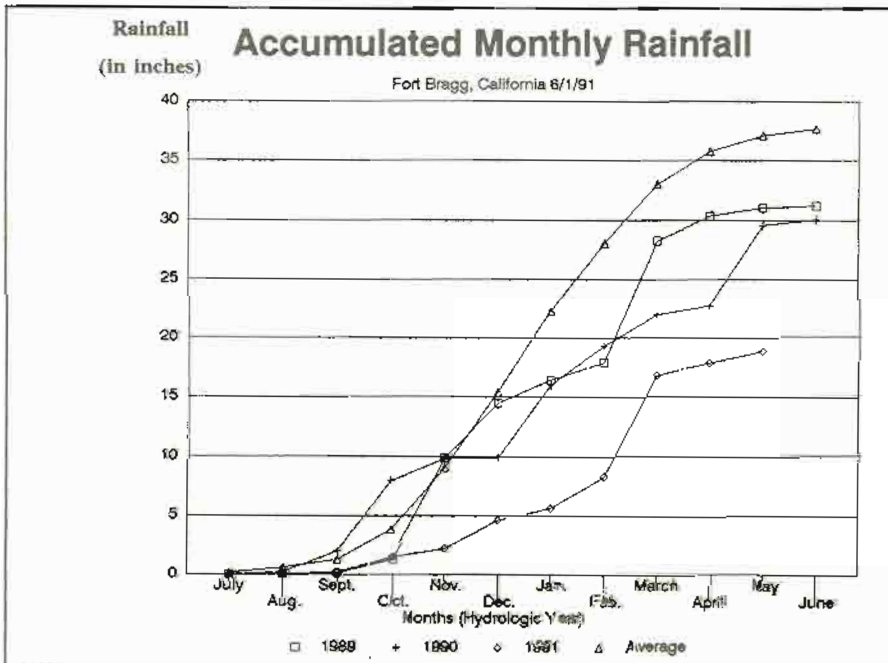

Figure 3. Cumulative rainfall by month for years 1991, 1990, and 1989 with average rainfall comparison.

Incorporating our current year's projection into the 5-year average statistics provides some sobering results. The projected statistics yield a mean of 37.18 inches and a standard deviation of 4.95 inches. For the period from 1987 through 1991, the projected annual average precipitation would be 26.69 inches. This represents the lowest 5-year average on record, greater than two standard deviations below the mean.

Conclusion

Precipitation in the Fort Bragg area has been consistently below average for the last several years, although they might be hard to characterize as drought years. But when our nearly completed year is included in the calculations, the statistics bear out a significant dry spell.

Visually there are subtle signs that we are in a drought condition. Although the redwood region remains green and lush, many homeowners are being compelled to drill deeper for water as their previously adequate wells run dry. The springtime conditions of our coastal rivers and tributaries are more characteristic of late summer flows. What was once taken for granted on this rain bathed coast has become an issue of major concern. The threat of wildfire also increases with each dry year. While fire is recognized as a natural part of the redwood ecosystem, its occurrence is infrequent. With this extremely dry period, there is a very real possibility of a major fire in this region.

Based on a 5-year moving average, this would be the worst drought condition to date in recorded history for Fort Bragg. The last major period of dry weather occurred during the early 1930's. This conclusion is based upon projected rainfall through the end of the hydrologic year. But projections can be inaccurate so we will keep you informed when the final rainfall for Fort Bragg is totaled.

Does Your Home Have Defensible Space???

HILLSLOPE HYDROLOGY RESEARCH AT CASPAR CREEK

Elizabeth T. Keppeler 1/ and
Peter H. Cafferata 2/

As part of the ongoing Caspar Creek Watershed Study on Jackson Demonstration State Forest, researchers from the US Forest Service and the California Department of Forestry and Fire Protection are investigating subsurface drainage in the headwaters of the basin. In order to predict how land use practices will impact stream systems, and hence habitats for aquatic organisms, we must develop an understanding of how water and sediment move down to the channel system. Subsurface flows are the primary source of stormflow in this region, where hillslopes are often prone to land slides.

At Caspar Creek, we are utilizing the latest technology to document how groundwater levels and soil moisture conditions vary from season to season and through storm events. In addition, the movement of water through subsurface soil pipes (naturally occurring underground channels) is being studied. Data collection on these hillslope processes began in 1986. We are gaining new insight into basic hydrologic mechanisms, and how they can be altered by logging and roading. This article offers a review of what we have learned to date.

Background Information

Over the years, scientists have generated several theories to explain subsurface drainage in wildland watersheds. It is well understood, for example, that when infiltrating water moves down through small soil pores (or the soil matrix) in the soil profile, it dampens and delays the streamflow response in comparison to systems where overland flow is the predominant process for routing rainfall to the channel. One dominant theory utilizing this soil matrix pathway, and that is useful in explaining observations made in this region, is that of the "expanding-contracting wedge" (Dunne 1978, Weyman 1973). During a rainfall event, a soil's zone of saturation expands up through the soil profile from an area of permanent saturation at the base of a slope near a stream channel. Rainfall enters at the soil surface and displaces soil water downward, expanding the zone of saturation upslope. Since infiltrating water travels through saturated soil much more efficiently than through unsaturated soil, this expanded saturated zone allows rapid subsurface stormflow to occur.

Soil pores (voids occupied by air or water) can be of sufficient size to change the way precipitation is routed to a stream channel. Large voids, called macropores, may efficiently route precipitation inputs from the soil surface to the saturated zone before the intervening layers have become saturated (Whipkey 1965). That is, "preferential flow" can occur through unsaturated layers when interconnected macropores of sufficient size exist in the soil profile (Morrison 1989). Soil pipes, or very large macropores, can be viewed as a form of preferential flow. These cavities originate from root decay, animal activities, solution (chemical) erosion, or weaknesses within subsurface soil horizons. Piping is found in many different types of terrain, and its importance in explaining hillslope processes is becoming widely recognized. Aside from rapidly routing stormflow, piping is also thought to play significant roles in hillslope erosion, channel formation, and road fill failures in swales (Sidle 1985).

Figure 1. Pre-logging photo of K 2 piping site.

Site Descriptions

Soil Piping

The Caspar Creek study sites are located within the North Fork watershed in moderately steep swales (zero-order basins), where surface flow channels have not developed. Soil pipeflow is being monitored at four small basins, ranging in size from less than 1 to 3.5 acres. Individual soil pipes are located between 1.5 and 6 feet below the ground surface; their diameters range from 1 to 18 inches. Subsurface discharge of water is captured at excavated soilfaces and routed to calibrated containers, where the height of water (stage) can be converted into a rate of flow (discharge) (see Figure 1). An electronic data recorder is used to record the stage at ten-minute intervals. Manual discharge measurements are also made to confirm the electronic records and to improve the container calibrations.

1/ Hydrologist, USDA Forest Service Redwood Sciences Watershed Lab, Fort Bragg, CA;
2/ State Hydrologist, California Department of Forestry & Fire Protection, Sacramento, CA.

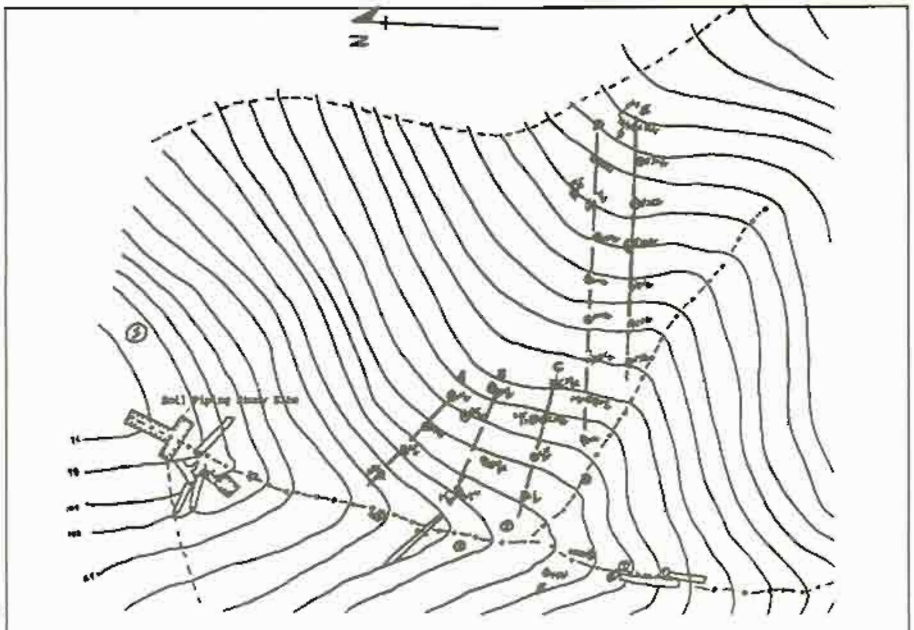

Figure 2. Layout of piezometers along a swale in Unit K, Caspar Creek.

One site serves as a control and is monitored as an undisturbed sub-basin covered with second-growth redwood and Douglas-fir trees. Two sites are located in the K unit of the Caspar East 1989 Timber Sale, which was clearcut and cable yarded in the summer of 1989. The fourth site is located in the E unit of the Rice 1990 Timber Sale, which is currently being harvested. This last site is unique in that it had a new road constructed through the swale approximately 100 feet above the piping excavation. The road was built as a total throughfill, to a depth of 6 feet at centerline of the road prism.

Groundwater and Soil Moisture Levels

In order to examine subsurface flow through the soil matrix, two of the swales located above piping sites have been instrumented with a network of piezometer wells. Piezometers are used to monitor groundwater levels in the saturated zone of a hillslope profile. Our wells consist of 1.5 inch diameter PVC pipe, with the lower 6 inches slotted to allow subsurface water levels to equilibrate within the well. The most extensive instrumentation of this type is located at the K2 site in the Caspar East Timber Sale (see Figure 2). At this site, 31 piezometers were installed by hand auguring through weathered sandstone and shale to hard bedrock (ranging from 6 to 26 feet below the ground surface). An additional 28 piezometers were installed to a depth of 5 feet, approximating the depth required to reach the bottom of the developed soil profile. The network is laid out along 5 transects running perpendicular to the slope, with approximately 15 feet spacing between instrument sites.

In addition to the piezometers at the K2 site, 25 soil tensiometers have been installed to monitor the soil moisture levels in the unsaturated part of the soil profile. Tensiometers are commonly used for agricultural purposes to determine when irrigation is needed. Readings from vacuum gages show soil water availability for plant use, as well as providing a relative indication of soil moisture content. Our tensiometers have been placed at depths of 1, 2, 3, 4, and 5 feet.

A second piezometer site was developed in the roaded piping swale described above. Here the piezometers are laid out in a single transect up the swale axis. Six piezometers were installed to hard bedrock (5 to 25 feet), two are at six feet (above a clay horizon), and one was placed in the center of the new spur road, at the interface between the original ground surface and the base of the road fill (see Figure 3). Data from both of these sites are collected using electronic data recorders that document water levels and/or tensions at 15 minute intervals. Manual measurements are made weekly in drier weather, and more frequently during large storm events.

Results to Date

Soil Piping

At the piping sites, peak discharges in excess of 200 gallons per minute (gpm) (almost 1/2 cubic foot per second) have

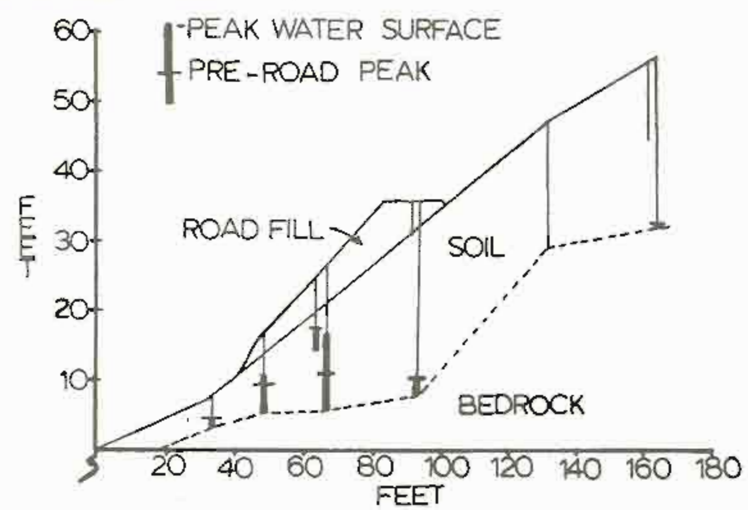

Figure 3. Unit E piezometer placement evaluating road fill influcences.

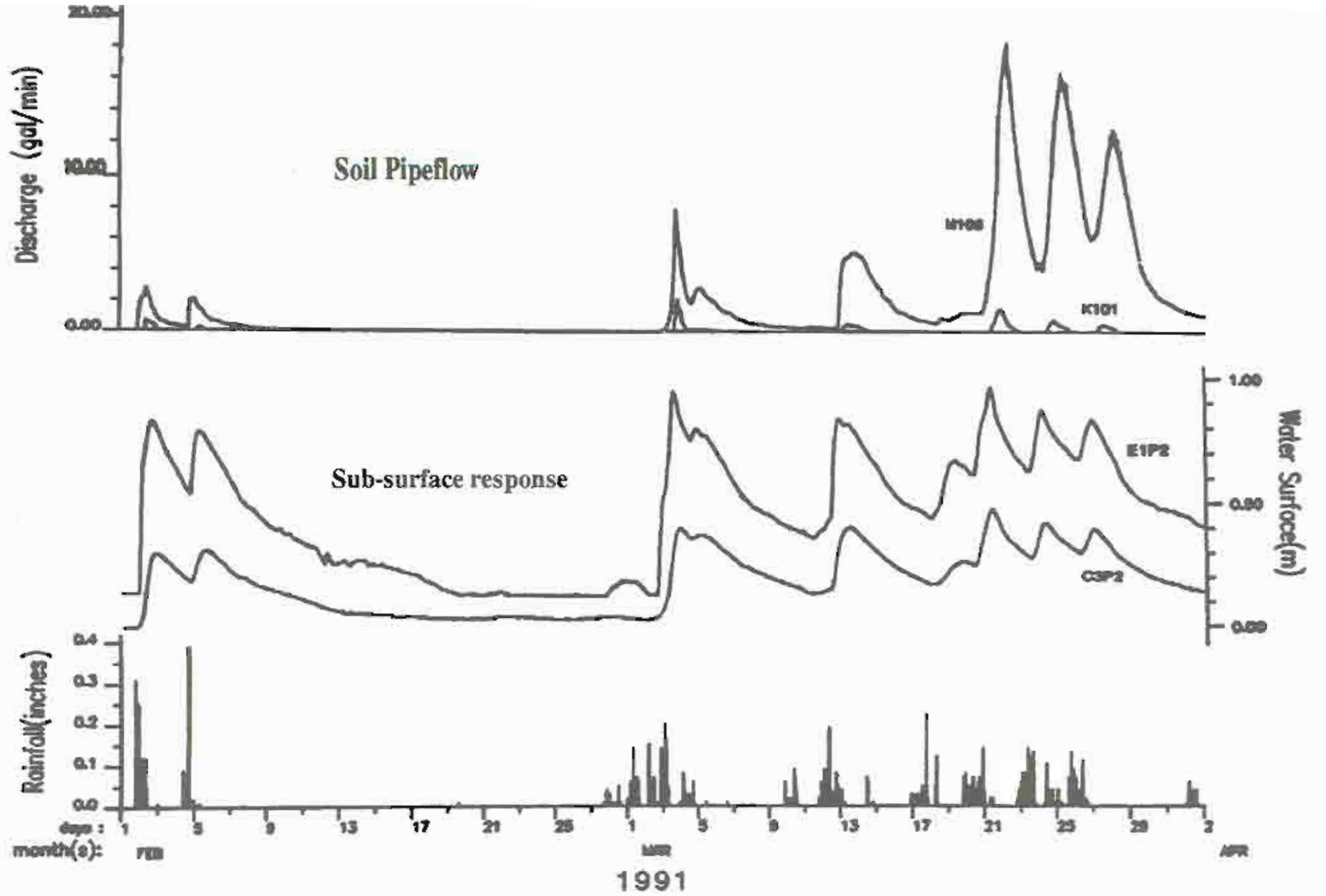

Figure 4. Soil pipe and piezometer response following precipitation.

been documented during the largest storm events. More typical winter storms produce peak pipe flows ranging from 0.2 to 50 gpm (Ziemer & Albright 1987). Soil pipes are quite flashy here. In mid-winter, they are quick to respond to precipitation, but their discharge volumes recede quickly after rainfall has ceased (see Figure 4). During non-storm periods, monitored soil pipes flow at much lower levels (gpm) and many are dry. Similarly, during the dry summer period, most soil pipes in our forested sites cease flowing, and a few inches of rain is required in the fall before they respond with normal winter flow volumes.

Dr. Robert Ziemer, Lead Hydrologist with the USFS Redwood Sciences Laboratory at Arcata, has demonstrated an interesting relationship between weather conditions and summer baseflow volumes. On foggy, overcast days when evapotranspiration from the forest canopy is low, pipe discharges are greater than on clear, sunny days. In addition, a diurnal fluctuation in summer pipe flows has been documented. Peak discharges occur in the mid-morning hours, while the lowest water levels are seen in the early evening hours. These observations suggest that the soil pipes are responsive to changes in soil moisture levels in the rooting zone due to evapotranspiration.

In the post-logging period, soil pipes that previously went dry during the summer are now maintaining limited baseflow. This is reasonable when one considers the effect of forest cover on soil moisture. Trees transpire considerable volumes of soil water (up to 300 gallons per day); therefore, timber harvesting generally results in increased soil moisture over the summer season. This additional moisture is then available to flow into the soil pipes, resulting in increased lowflow volumes.

Data gathered during the few storm events of 1989/90 and 1990/91 winters suggest that pipeflow from the logged sites has increased due to clearcut logging (see Figure 5). At one logged site this increase is taking the form of elevated discharge levels from previously monitored soil pipes. At the other logged site, the increase is occurring in the form of substantial discharge through a pre-existing soil pipe that surfaces 100 feet upslope from the instrumented site. This surfacing pipe flowed only rarely during the pre-logging period, but flow has been a common occurrence during storms since timber harvest. Data suggests that this pipe may be an "overflow" feature functioning only when the capacity of the smaller downslope pipe outlets is exceeded.

The increased winter peak pipeflows documented since logging can be explained in terms of wetter soils in the logged areas for the storms studied. That is, less rainfall is needed to satisfy a soil moisture deficit in the logged area, causing rainfall inputs to be translated more directly into pipeflow. The storms have generally been spaced several months apart, and apparently low level winter evapotranspiration has occurred in the forested basins. After logging, we have yet to study a "normal" winter with several storms occurring within a short time period. A second possible explanation is

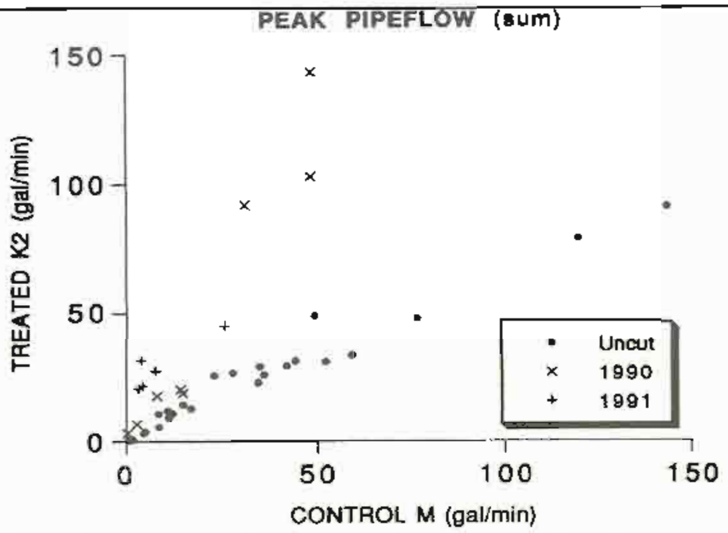

Figure 5. Pipeflow responses between control and harvested swales.

that falling and cable yarding has altered the basin hydrology, so that water is routed more efficiently through the subsurface topography. This seems less likely. No obvious change in pipeflow due to road building and limited log truck traffic has been detected as yet. It seems likely that the weight of the fill has not collapsed the monitored pipes under the road prism.

Monitoring also documented that soil pipes transport sediment. Although quantitative analyses of sediment transport in these pipes has yet to be done, field observations suggest that transport is quite variable. In the undisturbed state, minimal transport has been observed. After logging, elevated sediment discharges have been noted in one particular soil pipe. This has been attributed to disturbances associated with a windthrow of a medium-sized redwood tree immediately above the site. The root system displacement has disturbed the integrity of the subsurface channel, resulting in large amounts of erosion and sediment transport. This observation demonstrates the importance of residual tree stability where piping is thought to occur.

Groundwater

Upslope of the piping sites, the piezometer transects have documented dynamic and varied groundwater conditions. Of the 59 piezometers in the K2 swale, the shallower (5 foot) piezometers have shown minimal response to strong winter storms. This suggests there is no perched zone of saturation at this depth. Of the 31 deeper (bedrock) piezometer wells, 16 show significantly elevated water levels. The maximum piezometric head observed thus far in the study is nearly 10 feet, but more common responses are from 5 inches to 5 feet. The fact that half the deeper piezometers show largely no saturated response illustrates how permeable the weathered sandstone bedrock is in these coastal mountains or, alternatively, how permeated the hillslope is with pipes that function as "French drains." For the most part, areas exhibiting the greatest piezometric response are those located low on the slope near the swale axis. This observation supports the expanding- contracting wedge theory of subsurface drainage discussed earlier.

As has been observed for the soil pipes, piezometric response is mostly flashy (see Figure 4). Often, there is a lag time of 6 to 8 hours between the end of a major precipitation event and the highest water elevation recorded in a responding piezometer. This illustrates the length of time infiltrating water requires to travel through the soil matrix. The water elevations in the piezometers appear to peak about 1.5 hours after the soil pipes, but this relationship is quite variable (Ziemer and Rice 1990). Much of this variability is due to differences in depth to competent bedrock and type of substrate the hole was augured through. At some sites, the profile is predominantly hard, fractured sandstone, at others it is soft, granular sandstone, and at still others there are deep clay lenses. In addition, position on the slope appears to affect piezometric rise. The transect along the convex length of slope shows little response, while those along more concave portions of the slope are quite responsive.

Data from the roaded site may indicate altered piezometric response. In sites located under the fill slope of the new road, water levels have been recorded that are considerably higher than those recorded prior to road building. It is possible that compaction of the soil has altered the efficiency with which the soil matrix transports water. If subsurface flows are slowed while moving beneath the road prism, elevated groundwater would be expected. In extreme cases, this could cause slope failure (LaHusen 1985).

During the summer months, most of the piezometers are dry. Five, however, do maintain water elevations in the wells all year. Permanently saturated zones are probably explained by micro-depressions in competent bedrock topography. Timber harvesting has not had an obvious effect on piezometric response at the hillslope site in the K unit. No increase in peak piezometric levels or summer base levels has been detected by preliminary analyses.

Soil Moisture Levels

Soil moisture conditions at the hillslope site have been altered by clearcut timber harvesting. During the summer of 1990, soil moisture tensions in the root zone increased later in the season, and generally were lower (indicating wetter soil). It was not until September that moisture tensions increased. In earlier years, high tensions were reached by July.

While late May rains may have impacted the soil drying process in 1990, the absence of transpiring trees seems to be a more probable explanation. The data also shows that less rain was needed to saturate the soil in the fall after logging. Before harvest, 4 inches of precipitation was needed to saturate the soil to a depth of 36 inches. In the fall of 1990, these soils were saturated after about 2 inches of rainfall had fallen. Observations of soil moisture over the next several seasons will be needed to clarify the impacts of logging on soil moisture levels.

Final Thoughts

With the logging of the North Fork of Caspar Creek about half completed, much remains to be seen and evaluated. Hillslope hydrology studies complement measurements being made of stream suspended sediment concentrations, streamflow volumes, levels of bedload sediment movement, evaluations of anadromous fish habitats, macroinvertibrate insect diversities, and levels of woody debris accumulations in the channel system. Data collection will continue for several more years. Along the way, researchers from the USFS and CDF will analyze and explain their findings. It will, however, be several years before the tremendous amount of new information originating from the Caspar Creek Watershed Study is thoroughly analyzed and published.

References

Dunne, T. 1978 Field studies of hillslope flow processes. Chap. 7 in Hillslope Hydrology (ed. M.J. Kirkby). John Wiley & Sons. London.

LaHusen, R. 1985 Redwood country American Geomorphological Field Group: field group guide book (ed. M.E. Savina). pp 75-85.

Morrison, R. 1989 Monitoring strategies in the vadose zone. Subsurface monitoring: a case study approach for technical and legal strategies. Univ. of Wisconsin Department of Engineering. Madison.

Sidle, R. 1985 Groundwater influences on slope stability. In: Agronomy Abstracts: American Society of Agronomy. p 272.

Weyman, D. 1973 Measurements of the downslope flow of water in a soil. Jour. of Hydrology. 20:267-288.

Whipekey, R. 1965 Subsurface stormflow from forested slopes. IAHS. 10:74-85.

Ziemer, R. and J. Albright. 1987 Subsurface pipeflow dynamics of north-coastal California swale systems. In: Erosion and sedimentation in the Pacific Rim, proceedings of the Corvallis symposium (ed. R. Beschta, et al.) IAHS. 165:71-80.

Ziemer, R. and R. Rice. Tracking rainfall impulses through progressively larger drainage basins in steep forested terrain. In: Hydrology in mountainous regions. Chapter I - hydrological measurements; the water cycle, proceedings of two Lausanne symposia (ed. H. Lang and A. Musy). IAHS. 193:413-420.

JACKSON DEMONSTRATION STATE FOREST
802 N. MAIN STREET
FORT BRAGG, CA 95437