Title
Post-project appraisal of lower Ritchie Creek dam removal, Napa County

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Post-Project Appraisal of Lower Ritchie Creek Dam Removal, Napa County

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Abstract

Ritchie Creek drains 2.6 square miles before joining the Napa River north of Bale, California. A six-foot high dam was built in 1912 on Ritchie Creek to facilitate water development. The dam interfered with steelhead trout migration upstream to potential spawning habitats and was removed in 1993. Ten years after dam removal, we resurveyed four cross sections and compared them with the cross sections taken in the same location in 1993 just prior to dam removal. Our survey documented sediment erosion of 679 cubic yards upstream of the dam site, which is less than the probable yearly sediment yield for the watershed basin. Our survey also showed slight sediment aggradation of 99 cubic yards downstream of the dam site. In addition we surveyed a longitudinal profile of 1,162 feet in length and two additional cross sections at restoration sites.

I. Introduction

During the 20th century, many of the rivers in California were dammed in order to increase and store water supply, as well as provide flood control and hydropower (Heinz Center 2002). Some of the unintended and detrimental effects of dams on rivers include changing the hydrologic and geomorphic processes of the river system, degrading water quality, and blocking fish migration to their spawning habitat (Heinz Center 2002). As Californians become increasing concerned with restoring anadromous fish habitat to reduce risk of species extinction, they are considering the removal of dams which block upstream migration (Heinz Center 2002). Understanding the channel response to dam removal, especially sediment transport, can help inform dam removal decisions as well as help predict channel responses to post dam conditions (Heinz Center 2002).

Dams put an artificial brake in the longitudinal profile, causing an abrupt change in elevation (Mount 1995). While dams are in place, rivers deposit and store much of their sediment upstream. After the dam is removed, the river is once again allowed the opportunity to equilibrate and smooth out is longitudinal profile, resulting in redistribution of its stored sediment.

Ritchie Creek, located in Bothe-Napa Valley State Park ("Park"), Napa County, California, had a small dam (six-foot high, one-foot thick) which impeded fish passage. The Park removed the dam in 1993. Prior to removal, the Park surveyed and flagged four cross sections in 1993, which enabled us to survey cross sections in 2004 at the same location.

The objective of our study was to compared the pre-dam removal cross sections with the post-dam removal cross sections to observe changes in channel morphology and to gain a better understanding of the sediment transport which took place during the ten years since the dam was removed. We also surveyed the longitudinal profile and two cross sections at restoration sites[1] to provide a baseline analysis of the present geomorphologic condition enabling comparative analyses in the future.

II. Background

Ritchie Creek[2], a tributary of the Napa River, is perennial stream approximately 3.8 miles in length (Figure 1). It drains an area of 2.6 square miles and joins the Napa River a half-mile northwest of Bale, California. The upper two-thirds of Ritchie Creek's watershed lie entirely within Bothe-Napa Valley State Park, which has a total of approximately 3.1 square miles and is located along Highway 29 between Saint Helena and Calistoga.

In 1912, a six-foot high, one-foot thick dam was built on Ritchie Creek, approximately one mile upstream from its confluence with the Napa River to divert water for agriculture. After the land was acquired by the Park in the 1960s, staff began to advocate removal of the dam to facilitate fish passage.[3] Water rights and dam ownership issues delayed dam removal for 30 years. These issues were eventually resolved, and in August 1993, over 80 years after installation, the dam was removed.[4]

The January 1997 flood damaged a water system and septic facilitie at the Park and caused significant bank erosion. In response, park staff removed two upstream culverts (each approximately 6-feet (ft) in diameter). These culverts were located 987.5 ft upstream of the dam and lay underneath a road crossing the creek; the road was converted to a path (Figure 2). The

[1] One was a bank stabilization site; the other was a road-to-path conversion
[2] Ritchie Creek is spelled "Ritchey Creek" in some documents.
[3] Park staff also wanted the dam removed because it was believed to cause fish habitat degradation and downstream channel cutting, degraded archeological sites, and created a visual blight on the Park. (Project proposal for fiscal year 1994/95, provided by Art Fong, State Park Resource Ecologist for the Natural Heritage Section)
[4] Part of the dam still remained after initial removal. Two years later in 1995, the Park removed the rest of the dam.

Park also installed four bank stabilization treatments, three of which are located within our study reach (Figure 2).

III. Methods

We interviewed the following people who are familiar with Ritchie Creek and the dam removal project: Marla Hastings (Senior State Park Resource Ecologist for Diablo Vista District, interviewed March 12, 2004); Bill Grummer (State Park Ranger, interviewed March 24, 2004); Gary Fregien (Senior State Park Resource Ecologist, interviewed March 16, 2004); and Art Fong (State Park Resource Ecologist for the Natural Heritage Section, interviewed March 15 & 23, 2004). During these interviews we obtained file records that included maps, photos, documents, and notes. We also interviewed Bill Cox of California Department of Fish and Game on March 14, 2004 for information regarding USGS elevation markers.[5]

We chose one of the pins from the 1993 cross sections for our benchmark (93-B) (Figure 3). We used a two-foot contour topographic map of the site created in 1961 to determine our benchmark elevation (Figure 3). The 1993 survey team did not georeference their cross sections but based them on an assumed elevation of 100 ft, located at cross section A's left bank pin (93-A). The assumed elevation of 100 feet at 93-A corresponds to an elevation of 414.87 ft on the topographic map.

In two site visits, (March 23-24, and March 26), we surveyed six cross sections beginning from 150 feet below the former dam site and continuing to 1,012 feet above the former dam site (Figures 2, 4, 5, 6, 7, 8, 9) using a level and a rod. We also surveyed 1,162 ft of the river channel to construct a longitudinal profile that contained the elevations of the thalweg (TW), center line (CL), water depth, left bank (LB) and right bank (RB) (Figures 12, 13, 14). Four of the cross

[5] We would have preferred to use a USGS elevation benchmark for our survey work; however, although there should have been one located on the bridge where Ritchie Creek passes under Highway 29 (Figure 2), we could not locate it. The next nearest USGS elevation benchmark site was over two miles away, making it impractical to use.

sections were located at the same site as the cross sections taken in 1993, prior to dam removal. These cross sections were labeled A, B, C, and D (Figures 4, 5, 6, 7). We surveyed two of the cross sections, A and B, exactly at the site of the 1993 cross sections with the help of Mr. Grummer, State Park Ranger, who was able to locate all of the points pins put in by the original survey team for these cross sections. Mr. Grummer also was able to find one of the pins for cross section D, and we approximated the location of the other using the map done by the original survey team and Mr. Grummer's input. We did not locate either pin for cross section C; however, we were able to approximately duplicate the location of cross section C based on the map, Mr. Grummer's input, and remaining evidence of the dam location. We surveyed a cross section (E) at the site of one of the in-stream bank stabilization treatment (Figure 8), and we also surveyed a cross section (F) at the site of where the culvert was removed and the road was converted to a path (Figure 9).

The 1993 cross sections did not provide numerical values for its elevation points but were only available graph form in 1" = 50' scale (Figure 10). To obtain the coordinates, we transposed the graphed 1993 cross section into data points of elevation and distance. We extrapolated data points at all points of inflection on the 1993 cross section graphs and then used these data points to compare the 1993 cross sections to our 2004 cross sections.

In order to estimate the change in sediment in the 278 ft surrounding the former dam site, we graphed the 1993 and 2004 cross sections in AutoCAD and calculated the gain or loss of sediment in the surface area of each cross section (Figures 4, 5, 6, 7). We then estimated the volume of sediment (gained or lost) for the channel reach by taking the cross section difference in sediment and projecting it midway between cross section locations on the longitudinal profile (Figure 11).[6]

We estimated a low and high range of expected yearly annual sediment load for north coast watersheds from the results of Kondolf and Matthews (1991). That range is 0.27 to 1.04 acre-feet/mi^2/yr. We converted these units into ft^2/mi^2/yr and fit the range to the size of Ritchie Creek's watershed (2.6 mi^2). Finally, we reduced the range of expected annual sediment yield by 2/3rd to account for the dam's position at the bottom third of the watershed (Appendix).

IV. Results

The four cross sections (A, B, C, D) that were surveyed in 2004, correspond to cross sections that were surveyed in the same location in 1993, all of which showed varying degree of changes in their stream channel morphology (Figure 4, 5, 6, 7).

Cross section A, located 100 feet downstream of the former dam site (station 48 on the longitudinal profile), aggraded about 1.4 ft^2, for a section-wide increase of 19.8 ft^2. The left bank (a 20-foot cliff) eroded since 1993, and we estimated 168.5 ft^2 of sediment had been lost.

Cross section B, located 45 ft downstream of the former dam site (station 105 on the longitudinal profile), aggraded about 1.0 ft^2, for a section-wide increase of 28.3 ft^2 (Figure 5). We also observed right bank erosion that we have quantified as a loss of approximately 16.8 ft^2 of sediment.

Cross section C, located twenty feet upstream from the former dam site (station 175 on the longitudinal profile), shows sediment loss in the pre- to post dam cross section comparison (Figure 6). We estimate an overall total sediment loss of 98.7 ft^2.

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[6] The sediment gain and loss was only done for the length of the longitudinal profile bounded by cross section D upstream and cross section A downstream: this distance is 176 feet upstream from the dam and 102 feet downstream of the dam.

Cross section D is located 160 ft from the former dam site (station 326 on the longitudinal profile). We estimate the total loss of sediment in the riverbed of the cross section to be approximately 111.6 ft^2 (Figure 7).

We used the change in sediment of the four cross sections A, B, C and D to calculate the approximate loss of sediment in the riverbed from the former dam site to 176 ft upstream, and the aggegation of sediment in the riverbed from the former dam site to 102 ft downstream (Figure 11; Appendix). We calculated that in the ten years post dam removal, the river channel upstream of the former dam site (176 ft upstream) lost a total of 679 cubic yards of sediment, and that the river channel downstream (102 ft downstream) gained approximately 99 cubic yards of sediment, not including the losses from bank erosion at the outside bend at cross section A (Figure 11).

We calculated the range of expected annual sediment yield for a watershed basin the size of Ritchie Creek (at the site of the former dam) to have a low of 755 yd^3 and a high of 2,908 yd^3 (Appendix).

In addition to A, B, C, D cross sections, we also surveyed cross section E, located 818 ft upstream from the former dam site (station 968 on the longitudinal profile) (Figure 8). Cross section E is at the site of a bank stabilization project (Figure 2).

Finally, we surveyed cross section F, located 987.5 ft upstream from the former dam site (station 1137.5 on the longitudinal profile (Figure 9). Cross section F is the site of the road to path conversion in which two culverts were removed from the creek in 1997.

Our longitudinal profile spanned a distance of 1162 ft (Figure 12). Over the distance of our longitudinal profile (1162 ft) the thalweg gained 45.37 ft in elevation. This corresponds to a thalweg slope of 0.0390. The slope of the water surface elevation and centerline were identical to each other at 0.0394 and nearly identical to the slope of the longitudinal profile (0.0390). Additionally, the lower 300 ft of the profile has variation in the location of the thalweg and the center line of 0.0 to 1.98 ft. (Figure 12). The upper 862 ft of the profile has a variation of only 0.0 to 0.62 ft between the thalweg and the center line.

V. Discussion

When a small dam is removed, the sediment stored behind the dam can be expected to redistribute. The riverbed must reach a new equilibrium, including a smoothing and elimination of the abrupt change in elevation caused by the dam (Mount 1995).

Consistent with expectations, our results demonstrate sediment redistributed on Ritchie Creek post dam removal. We calculated that the dam stored approximately 679 cubic yards of sediment. This sediment eroded after removal, resulting in a change in the bed slope profile upstream and downstream (Figure 12). The calculation of 679 cubic yards of sediment is only an approximation, however, because it is based on sediment change observed at the cross sections. Although the cross sections are closely spaced (cross section A is only 278 feet apart from cross section D), the channel is complex with meanders, pools and riffles, which leave potential geomorphologic change unknown between the cross sections.

A significant portion of the stored sediment likely eroded during two large winter storms which took place in 1995. In January 1995, five months after dam removal, a three-day storm resulted in 10.8 inches of rain while a two-day storm the next winter, December 1995, dropped an additional 8.4 inches of rain (NOAA 1995). Concluding that these storm events of 1995 likely moved a bulk of the stored sediment is consistent with observations by Ms. Hastings (Senior State Park Resource Ecologist) who informed us that most of the sediment behind the dam was gone shortly after the dam removal due to winter storms (interview with Marla Hastings, March 12, 2004).

A release of 679 cubic yards of sediment is not highly significant in the context of the expected sediment yield for the watershed. Coastal range watersheds typically yield between 0.27 to 1.04 acre-feet(af)/mi^2/yr of sediment (Kondolf and Matthews 1991). This means that a watershed basin the size of Ritchie Creek (2.6 square miles) would likely yield between 755 and 2,909 cubic yards of sediment each year, at the location of the dam (Appendix). Thus, the conservative end of the expected sediment yield each year on Ritchie Creek is greater than the total volume of sediment released by the dam removal. Moreover, at the time of dam removal, the dam had been in place for 80 years and was at capacity with sediment (Rischbieter 1991). Unless the Park conducted regular dredging, it is likely bedload sediment had been passing over the top of the structure for some time (Kondolf and Matthews 1991). Therefore, Ritchie creek was probably not sediment starved, and the pulse of sediment from the dam removal would not have been the only sediment source over the last 80 years. The transportation of the stored sediment from the dam removal would likely not have had a long-term impact on Ritchie Creek.

Downstream of the dam, the comparison cross-sections show a slight aggregation of sediment in the bed channel (99 cubic yards, excluding bank erosion at cross-section A, B). Some of this aggradation is likely caused by the river adjusting to the removal of the break in its longitudinal profile. How much of the aggadation can be attributed to dam removal, however, is uncertain, since sediment had likely been passing over the dam for many years prior to the dam removal.

Our results show bank erosion at cross sections A and D. This bank erosion is likely caused by outside meander bends. At cross section A the river bends to the right, and the left bank has lost an estimated 19.8 ft^2 (Figure 4). The Park installed a revetment on the left bank of cross section A in 1977 (Figure 2), likely to prevent undercutting of the park campground road. At cross section D, the river turns to the left, which likely contributes to the slight erosion seen on the right bank (Figure 7). The meander bend effect, however, is complicated by the impact of dam removal. At cross section A (down stream of the dam), dam removal provided a pulse of sediment, some of which could have deposited at cross section A. The bank erosion caused by the meander at cross section A, therefore, may be understated. At cross section D (upstream of the dam), dam removal caused sediment erosion. The bank erosion caused by the meander effect on erosion at cross section D, therefore, likely is compounded by dam removal.

The 1993 cross section B located 45 ft downstream of the dam site shows incising on the right and left bank (Figure 5). The sediment starved water that had been flowing over the dam following 1912 dam construction likely contributed to the initial incising process. The removal of the dam, however, has not stopped the incising of the right and left bank (Figure 5). The continual incising of the banks at cross section B ten years after the dam removal illustrates that hydrologic changes which the dam induced can have continuing repercussions on the geomorphology of the stream channel even after post dam removal. Annual surveying cross section B would provide information on the yearly rate of incising of the river channel at this location.

Cross section C, located 24 ft upstream of the former dam, has lost an estimated 98.7 ft^2 of sediment (Figure 6). The loss of sediment is consistent with cross section C's location just upstream of the former dam site. It would be expected that removal of the dam, which previously blocked sediment transport, would facilitate the transport of the build up of sediment downstream.

While we were not able to compare cross section E and F to post dam removal conditions, they will be useful for future analyses by the park service of channel morphology and stability of Ritchie Creek.

The longitudinal profile shows a deep pool just below the dam, likely created by impact of water spilling over the dam for 80 years. We were not able to analyze pre and post dam longitudinal profile conditions because we did not have a pre-dam comparison profile[7]. However, the longitudinal profile will provide a baseline for the park service to conduct future analysis of channel morphology and stability of Ritchie Creek (Figure 12).[8]

The Park did an admirable job of pre-dam removal measurement and documentation. They surveyed cross sections to perform as baseline measurements, monumented the cross section pins, provided excellent mapping of the cross section locations, and took photographs. In ideal circumstances (and unlimited resources), we would have liked to have a longitudinal profile of the riverbed, not just water elevation, and documentation of material size above and below the dam as well. Additionally, resurveying the cross sections in the years immediately following the dam removal would have provided useful data about the rate of sediment transport.

[7] We would have liked to compare our longitudinal profile to one that was done in December 1989, but the 1989 longitudinal profile measured surface water elevation only. This made comparison difficult because the water flows are different between December (when the 1989 longitudinal profile was taken) and March (when ours was taken) and Ritchie Creek is not gaged. Additionally, the 1989 longitudinal profile used as its benchmark the top of the dam, which no longer exists. Accordingly, we could not meaningfully compare our longitudinal profile with the 1989 longitudinal profile.

[8] The Park did an admirable job of pre-dam removal measurement and documentation. They surveyed cross sections to perform as baseline measurements, monumented the cross section pins, provided excellent mapping of the cross section locations, and took photographs. In ideal circumstances and unlimited resources, we would have liked to have a longitudinal profile of the riverbed, not just water elevation, as well as documentation of material size above and below the dam. Additionally, resurveying the cross sections in the years immediately following the dam removal would have provided useful data about the rate of sediment transport.

VI. Conclusion

The results of our research demonstrate that sediment redistributed following the removal of Richie Creek dam. Upstream of the dam, 679 cubic yards of sediment eroded and downstream 99 cubic yards aggraded. Placing this in context of what is expected for sediment transport in a basin of this size, however, the sediment transported from upstream of the dam is not very significant: it represents less than one year of sediment yield for the basin.

Further erosion, of course, may still occur, especially if even larger storm events than what the site has undergone in the last ten years (such as a 100-year event) take place. However, because the supply of sediment stored behind the dam is finite and much of it may already have eroded already, the rate of sediment transported from dam storage will likely continue to diminish.

VII. References

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Hourly Precipitation Data: California

FIGURE 1. RITCHIE CREEK WATERSHED MAP

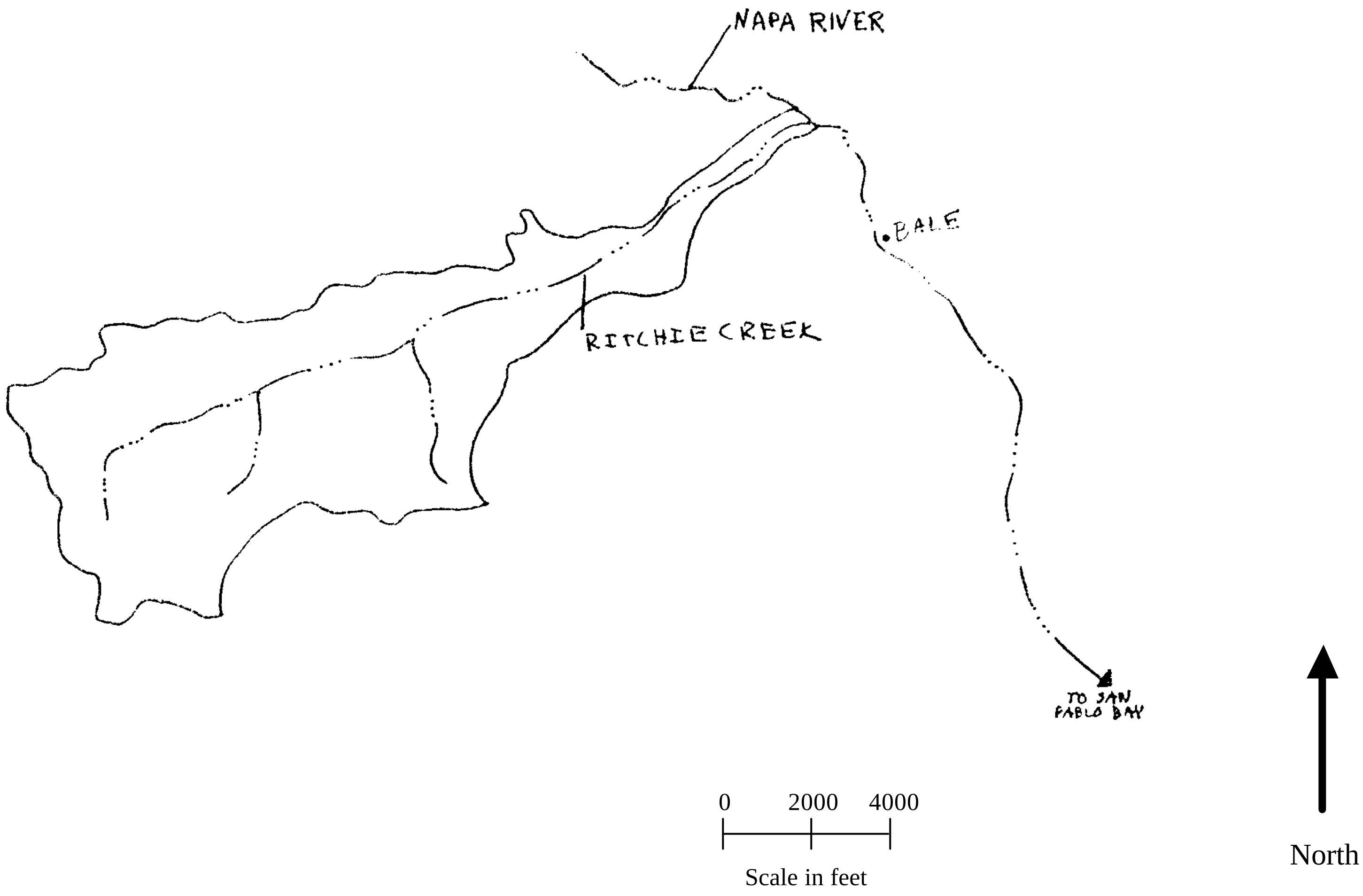


FIGURE 2. SITE MAP

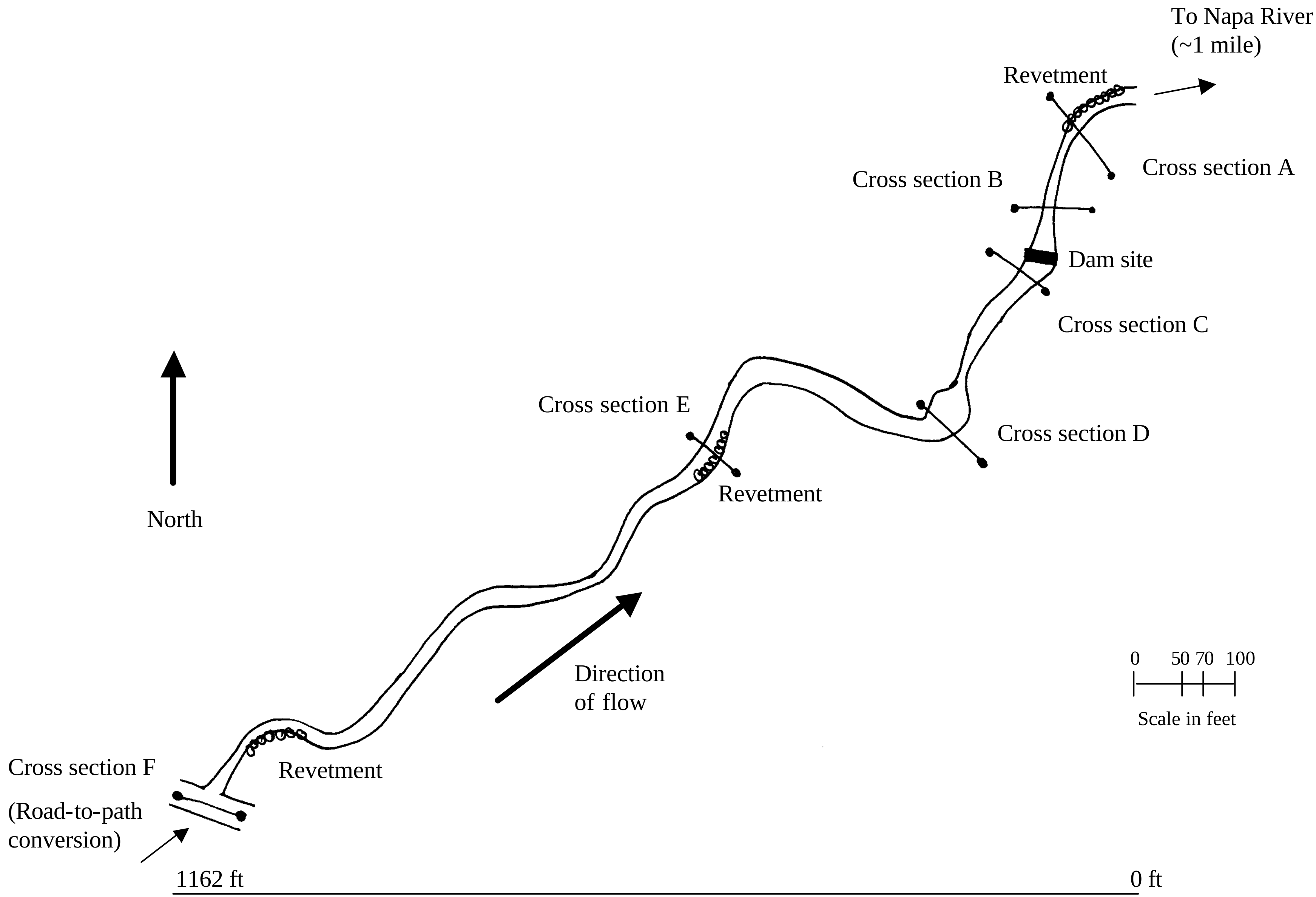


FIGURE 3. RITCHIE CREEK TOPOGRAPHIC MAP

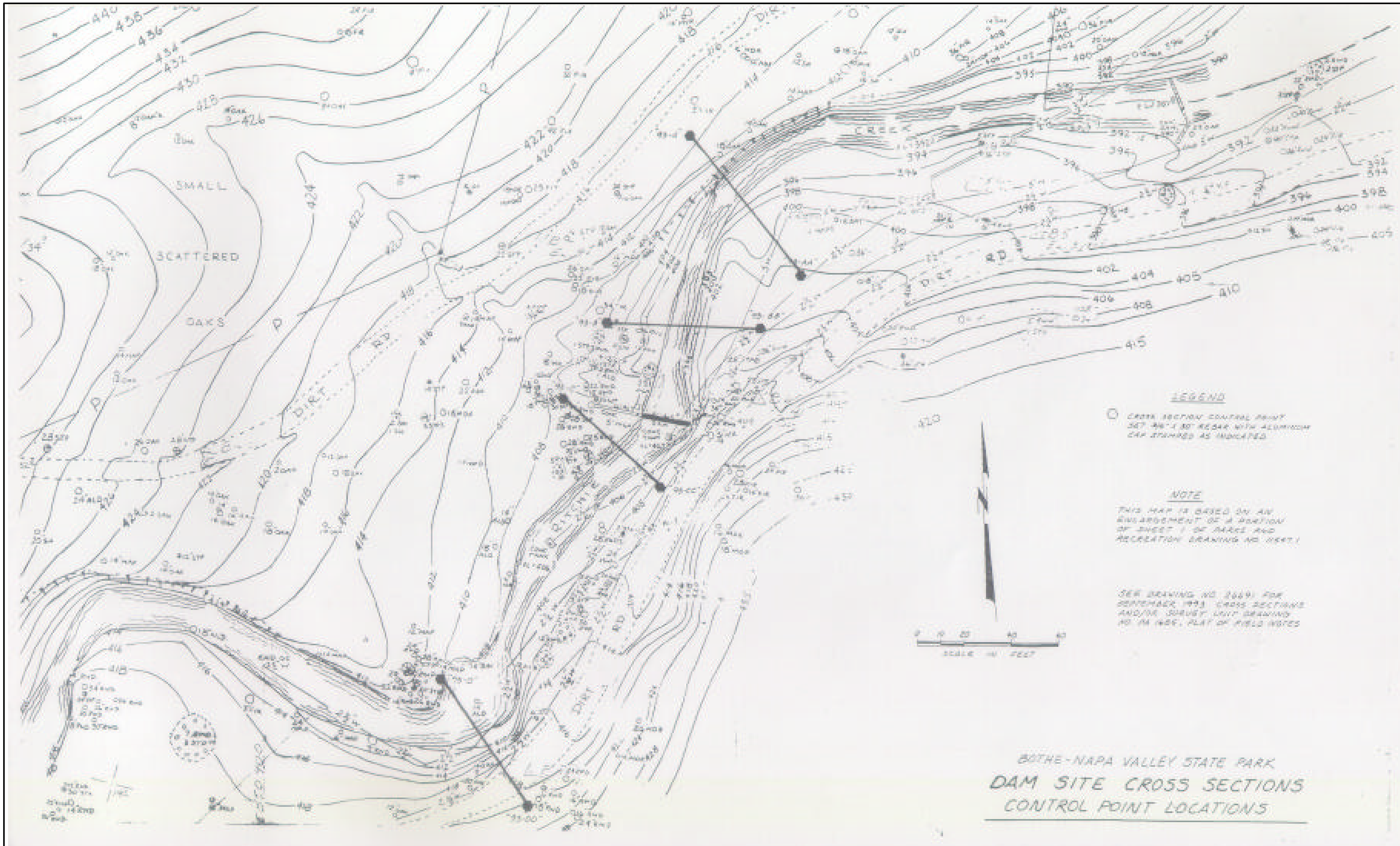


FIGURE 4. CROSS SECTION A

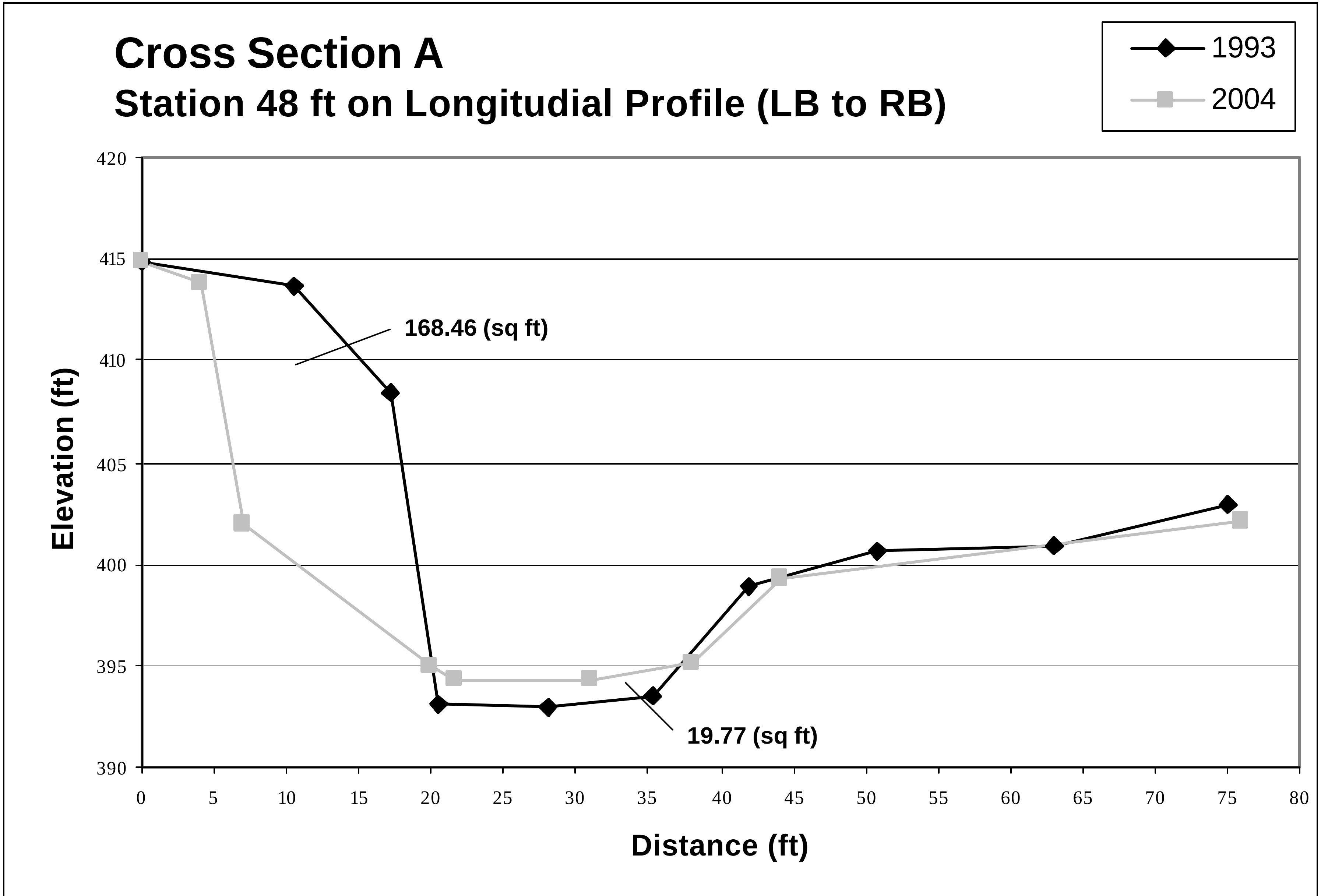


FIGURE 5. CROSS SECTION B

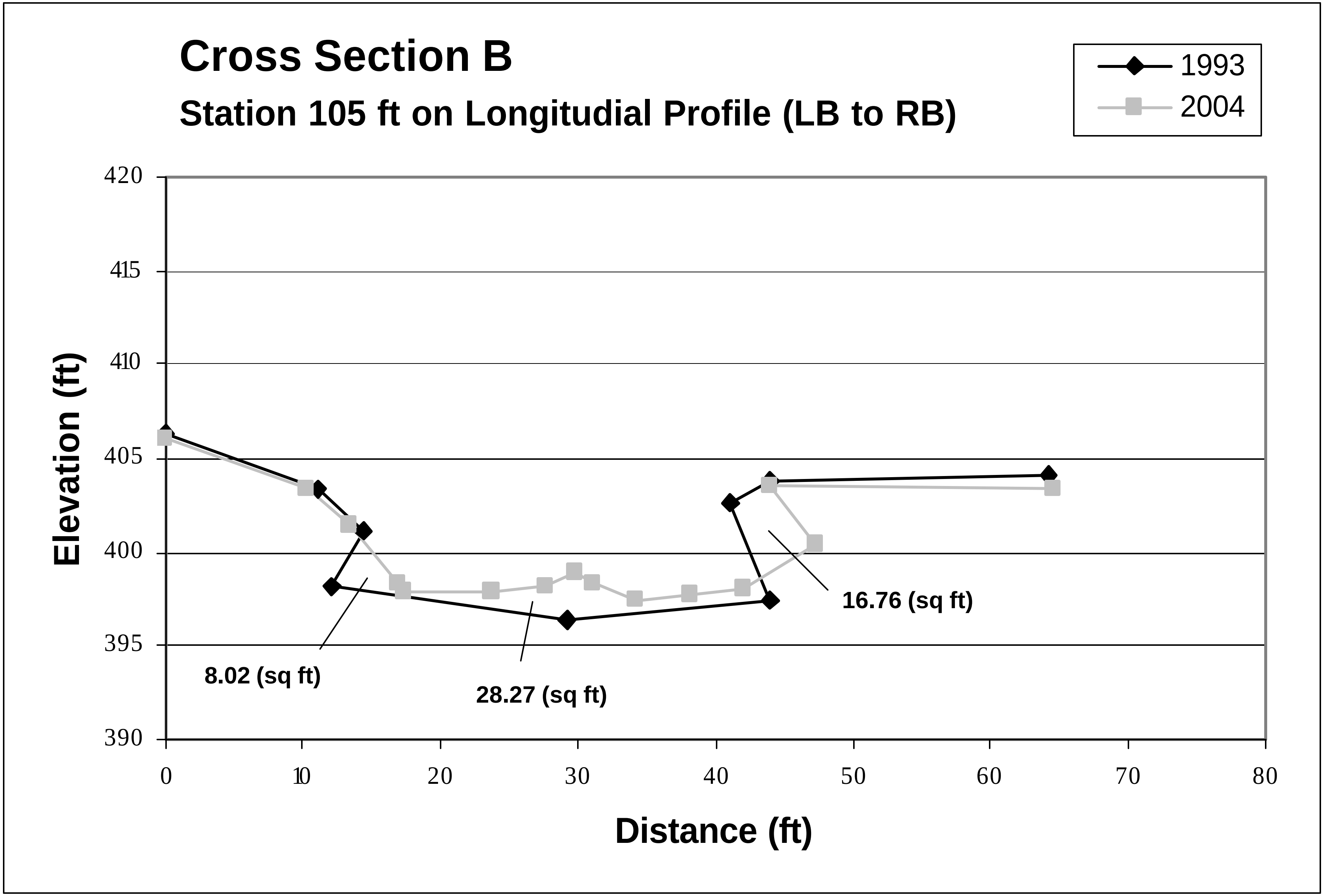


FIGURE 6. CROSS SECTION C

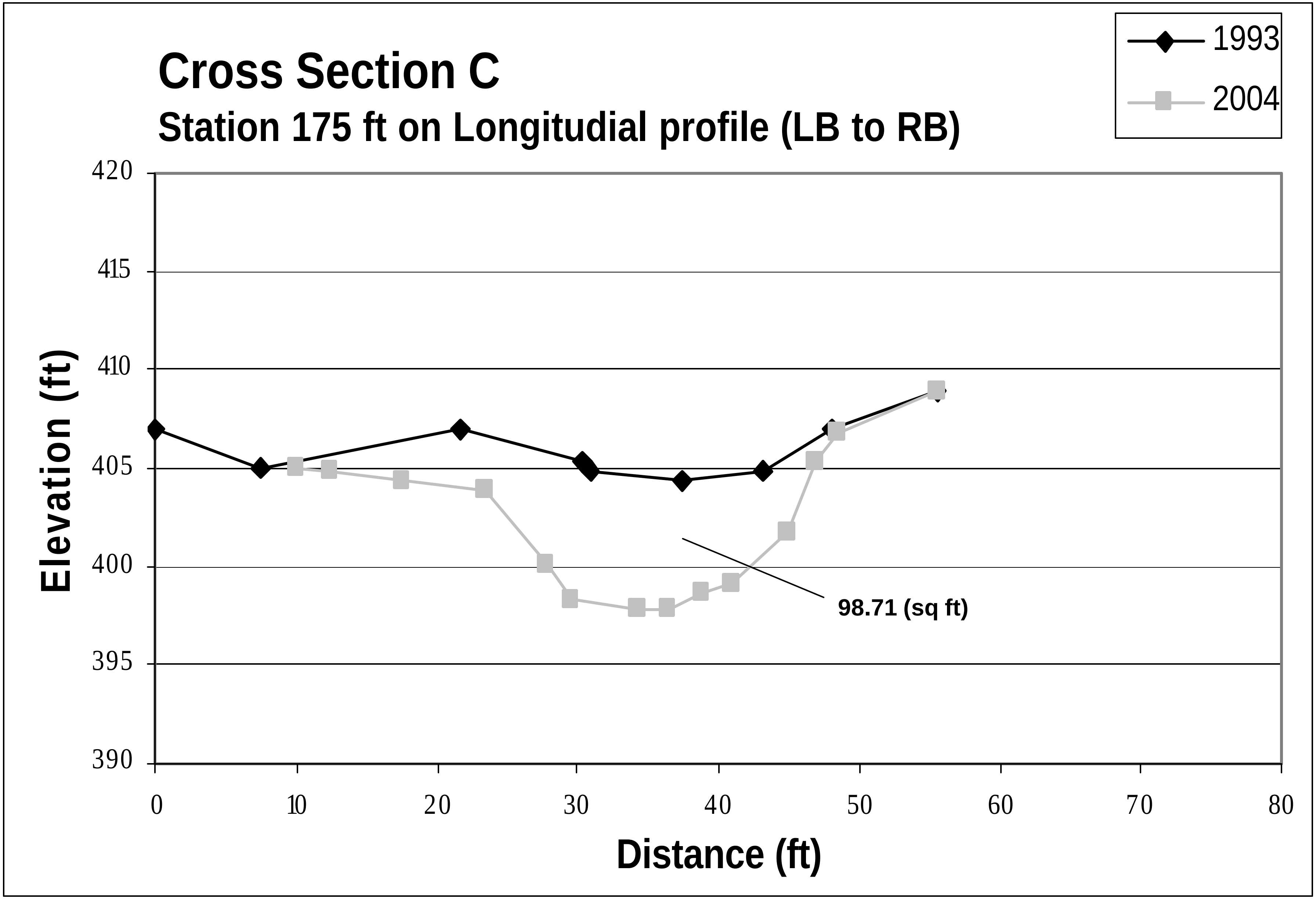


FIGURE 7. CROSS SECTION D

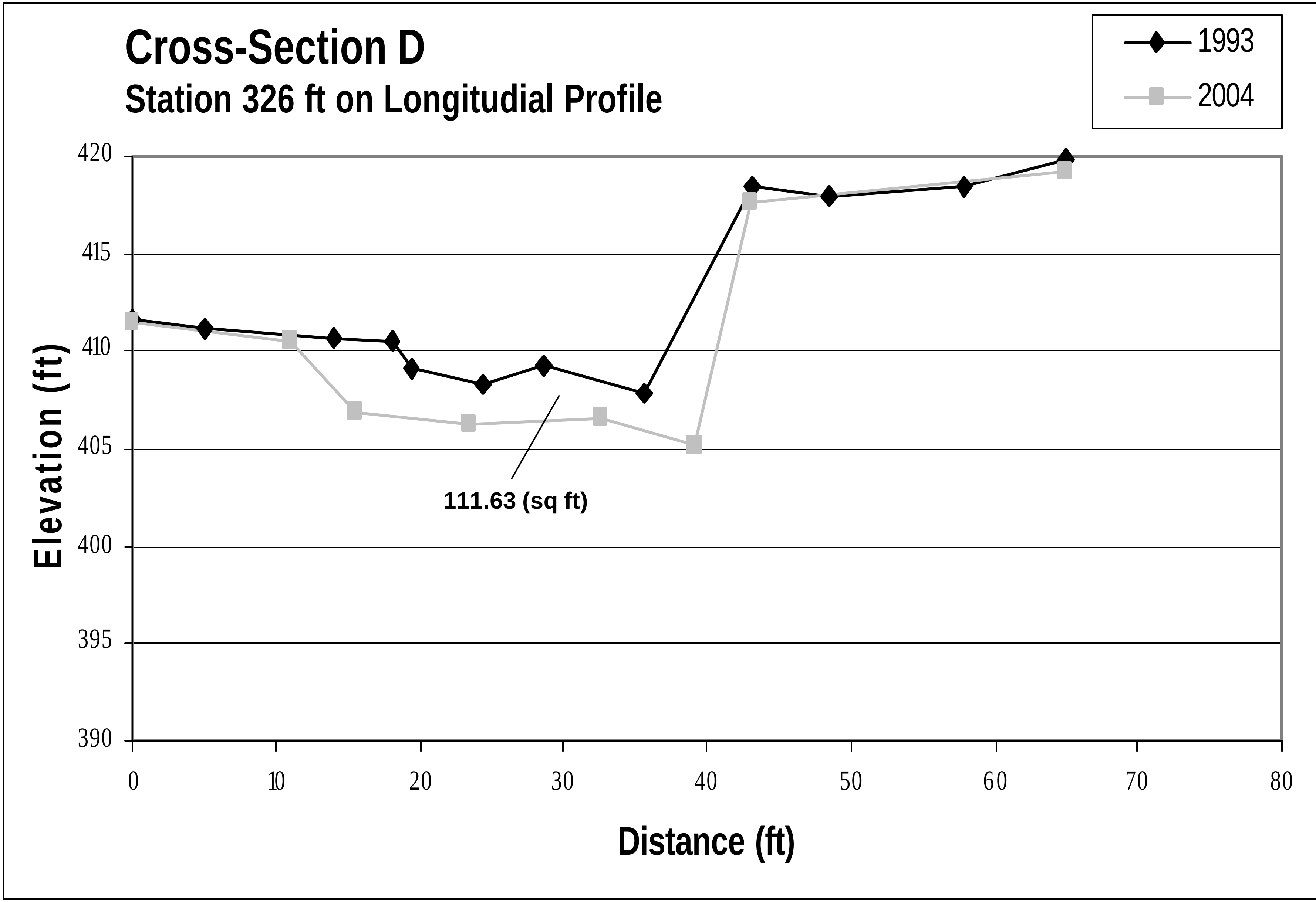


FIGURE 8. CROSS SECTION E

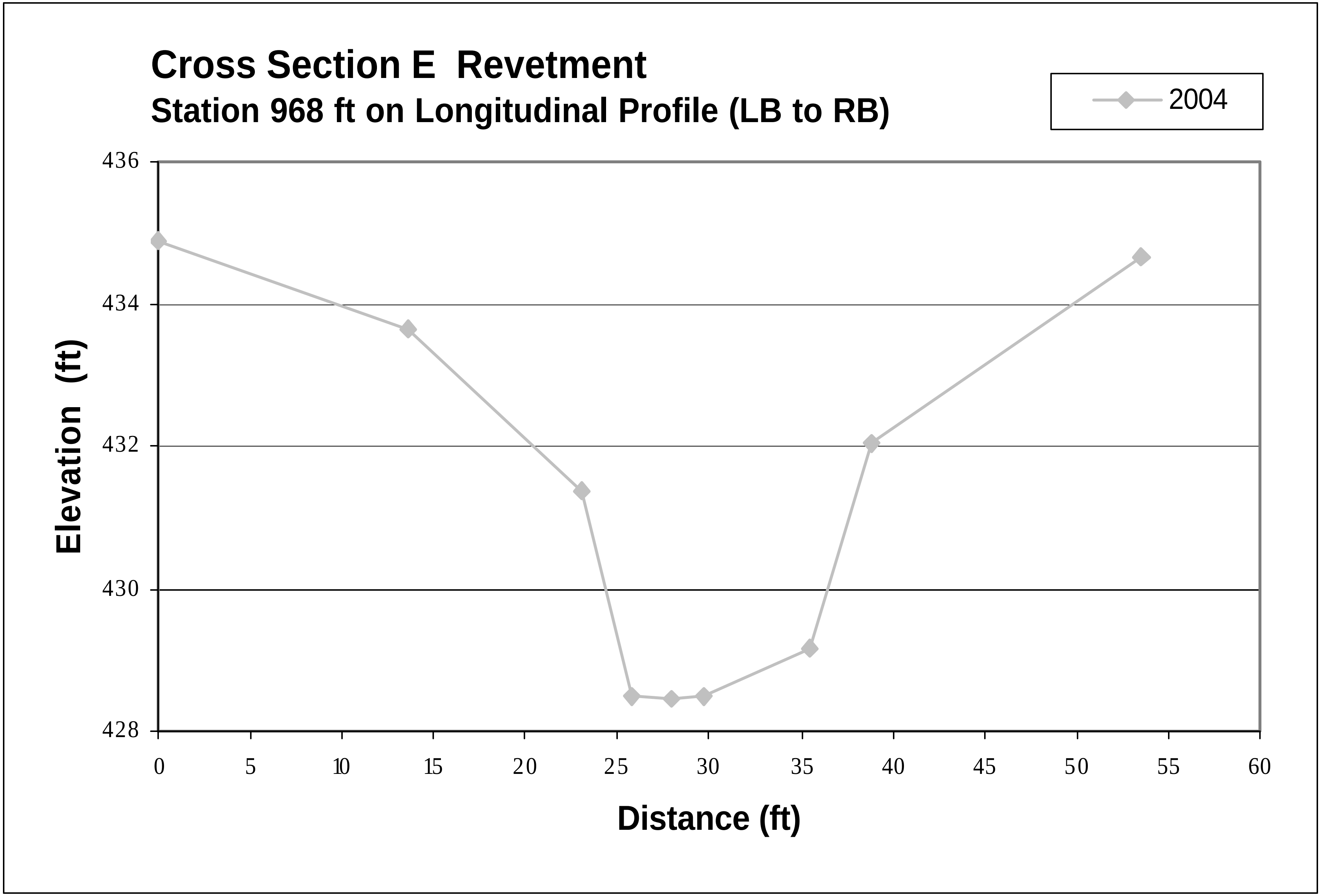


FIGURE 9. CROSS SECTION F

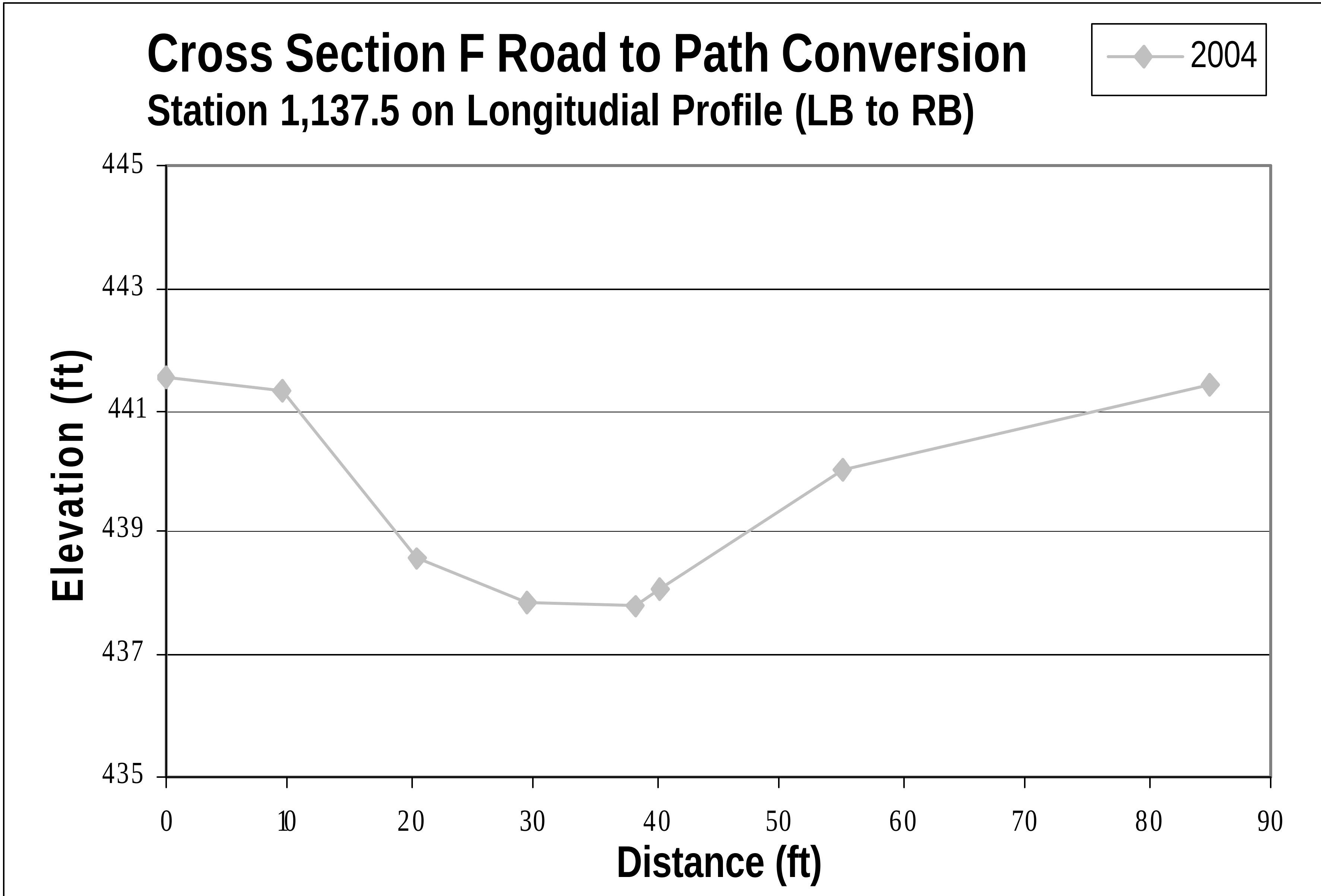
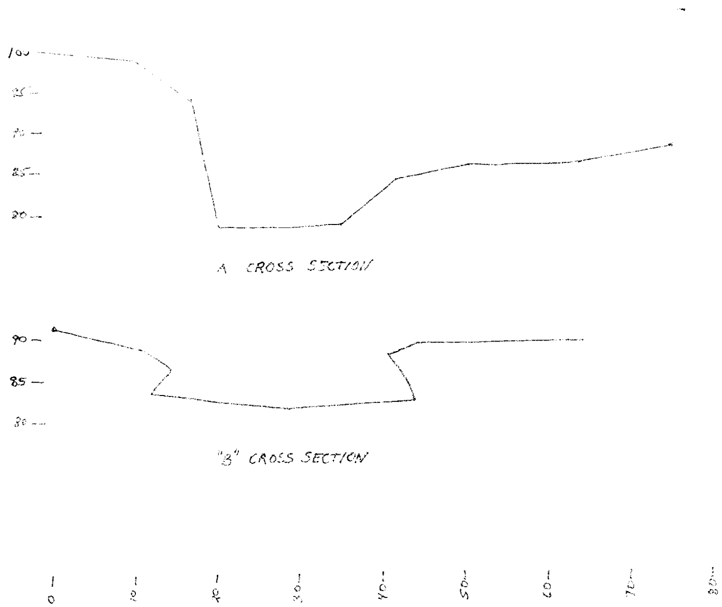
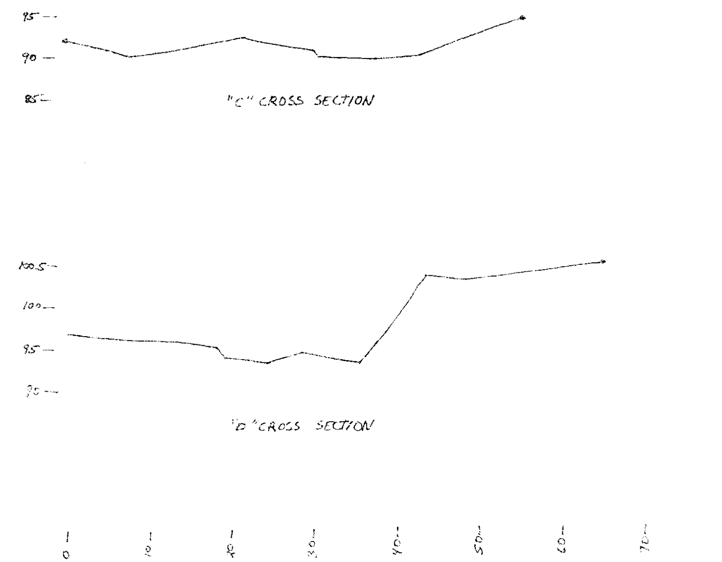


FIGURE 10. 1993 CROSS SECTIONS DATA

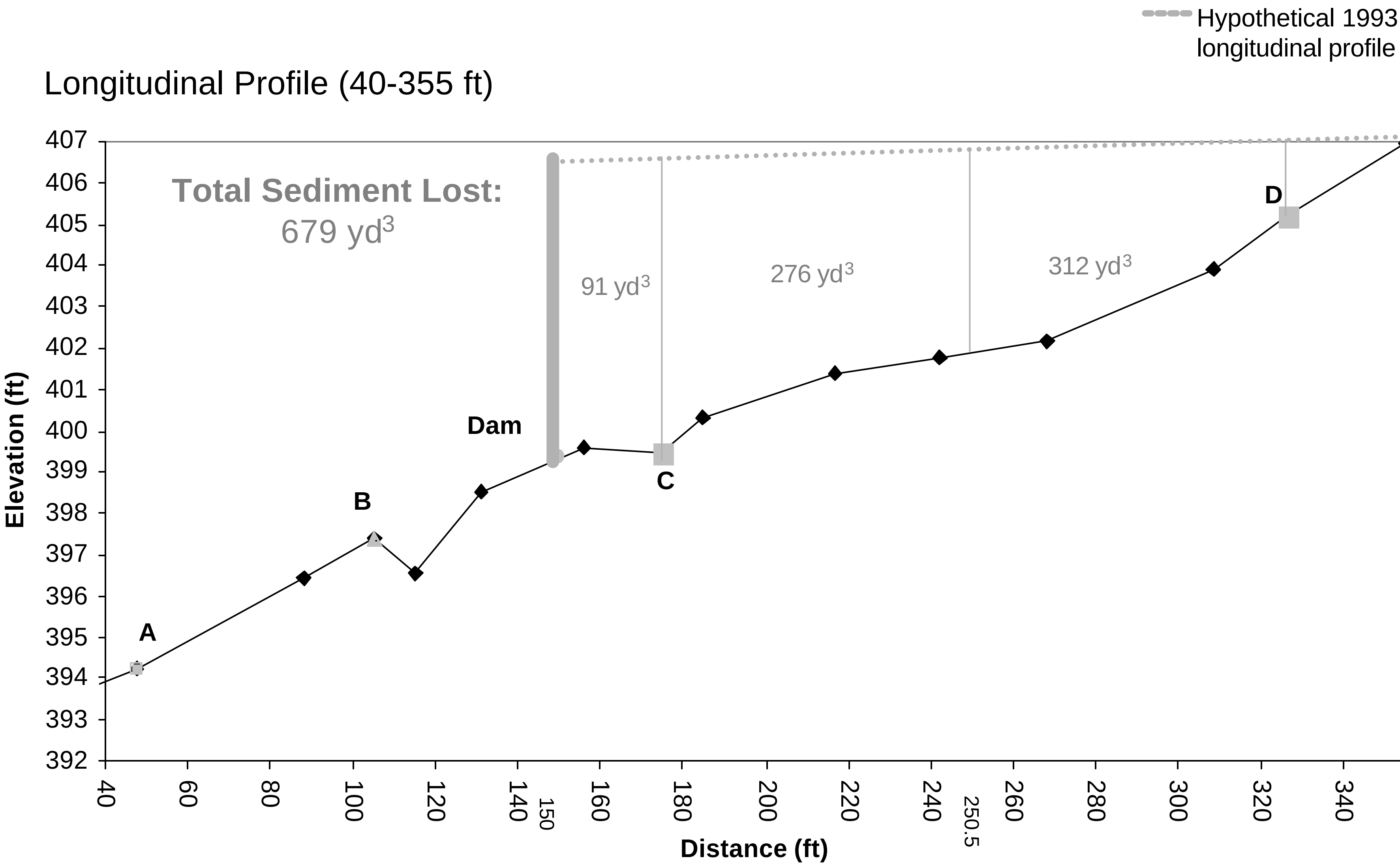


distance in feet



distance in feet

FIGURE 11. SEDIMENT EROSION 10 YEARS AFTER DAM REMOVAL



See appendix for illustration of calculation method

Sediment amount calculated by taking the area difference between the 1993 and 2004 cross-sections C, D and multiplying the area by the midpoint length between cross-sections: E.g., the 312 yd3 figure was calculated by taking the area difference between the 1993 and 2004 D cross-section and multiplying it by 75.5, which is the midpoint length between cross-section C and D.

FIGURE 12. LONGITUDINAL PROFILE - THALWEG AND CENTER LINE ELEVATIONS AND CROSS SECTION LOCATIONS

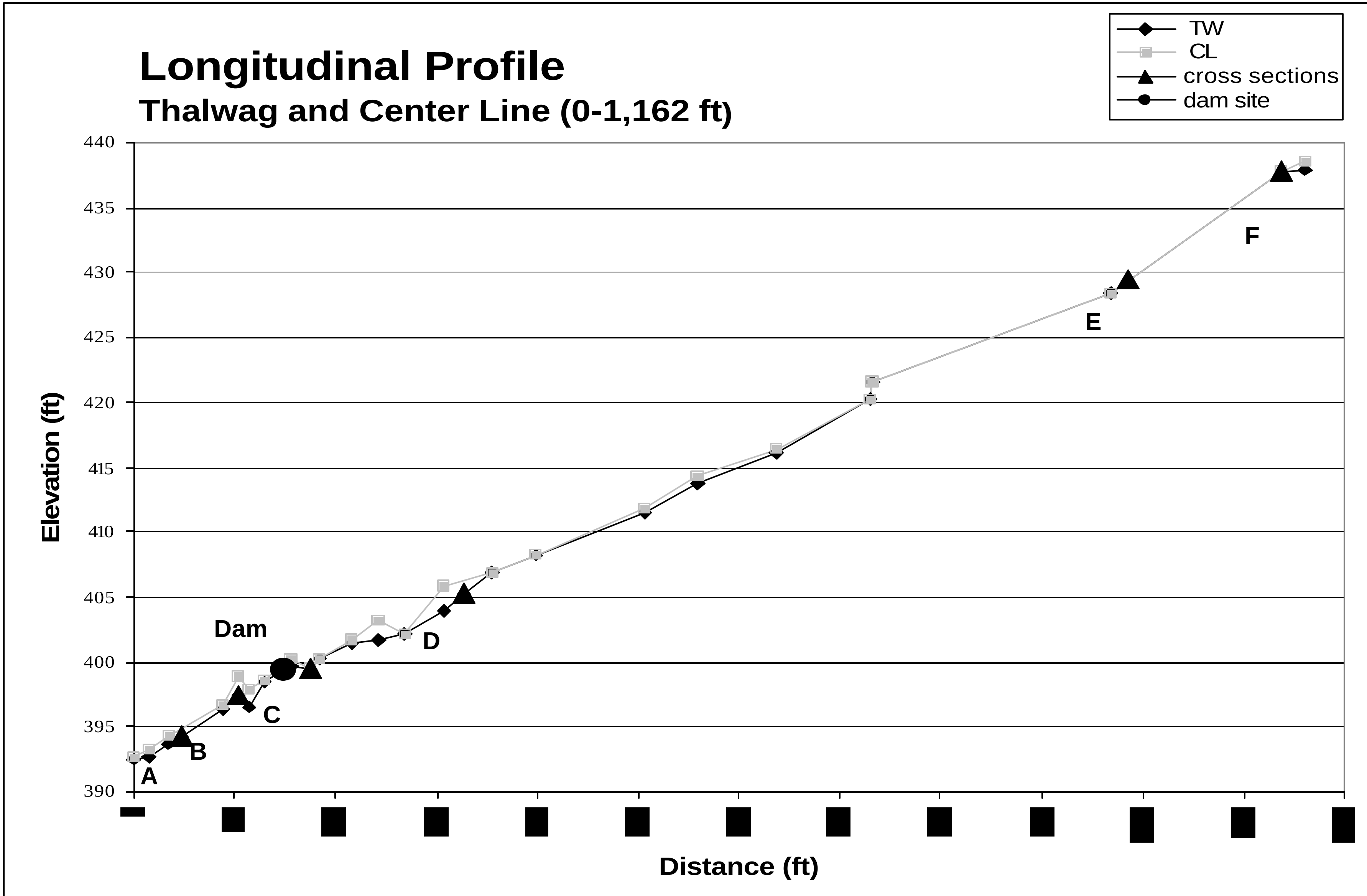


FIGURE 13. LONGITUDINAL PROFILE - THALWEG AND SURFACE WATER ELEVATIONS AND CROSS SECTION LOCATIONS

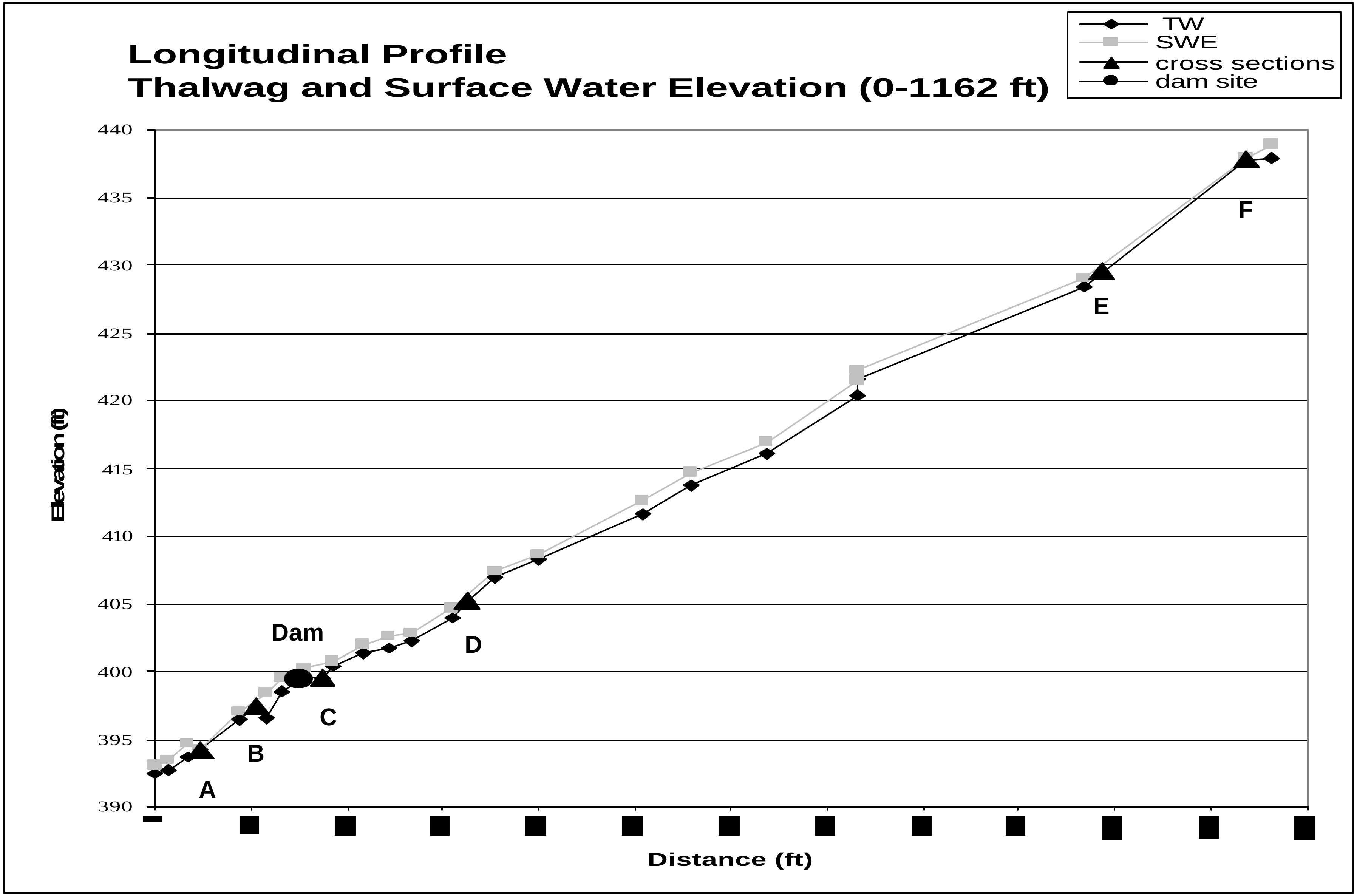
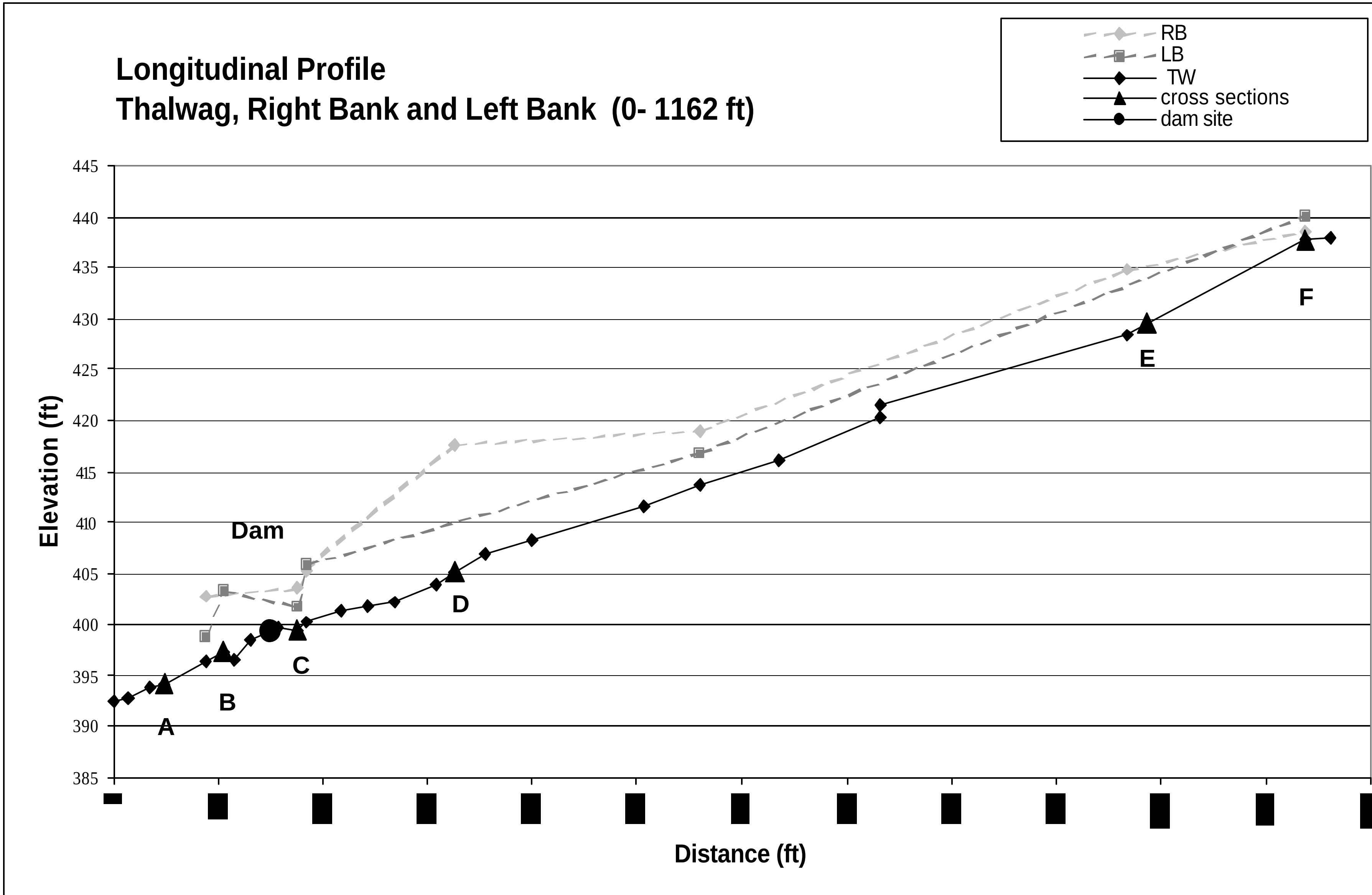


FIGURE 14. LONGITUDINAL PROFILE – THALWEG, RIGHT BANK AND LEFT BANK AND CROSS SECTION LOCATIONS



APPENDIX

SEDIMENT YIELD CALCULATIONS FOR RITCHIE CREEK WATERSHED AT FORMER DAM SITE

Relationships

Sediment yield rate for Northcoast watersheds	0.27 to 1.04	acre-feet/mi^2/yr						
1 acre-foot	43,560	ft^2						
Area of Ritchie Creek watershed	2.6	mi^2						
Location of dam in Ritchie Creek watershed	lower 1/3							

Calculations

How many feet of sediment in 1 acre-foot volume								
$43{,}560ft^2$ x 1 ft =	43,560	ft^3						
How many ft^3 in sediment yield range?								
lower range								
0.27 x $43{,}560ft^2$ =	11,761	$ft^3/mi^2/yr$						
upper range								
1.04 x $43{,}560ft^2$ =	45,302	$ft^3/mi^2/yr$						
How many ft^3 for the sediment yield in Ritchie Creek Watershed?								
lower range								
2.6 x 11,761 =	30,579	ft^3						
upper range								
2.6 x 45,302 =	117,786	ft^3						
How many cubic yards is this sediment yield?								
lower range								
30,579 / 27 =	1,133	cubic yards						
upper range								
117,786 / 27 =	4,362	cubic yards						
Reduction in sediment due to dam's location at bottom third of watershed								
lower range								
1,132 x (2/3) =	755	cubic yards						
upper range								
4,362 x (2/3) =	2,908	cubic yards						

<u>Total Sediment Yield</u>

755 to 2,908 cubic yards

CROSS SECTION DATA TABLES 1993 AND 2004

CROSS SECTION A

1993			
LB to RB (A-AA)			
Pt	Distance (x)	Hypo Elevation (y)	Real Elevation (y)
a	0	100	414.87
b	10.5	98.8	413.67
c	17.2	93.5	408.37
d	20.5	78.2	393.07
e	28	78.1	392.97
f	35.2	78.6	393.47
g	42	84	398.87
h	50.9	85.7	400.57
I	63	86	400.87
j	75	88	402.87

2004					
LB to RB (A-AA)					
Location on longitudial profile: 48 ft					
pt	Distance (x)	Hypo elevation	Real Elevation (y)		
a	0	100	414.87		
b	4	99	413.87		
c	7	87.07	401.94		
d	19.9	80.06	394.93		
e	21.7	79.38	394.25		
f	31	79.39	394.26		
g	38.1	80.28	395.15		
h	44.1	84.42	399.29		
I	76	87.28	402.15		

CROSS SECTION B

1993			
LB to RB (B-BB)			
Pt	Distance (x)	Hypo Elevation (y)	Real Elevation (y)
a	0	91.4	406.27
b	11	88.5	403.37
c	14.5	86.2	401.07
d	12	83.3	398.17
e	29.2	81.5	396.37
f	44	82.5	397.37
g	41	87.7	402.57
h	44	89	403.87
I	64.2	89.2	404.07

2004					
LB to RB (B-BB)					
Location on Longitudial profile 105 ft					
pt	Distance (x)	Hypo Elevation (y)	Real Elevation (y)		
a	0	91.13	406		
b	10.4	88.51	403.38		
c	13.5	86.55	401.42		
d	16.9	83.48	398.35		
e	17.3	83.05	397.92		
f	23.8	83.05	397.92		
g	27.6	83.23	398.1		
h	29.7	84.1	398.97		
I	31.2	83.45	398.32		
j	34.3	82.54	397.41		
k	38.1	82.92	397.79		
l	42	83.1	397.97		
m*	**47.3**	**85.54**	**400.41**		
n	43.9	88.71	403.58		
o	64.6	88.47	403.34		

*point m created from measuring length and width of incision on RB

CROSS SECTION DATA TABLES 1993 AND 2004 (continued)

CROSS SECTION C

1993			
LB to RB (C-CC)			
Pt	Distance (x)	Hypo Elevation (y)	Real Elevation (y)
a	0	92.1	406.97
b	7.5	90.1	404.97
c	21.7	92.1	406.97
d	30.3	90.5	405.37
e	31	89.9	404.77
f	37.5	89.5	404.37
g	43.2	90	404.87
h	48.1	92.1	406.97
I	55.5	94.1	408.97

2004					
LB to RB (C-CC)					
Location on Longitudial profile 175 ft					
Pt	Distance (x)	Adjusted x*	Real Elevation (y)	Hypo Elevation (y)	adjusted y*
a	0	10	406.66	90.14	405.01
b	2.4	12.4	406.46	89.94	404.81
c	7.5	17.5	406.02	89.5	404.37
d	13.4	23.4	405.51	88.99	403.86
e	17.7	27.7	401.78	85.26	400.13
f	19.5	29.5	400.04	83.52	398.39
g	19.6	29.6	400.04	83.52	398.39
h	24.3	34.3	399.54	83.02	397.89
I	26.5	36.5	399.46	82.94	397.81
j	28.8	38.8	400.33	83.81	398.68
k	31	41	400.7	84.18	399.05
l	35	45	403.47	86.95	401.82
m	36.8	46.8	407.02	90.5	405.37
n	38.5	48.5	408.47	91.95	406.82
o	45.5	55.5	410.62	94.1	408.97

* x and y adjusted to coordinate with 1993 cross section; adjustment made because only C location, not exact start and end points of 1993 cross section were known for the 2004 cross section

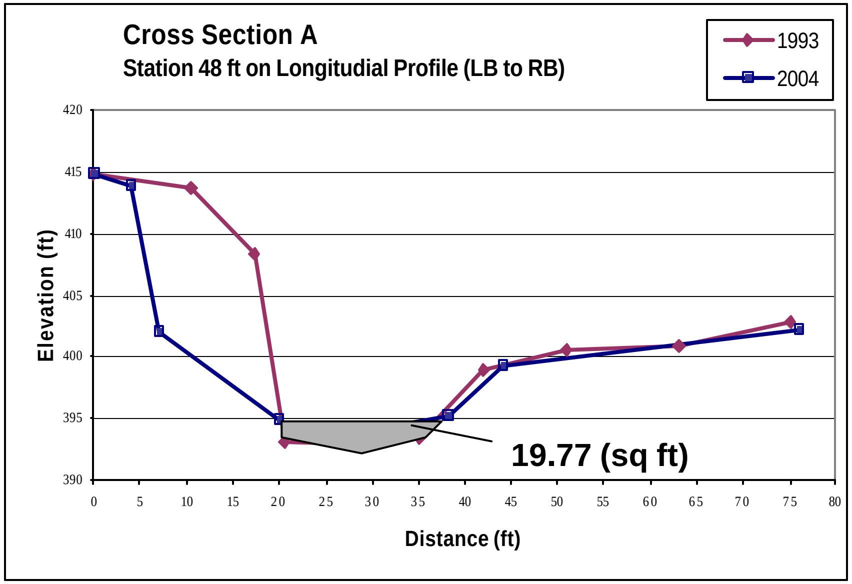
CROSS SECTION D

1993			
LB to RB (D-DD)			
Pt	Distance (x)	Hypo Elevation (y)	Real Elevation (y)
a	0	96.8	411.67
b	5	96.3	411.17
c	14	95.8	410.67
d	18.1	95.6	410.47
e	19.4	94.3	409.17
f	24.5	93.4	408.27
g	28.7	94.4	409.27
h	35.6	93	407.87
I	43.2	103.5	418.37
j	48.5	103	417.87
k	57.9	103.5	418.37

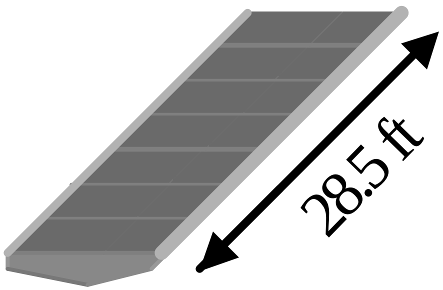
2004			
LB to RB (D-DD)			
Location on Longitudial profile 326 ft			
pt	Distance (x)	Hypo Elevation (y)	Real Elevation (y)
a	0	96.62	411.49
b	11	95.59	410.46
c	15.5	91.98	406.85
d	23.4	91.46	406.33
e	32.6	91.65	406.52
f	39.2	90.34	405.21
g	43	102.81	417.68
h	65	104.41	419.28

CALCULATION OF SEDIMENT EROSION AND DEPOSITION IN CHANNEL

Step 1: calculate area of change in cross section

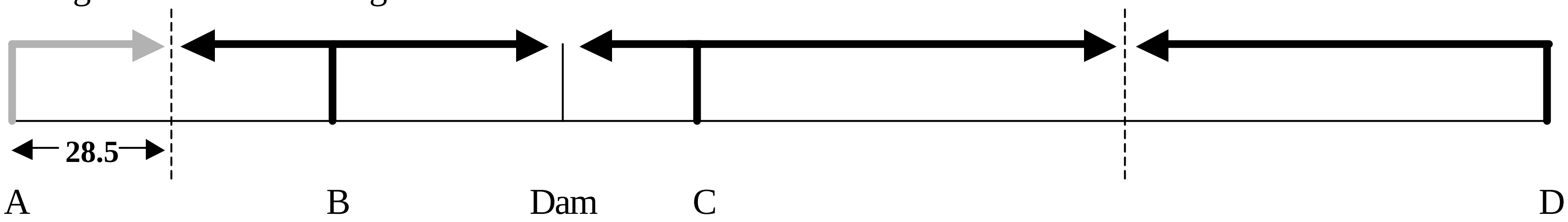


Step 2: project area into channel volume



Step 3: distribute cross section volumes across longitudinal profile

Longitudinal Profile Length



TOTAL SEDIMENT EROSION AND AGRRADATION