HILLSLOPE HYDROLOGY RESEARCH AT CASPAR CREEK

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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 sub-surface stormflow to occur.

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

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 weak-nesses 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).

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 tea-minute intervals. Manual discharge measurements are also made to confirm the electronic records and to improve the container calibrations.

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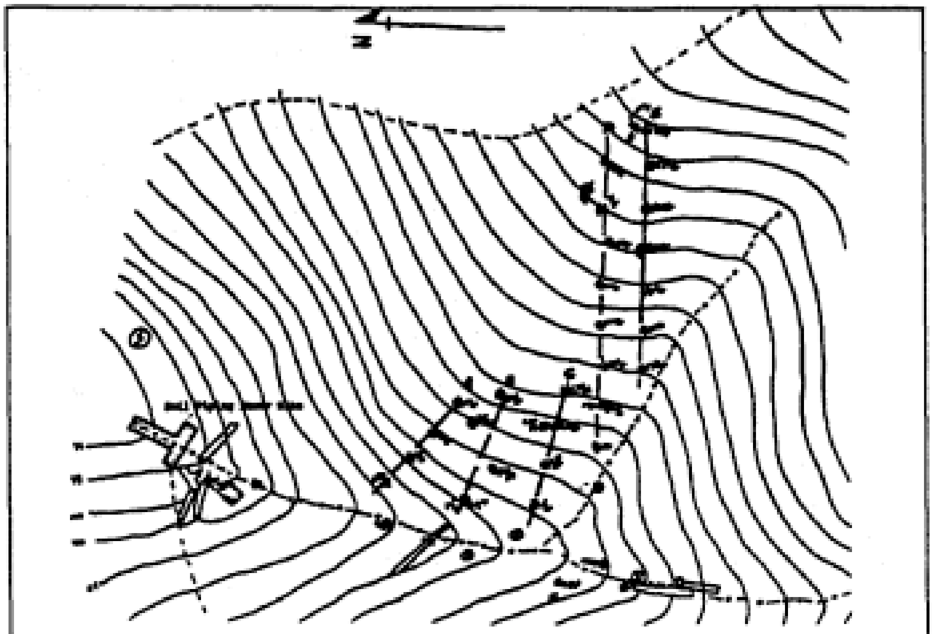

Figure 2. Layout of piezometers along a swale in Unit K, Caspar Creek.

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.

<u>Groundwater and Soil Moisture Levels</u>

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 15 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 is 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 S transects running perpendicular to the slope, with approximately 15 feet spacing between instrument sites.

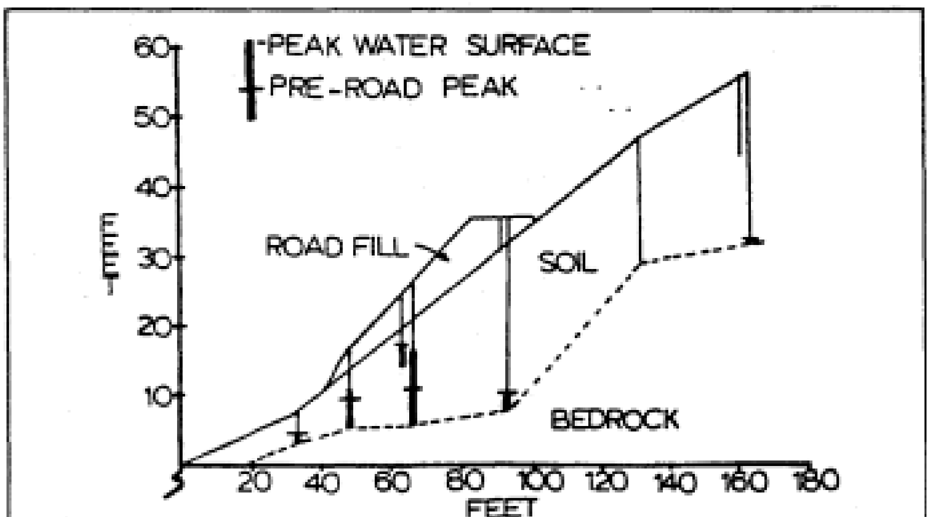

Figure 3. Unit E piezometer placement evaluating road fill influcences.

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. Sip piezometers were installed to hard bedrock (5 to 25 feet), two are at six feel (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

<u>Soil Piping</u>

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

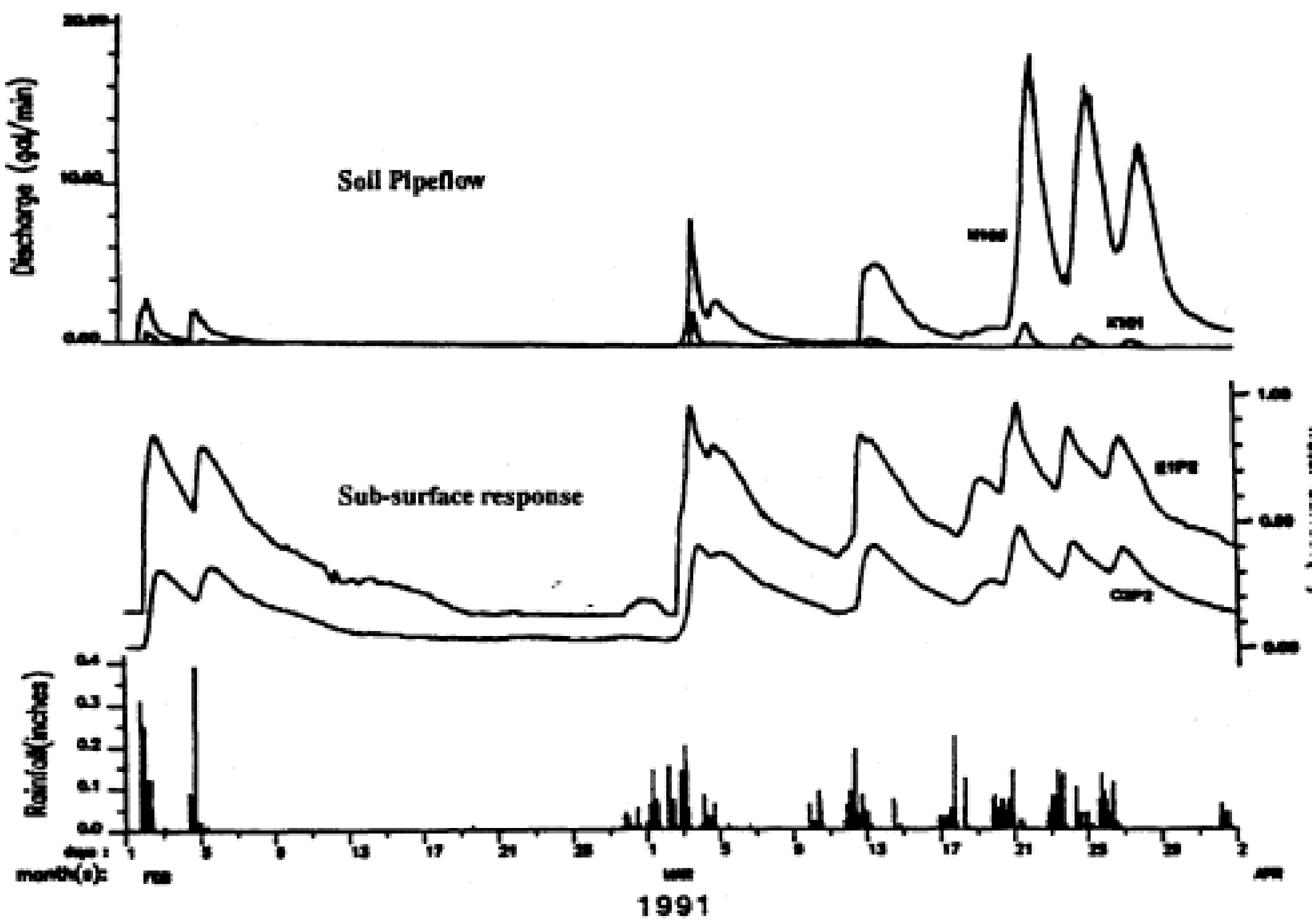

Figure 4. Soil pipe and piezometer response following precipitation.

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 midwinter, 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

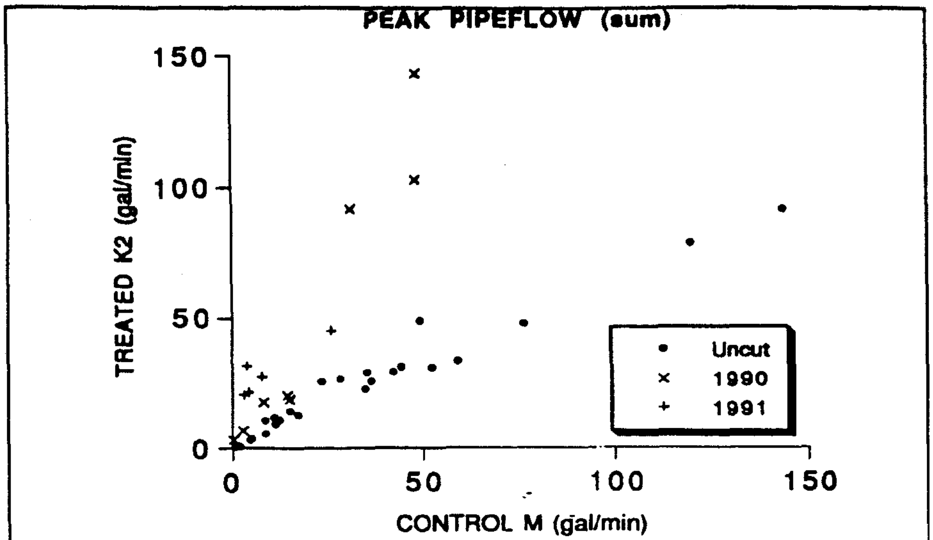

Figure 5. Pipeflow responses between control and harvested swales.

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.

<u>Groundwater</u>

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.

<u>Soil Moisture Levels</u>

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.

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