Tidal Channel and Marshplain Development

Cooley Landing Salt Pond Restoration

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Abstract: Post-project monitoring data shows that the Cooley Landing Salt Pond breached-levee restoration is meeting the established project objectives by creating diverse habitat, which is evolving towards a mature marsh system. Engineered design elements, including breach channel training berms and levee borrow ditch blocks, have encouraged the re-occupation of the historic tidal channel footprint and prevented the development of primary channels in the artificial borrow ditch. The restored marshplain has aggraded by a maximum of 0.6 to 0.8 ft in the last two years and vegetated with pickleweed. The breaches provide adequate tidal drainage and low tide drainage is controlled by the elevation of the rapidly eroding outboard mudflat channels.

Introduction

Problem Statement

This paper evaluates marshplain and tidal channel development for the Cooley Landing Salt Pond breached-levee tidal marsh restoration, located near the Dumbarton bridge and East Palo Alto in the southern San Francisco Bay, California (Figure 1), by analyzing topographic survey data collected by Philip Williams & Associates (PWA) and photo-documentation. Tidal marsh restoration projects in the San Francisco Bay Estuary have achieved variable success in creating diverse and complex habitat that mimics historic marsh conditions and processes, depending on restoration site conditions and the restoration design approach.

The restoration of diked, subsided[1] marshes occurs through the tidal deposition of suspended sediments and the re-colonization of marsh vegetation species. Tidal marsh restoration design must consider factors that can potentially delay marshplain development, such as restricted tidal action, limited sediment supply, and internally generated wind waves (Williams and Orr 2002). The formation of tidal channels in marsh restoration sites may be influenced more by artificial features (i.e. excavated ditches) than by natural processes (WWR 2003). In such cases, the restored channel morphology may lack the complexity of historic channel networks. For example, while the placement of dredge material accelerated the processes of sediment accumulation and

[1] Diked tidal marshes subside due to the decomposition of organic matter in the marsh surface and the lack of sediment supply.

vegetation colonization at the Faber Tract[2] restoration site (Williams and Orr 2002), the channel network did not follow the footprint of the historic channels preserved beneath the dredge material (Figure 2). The resulting channel network, which consisted of many straight branching channels draining to a single large and wide channel, is apparently due to the influence of the perimeter borrow ditches and the slope of the imported dredge material.

The Cooley Landing Salt Pond restoration design included elements to encourage the development of diverse habitat that will evolve towards a mature tidal marsh system in response to natural processes. These elements include breaching the outboard levee at the locations of two historic slough channels, constructing berms to guide the levee breach channels (channel training berms) and to block the borrow ditches along levees (borrow ditch blocks), and lowering the outboard levee. The intent of the restoration design was to meet the following objectives, which are indicators for the evolution of the site along the expected geomorphic trajectory towards a mature marsh system (PWA 1999):

- Encourage reestablishment of natural or historic tidal channels and prevent borrow ditches from becoming primary tidal channels
- Create vegetated marshplain habitat through the processes of marshplain and borrow ditch sedimentation and vegetation establishment on the marshplain, berms, and lowered outboard levee
- Provide adequate tidal circulation and drainage.

[2] The Faber Tract site, located just to the south of Cooley Landing and restored in 1972, was the first planned marsh restoration in the San Francisco Bay Estuary.

Background

The 150-acre Cooley Landing Salt Pond was restored in December 2000 by breaching the outboard levee. During its operation as a salt production pond, the marshplain subsided by approximately 2.3 ft due to the consolidation of subsurface soils and the lack of sediment supply from the bay and the slough channels filled with sediment due to the lack of tidal scour (PWA 1999). The footprint of the historic channel systems persists in the subsided marshplain (Figure 3). The construction material for the outboard levee was excavated from the historic marshplain, leaving a borrow ditch along the inside of the levee. Bay-ward of the outboard levee, there is a narrow strip of tidal salt marsh and beyond this there is an extensive mudflat.

PWA performed baseline monitoring prior to restoration (December 2000, referred to as pre-breach), immediately after restoration (January 2001, referred to as post-breach), and eight months after restoration (July to September 2001, referred to as Year 1). PWA monitored tide levels in the site and determined that the tidal range was not muted in the site and that the breach channels controlled low tide drainage (PWA et al 2002).

Methods

Tidal Channel Morphology

PWA surveyed 22 tidal channel cross-sections and two longitudinal thalweg in September 2003 and previously in Year 1 (July to September 2001) and prior to restoration (December 2000). PWA performed the surveys using a Total Station leveling system and NGVD elevation benchmarks established during site construction. Figure 4 shows the locations of the channel cross-sections and thalweg profiles.

I calculated channel cross-sectional area below MHHW, depth below MHHW, and channel top width for two cross-sections from both the north and south breaches. I estimated the expected equilibrium geometry for the breach channels from empirical correlations between tidal channel dimensions and marsh drainage area (Williams et al. 2002). These correlations are based on data from mature tidal marshes with marshplain elevations at MHHW[3]. I measured marsh drainage areas for each breach in Arcview GIS from a geo-referenced aerial photograph taken in September 2003 (see photo-documentation section below).

I also analyzed the aerial photograph to evaluate channel evolution where PWA did not collect cross-section surveys. I verified locations of historic channel re-occupation and identified portions of the channel network that did not follow historic channels. I measured the length of channel formed in artificial borrow ditches in Arcview GIS and calculated a borrow ditch density for the north breach drainage area. For comparison, I measured borrow ditch densities using a similar method for four other marsh restoration sites: Faber Tract, Carl's Marsh, Green Point, and Pond 2A. I reviewed background information on these restoration sites to aid in the interpretation of results (Williams and Orr 2002 and unpublished PWA data).

Marshplain Accretion

PWA surveyed a marshplain transect along the PG&E access boardwalk that crosses the Cooley Landing site in September 2003, Year 1, and prior to restoration (December 2000). PWA also measured the depth of sediment deposited over metal sedimentation

[3] These estimatee of equilibrium breach dimensions are based on the assumption that expected long-term equilibrium marshplain elevation will be at MHHW.

plates that were installed prior to restoration in September 2003 and in Year 1. PWA performed the surveys using a Total Station and NGVD elevation benchmarks as described in the Tidal Channel Morphology section above. Figure 4 shows the location of the marshplain transect and sedimentation plates.

Tidal Drainage

PWA surveyed a single water surface elevation in the south breach during the low tide cycle on September 24, 2003 and three water surface elevations in the north breach spanning during the low tide on September 25, 2003.

Photo-Documentation

I photographed site conditions at pre-established stations for this study during a low spring tide on September 27, 2003. I previously photographed the site at these stations immediately post-breach (January 2001) and prior to restoration (December 2000). I took photographs with a wide-angle lens (28 mm) and a leveled tripod.

S.S. Papadopolus & Associates provided PWA with a geo-referenced color infrared aerial photograph taken in September of 2003, shown in Figure 5. I analyzed the aerial photographs to distinguish qualitative patterns of developing tidal channels (in plan view) and marsh vegetation. I also measured the distance upstream that the main channel from the south breach has eroded from the 2003 aerial photograph in Arcview GIS.

Results and Discussion

Tidal Channel Development

The north and south breach longitudinal thalweg profiles (Figures 6 and 7) and the three breach channel cross-sections located bay-ward of the outboard marsh (Figures 8, 9, 10) show rapid erosion of the outboard mudflat channels. Since September 2001, the thalwegs of both breach mudflat channels have down-cut by an average of 1.5 ft. Farther out towards the Bay, the thalwegs of both mudflat channels slope upwards to a maximum thalweg elevation of –2.5 ft NGVD or 6.8 ft below MHHW. The expected long-term equilibrium depths for the north and south breach channels (7.7 and 8.1 ft respectively, Table 1) are approximately 1 ft below the current maximum thalweg elevation. The mudflat channels have also widened substantially compared to the breach channels upstream.

The cross-sections for the Cooley Landing breach cross-sections in the outboard marsh and at the former levee are plotted in Figures 11-14. In the outboard marsh, the cross-sectional area of the north breach channel has increased since September 2001. The channel thalweg depth and top width have not changed significantly. The channel through the north levee breach has down-cut by 1.3 ft at the thalweg and has widened through bank erosion since September 2001. If the current rate of channel erosion by down cutting persists, the channels will reach expected long-term depths within two years. The shell bed shown in the photographs in Figure 15 may slow the scour of the bottom of the north breach channel. The current cross-sectional areas and widths are larger than the predicted equilibrium dimensions and do not cause tidal muting within the site (PWA et al 2002).

The south breach channel has widened and down-cut by more than a foot in the outboard marsh (Figure 14). The amount of channel erosion in the outboard mudflat has been greater than channel erosion at the levee. A large hole has scoured to a maximum depth of 14.6 ft below MHHW (elevation -10.3 ft NGVD) in the south breach channel between the training berms. The aerial photograph shows the formation of mudflat channels that drain around the ends of the training berms. This suggests that the scour hole has formed as the mudflat areas on either side of the training berms drain around the ends of the berms. Due to channel scour caused by the large tidal prism draining through the south breach (see discussion of tidal drainage below), the current dimensions of the south breach channel are larger than the predicted long-term dimensions (Table 1). The force of this drainage would have certainly scoured the borrow ditch along the former levee in the absence of the training berms. A small channel has formed parallel to the north side of north training berm that connects to a short portion of the borrow ditch (Figure 16), however this small channel may not persist as the marshplain accumulates sediment and vegetation establishes.

The formation of a long linear channel in the borrow ditch parallel to the northeast site boundary is evident in the aerial photograph, shown in detail in Figure 16. The Cooley Landing restoration design did not include a borrow ditch block for this borrow ditch. The northeast site boundary truncates two large slough channels and therefore there are no low order historic channels in this part of the site that can be re-occupied. A short portion of a small channel has also occupied a segment of the borrow ditch north of the north breach, however this channel is relatively minor. The density of borrow ditch channels at Cooley Landing is significantly less than at four older marsh restoration sites (Table 2).

Cross-sections of lower order channels upstream of the south breach (Figure 17 to 20) show the re-occupation of these historic channels through scour. The marshplain transect along the PG&E boardwalk also shows the formation of several smaller channels (first and second order) across the site. PWA identified a channel nick-point that scoured the pre-breach grade of the historic channel bottom up to 800 ft upstream of the south breach by September 2001. Since then, the main branch of the historic channel has scoured beyond XS 6 (Figure 20), which is 2,500 ft upstream of the breach. At the back of the site near the boardwalk (Figure 21), this channel has filled with sediment, however the photo-documentation shows that other mudflat channels have formed in the location of historic channels in this part of the site (Figure 22).

Marshplain Development

The sedimentation plate data (Table 3) shows that sedimentation rates have increased dramatically at Cooley Landing over the last two years. The mudflat area drained by the culvert has received the least amount of sediment (Plate 1). In the first year, sedimentation was greater at the channel bank (Plate 2) than the adjacent marshplain (Plate 3). Now, cumulative sedimentation on the marshplain is greater than sedimentation near the channel.

The marshplain transect along the boardwalk (Figure 23) shows that the marshplain is aggrading across the site, except for a low mudflat area drained by the culvert in the southern portion of the site. The marshplain has aggraded by as much as 0.6 to 0.8 ft to an elevation of 2.6 ft NGVD (2.2 ft above MTL) along the northern half of the boardwalk transect. Along the southern boundary of the site, it has aggrades up to an elevation of 2.8 ft NGVD (2.4 ft above MTL). Low marsh vegetation species (i.e. cordgrass) establish on mudflats starting at elevations of 1 ft above MTL (1.4 ft NGVD for Cooley Landing). Most of the marshplain is above the minimum elevation for vegetation colonization. The color infrared aerial photograph (Figure 5) shows many individual colonies and larger patches of vegetation that are concentrated on the channel banks have established. Photo-documentation shows that the vegetation is pickleweed. Figures 24 and 25 shows the extensive pickleweed coverage that has colonized the outboard levee and channel training berms.

The borrow ditches have filled in with an average of 1 ft of sediment (Figures 26 to 28). The borrow ditch at the northern part of the site (Figure 28) has experienced the most sedimentation (1.5 ft) and is 1 ft below the adjacent marshplain. The elevations of the borrow ditches range from 1.2 to 1.5 ft NGVD, which are close to the minimum elevation for vegetation establishment. The borrow ditches have not vegetated probably due to the fact that the colonization elevation for pickleweed, which is the dominant species at the site, is above the minimum elevation for vegetation establishment (PWA, unpublished data).

Tidal Drainage

Figure 29 shows the water surface elevations surveyed in the north and south breach channels plotted with the predicted tide levels in the Bay. The low water survey elevations are –2.2 ft NGVD for the north breach and –2.3 ft NGVD for the south breach. The surveyed water surface elevations are more than a foot lower than the minimum water level determined for the south breach in September 2001 (-1 ft NGVD, PWA et al 2002).

The current minimum surveyed water surface elevations are slightly above the maximum mudflat channel thalweg depths (-2.5 ft NGVD). This suggests that the elevation of the mudflat channel thalweg controls low tide drainage. Currently, the majority of the site is drained at low tide and certain portions of the deeper channels remain subtidal. The formation of mudflat channel that cut around the south training berm of the south breach suggest that the limited rate of drainage through the culvert to the south of the south breach forces water from this area to drain to the south breach along a path where there is not a historic channel. However, the culvert does not limit site drainage as the area is adequately drained by the south breach.

Conclusions

The mudflat channels outboard of the Cooley Landing restoration site have rapidly eroded through the unconsolidated bay mud. The mudflat channel thalweg elevations currently control low tide drainage of the site, however the level of low tide drainage is adequate for draining most of the site. The development of the mudflat channels indicates that the design of short mudflat starter channels was effective and avoided the costly excavation of extensive mudflat channels.

Tidal channels have re-occupied the locations of major historic channels through the upstream migration of channel scour. The restored tidal channel system is sinuous and dendritic. Small low order channel systems near the back of the site have developed in locations of historic channels. The breach channel training berms and borrow ditch blocks have succeeded in preventing the formation of major tidal channels in the borrow ditch inboard of the former levee. A significant channel has formed in the northeast perimeter borrow, however the density of borrow ditches at Cooley Landing is low compared to other restoration sites. The restored system of tidal channels is developing into a complex system that mimics the characteristics of the historic habitat. Results suggest that the design approach may achieve historic tidal channel re-occupation within a time frame of three years for salt pond restoration sites with comparable conditions.

The restored marshplain is in a youthful state of development. The marshplain is evolving towards mature marsh through the processes of sedimentation and vegetation establishment. Sedimentation rates at the site have increased in the last two years and the marshplain has aggraded across the majority of the site. Sediment has accumulated in the borrow ditches on the inboard side of the levee, preventing the artificial features from dominating site habitat. Pickleweed colonies have established on the restored marshplain. Pickleweed has also extensively colonized the former levee and channel training berms.

The physical evolution of the site has created diverse habitat conditions characterized by a complex system of dendritic and sinuous tidal channels and vegetated marshplain. The restoration design has achieved the project objectives by encouraging the formation of desirable physical habitat. The monitoring results confirm the success of an engineered approach to restoring complex tidal marsh habitat through natural processes.

References Cited

Philip Williams & Associates (PWA), Wetlands Research Associates, Inc., and S.S. Papadopulos & Associates, Inc. 2002. Cooley Landing Salt Pond Restoration baseline and Year 1 monitoring report. Prepared for Aventic CropScience USA, North Carolina and Midpeninsula Regional Open Space District, Los Altos, California. 23 pp.

Philip Williams & Associates (PWA). 1999. Hydrologic analysis and design of the Cooley Landing tidal marsh restoration. Prepared for Rhone-Poulenc Inc., Geomatrix Consultants, Inc. and S.S. Papadopulos & Associates, Inc. 23 pp.

Wetland and Water Resources (WWR). 2003. Monitoring Report #2: May 1998 to Fall 2002, Project Years 5-8, Petaluma River Marsh (Carl's Marsh), Sonoma County, California. Prepared for the California State Coastal Conservancy and Sonoma Land Trust. 50 pp.

William, P.B. and M.K. Orr. 2002. Physical evolution of restored breached levee salt marshes in the San Francisco Bay Estuary. *Restoration Ecology*. 10: 527-542.

Williams, P.B., M.K. Orr, and N.J. Garrity. 2002. Hydraulic geometry: a geomorphic tool for salt marsh restoration design. *Restoration Ecology*. 10:

Table 1. Surveyed and predicted long-term equilibrium breach dimensions below or at MHHW.

		XSA (ft^2)	Depth (ft)	Width (ft)
South Breach (Drainage Area = 57 ac)	At levee (XS12)	470	8.9	85
	Outboard marsh (XS13)	500	9.6	71
	Expected long-term equilibrium	*290*	*8.1*	*64*
North Breach (Drainage Area = 44 ac)	At levee (XS17)	340	7.2	90
	Outboard marsh (XS18)	290	7.0	88
	Expected long-term equilibrium	*240*	*7.7*	*55*

Table 2. Borrow ditch channel characteristics in San Francisco Bay Estuary tidal marsh restoration sites

		Site Information[1]					Borrow Ditch Channel Data		
Region	**Site**	Previous Land Use	Restoration Design	Initial Elevation/ Subsidence (ft below MHHW)	Age[2] (years)	Area (ac)	Number of Channels	Total Length (ft)	Density (ft/ac)
South Bay	**Cooley Landing[3]**	salt production	Borrow ditch blocks, channel guide berms	2.3	**2.8**	101	4	2,300	**23**
	Faber Tract	agriculture	Dredge material placement	1.3	23	80	2 or 3	5,680	71
Petaluma River	Carl's Marsh (aka Petaluma River Marsh)	agriculture	Pilot channel excavation and berm construction	6.4	8	46	2	2,570	56
	Green Point (aka Toy Property)	agriculture	Channel excavation and sidecast	4.4	13	54	2	4,470	83
Napa River	Pond 2A	salt production	None	0.3	5	550	4	21,450	39

1- From Williams and Orr 2002
2- Age represents the time between the date the site was breached and the date of that the aerial photograph I analyzed was taken.
3- The area for Cooley Landing includes only the drainages for the north and south breach and excludes the area I assumed is drained by the culvert.

Table 3. Sedimentation plate data.

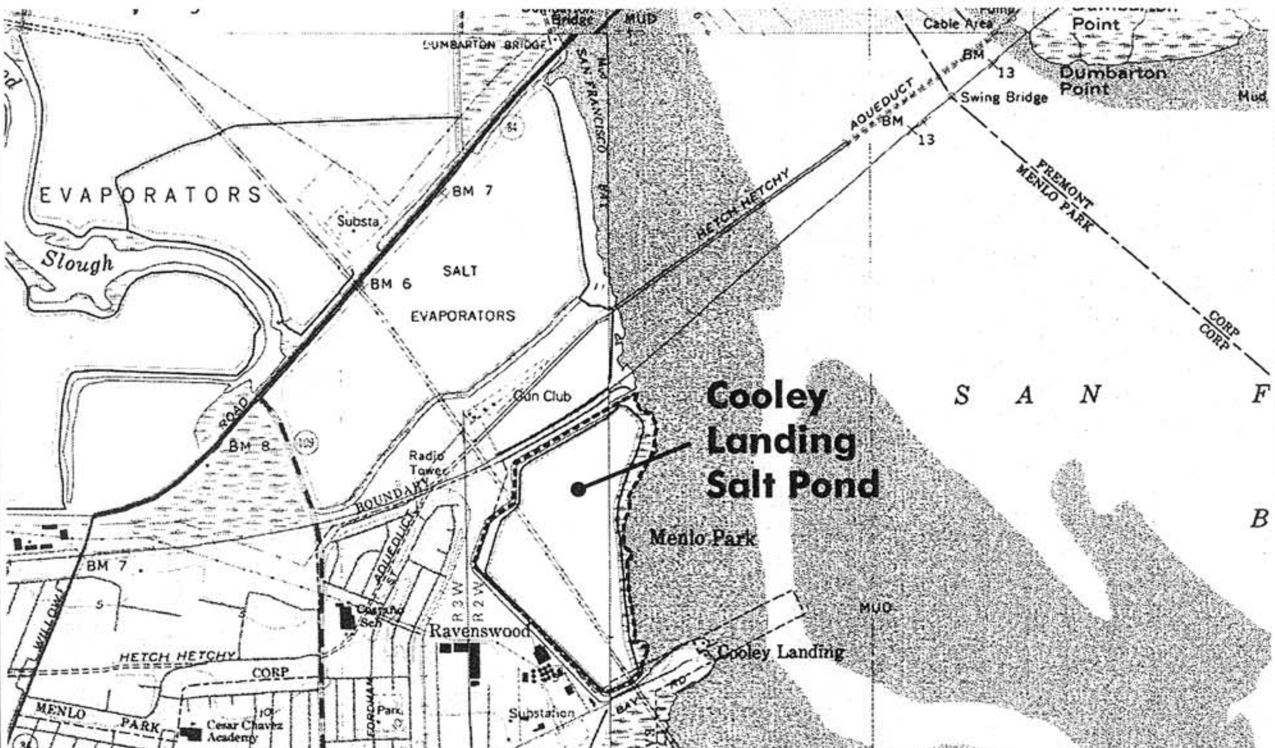
Sedimentation Plate #:		1	2	3	4	5	6
9/18/01 (0.7 years)	*Depth (ft)*	*0.01*	*0.10*	*0.06*	*NA*	*0.08*	*.02*
	Rate (ft/yr)	0.01	0.13	0.08	NA	0.11	.03
9/25/03 (2.8 years)	*Depth (ft)*	*0.17*	*0.41*	*0.53*	*NA*	*NA*	*NA*
	Rate (ft/yr)	0.06	0.15	0.19	NA	NA	NA

figure 1

Cooley Landing Salt Pond Menlo Park, California

Site Location Map

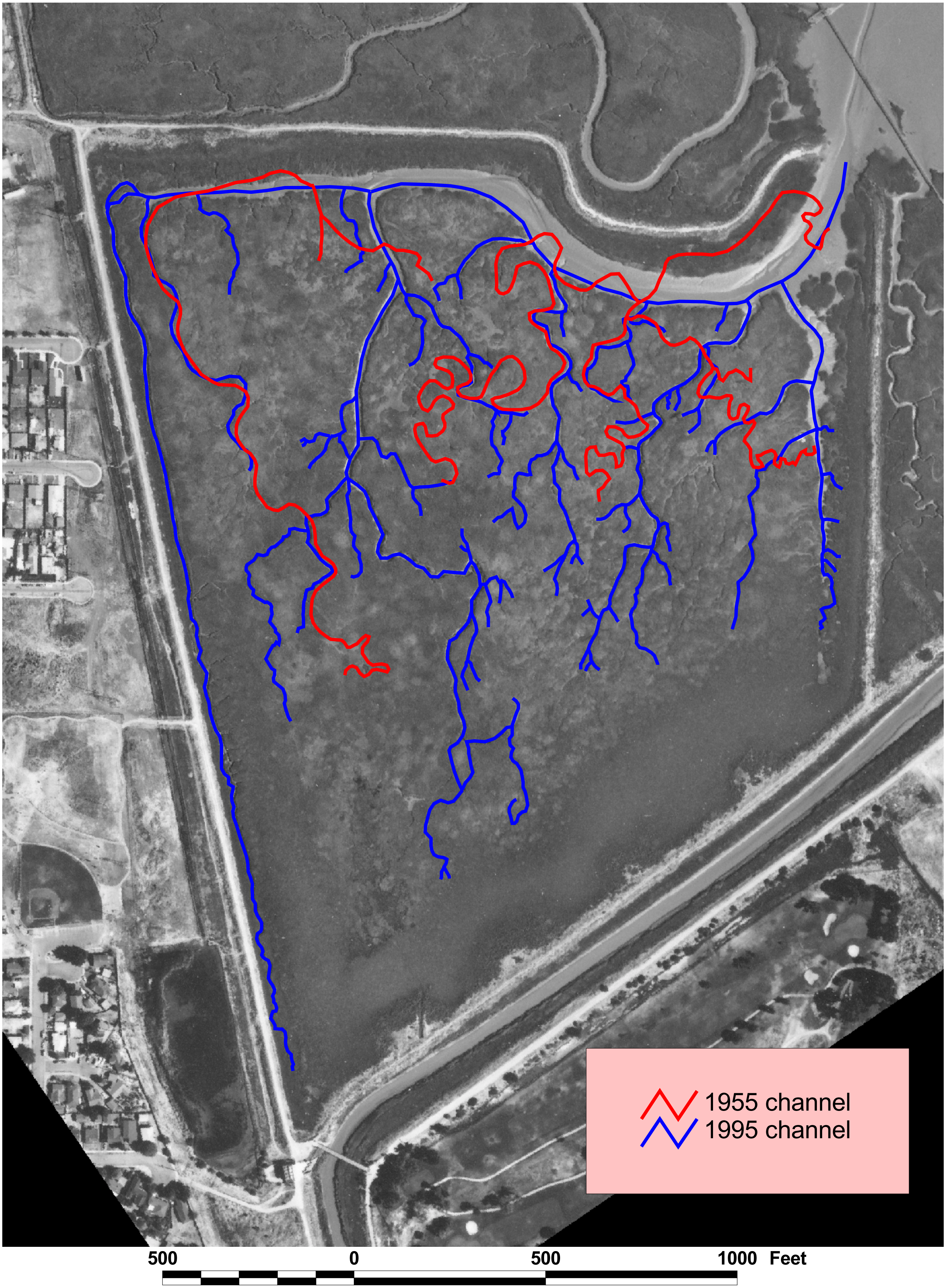
Source: PWA 1995



PWA

1225Cooley fig 1.cdr

Figure 2. Restored and historic tidal channels at Faber Tract.



Cooley Landing Marsh, September, 1948

Cooley Landing Marsh, August, 1997

figure 3

Aerial Photographs of Cooley Landing, 1948 and 1997

Cooley Landing Marsh Restoration Project

PWA

1225 cooley fig 3.cdr

Source: PWA 1999

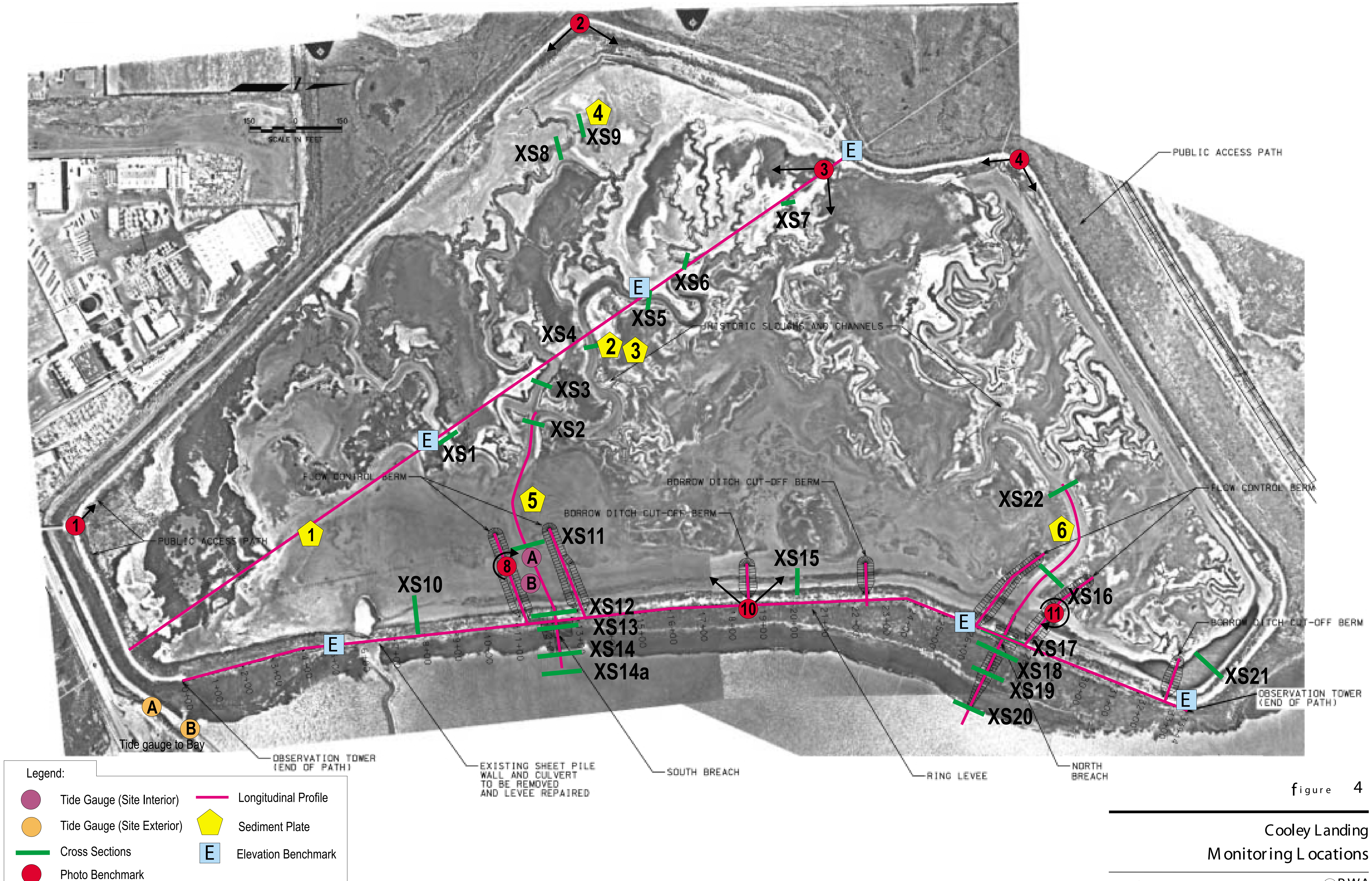


figure 4

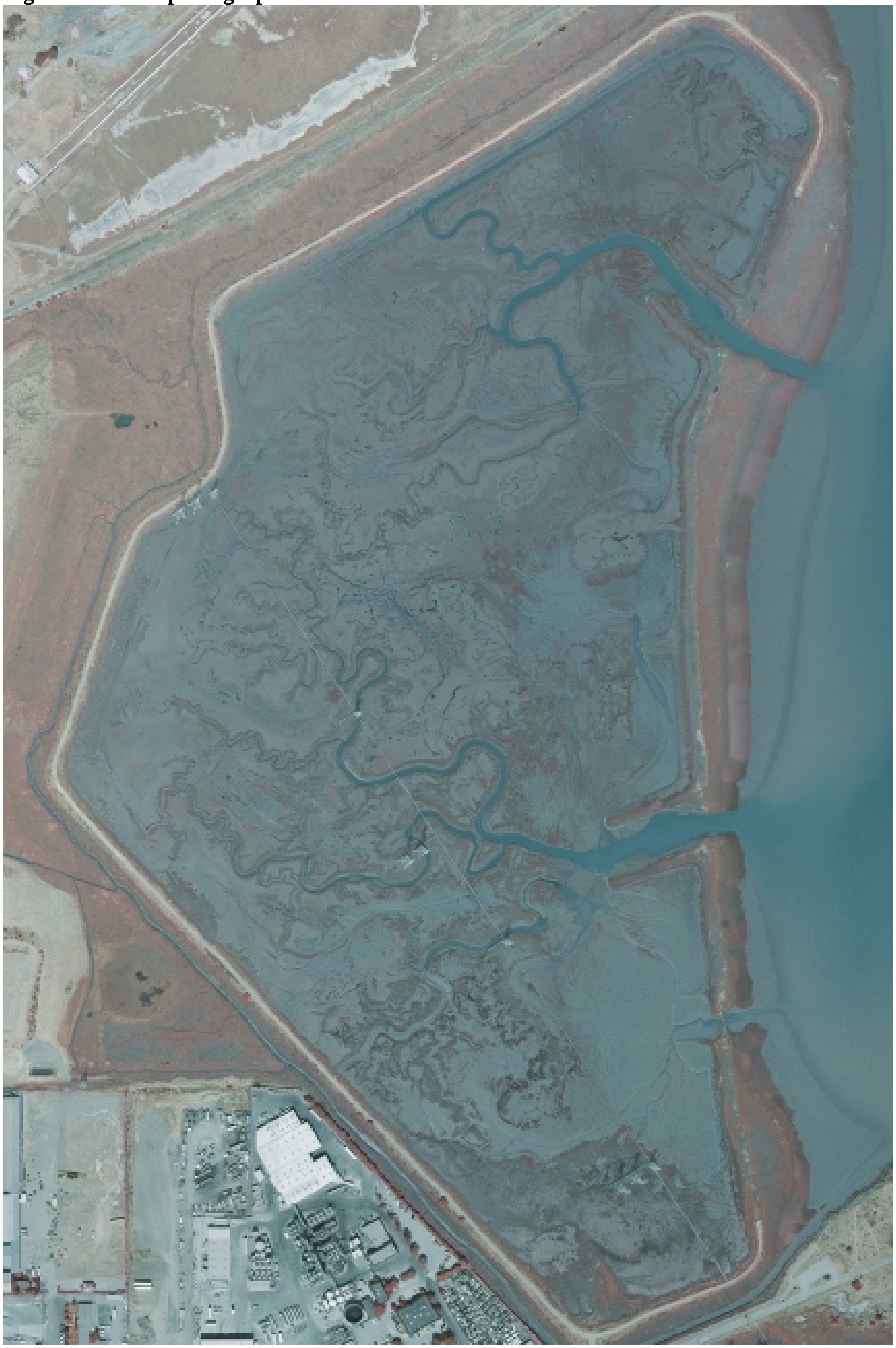
Cooley Landing
Monitoring Locations

Source: PWA 2002

PWA

RevFig#s-Jan2002/Monitorloctn.cdr

Figure 5. Aerial photograph of site taken on 9/22/03.



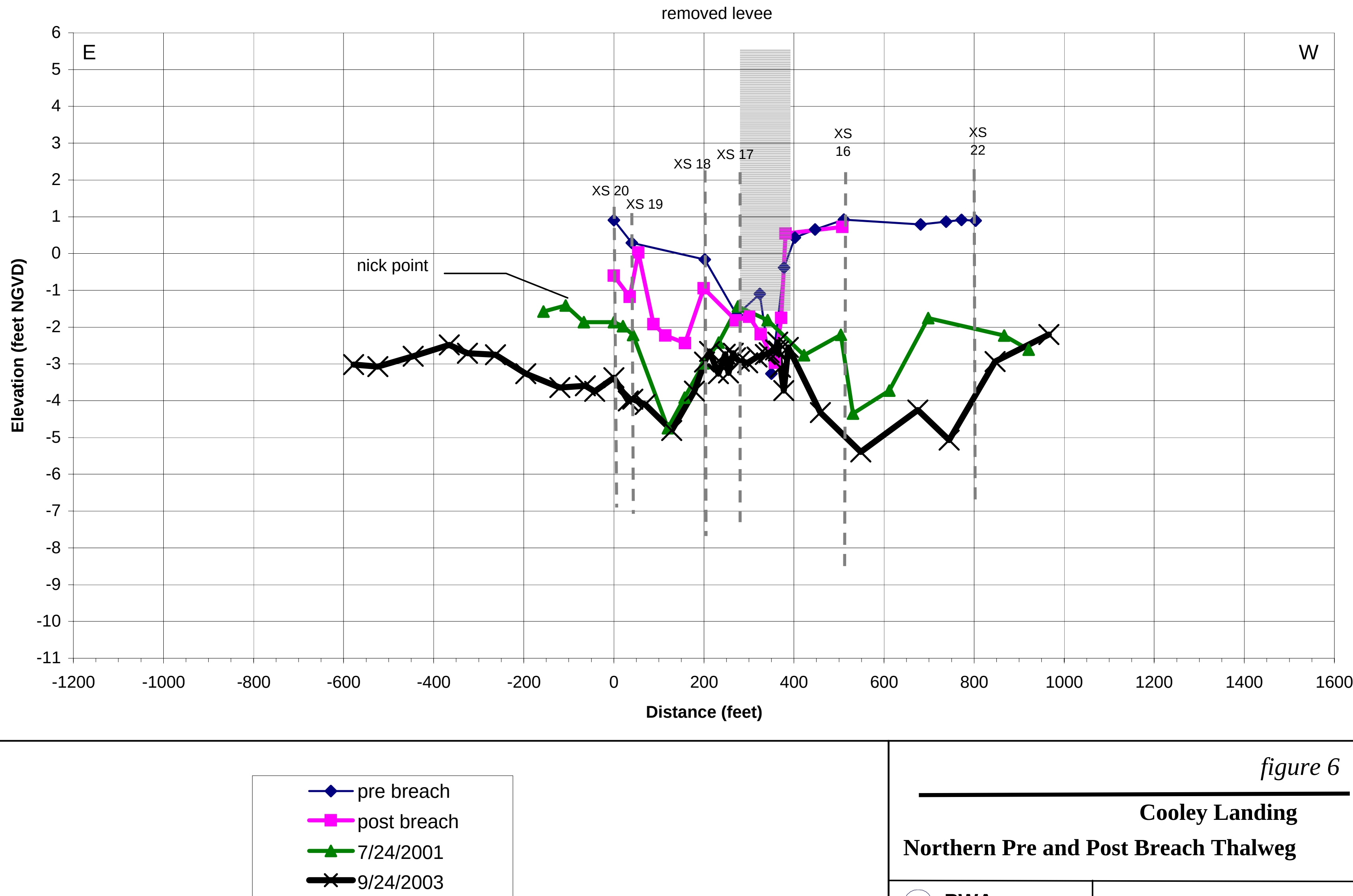


figure 6

Cooley Landing

Northern Pre and Post Breach Thalweg

PWA

PWA#: 1690

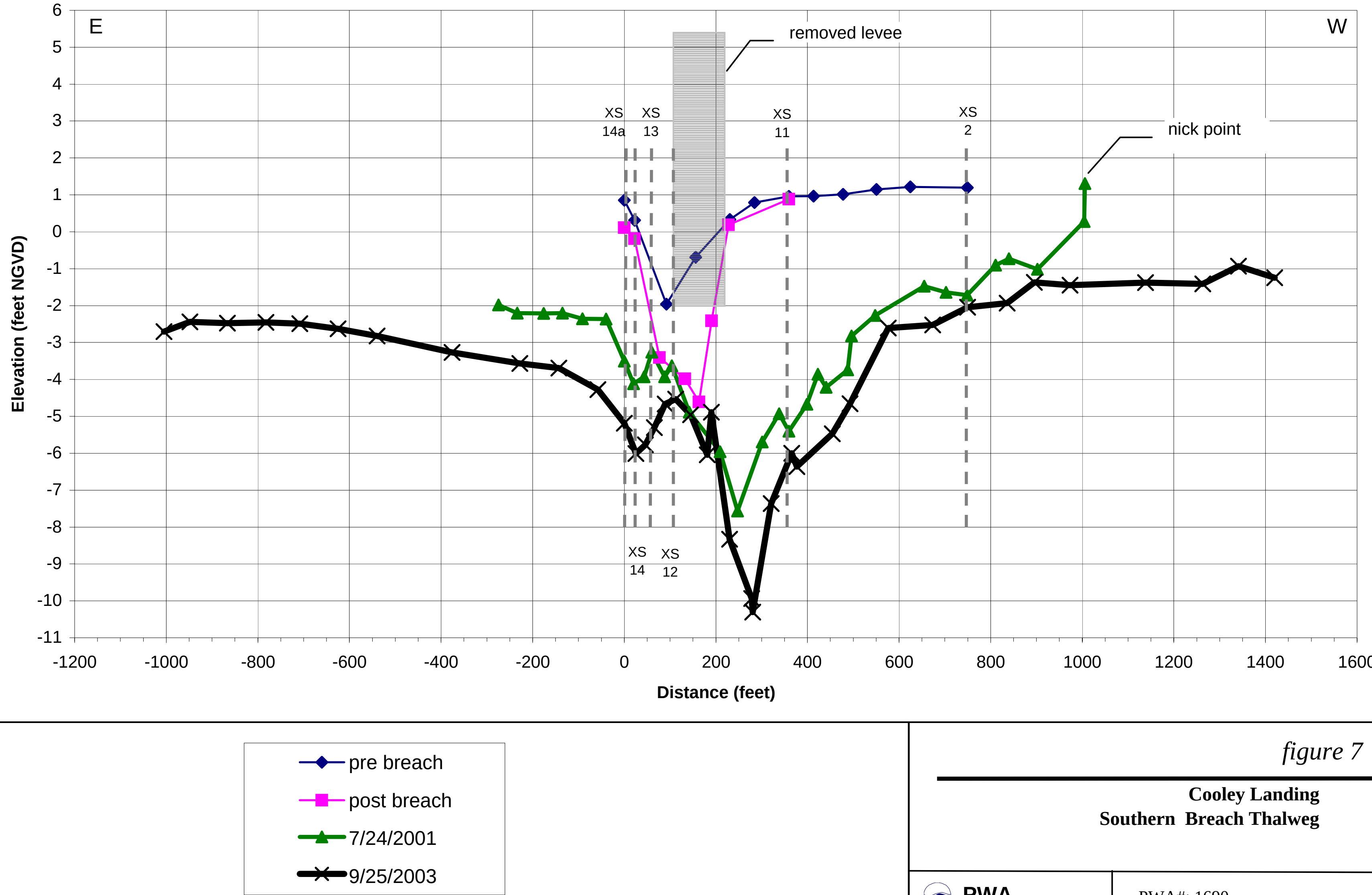


figure 7

Cooley Landing
Southern Breach Thalweg

PWA PWA#: 1690

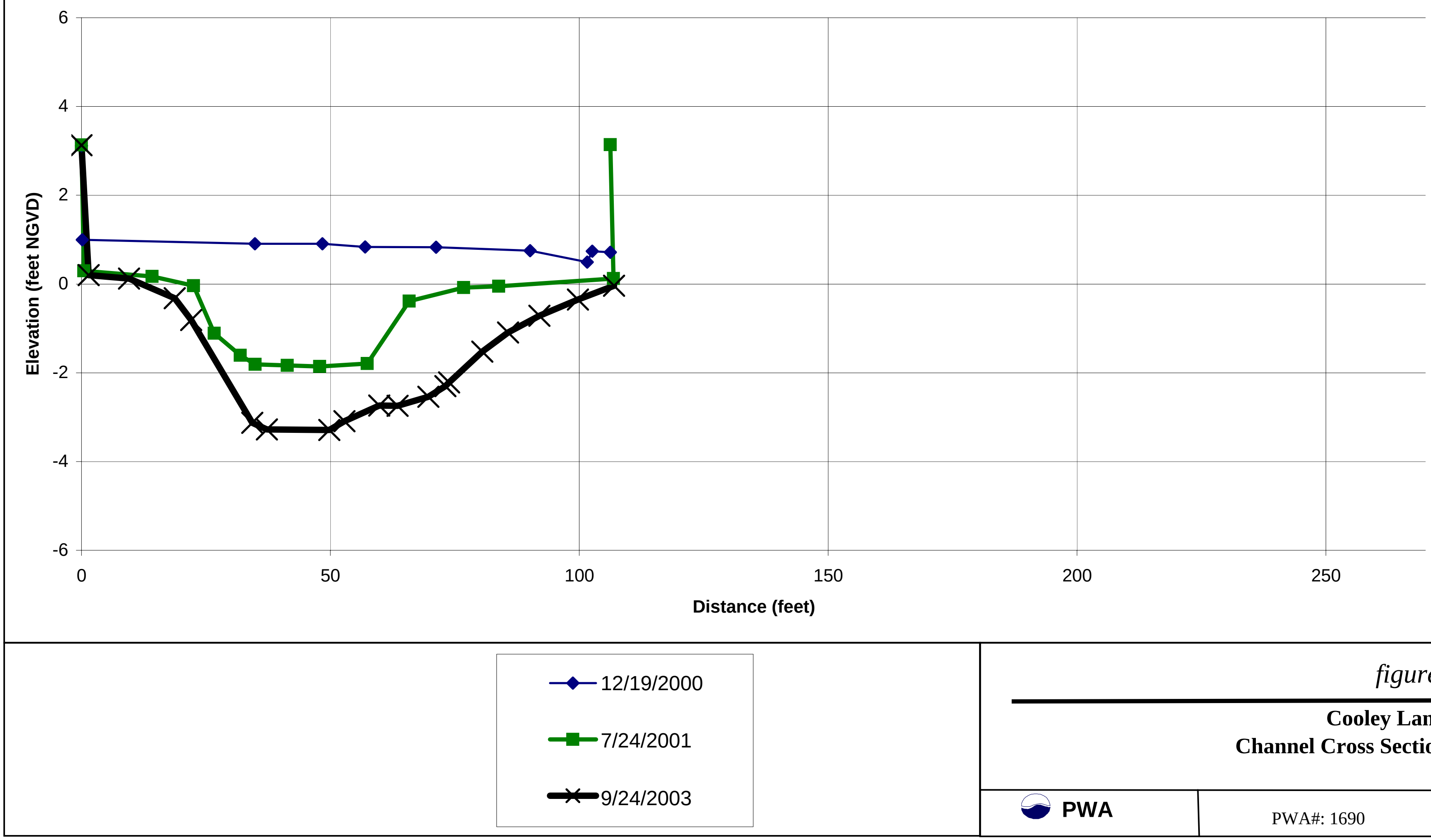


figure 8

Cooley Landing
Channel Cross Section 20

PWA

PWA#: 1690

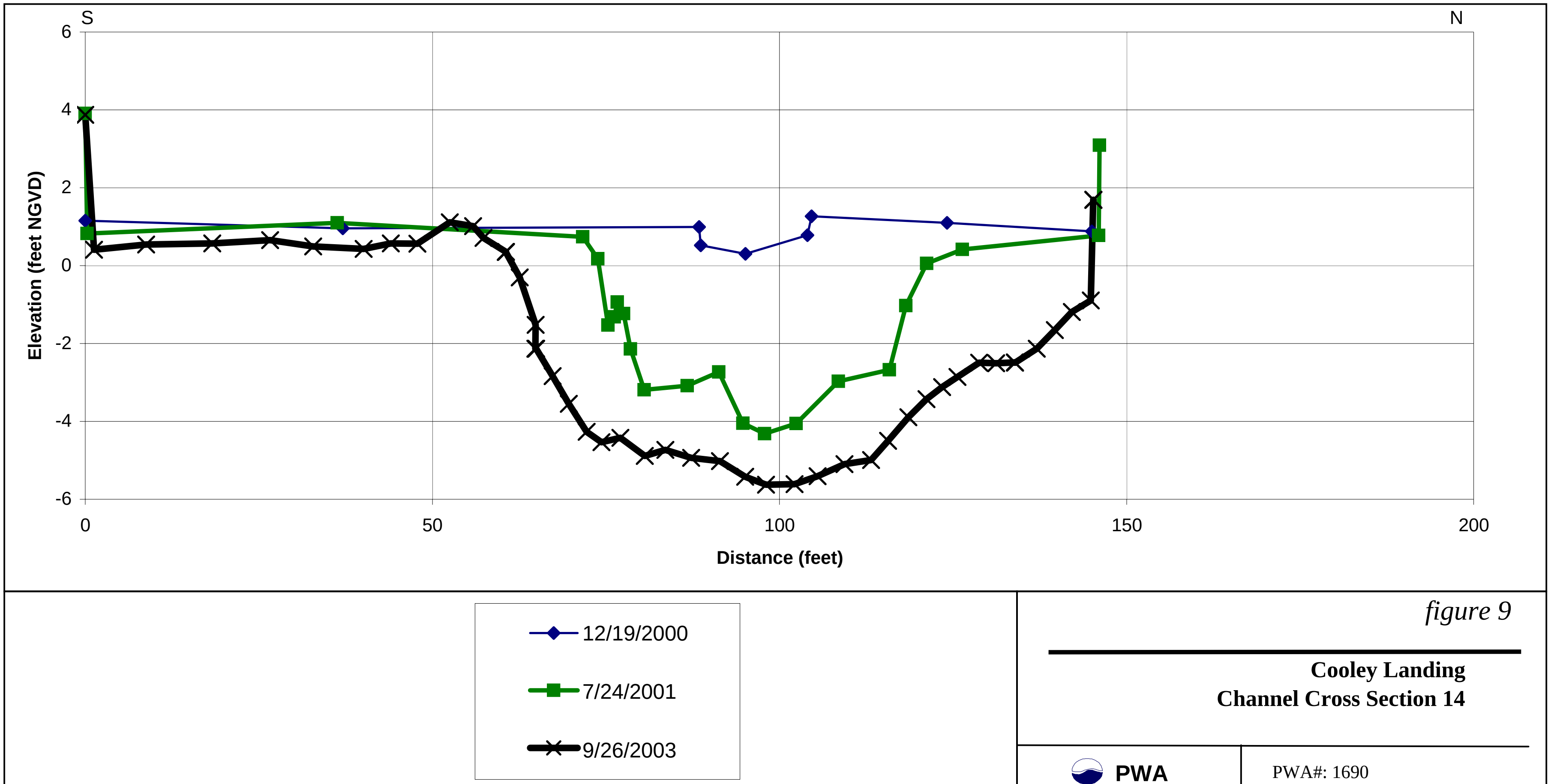


figure 9

Cooley Landing
Channel Cross Section 14

PWA

PWA#: 1690

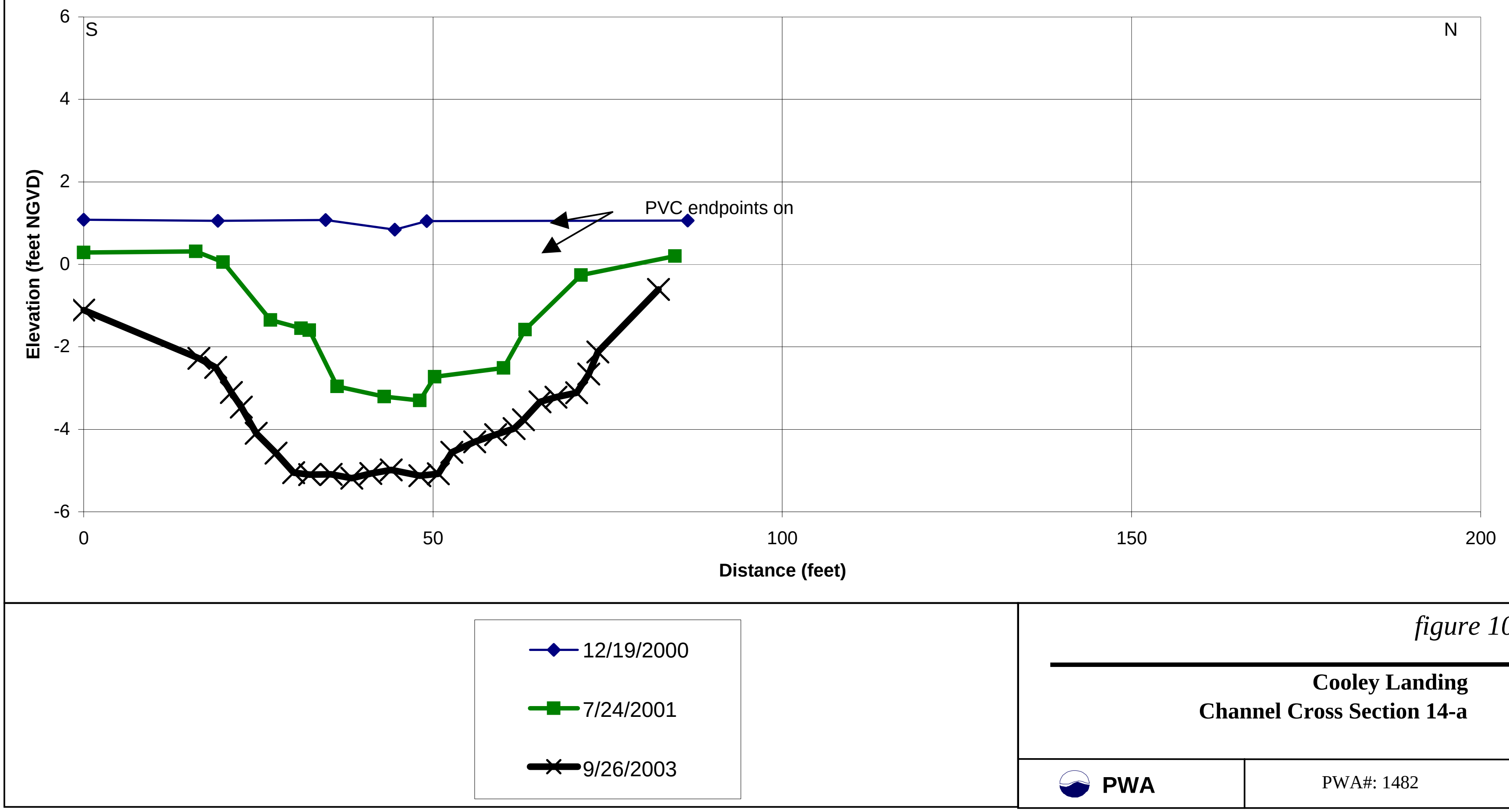
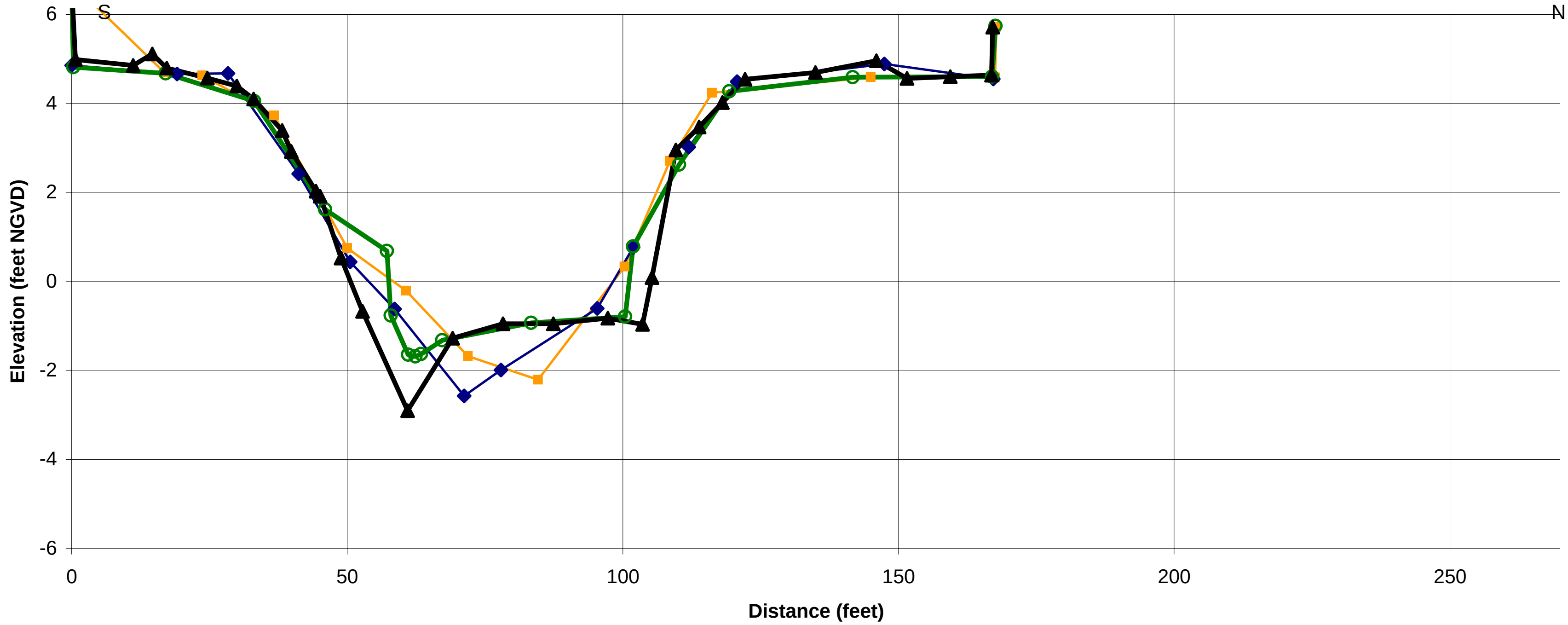


figure 10

Cooley Landing
Channel Cross Section 14-a

PWA

PWA#: 1482



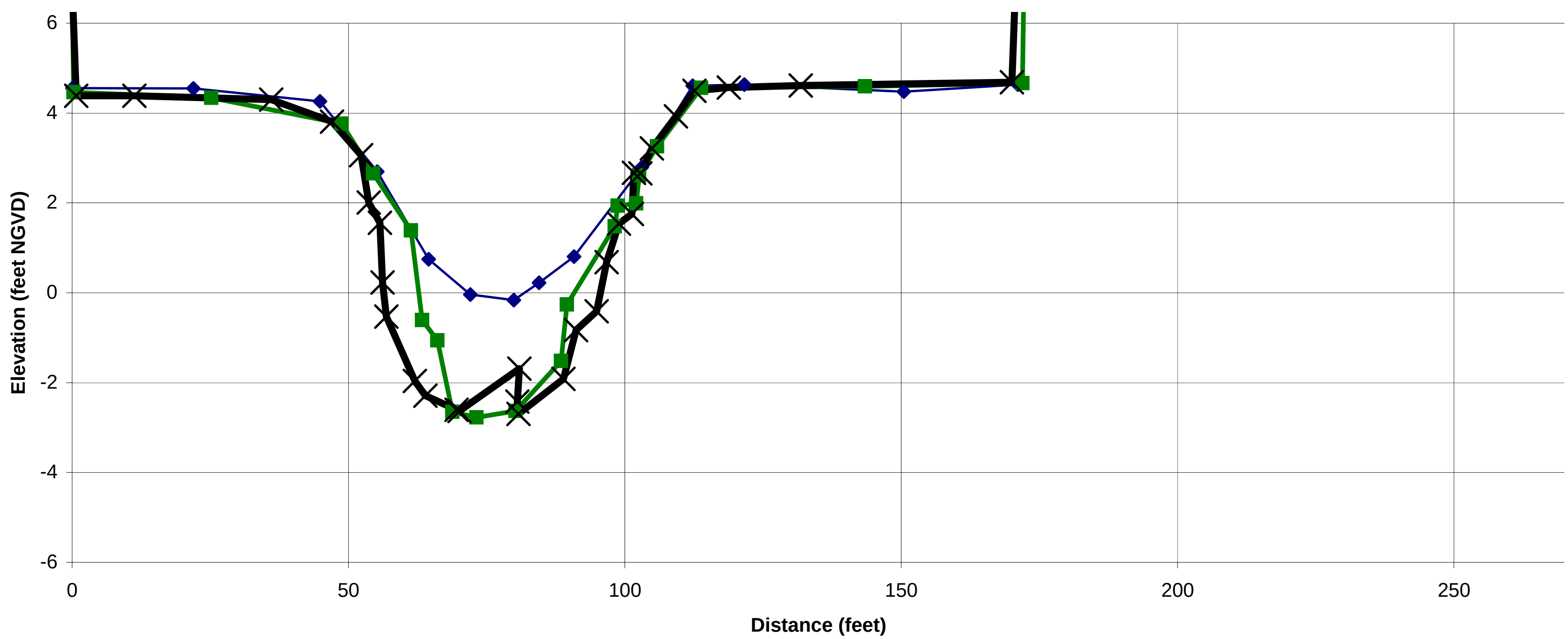
12/18/2000
1/5/2001
7/24/2001
9/24/2003

figure 11

Cooley Landing, Post Breach
Channel Cross Section 17

PWA

PWA#: 1690



12/19/2000
7/24/2001
9/24/2003

figure 12

Cooley Landing
Channel Cross Section 18

PWA

PWA#: 1690

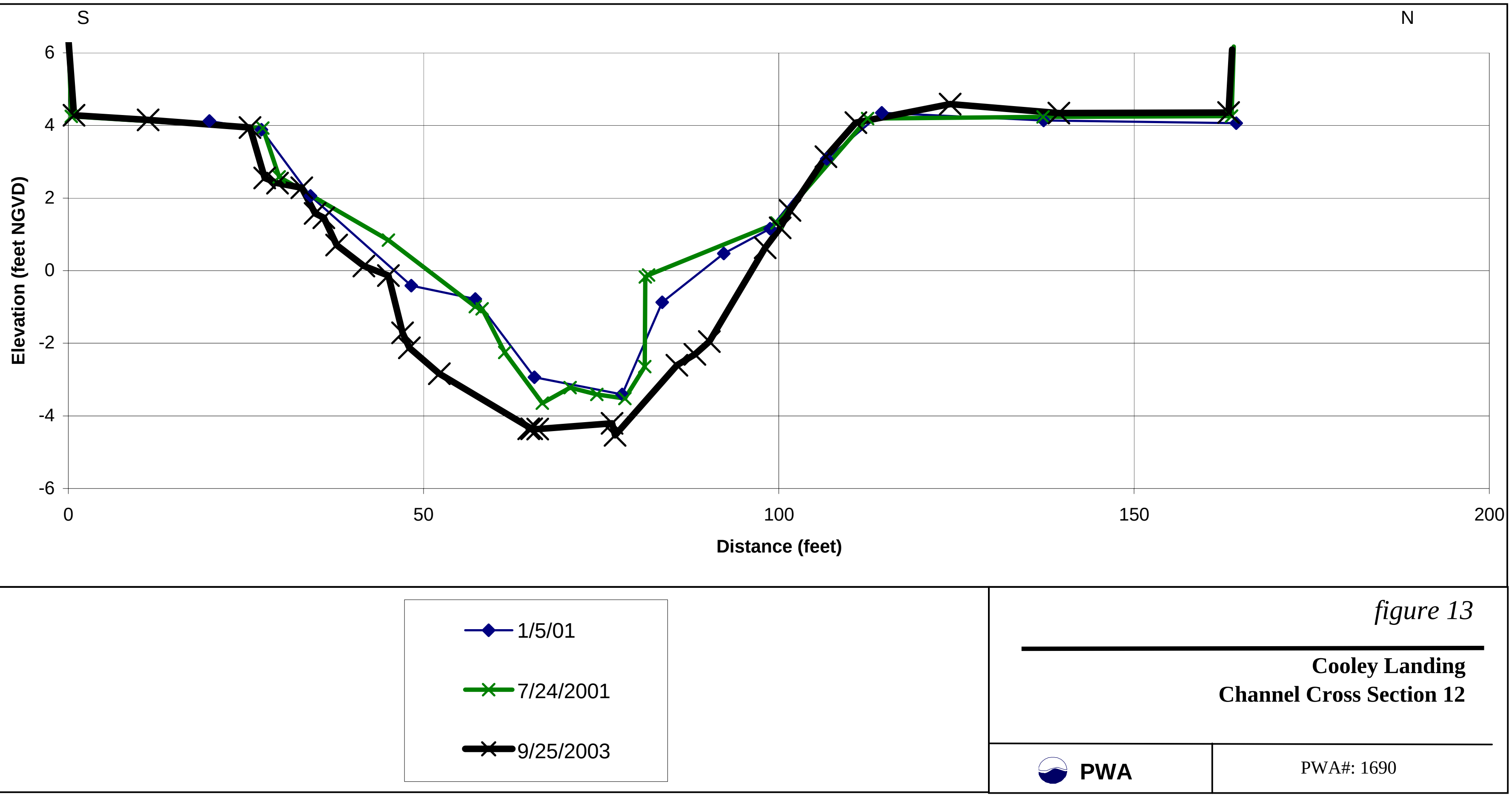


figure 13

Cooley Landing
Channel Cross Section 12

PWA

PWA#: 1690

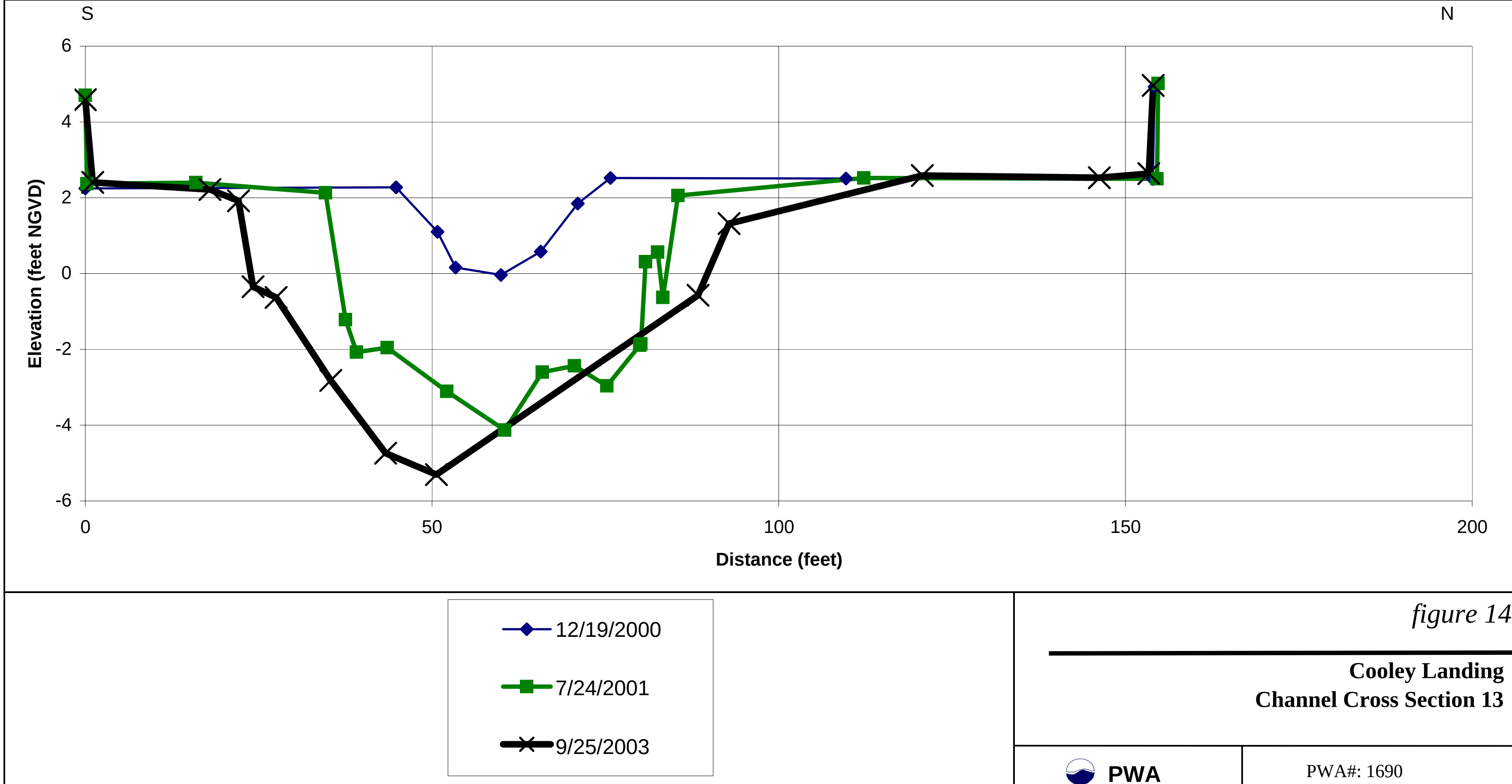


figure 14

Cooley Landing
Channel Cross Section 13

PWA

PWA#: 1690

Figure 15. North breach channel.

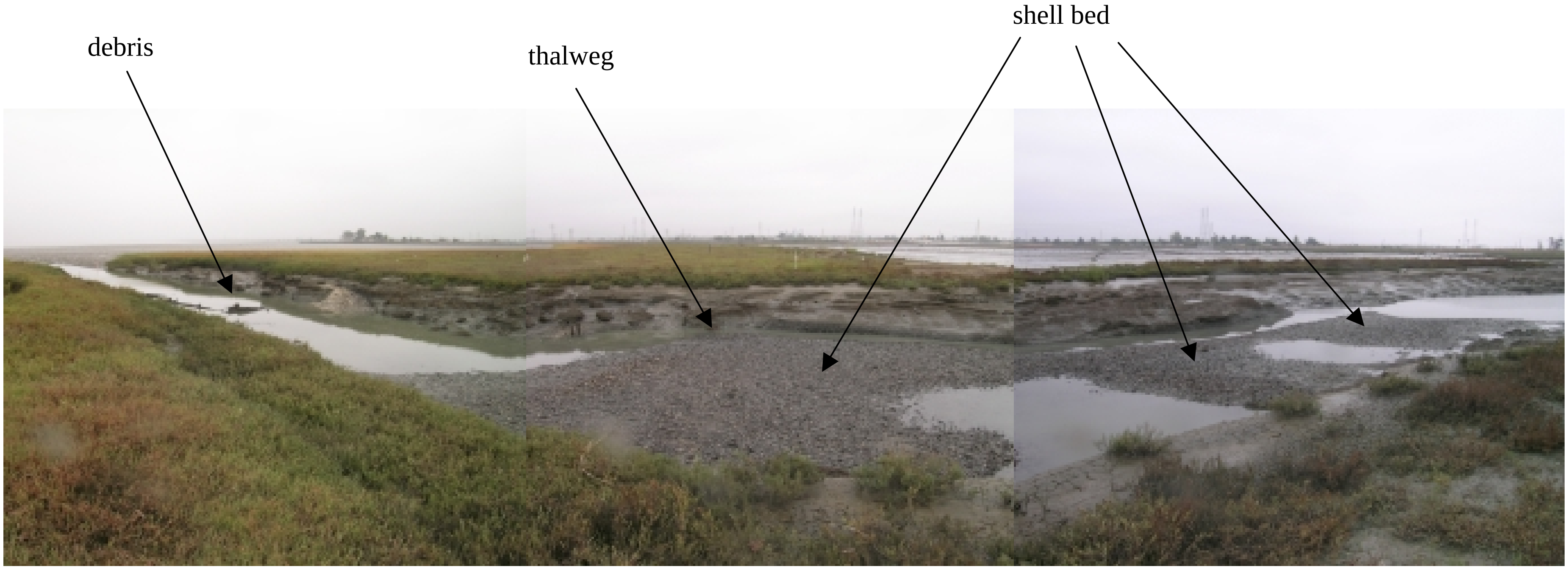
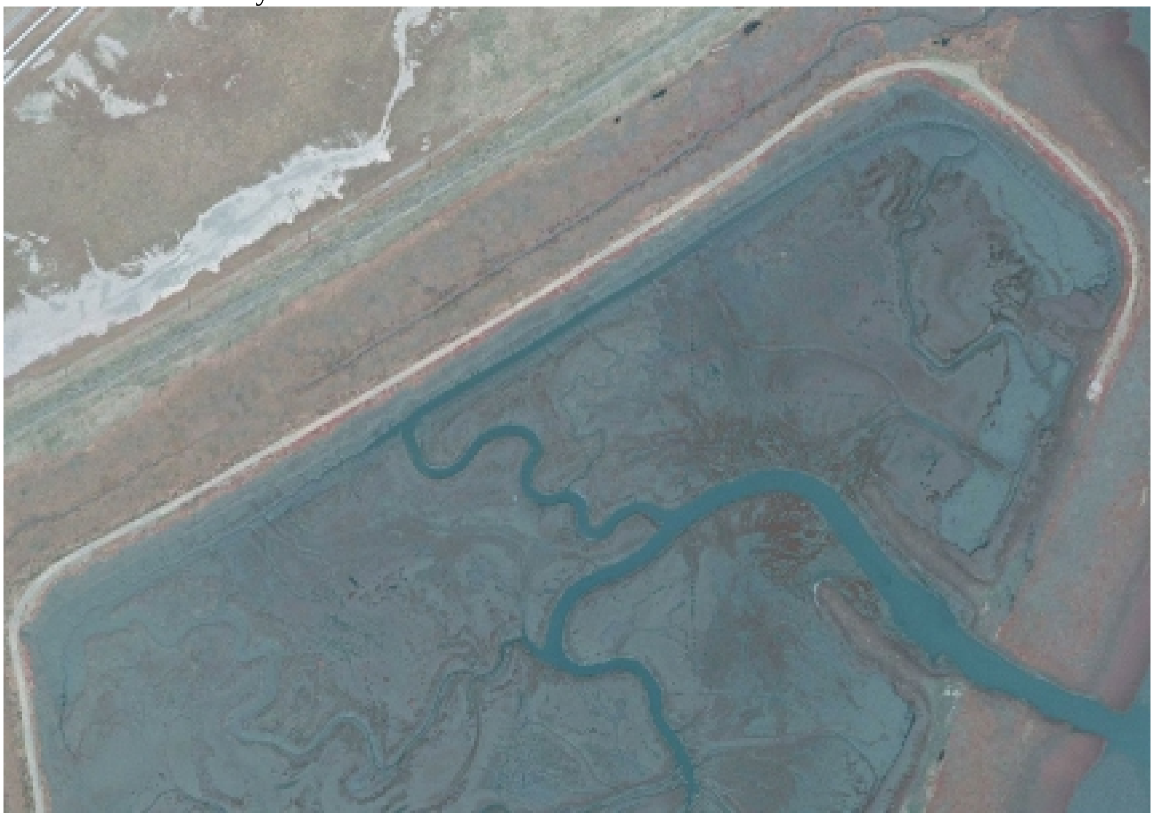
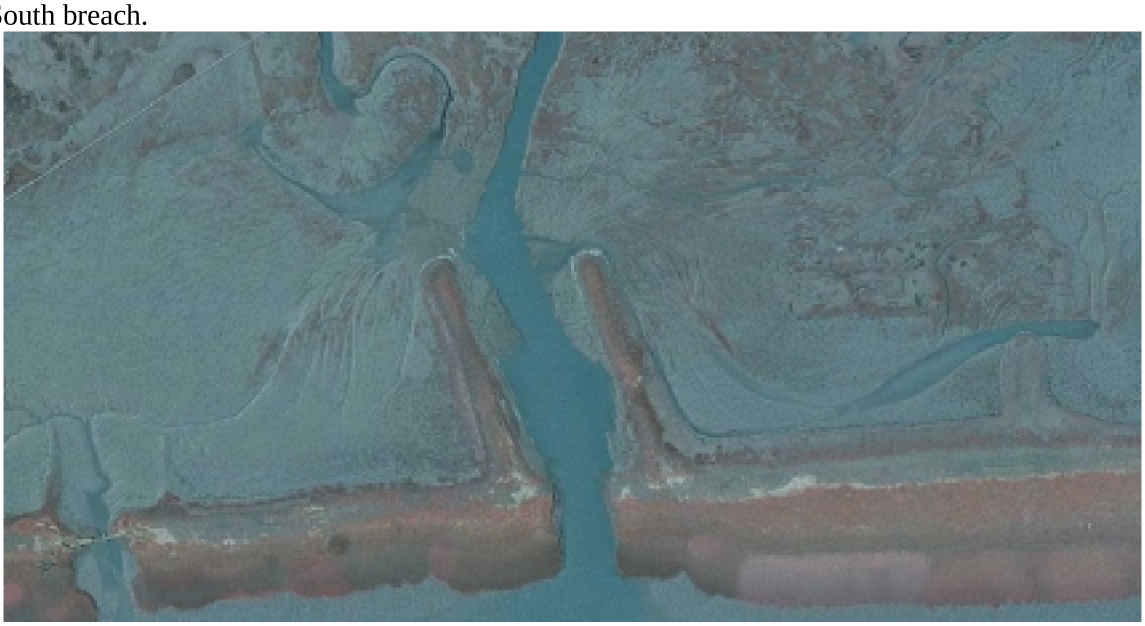


Figure 16. Aerail photograph details (9/22/03).

a) Northeast site boundary.



b) South breach.



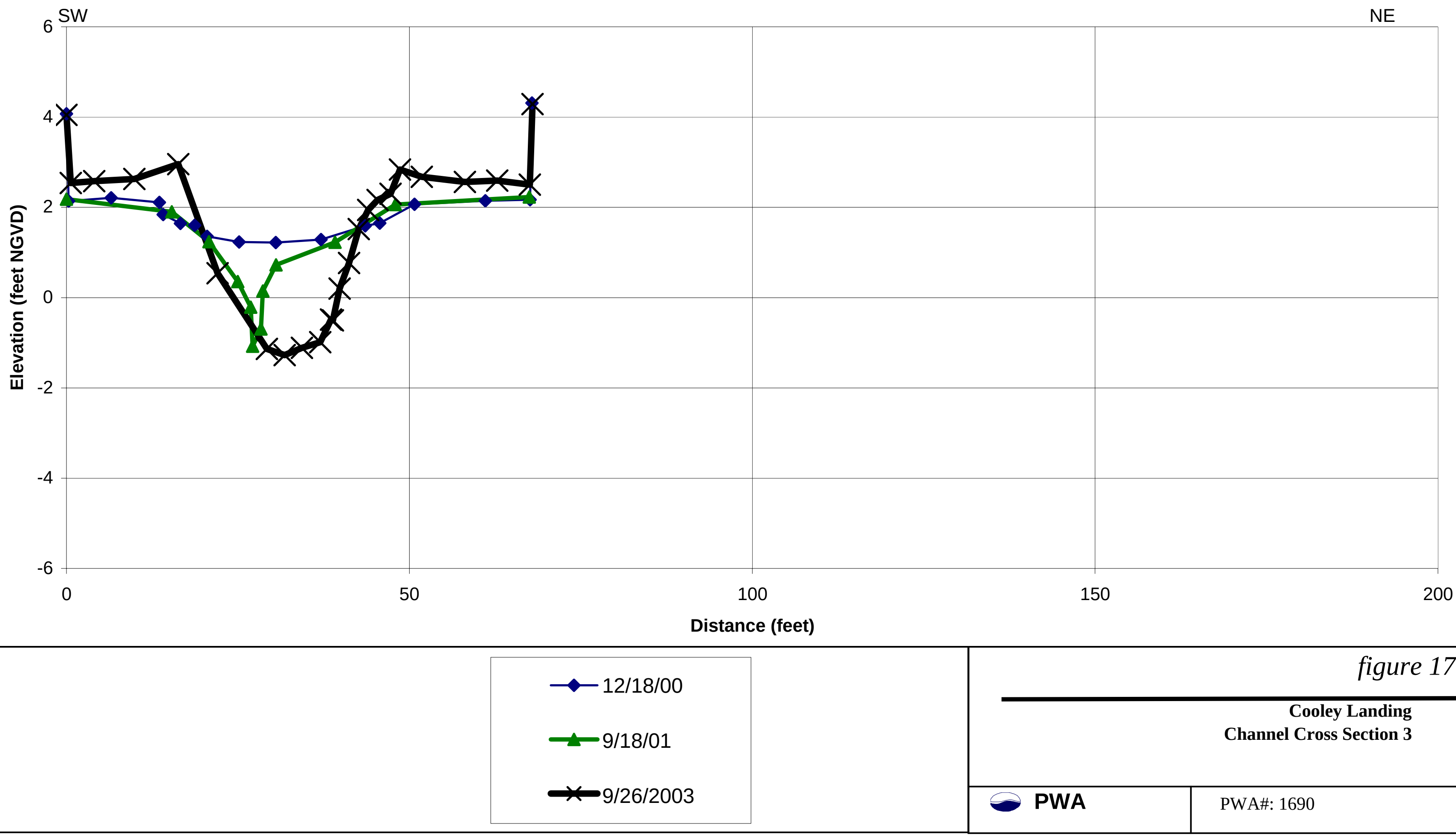


figure 17

Cooley Landing
Channel Cross Section 3

PWA

PWA#: 1690

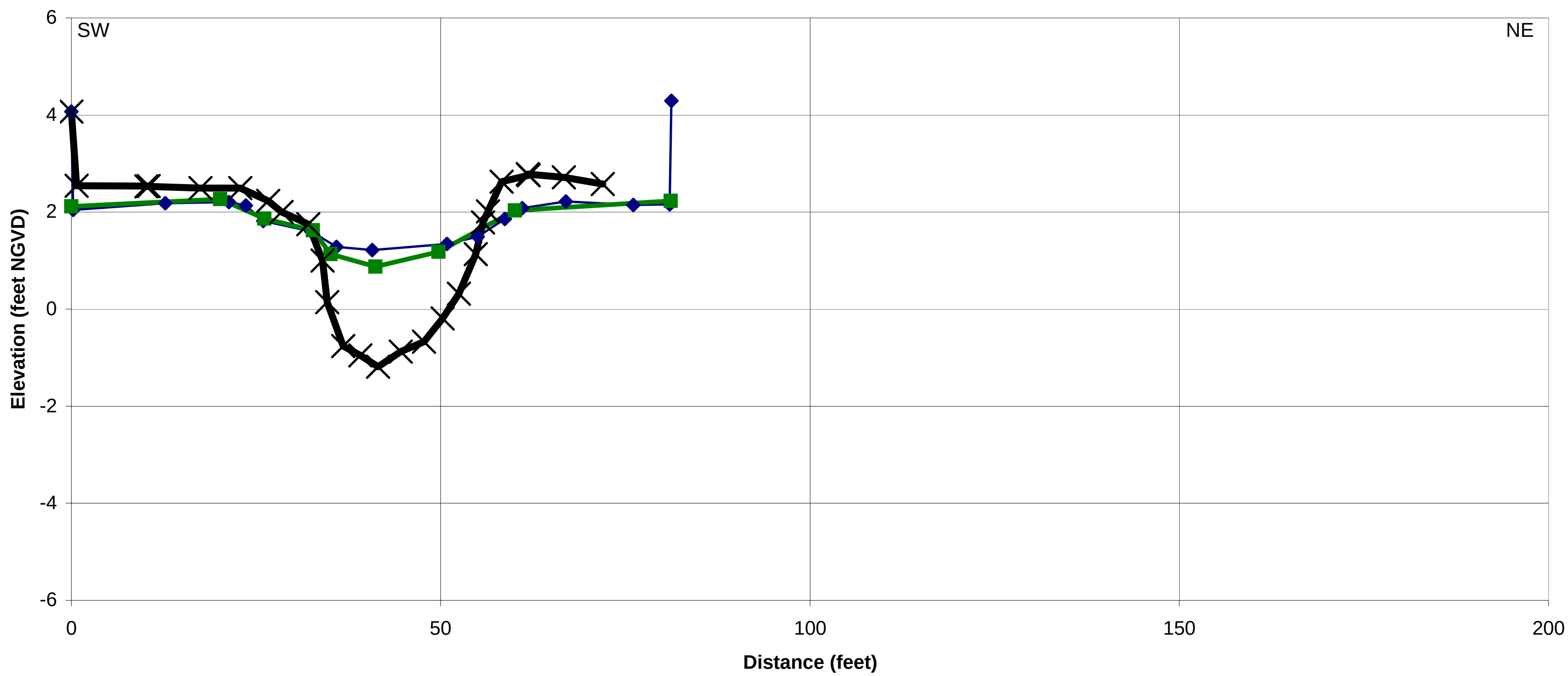


figure 18

Cooley Landing
Channel Cross Section 4

PWA

PWA#: 1690

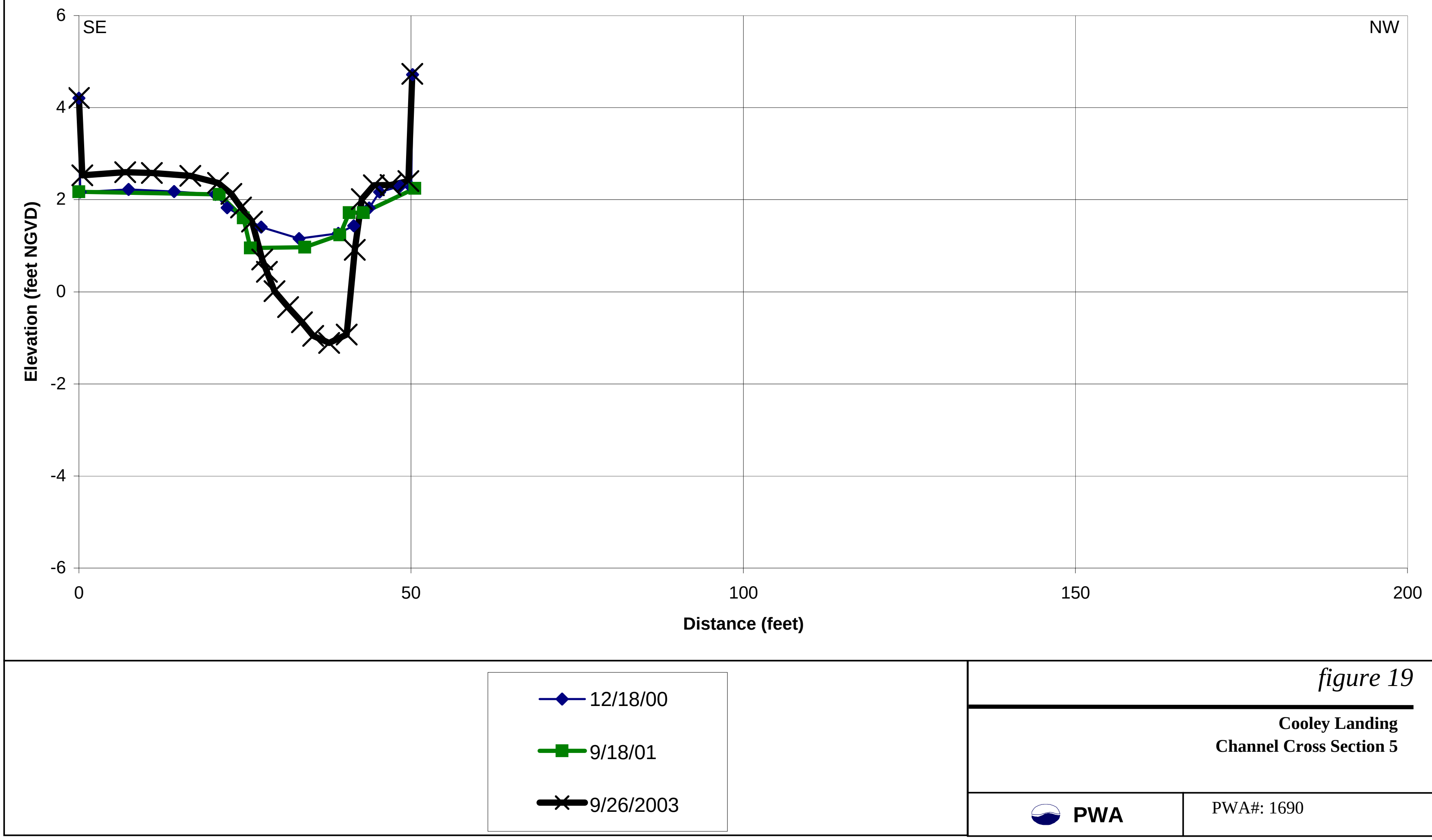


figure 19

Cooley Landing
Channel Cross Section 5

PWA

PWA#: 1690

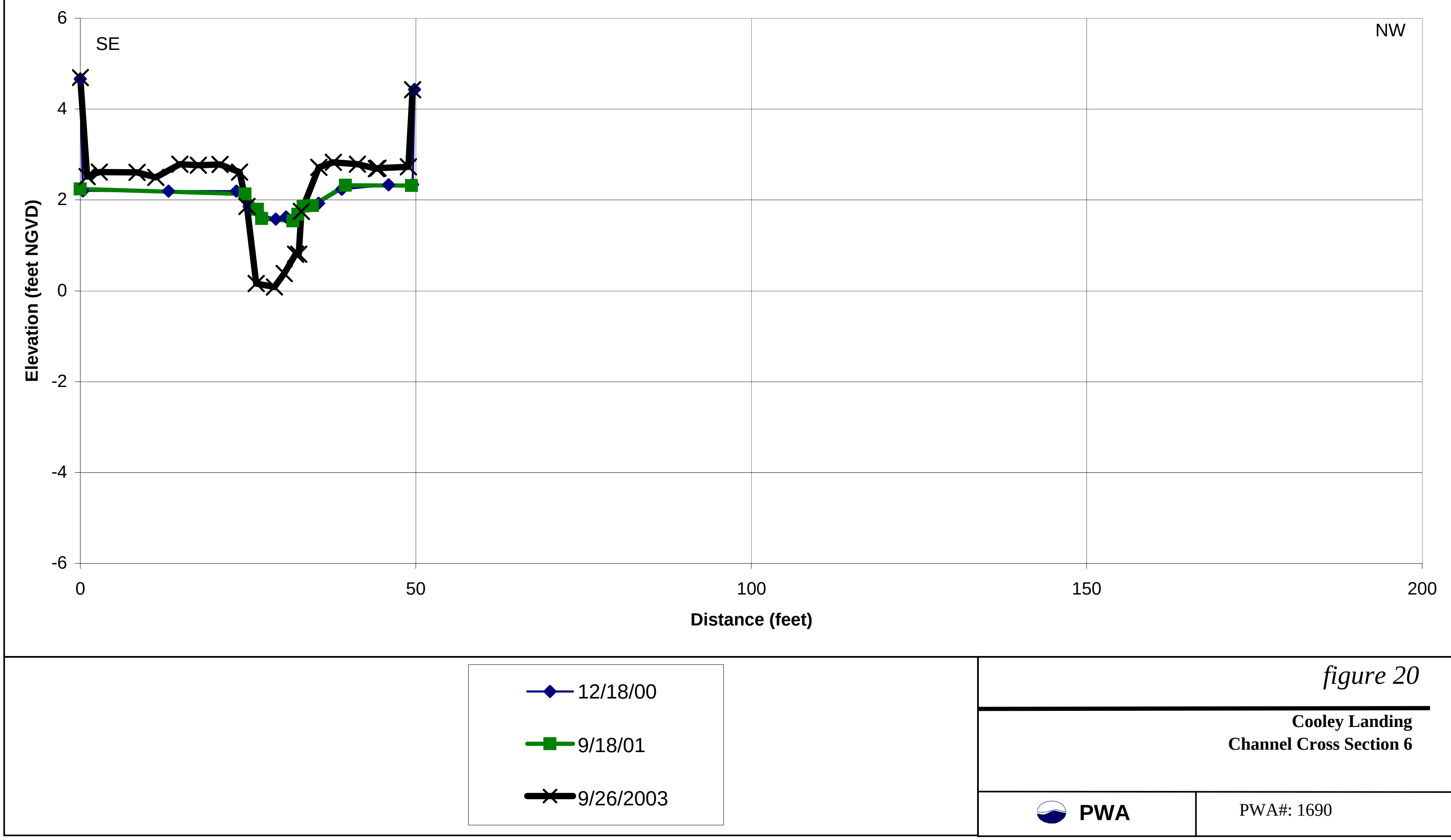


figure 20

Cooley Landing
Channel Cross Section 6

PWA

PWA#: 1690

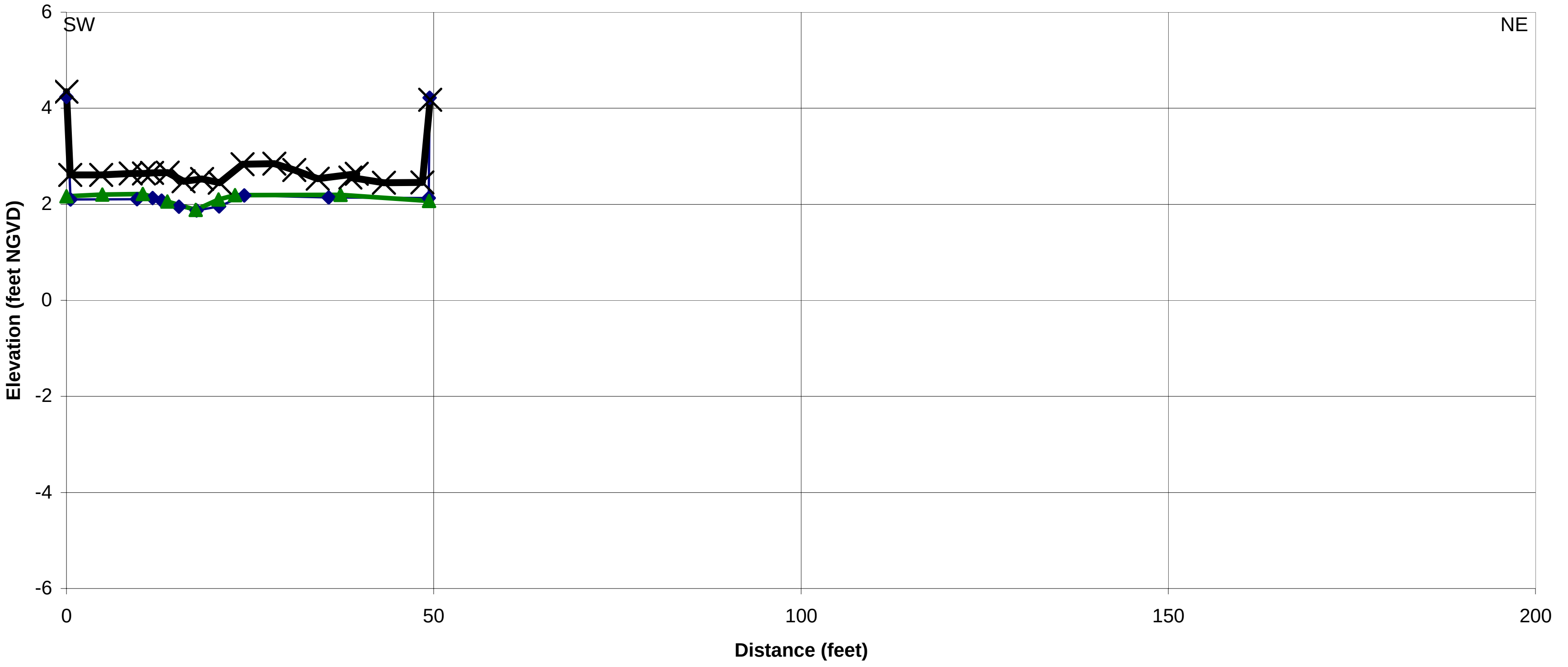


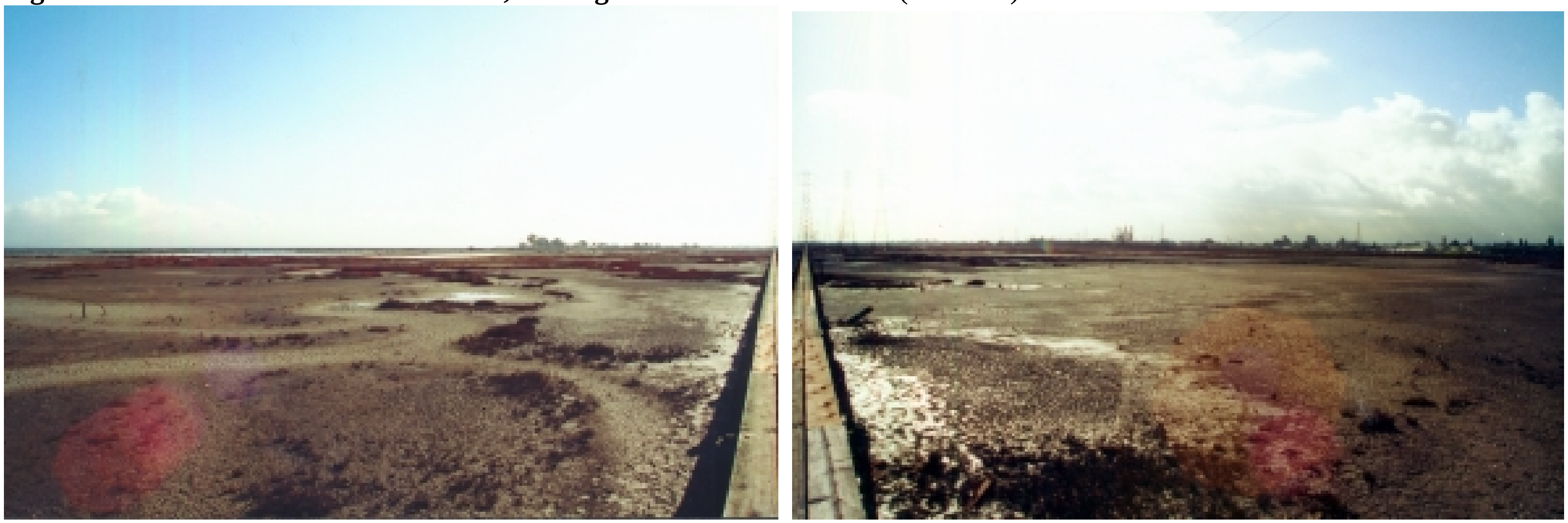
figure 21

Cooley Landing
Channel Cross Section 7

PWA

PWA#: 1690

Figure 22. North-west end of boardwalk, looking south-east. Pre-Breach (12/12/00)



Year 3 (9/27/03)

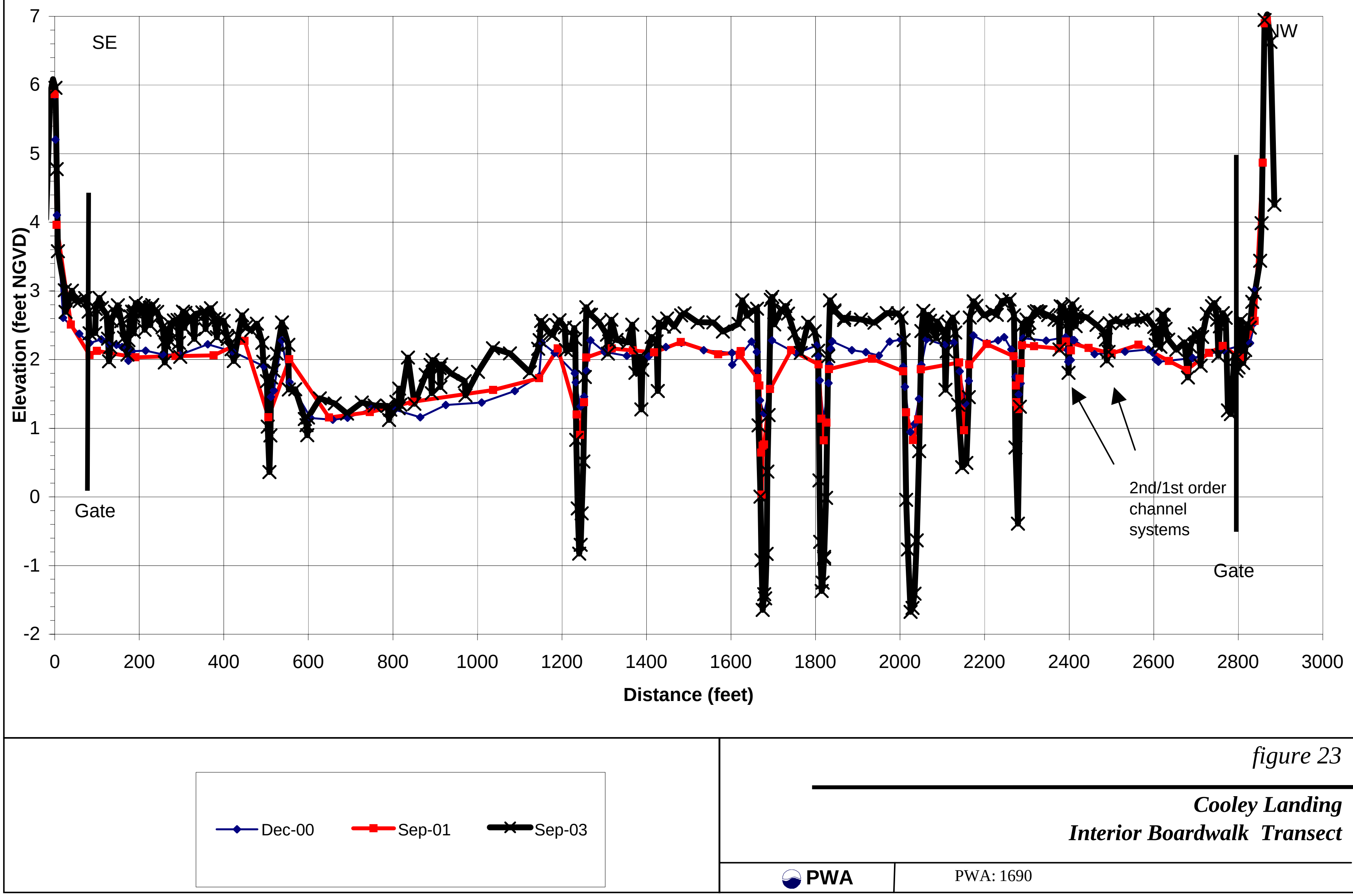


figure 23

Cooley Landing
Interior Boardwalk Transect

PWA

PWA: 1690

Figure 24. Outboard levee and south training berm of south breach. Post-breach (1/17/01)

Year 3 (9/27/03)

Figure 25. Tip of south channel training berm of south breach looking west.

Post-Breach (1/17/01)

Year 3 (9/27/03)

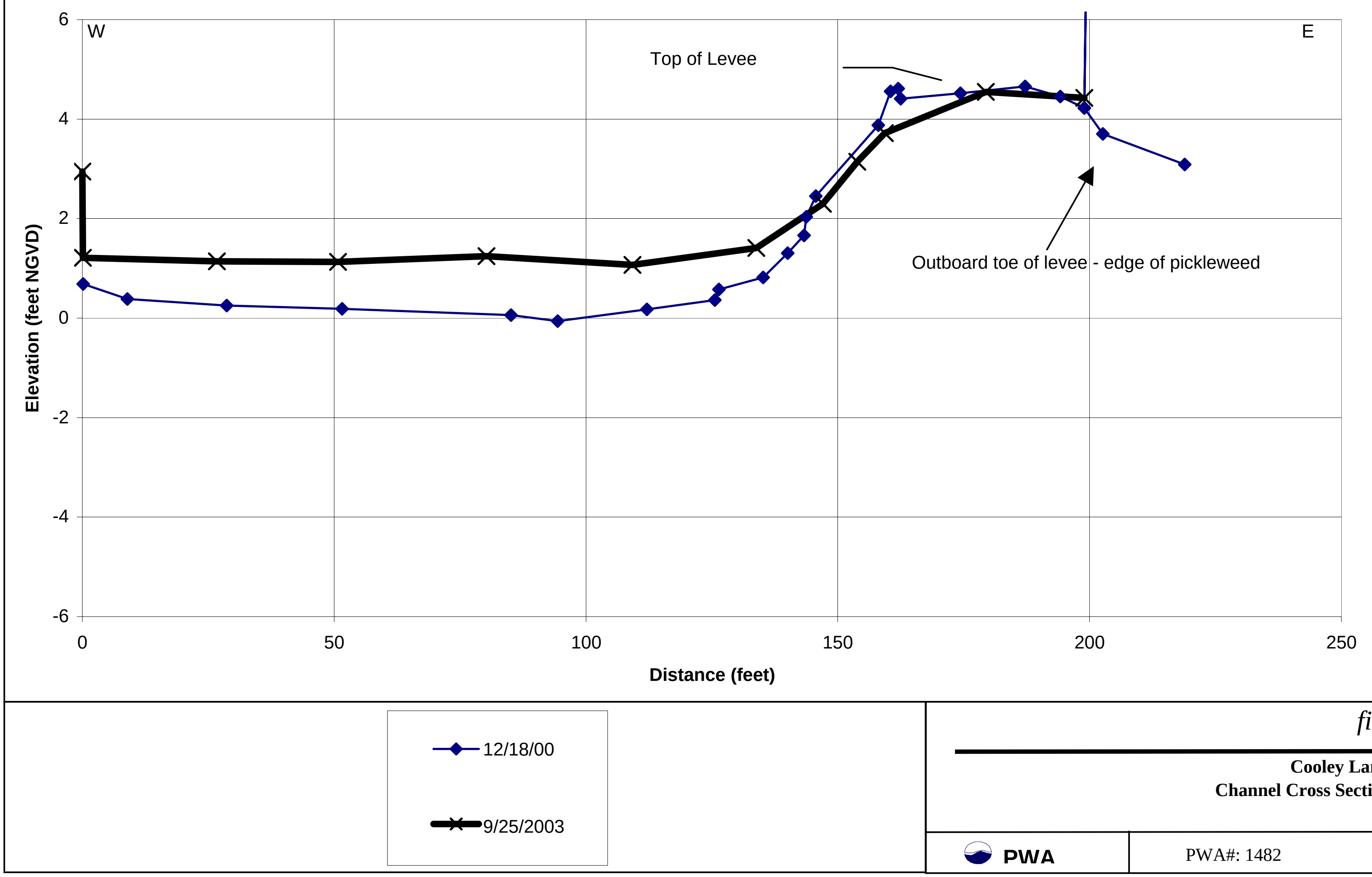


figure 26

Cooley Landing
Channel Cross Section 10

PWA

PWA#: 1482

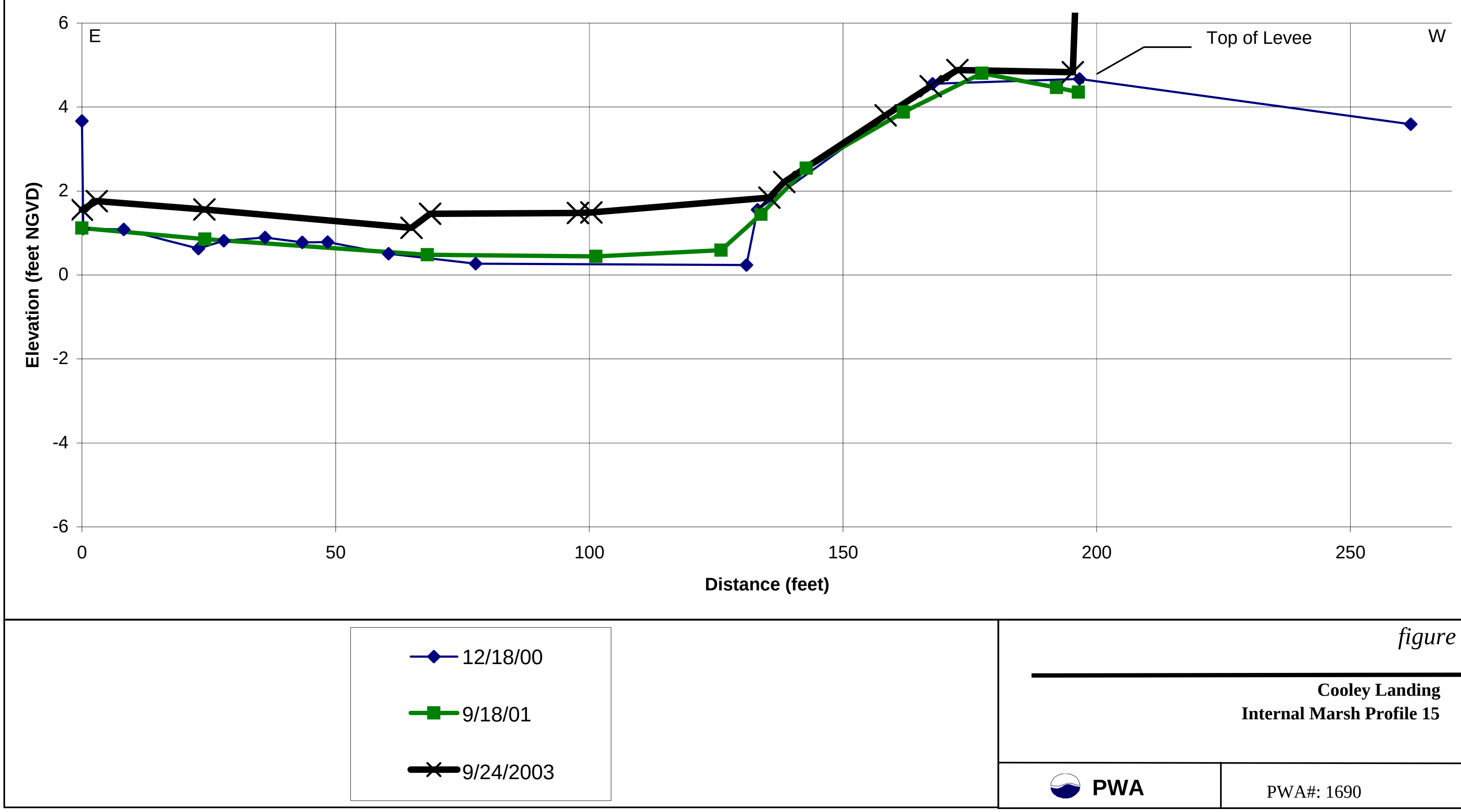


figure 27

Cooley Landing
Internal Marsh Profile 15

PWA

PWA#: 1690

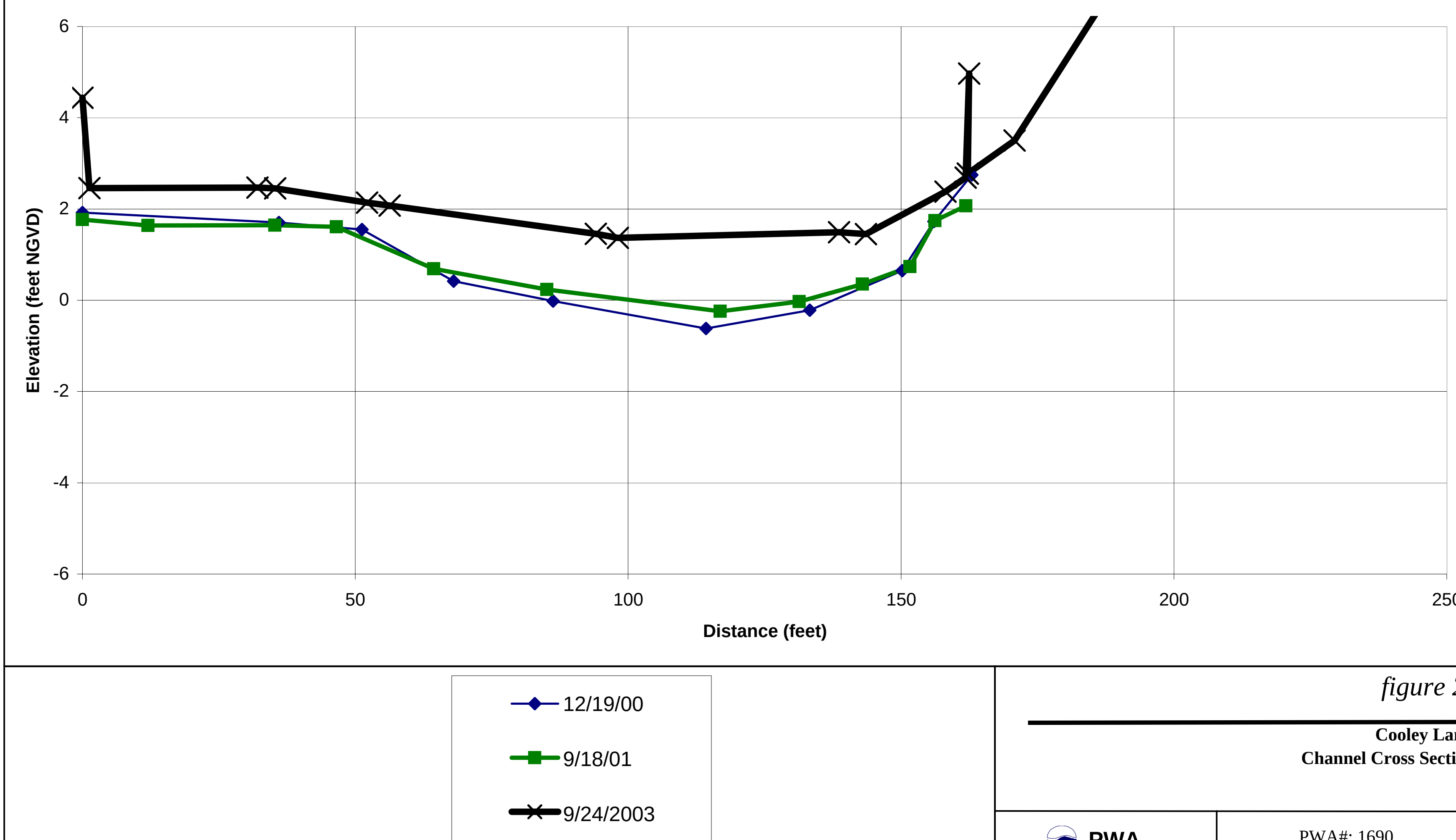


figure 28

Cooley Landing
Channel Cross Section 21

PWA

PWA#: 1690

Figure 29. Surveyed water surface elevations and predicted tide levels.