

Analysis of the
1998 Garcia Estuary Cross Sections
by
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In July of 1991, the Mendocino County Water Agency established nine cross-sections between the parking area at the end of Minor Hole Road and the beach. The cross-sections were established as part of the Mendocino County Resource Conservation District's (RCD) effort to prepare the *Garcia River Enhancement Plan*. The 1991 cross-sections used an arbitrary elevation datum.

Scott McBain surveyed six of the nine cross-sections again in March of 1995 as part of the RCD's Garcia River Estuary study. David Russell surveyed in a network of benchmarks around the perimeter of the estuary, in conjunction with the McBain cross section survey. The coordinates of the benchmarks from Russell's survey are in the 1983 California Coordinate System and the elevations are in feet above sea level. Establishing the coordinate system in the estuary will allow future monitoring teams to locate the positions of all the surveyed markers, even if the stakes have been washed away or buried.

In October of 1998, Dennis Jackson surveyed five of the six cross-sections that were surveyed by Scot McBain in March of 1995. A substantial number of ground shots were also taken between the cross sections, see Figure 1. The sixth cross section, Estuary Mouth Cross Section 2, was not directly surveyed because neither endpoint stake could be located. A line was surveyed at the approximate location of the missing cross section. The 1991 field notes were used with the 1995 coordinate system to improve our field estimate of the location of the Estuary Mouth Cross Section 2. The missing cross section was then estimated from ground shots that were taken nearby.

The approximate locations of the six cross-sections were marked on aerial photos from September of 1991 and are shown in Figures 2 through 4. An oblique aerial photo from the fall of 1998 is shown in Figure 4. Figure 5 is a photo mosaic of the base photos used in Figures 1 through 3. Comparison of Figures 4 and 5 shows the overall changes in the estuary between 1992 and 1998.

Tides effect the water surface elevation at all the cross sections surveyed in 1998. Therefore, the water surface reveals no information about the downstream control. The tides ranged from 5.6 feet to 0.3 feet during the 1998 survey. Figure 12 shows the daily tidal fluctuations during the 1998 survey. The high-high tide occurred between noon and 2 p.m. each day. The low-low tide occurred between 6:30 p.m. and 8:30 p.m. each day. The unfortunate timing of the tides made it difficult to survey the thalweg of the cross sections.

See the *Analysis of the 1998 Garcia River Cross Sections* (Jackson, April 1999) for a discussion of flood history of the Garcia River since 1991. Two of the largest floods on record occurred in 1995 and 1997.

Table 1 summarizes the area of the cross sections and changes in area relative to 1991. The cross section area is calculated by drawing a horizontal line across the diagram of the cross section at a specific reference elevation and determining the area between the reference line and the ground surface. An increase in area represents erosion and a decrease represents deposition. Table 2 summarizes the thalweg elevations. Table 3 gives the distances between adjacent cross sections.

The thalweg of cross sections 2, 3 and 4 were not measured because of the depth of water exceeded four feet. Two methods were used to estimate the thalweg for these three cross sections. The first method was to use the deepest point measured as the estimate of the thalweg. The second method was to use the cross-channel slope of the streambed, at the deepest point measured, to estimate the thalweg. The two sets of thalweg estimates are shown in Table 2. The two sets of thalweg estimates were also used to calculate two respective sets of cross section area. The two sets of area estimates are shown in Table 1.

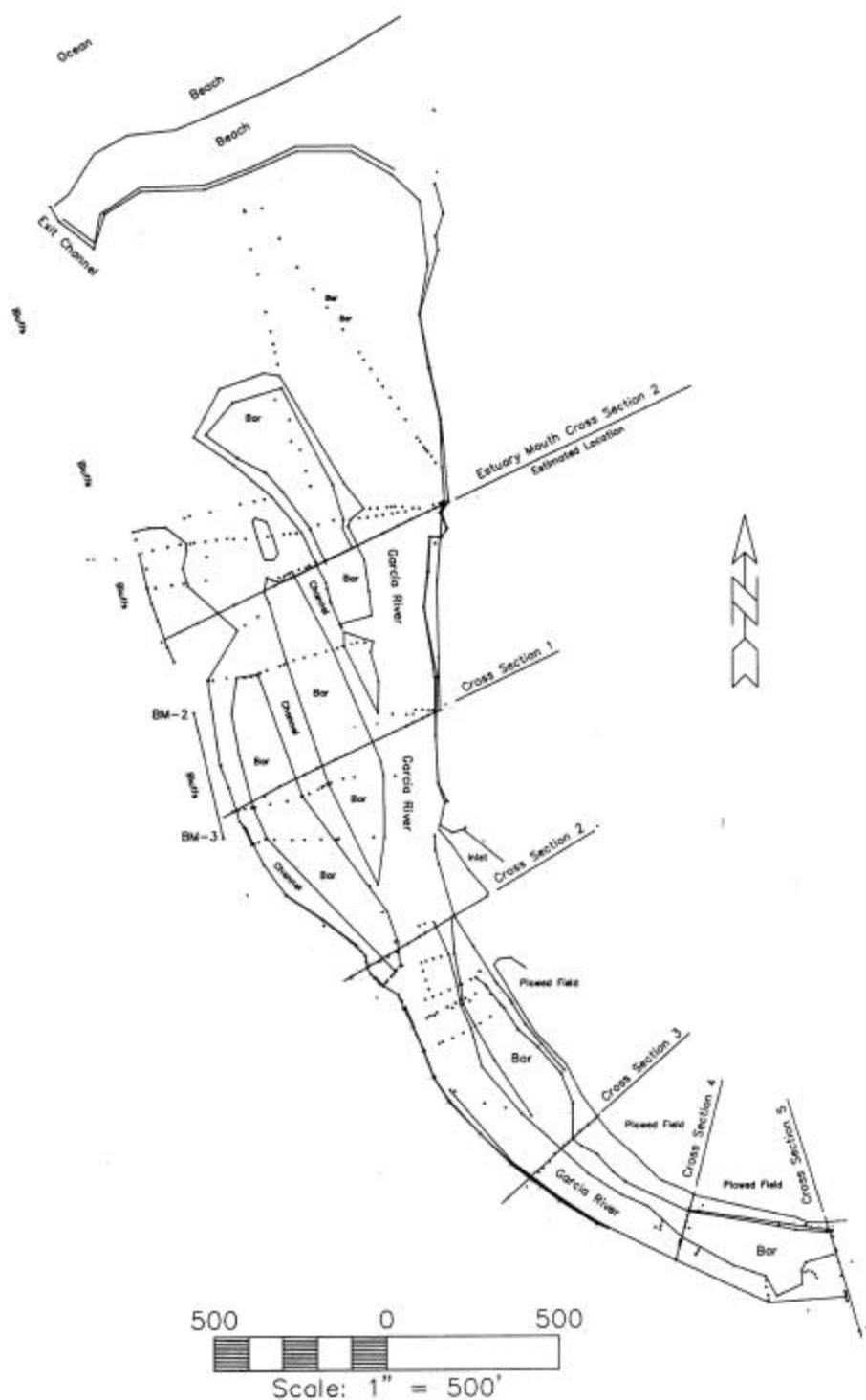


Figure 1. Map of Garcia River Estuary showing the points between cross sections. Lines connecting points are topographic break lines.

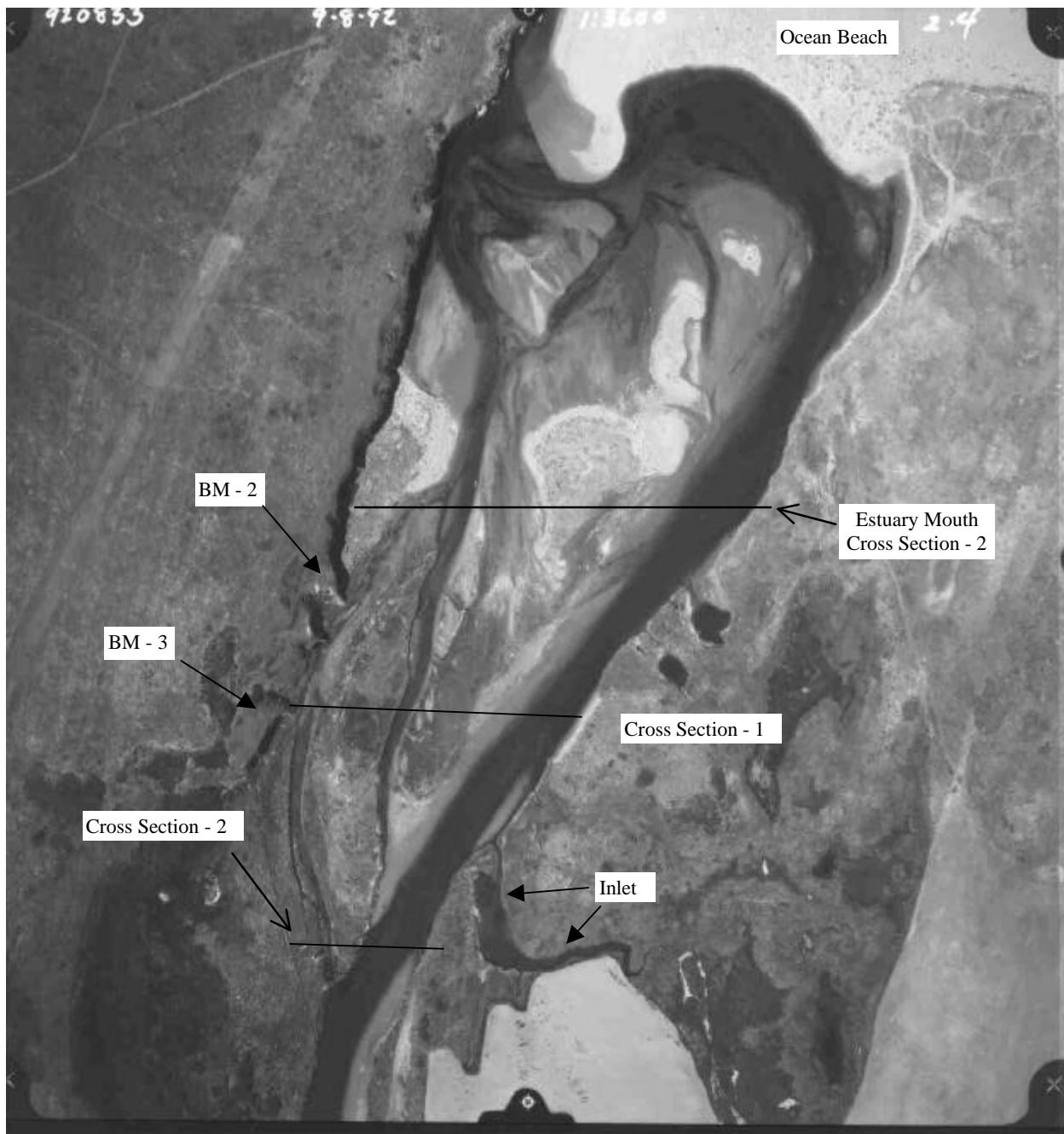


Figure 2. Location of Garcia River Estuary cross sections surveyed in 1998. September 1992 aerial photo.

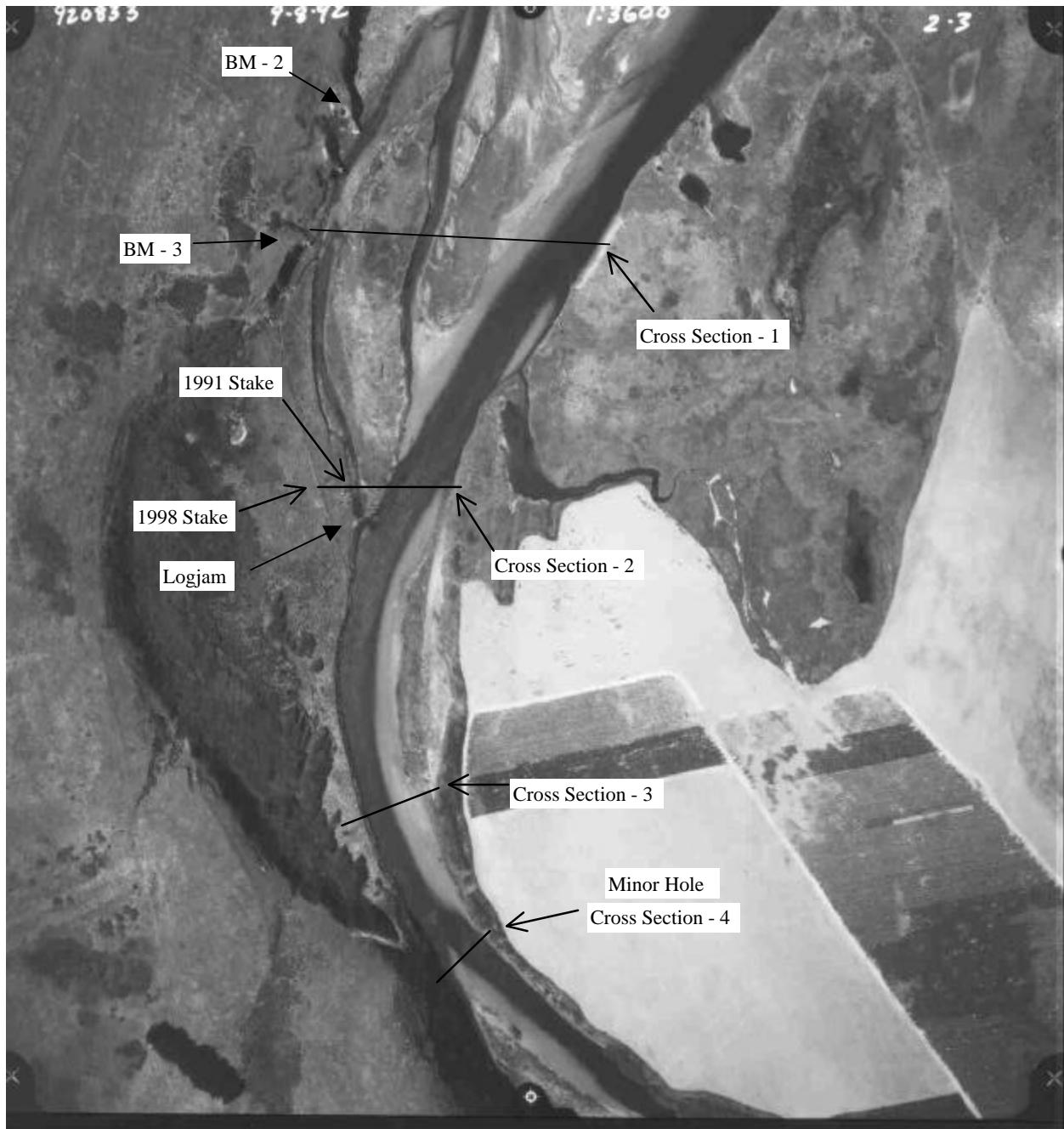


Figure 3. Location of Garcia River Estuary cross sections surveyed in 1998. September 1992 aerial photo.

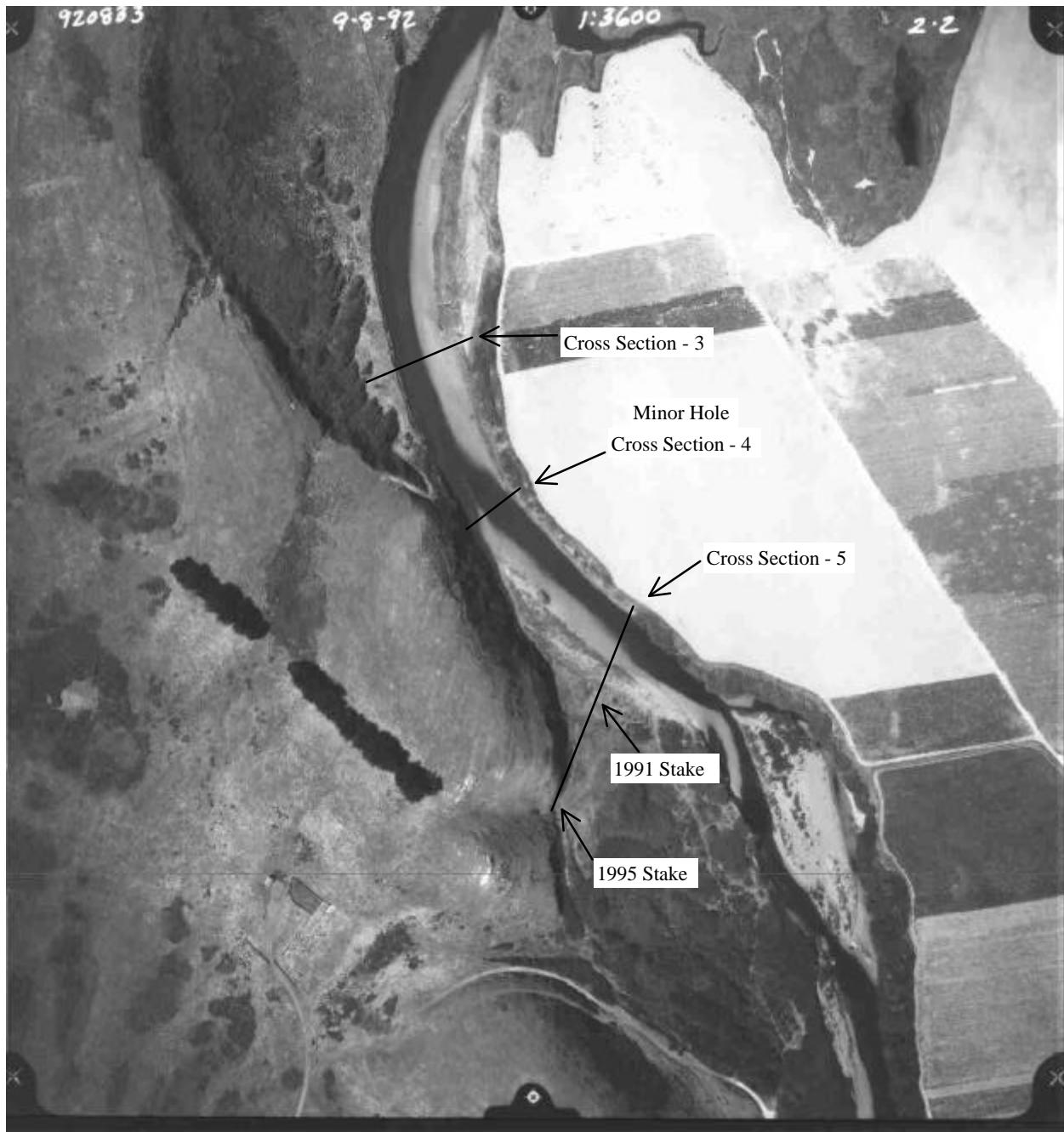


Figure 4. Location of Garcia River Estuary cross sections surveyed in 1998. September 1992 aerial photo.



Figure 5. Fall 1998 oblique aerial photo of Garcia River estuary. Ocean is to the left.



Figure 6. Photo mosaic of September 1992 aerial photos. Ocean is to the left.

Table 1. Cross section area, in square feet, for the Garcia Estuary cross sections.

Cross Section	Absolute Area, square feet				Area Relative to 1991
	1991	1995	1998 (a)	1998 (b)	
5	1936	1958	1930		100.0%
4	1094	1108	1087	1170	100.0%
3	1208	1208	1290	1297	100.0%
2	1378	1376	1406	1432	100.0%
1	2622	2886	2954		100.0%
Mouth-2	4787	4619(d)	4175(e)		100.0%

- (a) The deepest measured point in the channel was used as the estimate of the 1998 thalweg.
- (b) The cross-channel slope of the bed was used to estimate the 1998 thalweg.
- (c) The 1998 thalweg was estimated for Cross Sections 2, 3 and 4. Therefore, the area shown probably a minimum, the actual area may be greater
- (d) Location of left bank endpoint estimated.
- (e) The 1998 survey for the Mouth 2 cross section was estimated from nearby ground shots.

Table 2. Thalweg elevations for the Garcia River Estuary cross sections, feet above sea level.

Cross Section	1991	1995	1998 (a)	1998 (b)
5	-0.6	-0.6	0.7	
4	-2.0	-2.4	-2.4	-6.9
3	-3.9	-4.0	-2.4	-2.4
2	-2.5	-3.8	-1.5	-2.3
1	-1.8	-2.8	-2.2	
Mouth-2	-1.2	-1.4	-0.6	

- (a) The deepest measured point in the channel was used as the estimate of the 1998 thalweg.
- (b) The cross-channel slope of the bed was used to estimate the 1998 thalweg.
- (c) The 1998 thalweg was estimated for Cross Sections 2, 3 and 4. Therefore, the area shown is probably a minimum, the actual area may be greater
- (d) The 1998 survey for the Mouth 2 cross section was estimated from nearby ground shots.

Table 3. Approximate distance, measured along the right edge of water, between cross sections. The cross sections are listed from upstream to downstream.

Cross Section	Approximate Distance Along the Channel between Cross Sections feet
5	0
4	482
3	435
2	762
1	622
Mouth-2	611
Beach	1,100

Discussion of the Ground Shots

Numerous ground shots were taken between the cross sections. Shots were taken along the edge of water of the estuary and the adjacent top of bank. These ground shots will be invaluable in assessing changes in the extent of the estuary. Shots were also taken across the estuary and river channel in several areas. The points in the channel and estuary will be useful in monitoring changes in volume of the sediment stored in the estuary.

Discussion of the Cross Sections

Cross section 5 is the upstream most cross section. In 1998, there was a riffle just downstream of the cross section. The left bank benchmark from 1991 was not found in 1998. The coordinates of the left bank benchmark were established in 1995. A wooden stake was driven in the ground at the approximate location of the 1991-left-bank benchmark.

By 1995, a shoal had replaced the thalweg by the right bank. The thalweg had shifted to the left bank but stayed at the same elevation of -0.6 feet. There was some minor deposition on the left bank.

By 1998, the width of the low-flow channel had widened over 50 feet. Material had been deposited across the entire channel bottom causing the thalweg to rise 1.1 feet to an elevation of +0.7 feet. The channel widened at the expense of the left bank bar.

Figure 7 shows the three surveys of cross section 5. In 1991, the thalweg was against the right bank. The elevation of the thalweg was -0.6 feet, indicating that water surface elevation is influenced by tidal action.

The cross section area is calculated by drawing a horizontal line across the diagram of the cross section at a specific reference elevation and determining the area between the ground surface and the reference line. The elevation of the reference line for cross section 5 was 9.55 feet.

Because of the inherent errors in determining the cross section area, we require at least a one percent change in area before we can say that a real change has occurred.

The area of the cross section (Table 1) increased slightly (101.1% of the 1991 area) between 1991 and 1995 indicating net erosion of material from the cross section. By 1998 the area decreased to just slightly less than its 1991 value (99.4%). However, since the decrease in area was less than 1% we judge that the 1998 cross section area is the same as the 1991 area.

Figure 4 shows that, in 1992, there was a bar stretching from upstream of cross section 5 down to cross section 4 along the left bank. By 1998, this bar was no longer visible and the river hugged the cliff on the left bank.

Cross Section 4

Cross section 4 is located at Minor Hole, approximately 482 feet downstream of cross section 5. In 1991, the end of the bar along the left bank reached just downstream of the cross section. The higher tides inundate the bar. The surveys of cross section 4 for 1991 and 1995 are very similar. The reference elevation for calculating the area of cross section 4 was 8.0 feet above sea level.

Figure 8 shows the three surveys of cross section 4. The survey of 1998 shows that the deeper portion of the channel, near the left bank, has widened about 20 feet. The tidal conditions at the time of the survey made it impossible to wade completely across the channel. The deepest point measured in 1998 was -2.4 feet and was 42.5 feet from the location of the left bank stake. The depth of the true thalweg was not determined. Note that the elevation of the 1995 thalweg was also -2.4 feet, the same as the deepest point measured in 1998.

The thalweg for cross section 4 was estimated using two different methods. The first method was to assume that the deepest point measured is a good estimate of the thalweg. By this method the thalweg for cross section 4 is -2.4 feet.

The second method was to use the cross-channel slope, at the deepest point measured, to estimate the thalweg. This method yields -6.9 feet as an estimate of the thalweg elevation.

The widening of the deeper portion of the channel was accompanied by deposition in the right hand half of the channel. The cross section area increased slightly between 1991 and 1995, the 1995 area was 101.2% of the 1991 area. Using the deepest point measured as the thalweg, the 1998 cross section area was 99.4% of the 1991 area, indicating virtually no change in cross section area. Using the cross-channel slope to estimate the thalweg leads to a cross section area of 106.9% of the 1991 area, indicating an increase in cross section area. Taken together, the two area estimates clearly show that net deposition did not occur at the cross section. Furthermore, the two area estimates indicate the cross section area probably increased, indicating the cross section experienced erosion.

Field observations show that the bar along the left bank, between cross sections 4 and 5, in Figure 4, is no longer there. The distance between the cross sections is too great to adequately characterize the changes that have occurred. To help alleviate this problem in future surveys; we took a number of spot elevations, between cross sections 4 and 5, on the exposed gravel along the right bank and in the channel.

Cross Section 3

Cross section 3 is located about 435 feet downstream of cross section 4 (Minor Hole). The level of the tide prevented locating the thalweg at cross section 3. One method of estimating the thalweg is simply using the deepest point measured. In 1998, the deepest point measured was -2.4 feet below sea level. Another estimate of the thalweg is to used the cross-channel slope, which yields -3.2 feet.

The thalweg lies along the left edge of the channel. Figure 3 shows that the left side of the channel is the outside of a bend. The deepest point actually surveyed had an elevation of -2.4 feet and was about 24 feet away from the left edge of the channel.

Figure 9 shows the graph of the three surveys. Between 1991 and 1995 the cross section area remained the same. The two estimates for the 1998 thalweg yielded areas of 1290 and 1297 square feet, or 106.8% and 107.4%, respectively. There is less than 1% difference between the two area estimates so we can conclude that there is no real difference between the two estimates. Thus, between 1995 and 1998 the cross section area increased about 7%, indicating erosion of the cross section. The reference elevation for calculating the area of cross section 3 was 7.54 feet above sea level.

Figure 4 shows that approximately one vertical foot of material was removed in the tidal zone on the right bank. Deposition occurred on the upper right bank, above +4.0 feet in elevation.

The left bank endpoint placed in 1991 was lost between 1995 and 1998. The top of the bank retreated about 6 feet between 1991 and 1998. In 1995, McBain placed an additional pin about 80 feet away from the bank.

Spot elevations were taken in the channel and along exposed gravel on the right bank. Spot elevations were also taken on the top of the left bank and at the left edge of water at several locations between cross sections 4 and 2. These spot elevations will be invaluable for assessing future changes in this section of the estuary.

Cross Section 2

Figure 10 shows the three surveys of cross section 2. Cross section 2 is located about 762 feet downstream of cross section 3, see Figures 1, 2 and 3. The cross section passes about 68 feet downstream

of the side channel on the left bank. On the right bank, the cross section is about 286 feet upstream of the mouth of the small inlet. There is a logjam across the mouth of the left bank side channel.

The logjam has caused significant local scour in the main channel. The scour and the cover of the logjam create some of the best fish habitat available in the estuary. During the survey, we observed an otter resting on the logjam.

The logjam has also caused bank scour along the side channel. The scour of the side channel caused the loss of the left bank pin. However, the coordinates of the left bank pin were established in 1995 so, we were able to locate its former position. A new left bank pin was placed in 1998 adjacent to the fence line.

Tidal conditions again prevented wading across the channel along the cross section. Using the deepest point measured as the estimate of the thalweg yields an elevation of -1.5 feet. Using the cross-channel slope to estimate the thalweg yields -2.3 feet below sea level.

Between 1991 and 1995 the area of cross section 2 changed by only 0.2%, so, we judge that there was no real change in cross section area. The deepest point measured estimate of the thalweg yields a 1998 cross section area that is 99.7% of the 1991 area, indicating that there was no real change in area. The estimate of the thalweg derived from the cross-channel slope yields a 1998 cross section area that is 103.9% of the 1991 area, indicating that the cross section experienced erosion. The reference elevation for calculating the area of cross section 2 was 6.11 feet above sea level.

Taken together, the two area estimates clearly show that net deposition did not occur at the cross section. Furthermore, the two area estimates indicate the cross section area probably increased, indicating the cross section experienced erosion.

The scour hole on the left bank side channel appears to offset the deposition in the main channel on the 1998 survey. Of course, the deposition in the main channel may be an artifact of our attempt to estimate the thalweg elevation.

Cross Section 1

Figure 11 shows the three surveys for cross section 1. Cross section 1 is approximately 622 feet downstream of cross section 2. The cross section starts on the left bank at the base of the bluff. BM-3 is on the bluff above the cross section endpoint, but the endpoint is not visible from BM-3. However, the endpoint for cross section 1 is visible from BM-2 on the bluff just to the north, see Figures 1 and 2.

There are three distinct channels visible at cross section 1. The small channel on the left bank starts just upstream of cross section 2. This is the channel with the logjam. The central channel starts a short distance downstream of cross section 2. The channel on the right is the main river.

The thalweg of the small channel on the left bank has risen about 0.5 feet since 1991. The channel bottom is now more uniform than it was in 1991.

The bar between the left and central channels has been significantly eroded along its right edge. The central channel has changed from a narrow deep channel in 1991 and 1995 to a broad channel in 1998. The thalweg of the central channel has risen about 0.75 feet since 1991. Its width increased from about 50 feet in 1991 to about 100 feet in 1998. The increase in channel width came at the expense of the bars on each side of the central channel.

The thalweg of the main river channel was at an elevation of -2.2 feet, in 1998. So, the thalweg has risen since 1995 but declined in elevation since 1991. The left bank of the river channel has eroded slightly, but the cross section endpoint was still in place.

The area of the cross section has increased with each successive survey. Between 1991 and 1995 the area increased by 10%. Between 1995 and 1998, the area increased an additional 2%, relative to 1991. Thus,

erosion appears to be the dominant process at this cross section. The reference elevation for calculating the area of cross section 1 was 6.7 feet above sea level.

Cross Section Mouth-2

Figure 12 shows the three surveys for cross section Mouth-2. In 1995, McBain could not locate the left bank endpoint. As a result, the alignment of the 1995 cross section was not accurate so, the total length of the cross section is not the same as the 1991 length. In 1998, neither endpoint could be located. However, the coordinates of the right bank endpoint were established in 1995 so it was possible to locate the position of the stake. It was found that the right bank had eroded several feet and that the right bank endpoint had been washed out. No coordinates were established for the 1991 or 1995 left bank endpoints. Therefore, we used diagrams from the 1991 field notes to select a line to shoot. Processing the data, after the survey was performed, gave us an opportunity to estimate the coordinates of the stations and turning points used to shoot the cross section in 1991. It turns out that the line we shot in the field reached the left bank downstream of the 1991 cross section. Therefore, we had to estimate much of cross section Mouth-2 from nearby ground shots. However, this did not effect our main channel shots since they are close to the known right bank endpoint.

The thalweg of the main channel is near the right bank. The thalweg elevation declined from 1991 to 1995 and then rose from 1995 to 1998. The thalweg was 0.6 feet higher in 1998 than it was in 1991. A low bar had formed near the left edge of the main channel in 1998.

Between 1991 and 1995 the central bar, between 450 feet and 650 feet on Figure 12, grew significantly. However, between 1995 and 1998, the left 50 feet of the central bar was eroded.

In 1991 there were two bars and three channels between the left bank and the central bar. By 1998, deposition filled the middle channel creating a single bar from the two bars adjacent to the filled in middle channel. In 1995, the thalweg of the far-left channel was -1.3 feet. By 1998, the thalweg had risen about 1.8 feet to an elevation of +0.5 feet.

The total cross section area has declined each year at cross section Mouth-2, indicating that deposition was the dominant process at the cross section. The deposition appears to have been concentrated in the side channels and I the main channel. The emergent central bar appears to have been eroded. The reference elevation for calculating the area of cross section mouth-2 was 7.66 feet above sea level.

A comparison of aerial photos (Figure 4) suggests that the areal extent of the central bar decreased between 1992 and 1998. However, it is not possible to ascertain if there was deposition in the channels to offset the erosion of the central bar observed on the aerial photos. Additional cross sections are needed on both the upstream and downstream side of the Mouth-2 cross section to track changes below the water surface. Additional cross sections toward the ocean would be very helpful since the distance between cross section mouth 2 and the beach is approximately 1,100 feet. The additional ground shots we took between cross section mouth 2 and the beach at the waters edge and on top of the adjacent bank plus the shots we took in the channel between will provide invaluable information about changes in the lower part of the estuary if the estuary is ever surveyed again.

Summary

The cross section area of cross section 5 remained virtually unchanged since 1991, indicating a balance between erosion and deposition at the cross section. At cross sections 2 and 4, the conservative estimate of the thalweg provided by using the deepest point measured showed no change in cross section area between 1991 and 1998. Using the cross-channel slope to estimate the thalweg at cross sections 2 and 4 resulted in an increase in cross section area, indicating net erosion. Cross section 3 showed net erosion between 1991 and 1998 for both methods of estimating the thalweg. Cross sections 1 and 3 experienced

net erosion between 1991 and 1998 as indicated by an increase in cross section area. Only cross section Mouth-2 showed net deposition between 1998 and 1991.

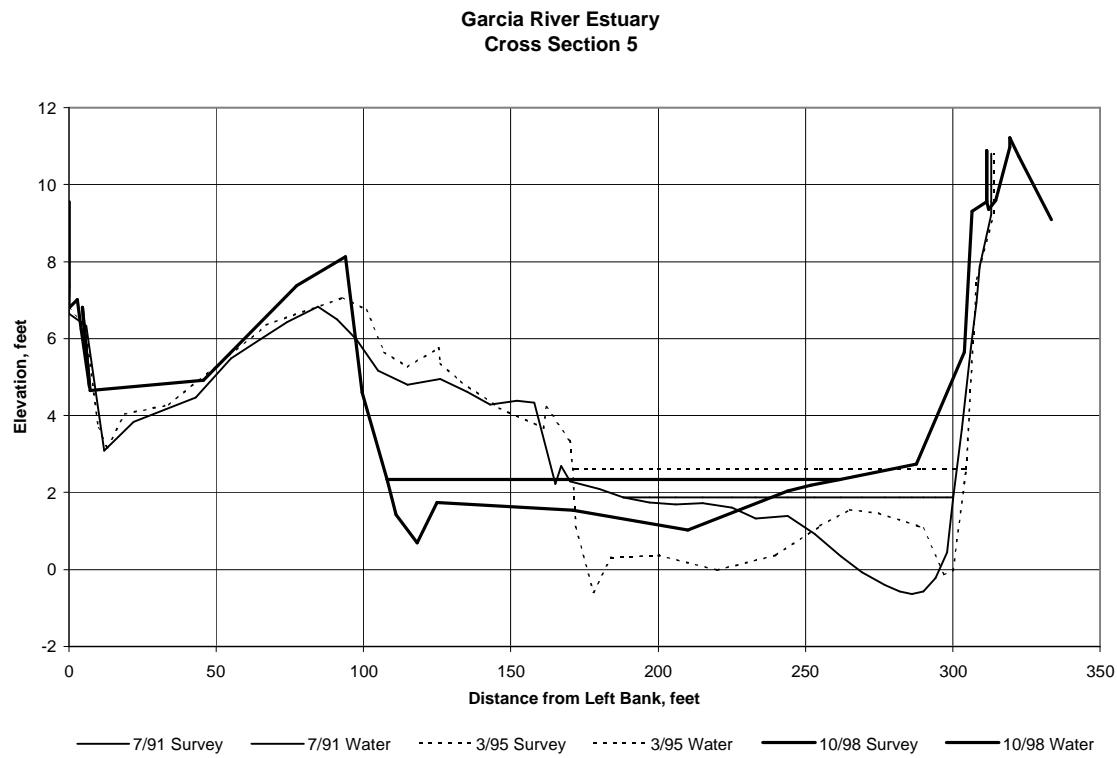
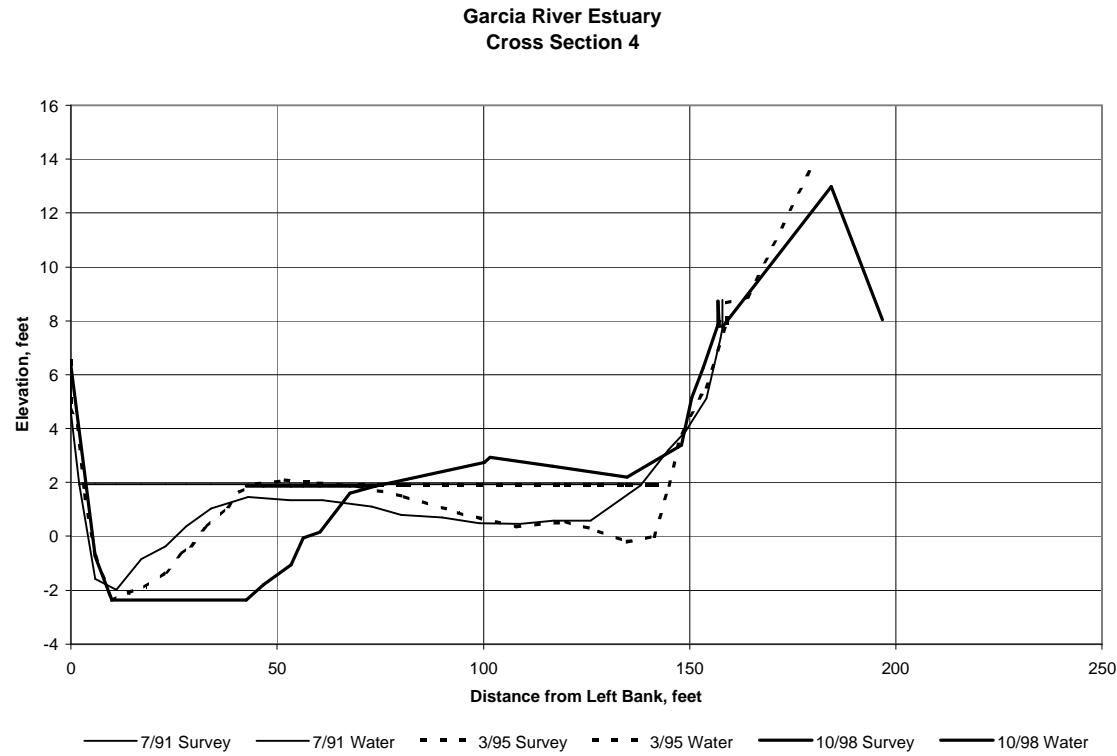
The cross section data indicate that erosion has been the dominant process in the estuary, between cross sections 1 and 5. This is notable since two of the largest floods on record occurred during the period. The only significant deposition occur along cross section Mouth-2. However, aerial photo evidence suggests that erosion of the emergent central bar may be occurring in the lower estuary which may offset the deposition in the channels indicated by the mouth-2 cross section.

The numerous ground shots that were taken between the cross sections will provide a much better data set to assess future changes in the estuary than existed prior to our survey.

Recommendations

The existing cross sections are spaced too far apart to give a clear picture of changes in the estuary. Doubling the number of cross sections would greatly improve the network's ability to track changes in the width and the depth of the channels in the estuary.

Aerial photos should also be obtained when the cross section network is re-surveyed.

**Figure 7.** Garcia Estuary Cross Section 5. Approximately 480 feet upstream of Minor Hole.**Figure 8.** Garcia Estuary Cross Section 4. Located at Minor Hole. The thalweg was not measured. The thalweg shown in the graph of the cross section is the deepest point measured, which is the same as the 1995 thalweg.

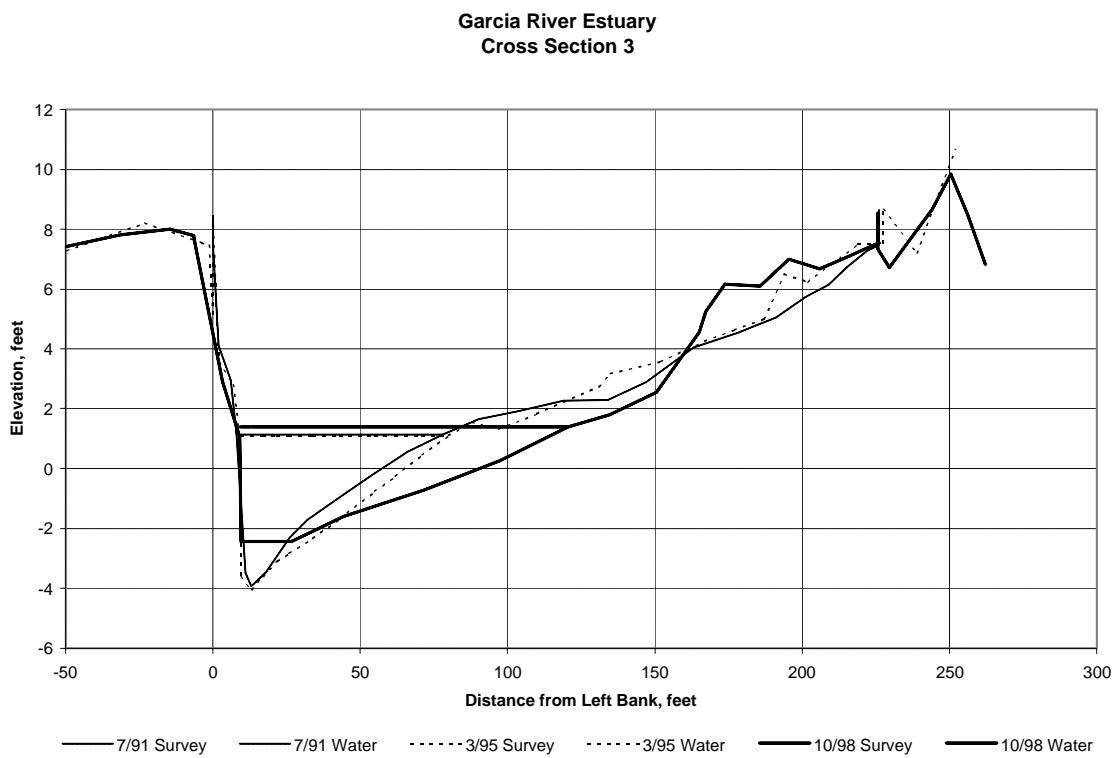


Figure 9. Garcia Estuary Cross Section 3. Located 435 feet downstream of Minor Hole. The thalweg was not measured. The thalweg shown in the graph of the cross section is the deepest point measured.

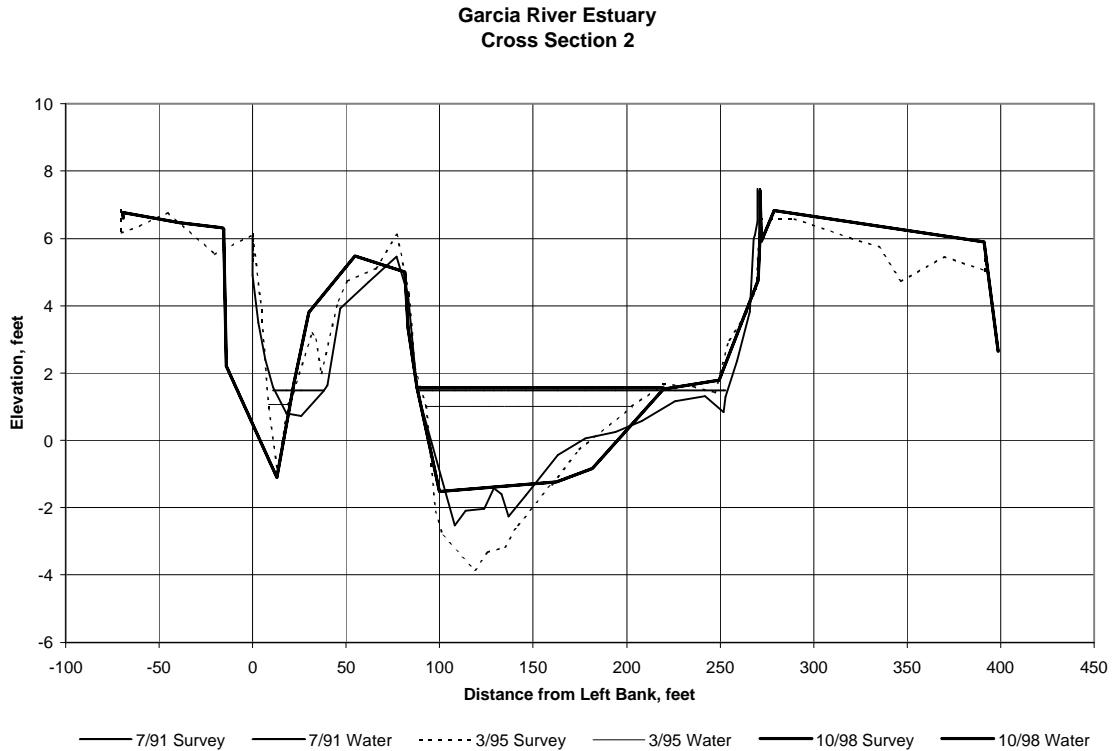
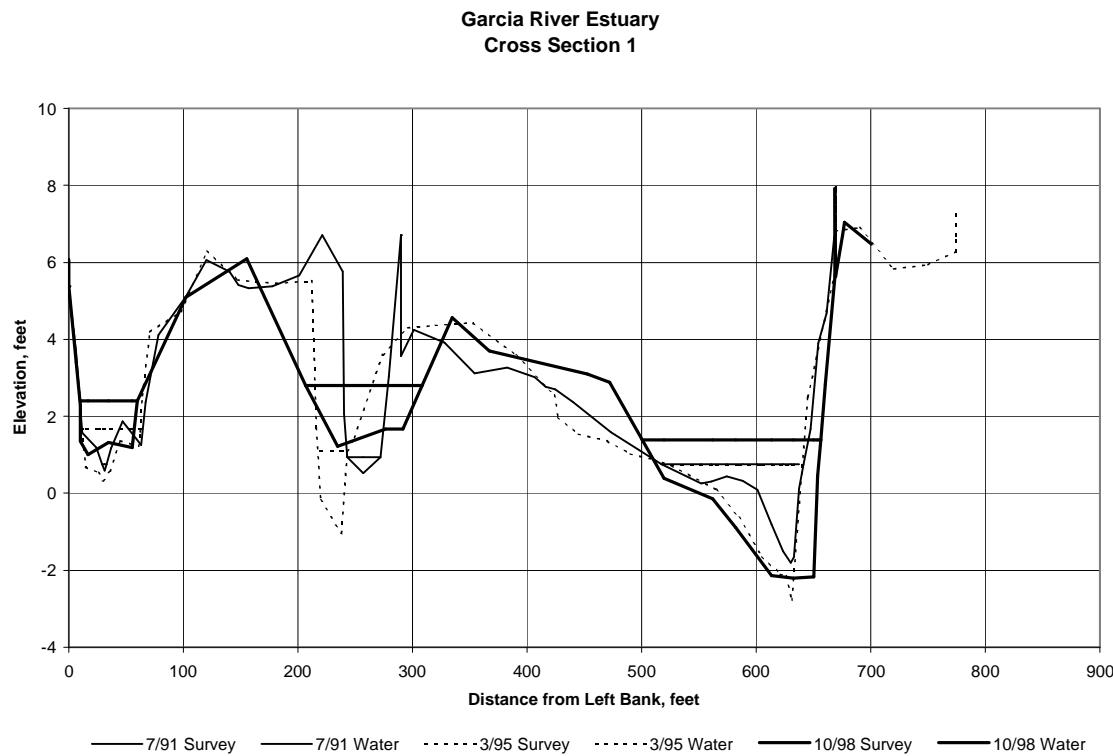
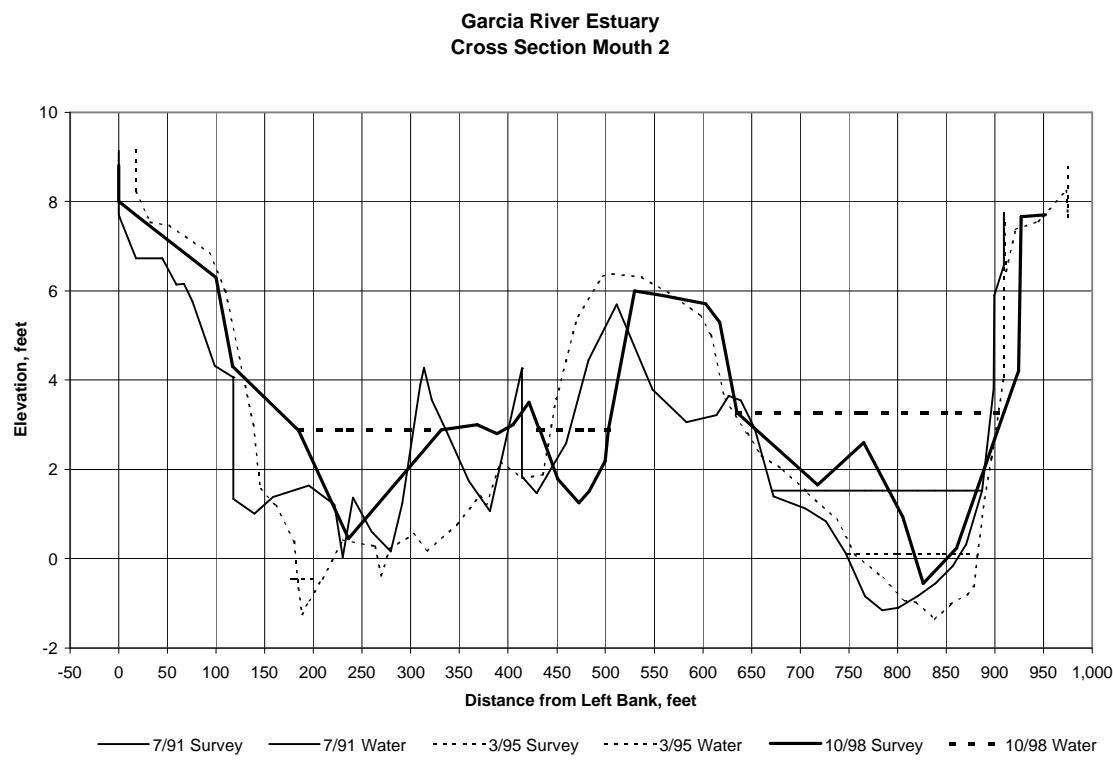


Figure 10. Garcia Estuary Cross Section 2. Located near head of side, just downstream of logjam. The thalweg was not measured. The thalweg shown in the graph of the cross section is the deepest point measured.

**Figure 11.** Garcia Estuary Cross Section 1. Located at base of the bluff, below BM-3.**Figure 12.** Garcia Estuary Cross Section Mouth 2. Located at base of bluff and north of BM-2.

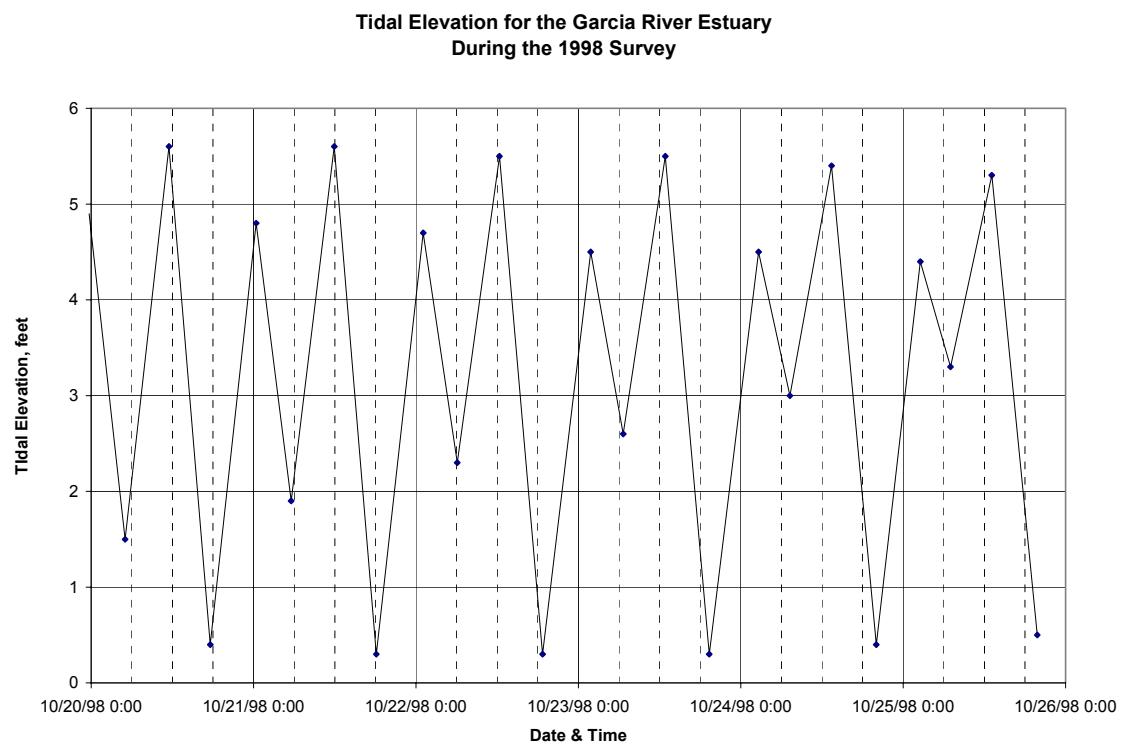


Figure 13. Tides for the Garcia Estuary during the October 1998 survey.