Analysis of the
1998 Garcia River Cross Sections

by
Dennis Jackson

A total of 24 cross sections were surveyed on the Garcia River between October 25 and October 30, 1998. Two cross sections were surveyed on the Kendall property near the power line crossing. Three cross sections were surveyed at Conner Hole, the site of the former USGS gaging station. Two cross sections were surveyed near the Eureka Hill Bridge crossing. Thirteen cross sections were surveyed between the gravel processing plant at Windy Hollow Road and the Kendall property. All of the cross sections were done with a Sokkia total station. Five cross sections were also surveyed in the estuary. The estuary cross sections are discussed in a seperate report.

The 1998 data was processed in the essentially the same manner as the 1996 and 1997 data. The procedure to calculate cross section area was modified slightly. The modified procedure was applied to all the previous cross sections. The report for 1998 was prepared by updating the 1997 report.

The purpose of this analysis is to see what the cross section data for the Garcia River can tell us about the equilibrium balance of the river. It is important to determine if the main stem of the Garcia River is in dynamic equilibrium or if it is aggrading or degrading (incising). In his book, Fluvial Processes in Geomorphology, (p267), Luna Leopold describes the concept of equilibrium as follows:

> *Despite difficulties of definition the concept of equilibrium is a useful one. It implies both an adjustability of the channel to changes in independent variables such as load and discharge and a stability in form and profile. The latter aspect, stability, is implied in the distinction between grade (equilibrium) and aggradation or degradation - the progressive building up or lowering of the channel bed. The unit of time here is significant; a channel in equilibrium may scour or fill. Those are short-lived changes. ... As a rule the condition of equilibrium has been observed, measured or thought of in terms of some intermediate time scale.*

Any single event may result in scour or deposition in a reach. However, net fill or scour, in a reach, would have to occur over a period of several years before the reach could be said to be aggrading or degrading. Figure 1 shows the passage of a bed material wave at the USGS gaging station at Conner Hole (details of the graph are discussed on page 2). Figure 1 provides evidence that the riffle crest below the gage rose from 1969 to 1975 and eroded from 1976 to 1983. Figure 1 shows that a period of fill was followed by a period of scour demonstrating Leopold's assertion that equilibrium acts on an intermediate time scale. It is my opinion that the mainstem of the Garcia River is in equilibrium when considered over a time scale of approximately 10 to 20 years.

Figure 1 shows that equilibrium can be achieved, over a decade, by alternating scour and fill. The processes of aggradation and degradation require different management responses. If the river is incising into its bed it would be prudent to curtail all gravel extraction from the main stem in order to protect the aquatic habitat and the bridges that cross the river. If the river is aggrading steps should be take to decrease the amount of sediment being delivered to the river.

The Garcia River is underlain by a clay layer in several locations. In 1996, at least 80 linear feet of clay were exposed along the right bank of the low flow channel on the Hooper property. The floods of 1997 deposited material in the low flow channel covering the clay. During the fall of 1990, the author observed blue clay being excavated from a trench in the low water channel downstream of Conner Hole. The trench was being dug in an unsuccessful attempt to keep the low water channel against the right bank. A layer of cemented aggregate was observed during the summer of 1992 just upstream of Conner Hole. During the summer of 1994 a layer of cemented aggregate was exposed at the upstream end of the access road from the gravel processing plant near Windy Hollow Road. The layer of cemented aggregate was further exposed in 1997.

If the river starts to incise the underlying clay or cemented aggregate will be further exposed. Exposure of cemented aggregate or the clay layers would degrade the aquatic habitat by reducing the area suitable for the production of benthic organisms. Exposure of clay layers would also degrade the water quality by introducing fine sediment directly into the water.

Long term monitoring of channel cross sections is an invaluable tool for observing trends in a river. Changes in thalweg depth and water surface elevations can be monitored over time. Recording the water surface elevation is an important part of the cross section survey. The water surface elevation gives a clue as to whether the downstream control for the section is building or eroding. Part of the variation in the water surface elevation is due to changes in the flow from year to year. However, annual changes in flow account for only a couple of tenths of a foot of change in the water surface elevation. This can be demonstrated by looking at a rating table for the abandoned stream gaging station on the Garcia River..

The term "stage" refers to the elevation of the water surface relative to the gage datum. A stream gaging station records changes in the stage over time. A rating table for a stream gaging station defines the relationship between the stage and the volume of flow or discharge. The last rating table for Conner Hole constructed by the USGS, No. 20, shows that when the stage is 2.1 feet the flow is 16.0 cfs. Increasing the stage by 0.1 foot to 2.2 feet results in the flow increasing to 25.5 cfs. This is an increase of 9.5 cfs, or a 60% increase in flow. Increasing the stage to 2.3 feet increases the flow to 35.0 cfs which is more than double the flow at 2.1 feet of stage. Thus a 0.2 foot change in stage was sufficient to double the flow, for the conditions that prevailed when rating No. 20 was constructed. The actual change in flow for a 0.1 foot increase in stage depends on the actual conditions in the river. However, the concept that during low flow conditions, a small change in water surface elevation (~0.2 feet) can result in doubling the discharge is an important consideration when evaluating cross sections. Changes in the water surface elevation of more than plus or minus 0.2 feet could be considered indicative of changes to the downstream control. Thus, a drop of more than 0.2 feet in water surface might indicate that the downstream control eroded. Similarly, a rise of more than 0.2 feet might indicate that material was deposited on the downstream control.

In April of 1991, Jackson prepared a graph of the stage for 100 cfs at the Conner Hole gaging station (see Figure 1). The data for the graph were obtained by looking at all of the available rating curves and reading the stage which was required for 100 cfs of flow and for 10 cfs of flow. The graph shows that the case for 10 cfs mirrors the 100 cfs case. Figure 1 shows that during the period, January 1969 to December 1969, the stage required for 100 cfs of flow was 3.5 feet. By February 1975 the required stage to produce 100 cfs flow had risen to 5.6 feet, a 2.1 foot increase in six years, for an average rate of 0.35 foot per year. The increase in stage required to produce 100 cfs of flow indicates that the downstream control (riffle crest) for the gaging pool must have risen. This implies that the low water channel of the reach below the gaging station aggraded relative to its 1969 condition. By December 1982 the stage required for 100 cfs of flow had dropped to 3.0 feet, a drop of 2.6 feet in seven years, for an average rate of 0.37 feet per year. The decrease in stage required for 100 cfs of flow implies that the riffle crest below the gage eroded, relative to its 1975 condition. Figure 1 indicates that a wave of bed material passed the USGS gaging station during the period January 1969 to September 1983, when the record ended because the station was closed.

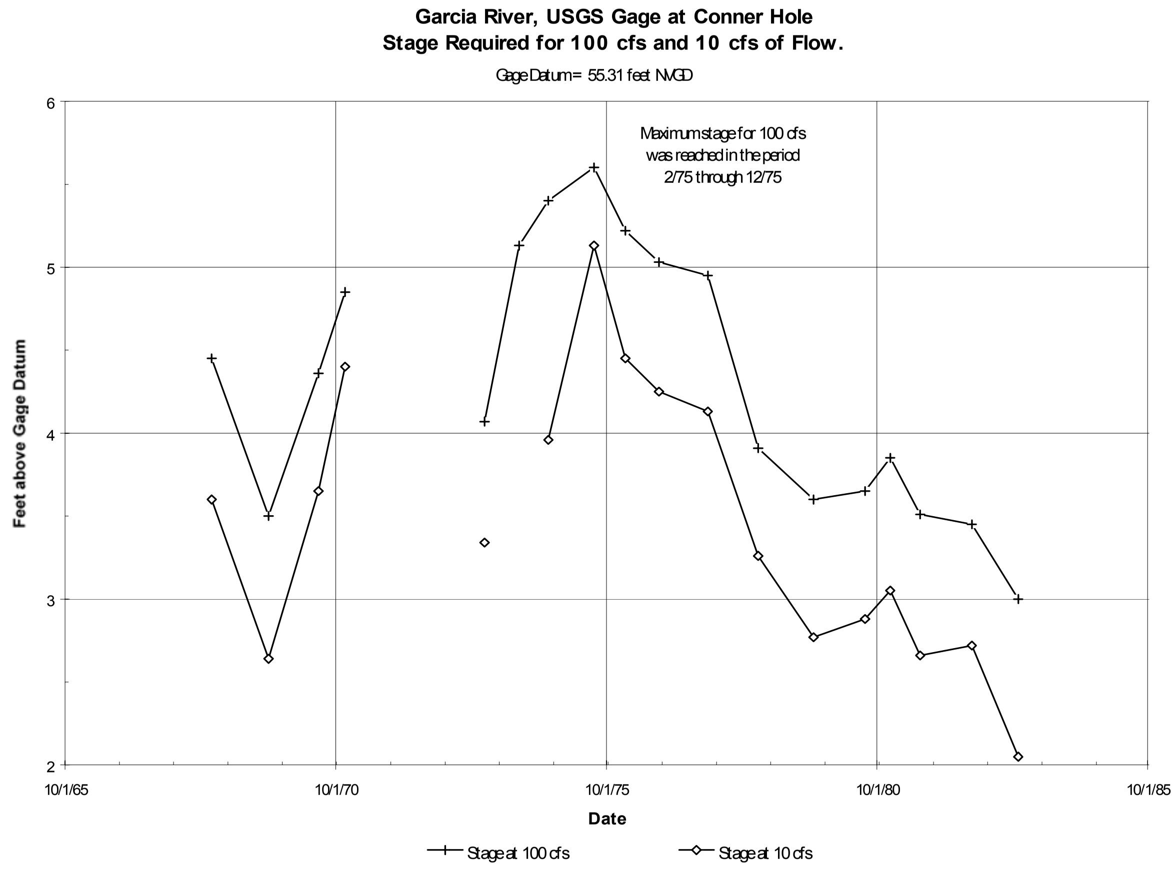


Figure 1. Water surface eleation (stage) required to maintain a floww of 100 cfs. The stage is grpahed at the mid-point of each rating period. For example, the maximum stage is plotted at the mid-point of the period February 1975 - December 1975.

It is strongly recommended that a low flow rating curve be developed for Conner Hole. This was attempted in 1992-1993 but soil creep disturbed the lowest staff gage at the station. A new staff was installed in the fall of 1995. The new staff is in a protected location and should not be subject to further soil creep. The development of a new low flow rating curve would relate the present conditions in the river to the graph of stage for 100 cfs of against time. This would indicate whether the river has incised relative to its 1983 condition.

Besides developing a new low flow rating curve it is recommended that the elevation of the present gage datum be confirmed by surveying the staff gages and USGS benchmark. USGS records give the gage datum as 55.31 feet NVGD and that the bronze marker on the right bank is 18.82 feet above the gage datum or 74.13 feet NVGD. The 1992 survey of the river, associated with the bentonite clean up, indicated that the elevation of the benchmark at the gaging station reported by the USGS was 0.59 feet lower than reported by the 1992 survey. However, all the cross section surveys have used the 74.13 feet elevation for the bronze marker, as reported by the USGS.

The following is a rough first approximation of the current stage required for 10 cfs of flow. The water surface at the Conner Hole cableway was 56.7 feet NVGD on October 23, 1996. Assuming that the flow was 10 cfs on October 23, 1996, and assuming that the gage datum reported by the USGS is correct then, the stage on October 23, 1996, was 1.4 feet (=56.7' - 55.3'). If these values are correct, the downstream control has eroded 0.6 feet relative to its 1983 condition. If, on the other hand, the gage datum is actually 55.9 feet NVGD (0.59 feet higher) in conformance with the 1992 survey, then the stage on October 23, 1996, was 0.8 feet above the gage datum. If the flow on October 23, 1996, was close to 10 cfs then this would mean that the downstream control had eroded 1.2 feet relative to its 1983 condition. It must be emphasized that this was only a rough calculation and may not reflect the actual condition of the river. The purpose of the calculation is to demonstrate the value of creating a low flow rating table for Conner Hole.

Flood Events:

The force of the flowing water and transported sediment works to shape the bed and banks of the river. The greater the flow of water the more energy is available to alter the channel. Figure 2 shows the recorded and synthesized annual peak flood discharges for Conner Hole. Table 1 lists the magnitude and frequency of the annual peak discharge since 1991. The flood frequency was recalculated using all available observed data, including the 1998 event. None of the synthesized data were used in recalculating the flood frequency. The flood frequencies shown in Table 1 were calculated by the Gumbel Extreme Value method. Figure 3 shows the recalculated flood frequencies.

The synthesized data were estimated statistically from the Navarro River gage by Graham Matthews. Instrument problems at the Navarro gage in 1992 resulted in no data for that year being available, so it was not possible to estimate the 1992 peak discharge fo rthe Garcia River.

The stage data for 1993 through 1996 was provided by the Friends of the Garcia. Since the fall of 1992 they have operated a stage recorder at the site of the abandoned USGS stream gaging station located at Conner Hole (Bar 13, river mile 8.2). The conversion from stage to discharge was done using a regression of discharge versus stage to extend the USGS rating table number 20 above a stage of 16.0 feet (see Appendix B for the regression output). A graph showing the regression and all the peaks recorded by the USGS is shown as Figure 4 The graph shows that all the peaks, except for nine, fall very close to the regression line. The nine peaks that do not lie on the regression line all occurred between 1963 and 1967 when the first rating table for the station was being constructed. Figure 4 shows that the regression equation derived from the upper portion (9.0' to 16.0') of rating curve number 20 provides a reasonable estimate of flood magnitude up to the top of the right bank at 18.0' above the gage datum. Thus, the estimated magnitudes of peak flood events at Conner Hole since 1993 are reasonably accurate.

Table 1. Annual Peak Flow and Return Period for 1991 to 1998. Return periods calculated using the Gumbel extreme value method with 32 years of data.

Year	Stage feet	Annual Peak Flood cfs	Return Period years
1991	Synthezied	9500	1.3
1992	n/a	n/a	n/a
1993	14.8	20,300	3.5
1994	8.8	4,400	1.0
1995	17.9	32,500	17.2
1996	12.0	11,700	1.5
1997	17.4	30,200	12.6
1998	14.4	18,900	3.0

The two year return period flood event ; of bankfull discharge or the dominate

Figure 2. Annual Peak Floods on the Garcia River at the Conner Hole Gaging Station.

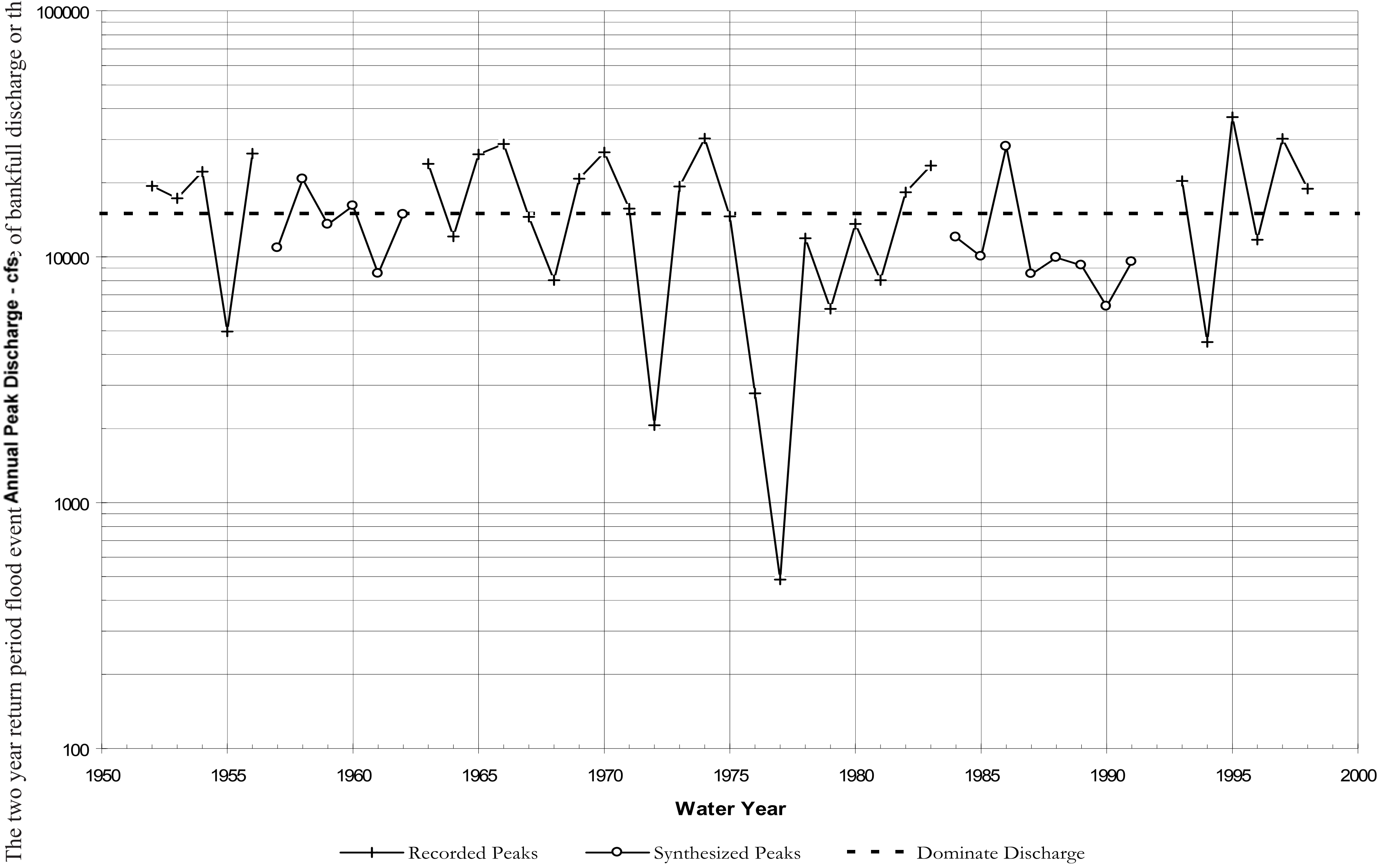


Figure 3. Annual Peak Flood Recurrence Interval for Garcia River Former USGS Gage No. 11467600, Based on 32 Years.

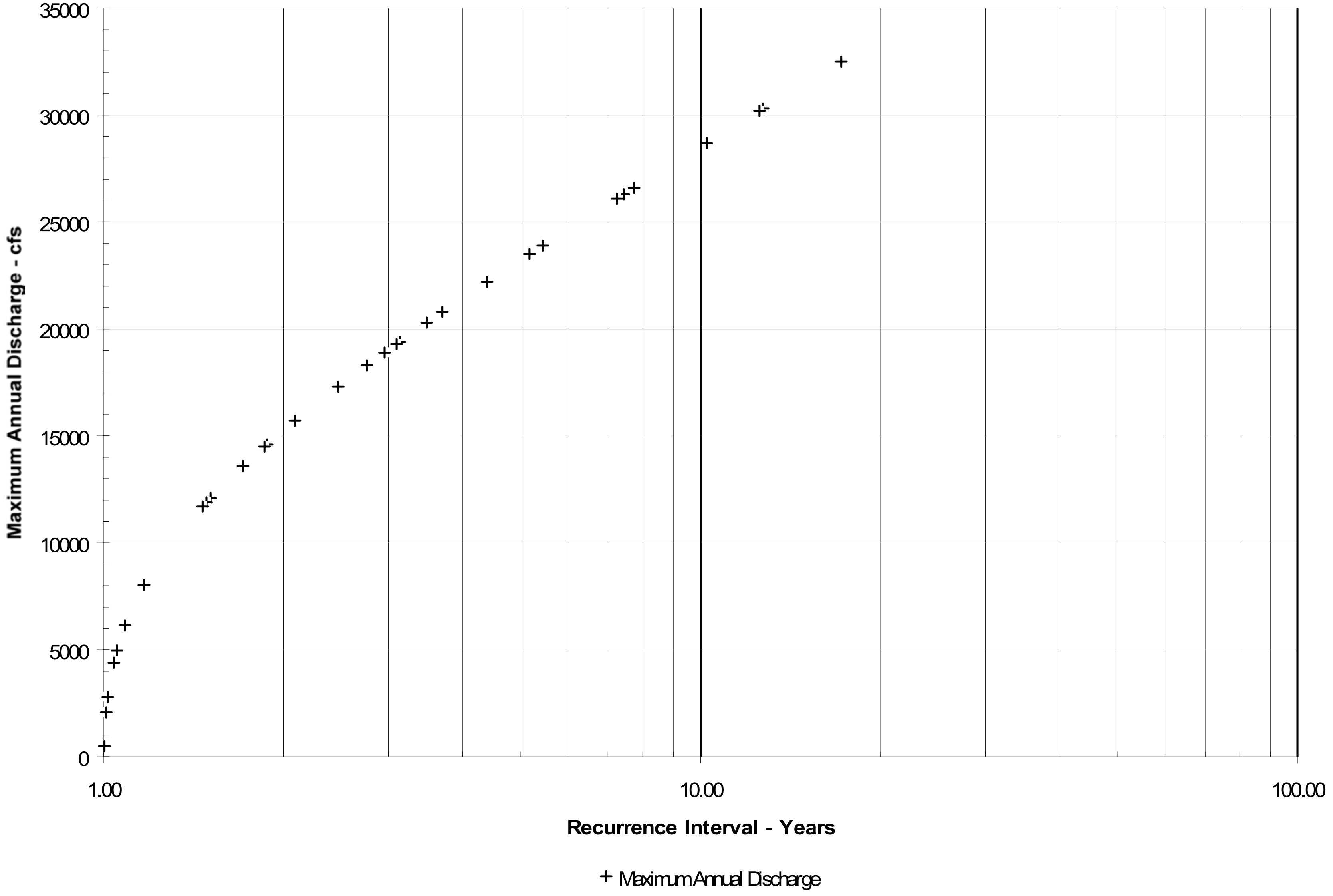
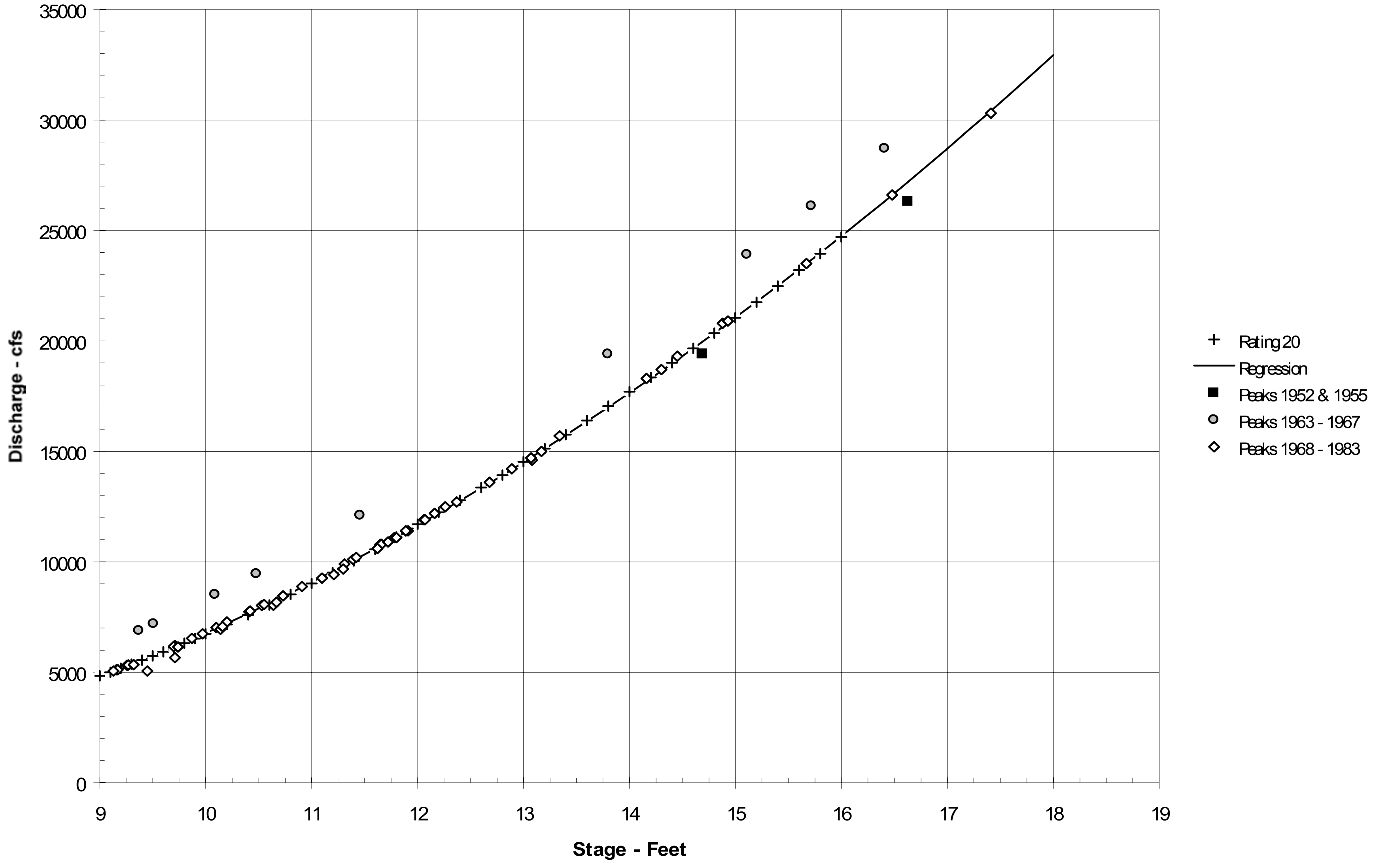


Figure 4. Garcia River at Conner Hole Regression
Based on USGS Rating Curve No. 20



discharge. In the 1996 Garcia River Gravel Management Plan, by Philip Williams and Associates (PWA) the two year return period flow is listed as 14,000 cfs at Conner Hole. The new flood frequency calculation gives the two-year return period flood as 15,200 cfs. The dominate discharge is defined as the flow, that over time, transports the majority of the sediment and is responsible for creating and maintaining the characteristic size and shape of the channel (Leopold et al., 1964). The dominant discharge for the Garcia River at the former USGS gaging station at Conner Hole was calculated to be 15,000 cfs by PWA (see Garcia River Gravel Management Plan.). The new flood frequency calculation assigns a 1.95 year return period to the dominate discharge. Thus, there is little difference between the two-year flood and the dominate discharge for the Garcia River.

Some flood events seem to cause pools to fill and other floods scour pools. Tom Lisle, a researcher at the USDA Pacific Southwest Range and Experiment Station in Arcata, CA, has shown that for flows less than a certain critical discharge, pools are subject to deposition and riffles are subject to scour. Above the critical discharge, the situation reverses and the pools are zones of scour and riffles are deposition zones. Lisle's critical discharge has not been determined for the Garcia River. The 1996 topographic map of the Garcia River channel in the bentonite study area suggests that the peak flood event of 1996 (11,700 cfs at Conner Hole) was greater than Lisle's critical discharge so the pools were scour zones. One pool was scoured to a depth of 8 feet and another was scoured to a depth of 6 feet.

It would be useful to review the sequence of topographic maps made to monitor the bentonite spill and observe the change in pool depth over time. In particular, it would be useful to see if the maps support the notion that the 1994 peak flow event of 4,500 cfs is less than Lisle's critical discharge. If the 1994 event was less than the critical discharge the map, made in the fall of 1994, should show deposition in the pools. Knowing when flows are less than Lisle's critical discharge would help separate events that cause temporary filling from long term aggradation.

Origin of the Sediment Wave:

The graph of Stage Required for 100 cfs of Flow (Figure 1) suggests a wave of sediment past the Conner Hole Gaging station between 1968 and 1983. Figure 5 is a graph all of the peak discharges recorded at the Conner Hole gaging station. Figure 5 suggests the cause of the sediment wave. The graph of the sediment wave, Figure 1, shows that the rise of the sediment wave started in 1969 and crested in 1975. Figure 5 shows that only two of the eight years between 1968 and 1975 had peak discharges less than the dominant discharge of 15,000 cfs. However, for the next eight years only two years had peak discharges greater than the dominate discharge. (These observations do not imply that there is an eight year weather cycle on the Garcia).

The occurrence of peak discharges equal to or greater than the dominant discharge implies above average rainfall and saturated conditions in the watershed. The primary cause for a slide to occur on steep topography is saturated soil. Saturated conditions also increase the occurrence of debris flows. Slides terminating in a watercourse are an important means of delivering coarse and fine sediment to the channel. Debris flows are slurries of earth and water that travel at high speed down steep (channel slope > 8%) canyons. Overland flow, on the other hand, delivers only fine material to the river system, assuming that an adequate vegetated buffer exists. The steep topography of the upper watershed suggests that debris flows can occur on the smaller steep tributaries. Personal observation of the mainstem of the Garcia River between Voohris Grove and the Eureka Hill Bridge revealed several large slides that terminate directly in the river. Many of the bars above the bridge had an abundance of cobble size material on the surface. Below Eureka Hill Bridge there are fewer slides terminating in the river and cobble is less abundant.

Between 1968 and 1975, when the sediment wave was cresting, there were probably several significant slides and debris flows delivering material directly to the river. Furthermore, the numerous large peak flows provided the required power to transport the introduced material down the channel towards the gaging station. Between 1976 and 1983, when the sediment wave was waning, there were probably very few slides so the sediment supply to the river was greatly reduced. Furthermore, the weaker flows lacked the power to transport the larger size classes of the material delivered to the channel. Most of the material transported during the dry period (1976-1983) was probably eroded from the stored material on the bed of the channel.

Figure 2 shows that the twenty-four year period from 1954 to 1975 had a total of sixteen years with annual peak discharges greater than the dominate discharge (66%), indicating that the period probably had a large input of material into the channel and the power to transport the material. Figure 2 also shows that the twenty-one year period from 1976 to 1996 had a total of five years with annual peak discharges greater than the dominate discharge (25%), indicating that very little new coarse material was delivered to the channel.

The flood of 1993 appears to be the start of a period characterized by frequent large peak discharges. Four of the last six years (66%) have had peak discharges greater than the dominate discharge. Thus, if the sequence of years with large discharges continues it is likely that large amounts of new material will be delivered to the channel and a new sediment wave will travel down the river. Of course, a dry period could begin at any time, which could potentially result in further incision.

The Garcia River has probably been subjected to several such cycles of heavy input and transport followed by a lack of input and reduced transport power. These cycles result in waves of bed material moving down the channel. It is likely that this process is continuing today and will also occur in the future. Of course, we can not predict future sequences of wet and years.

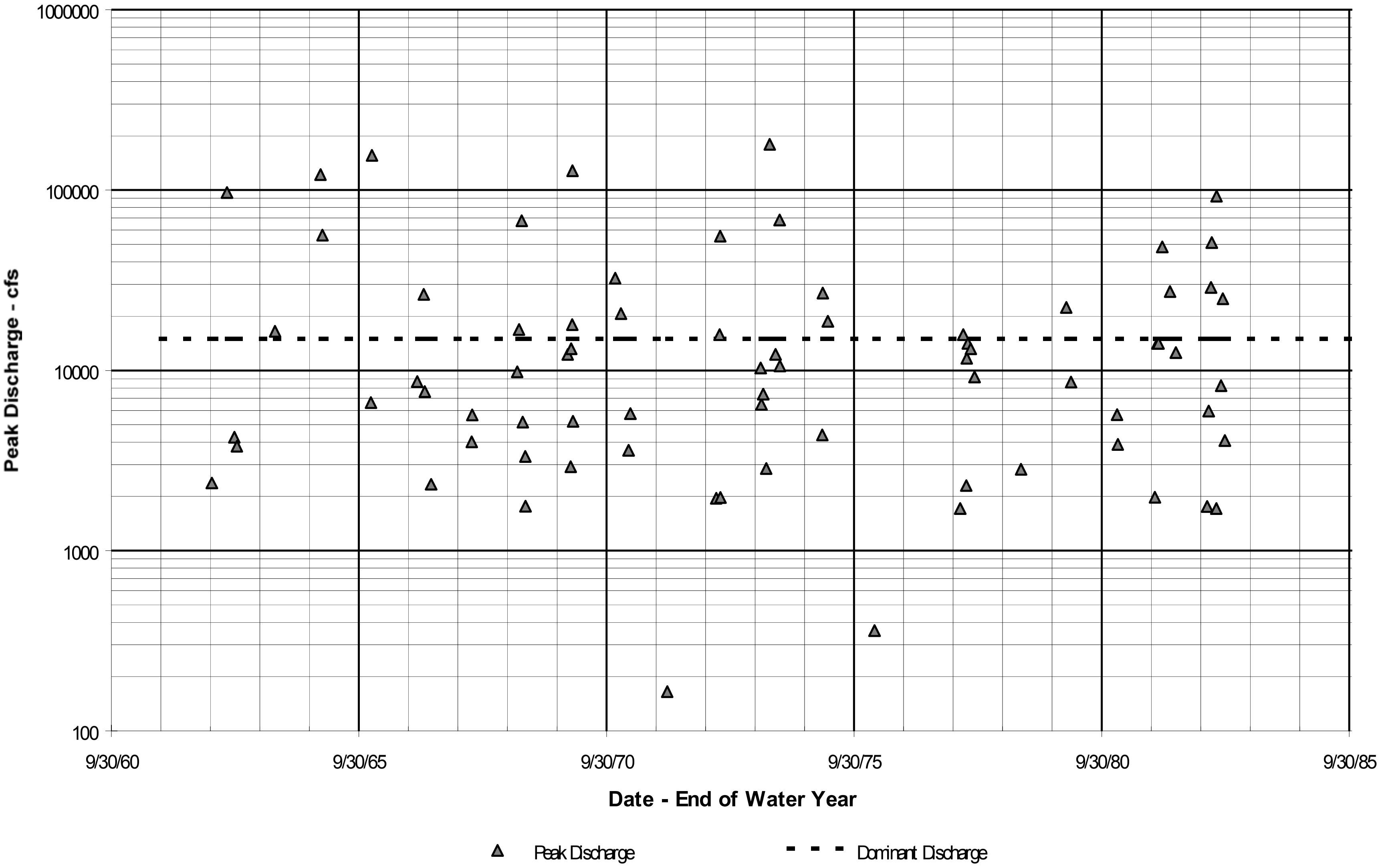
The Conner Hole gaging station is 0.7 miles below the North Fork. The North Fork is the last large tributary to the Garcia. Below the confluence of the North Fork the river tends to be in a wider valley so there are fewer slides that can contribute material directly to the river. Thus below the North Fork the major source of bed load is the material stored in the bed and banks of the river.

Shape of the Sediment Wave

The shape of a wave can be characterized by its amplitude (height), wavelength and period. A sediment wave has a shape in time and a shape in space. Figure 1 shows the shape of a sediment wave in time. Figure 1 is based on repeated measurements taken at the same location (Conner Hole) over many years. The amplitude of the wave in Figure 1 is approximately 2 feet. In January 1969 the gage height for a 100 cfs flow was 3.5 feet. By February 1975 the gage height for a 100 cfs flow had increased to 5.6 feet. The rating remained at 5.6 feet for a 100 cfs flow until December 1975, a period of almost one year. By January 1979 the gage height for 100 cfs of flow was 3.6 feet. Thus, it took five years to for the 100 cfs gage height to reach its maximum and four years to return to near its 1969 level. Thus, Figure 1 gives some information about the period of the sediment wave, that is the time it takes for the wave to pass a fixed point. However, Figure 1 does not given any information about the wavelength.

To understand the shape of a sediment wave in space we must understand how material is stored in the river channel. Material is stored in the low water channel, on bars and in the banks/floodplain. The low water channel is made up of pools, glides, runs and riffles. Riffles occur at the downstream end of pools and control the flow out of the pool and the depth of the pool. Lisle has pointed out that scour occurs in pools and coarse material is deposited on riffles during significant flood events. Below a certain flow the situation reverses and material is deposited in pools and transported over riffles. Material in the low water channel is exposed to a wider range of flow conditions than the material stored on bars or in the banks/floodplain. However, the flows that are confined to the low water channel have less ability to transport

Figure 5. USGS Peak Discharges for Garcia River at Conner Hole for Water Years 1963-1983



material than larger flows and can not change the path of the low water channel. However, flows that do not cover a bar might still be able to rearrange the material in the low water channel.

Bars are the most obvious location of stored material. Flows close to bankfull are required for material to be deposited or eroded from the surface of the larger bars. As a bar grows in size it effects the distribution of forces exerted on the bar surface and channel bottom. The change in forces act to limit the growth of the bar. For example, as a bar increases its height less water can flow over its top, the shallower water above the bar can carry less material so the increase in bar height is slowed. Similarly, an increase in bar height can increase the scour in the low water channel which can lead to the erosion of the edge of the bar limiting its lateral growth. The flows that can cover the larger bars have the power to significantly alter the low water channel by changing its course or causing significant scour or deposition.

The banks/floodplain also store material. Floods that over-top the banks can cause deposition on the floodplain and can cause erosion of the banks. The erosion of the banks can be caused by scour of the low channel resulting in the banks becoming too steep. Changes in the direction of flow can cause the full force of the river to be directed against a bank which can then be quickly eroded. Banks can also be eroded at the point where flood waters return to the main channel.

Figure 1 tracks the elevation of the riffle crest that controls the flow out of the gaging station pool. That is, Figure 1 is a measure of the amount of material stored in the low water channel. Deposition on the riffle crests may or may not be accompanied by a significant growth of the gravel bars in the reach. Similarly, erosion of the riffle crests may or may not be associated with a decrease in the size of the gravel bars in the reach.

A picture of the shape of the wave, from Figure 1, in space is not available. A survey of the elevation of the riffle crests over several miles of channel would be required. The resulting longitudinal profile would have to be corrected for gradient. There is no data for the Garcia River that shows the shape of a sediment wave in space. So no information about wavelength or the velocity of the sediment wave is available.

Of coarse, it is a simplification to think that there is only a single sediment wave traveling down the Garcia River. Each new input event can be associated with a wave of bed material that travels down the channel. However, these waves become superimposed on one another and appear, over time, as an irregular wave. Several factors influence the shape of a sediment wave as it travels down the river towards the ocean. The following are of some of the factors that determine the shape of a sediment wave in time and in space.

the pattern of wet and dry years,
the amount and caliber of input,
the location of the sediment inputs along the drainage network,
gravel extraction or channel modification

The pattern of wet and dry years is perhaps the most important factor in producing a sediment wave on a river. The sediment wave pictured in Figure 1 demonstrates the effect of a period of wet years followed by a period of dry years. The five years of increasing gage height (1969-1975) was a wet period with 16 flood peaks in excess of 10,000 cfs. During the period with the maximum gage height for a 100 cfs flow (1975) there were 5 events with peaks greater than 10,000 cfs. The four years of decreasing gage height (1975-1979) was a dry period with only 6 flood peaks in excess of 10,000 cfs.

The pattern of wet and dry years also influence the amount and caliber of coarse material delivered to the river channel. Large peak flood events are the result of saturated conditions in the watershed which trigger slides and debris flows. The location of slides and debris flows determine the amount of coarse material delivered to the stream network. For example, slides that terminate in a stream deliver material directly to the drainage network, whereas, slides that end on a hillslope do not directly contribute material to the drainage network. The soils, geology and topography determine the type, nature and location of potential areas of slides and debris flows in a watershed. Land use practices, such as road construction and maintenance, forestry practices and agricultural practices, play an important role in determining which potential slides are activated. Natural disturbances, such as fire, also play a role in activating potential slides.

The maximum caliber (size) of load delivered to the stream channel is determined by the geology of the watershed. The actual size of material delivered to the drainage network depends on the topography, location of slides, the presence of vegetated buffers between slides and the drainage network, and land use practices.

In general, waves tend to dissipate as they travel. For example, the ripples from a rock thrown into a quiet pond decrease in size with distance. Similarly, the amplitude of a sediment wave can be expected to decrease with distance from the sediment input zone of a watershed. There is not enough data for the Garcia River to show how the amplitude of a sediment wave changes as the wave moves down the channel. Similarly, except for Conner Hole, we do not know when the peak of the sediment wave, pictured in Figure 1, passed any other point on the Garcia River.

The amount of bedload transported out of a short section of river is determined by the amount of material transported into the section and the amount of erosion/deposition that occurs in the section. When gravel is extracted from a section the shape of the channel is modified in a manner to encourage more deposition than would have otherwise have occurred. Thus, less material is transported downstream. Hence, the amplitude of the sediment wave will be decreased as it passes a gravel extraction site. The reduction in amplitude should persist after gravel is no longer extracted.

Areas of Bank Collapse

Four areas of significant bank failure have been observed on the Garcia River below Eureka Hill Bridge at Bar 9, on the Hooper and Kendall properties and below Windy Hollow Road.

At Bar 9, the 1995 flood event exposed several large vertical redwood stumps on the left bank. These stumps were exposed when a section of bank was eroded back feet . The base of the stumps is at about the low water level. Bar 9 is just upstream from the Buckridge gravel extraction area on Bars 11 and 12. Besides the usual bar skimming operations a long deep trench was dug along the thalweg in 1990. The trench destabilized the river bed. Surveys that were conducted before and after flows effected the trench show that the river bed lowered upstream of the trenching operation. The incision exposed wood pilings in the river near Bar 10 and further exposed a group of boulders upstream of Bar 11. It is reasonable to expect that the trench induced incision played a role in destablizing the bank at Bar 9.

A significant length of the left bank collapsed at Bar 19 on the Hooper property. Since 1993 the thalweg shifted from the center of the channel to the right bank and back to the left bank. There may be a relationship between the shifting of the thalweg and the passage of the sediment wave. This event has not been researched enough to determine a likely cause.

In 1996 several hundred feet of bank collapsed on the right bank on the Kendall property downstream of Bar 26. The 1997 flood event resulted in several hundred additional feet of bank collapse. Review of aerial photographs taken in 1972, 1988, 1990, 1993, 1995 and 1996, see Figure 6, show that by 1988 the low water channel was positioned to deliver the full thrust of the river to the bank that would fail. The only thing that was lacking from 1988 to 1993 was a sufficiently large flood event to cause the bank to col-

Figure 6(a). Kendall bend in 1972. Flow is from right to left. North is towards top of photo. See Figure 8 for location of Kendall cross sections.

Figure 6(b). Kendall bend in 1988. Flow is from right to left. North is towards top of photo. See Figure 8 for location of Kendall cross sections.

Figure 6(c). Kendall bend in 1990. Flow is from right to left. North is towards top of photo. See Figure 8 for location of Kendall cross sections.

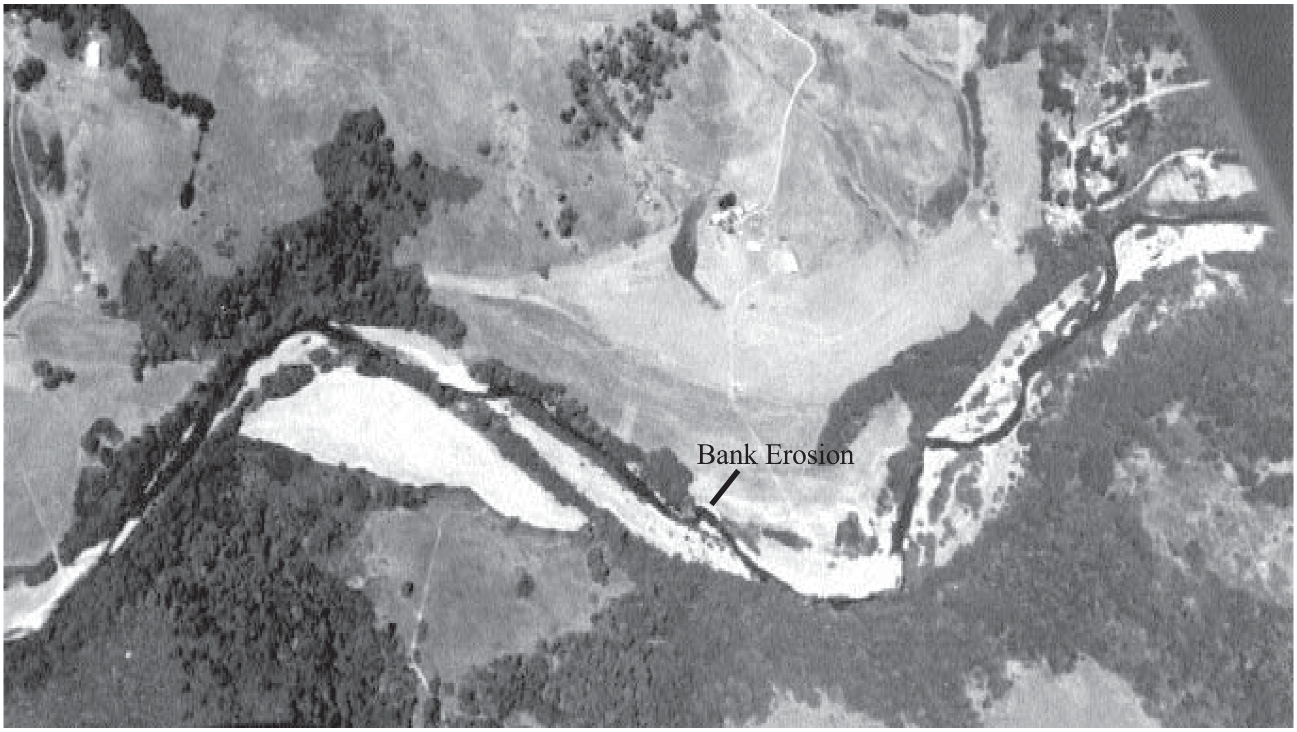


Figure 6(d). Kendall bend in 1993. Flow is from right to left. North is towards top of photo. See Figure 8 for location of Kendall cross sections.

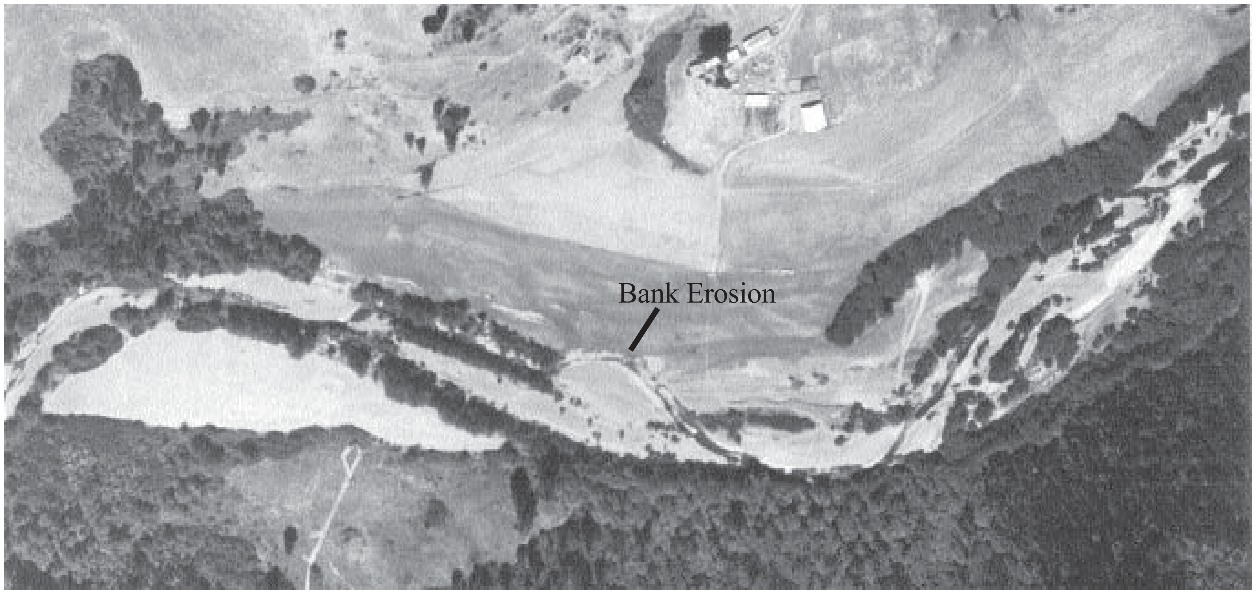


Figure 6(e). Kendall bend in 1995. Flow is from right to left. North is towards top of photo. See Figure 8 for location of Kendall cross sections.

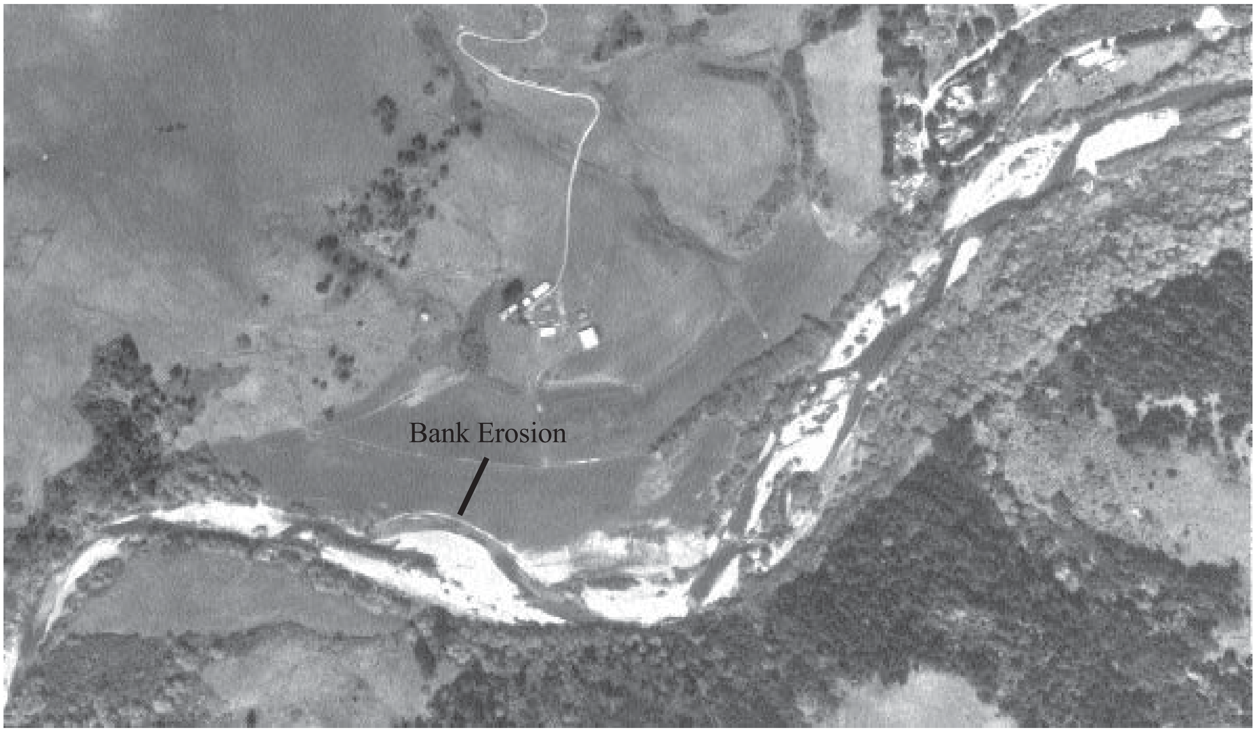


Figure 6(f). Kendall bend in 1996. Flow is from right to left. North is towards top of photo. See Figure 8 for location of Kendall cross sections.

lapse. What caused the low water channel to shift from its 1972 position to its 1988 position?

The sediment wave pictured in Figure 1 had not yet reached its maximum height in 1972. Since the Kendall property is 3 miles downstream of Conner Hole, it is certain that the crest of the sediment wave arrived at Kendall's sometime after 1972. In 1983 the sediment wave had completely passed Conner Hole. The 1972 aerial photo (Figure 6a) shows a single long bar on the left bank extending from the turn at the Manchester Rancheria down to the Kendall turn. The long bar is almost completely free of vegetation. The 1972 image still shows the effect of the winter of 1970 which had four floods greater than 10,000 cfs, including a 26,600 cfs event. Between the 1972 photo and the 1988 photo there were five years with events larger than the dominate discharge of 15,000 cfs, including a 30,300 cfs event in 1974. The 1988 photo (Figure 6b) shows that the low water cuts the single long bar between the Rancheria and the Kendall bend. It is possible that the passage of the sediment wave contributed to building the Bar 25 at the Kendall bend resulting in the river entering the bend later than it did in 1972. Another possibility is that the mining of Bar 23 at the Rancheria in the late 1980's lowered the bar enough to allow the course of the low water channel to shift to the left bank further upstream at the Rancheria resulting in the river approaching the Kendall bend differently.

The Garcia River channel below Windy Hollow Road experienced numerous bank failures in 1996 and 1997. The channel below Windy Hollow Road was narrower than the channel above Windy Hollow. Aerial photos show gravel deposits in the field downstream of Windy Hollow Road on the south bank indicating flow left the river channel and traveled along the base of the bluff towards Hathaway Creek. Logs were placed in the banks along the channel below Windy Hollow Road many years ago. The channel through that reach has been made artificially narrow. The recent large floods have restored some of the lost capacity.

Bentonite Monitoring Cross Sections:

The gravel bars upstream of Windy Hollow Road were mined by Baxman Sand and Gravel until 1991. Baxman Sand and Gravel established eight cross sections to monitor the river. Five of Baxman's eight cross sections were found and surveyed by the Mendocino County Water Agency (MCWA) in 1991. The 1991 survey was part of the Resource Conservation District's (RCD) Watershed Assessment.

In 1992 a bentonite spill occurred on an unnamed tributary that enters the Garcia River on the left bank, upstream of the processing plant. The area was surveyed by Ross Stevenson and Associates in 1992 as part of the clean up of the spill. However, the resulting map was never converted to the state plane coordinate system. Consequently, the results of that survey are not available for comparison.

Fourteen cross sections were surveyed by MCWA in 1993 and 1994 as part of the bentonite spill monitoring program. Graphs of the cross sections surveyed in 1998 are in the appendix. Welty and Associates prepared topographic maps of the reach in 1995 and 1996 as part of the spill monitoring program. Figure 7 is a map of the cross section endpoints which shows the relative locations of all of the cross sections established by the Mendocino County Water Agency (MCWA) in 1993. On the attached map, Bax-1 through Bax-6 refer to cross sections established by Baxman Sand and Gravel and recovered by MCWA in 1991. Bar 30 lies between Bax-1 and Bax-4. The 1995 and 1996 contour maps were created using aerial photos and ground control. The left bank of the river is under a dense canopy of riparian woods. The thick forest cover decreases the accuracy of aerial photo interpretation of ground elevations. Welty and Associates took only a few ground control shots in the riparian forest. The 1993 and 1994 MCWA surveys also took only a few shots in the dense riparian forest on the left bank. Therefore, the year to year variation of the left bank may be an artifact of the survey techniques and may not represent real changes in topography of the left bank.

The 1996 topographic map for the reach shows that all of the significant pools are located away from the cross sections. The historic pool between cross section 302 and Baxman-2 deepened and was about 8 feet deep in 1996. However, the pool appeared to be approximately 6 feet deep in 1997 and about 5 feet in 1998.

In 1996 there was a 6 foot deep pool between Baxman-4 and cross section 1802. A diving platform was constructed next to this pool. This pool was between the downstream end of Bar 30 and the upstream end of Bar 31. In 1997 the river eroded the head of Bar 31 and deposited material extending Bar 30 downstream past cross section 1802. The low flow channel now crosses the head of Bar 31 and the 1997 location of the pool was shifted approximately 100 feet to the west-southwest. The pool, in 1997, was about 4 feet deep.

The head of Bar 31 continued to erode in 1998. The low-flow channel at Baxman-4 shifted about 25 feet across the head of Bar 31. The 1998 right edge of the low-water channel at cross section 1802 was near its 1997 position. However, the width of the low-water channel increased by about 25 feet by eroding an additional 25 feet of Bar 31.

In 1992, the river began to erode the access road in the channel connecting the processing plant to Bar 30. The road was a bench cut along the bottom of the right bank. This section of river lies between cross section 802 and Baxman-4. The 1993 event completely removed the road and eroded the right bank just downstream of Bar 30, causing a few trees to fall into the river. The 1995 flood eroded the right bank a little more.

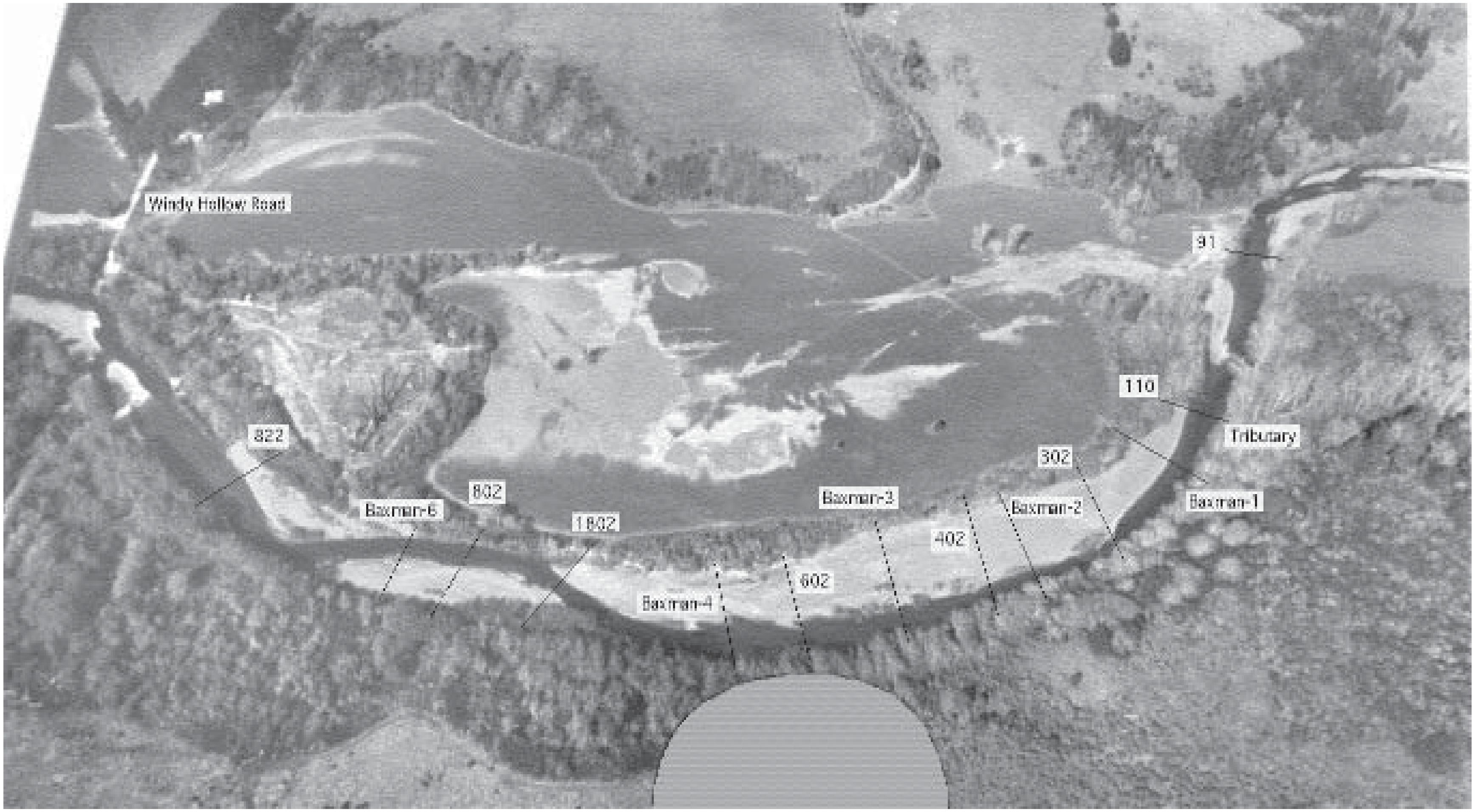
A 4.5 foot deep pool was located about 225 feet upstream of cross section 92 in 1996. No information about this pool was obtained in 1991. It is possible that the 1992 survey by Ross Stevenson & Associates recorded the channel bottom in the area of this pool. The 1993 survey showed a pool in this general location. This area was not visited in 1997 or 1998.

Until 1993, the County traditionally installed a temporary summer crossing at Windy Hollow Road. The summer crossing was a temporary bridge structure. Placement of the bridge required significant grading in the river channel. Berms were also constructed to prevent people driving up the river bed. The bridge structure was removed in the fall. It is unclear what effect the berms and grading had on bedload transport through the reach since no cross sections were taken near the crossing.

During near bankfull events, a portion of the flow leaves the river channel along the south bank in the vicinity of Windy Hollow Road and flows along the bluff to the south of the river. This overland flow re-enters the river just above the estuary. This flow reportedly closes Highway 1, at the base of the bluffs south of the river, when the staff gage on the old pier at Eureka Hill Bridge reads about 12 feet. The loss of this flow reduces the sediment transport power of the river below Windy Hollow Road. The loss of transport power below Windy Hollow Road implies that the bed material size should be smaller below Windy Hollow Road. The channel below Windy Hollow appeared to be narrower than the channel upstream. It is suspected that bank stabilization efforts resulted in a reduction of channel capacity below Windy Hollow. The 1997 flood caused extensive bank erosion downstream of Windy Hollow Road and may have restored some of the lost channel capacity.

The 1995 flood event was the largest flood ever recorded on the Garcia River. During this event several hundred feet of bank collapsed on the Kendall property, about 2,000 feet upstream of the study reach. Several hundred additional feet of bank on the Kendall property collapsed during the January 1997 flood event, the third largest on record. Coarse material from the bank collapse appears to have been deposited

Figure 7. Map of Bentonite monitoring cross sections. Photo from 1997. Photo shows flood deposits on the floodplain.



on Bar 30. However, the low flow channel adjacent to Bar 30 appears to be, on average, slightly lower relative to 1993 and relative to 1997. Thus, relatively little deposition occurred in the low flow channel adjacent to Bar 30 in 1998 supporting the notion that a high bar helps prevent deposition in the low flow channel.

The Tables 2, 3 and 4 summarize the 1991 through 1998 survey data. Table 2 and Figure 10 show the maximum water depth at each cross section. The Table 3 and Figures 8 and 9 give the water surface and thalweg elevation. Table 4 gives the cross section area and the relative net change in cross section area.

The relative change in thalweg elevation shown in Table 3 and Figure 9 shows that, from 1993 to 1998, the overall tendency was for the water surface and thalweg to rise upstream of the Baxman-1 cross section. During the same period the water surface and thalweg lowered between cross section 302 and Baxman-4. This suggests that material from the Kendall bank collapse was deposited in the low-water channel of the upper reach but, material was eroded from the low-water channel adjacent to Bar 30 and deposited downstream of the Baxman-6 cross section. The deposition at the downstream end of the reach may also be associated with the loss of flow over the left (south) bank at Windy Hollow Road and the resulting decrease in transport capacity.

Bar 31 was extended downstream. In 1993 Bar 31 ended at Baxman-6. By 1998 Bar 31 extended just downstream of cross section 822. The downstream extention of Bar 31 was accompanied by a retreat of the upstream end of Bar 31. The low-water channel also shifted to the right bank from the left bank downstream of Baxman-6.

The cross sectional area was calculated for each cross section. The area calculation was performed by setting a reference elevation, at each cross section, above the river bed. The area by coordinate method was used to determine the area between the plane of the reference elevation and the bed. The method is the same as that used for calculating the area of flow when making a discharge measurement. An increase in cross sectional area represents erosion. A decrease in cross sectional area represents deposition. Because of the inherent errors in data collection, a minimum of a one percent change in cross sectional area must occur before a real change can be said to have occurred. The cross sectional area was calculated for the low water channel and the dry portion of the channel. The area below the water surface was also calculated. The percentage change in cross sectional area relative to 1993 for each portion of the cross section was also calculated. The results are shown in Table 4.

There is an inherent problem with partitioning the channel into the dry portion and the wetted portion. A change in water surface elevation due to a change in the downstream control can change the cross sectional area of the low flow channel. For example, if the downstream control builds, the water surface will rise which increases the area of the low flow channel. Thus, the resulting change in cross sectional area is may not necessarily indicate deposition or erosion at the cross section.

Table 4 gives the net change in cross sectional area, from 1993 to 1998 for each of the thirteen cross sections. The net change in area for each year was calculated by dividing the area for a given year by the area for 1993. Since each cross section had a different absolute cross sectional area, the percentages in Table 2 are not truly comprable between cross sections. That is a change of 5% at one cross section is not equivalent, in absolute area, to a 5% change at another cross section.

The data in Table 4 reveals that, relative to 1993, there was a decrease in area (deposition) at 10 of the 13 cross sections in 1998, relative to 1993. Twelve of the thirteen cross sections had a decrease in the area (deposition) outside of the low-water-channel. The data shows that most of the deposition was in the Dry Area of the channel. Only 3 of the 13 cross sections showed a decrease in area (deposition) relative to 1993. The graphs of the cross sections show that the height of the bar steadily increased from 1993 to

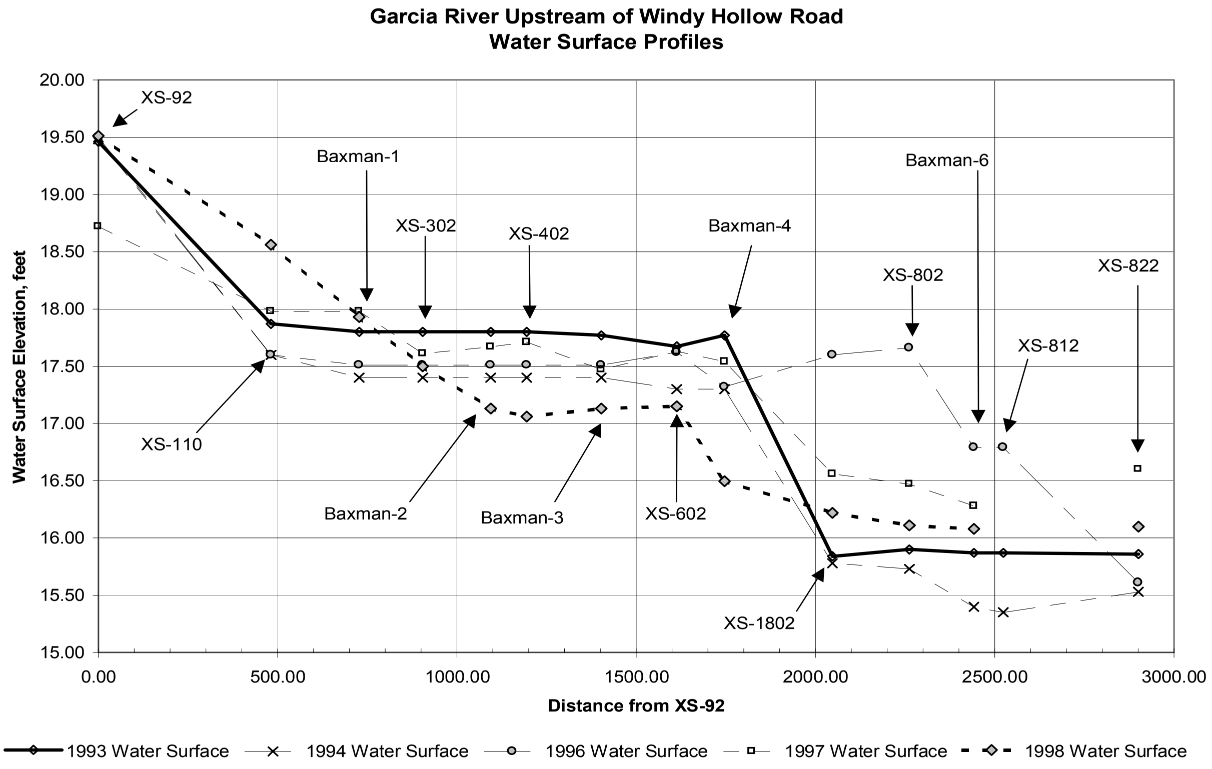


Figure 8. Water surface profiles for the Bentonite Monitoring cross sections.

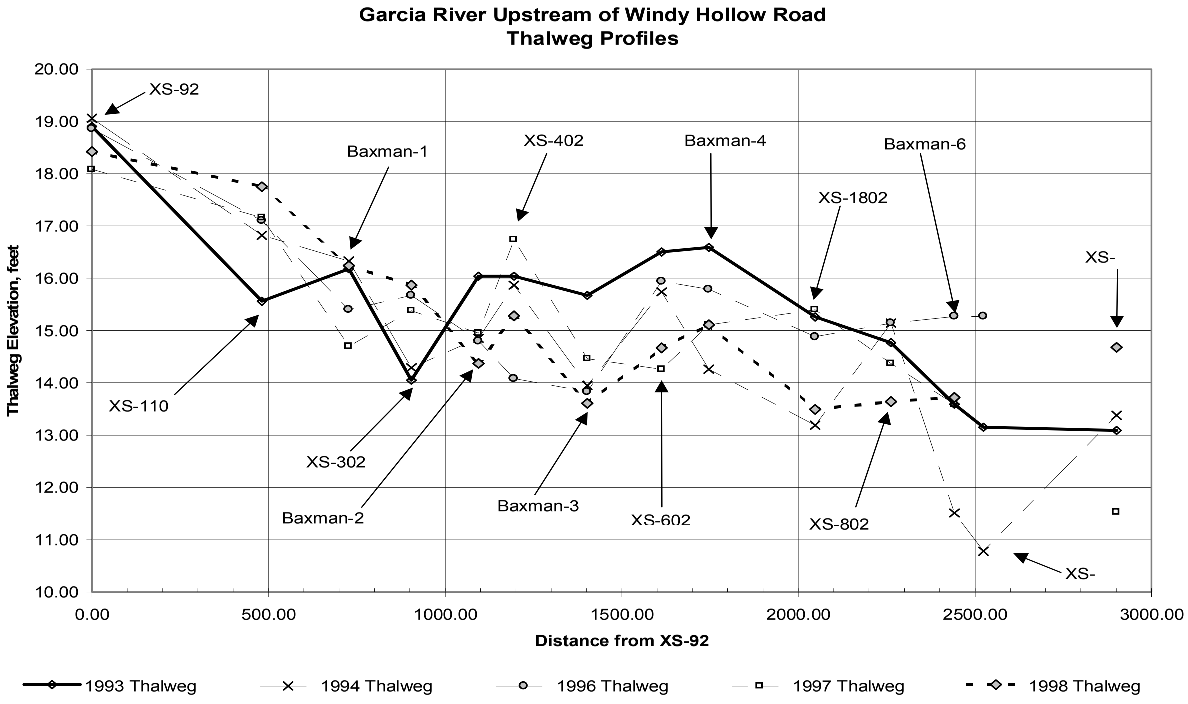


Figure 9. Thalweg profiles for the Bentonite Monitoring cross sections. The line connecting the thalweg data points does not represent the thalweg between the data points. Data points are connected by lines for clarity only.

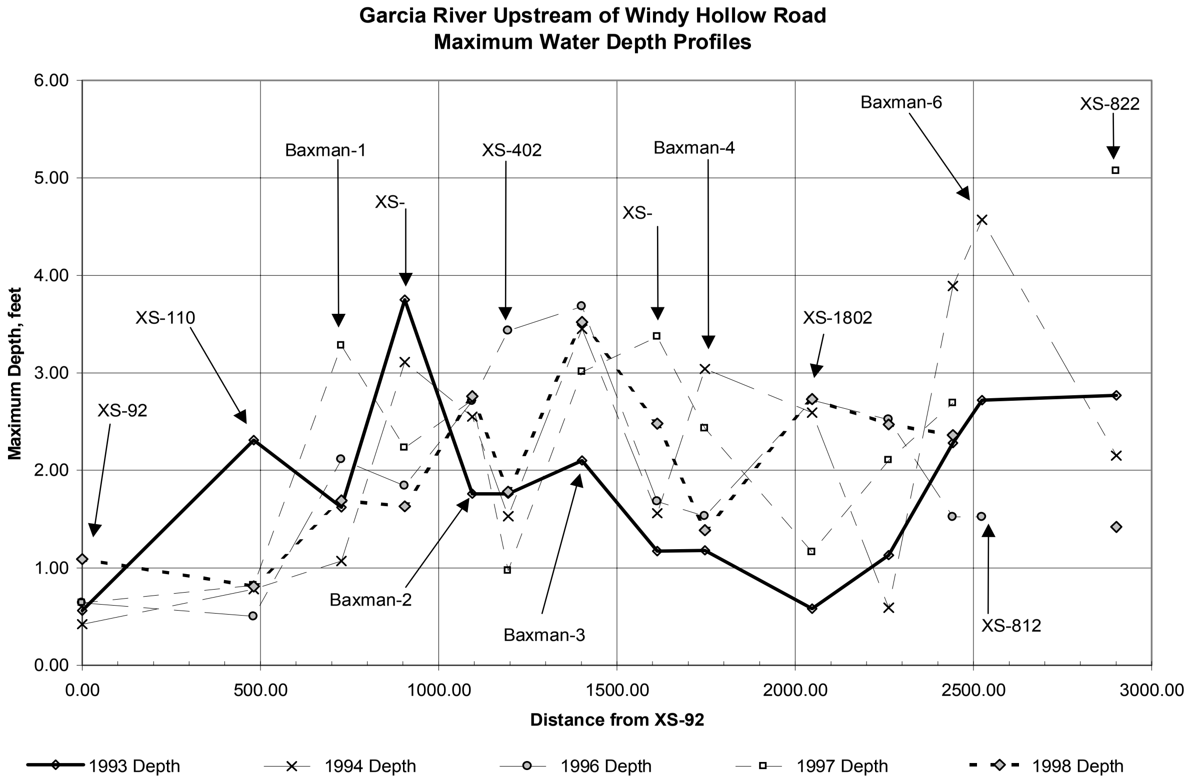


Figure 10. Maximum water depth profiles for the Bentonite Monitoring cross sections. The line connecting the maximum depth data points does not represent the maximum depth between the data points. Data points are connected by lines for clarity only.

Table 2. Maximum water depth at each bentonite monitoring cross section.

Cross Section	1991 Maximum Water Depth	1993 Maximum Water Depth	1994 Maximum Water Depth	1995 Maximum Water Depth	1996 Maximum Water Depth	1997 Maximum Water Depth	1998 Maximum Water Depth
92		0.6	0.4		0.6	0.6	1.1
110		2.3	0.8		0.5	0.8	0.8
Baxman-1	1.5	1.6	1.1	0.7	2.1	3.3	1.7
302		3.8	3.1	2.5	1.8	2.2	1.6
Baxman-2	2.0	1.8	2.6	3.5	2.7	2.7	2.8
402		1.8	1.5	1.7	3.4	1.0	1.8
Baxman-3	2.3	2.1	3.5	3.4	3.7	3.0	3.5
602		1.2	1.6	2.0	1.7	3.4	2.5
Baxman-4	1.1	1.2	3.0	4.0	1.5	2.4	1.4
1802		0.6	2.6		2.7	1.2	2.7
802		1.1	0.6		2.5	2.1	2.5
Baxman-6	1.7	2.3	3.9		1.5	2.7	2.4
812		2.7	4.6		1.5		
822		2.8	2.2			5.1	1.4

Table 3. Water surface and thalweg elevations for the Bentonite Monitoring cross sections.

	1991		1993		1994		1995		1996		1997		1998	
Cross Sectio	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
92			19.5	18.9	19.5	19.1			19.5	18.9	18.7	18.1	19.5	18.4
110			17.9	15.6	17.6	16.8			17.6	17.1	18.0	17.2	18.6	17.8
Baxman-1	18.5	17.1	17.8	16.2	17.4	16.3	17.6	16.9	17.5	15.4	18.0	14.7	17.9	16.2
302			17.8	14.1	17.4	14.3	17.4	14.9	17.5	15.7	17.6	15.4	17.5	15.9
Baxman-2	18.2	16.2	17.8	16.0	17.4	14.9	17.3	13.8	17.5	14.8	17.7	15.0	17.1	14.4
402			17.8	16.0	17.4	15.9	17.5	15.8	17.5	14.1	17.7	16.7	17.1	15.3
Baxman-3	18.2	15.9	17.8	15.7	17.4	14.0	17.3	14.0	17.5	13.8	17.5	14.5	17.1	13.6
602			17.7	16.5	17.3	15.7	17.4	15.4	17.6	15.9	17.6	14.3	17.2	14.7
Baxman-4	16.4	15.3	17.8	16.6	17.3	14.3	17.5	13.4	17.3	15.8	17.5	15.1	16.5	15.1
1802			15.8	15.3	15.8	13.2			17.6	14.9	16.6	15.4	16.2	13.5
802			15.9	14.8	15.7	15.1			17.7	15.1	16.5	14.4	16.1	13.6
Baxman-6	14.4	12.6	15.9	13.6	15.4	11.5			16.8	15.3	16.3	13.6	16.1	13.7
812			15.9	13.2	15.4	10.8			16.8	15.3				
822			15.9	13.1	15.5	13.4			15.6		16.6	11.5	16.1	14.7

	1991		1993		1994		1995		1996		1997		1998	
Cross Sectio	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
92			0.0	0.0	0.0	0.2			0.0	0.0	-0.7	-0.8	0.1	-0.5
110			0.0	0.0	-0.3	1.3			-0.3	1.5	0.1	1.6	0.7	2.2
Baxman-1	0.7	0.9	0.0	0.0	-0.4	0.1	-0.2	0.7	-0.3	-0.8	0.2	-1.5	0.1	0.1
302			0.0	0.0	-0.4	0.2	-0.4	0.9	-0.3	1.6	-0.2	1.3	-0.3	1.8
Baxman-2	0.4	0.2	0.0	0.0	-0.4	-1.2	-0.5	-2.3	-0.3	-1.2	-0.1	-1.1	-0.7	-1.7
402			0.0	0.0	-0.4	-0.2	-0.3	-0.2	-0.3	-2.0	-0.1	0.7	-0.7	-0.8
Baxman-3	0.4	0.2	0.0	0.0	-0.4	-1.7	-0.4	-1.7	-0.3	-1.8	-0.3	-1.2	-0.6	-2.1
602			0.0	0.0	-0.4	-0.8	-0.2	-1.1	-0.1	-0.6	0.0	-2.2	-0.5	-1.8
Baxman-4	-1.3	-1.3	0.0	0.0	-0.5	-2.3	-0.3	-3.2	-0.4	-0.8	-0.2	-1.5	-1.3	-1.5
1802			0.0	0.0	-0.1	-2.1			1.8	-0.4	0.7	0.1	0.4	-1.8
802			0.0	0.0	-0.2	0.4			1.8	0.4	0.6	-0.4	0.2	-1.1
Baxman-6	-1.5	-0.9	0.0	0.0	-0.5	-2.1			0.9	1.7	0.4	0.0	0.2	0.1
812			0.0	0.0	-0.5	-2.4			0.9	2.1				
822			0.0	0.0	-0.3	0.3			-0.3		0.7		0.2	1.6

Table 4. Summary of changes in area (square feet) of the Bentonite Monitoring cross sections relative to 1993. Values greater than 100% indicate erosion relative to 1993. Values less than 100% indicate deposition relative to 1993.

Cross Section	Reference Elevation	Year	Total Area Below Reference	Outside of Low-Water Channel Below Reference	Area of Low-Water Channel Below Reference	Area of Low-Water Channel Above Water	Total Area Below Water	Relative Area Below Reference	Outside of Low-Water Channel Below Reference	Area of Low-Water Channel Below Reference	Area of Low-Water Channel Above Water	Relative Area Below Water
XS-92		1991	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-92	24.45	1993	638	312	326	307	19	100%	100%	100%	100%	100%
XS-92		1994	619	417	202	191	11	97%	134%	62%	62%	56%
XS-92		1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-92		1996	635	317	318	299	19	99%	101%	98%	97%	103%
XS-92		1997	704	350	354	332	21	110%	112%	108%	108%	113%
XS-92		1998	623	271	351	326	25	98%	87%	108%	106%	134%
XS-110		1991	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-110	28	1993	1351	834	516	478	38	100%	100%	100%	100%	100%
XS-110		1994	1325	958	367	352	15	98%	115%	71%	73%	41%
XS-110		1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-110		1996	1237	836	401	395	5	92%	100%	78%	83%	14%
XS-110		1997	1177	538	640	612	27	87%	64%	124%	128%	72%
XS-110		1998	1190	422	768	729	39	88%	51%	149%	152%	104%
Bax-1	25.66	1991	984	664	320	293	27	92%	121%	62%	65%	43%
Bax-1		1993	1065	551	515	452	62	100%	100%	100%	100%	100%
Bax-1		1994	1035	686	348	327	21	97%	125%	68%	72%	34%
Bax-1		1995	1007	588	419	399	20	94%	107%	81%	88%	32%
Bax-1		1996	1056	682	375	314	61	99%	124%	73%	69%	98%
Bax-1		1997	952	449	503	399	103	89%	82%	98%	88%	166%
Bax-1		1998	946	489	457	393	64	89%	89%	89%	87%	103%
XS-302		1991	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-302	24.9	1993	911	619	293	228	65	100%	100%	100%	100%	100%
XS-302		1994	964	695	269	219	50	106%	112%	92%	96%	77%
XS-302		1995	994	678	316	256	61	109%	110%	108%	112%	94%
XS-302		1996	926	621	305	269	35	102%	100%	104%	118%	55%
XS-302		1997	807	561	247	226	21	89%	91%	84%	99%	32%
XS-302		1998	924	539	385	363	22	101%	87%	132%	159%	35%
Bax-2	25.42	1991	1092	693	399	322	77	104%	125%	81%	74%	130%
Bax-2		1993	1048	555	492	433	59	100%	100%	100%	100%	100%
Bax-2		1994	1095	518	577	473	104	105%	93%	117%	109%	175%
Bax-2		1995	1000	498	502	429	73	95%	90%	102%	99%	123%
Bax-2		1996	937	478	459	397	61	89%	86%	93%	92%	104%
Bax-2		1997	851	424	426	339	87	81%	76%	87%	78%	148%
Bax-2		1998	1012	494	518	414	105	97%	89%	105%	96%	177%
XS-402		1991	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-402	30.26	1993	2252	1386	866	788	78	100%	100%	100%	100%	100%
XS-402		1994	2203	1359	844	784	60	98%	98%	97%	99%	77%
XS-402		1995	2113	1367	746	696	50	94%	99%	86%	88%	64%
XS-402		1996	2088	1348	740	621	119	93%	97%	85%	79%	153%
XS-402		1997	1977	1255	722	686	36	88%	91%	83%	87%	46%
XS-402		1998	2190	1284	907	828	79	97%	93%	105%	105%	101%

Table 4 Continued.

Cross Section	Reference Elevation	Year	Total Area Below Reference	Total Area Outside of Low-Water Channel Below Reference	Total Area of Low-Water Channel Below Reference	Total Area of Low-Water Channel Above Water	Total Area Below Water	Relative Area Below Reference	Relative Area Outside of Low-Water Channel Below Reference	Relative Area of Low-Water Channel Below Reference	Relative Area of Low-Water Channel Above Water	Relative Area Below Water
Bax-3	25.16	1991	1433	912	521	405	91	142%	204%	92%	83%	122%
Bax-3		1993	1012	447	565	491	74	100%	100%	100%	100%	100%
Bax-3		1994	1166	465	701	536	165	115%	104%	124%	109%	222%
Bax-3		1995	972	251	721	540	181	96%	56%	128%	110%	244%
Bax-3		1996	950	344	606	437	169	94%	77%	107%	89%	228%
Bax-3		1997	908	247	661	515	145	90%	55%	117%	105%	196%
Bax-3		1998	952	234	718	536	181	94%	52%	127%	109%	244%
XS-602		1991	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-602	25.195	1993	1280	718	562	501	62	100%	100%	100%	100%	100%
XS-602		1994	1344	773	571	515	56	105%	108%	102%	103%	90%
XS-602		1995	1178	673	505	425	80	92%	94%	90%	85%	129%
XS-602		1996	1108	630	478	427	51	87%	88%	85%	85%	83%
XS-602		1997	1008	331	677	534	144	79%	46%	120%	107%	232%
XS-602		1998	1099	424	675	608	67	86%	59%	120%	121%	109%
Bax-4	24.06	1991	1194	855	339	312	27	102%	117%	78%	83%	45%
Bax-4		1993	1167	733	434	375	59	100%	100%	100%	100%	100%
Bax-4		1994	1288	799	489	366	123	110%	109%	113%	98%	207%
Bax-4		1995	1231	685	546	387	159	105%	93%	126%	103%	268%
Bax-4		1996	1145	822	323	279	44	98%	112%	74%	74%	74%
Bax-4		1997	872	556	317	290	27	75%	76%	73%	77%	45%
Bax-4		1998	961	658	303	278	25	82%	90%	70%	74%	43%
XS-1802		1991	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-1802	27.71	1993	2079	1777	302	292	10	100%	100%	100%	100%	100%
XS-1802		1994	2193	1608	585	509	76	105%	90%	194%	174%	769%
XS-1802		1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-1802		1996	1469	936	533	442	91	71%	53%	177%	151%	925%
XS-1802		1997	1762	1462	300	283	17	85%	82%	99%	97%	169%
XS-1802		1998	1908	1272	636	570	66	92%	72%	211%	195%	673%
XS-802		1991	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-802	27.187	1993	2036	1579	458	429	29	100%	100%	100%	100%	100%
XS-802		1994	1970	1493	477	462	14	97%	95%	104%	108%	50%
XS-802		1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-802		1996	1975	1140	835	720	115	97%	72%	182%	168%	399%
XS-802		1997	1780	1262	518	465	53	87%	80%	113%	108%	185%
XS-802		1998	1861	1269	592	534	58	91%	80%	129%	124%	202%
Bax-6	21.53	1991	848	680	168	154	14	121%	172%	55%	59%	32%
Bax-6		1993	700	396	303	258	45	100%	100%	100%	100%	100%
Bax-6		1994	835	363	471	357	115	119%	92%	155%	138%	255%
Bax-6		1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Bax-6		1996	730	404	326	270	56	104%	102%	108%	105%	125%
Bax-6		1997	716	442	273	195	78	102%	112%	90%	76%	173%
Bax-6		1998	679	355	324	254	70	97%	90%	107%	98%	156%
XS-822		1991	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-822	21.448	1993	690	172	518	417	101	100%	100%	100%	100%	100%
XS-822		1994	720	154	566	436	130	104%	90%	109%	105%	128%
XS-822		1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
XS-822		1996	590	205	385	367	18	85%	119%	74%	88%	18%
XS-822		1997	577	113	464	340	124	84%	66%	90%	82%	123%
XS-822		1998	708	294	414	359	55	103%	171%	80%	86%	54%

1997. Thus, the data support the notion that a high bar helps prevent deposition in the low flow channel.

The general deposition through bentonite monitoring reach is probably the result of two factors. The first factor is that past mining lowerered the bar surface which should act to decrease the sediment transport capacity through the reach. The second factor is the bank failure just upstream on the Kendall property supplied a large amount of material to the system.

A review of the changes at each cross sections will be given starting at the upstream end and progressing downstream. At cross section 92, the water surface rose about -0.7 feet and the thalweg rose about 0.4 feet, from 1997 to 1998, (see Table 3 and Figures 8 and 9). Between 1993 to 1996 there was virtually no change in the water surface and thalweg elevations at this cross section. Overall the cross section area decreased by 3% since 1993, see Table 4, showing deposition. Deposition occurred along the left (east) bank burying the reference stake. In 1998, a tree fell over the left bank stake.

In 1997 a mid-channel bar developed at the mouth of the bentonite spill tributary, see cross section 110. The mid-channel bar was still present in 1998. The 1998 thalweg at cross section 110 has risen 2.2 feet since 1993, see Table 3. The water surface rose only 0.7 feet since 1993. In general, there has been deposition at this cross section. The cross section area data may be misleading since the left end of the 1993 and 1994 cross sections may have been different.

The water surface and thalweg at the Baxman-1 cross section has risen 0.1 feet since 1993. The surface of Bar 30, on the right (north) bank, rose about 1.5 - 2 feet between 1993 and 1997. The deposit on the bar was eroded in 1998. The overall cross section area has decreased by -11%, relative to 1993. The area below water increased by 3% and the area of the dry portion of the channel decreased by -11%. The surface of Bar 30 has eroded relative to its 1997 level.

The lower portion of a riffle and a small bar are now in the low-water channel at cross section 302. The pool just below cross section 302 has been partially filled. The riffle has decreased the area below water at the cross section by -65%, relative to 1993. The wetted portion of the low-water channel has grown 10% relative to 1997. The thalweg elevation increased by 1.8 feet since 1993. The water surface has dropped 0.3 feet since 1993. Overall, there has been a minor amount of erosion since the area has increased by less than 2% since 1993. The surface of Bar 30 has eroded relative to its 1997 level.

The Baxman-2 cross section was surveyed in 1991. The 1993 event buried the monument on the right (north) bank. The monument has not been see since 1991. The cross section could not be located in either 1993 or 1994. In 1995 its position was estimated from the field notes and the 1995 topographic map. The estimated position was applied to the 1993 - 1996 topographic maps to obtain cross sections for those years. In 1997, the estimated position was located in the field, monumented and surveyed. The original right bank monument eluded efforts to locate it in 1997. Between 1993 and 1998 the thalweg dropped -1.7 feet and the water surface dropped -0.1 feet. The water surface elevation has dropped -0.7 feet since 1991. Deposition has resulted in the cross section area decreasing by -5% since 1993. The deposition has been primarily on the right bank (Bar 30). The low water channel expanded by 77% since 1993 as the thalweg lowered and the edge of Bar 30 eroded. The surface of Bar 30 rose as the thalweg dropped, supporting the notion that bar height helps maintain a deep thalweg. Note that the 1998 bar surface is about 0.5 feet lower than the 1997 bar surface.

A significant amount of deposition occurred in the low water channel at cross section 402 in 1997. A portion of the material deposited in 1997 was eroded in 1998. The 1998 thalweg was rose -0.8 feet lower than the 1993 thalweg. The 1998 thalweg was 1.5 feet lower than in 1997. The water surface dropped -0.7 feet relative to 1993. The area below water increase by 1.5% relative to 1993. Since 1993 the overall area cross section area has decreased 2.7% indicating a minor amount of deposition. The surface of the bar and thalweg have risen, relative to 1993. The surface of Bar 30 has eroded relative to its 1997 level.

The graph of the Baxman-3 cross section, see Appendix, shows that approximately 5 feet of material has been deposited on the bar since 1991. Most of the material was deposited in 1993. The area outside of the low-water channel decrease to 52%-of its 1993 value. The thalweg dropped -2.3 feet from 1991 to 1997. Most of the drop in thalweg elevation occurred in 1994. Since 1993, the low-water channel has increased its area by 2.4 times. The water surface is -0.6 feet lower than it was in 1993. Note that the drop in thalweg elevation was accompanied by an increase in bar height.

Between 1993 and 1997, deposition on Bar 30 has caused a -51% reduction in area of the dry portion of the channel at cross section 602. The thalweg has dropped -1.8 feet relative to 1993. The area of the low water channel has increased by 9%, relative to 1993. The surface of Bar 30 rose as the thalweg dropped. The low-water channel has shifted towards the left bank. A 15 foot wide shelf has been eroded from the left bank. The shelf was at the same level as the 1991 bar surface. The thalweg has shifted 25 feet and is now at the base of the left (south) bank.

The low water channel of Baxman-4 shows a progressive shift towards the left (south) bank as the river eroded the upstream end of Bar 31 and the downstream end of Bar 30 has extended downstream. The thalweg elevation has decrease -1.5 feet since 1993 but it is only -0.2 feet lower than it was in 1991. The water surface has dropped -1.3 feet since 1993 and has the same elevation it had in 1991.

Just below Baxman-4 the river turns towards the north (right) and separates Bar 30 from Bar 31. Bar 30 has extended downstream past cross section 1802. The low water channel has shifted to the south (left) bank. In 1997 the low flow channel occupied the former central portion of Bar 31. The overflow channel adjacent to the riparian forest on the south bank of Bar 31 has been filled in. A significant amount of fine material was deposited in the riparian forest. The thalweg is -1.8 feet lower than it was in 1993 and the water surface is 0.4 feet higher than it was in 1993.

Bar 31 is building at the downstream end. The head of Bar 32, adjacent to the processing plant, has eroded. In 1997 the result of these two events was that the low water channel had shifted from near the left bank to the right bank.. The loss of material from the head of Bar 32 has re-exposed a layer of cemented aggregate. In 1998, the river shifted and virtually removed Bar 32. The shift of the river to the right bank was accompanied by the extension of Bar 31 along the left bank. Bar 31 now extends down past cross section 822.

The low-water channel at cross section 1802 has shifted towards the left bank. The south (left) edge of the low-water channel is at the edge of the riparian forest along Bar 31. Bar 30 has extended downstream about 50 feet and the head of Bar 31 has retreated a similar distance. About 2 feet of fine material was eroded from the 1997 riparian forest deposit on the left bank. About 3 feet of material has been deposited in the secondary flow channel next to the erosion fence on the left bank.

In 1993 cross section 802 was at the upstream edge of the exposed cemented gravels. The graph of the cross section suggests that the cemented aggregate, at cross section 802, was eroded away in 1995. In 1997 cemented aggregate was observed 40 feet upstream of Baxman-6 or about 140 feet downstream of its location in 1993. Table 4 shows that the thalweg 1998 dropped -1.1 feet from the 1993 level. Table 4 also shows that the 1998 water surface has risen 0.2 feet since 1993. The Table 4 shows that the area of the low-water channel increased 200% between 1993 and 1998. The graph of the cross section indicates that the right (north) edge of the channel eroded relative to 1993 and that there was deposition on the left bank.

In 1991, the low-water channel at Baxman-6 was at the base of the left (south) bank. In 1997, the low-water channel shifted to near the right (north) bank. However, the low-water channel returned to the left (south) bank a few feet below Baxman-6, in 1997. In 1998, the low-water channel shifted another 25 feet to the north but, the low-water channel remained along the right (north) bank. At the same time, Bar 31 was extended downstream to cross section 822, Bar 31 is attached to the left (south) bank.

The low water channel at Baxman-6 went from 20 feet in width in 1991 to 75 feet in width in 1996 and back to 35 feet in width in 1997. In 1998, the low water channel was about 48 feet wide. Most of this increase in width occurred during the winter of 1993-94. The increase in width of the low water channel, in 1994, appears to have set up conditions to promote deposition on the downstream end of Bar 31. The 1998 water surface elevation and thalweg elevation are almost equal to their 1993 values.

In 1997, some trees fell over upstream of cross section 822 on the left (south) bank. These trees appear to have helped create a scour pool which was -1.6 feet deeper in 1997 than in 1993. However, in 1998 the end of Bar 31 extended downstream and buried the scour hole that formed in 1997. A backwater area formed between Bar 31 and the left bank. The base of the left bank was eroded. The extension of Bar 31 downstream was accompanied by a shift in the low-water channel towards the right (north) bank. The shift of the low-water channel eroded about 30 feet from the edge of Bar 32. Bar 32 has been almost completely replaced by Bar 31.

The elevation of the thalweg at each cross section has fluctuated a little from year to year. The average change in thalweg elevation for the reach in 1998, relative to 1993, was -0.4 feet. A minor amount of change after two large floods, indicating that the thalweg elevation is fairly stable. The bars are building after having been mined prior to 1991. The increase in bar height appears to be playing a role in preventing serious deposition in the thalweg..

The data from the cross sections above Windy Hollow Road does not support the notion that the Garcia River is aggrading in the reach. The bank collapse just upstream on the Kendall property supplied the river a significant volume of bedload, however, there was only limited deposition in the low-water channel and the overall tendency was for a small decline in the thalweg elevation. So, the data show that the river is actively moving its bedload through the reach. The data also show that the river is in the process of rebuilding bars that had been mined prior to 1991. The Windy Hollow Road cross section data support the idea that the river is in dynamic equilibrium. However, the notion that the river is in the early stages of incision (degrading) can not be ruled out by the data.

Kendall Cross Sections:

Two cross sections were established near the power line crossing on the Kendall property by Mendocino County Water Agency (MCWA) in the summer of 1991 as part of the Resource Conservation District's (RCD) Garcia River Assessment. The upstream cross section was located upstream of the power line crossing at the head (upstream end) of Bar 28, see Figure 8. The downstream cross section is approximately 400 feet downstream of the powerlines. The cross sections were re-surveyed in October of 1993 by MCWA as part of bentonite spill monitoring effort. The state plane coordinates were established for the endpoints of the cross sections during the 1993 survey.

In early 1995 the Garcia River experienced a flood with a peak flow estimated at 32,500 cfs with a stage of 17.9 feet. The 1995 event was the largest event ever recorded at the Conner Hole gaging station. The event resulted in approximately 400 hundred feet of bank erosion along the north (right) bank, just below Bar26. The erosion ended approximately +600 feet upstream of the MCWA cross section near the

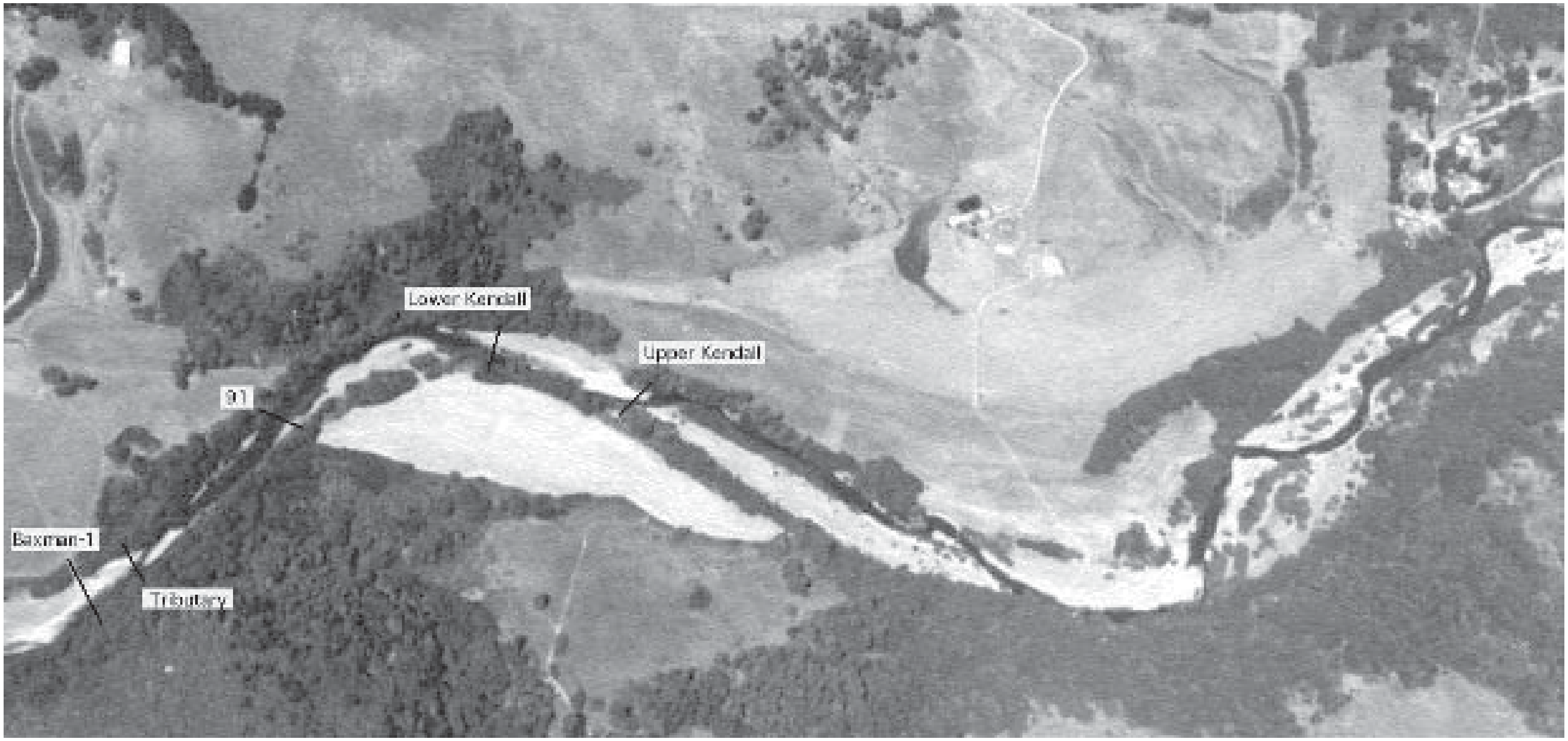


Figure 8. Map of Kendall cross sections and upstream bentonite cross sections. Photo from 1993. Flow is from right to left.

powerline crossing. In January 1997 the third largest flood recorded on the Garcia River occurred, it had a stage of 17.4 feet and the peak flow is estimated to be 30,200 cfs. The 1997 event extended the erosion an additional +600 feet downstream of the 1995 damage. The 1998 flood season continued to extend the bank damage downstream. One result of the continued bank collapse is that a significant source of bedload was made available for transport downstream past the Kendall cross sections.

Bar 26 (see Figure 8) is a point bar on the right (north) bank of the river. Directly across from Bar 26 a steep hill rises up from the river. The hill forces the river to turn towards the west. A review of a sequence of aerial photographs (see Figures 6(a)-(f)) reveals that the point where the river first contacts the hill has shifted downstream with time. Consequently, the river now "bounces" off the hillside instead of "glancing" off as it did in 1972. The change in exit angle has resulted in the main force of the river being directed at the right bank just below Bar 26. The exit angle has changed slightly each year shifting the point of contact on the north bank further downstream.

The 1995 event significantly changed the channel at the upstream end of Bar 28 at the location of the MCWA cross section upstream of the power line crossing. In 1996, a search of the ground failed to locate either endpoint of the upstream MCWA cross section. The 1991 right bank monument appears to have been lost since the small bench it was on had eroded away. The 1991 left bank monument was buried under flood debris. In 1996, the total station was not available so the coordinates could not be used to find the upstream cross section. A new pair of monuments (rebar, 2 feet long) were installed in 1996 at the approximate location of the lost upstream cross section. After the cross section was surveyed the NVGD elevation was brought in from stake 92 of the bentonite spill monitoring program.

In 1997 and 1998, a total station was used to relocate the cross section established in 1991. The left bank stake of the upstream cross section was found but the top 1.5 feet was bent over. The 1996 left (south) bank pin is located 52 feet downstream of the 1991 left bank pin. The 1996 right (north) bank was located about 72 feet upstream of the 1991 right bank pin. Thus, the 1991 and 1996 cross sections intersect in central portion of the channel. So, the 1991cross section is not directly comparable to the 1996 cross section. The 1997 and 1998 cross sections were surveyed along the 1991 cross section. The January flood of 1997 eroded the right bank and washed away the grove of trees where the 1996 right bank monument was placed therefore, the 1996 cross section was not re-surveyed in 1997 or 1998.

The graph labeled Kendall Upstream Cross Section (see Appendix) shows the 1998 survey was superimposed on the previous surveys. The left bank monument of the 1991 survey was used as the origin for the distance measurements. The 1996 cross section was placed so that the 1996 left edge of water coincided with the 1991 left edge of water. The 1996 cross section goes through a pool at 150 from the left bank (see graph in Appendix). The pool shown on the 1996 survey was upstream of the actual cross section. The segment between 70 feet and 100 feet on the 1996 survey is more representative of the conditions along cross section established in 1991.

The location of the 1996 left bank shown on the graph is probably reasonable. The 1996 survey crosses a riffle between 75 and 106 feet on the graph.. In 1991 and 1993 the riffle was upstream of the cross section. The pool that lies between 100 feet and 150 feet on the 1996 cross section is over 5.3 feet deep. This pool was completely filled in by material from the adjacent bank failure in 1997.

Table 5(a) shows the water surface elevation and thalweg elevation for each survey. Between 1991 and 1993 the water surface elevation of the upstream cross section dropped -0.6 feet and the thalweg elevation dropped -0.8 feet. The drop in water surface shows that the control riffle was eroded by the 1993 storms. Between 1993 and 1998 the water surface elevation of the upstream cross section rose 3.3 feet and the thalweg elevation rose 3.4 feet. The rise in water surface and thalweg elevation between 1993 and 1998 probably was caused by the bedload contributed to the river by the bank collapse.

Table 5(a). Water surface and thalweg elevations for the Kendall cross sections.

	1991		1993		1995		1996		1997		1998	
Cross Section	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
Upstream - 1991	20.6	19.4	20.0	18.7					24.1	23.2	23.3	22.0
Upstream - 1996							20.6	19.7				
Downstream - 1991	20.2	16.8	19.5	17.0					20.3	18.4	21.5	19.7
Downstream - 1996							20.4	18.2	20.6	18.5	21.4	20.1

Table 5(b). Maximum water depth for the Kendall cross sections.

	1991	1993	1995	1996	1997	1998
Cross Section	Max Water Depth	Max Water Depth	Max Water Depth	Max Water Depth	Max Water Depth	Max Water Depth
Upstream - 1991	1.2	1.4			0.9	1.2
Upstream - 1996				0.9		
Downstream - 1991	3.4	2.6			1.9	1.8
Downstream - 1996				2.2	2.1	1.3

Table 5(c). Relative changes in the water surface and thalweg elevations for the Kendall cross sections.

	1991		1993		1995		1996		1997		1998	
Cross Section	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
Upstream - 1991	0.0	0.0	-0.6	-0.8					3.5	3.8	2.7	2.6
Upstream - 1996							-0.1	0.2				
Downstream - 1991	0.0	0.0	-0.7	0.2					0.1	1.6	1.2	2.9
Downstream - 1996							0.2	1.4	0.3	1.7	1.2	3.3

Table 6. Cross section area and relative changes in cross section area for the Kendall cross sections.

Cross Section	Reference Elevation	Survey Year	Total Area Below Referenc	Total Area Outside of Low-Water Channel Below Reference	Total Area of Low-Water Channel Below Reference	Total Area Below Water	Relative Area Below Referenc	Relative Are Outside of Low-Water Channel Below Reference	Relative Area of Low-Water Channel Below Reference	Relative Area Below Water
Upstream - 1991	28.8	1991	958	854	104	6	100%	100%	100%	100%
Upstream - 1991	28.8	1993	992	805	186	13	104%	94%	180%	229%
Upstream - 1991	28.8	1994	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Upstream - 1991	28.8	1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Upstream - 1991	28.8	1996	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Upstream - 1991	28.8	1997	1348	1171	177	13	141%	137%	170%	226%
Upstream - 1991	28.8	1998	1500	1195	305	32	157%	140%	294%	565%
Upstream 1996	28.8	1996	1344	378	966	184	100%	100%	100%	100%
Downstream-1991	27.7	1991	1015	477	538	156	100%	100%	100%	100%
Downstream-1991	27.7	1993	988	455	533	95	97%	95%	99%	61%
Downstream-1997	27.7	1997	1029	659	370	27	101%	138%	69%	17%
Downstream-1997	27.7	1998	1042	267	774	205	103%	56%	144%	131%
Downstream-1996	27.7	1996	942	484	458	91	100%	100%	100%	100%
Downstream-1996	27.7	1997	962	654	308	34	102%	135%	67%	37%
Downstream-1996	27.7	1998	1451	477	973	81	154%	99%	212%	88%

The overall channel widened by about 120 feet between 1993 and 1997. The thalweg rose 3.8 feet between 1991 and 1997, see Table 5. The water surface rose 3.5 feet 1991 and 1997. The rise of both the thalweg and the water surface is the result of the large amount of material delivered to the channel by the Kendall bank collapse.

The channel widened another 130 feet in 1998. However, the thalweg dropped -1.2 feet between the 1997 and 1998 surveys and the water surface dropped -0.8 feet. Even though the bank continued to collapse, the river was able to erode the low-flow channel and deepen the thalweg. The downstream control was also eroded since the water surface dropped.

The 1997 low flow channel was divided into two channels at the upstream cross section. The thalweg of the larger low-flow channel was about 1.6 feet higher than the smaller channel. The larger low-flow channel was located adjacent to the left (south) bank. There was a 3 foot high berm (1997) at about where the right (north) bank was in 1993. In 1998 there was only one low-flow channel at the upstream cross section. In 1997, the total cross section area expanded by 141% with the dry channel expanding by 145%, see Table 6. In 1998, the channel cross sectional area was 157% what it was in 1991.

The 1998 bar surface north of the low-water channel was altered by heavy equipment. Bulldozer tracks were visible between 157 feet and 435 feet along the upstream cross section, see graph of upstream Kendall cross section in the Appendix. The 1991 and 1993 right bank was at about 165 feet. A small part of the 1998 increase in channel cross section area may be due to the equipment lowering the bar surface.

The second cross section on the Kendall property was located about 500 feet downstream of the first cross section. In 1996, the endpoints for the downstream cross section could not be found. The left bank endpoint appeared to have been lost due to bank failure. The right bank pin was buried under a log jam. The total station was not available for use so the coordinate system could not be used to locate the cross section. So, a guess at the location of the cross section was made and rebar pins were driven on both banks at the approximate location of the 1991 cross section.

The next year, the total station was used to locate the right bank pin. The 1997 data was taken with the total station. The 1997 data showed that the 1996 cross section was parallel to the 1991 cross section but, it was about 45 feet downstream of the 1991 location. Unfornately, the coordinates for the 1991 left bank pin were not available in the field. This led to the incorrect assumption that the 1996 was close to the 1991 left bank pin. The 1996 left bank pin is actually about 45 feet downstream of the 1991 left bank pin. The NVGD elevation was carried in from the bentonite monitoring area.

The difficulty in finding the endpoint markers has lead to the following situation. The 1991 and 1993 survey were taken along the same cross section. The 1996 survey and one of the 1997 cross sections were taken on line parallel to the 1991 cross section but, about 45 feet downstream. A second 1997 survey and the 1998 survey were taken along a line connecting the 1991 right bank pin and the 1996 left bank pin. The 1991 cross section line has not been surveyed since 1993. However, the channel on the right bank is fairly uniform and the 1996, 1997 and 1998 cross sections capture the general shape of the channel along the 1991 cross section line.

The data from the 1991 and 1993 surveys of the 1991 downstream cross section line were graphed along with the 1997 and 1998 surveys that started at the 1991 right bank pin and ended at the 1996 left bank pin. The graph is in the Appendix.

In 1996, a 50 foot portion of the left bank slid into the river near the location of the 1996 endpoint. A group of trees was on the portion of the bank that slid. In 1997, some of those trees were lying in the channel and some of the trees were lying against the bank and project back into the field. Except for the slide, the channel was fairly uniform above and below the cross section. The slide is downstream of the

1991 cross section line. The left bank portion of the 1997 and 1998 cross sections is influenced by the slide.

The 1997 and 1998 surveys along the line connecting the 1996 left bank pin to the 1991 right bank pin was superimposed on the graph of the 1991 and 1993 surveys. Even though the 1997 and 1998 cross sections were not located exactly on the 1991 cross section they are close enough to indicate the general conditions in the channel. A significant amount of material was eroded from the bar on the right bank. Likewise, a significant amount of material was deposited in the low water channel.

From 1991 to 1993 the water surface, for the downstream cross section, dropped -0.6 feet indicating that the downstream control was eroded by the 1993 storms. The thalweg, at the downstream cross section, rose 0.2 feet and shifted to the right bank, between 1991 and 1993. The change in the thalweg from 1991 to 1993 may be due to the slumping of the left bank. The storms of 1993 also deposited up to two feet of material on the bar, primarily in the riparian strip near the low water channel. The 1996 water surface was 0.9 feet higher than in 1993 indicating that material was deposited on the downstream control for the reach. The thalweg along the 1996 cross section was 1.4 feet higher than the thalweg measured along the 1991 cross section in 1991. The deposited material may be the result of the failure of the left bank and material transported from the large bank failure upstream. Also, the surface of the bar lost up to two feet of material across a significant portion of its width between 1993 and 1996. Compared to the 1991 data, the 1996 water surface elevation rose about 0.3 feet, at the downstream cross section, and the thalweg rose 1.4 feet. The rise in both water surface and thalweg elevation may be the result of the deposition of bedload contributed to the river by the 1995 bank failure upstream and by the slumping of the left bank at the cross section.

Table 6 gives the cross sectional area for the Kendall cross sections. The 1996 upstream cross section cross the stream at a different angle than cross sections surveyed in previous years, therefore, its area is not comparable to the other two years. The area of the 1997 and 1998 cross sections are not strickly comparable to the area of the 1991 and 1993 cross sections. However, Table 6 does compare the 1997 and 1998 cross section area to the 1991 cross section area.

The area of the downstream cross section increased by 1% between 1991 and 1997. The area of the dry channel increased by 39% and the area of the low water section decreased by -32% . Thus the deposition in the low water channel essentially matches the erosion from the bar. The area below the low water surfacedecreased by -83% reflecting the effect of the left bank slide on the area of the low flow channel and the deposition in the low water channel. Of course the material that was eroded from the bar was carried downstream and was not simply shifted into the low water channel at this cross section.

The graph, in the Appendix, labeled *Kendall Downstream Cross Section Established in 1996,* shows the 1997 and 1998 cross sections superimposed on the 1996 cross section. This cross section is the furthest downstream. There is a slide on the left bank in the region between 150 feet to 175 feet from the right bank. The river undercut the slide by an unknown amount, in 1997, so the wetted channel actually extended some distance under the slide. The slide lost more material in 1997. Material was also eroded from the right bank ba in 1997. Significant deposition occurred in the low water channel, in 1997, resulting in a 63% reduction in the area of the low water channel. The water surface and thalweg both rose about 0.2 feet between 1996 and 1997.

In 1998, the right bank bar was was replaced by the low-water channel, at the downstream cross sections. A-gravel berm formed along the base of the left (south) bank. There was a backwater area between the gravel berm and the left bank. The 1998 cross section area was 54% greater than it was in 1996, reflecting the loss of the right bank bar. The thalweg rose 1.9 feet and the water surface rose about 1 foot.

Both the upstream and downstream Kendall cross sections show a pattern of erosion followed by deposition. The large bank failure upstream may be the source for most of the deposition at both of the cross sections and their respective downstream controls. The 1997 and 1998 floods dramatically altered the upper cross section. The downstream cross section maintained its width but the right bank bar was significantly removed and the low-flow channel shifted to the former location of the right bank bar.

The large bank collapse at Kendall's may have been the result of alterations in the channel upstream of the Kendall bend that changed how the river was approached the hillside on the south (left) bank at the Kendall bend. Gravel was mined from Bar 23 on the Manchester Rancheria in the late 1980's possibly causing the low water channel to shift to the left bank sooner and subsequently entering the Kendall bend further downstream than it did in 1972. Another possibility is that the sediment wave, shown in Figure 1, caused Bar 25 on the upstream side of the Kendall bend to build resulting in the river entering the turn further downstream.

The thalweg and water surface rose significantly at downstream cross sections between 1997 and 1998. However, the water surface and thalweg both declined at the upstream cross section between 1997 and 1998. Therefore, the channel slope has been decreased through the reach. Consequently, we would expect to observe deposition through the reach on the 1999 survey.

The impact of the Kendall bank collapse was felt through the bentonite monitoring section mainly as deposition on the bars with little to no deposition in the low flow channel. Because of the size of the bank collapse and the close proximity of the Kendall cross sections to the bank collapse the data for these two cross sections can not be used to judge if the Garcia River is in dynamic equilibrium for the period 1991 through 1998.

Hooper Cross Sections:

In 1991 MCWA established four cross sections at Hooper's as part of the RCD's Watershed Assessment. The layout of these cross sections is shown on the Figure 9. In 1993, the Friends of the Garcia River engaged David Russell, a surveyor from Mendocino, to survey the cross sections and find points from the 1992 AT&T. Personnel from MCWA assisted Mr. Russell in locating the cross section endpoints. The AT&T points were used to put the cross sections on the State Plane Coordinate system. On July 31, 1996, Graham Matthews surveyed two cross sections on the Hooper property. In April 1997, MCWA surveyed cross sections number 1 and 3. The other two cross sections were surveyed on August 30, 1997 by the author. All four cross sections were surveyed in October of 1998.

The storms of 1993 began to erode the right bank upstream of the cross sections, near the Hooper - Olsen property boundary. The beginning of the bank erosion accompanied by the low water channel shifting from the center of the active channel to the right bank. The storms of 1994 continued the process. The large flood of 1995 caused the loss of approximately three acres of bank. The 1995 event also created a +7 foot deep pool downstream of the bank erosion but upstream of the cross sections. The storms of 1997 and 1998 continued the bank erosion process. The bank erosion has contributed a significant volume of bedload to the river just upstream of the Hooper cross sections.

Figures 10 and 11 show the water surface and thalweg profiles for each year the cross sections were surveyed. The 1998 survey had the lowest water surface and thalweg elevation at all of the Hooper cross sections. This general incision occurred even though the bank collapse at the Hooper - Olsen property boundary has been contributing bedload during the last few years.

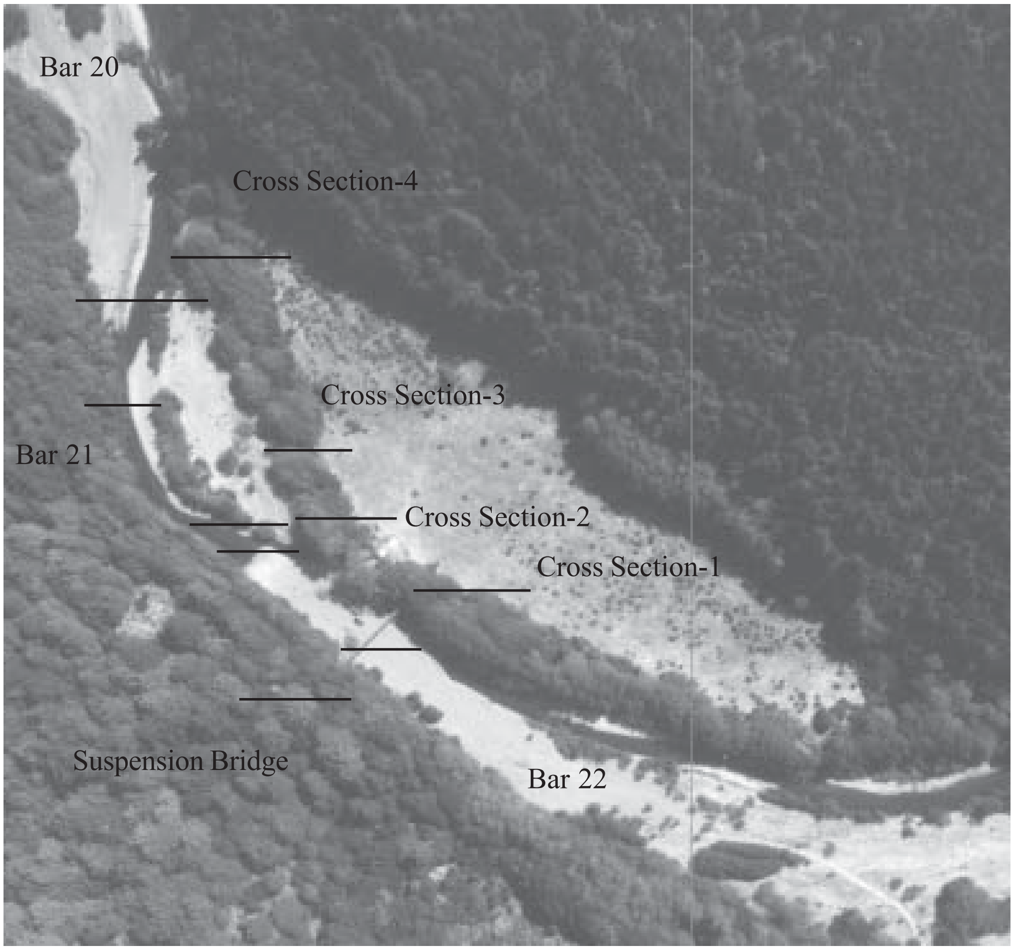


Figure 9. Map of the Hooper cross sections.

Cross section 1 is located approximately 135 feet downstream of the site of the suspension bridge (see Figure 9). The suspension bridge was destroyed by the 1993 flood. Between 1991 and 1993 the water surface dropped 0.3 feet and the thalweg rose 0.3 feet (see Table 7(c)). From 1991 to 1993 the low water channel narrowed by 10 feet with the deposition of up to 3 vertical feet of material along the right edge of the low water channel. The rise in the thalweg plus the deposition along the right margin resulted in a -61% decrease in the area below water and a -36% decrease in the area of the channel occupied by the low water channel (see Table 8). The surface of the bar lowered about 2 feet between 1991 and 1993. The loss of material from the bar and the deposition of material along the edge of the low flow channel resulted in a 40% increase in the area of the dry portion of the channel. The total cross sectional area changed by only 4% from 1991 to 1993.

By 1996 the surface of the bar had returned to its 1991 level and there was virtually no net difference in total cross sectional area. The 1996 water surface was not noted on the field notes. The original guess was 34.5 feet which, after review of the data has been revised to 35.9 feet. The 1996 water surface was 0.3 feet higher than in 1991 indicating a small amount of deposition on the control. The 1996 thalweg was -1.4 feet lower than the 1991 thalweg, exposing clay on the bottom of the channel. The flood of 1995 also filled the right bank secondary flow channel and buried the right bank endpoint.

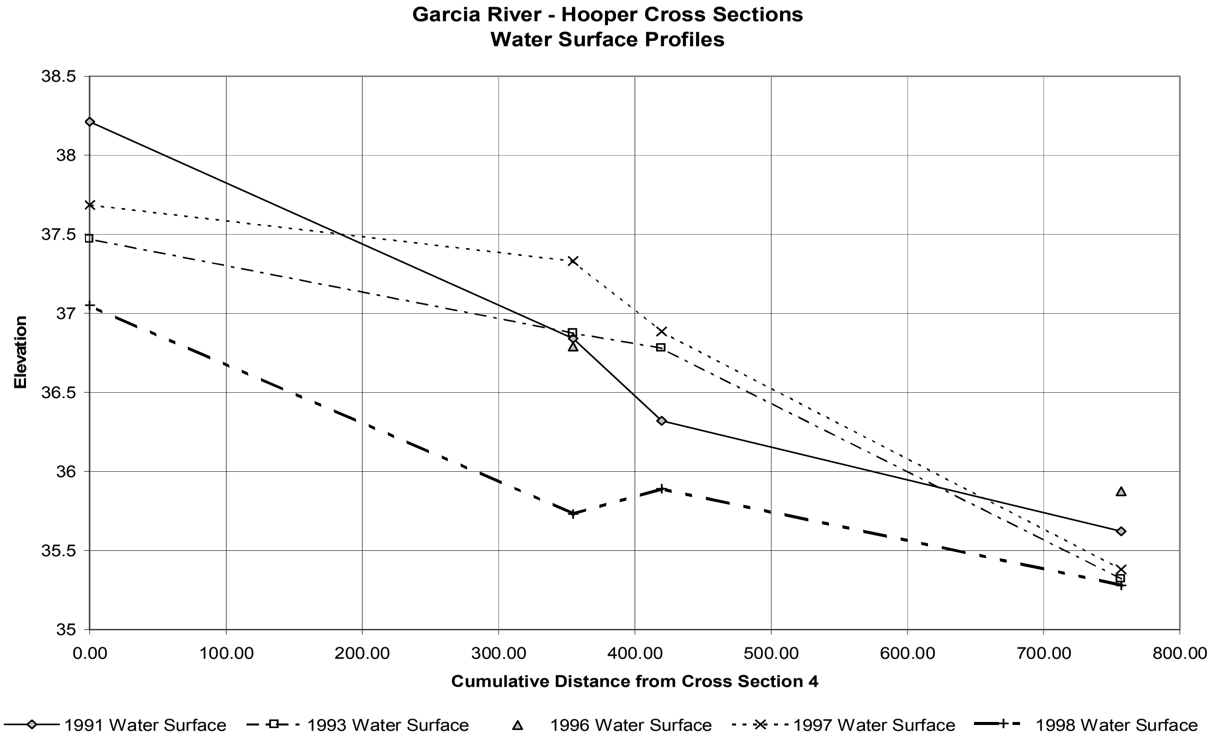


Figure 10. Water surface profiles for the Hooper cross sections.

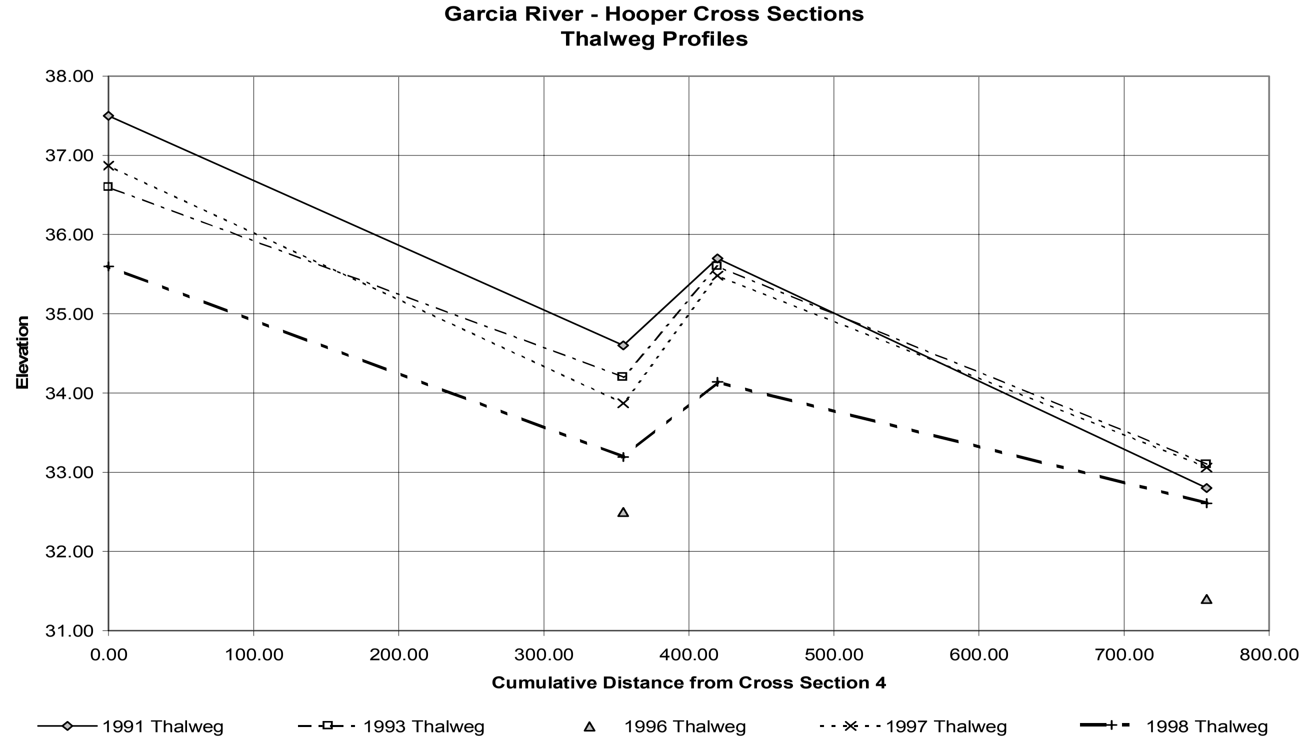


Figure 11. Thalweg profiles for the Hooper cross sections.

Table 7(a). Water surface and thalweg elevations for the Hooper cross sections.

	1991		1993		1995		1996		1997(a)(b)		1998	
Cross Section	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
MCWA-1	35.6	32.8	35.3	33.1			35.9	31.4	35.4	33.1	35.0	32.6
MCWA-2	36.3	35.7	36.8	35.6					36.9	35.5	35.9	34.1
MCWA-3	36.8	34.6	36.9	34.2			36.8	32.5	37.3	33.9	35.7	33.2
MCWA-4	38.2	37.5	37.5	36.6					37.7	36.9	36.6	35.6

Table 7(b). Maximum water depths for the Hooper cross sections.

	1991	1993	1995	1996	1997(a)(b)	1998
Cross Section	Maximum Depth	Maximum Depth	Maximum Depth	Maximum Depth	Maximum Depth	Maximum Depth
MCWA-1	2.8	2.2		4.5	2.3	2.4
MCWA-2	0.6	1.2			1.4	1.8
MCWA-3	2.2	2.7		4.3	3.5	2.5
MCWA-4	0.7	0.9			0.8	0.9

Table 7(c). Relative changes in the water surface and thalweg elevations for the Hooper cross sections.

	1991		1993		1995		1996		1997(a)(b)		1998	
Cross Section	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg		
MCWA-1	0.0	0.0	-0.3	0.3			0.3	-1.4	-0.2	0.3	-0.6	-0.2
MCWA-2	0.0	0.0	0.5	-0.1					0.6	-0.2	-0.4	-1.6
MCWA-3	0.0	0.0	0.1	-0.4			0.0	-2.1	0.5	-0.7	-1.1	-1.4
MCWA-4	0.0	0.0	-0.7	-0.9					-0.5	-0.6	-1.7	-1.9

(a) Cross Sections 1 & 3 were surveyed in April 1997.
(b) Cross Sections 2 & 4 were surveyed in late August 1997.

Table 8. Cross section area and relative changes in cross section area for the Hooper cross sections.

Cross Section	Reference Elevation	Year	Total Area Below Reference	Total Area Outside of Low-Water Channel Below Reference	Total Area of Low-Water Channel Below Reference	Total Area Below Water	Relative Area Below Reference	Relative Area Outside of Low-Water Channel Below Reference	Relative Area of Low-Water Channel Below Reference	Relative Area Below Water
Hooper XS-1	43.03	1991	928	485	443	94	100%	100%	100%	100%
Hooper XS-1		1993	963	681	282	36	104%	140%	64%	39%
Hooper XS-1		1996	923	403	521	154	100%	83%	118%	163%
Hooper XS-1		1997	695	303	392	71	75%	62%	89%	75%
Hooper XS-1		1998	952	509	443	80	103%	105%	100%	85%
Hooper XS-2	45.61	1991	1123	889	234	11	100%	100%	100%	100%
Hooper XS-2		1993	1142	948	194	13	102%	107%	83%	116%
Hooper XS-2		1997	1280	953	327	24	114%	107%	140%	226%
Hooper XS-2		1998	1442	1068	374	37	128%	120%	160%	345%
Hooper XS-3	46.06	1991	1142	417	725	65	100%	100%	100%	100%
Hooper XS-3		1993	1193	627	566	87	104%	151%	78%	134%
Hooper XS-3		1996	1234	403	831	120	108%	97%	115%	184%
Hooper XS-3		1997	1307	591	716	105	114%	142%	99%	160%
Hooper XS-3		1998	1572	790	782	44	138%	190%	108%	67%
Hooper XS-4	47.21	1991	1315	889	426	21	100%	100%	100%	100%
Hooper XS-4		1993	1527	1070	456	27	116%	120%	107%	124%
Hooper XS-4		1997	1512	1004	508	22	115%	113%	119%	104%
Hooper XS-4		1998	1473	1235	238	19	112%	139%	56%	87%

The area of the channel occupied by the low water channel had increased by 18% from 1991 to 1996. The area below the low-flow water surface increased by 63% between 1991 and 1996. In 1996, the right edge of the low water channel had eroded laterally about 5 feet, relative to its 1991 location. The lateral erosion of the right edge of the low water channel exposed approximately 80 feet of clay along the margin of the bar, in the vicinity of the cross section.

The 1997 event deposited material in the low flow channel burying the clay. The width of the low flow channel decreased by about five feet. The water surface fell about 0.5 feet relative to 1996 and about declined about 0.2 feet, relative to 1991. In 1997, the thalweg rose about 1.6 feet relative to 1996 and rose 0.2 feet, relative to 1991. The cross section area below the water surface declined -25% in 1997 compared to 1991. The deposition from the 1997 flood decreased the channel cross section area of the dry portion of the channel by -38% compared to 1991.

The 1998 floods eroded material from the bar and low water channel at cross section 1. The total cross section area returned to its 1991 value. The area below the low-flow water surface was only 85% of its 1991. The 1998 water surface was 0.6 feet lower than in 1991. The decline in water surface elevation appears to explain most of the difference in area below the low-flow water surface between 1991 and 1998.

At cross section 1 clay was visible on the left bank, above the low water surface, during the original survey in 1991. No clay was visible on the right margin of the low water channel during the 1991 survey. Furthermore, no clay was visible in the thalweg of the channel in 1991. The clay on the margin of the bar first became visible during the winter of 1994, however, no survey was performed in 1994.

The clay in the left bank may be related to the San Andreas fault and may have been exposed for a very long time. The layer of clay that was exposed in 1996 does not necessarily mean that the river recently cut through the clay. It is possible that the river cut into the clay layer in the past and material was deposited on top of the eroded surface. The recent floods may have just re-exposed a previously eroded surface. This idea is supported by the filling of the low water channel in 1997.

Another possibility is that the river flowed along the right bank in the past and then shifted to the far left bank where it is today. During this process it "skipped over" the clay in the right bank gravel bar, leaving it as a relic. This still implies incision but the incision may have happened many years ago. This possibility could be investigated by examining the older aerial photos to see if the river ever flowed along the right bank.

Cross section 2 was surveyed in 1991, 1993, 1997 and 1998. In 1991, cross section 2 traversed the upstream end of the suspension bridge bar (Bar 22) on the right (northeast) bank. Each survey shows that the upstream end of the suspension bridge bar has been eroded, relative to 1991. By 1998, the low-flow channel had lowered -1.6 feet and had shifted to the right, eroding about 20 feet from the edge of Bar 22. The water surface was -0.4 feet lower in 1998 than it was in 1991, see Figures 10 and 11. In 1997, the secondary channel carried flow in the summer and the head of Bar 22 was a peninsula in late August. The 1998 floods deposited enough material at the head of Bar 22 to bury the secondary channel.

The surface of Bar 21 on the left (southwest) bank of cross section 2 has eroded, relative to 1991. However, by 1998, Bar 21 had extended approximately 15 feet into the low water channel. It is possible that the extension of Bar 21 played a role in the erosion of the head of Bar 22. The maximum depth of the low-flow channel was 1.8 feet during the October of 1998 compared to 0.6 feet in July 1991. The area of the cross section below water was 3.45 times the 1991 area, see Table 8. The 1998 total area of the low water channel was 60% greater than it was in 1991. The area of the dry portion of the bar increased by 20%, relative to 1991. The total cross section area increased by 28% relative to 1991. Thus there has been net erosion at cross section 2 with the majority of the erosion concentrated on the bars.

Cross section 3 was surveyed in 1991, 1993, 1996, 1997 and 1998. In 1996 Graham Matthews surveyed the cross section. He could not locate the left bank stake for cross section 3. So, he drove a spike in an alder and used it as the left bank endpoint. The 1996 left bank end point is about 25 feet downstream of the 1991 cross section line.

In 1997 and 1998, a total station was used to locate the cross section endpoints. However, the missing left bank monument for cross section 3 could not be recovered even with the total station. The coordinates for the missing monument were located but the stake was not found. The spike in the alder tree, placed in 1996, was about 25 feet downstream of the location of the missing monument. Since the 1996 survey used the same right bank monument the data can be used without introducing significant error.

The water surface elevation for cross section 3 was not recorded in 1996. The 1996 analysis of the data assumed a water surface elevation of 34.5 feet. Re-evaluation of the data suggests that 36.79 feet is a better estimate of the 1996 water surface elevation. The 1996 survey stops about 45 feet from the 1996 left bank endpoint (spike in alder). Thus, the area calculation for 1996 are approximate, at best.

The 1997 survey showed that there was net erosion at cross section 3 since the area increased by 14%, relative to 1991. Most of the erosion occurred in the dry channel since its area increased 42%, relative to 1991. However, a minor amount of deposition occurred in the low water portion of the channel causing its area to decreased by -1%, relative to 1991. The area of the channel below water increased by a 61% relative to 1991. A portion of the increase in area was due to the thalweg lowering -0.7 feet and a portion of the increase is due to the water surface rising 0.5 feet.

In 1998, parts of the surface of Bar 21 were 5 feet lower than it was in 1991. The total cross section area, in 1998, was 38% greater than what it was in 1991 (Table 8). The cross section area outside the low-water channel (Bar 21) increased 90% between 1991 and 1998.

Cross section 4 was surveyed in 1991, 1993, 1997 and 1998. The low-flow channel has shifted to the left towards Bar 21, about 30 feet. The shift of the low-flow channel to the left was accompanied by a lowering of the channel. The 1998 thalweg was -1.9 feet lower than it was in 1991 and the water surface was -1.65 feet lower. The end of Bar 20, on the right (east) bank has extended a similar distance to the west. The shift in the low flow channel has been accompanied by the erosion of the edge of Bar 21 long the low flow channel.

A significant portion of Bar 21 has been eroded from the vicinity of Cross Section 4. However, the extension of Bar 20 to the west was caused by the deposition of an amount similar to what was lost from Bar 21 between 1993 and 1998. The simultaneous erosion and deposition of material on different portions of the cross section has resulted in only a 12% change in the total cross section area between 1991 and 1998. The low-water channel is now a riffle. In 1991, it was wider but, the water had a lower velocity. The narrower width has resulted in a 13% decrease in the area of the low-flow channel.

The data from the Hooper cross sections show that the Garcia River has slightly incised since 1991. The thalweg, at the four cross sections, has lowered an average of -1.3 feet and the water surface has dropped and average of -0.8 feet. There has been less incision at cross section 1, at the downstream end of the reach. The slope of the low-water surface has declined from about 0.003 in 1991 to about 0.002 in 1998. The decline in slope should act to increase the potential for deposition in the reach during the 1999 flood events. The clay at cross section 1 is no longer visible. The bank collapse upstream may be providing enough material to temporarily slow the incision process and prevent the bed from scouring at cross section 1. If the scouring of the bed continues and more clay is exposed, the value of the aquatic habitat in the reach will be diminished.

Conner Hole Cross Sections:

Conner Hole is located at Bar 13, approximately 4,000 feet downstream of the confluence with the North Fork. The USGS operated a continuous record stream gage at Conner Hole from 1962 to 1983, and a crest gage from 1951 to 1956. The Friends of the Garcia River installed a stage recorder at the location of the USGS gage in the fall of 1992.

In the summer of 1991, MCWA established three cross sections at Conner Hole as part of the RCD's watershed assessment project. All three cross sections were surveyed in 1991, 1993, 1996, 1997 and 1998. The cableway cross section was also surveyed in 1995 by MCWA. The USGS surveyed the reach in 1956 and 1963 for slope-area estimates of the peak flows in the range of 23,000 to 26,000 cfs. The slope-area cross sections were surveyed during the winter between storm events. The slope-area surveys estimated the flood water surface profile and cross sectional area of the channel for the peak flood events from field evidence.

The upstream MCWA cross section is located at the site of the USGS cableway. The right bank endpoint is the USGS benchmark on the A-frame anchor block. The benchmark is 18.82 feet above the gage datum which has an elevation of 55.31 feet NVGD. Thus, the NVGD of the benchmark is 74.13 feet NVGD. The left bank endpoint is a piece of rebar located near the stage recorder. Both of the endpoints were found to be in good condition, in 1997.

An analysis of the USGS gaging station discharge notes (Jackson, 1991) showed that a resistant layer appears to exist at -6.0 feet below gage datum or 49.31 feet NVGD. Figure 13, (same as Figure 4.5 of the Garcia River Gravel Management Plan, August 1996) shows that, for flows greater than 5,000 cfs (gage height = 9.10 feet, or 64.41 feet NVGD), the vertical bed scour appears to cease at about 6.0 feet below the gage datum. As flow increases beyond 5,000 cfs, the figure shows that the gravel bar on the right bank is scoured laterally. All of the rating curves developed by the USGS are the same above 5,700 cfs, suggesting that the scour developed at flows above 5,000 cfs washes away any irregularities in the channel.

Both the 1956 and 1963 slope-area measurements used a cross section located near the cableway. The Figure 14 shows these early cross sections with the 1996 and 1998 data. The level of the dominate discharge, 15,000 cfs, has also been added to Figure 14 for comparison. Figure 14 shows that the cross section is very stable. From 1956 to 1963 the thalweg rose 0.6 feet. Between 1963 and 1996 the thalweg dropped 0.8 feet. Thus, in the forty years from 1956 to 1996 the thalweg changed by 0.2 feet. However, the thalweg elevation during most of this forty year period is unknown. That is, the actual thalweg elevation during a given year may have been significantly different from the values measured in 1956, 1963, 1996 and 1998. In fact, the graph of the sediment wave shown in Figure 1 suggests that, between 1968 and 1983 the thalweg obtained its highest level around 1975.

The data used to form the graph of the sediment wave in Figure 1 was collected by the USGS at the Conner Hole cableway. Figure 1 tracks the water surface elevation required for the discharge of 100 cfs. Figure 15 compares the thalweg elevation from 19 cableway discharge measurements with the data from Figure 1. Figure 15 also shows the surveyed thalweg elevations. An analysis of the USGS gaging station discharge notes (Jackson, 1991) showed that the thalweg elevation, during discharge measurements, was related to the magnitude of the discharge being measured. Jackson developed the following regression equation to estimate the thalweg based on the log of the discharge.

$$\text{Thalweg (relative to gage datum)} = -6.7133 \times \text{Log(Discharge)} + 20.234. \qquad R^2 = 0.7886$$

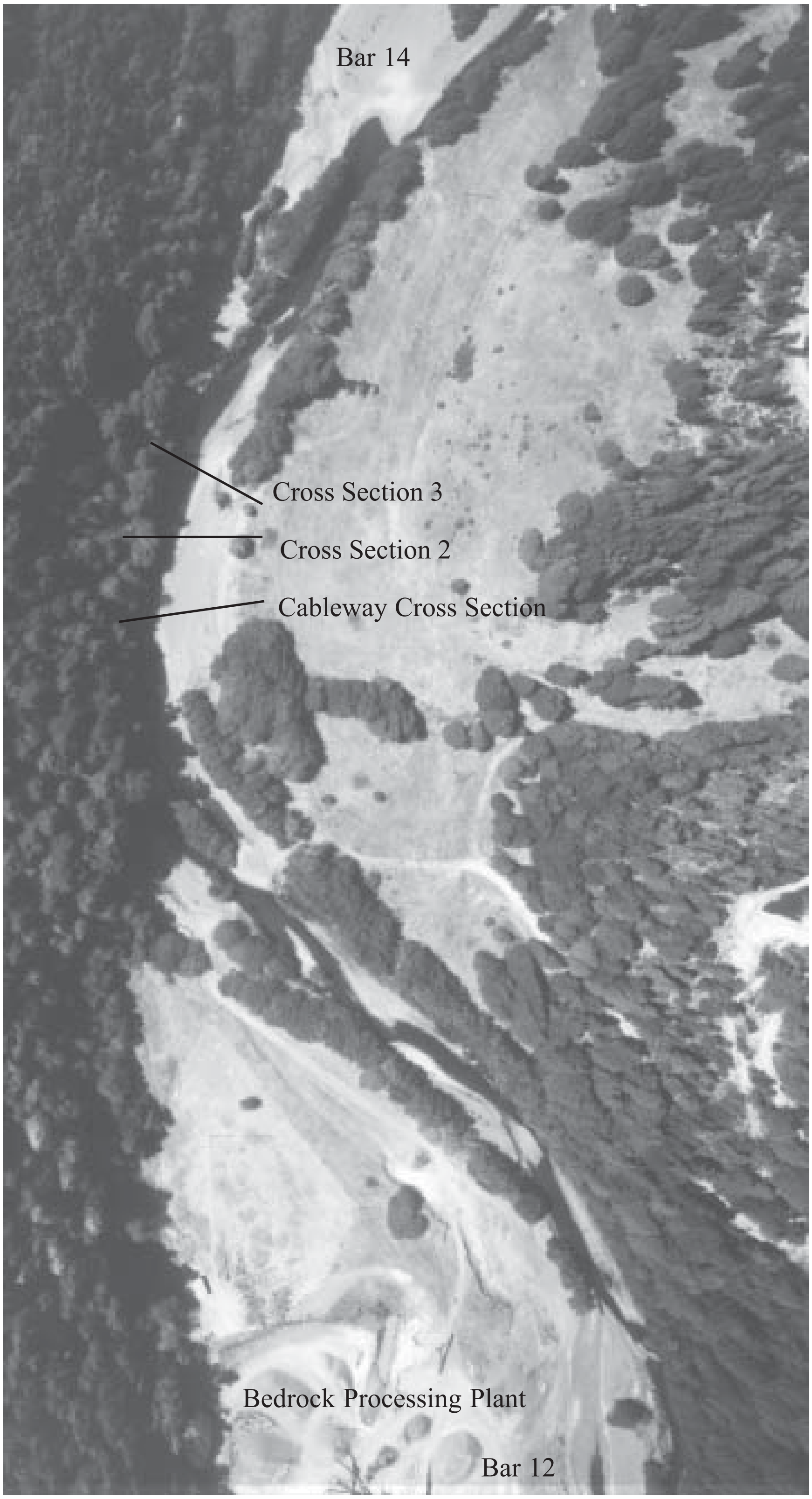


Figure 12. Conner Hole gaging station cross sections. River flows towards top of photo. Photo from September 1992.

Figure 13. Comparison of the 1963 slope-area measurement with three cross sections derived from cableway discharge measurements.

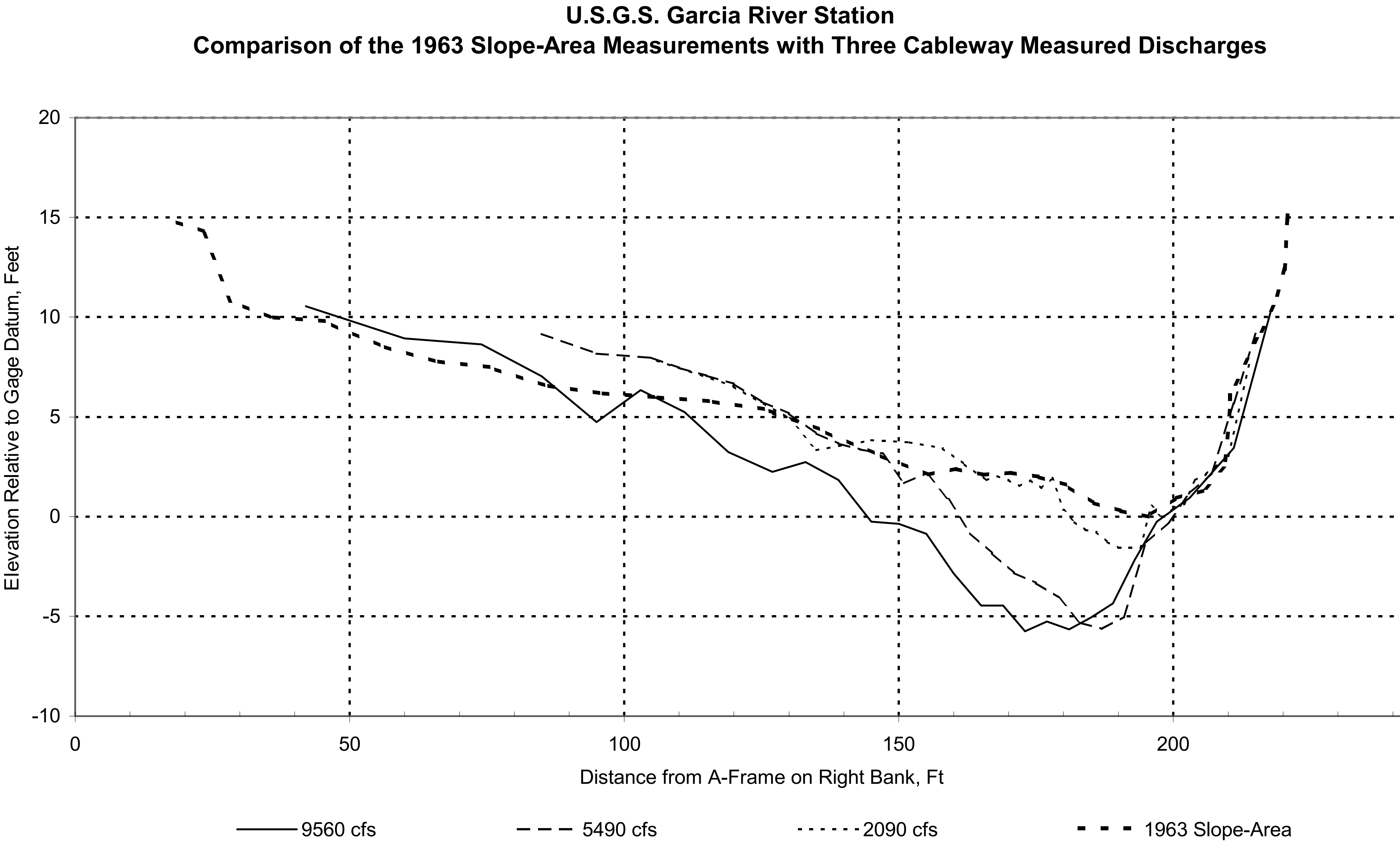


Figure 14. USGS slope-area surveys from 1956 and 1963 compared to the 1996 and 1998 surveys

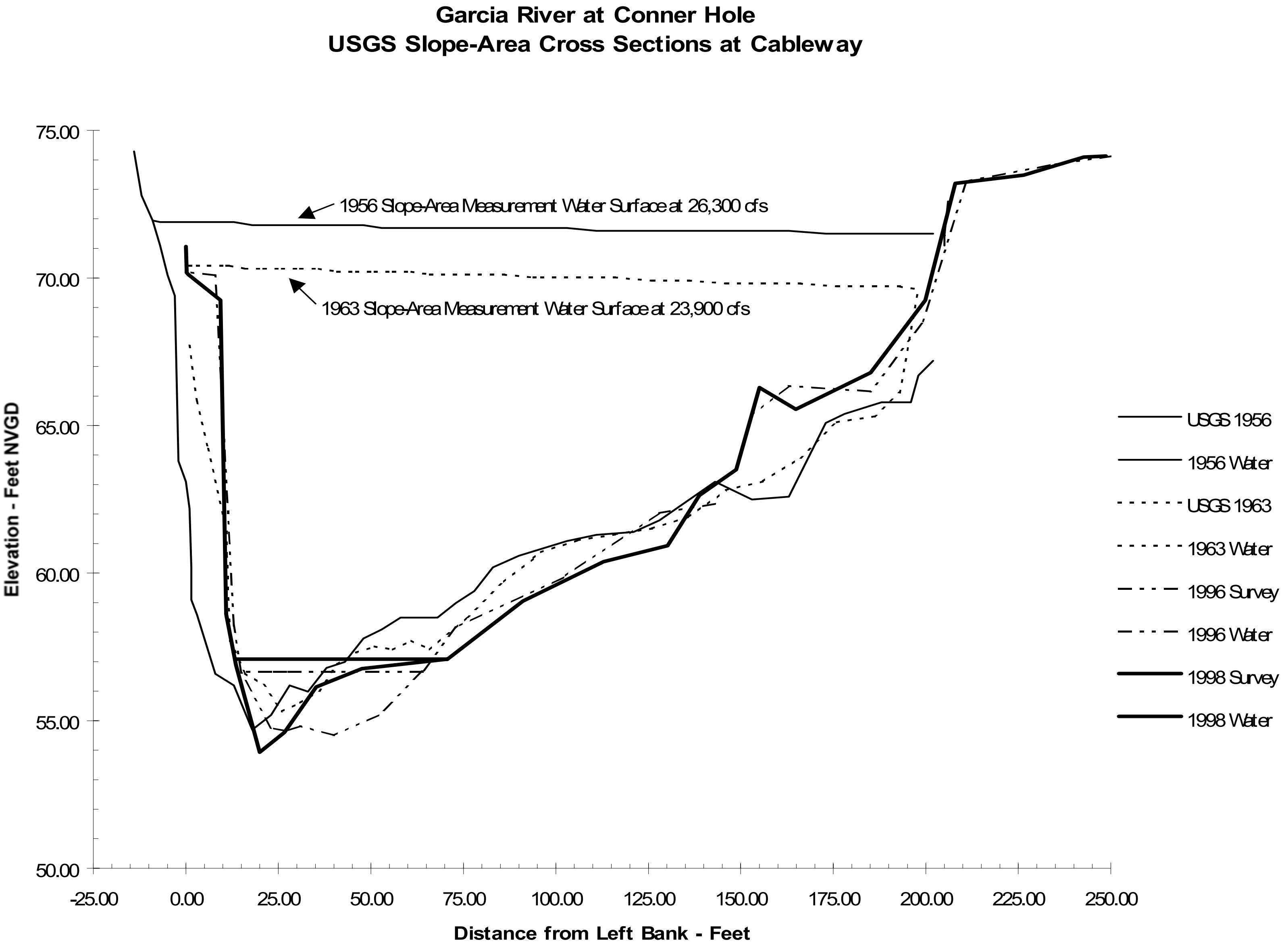


Figure 15. Thalweg elevations derived from cableway discharge measurements at the Conner Hole gaging station on the Garcia River.

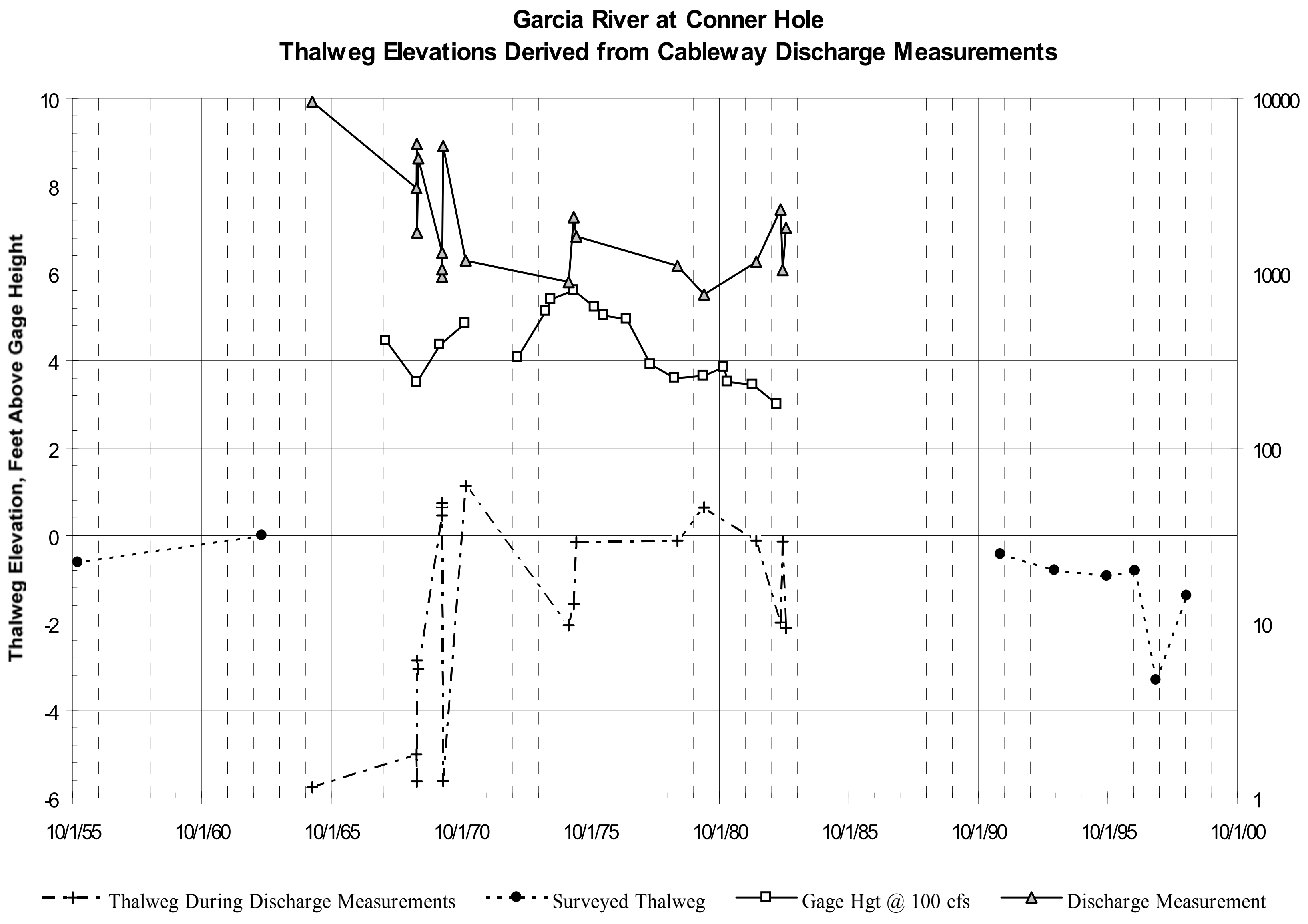


Table 9(a). Water surface and thalweg elevations for the Conner Hole cross sections.

	1991		1993		1995		1996		1997(a)(b)		1998	
Cross Section	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
Cableway	57.4	54.9	58.7	54.5	58.2	54.4	56.7	54.5	56.8	52.0	57.1	53.9
MCWA-2	57.4	56.1					56.7	55.8	56.8	54.7	57.1	56.0
MCWA-3	57.3	56.8	58.7	55.8			56.0	55.2	56.8	55.3	56.6	55.8

Table 9(b). Maximum water depths for the Conner Hole cross sections.

	1991	1993	1995	1996	1997(a)(b)	1998
Cross Section	Maximum Depth	Maximum Depth	Maximum Depth	Maximum Depth	Maximum Depth	Maximum Depth
MCWA-1	2.5	4.2	3.8	2.2	4.8	3.2
MCWA-2	1.3			0.9	2.1	1.1
MCWA-3	0.6	2.9		0.8	1.5	0.8

Table 9(c). Relative changes in the water surface and thalweg elevations for the Conner Hole cross sections.

	1991		1993		1995		1996		1997(a)(b)		1998	
Cross Section	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
MCWA-1	0.0	0.0	1.3	-0.4	0.8	-0.5	-0.8	-0.4	-0.6	-2.9	-0.3	-1.0
MCWA-2	0.0	0.0					-0.7	-0.3	-0.6	-1.4	-0.3	-0.1
MCWA-3	0.0	0.0	1.3	-1.0			-1.4	-1.6	-0.5	-1.4	-0.8	-1.0

Table 10. Cross section area and relative changes in cross section area for the Conner Hole cross sections.

Cross Section	Reference Elevation	Year	Total Area Below Reference	Total Area Outside of Low-Water Channel Below Reference	Total Area of Low-Water Channel Below Reference	Total Area Below Water	Relative Area Below Reference	Relative Area Outside of Low-Water Channel Below Reference	Relative Area of Low-Water Channel Below Reference	Relative Area Below Water
Cableway	70.20	1991	2070	1326	744	28	100%	100%	100%	100%
Cableway		1993	2052	1037	1015	200	99%	78%	136%	723%
Cableway		1995	1750	902	848	322	85%	68%	114%	1166%
Cableway		1996	1833	1097	736	72	89%	83%	99%	261%
Cableway		1997	2024	1251	773	89	98%	94%	104%	323%
Cableway		1998	2431	1453	978	228	117%	110%	131%	825%
Conner XS-2	73.02	1991	2706	1516	1190	66	100%	100%	100%	100%
Conner XS-2		1993	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Conner XS-2		1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Conner XS-2		1996	2806	1850	955	24	104%	122%	80%	36%
Conner XS-2		1997	2933	958	1974	122	108%	63%	166%	186%
Conner XS-2		1998	2688	1669	1019	71	99%	110%	86%	108%
Conner XS-3	69.73	1991	2442	1829	613	18	100%	100%	100%	100%
Conner XS-3		1993	2656	680	1976	44	109%	37%	323%	251%
Conner XS-3		1995	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Conner XS-3		1996	2647	2293	354	10	108%	125%	58%	54%
Conner XS-3		1997	2809	1697	1112	77	115%	93%	182%	436%
Conner XS-3		1998	2581	2093	488	60	106%	114%	80%	338%

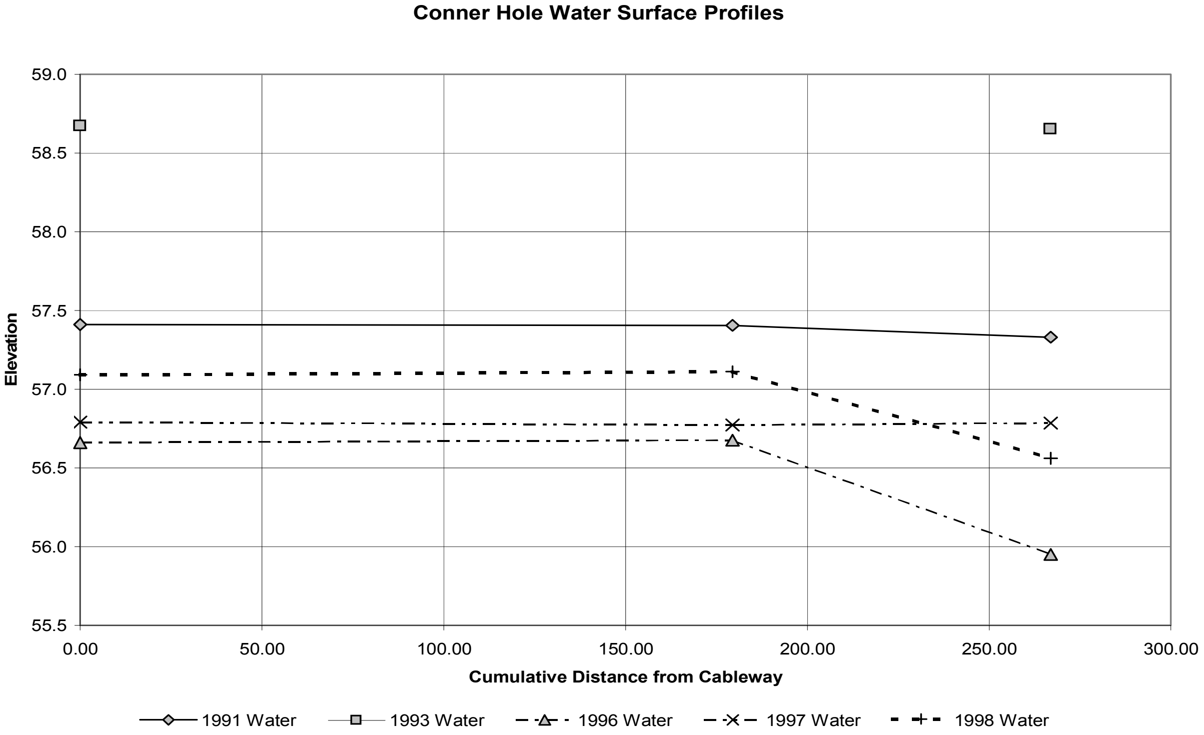


Figure 16. Water surface profiles for Conner Hole.

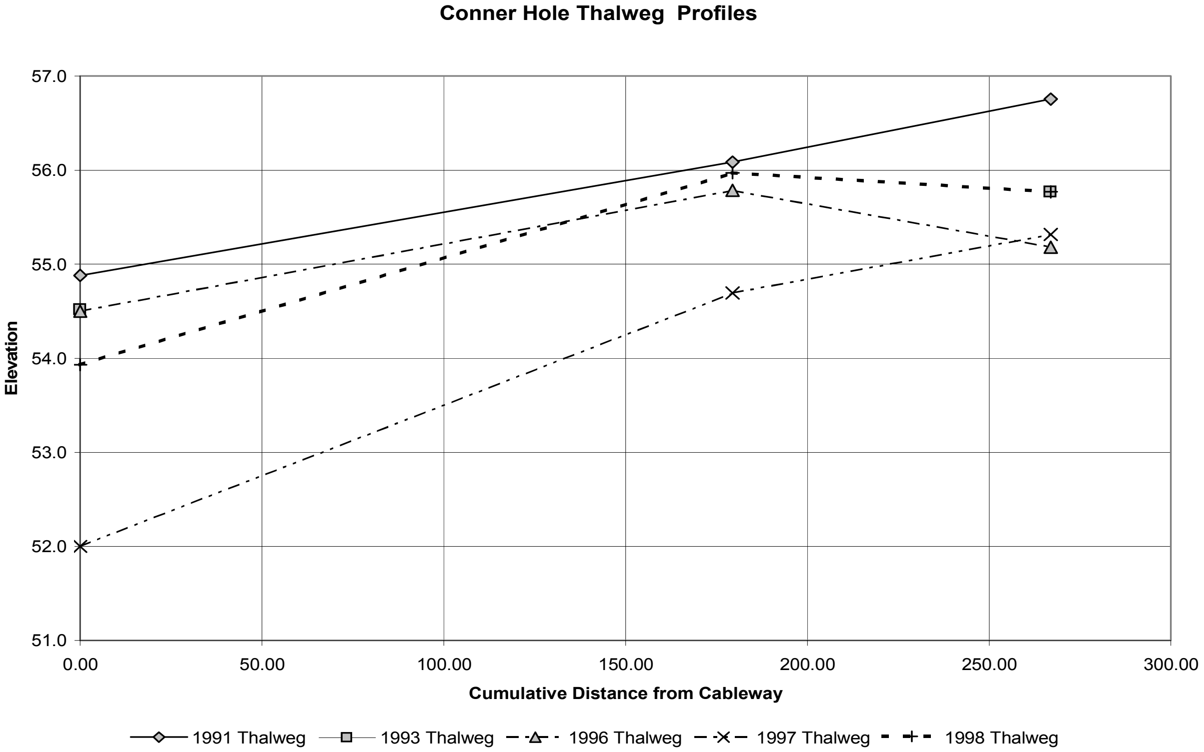


Figure 17. Thalweg profiles for Conner Hole.

The above regression explains 78.8% of the variation ($R^2 = 0.7886$) in the thalweg elevation observed during discharge measurements. This equation can only be used with confidence for flows less than 9,560 cfs.

Nine of the 19 cableway measurements were taken in 1969 and 1970. This clustering of the cableway measurements makes comparing the thalweg elevation observed during discharge measurements to the gage height at 100 cfs difficult. However, there does appear to be a weak correspondence between the observed thalweg elevation and the stage required for 100 cfs flow. The observed thalweg during flow measurements fluctuated between +1.1 and -5.8 feet gage height for the 19 cableway measurements made between January 5, 1965 and April 28, 1983. The summer thalweg elevation would probably be equal to or higher than the observed thalweg elevation of a cableway discharge measurement. This is because late spring and early summer discharges would have a tendency to deposit material in the thalweg. Thus, the summertime thalweg elevation was never lower than the thalweg elevation observed during flow measurements for the period when the USGS station was active.

All the surveyed thalweg elevations fall within the range, +1.5 and -2.5 feet gage height, except for the August 1997 survey. The August 1997 thalweg measurement, -3.3 feet gage height, is the lowest surveyed thalweg elevation recorded since 1955. This drop in thalweg elevation might be the result of the passage of the sediment wave followed by a dry period from 1984 to 1992 plus the removal of bed material by the gravel mining operation just upstream at Buckridge Road from 1986 to 1996.

The discussion about the origin of the sediment wave, see page 8, suggests that the series of large flows that began in 1993 could result in another sediment wave traveling down the Garcia. The sediment wave could take several years to reach Conner Hole because the number of slides that terminate in the river is higher upstream of Eureka Hill Road than below it. Material delivered to the river above Eureka Hill Bridge could take several storms, and therefore several years, to be transported down to Conner Hole. Thus, the thalweg at Conner Hole might lower until material from upstream arrives.

The gravel mining at Buckridge Road removed a significant amount of gravel from the riverbed between 1986 and 1996. The removal of this material has created conditions that favor deposition. The tendency for material to be deposited in the Buckridge area will decrease the amount of material that is available to be transported downstream to Conner Hole until the bars build to their pre-mining size. Thus, it is possible that the thalweg at Conner Hole may be expected to drop in elevation in response to large storm events until the Buckridge area has recovered from the effects of mining.

Figure 14 shows that the lower part of the channel appears have increased in width by 50% since 1956. The increase in width has occurred at the expense of the gravel bar on the right bank. The 26,300 cfs flood event in 1956 may have deposited a significant amount of material on the right bank gravel bar. Bed material is stored on this bar between flood events. The erosion of this bar, relative to 1956, suggests a decrease in local availability of bed material from 1956 to 1997. This is consistent with the above discussion concerning the passage of the sediment wave and the impact of gravel mining at Buckridge Road.

Olsen Creek, the tributary, just upstream of the cableway, did not deposit sufficient material in its delta to be visible on either the 1956 or 1963 cross section. The 1995 event formed a large deposit at the mouth of the tributary. This deposit is the "hump" on the cross section between 145 feet and 185 feet on Figure 14 and the graph of the cableway cross sections in the appendix. It would be useful to find out the land use history of the watershed drained by the tributary that enters the Garcia just upstream of the cableway on the right (north) bank.

Table 9 shows the water surface and thalweg elevations. Table 10 gives the cross sectional area data for the surveys since 1991. The graph, in the appendix, labeled Cross Section at Cableway shows the cableway surveys from 1991, 1993, 1995-1998. The floods of 1993 eroded the right bank gravel bar, relative to 1991. The 1993 floods also appear to have built up the downstream riffle that controls flow out of the pool because the October 1993 water surface is 1.3 feet higher than the July 1991 water surface (Table 9). The higher 1993 water surface prevented the rod man from crossing the river on the cross section, as indicated by the missing 1993 data. The 1995 flood, the largest recorded at this location, deposited material on the right bank gravel bar.

However, most of the material deposited by the 1995 flood was concentrated in the delta that formed at the mouth of Olsen Creek, the small tributary on the right bank just upstream of the cableway. Table 10 shows that the delta deposits resulted in an 16% decrease in cross sectional area from 1991 to 1995. Table 10 also shows that the total cross section area of the cableway cross section has been expanding since 1995, indicating that erosion has been outpacing deposition at the cross section.

The summer water surface reached its maximum elevation (58.7 feet) during the 1993 survey, indicating that the downstream control reached its maximum elevation. The water surface progressively lowered until it reached its lowest level (56.7 feet) in 1996. Since 1996, the control appears to have been building since the water surface elevation has been progressively rising. In 1998, the water surface was 57.1 feet, only 0.3 feet lower than it was in 1991.

The thalweg at the cableway cross section was nearly constant between 1991 and 1996 with its value ranging from 54.4 to 54.9 feet. In 1997, the thalweg dropped to 52.0 feet. In 1998, the thalweg rose to 53.9 feet, only 0.5 feet lower than it was in 1991.

Figure 1 shows that in 1983 a stage of 2.05 feet (57.2 feet NVGD) was required to produce a flow of 10 cfs. The 1983 rating table shows that at a stage of 2.3 feet (57.6 feet NVGD) the flow was 35 cfs. In 1991 the water surface elevation was 57.4 feet NVGD. It is reasonable to assume that the flow, on the date of the 1991 survey, was in the range from 10 cfs to 35 cfs. Therefore, the elevation of the control riffle in 1991 was about the same as in 1983.

The second cross section is about 180 feet downstream of the cableway at the site of a footbridge. The footbridge is no longer in existence but, its foundation is clearly visible on the right bank. This cross section was surveyed in 1991, 1996, 1997 and 1998. The graph of Cross Section 2 at Abandoned Footbridge (appendix) shows the results of the four surveys. The thalweg dropped -0.3 feet between 1991 and 1996. The thalweg dropped an additional -1.1 feet in 1997. In 1998, the thalweg returned to its 1996 level. The water surface dropped 0.7 feet between 1991 and 1996 (Table 8). The water surface rose 0.1 feet in 1997. In 1998, the water surface rose, relative to 1997, and was -0.3 feet lower than it was in 1991

Between 1991 and 1996 approximately 3 feet of bed material was eroded from the right bank gravel bar and some material was deposited at the bottom of the left bank. The erosion of the right bank bar continued in 1997. After the 1997 event, the right bank bar had been replaced by a deep backwater area. The 1997 water surface extended completely across the bottom of the channel. However, a submerged remnant of the right bank bar remains as a mid-channel bar or shoal. The floods of 1998 deposited a significant amount of material on the right bank which, buried the backwater that formed in 1997.

The erosion of the bed between 1991 and 1996 resulted in a 3% increase in cross section area (Table 9). The additional erosion in 1997 increased the cross section area an additional 5%. The deposition on the right bank in 1998 has returned the cross section area to almost exactly what it was in 1991.

The third cross section is about 90 feet downstream of the second cross section. The right bank end is about 38 feet downstream of the right end of the second cross section. After this cross section was established in 1991. Rau and Associates' Ishizaki cross section No. 5 intersects MCWA’s cross section 3 in mid-channel. Cross section 3 was surveyed in 1991, 1993, 1996-1998. The graph labeled Downstream of

Footbridge (appendix) shows the data from the five surveys. The 1991 data shows a peak at 45 feet from the left bank. This peak is the berm constructed by Bedrock in October of 1990 in an unsuccessful attempt at keeping the river in its low water channel along the far right edge of Bar 14.

Table 9 shows that the cross section eroded (increase in area) from 1991 through 1997. There was some deposition in 1998 since the cross section area decreased from its 1997 value. However, erosion of the cross section dominated from 1991 through 1998 since the area in 1998 was greater than the area in 1991.

In 1991, a riffle occupied the low flow channel at cross section 3. This riffle was the control for the gaging station pool. The crest of the riffle was just upstream of cross section 3. The flood of 1993 eradicated the berm constructed by Bedrock and built up the downstream control. Between 1991 and 1993, the thalweg dropped 1 foot and the water surface rose 1.3 feet (Table 9). The drop in the thalweg and rise in water surface resulted in an 8% increase in cross section area (Table 10). The 1993 survey shows that the low flow channel occupied the entire channel bottom. The 1993 flood completely buried the 1991 low flow channel and shifted the thalweg from near the left bank to the base of the right bank.

By 1996, the left bank bar had re-emerged as the upstream extension of bar 14 as the water surface dropped -2.7 feet relative to 1993. The thalweg lowered another -0.6 feet between 1993 and 1996 (Table 9) and shifted away from the bottom of the right bank. In 1996, a riffle again occupied the low flow channel at cross section 3 and the control for the gaging station pool was at the top of the riffle.

In 1997, the thalweg was once again at the base of the right (north) bank. The water surface rose 0.8 feet and the thalweg rose 0.1 feet, relative to 1996. In 1998, the declined an additional -0.3 feet, relative to 1997. The thalweg rose 0.4 feet from 1997 to 1998.

Part of the decline in the water surface and thalweg elevation at cross section 3 might be explained by the 1993 shift in the low water channel at Bar 14 just downstream. The surface of Bar 14 had been significantly lowered by gravel extraction between 1988 and 1990. The lower bar surface was not able to topographically steer the river around the right edge of Bar 14 resulting in the river cutting through the bar.

The width of the river channel increases downstream as the center of Bar 14 is approached. The USGS slope-area topographic map clearly shows the widening of the channel. A copy of the USGS map is available at the MCWA office. The downstream widening of the channel may explain why the 1993 flood event deposited 1.3 feet of material on the control downstream of cross section 3.

Taken together, the three cross sections at Conner Hole show that events like the 1993, 1995 and 1997 floods may deposit material in the pool and on the riffle, but the deposited material is soon eroded away. The data from these three cross sections do not support the idea that the Garcia River is aggrading at Conner Hole. The data show that both the 1996 - 1998 thalweg and water surface elevations were lower than they were in 1991, at all three cross sections. Given the decline in water surface and thalweg elevations it is possible that the river is beginning to incise at Conner Hole. This may be a direct impact of the gravel mining that occurred on Bars 11 and 12 upstream from 1986 through 1996 and the the 1988 mining downstream at Bar 14.

Figure 15 supports the notion that, for the period 1956 through 1996, the Conner Hole reach was in dynamic equilibrium. However, the continued lowered water surface and thalweg elevations in 1998 gives rise to a concern that further incision may occur at Conner Hole. Figure 1 and Figure 15 suggest that a sediment wave moved passed Conner Hole between 1963 and 1983. Figure 2 suggests that the relative dry period from 1984 to 1992 resulted in less slide activity in the watershed and therefore less bed material was delivered directly to the river. The decrease in delivery of bed material to the river plus the impact of the gravel extraction operation at Buckridge Road indicate a strong possibility that further incision at Conner Hole is likely. If the incision at Conner Hole continues the incision process would be expected to propagate downstream since there are no significant tributaries below Conner Hole to make up for the decrease in supply of bedload. However, if the wet period that began in 1993 continues, the supply of bed material reaching Conner Hole could be expected to increase which might halt the incision.

Eureka Hill Bridge Cross Sections:

In 1992, the USGS began to collect sediment transport data at the Eureka Hill Bridge under a contract with MCWA. The USGS installed a wire reel on Eureka Hill Bridge to measure stage. Under a cooperative agreement between MCWA and the Friends of the Garcia River, a datalogger was installed on the old bridge pier, on the left bank, downstream of the existing bridge, in the fall of 1992. In the fall of 1993, a second datalogger was installed upstream of the bridge on the left bank. The datalogger was equipped with a modem so the river stage could be checked remotely. Discharge measurements were made during low to medium flow by MCWA personnel to assist in the preparation of a rating curve for the two dataloggers.

In September of 1993 MCWA personnel made a topographic map of the reach from 400 feet below the bridge to about 1,500 feet above the bridge and surveyed cross sections at the two dataloggers. In September of 1995 Philip Williams & Associates (PWA) surveyed three cross sections and prepared a longitudinal profile for the reach running from about 1,000 feet below the bridge to about 400 feet above the bridge. They also surveyed the cross sections at the two dataloggers. These two cross sections were also in October of 1996, in August of 1997 and in October of 1998.

The datalogger upstream of the bridge was dubbed "Salmon" by MCWA. The graph labeled Salmon Datalogger (appendix) shows the data from the four surveys. Table 11 shows that the thalweg dropped -0.3 feet between 1993 and 1995 and then rose 0.6 feet in 1996 followed by a drop of -1.3 feet in 1997. In 1998, the thalweg rose about 0.4 feet from its 1997 level. The 1998 thalweg level was -0.6 feet lower than its 1991 level.

The water surface remained virtually unchanged between 1993 and 1995. In 1996, the water surface declined -0.4 feet from its 1993 level. The water surface declined another -0.2 feet in 1997 and then rose 0.2 feet in 1998. So, the 1998 water surface was -0.4 feet lower than the 1991 water surface. The drop in the water surface indicates that the control for the gaging pool has lowered, relative to 1993.

Table 12 shows that the cross section area remained about the same from 1993 to 1995 and then decreased -6% in 1996 followed by a 7% increase in 1997. In 1998, the cross section area decreased about 4%. Overall, the cross section area shows there was deposition between 1993 and 1998 at the Salmon cross section.

There has been noticeable bank erosion along the left bank near the staff gage. The lowest staff gage appears to be leaning slightly towards the center of the channel. The thalweg, next to the leaning staff gage, is -0.6 feet lower than it was in 1993. However, the rest of the bed of the low-flow channel is at at almost the same level as it was in 1993. Most of the decrease in the area below the low-flow water surface is due to the -0.4 foot decline in water surface. The dry portion of the channel experienced deposition in 1998 that decreased its cross section area by 12% from its 1993 value.

The graph labeled Old Pier (appendix) shows the five surveys conducted at the pier datalogger downstream of Eureka Hill Bridge. From 1993 to 1995 the thalweg dropped -0.6 feet, the water surface rose 0.7 feet (Table 11) and the low water channel widened about 12 feet. The low-water channel continue to widen by eroding the gravel bar on the right bank each year from 1996 through 1998 so its final width was 325 feet wider than in 1993.

Figure 18. Map of Eureka Hill Bridge cross sections,. Photo from September 1992. Flow is from the top of the picture towards the bottom.

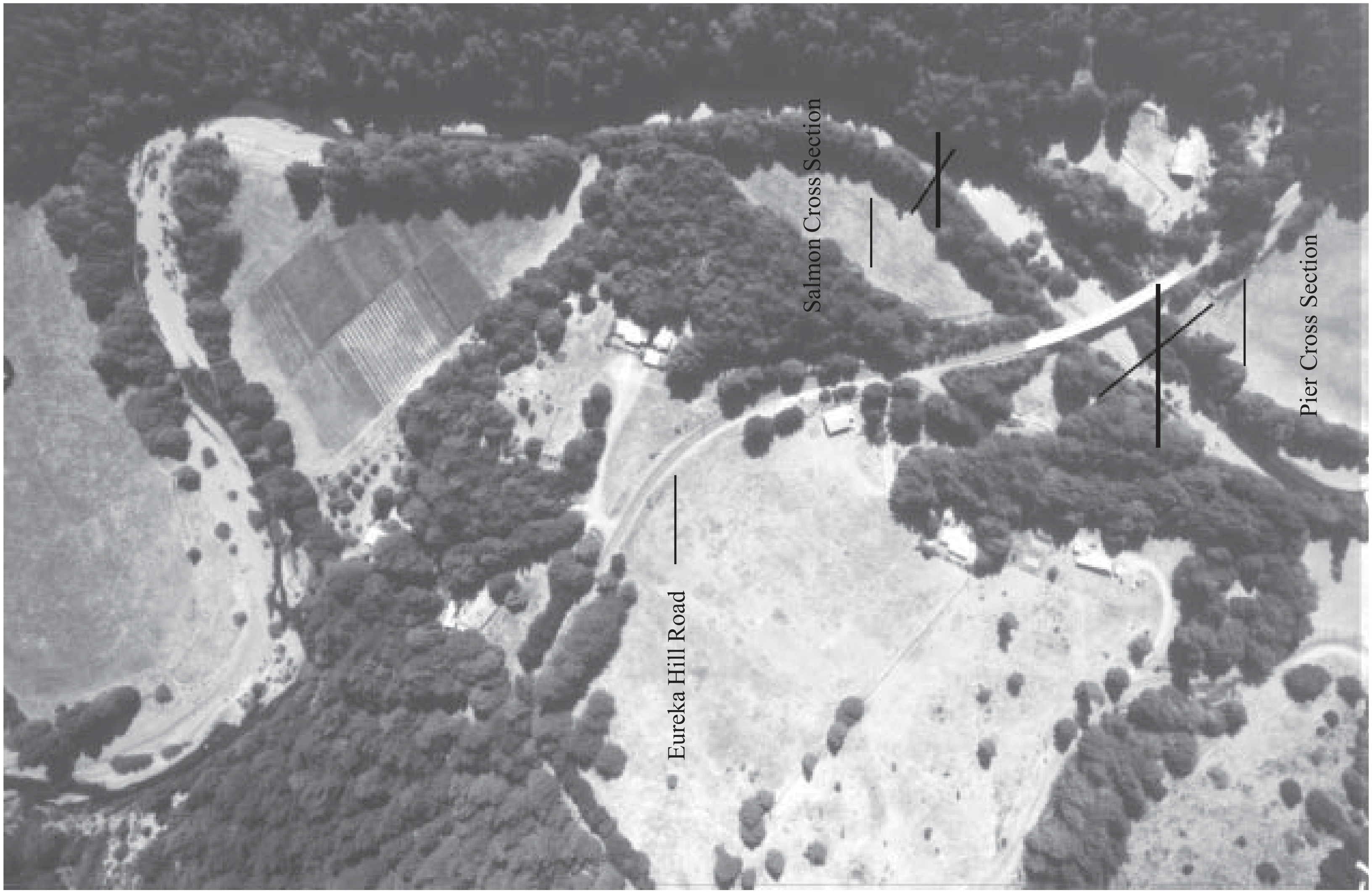


Table 11(a). Water surface and thalweg elevations for the Eureka Hill Bridge cross sections.

	1993		1995		1996		1997		1998	
Cross Section	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
Pier	83.6	82.1	84.3	81.5	83.6	81.5	83.7	81.6	83.6	82.6
Salmon	85.2	82.7	85.2	82.4	84.7	83.0	84.6	81.7	84.8	82.2

Table 11(b). Maximum water depths for the Eureka Hill Bridge cross sections.

	1993	1995	1996	1997	1998
Cross Section	Maximum Depth	Maximum Depth	Maximum Depth	Maximum Depth	Maximum Depth
Pier	1.4	2.8	2.1	2.1	1.1
Salmon	2.4	2.8	1.7	2.9	2.6

Table 11(c). Relative changes in the water surface and thalweg elevations for the Eureka Hill Bridge cross sections.

	1993		1995		1996		1997		1998	
Cross Section	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg	Water	Thalweg
Pier	0.0	0.0	0.7	-0.6	0.0	-0.6	0.1	-0.6	0.0	0.4
Salmon	0.0	0.0	0.1	-0.3	-0.4	0.3	-0.6	-1.0	-0.4	-0.6

Table 12. Cross section area and relative changes in cross section area for the Eureka Hill Bridge cross sections.

Cross Section	Reference Elevation	Year	Total Area Below Reference	Total Area Outside of Low-Water Channel Below Reference	Total Area of Low-Water Channel Below Reference	Total Area Below Water	Relative Area Below Reference	Relative Area Outside of Low-Water Channel Below Reference	Relative Area of Low-Water Channel Below Reference	Relative Area Below Water
Pier	91.81	1993	1148	825	323	41	100%	100%	100%	100%
Pier		1994	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Pier		1995	1184	716	468	107	103%	87%	145%	260%
Pier		1996	1156	789	367	159	101%	96%	113%	386%
Pier		1997	1132	596	536	81	99%	72%	166%	196%
Pier		1998	1158	572	586	35	101%	69%	181%	84%
Salmon	99.20	1993	1698	718	980	55	100%	100%	100%	100%
Salmon		1994	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Salmon		1995	1694	732	962	62	100%	102%	98%	113%
Salmon		1996	1591	795	797	21	94%	111%	81%	39%
Salmon		1997	1707	771	936	71	101%	107%	96%	130%
Salmon		1998	1637	634	1002	41	96%	88%	102%	75%

The rise in water surface shows that material was deposited on the downstream control between 1993 and 1995. The material that was deposited on the downstream control may have come from the material lost along the cross section. Between 1995 and 1996 there was minor scour across most of the low flow channel but the thalweg elevation and cross section area remained unchanged. However, the water surface dropped 1.1 feet between 1995 and 1996 indicating that the downstream control eroded. In 1997, the water surface returned to its 1993 level and remained there in 1998.

In 1995, the thalweg declined -0.6 feet , relative to 1993 and remained at that level in 1996 and 1997. In 1998 the thalweg rose 0.4 feet.

The 1998 cross section showed a minor amount of net deposition, relative to 1993, since its area decreased by about -2%. The widening of the low-flow channel decreased the width of the gravel bar on the right bank. The erosion of the edge of the gravel bar was balanced by deposition along the left bank, deposition behind the old bridge pier and the rise in the thalweg relative to 1993.

The data from these two cross sections do not support the idea that the Garcia River is aggrading or incising. The data shows that the thalweg of the pier cross section rose 0.4 feet while the thalweg for the Salmon cross section drop -0.6 feet, relative to 1998. The water surface for the pier cross section remained unchanged but, there was a -0.4 foot drop in the water surface at the Salmon cross section. The mixed results for both the thalweg and the water surface do not support the idea that the river is incising at Eureka Hill Bridge. The data show no clear evidence of a sediment wave or trough moving through the reach during the study period. The data for these two cross sections appear to support the notion that the Eureka Hill Bridge reach is in dynamic equilibrium, for the period 1993 through 1998.

Summary of the Cross Sections:

Aerial photos show that there has been significant bank erosion below Windy Hollow Road, the Kendall property, the Hooper property near the Olsen - Hooper boundary and at Bar 9. Peter Dobbins (Friends of the Garcia) has estimated that, since 1994, the combined amount of material that has been eroded from the banks of these four areas was over 140,000 cubic yards. However, estimates of the total deposition on the Garcia River below Bar 9 have not been made. It is important to remember that a significant fraction of the material eroded from a large bank failure may be deposited downstream of the collapse.

The channel below Windy Hollow Road has visually appeared narrower than the channel above the road. The observation that the Garcia River routinely overflows its banks at Windy Hollow Road, at flows less than bankfull, suggests that the channel was actually narrower below Windy Hollow Road than it was above the road. The bank erosion that recently occurred below Windy Hollow Road can be seen as a geomorphic response to a constricted channel.

The overall channel width has remained constant at all of the cross sections except for the cross sections at Kendall's. The downstream Kendall cross section has widened slightly due to a small bank failure. The upstream Kendall cross section dramatically widened after the January 1997 storm. It is possible that the Kendall bank collapse was caused by management practices including alterations to the channel upstream of the failure and removal of riparian vegetation and is not necessarily indicative of an unstable system. Similarly, the numerous bank failures below Windy Hollow Road might be the result of past management practices that constricted the channel.

Table 12 shows the change in water surface elevation and thalweg elevation relative to either 1991 (9 cross sections) or 1993 (15 cross sections). The cross sections that were compared to 1993 are the 14 bentonite monitoring cross sections and the two Eureka Hill Bridge cross sections. A change of plus or minus 0.5 feet is considered significant. The Kendall, Hooper and Conner Hole cross sections were compared to 1993.

Four of the nine cross sections showed a significant decline in water surface elevation, relative to 1991. The decline in water surface ranged from -0.5 to -0.6 feet. Two of the cross sections showed a change of less than 0.5 feet and are judged to be unchanged. Three cross sections showed a rise in the water surface elevation ranging from 0.5 to 3.5 feet.

Five of the nine cross sections showed a decrease in the thalweg elevation ranging from -0.6 to -2.9 feet. Two of the cross sections showed less than 0.5 feet of change in the thalweg elevation. Two of the cross sections showed an increase in the thalweg elevation ranging from 1.6 feet at the downstream Kendall cross section to 3.8 feet at the upstream Kendall cross section. The upstream Kendall cross section traverses a dramatic bank failure. Five cross sections showed a significant decline in both water surface elevation and thalweg elevation. These five cross sections were; cross section 4 at Hooper's; all the three of the cross section at Conner Hole and the Salmon cross section at Eureka Hill Bridge.

Only the upstream Kendall cross section showed a significant rise in both the water surface elevation and thalweg elevation. This cross section also traverses the dramatic bank failure that occurred in 1997 and is just downstream from the location of the 1`995 bank failure at Kendall's.

There three cross sections bentonite monitoring cross sections showed an increase in water surface, relative to 1993, ranging from 0.9 to 1.8 feet. Ten of the bentonite cross sections and one of the Eureka Hill Bridge cross sections did not show a significant change in the water surface elevation. A single Eureka Hill Bridge cross section showed a decline in water surface elevation.

Seven of the bentonite monitoring cross sections showed a decline in the thalweg elevation ranging from -0.6 to -2.0 feet. Both of the two Eureka Hill Bridge cross section showed a decline in the thalweg elevation ranging from -0.6 to -1.0 feet. Three of the bentonite monitoring cross sections showed an increase in the thalweg elevation ranging from 1.5 to 1.7 feet. Three of the bentonite monitoring cross sections showed no significant change in thalweg elevation.

The overall trend at the nine cross sections, compared to 1991, is a decline in both water surface elevation and thalweg elevation, relative to 1991. The tendency for the water surface elevation to decline indicates that the downstream control riffles are being eroded. The drop in thalweg depth shows that the bed is scouring. The erosion of the control riffles and scouring of the bed may be an indication that less bedload is being supplied from above Eureka Hill Bridge.

The overall trend at the fifteen cross sections, compared to 1993, is a decline in the thalweg elevation, relative to 1993. The overall trend for the water surface, compared to 1993, is to show no significant change.

Conclusions:

Five sets of cross sections were studied on the Garcia River between Windy Hollow Road and the Eureka Hill Bridge. All of the available cross section data show that the Garcia River, in the study reach, is not aggrading. Erosion is the dominant process at two of the five sets of cross sections,Conner Hole and Hooper. The Eureka Hill Bridge cross sections appear to be in dynamic equilibrium. The significant bank erosion occurred at the Kendall cross sections. The bank erosion increased the width of the channel at the upstream cross section and resulted in the thalweg rising 2.6 feet. The large bank collapse at Kendall's resulted in significant fill at the cross sections just downstream. The size and proximity of the bank collapse and the limited amount of data for the Kendall cross sections limits their usefulness in judging if the river is in equilibrium.

Eleven of the bentonite monitoring cross sections showed overall deposition. But, eight of the bentonite monitoring cross sections showed a decline in thalweg elevation. There was extensive gravel mining on through this section until prior to 1991. Therefore, the observed overall deposition may just be the response to the artificially low bars created by the mining.

The mining of Bars 11 and 12 just upstream of Conner Hole has induced deposition on those bars thus reducing the amount of material that was transported down to Conner Hole. The reduction in supply from mining plus the reduction in supply from the recent dry period is probably responsible for the incision at Conner Hole. These factors may also be playing a role at the Hooper cross sections which lie further downstream. The only way to determine if the river will continue to incise is to continue to collect cross section data and be prepared to document other changes.

The cross section data appears to support the idea that increased bar height diminishes the tendency to deposit material in the low water channel. For example, as the bentonite monitoring bars have increased in size, the adjacent thalweg has tended to lower.

Recommendations:

1. A low flow rating curve for Conner Hole should be developed. A low flow rating curve will be a valuable long term monitoring tool because it will tie present conditions at the old USGS gage to the historic conditions. Thus, the condition of the river relative to 1963 through 1983 can be assessed.

Survey the staff gages at Conner Hole and verify that the current gage datum equals the USGS gage datum.

2. Establish a monitoring program of the exposed clay on Hooper's property. The program should include additional cross sections and photographs and video footage.

3. Convert the Ross Stevenson & Associates 1992 map of the bentonite spill area to state coordinates. Review all the topographic maps made to monitor the bentonite spill. Use the maps to track pool depth over time. Determine if 4,500 cfs is less than Lisle's critical flow to scour pools by seeing if the pools on in the bentonite study area filled in 1994.

4. Establish cross sections at the downstream controls for the dataloggers at Conner Hole and Eureka Hill Bridge. This will allow direct measurement of erosion or deposition on the control.

5. It would be beneficial to make a longitudinal profile for each of the cross section study areas in addition to the cross section surveys. Each longitudinal profile should be at least 20 channel widths, roughly 4,000 feet. The elevation of riffle crests should be especially targeted to detect the presence of sediment waves. Changes in channel morphology are not being adequately documented by the cross section surveys.

6. Take cross sections at the Highway 1 Bridge.

9. Update the rating curve for Eureka Hill Bridge. MCWA developed a rating curve for Eureka Hill Bridge using discharge measurements collected by the USGS, MCWA and FrOG. More recent discharge measurements should be added to those used to construct the rating curve.

10. Add cross sections to the Hooper, Conner and Eureka Hill monitoring sites.