10-2002

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by

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A Technical Report Obtained Under
Contract with
The Virginia Department of
Conservation and Recreation
for
The Board on Conservation and Development
of Public Beaches
and
the Town of Colonial Beach

October 2002

EXECUTIVE SUMMARY

The Town of Colonial Beach occupies a peninsula between the Potomac River and Monroe Bay and has approximately 2.5 miles of publicly-owned shoreline. Two areas on the Potomac River have been enhanced as recreational beaches for swimming and sunbathing. Central Beach is located just south of the Town Pier and is the main recreational beach. Castlewood Beach is south of Central Beach near the entrance to Monroe Bay.

In 1982, breakwater and beach fill systems were completed at Central and Castlewood beaches. Four gapped breakwaters were constructed at Central Beach, and 50,000 cubic yards of sand was placed. At Castlewood Beach, three gapped breakwaters and 16,000 cubic yards of sand were placed, and a terminal groin was constructed to reduce shoaling in the entrance channel to Monroe Bay.

The purpose of this report is to document the recent history of Colonial Beach's Potomac River shoreline as well as assess the historical shoreline evolution and status of the beach zone. Review of previously-published literature, field survey data, aerial photos, and computer modeling were used to address the study objectives.

In order to quantify the general wave climate acting upon the Colonial Beach shoreline and to provide our wave refraction model with reasonable incident wave conditions, it was necessary to evaluate the local wind/wave climate using wind data from nearby Quantico. These data are used to determine effective fetch for each grid and are input to the SMB program which provides wave height and period for a suite of wind speeds and water levels of the project shore.

The predicted wave heights and periods for the four subject directions (N, NE, E, and SE) are used as input to the hydrodynamic model, RCPWAVE. RCPWAVE takes a simulated incident wave condition at the seaward boundary of the grid and allows it to propagate shoreward across the nearshore bathymetry. The results of the RCPWAVE analysis are wave vector and wave orthogonal plots showing wave attenuation and refraction across the nearshore and shoreline that allow us to determine the net movement of littoral materials.

Vertical aerial photography through time reveal that little beach has existed along Colonial Beach's shore. Since 1937, sandy beaches have only existed in isolated pockets. Various types of shore protection structures were constructed to abate erosion and protect infrastructure as beach width narrowed where it had previously existed. However, after the installation of the breakwaters, stable beaches were created at Central and Castlewood beaches.

Sediment analysis revealed that the native grain size along Colonial Beach's shore was relatively coarse. Recent beach fills at Central have reduced the percent of gravel in each sample and the median grain size at the beach berm and toe. However, at the toe of the beach, the sediment is becoming coarser as the fill material is equilibrated.

Beach profile analysis at Central Beach revealed a stable, protective beach. Measured change occurred behind the breakwaters as the upper berm retreated over the last two years. The permeability of the breakwaters does not allow full highwater attachment of a tombolo. However, net change between 1998 and 2002 indicates that the tombolo berm is closer to the breakwater than it was and that overall, the embayments have retreated toward equilibrium.

The change in the state of the beach at both Central Beach and Castlewood beach has been marked. Wide, usable, protective, stable recreational beaches have been created. The town shoreline north of Central Beach, the proposed area of redevelopment by the Town has been relatively stable in recent years thanks in part to the stability created by the breakwaters and beach fill at Central Beach which has "pinned" its south boundary and prevented sand loss down river.

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I. INTRODUCTION

A. Background and Purpose

The Town of Colonial Beach occupies a peninsula between the Potomac River and Monroe Bay (Figure 1). Approximately 2.5 miles of the shoreline is publicly-owned. Two areas on the Potomac River have been enhanced as recreational beaches for swimming and sunbathing. Central Beach is located just south of the Town Pier and is the main recreational beach. Castlewood Beach is south of Central Beach near the entrance to Monroe Bay

In 1982, breakwater and beach fill systems were completed to abate erosion and restore the beach along the Town's shoreline. Four gapped breakwaters were constructed at Central Beach, and 50,000 cubic yards of sand was placed as part of an U.S. Army Corps of Engineers shore project. At Castlewood Beach, three gapped breakwaters and 16,000 cubic yards of sand were placed, and a terminal groin was constructed to reduce shoaling in the entrance channel to Monroe Bay. Sections of the shoreline had a rock revetment placed along it by 1986. A project in 1989 called for 1,250 cubic yards of sand, breakwater maintenance, and cleanup and removal of small rocks from the river bed at the toe of the beach at Central Beach. In the fall of 1992, the Town, in conjunction with the U.S. Army Corps of Engineers replenished Central Beach with 11,200 cy of sand. In the mid-1990s, the Virginia Department of Transportation put in additional riprap revetment along a large section of Colonial Beach's shoreline. Prior to that, a mix of different types of materials had been placed along the shore to abate erosion. In 1998, approximately 2,100 cubic yards of sand was place primarily on Central Beach with some on Castlewood. Again in the winter of 1999, more sand was placed on Central and Castlewood Beaches.

The purpose of this report is to document the recent history of Colonial Beach's Potomac River shoreline as well as assess the historical shoreline evolution and status of the beach zone. Integrating an understanding of recent anthropogenic impacts with long-term change provide a detailed picture of how this shoreline is evolving. It also provides a means to determine the effectiveness of management strategies employed along this stretch of shore.

B. Scope of Study

Specific shore change is addressed at Central Beach through recent beach profiles. However, much of the Town's Potomac River shore is considered for shore change and management issues. In addition, at the Town's request, an analysis was performed on beach fill template data from the original beach and breakwater project and profile data taken after project installation at Central Beach. The purpose of that analysis was to determine the change in sand volume between the template, after the project was installed and in recent years. The report and data provided to the U.S. Army Corps of Engineers is in Appendix I.

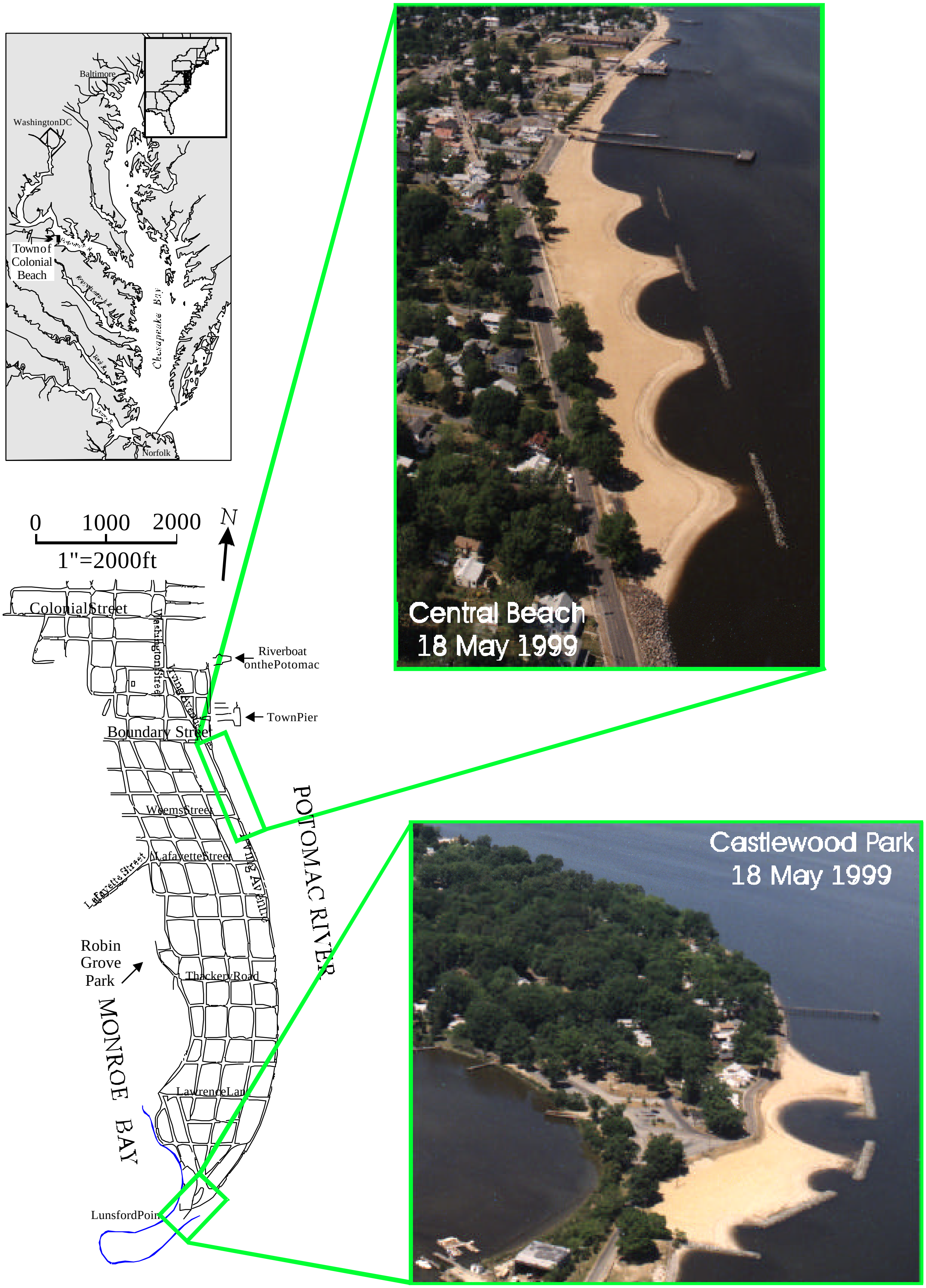


Figure 1. Location of Central and Castlewood Beaches along the Town of Colonial Beach's shore.

C. Approach and Methodology

Review of previously-published literature, field survey data, aerial photos, and computer modeling were used to address the study objectives. Personnel at VIMS began monitoring Central Beach in April 1998 (Table 1). Eighteen profiles were established along the shore and are monitored semi-annually (Figure 2). The profile terminology used in this report is demonstrated in Figure 3. Historic and recent aerial images were used to evaluate changes in shoreline conditions through time.

Table 1. Beach profile data available for Central Beach in Colonial Beach.

Date	Survey Number	Profile Number	Comments
30 April 1998	100	1,3,5,7,9,11,13,15,17	Post-Twin Northeaster
26 May 1998	101	1,3,5,7,9,11,13,15,17,18	
28 October 1998	102	1,3,5,7,9,11,13,15,17,18	
23 April 1999	103	1,3,5,7,9,11,13,15,16,17,18	
23 September 1999	104	1,3,5,7,9,11,13,15,17,18	Post-Hurricane Dennis
2 June 2000	105	1,3,5,7,9,11,13,15,17,18	
3 October 2000	106	1-18	
25 June 2001	107	1-18	
19 November 2001	108	1-18	Baseline Reset
12 June 2002	109	1-18	

In order to quantify the general wave climate acting upon the Colonial Beach shoreline and to provide our wave refraction model with reasonable incident wave conditions, it was necessary to evaluate the local wind climate. The long-term wind data for Quantico are applicable at Colonial Beach (Table 2). These data are used to generate a corresponding wave field using procedures developed by Sverdrup and Monk (1947) and Bretschneider (1958) as modified by Kiley (1982). SMB is a shallow water estuarine wind-generated wave prediction model; it generates waves which cross the Potomac River and are directed toward Colonial Beach. The procedure involves the following steps for each grid:

- Determine effective fetch for each grid using procedures outlined in the U.S. Army Corps of Engineers Shore Protection Manual (1984).
- Use the above data as input into the SMB program which provides wave height and period for a suite of wind speeds and water levels.

Effective fetch, a parameter in wind wave growth, was determined for the four directions, north (N), northeast (NE), east (E), and southeast (SE), which are assumed to significantly impact Colonial Beach. The southerly wind field has a significant impact on the Colonial Beach shore, but it was difficult to model numerically. The more oblique the input waves are to the bathymetric contours and the shoreline, the more difficult it is to numerically simulate wave changes across the grid. The wind field evaluation and effective fetch as well as bathymetric

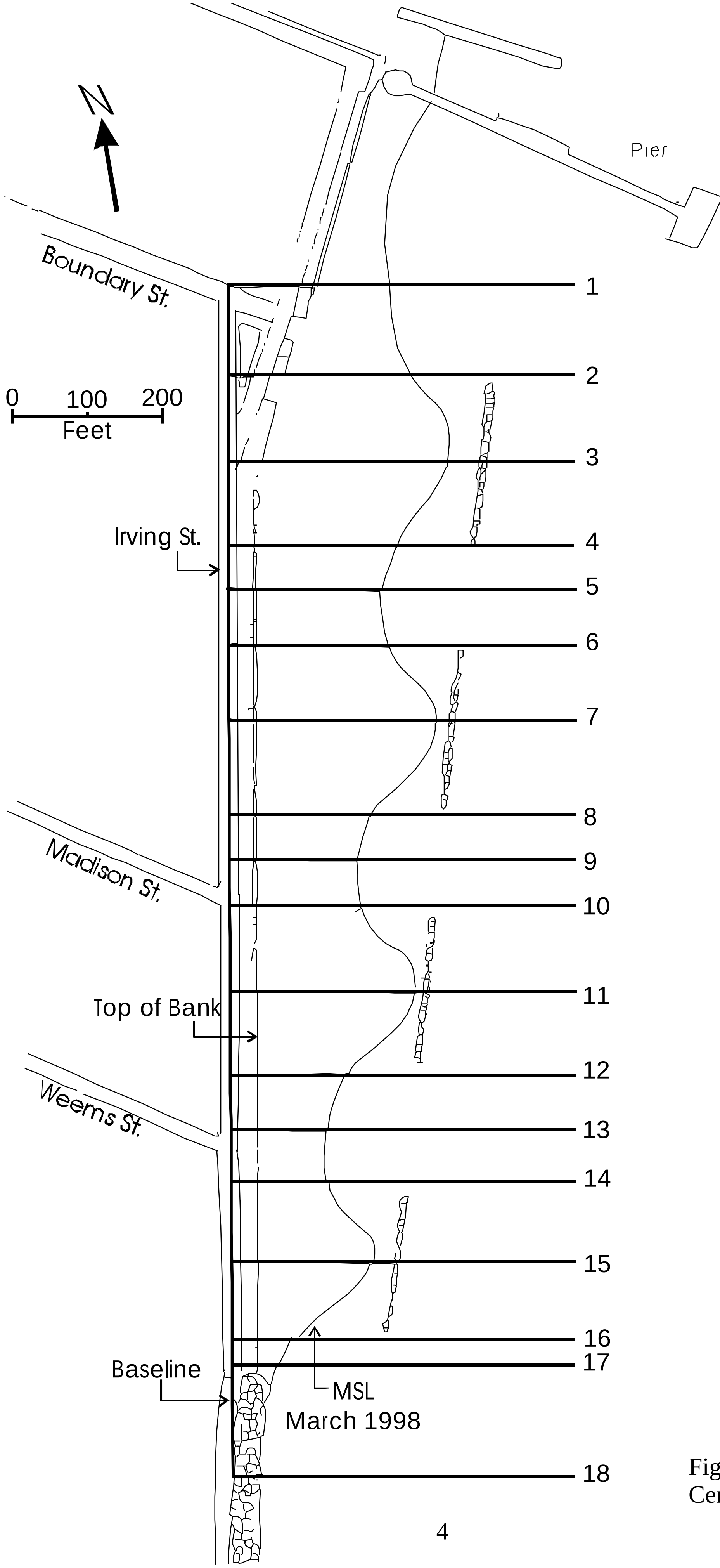


Figure 2. Survey baseline for Central Beach in Colonial Beach.

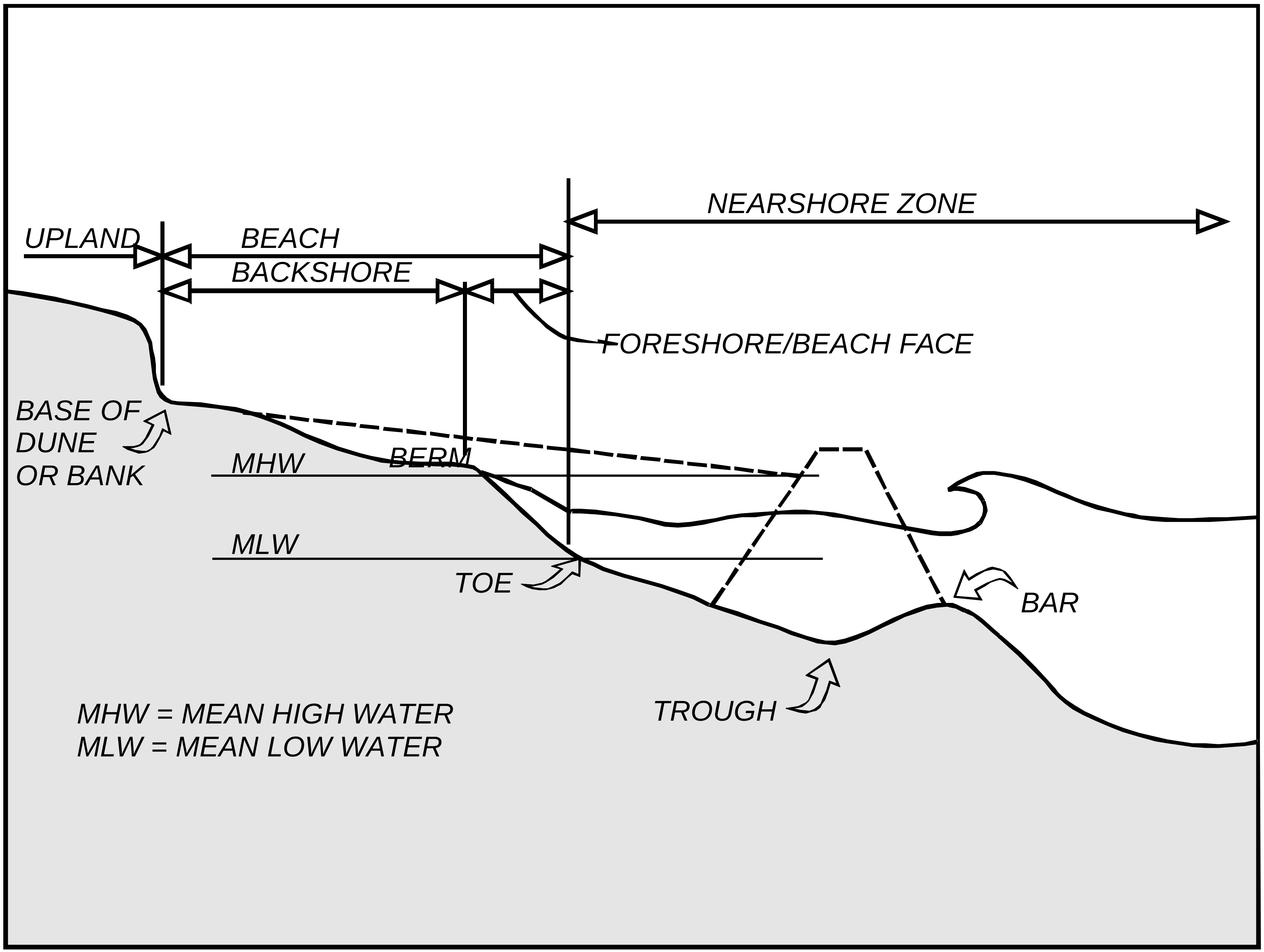


Figure 3. Profile terminology used in this report. Beach profiles with a breakwater and subaerially attached tombolo are shown dashed.

contours and storm surge are input to the SMB program which provides wave height, period, and length for a suite of wind speeds. In this case, wind speeds of 8, 16, 26, 36, 46, and 60 mph were used. Specified water levels ranged from 2 to 9.5 feet. Offshore, the wind and wave direction were assumed the same. However, at about -15 ft MLW, the waves enter the nearshore shoaling region and must be evaluated using a hydrodynamic wave refraction model. The predicted wave heights and periods for the four subject directions (N, NE, E, and SE) are used as input to the hydrodynamic model, RCPWAVE. The process, which calculates the impinging wave climate at a site, was developed and used during previous projects (Hardaway *et al*., 1991; Hardaway *et al*., 1993; Milligan *et al.*, 1995).

Table 2. Summary wind conditions at Quantico from 1973-2001.

		WIND DIRECTION								
Wind Speed (mph)	**Mid Range (mph)**	**North**	**North east**	**East**	**South east**	**South**	**South west**	**West**	**North west**	**Total**
< 5	3	5703* 3.21+	3330 1.87	3868 2.18	4792 2.70	12257 6.90	4291 2.42	7070 3.98	15437 8.69	56748 31.95
5-11	8	17454 9.82	10087 5.68	6504 3.66	8117 4.57	22593 12.72	8515 4.79	13391 7.54	18453 10.39	105114 59.17
11-21	16	3698 2.08	1460 0.82	386 0.22	517 0.29	2030 1.14	1156 0.65	1129 0.64	4601 2.59	14977 8.43
21-31	26	165 0.09	64 0.04	34 0.02	21 0.01	60 0.03	64 0.04	102 0.06	274 0.15	784 0.44
31-41	36	7 0	1 0	2 0	0 0	1 0	1 0	7 0	7 0	26 0.01
41-50	46	0 0	0 0	0 0	0 0	1 0	0 0	0 0	0 0	1 0
>50		1 0	3 0	3 0	3 0	4 0	0 0	7 0	5 0	26 0.01
Total		27028 15.20	14945 8.41	10797 6.08	13450 7.57	36946 20.79	14027 7.9	21706 12.22	38777 21.82	177676 100.00

*Number of occurrences +Percent

RCPWAVE is a linear wave propagation model designed by the USACE (Ebersole *et al.*, 1986) for engineering purposes. It computes changes in wave characteristics that result naturally from refraction, shoaling, and diffraction over complex topography. To this fundamental, linear theory-based model, routines to estimate wave energy dissipation due to bottom friction have been added (Wright *et al.*, 1987). The use of RCPWAVE to model the hydrodynamics at Colonial Beach assumes that only the offshore bathymetry affects wave transformation; the application does not include the effects of tidal currents.

RCPWAVE takes a simulated incident wave condition at the seaward boundary of the grid and allows it to propagate shoreward across the nearshore bathymetry. Frictional dissipation due to bottom roughness is accounted for in this analysis and is relative in part to the mean grain size of the bottom sediment. Waves also tend to become smaller over shallower bathymetry and remain larger over deeper bathymetry. Upon entering shallow water, waves are subject to refraction, in which the direction of wave travel changes with decreasing depth in such a way that wave crests tend to become parallel to the depth contours. Irregular bottom topography can cause waves to be refracted in a complex way and produce variations in the wave height and energy along the coast. In general, waves break when the ratio of wave height to water depth equals 0.78 (Komar, 1976).

RCPWAVE requires the creation of bathymetric grids in order to refract and shoal waves. Two grids (Figure 4) of the study region were digitized from a National Oceanic and Atmospheric Administration chart no. 12286, updated to 23 January 1993 by BBA Chart Kits. Bathymetric Grid 1 was used for the southeast, east and northeast wind conditions while bathymetric Grid 2 accommodates the north winds.

The results of the RCPWAVE analysis are wave vector and wave orthogonal plots showing wave attenuation and refraction across the nearshore and shoreline that allow us to determine the net movement of littoral materials. Wave vector plots show modeled wave orthogonals that have a magnitude and direction associated with them. Wave orthogonal plots can indicate areas of the shoreline that might be impacted by a convergence or divergence of wave energy. Areas of convergence indicate an increased amount of energy is impacting a section of shore whereas divergence indicates that the wave orthogonals are spreading out resulting in a lesser amount of energy impacting that shore.

The conditions input into RCPWAVE are listed in Table 3. The direction is a wind blowing from the north/northeast/east/southeast generating a wave orthogonal bearing to the southwest/west/northwest or 180ºTN/235ºTN/270ºTN/315ºTN. The wave condition number is an assigned designation for each case run through RCPWAVE. The water level is the estimated storm surge, in ft above MLW, associated with each event. The modal, or annual average conditions, described by the 16, 26, and 36 mph winds were run at spring high water or slightly above. Significant wave height and period were determined by the SMB analysis.

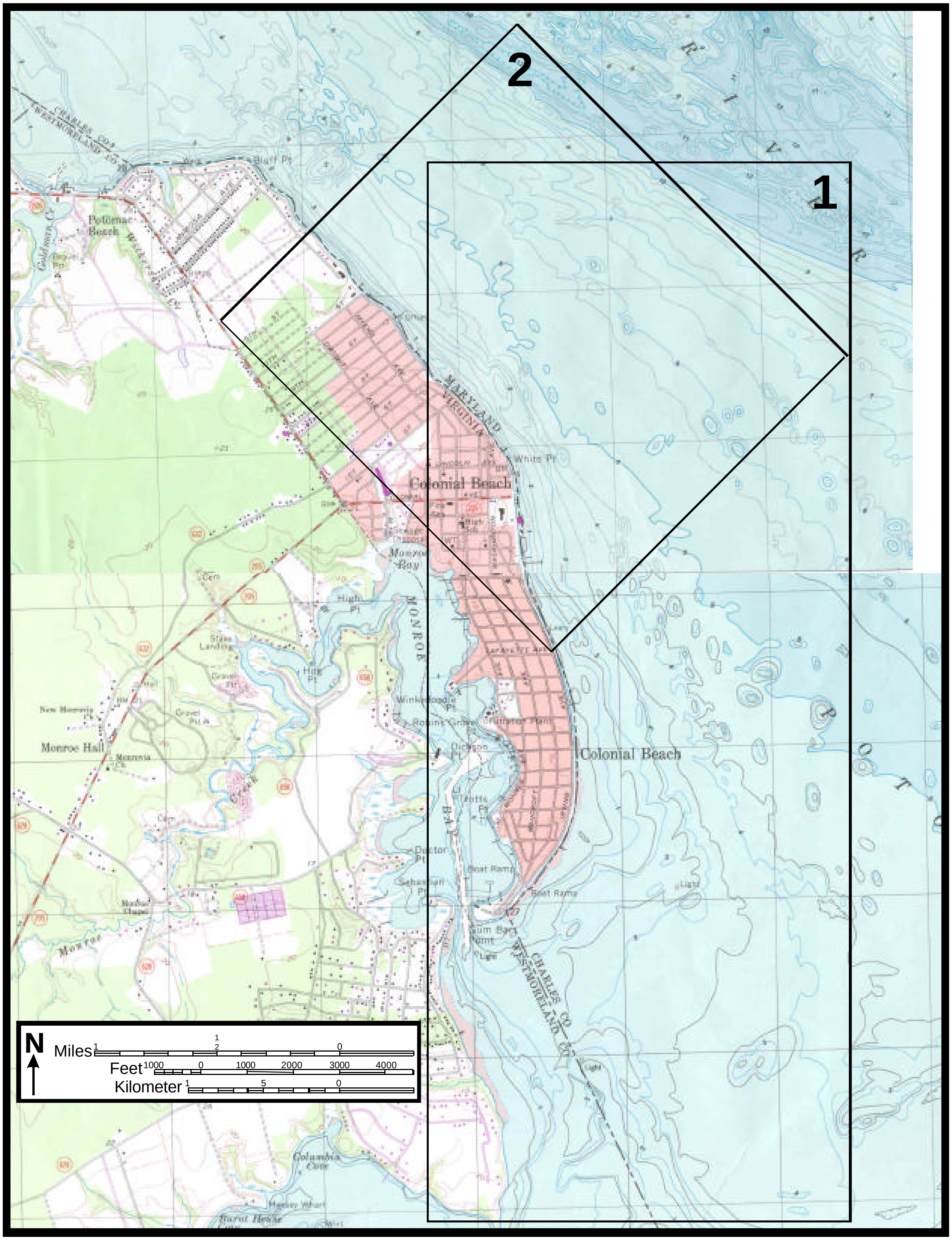


Figure 4. Bathymetric grids used in the RCPWAVE analysis.

Table 3. RCPWAVE input conditions (SMB output).

Direction and Bearing	Case Number	Wind Speed (mph)	Surge (ft)	Height (ft)	Period (seconds)
North 180 deg TN	1	16	2.0	1.31	2.42
	2	26	3.0	2.26	3.08
	3	36	4.0	3.15	3.08
	4	46	5.0	4.07	4.03
	5	50	7.0	4.46	4.21
	6	60	8.0	5.35	4.57
	7	70	9.0	6.20	4.90
Northeast 225 deg TN	8	16	2.0	1.4	2.48
	9	26	3.0	2.36	3.17
	10	36	4.0	4.10	4.16
	11	46	5.0	4.13	4.18
	12	50	7.0	4.56	4.36
	13	60	8.0	5.41	4.76
	14	70	9.0	6.23	5.12
East 270 deg TN	15	16	2.0	1.60	2.55
	16	26	3.0	2.46	3.25
	17	36	4.0	3.35	3.80
	18	46	5.0	4.26	4.28
	19	50	7.0	4.69	4.48
	20	60	8.0	5.54	4.89
	21	70	9.0	6.39	5.27
Southeast 315 deg TN	22	16	2.0	1.5	2.54
	23	26	3.0	2.39	3.24
	24	36	4.0	3.25	3.79
	25	46	5.0	4.10	4.27
	26	50	7.0	4.52	4.46
	27	60	8.0	5.31	4.87
	28	70	9.0	6.10	5.24

II. COASTAL SETTING

A. Hydrodynamic Processes

1. Wind/Wave Climate

The wave climate in the Chesapeake Bay is characterized by fetch-limited and depth-limited conditions. For this study, the main hydrodynamic forces operating along the project area are the waves and wave-induced currents and tidal currents. The assessment of hydrodynamic conditions along the Colonial Beach shoreline results in the determination of the annual, average or modal conditions as well as the storm conditions impacting the site. The assessment is based on the wind field analysis as well as the hydrodynamic modeling. Colonial Beach has effective fetches to the north, northeast, east, and southeast of 5.2 nautical miles (nm), 6.4 nm, 8.3 nm and 8.0 nm, respectively. Effective fetch is a measure of the size of waves that can be generated at a shoreline. Winds less than 7 mph were not used in the analysis because they typically generate wind chop which is not sufficiently large or organized to move sediment. Winds from 10-36 mph generate local wind waves when propagated over a fetch (Ludwick, 1987).

Wind data taken between 1945 and 1975 at Quantico Marine Corps Base was analyzed in U.S. COE (1980). Observed storm winds (sustained 44 mph winds) were from the east. Average wind speeds over those 30 yrs showed that the three dominant wind directions were the northeast, south-southeast, and east-southeast. Analysis of wind data taken Quantico between 1973 and 2001 showed that the southerly condition dominated at the lower wind speeds (1-11 mph). While the southerly component is still significant at 11-21 mph range, the north and northwest conditions dominate. At the highest wind speeds indicating storm conditions, the northwest, north and west conditions dominate.

Long-term wind frequencies of the directions that impact the study shoreline indicate the south wind is dominant in the 5-31 mph range followed by the northwest, then the north. The beach orientation tends to protect the shore from direct northwest storm events. The southerly wind component may indirectly effect the Colonial Beach shore as generated waves refract around the Gum Bar Point. The east and southeast directions which have the longest effective fetches provide the largest potential wave. The U.S. COE (1980) projected a maximum design wave with a 45 mph sustained wind from the east-southeast with a deep water significant wave height of 4.5 ft and a period of 4.65 seconds. The SMB analysis resulted in a slightly smaller wave with a wave height of 4.2 ft and a period of 4.28 seconds.

Two types of storms can impact the area. A storm that will impact Colonial Beach from the southeast is a hurricane or other low-pressure system off the Atlantic coast of the Eastern Shore. A storm of this type could generate large waves over the southeast fetch as well as produce a large storm surge. However, this is a rare event, and the wind data indicate that storm conditions experienced at Colonial Beach are generally from the northeast. These second, more frequent types of storms are the extra-tropical storms or northeasters. Northeasters have a smaller storm surge than a hurricane but can last several tidal cycles longer.

The nearshore region varies along the study site. This has an impact on the wave climate in that the wider shallow nearshore regions will tend to attenuate wave action more than narrower shelves. At Colonial Beach, the nearshore is relatively narrow and steep at the northern end of the town with the 15 ft contour approximately 1,400 ft from the shore at the bend in the shoreline near Lincoln Avenue at White Point. At the southern end of Colonial Beach near Gum Bar Point, the 15 ft contour is approximately 11,000 ft from the shoreline.

RCPWAVE allows us to determine the wave climate along a shore reach. Figures 5A, 5B, and 5C show the typical results of the RCPWAVE analysis along Colonial Beach for modal wind conditions (26 mph sustained wind with a 3 ft surge) from the northeast, east and southeast. This case is indicative of less than a one-year event. Under modal conditions, the offshore bathymetry tend to disperse waves at Central Beach when the winds come from the east and southeast. From the northeast, wave trajectories are not dispersed, but they also are not concentrated. However, just north of Central Beach, a small area of wave concentration is indicated under northeast wave conditions.

Trajectory plots demonstrate how wave patterns are established offshore at the 4 m and 5 m contours. The wave trajectories resulting from a northeast storm wave are shown in Figure 6. This case used a 60 mph wind with an 8 ft surge. This is indicative of approximately a 50-yr event. As under modal conditions, the wave do not tend to concentrate directly at Central Beach, but farther north toward Lincoln Avenue, they do tend to increase.

2. Tides and Storm Surge

The beach has a mean tide range of 1.66 ft and a spring tide range of 1.97 ft (NOAA website, 2002). Storm surge may pose a threat to certain resources regardless of potential wave impacts. The wave climate assessment included a determination of the frequency of storm surges and flooding based on FEMA’s Flood Insurance Studies (Table 4). This assessment is critical when determining the potential impacts of the local wave climate and related storm surge on shoreline management strategies.

Central Beach is backed by a high bank which serves to protect the upland from storm damage. Most upland structures, with the exception of the bathrooms, would be protected against the highest predicted storm surge, the 100-yr event with wave action. The beach and bank protect the road, parking lot and parking meters at the site. Areas to the north of Boundary Road to Lincoln Avenue are more flood prone.

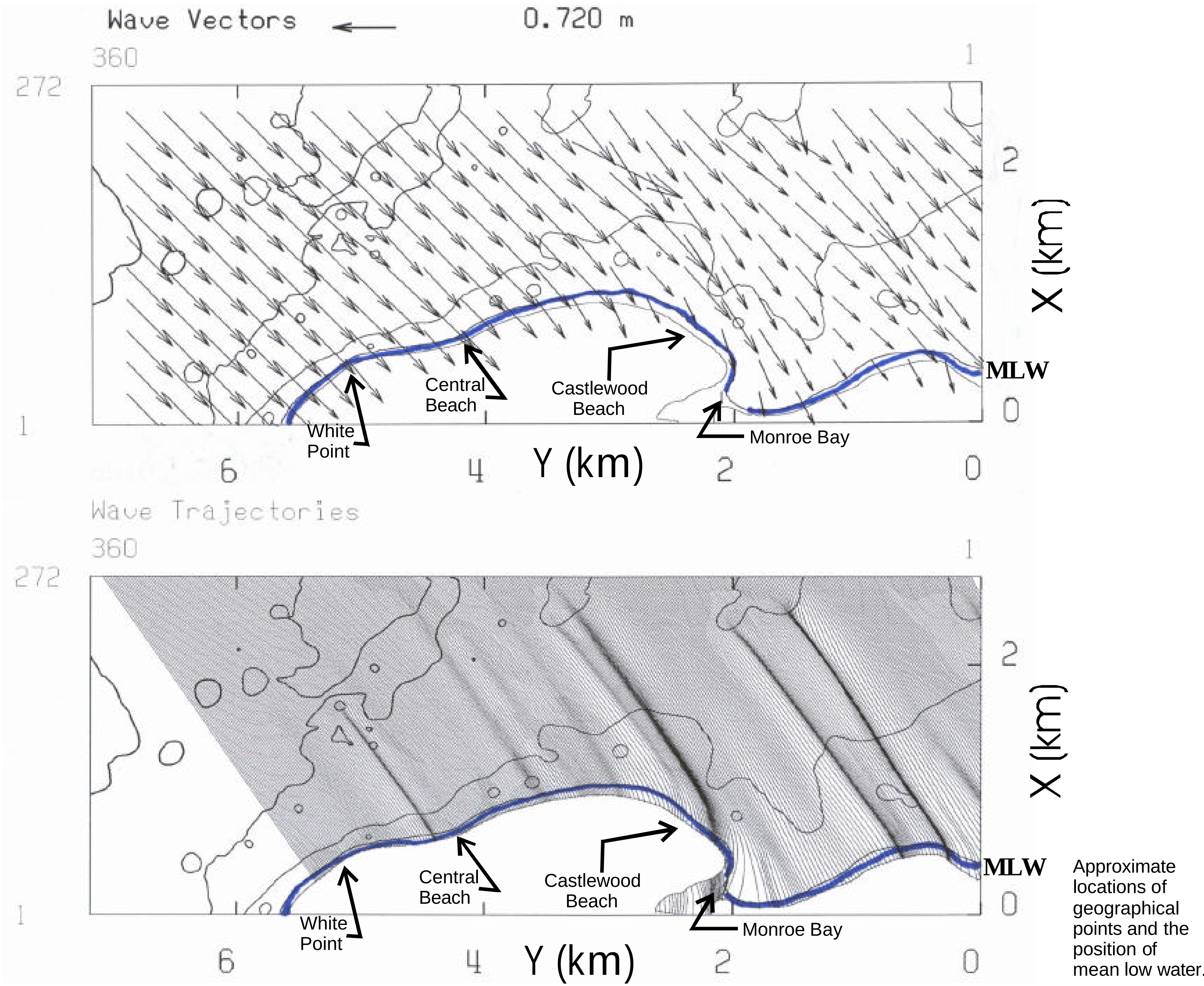


Figure 5A. Wave vectors and trajectories for Grid 1. Input conditions utilize a 26 mph wind and 3 ft water surge from the northeas.t

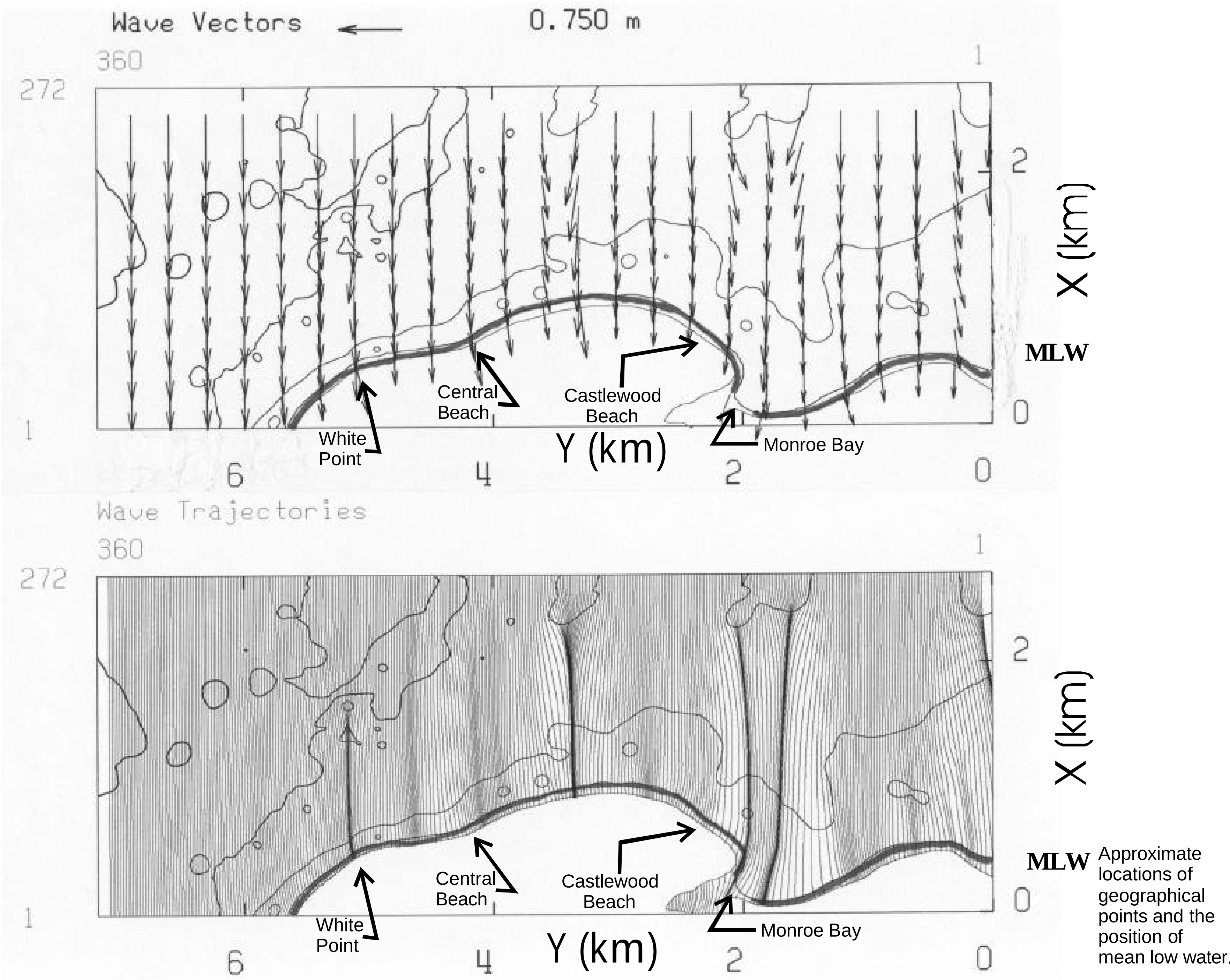
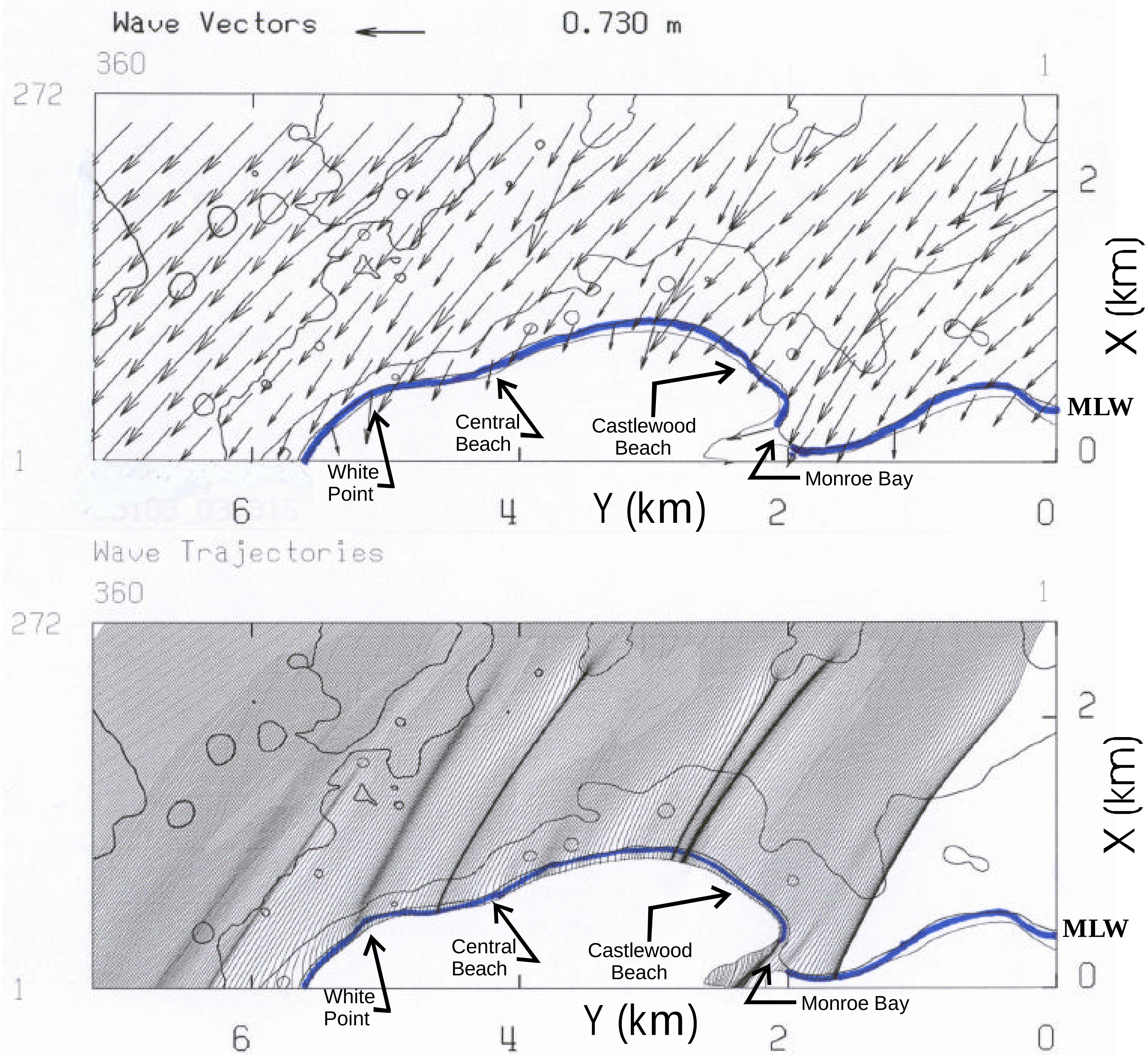
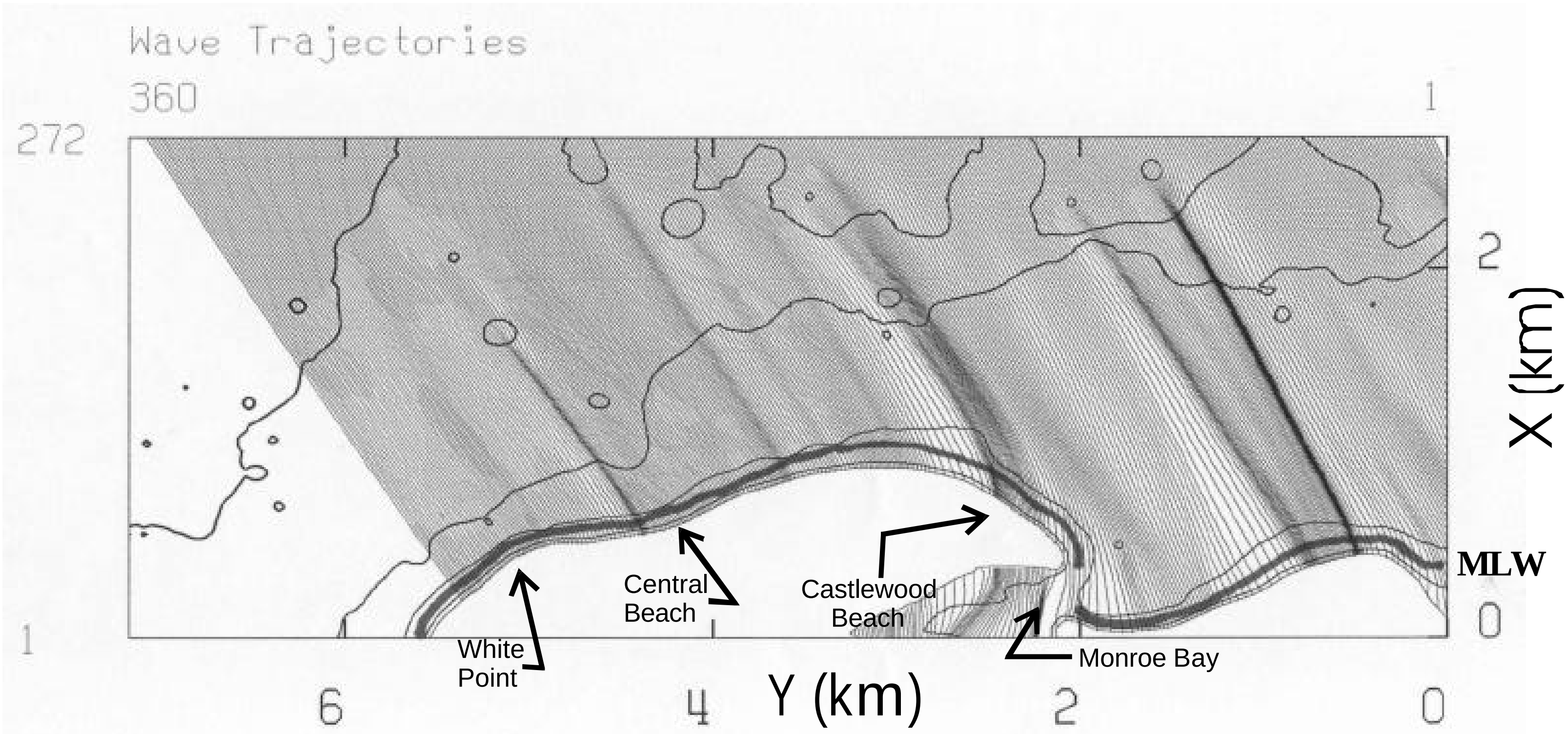


Figure 5B. Wave vectors and trajectories for Grid 1. Input conditions utilize a 26 mph wind and 3 ft water surge from the east.



Approximate locations of geographical points and the position of mean low water.

Figure 5C. Wave vectors and trajectories for Grid 1. Input conditions utilize a 26 mph wind and 3 ft water surge from the southeast.



Approximate locations of geographical points and the position of mean low water.

Figure 6. Wave trajectory for Grid 1 under a northeast storm condition.

Table 4. Storm surge levels as shown in U.S. Army Corps of Engineers (1990).

Frequency (years)	Exceedance Frequency (%)	Stage (ft MLW)
500	0.2	11.4
100	1	9.15
50	2	8.3
10	10	6.7
5	20	6.2
1.0	100	3.4

B. Physical Setting

1. Shore Morphology

Much of the Town of Colonial Beach exists on a peninsula between the Potomac River and Monroe Bay. The geology of the upland is described as undifferentiated Lynnhaven and Poquoson Members of the Tabb Formation. The Tabb Formation was created during the Upper Pleistocene 70,000-120,000 years ago. The Lynnhaven and Poquoson members are described as pebbly and cobbly grading into finer sand and silt.

Vertical aerial photos taken in 1937, 1969, 1987, 1994, 2001 (Figures 7A through 7E) were assessed. Historically, little beach has existed along most of the Colonial Beach shore. In 1937 (Figure 7A), some sand did reside in the pocket formed by the curve in the shoreline at Boundary Street where Central Beach now exists. The photo also seems to indicate a vegetated backshore. Erosion of the upland along this stretch of shore probably provided little beach quality sand. The larger pebbles and cobbles are difficult to transport alongshore, and the finer sand and silt are likely transported quickly along or offshore. The existence of Gum Bar Point indicates transport to the south. In 1937, the shoreline may have partially been fringe marsh at the southern end of Colonial Beach. The beach was particularly narrow north of the northern headland at Lincoln Avenue. Few shoreline structures existed in 1937 - just a few piers along the northern section of this reach.

By 1969 (Figure 7B), many structures appeared along the shore. At least 9 piers and 23 groins were visible in the photo. The beach area still existed at the pocket at Boundary Street. However, it was narrower than in 1937 with a reduced backshore area. At Gum Bar Point, sand had filled in the marsh headlands. The Monroe Bay shore had been hardened at the Point. This allowed the formation of a sand spit at the southernmost point of Colonial Beach. North of the headland at Lincoln Avenue, sand beach only existed in small pockets.

Figure 7. Vertical aerial photos of Colonial Beach in A) 1937 and B) 1969

Figure 7. Vertical aerial photos of Colonial Beach in C) 1987.

Figure 7. Vertical aerial photos of Colonial Beach in D) 1994.

Figure 7. Vertical aerial photos of Colonial Beach in E) 2001.

In 1977, the shoreline had a variety of structures along it in an attempt to abate erosion. At Central Beach, a concrete revetment existed along the shore (Figure 8). Farther south toward Castlewood Beach, sandbags and broken concrete were placed along the shore. At Castlewood, a sand beach existed probably because of the resistance of the underlying marsh substrate to erosion as well as the transport of sand into the area. Figure 9 shows the types of materials placed along the beach. Erosion, indicated by the fallen tree, resulted in the placement of sandbags both alongshore and offshore as groins. Broken concrete and other materials also were placed along the shore.

The 1987 photo (Figure 7C) shows the seven breakwaters constructed at Central Beach and Castlewood Beach. The breakwaters and beach fill created wide recreational beaches at these two subreaches. The more cohesive management strategy reduced the number of large piers and groins along the shore south of Lincoln Avenue. However, along several sections of the shore between Central and Castlewood Beaches, lower level photos show many of the small groins still existed. Much of the shoreline did have a rock revetment along it.

By 1994 (Figure 7D), the stone revetment had been placed along much of the Town's shoreline south of Central Beach. Overall beach width increased at Central Beach and Castlewood as sand accumulated behind the breakwaters mostly as a result of beach nourishment. In addition, another set of breakwaters were constructed at Gum Bar Point to limit sand movement into the entrance channel to Monroe Bay. The breakwaters are on privately-owned property.

In 2001 (Figure 7E), the beach width at Central Beach appears to be slightly reduced while Castlewood seems to have changed little since 1994. Several piers were built along the shoreline. Figure 10 shows the shore position at the Riverboat pier in 1981 and 2002. Along this particular section of shore, little change has occurred. This is probably due to the input of sand to the system at Central Beach that is occasionally transported north and trapped by the groins.

2. Sediments

The sedimentology of the study area is based on both active processes as well as the underlying geology of the region. Sorting and winnowing of the sediments by the littoral currents and waves occurs continuously in the nearshore region and erosion can expose outcrops of material deposited long ago. At Colonial Beach, the native sediment type is relatively coarse (Table 5). In general, the median grain size at Central Beach has increased at the toe of the beach (MLW) while decreasing at the berm (MHW). The sediment data from 1946 and 1974 was published by U.S. COE (1980).

17 May 1977

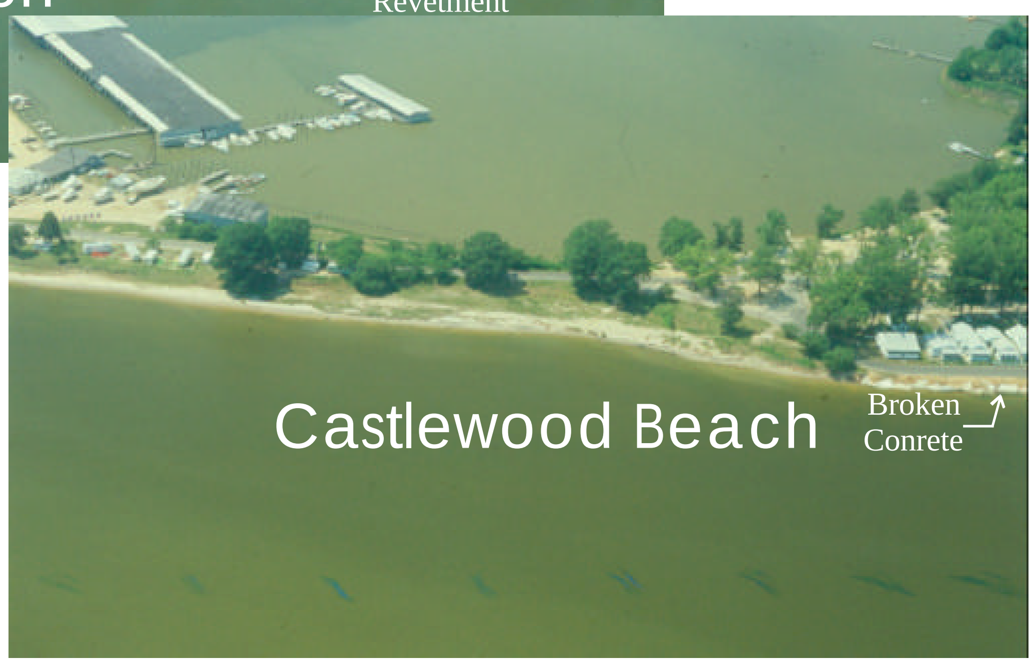


Figure 8. State of the Colonial Beach's shore in May 1977.

Figure 9. State of the shore on 26 June 1977. A variety of structures existed along the shore.

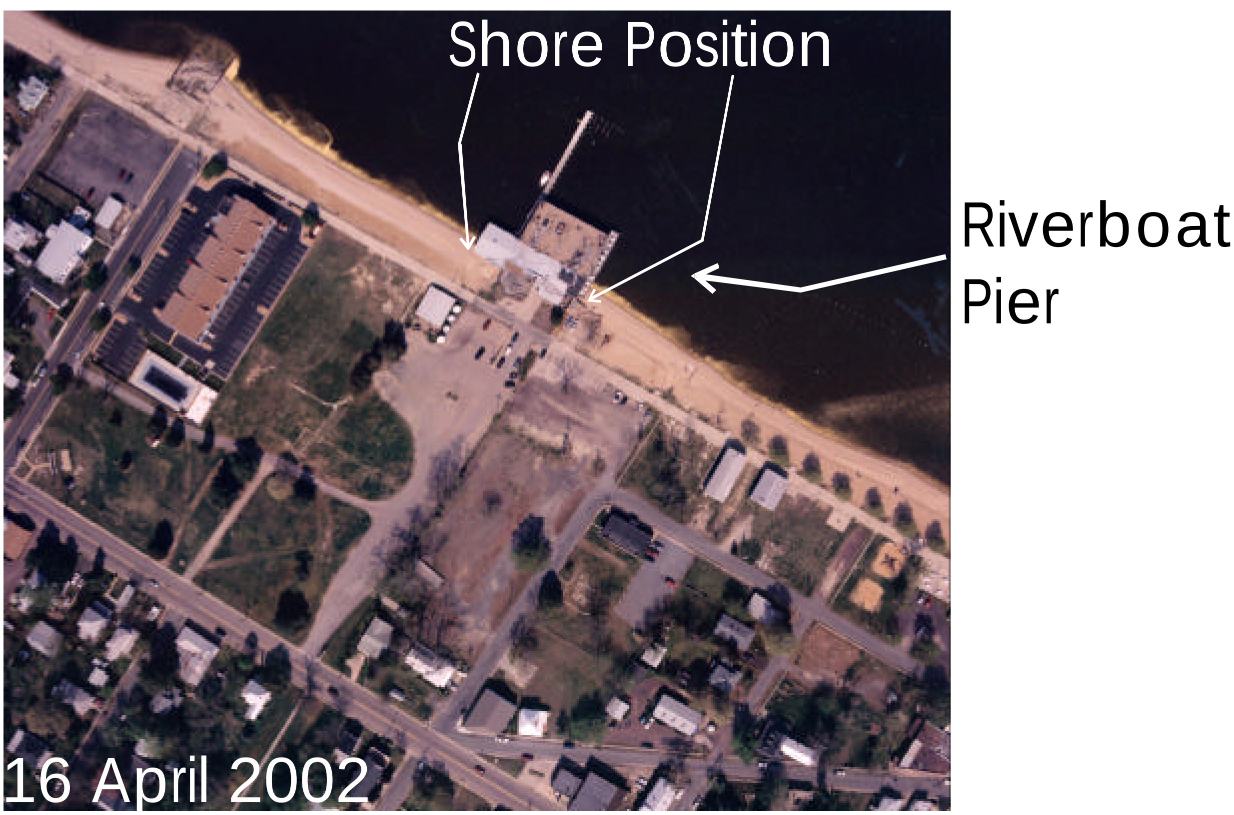


Figure 10. Position of the shore at the Riverboat pier in 1981 and 2002.

Table 5. Grain size (median diameter) at Colonial Beach from published data and sampled data.

Sample Location	Central Beach Median Diameter (mm)				Castlewood Beach Median Diameter (mm)	
	1946	1974	1998	2001	1946	1974
MHW	1.26	1.97	0.57	0.34	0.42	1.61
MLW	2.49	5.16	11.19	12.45	2.62	1.13

Sediment data taken at morphologic locations along profiles 5, 9, and 13 were analyzed for grain size parameters. Figure 11 shows the percent of the sample that is considered gravel (grain size over 2 mm) for samples taken at the berm and the toe of the beach through time. The amount of gravel at the berm has decreased through time at all profiles. The percent of gravel in the sediment samples decreased at the toe until June 2000 when it started increasing again. Figure 12 shows the median sample grain size at the berm and the toe through time at all three profiles. The trend is the same as the percent gravel; the grain size has decreased at the berm and at the toe, it decreased until June 2000 when it started increasing again. This is likely due to the influence of the beach fills. Smaller grained sand was placed on the beach decreasing grain size at the berm and the toe. However, the beach adjusted to the fill. While the smaller grained sand remained on the berm, it was transported away from the toe which is generally the most energetic portion of the beach and typically more gravelly than other parts of the beach.

3. Sediment Transport

Sediment transport is, in large part, due to the influence of waves along the shore. At Central Beach, sediment transport occurs alongshore and offshore only during local storm events which occur five to six times per year (U.S. COE, 1980). Swell-type waves do not occur in fair weather so sediment moved offshore during storms does not move back to the beach and is lost to the system. Little natural alongshore transport is received at Central Beach, particularly just south of this section where the revetment occurs. However, the northern end of the site is open allowing transport into and out of the breakwater area resulting in variable volumes when sand moves through the system.

At Castlewood Beach, however, storm waves tend to drive sediment alongshore due to its northeast-southwest orientation. Sediment moves to the southwest toward the entrance to Monroe Bay. The Corps (1980) found that the entrance channel of Monroe Bay was shoaling at a rate of 1,500 cy/yr. However, offshore sand transport during east and east-southeast storm events also plays a major role in erosion at Castlewood. This section of Colonial Beach's shoreline eroded at about 4 ft/yr between 1944 and 1977 losing about 3,400 cy of sand per year. The U.S. COE (1980) estimated that the initial beach fill and breakwater project would require maintenance at a rate of 1,250 cy for Central Beach and 1,570 cy at Castlewood every two to three years.

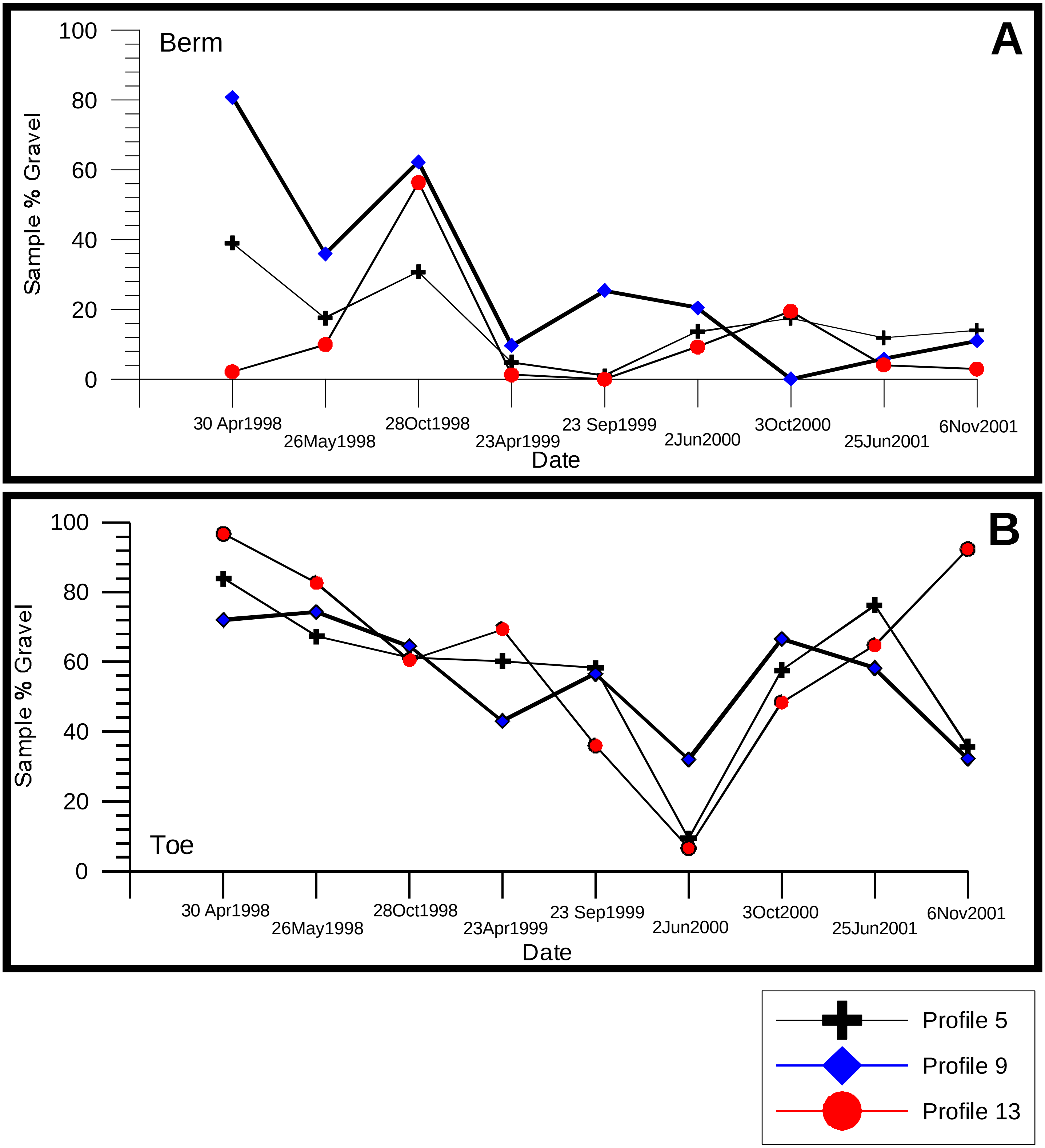


Figure 11. Percent of sediment sampled that is larger than 2 mm at all three profiles through time at the A) berm and B) the toe of the beach.

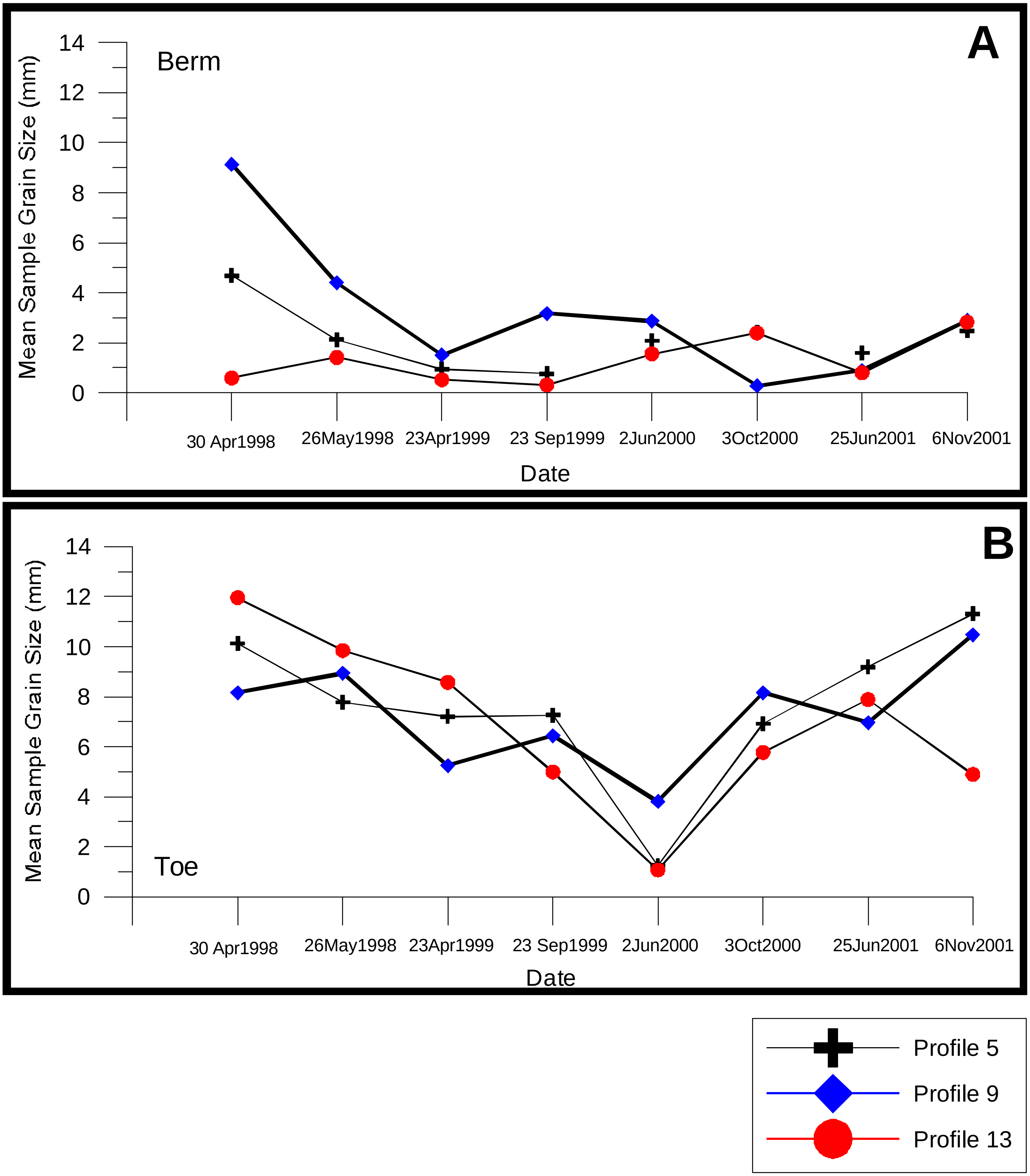


Figure 12. Mean sediment sample grain size at all three profiles through time at the A) berm and B) toe of the beach.

Utilizing wave vector output from the RCPWAVE analysis, a limited-scope littoral transport-potential analysis was performed. The wind/wave height and angle to the shore at the Colonial Beach shoreline were determined from the RCPWAVE output. The northeast, east, and southeast modal conditions only were used in the analysis. Modal conditions are the annual average waves at the site. For the purpose of this report, it is the predicted wave height and angle from a 16 mph, 26 mph, and 36 mph wind from the three main directions of influence that could be modeled (northeast, east, and southeast). Figure 13 shows the resultant transport vectors. The vectors were calculated using the energy flux method for determining sediment transport (USACE, 1984). The shoreline is divided into morphologic sections based on approximate shore orientation. Section A at Central Beach has the greatest transport rate toward the south. The rate decreases down the shoreline through Sections B (Central Beach breakwater section) and C. These rates are only based on the wave height and angle. The analysis does not account for sediment amount and types available for transport or the presence of structures. These rates are close to annual beach fill maintenance estimated by the Corps of Engineers.

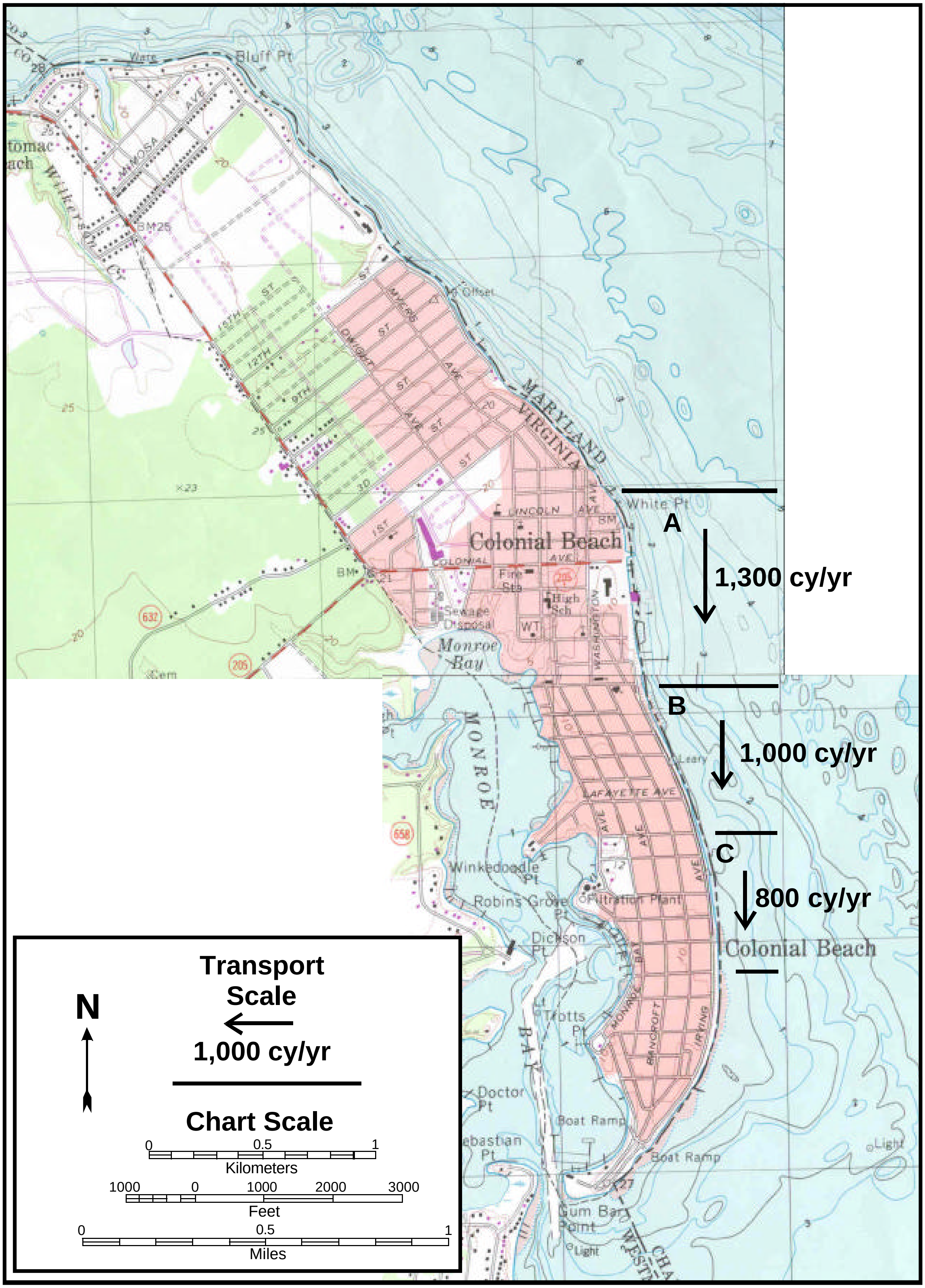


Figure 13. Approximate littoral transport rates along Colonial Beach's shore.

III. BEACH CHARACTERISTICS

A. Beach Profiles and their Variability

Semi-annual monitoring by personnel in the Shoreline Studies Program began at Central Beach in the spring of 1998. Plots of profile data taken between 2000 and 2002 are shown in Figures 14A through 14R. Little net change has occurred at Central Beach. Upper berm retreat or adjustment was noted at profile 2 and behind all four breakwaters. Behind the southernmost breakwater (profile 15), the lower berm advanced while the upper berm retreated. Profile 14 showed the greatest net change; the bank face showed an increase in sand while the beach face retreated. Changes in sand elevations at specific points along the shore may be the result of shifting of sediment within the embayments as a response to changes in the wave climate. Also, the bulldozing of the beach for maintenance and cleaning impact the beach profiles.

B. Analysis of Beach Profile Data

One portrayal of shore change is the movement of a tidal contour through time. Following traditional methods, the position of mean high water (MHW) for each study profile was plotted through time (Figures 15A and 15B). For the 1998-2000 data set, all the beach profiles were not surveyed. This results in the shoreline not plotting the same as the later dates. Figures 15A and 15B also show very little net change along the shoreline. In April 1999, the tombolo berm behind each breakwater was at its closest point. By June 2000, it had retreated. Between April 1998 and May 2002 (Figure 16), the net position of MHW has advanced behind each breakwater (1, 2, 3, and 4) and retreated in the apex of each embayment (A, B, C). The tombolo berm behind breakwaters 1 and 4 are the most susceptible to change since they are on the ends of the system. Embayment B tends to be the most stable since it is enclosed within the system.

In October of 2000, all 18 profiles began to be surveyed instead of every other profile. Calculations for the beach system volume are slightly different but are comparable. Figure 17 shows the overall volume change along Central Beach through time. The small beach fills are noted. In general, the net measured change in volume between 1998 and 2002 has been a net gain of approximately 3,000 cubic yards (cy).

One problem that Central Beach has, which is not reflected in the beach profile data, is the outfall pipes that exit through the beach. Figure 18 shows the result of storm water drainage after Hurricane Floyd passed through the area in 1999. But even under non-storm events, large channels are created through the beach.

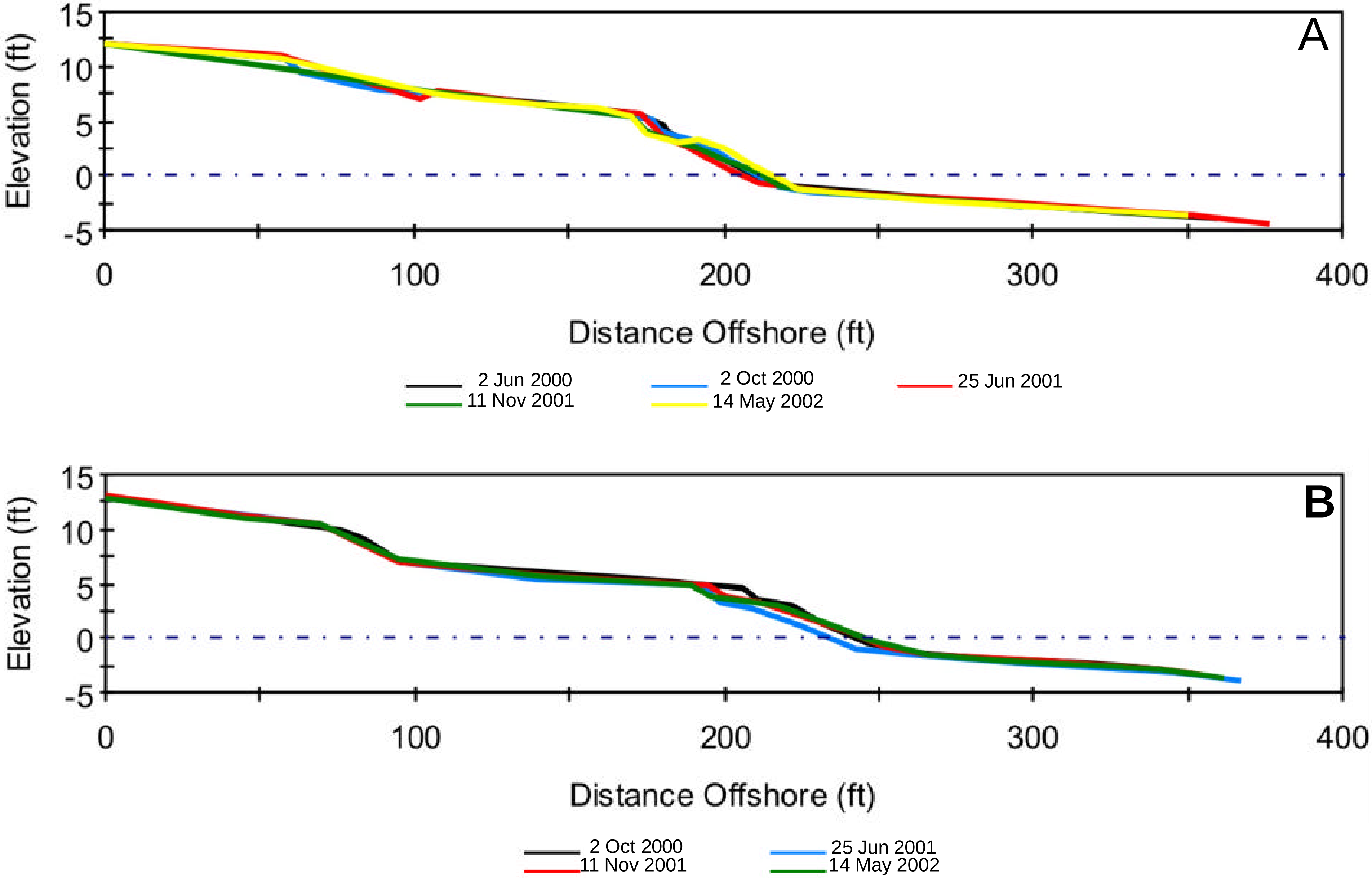
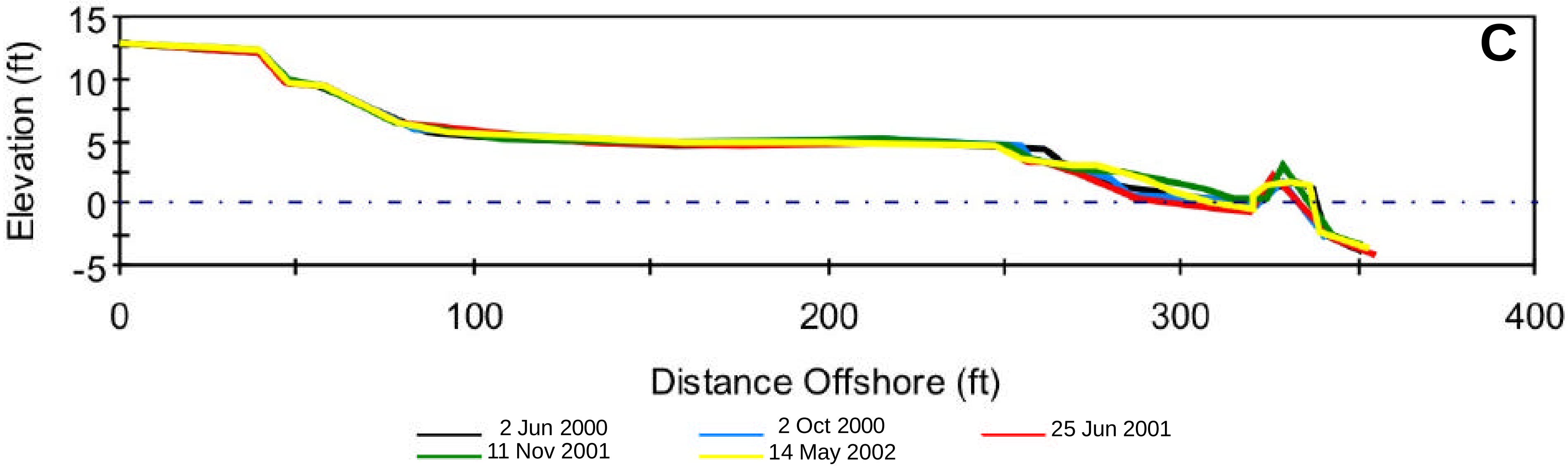


Figure 14. Beach survey data taken between June 2000 and May 2002 at A) Profile 1 and B) Profile 2.



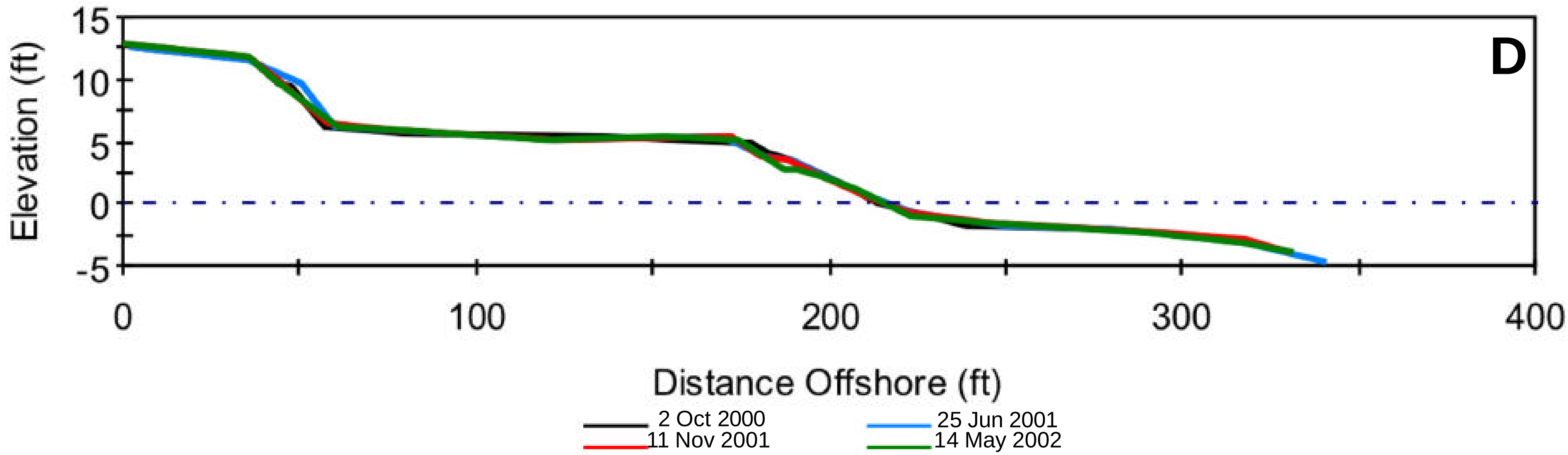


Figure 14. Beach survey data taken between June 2000 and May 2002 at C) Profile 3 and D) Profile 4.

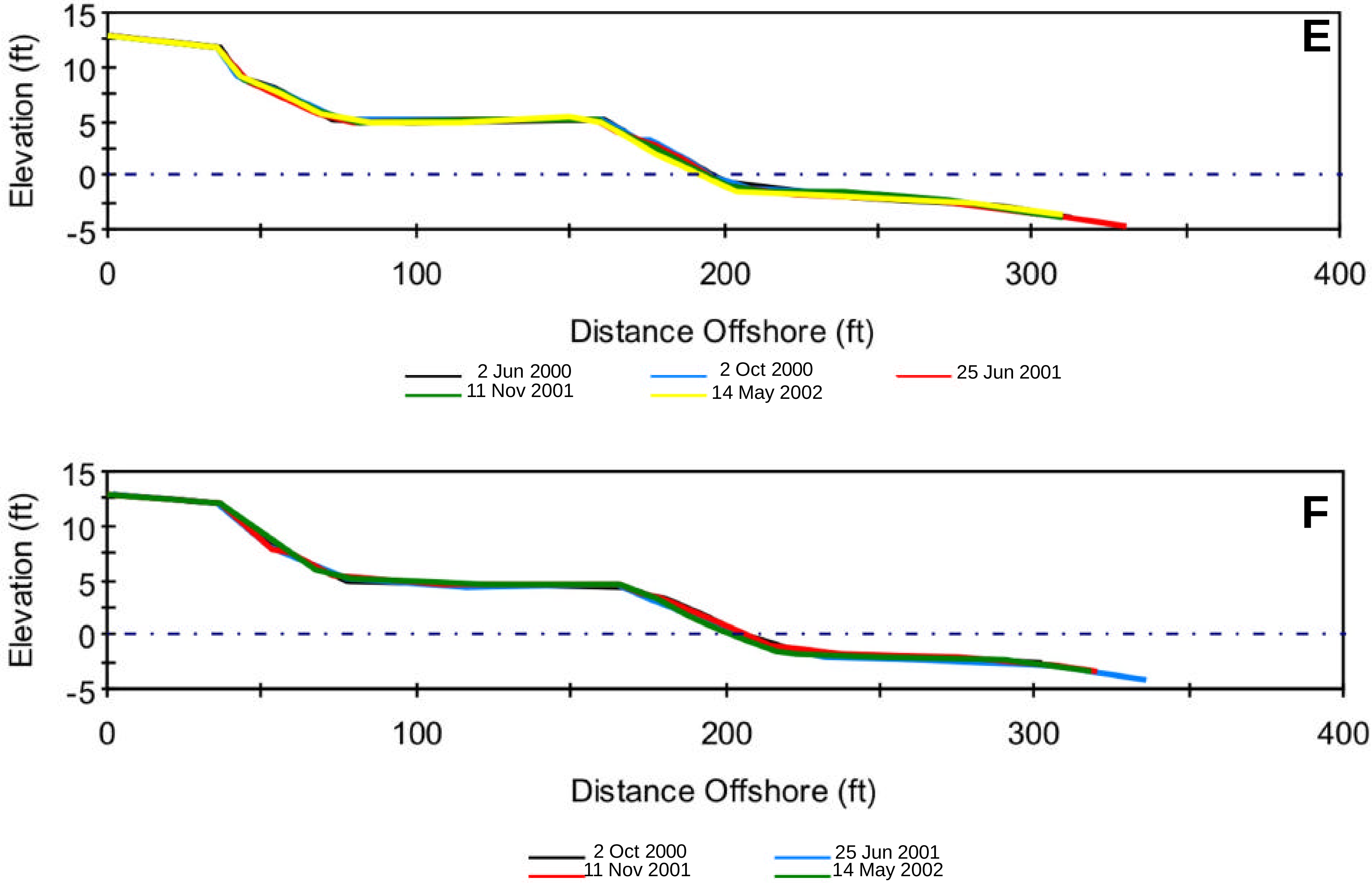


Figure 14. Beach survey data taken between June 2000 and May 2002 at E) Profile 5 and F) Profile 6.

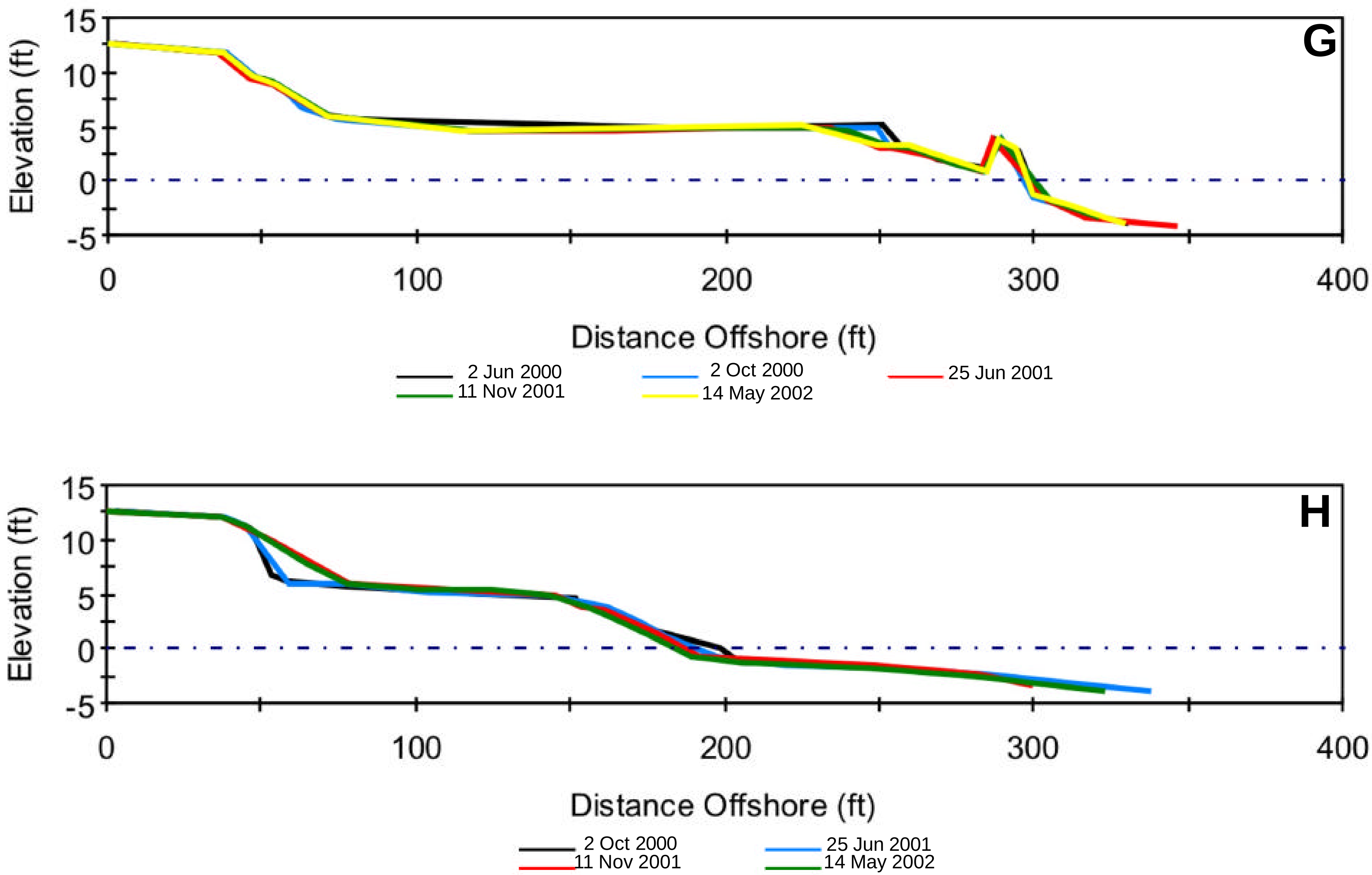
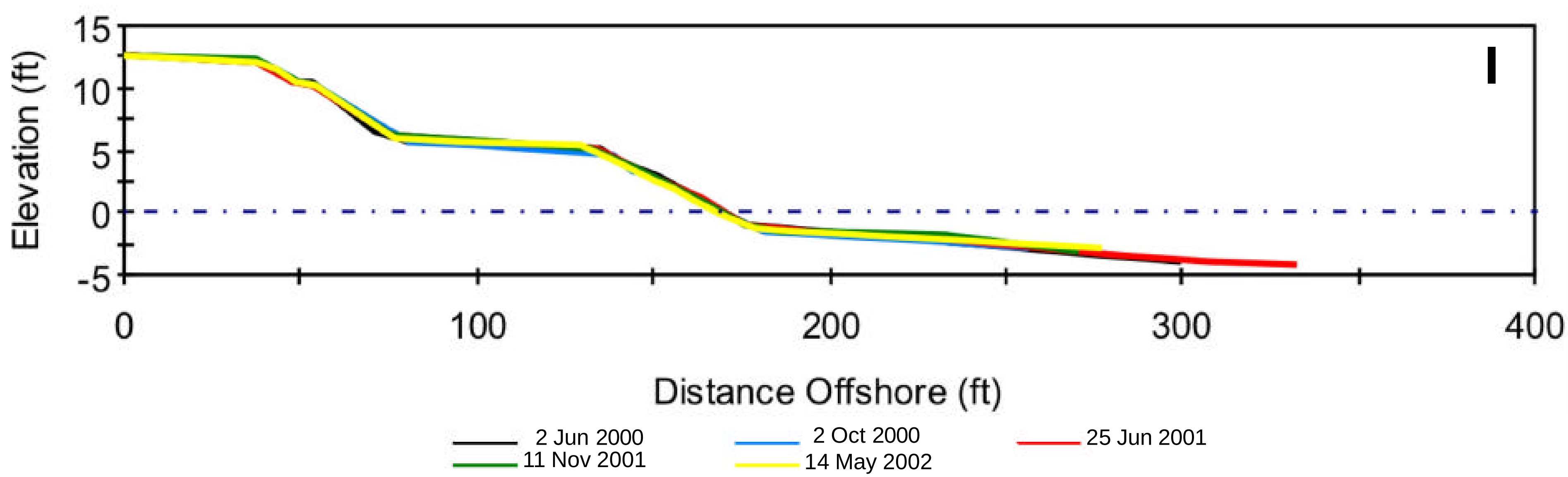


Figure 14. Beach survey data taken between June 2000 and May 2002 at G) Profile 7 and H) Profile 8.



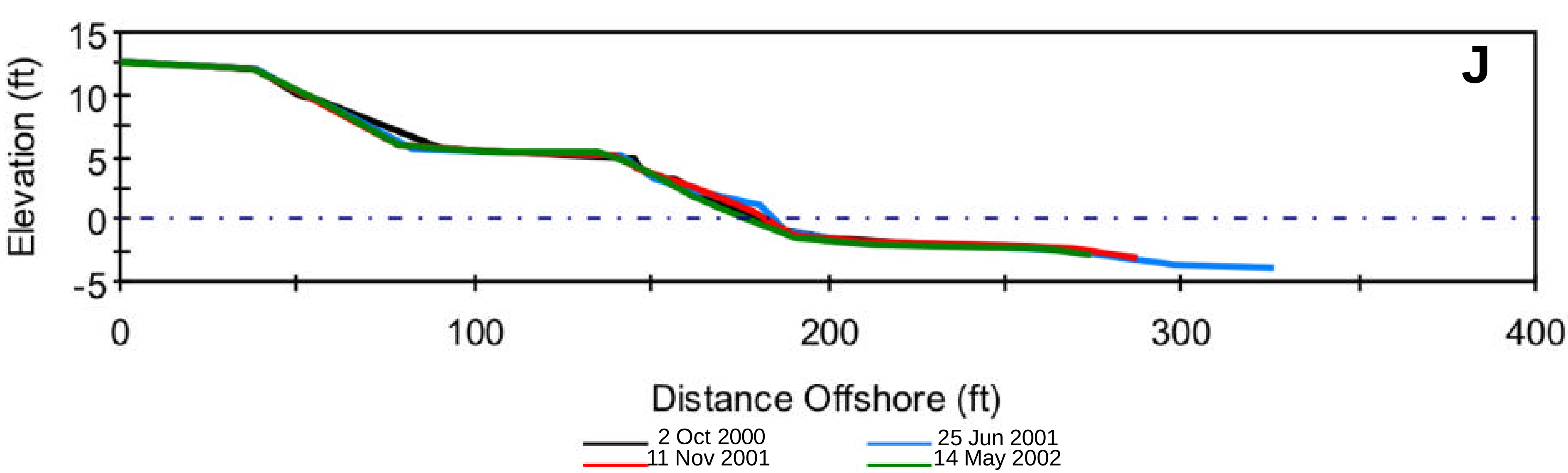
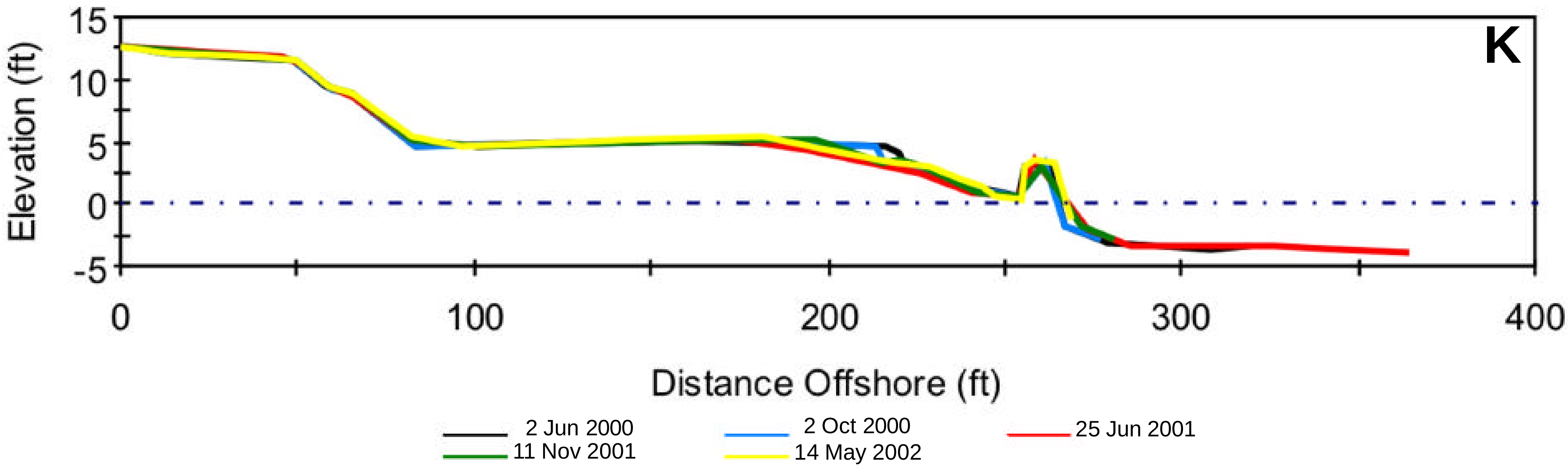


Figure 14. Beach survey data taken between June 2000 and May 2002 at I) Profile 9 and J) Profile 10.



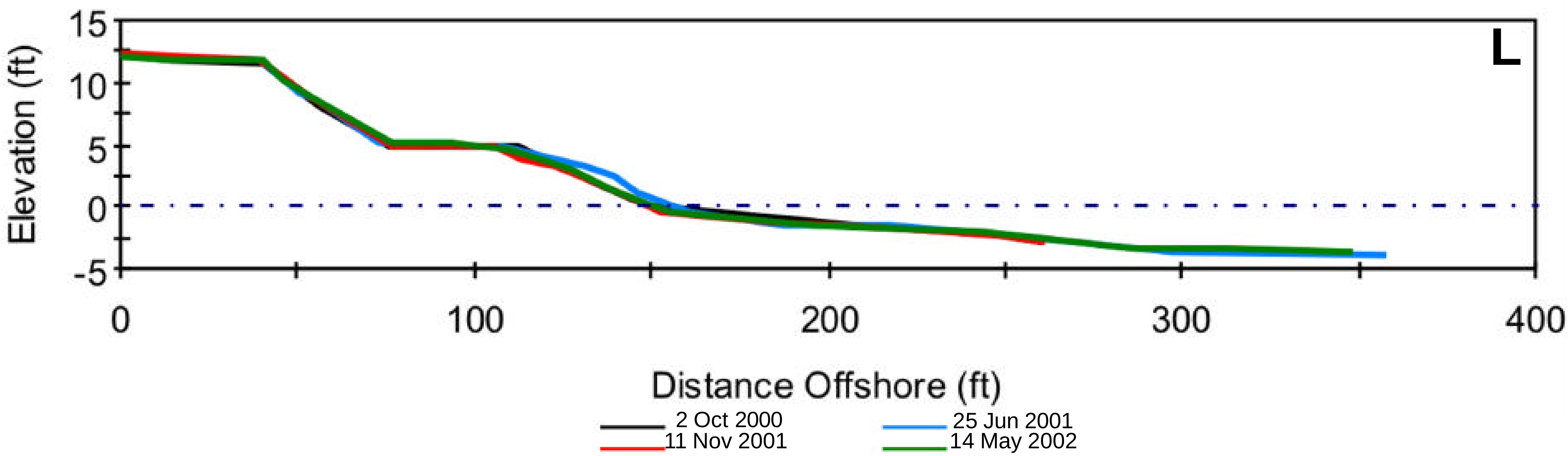
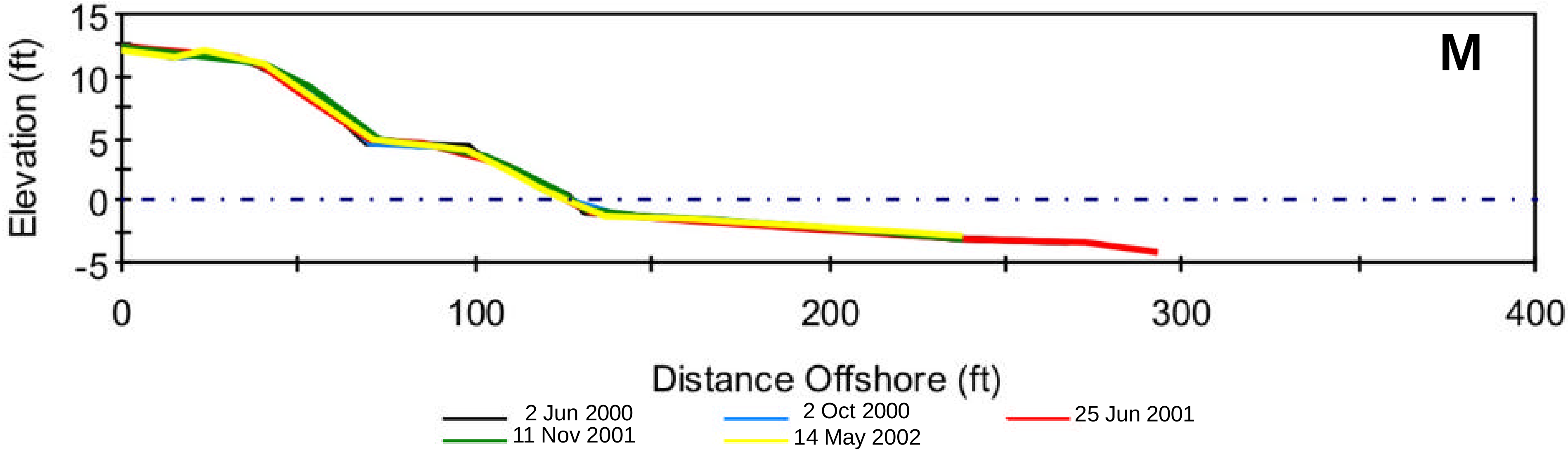


Figure 14. Beach survey data taken between June 2000 and May 2002 at K) Profile 11 and L) Profile 12.



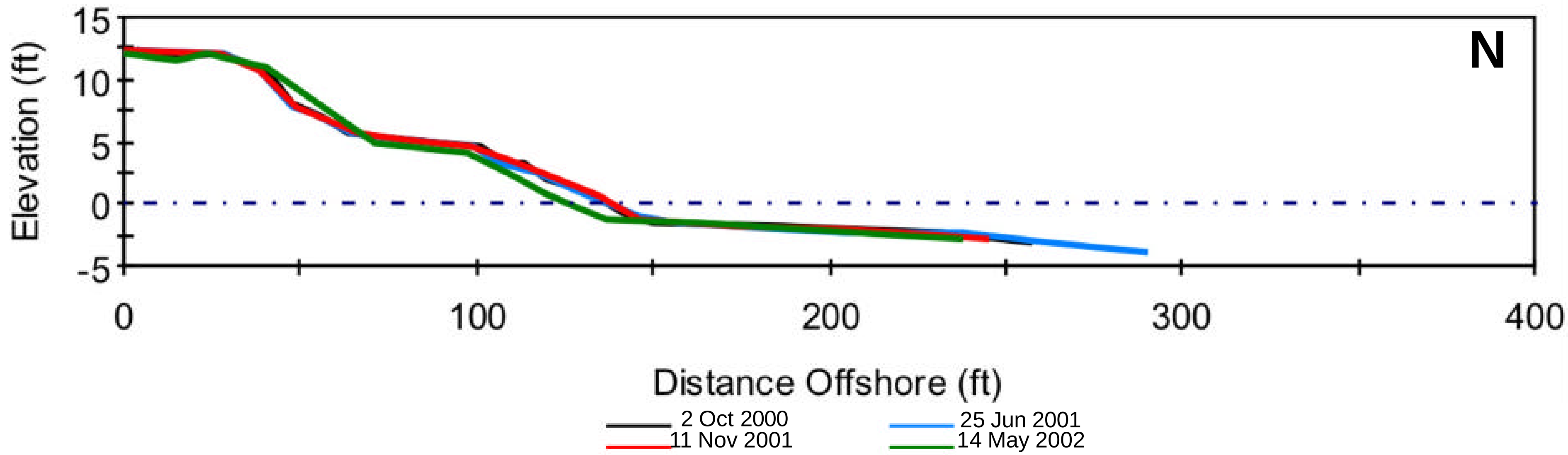


Figure 14. Beach survey data taken between June 2000 and May 2002 at M) Profile 13 and N) Profile 14.

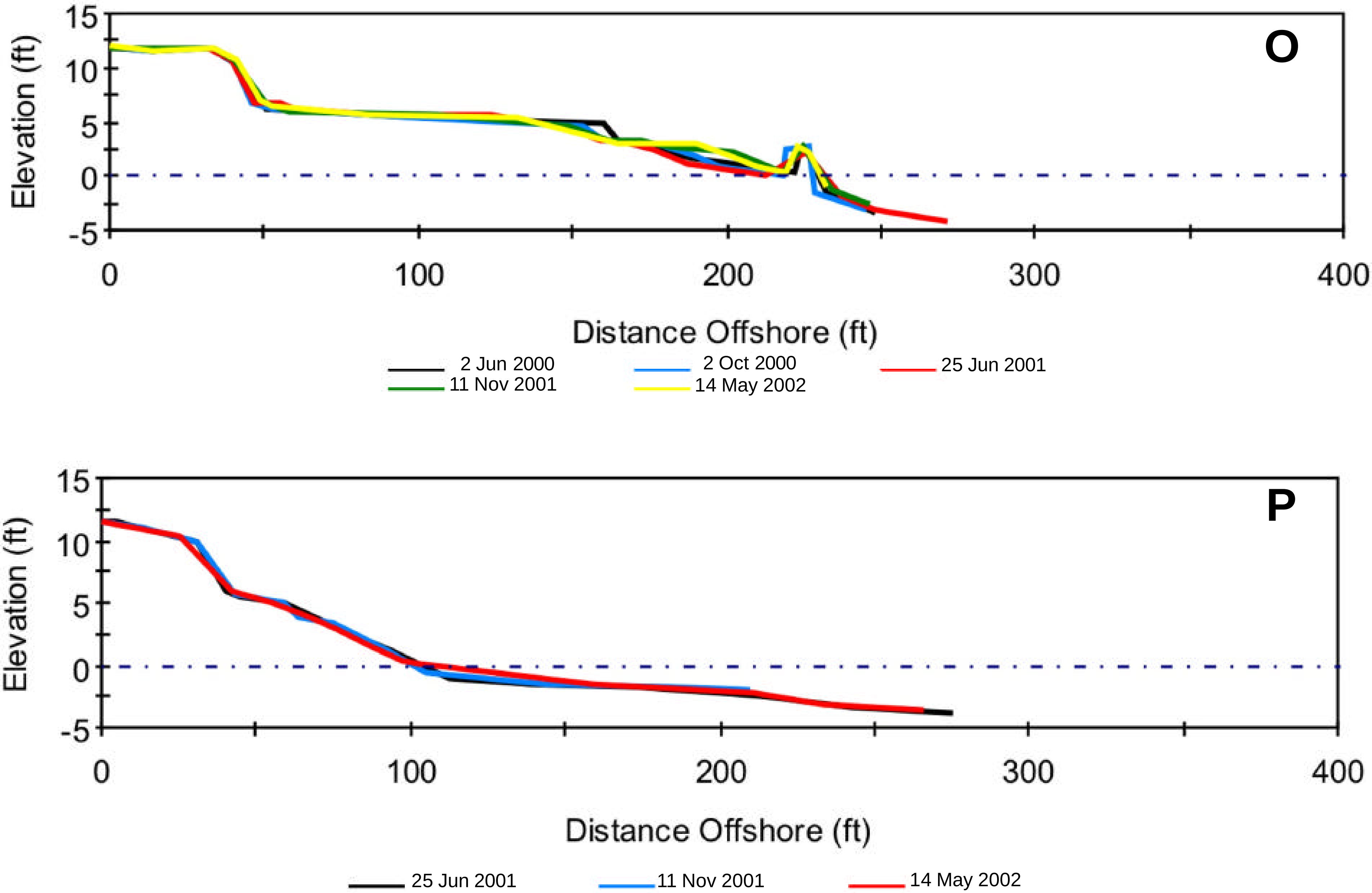


Figure 14. Beach survey data taken between June 2000 and May 2002 at O) Profile 15 and P) Profile 16.

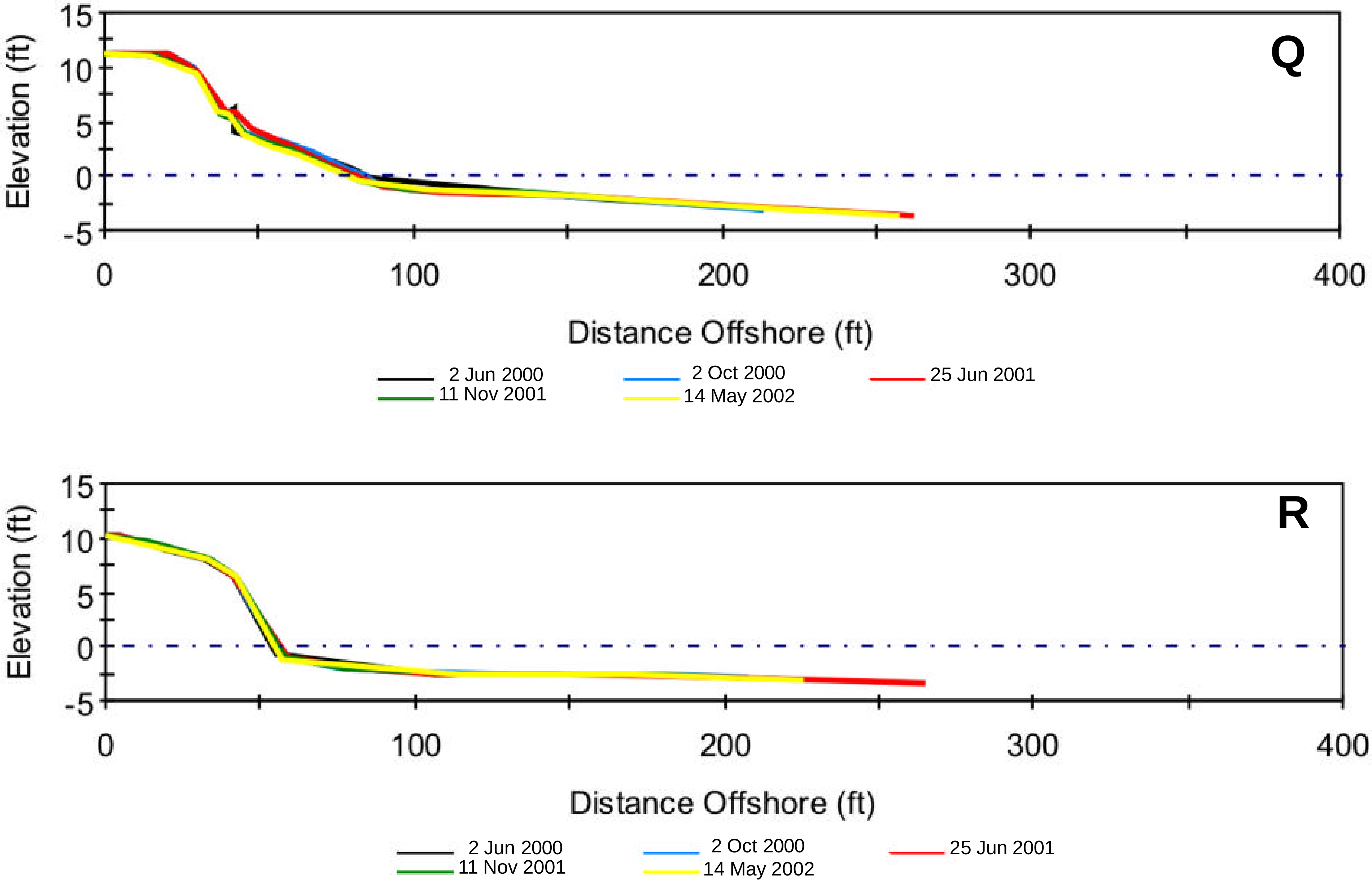
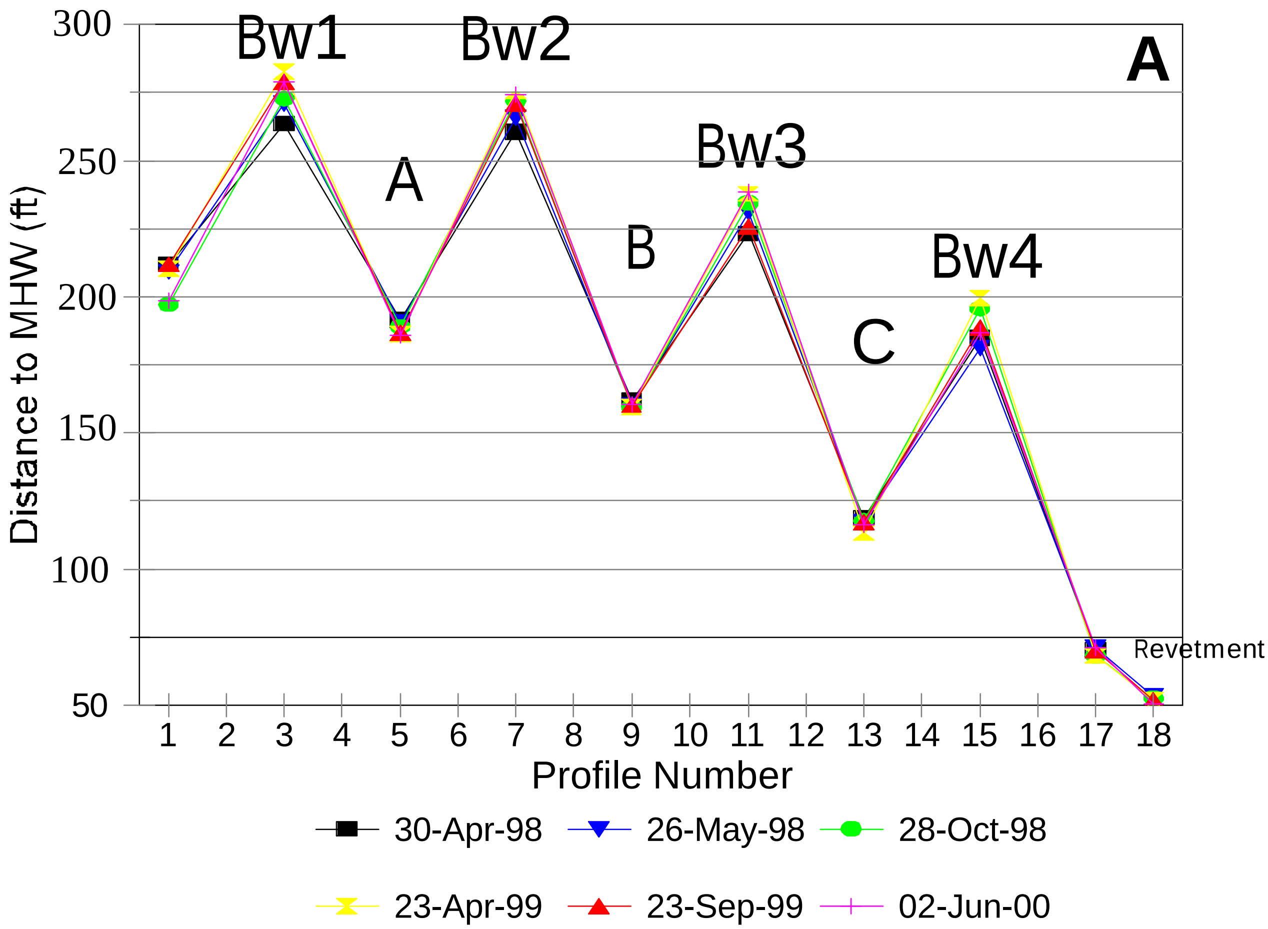


Figure 14. Beach survey data taken between June 2000 and May 2002 at Q) Profile 17 and R) Profile 18.



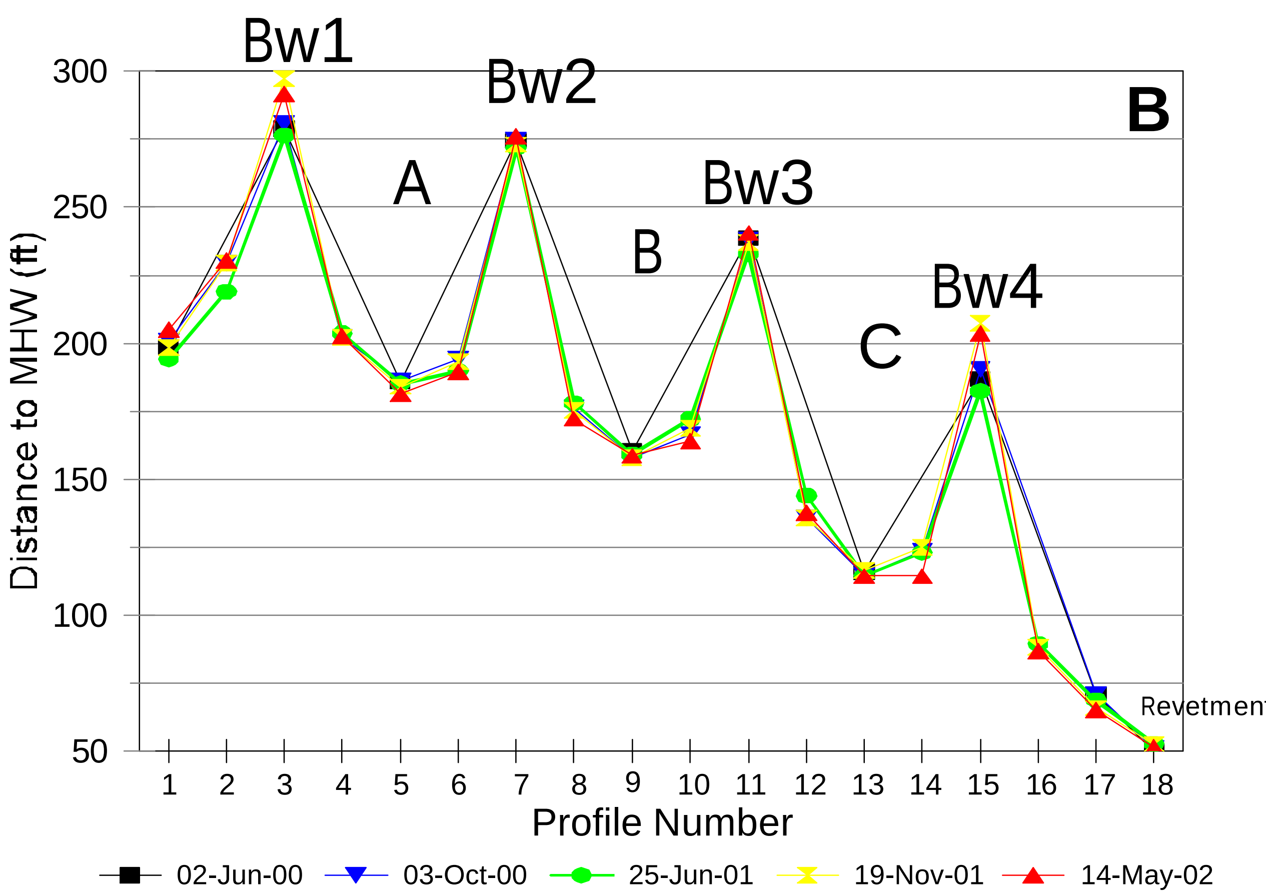


Figure 15. Distance from the baseline to MHW at Central Beach between A) 1998-2000 and B) 2000-2002.

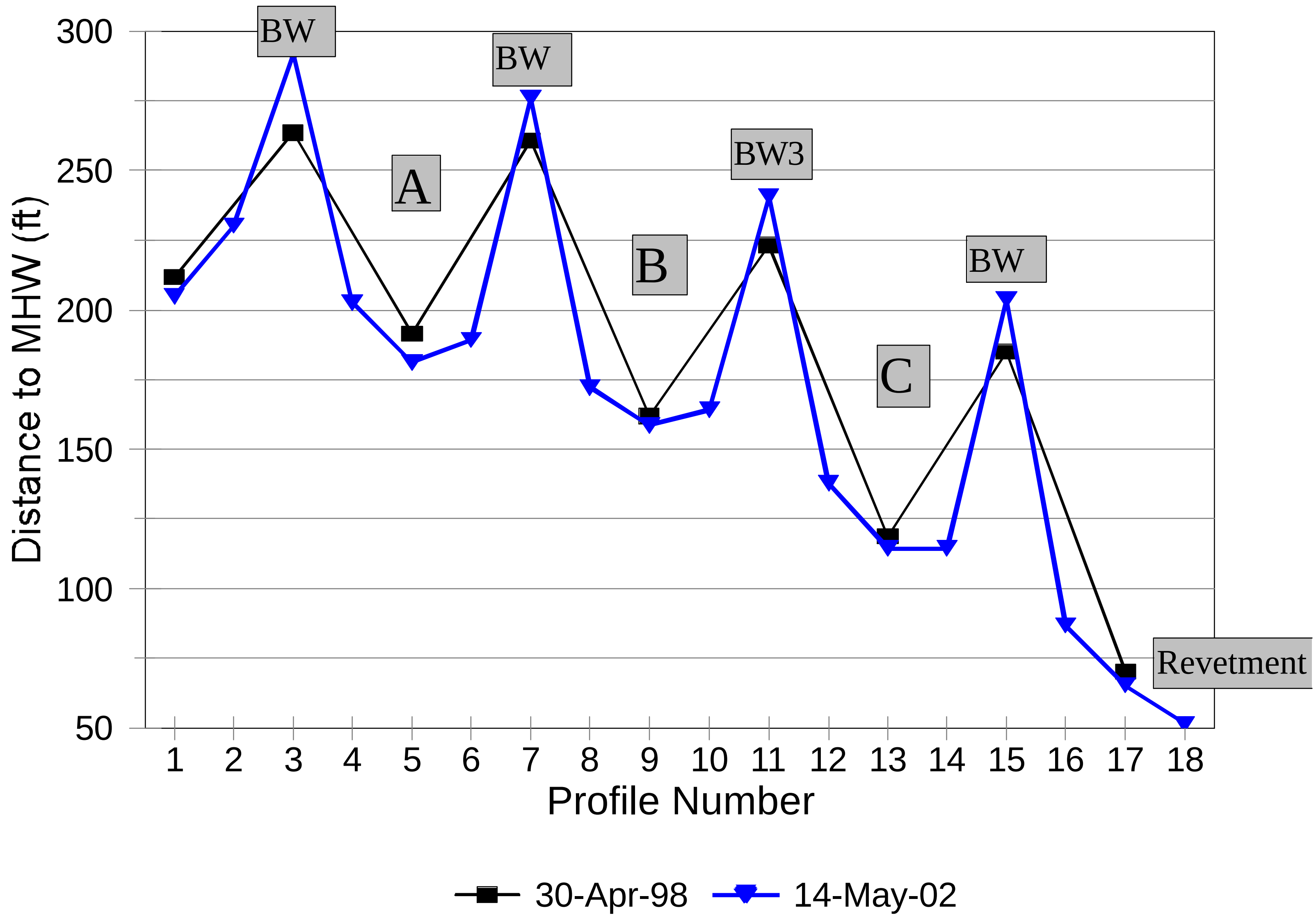


Figure 16. Net change in the distance from the baseline to MHW between 1998 and 2002.

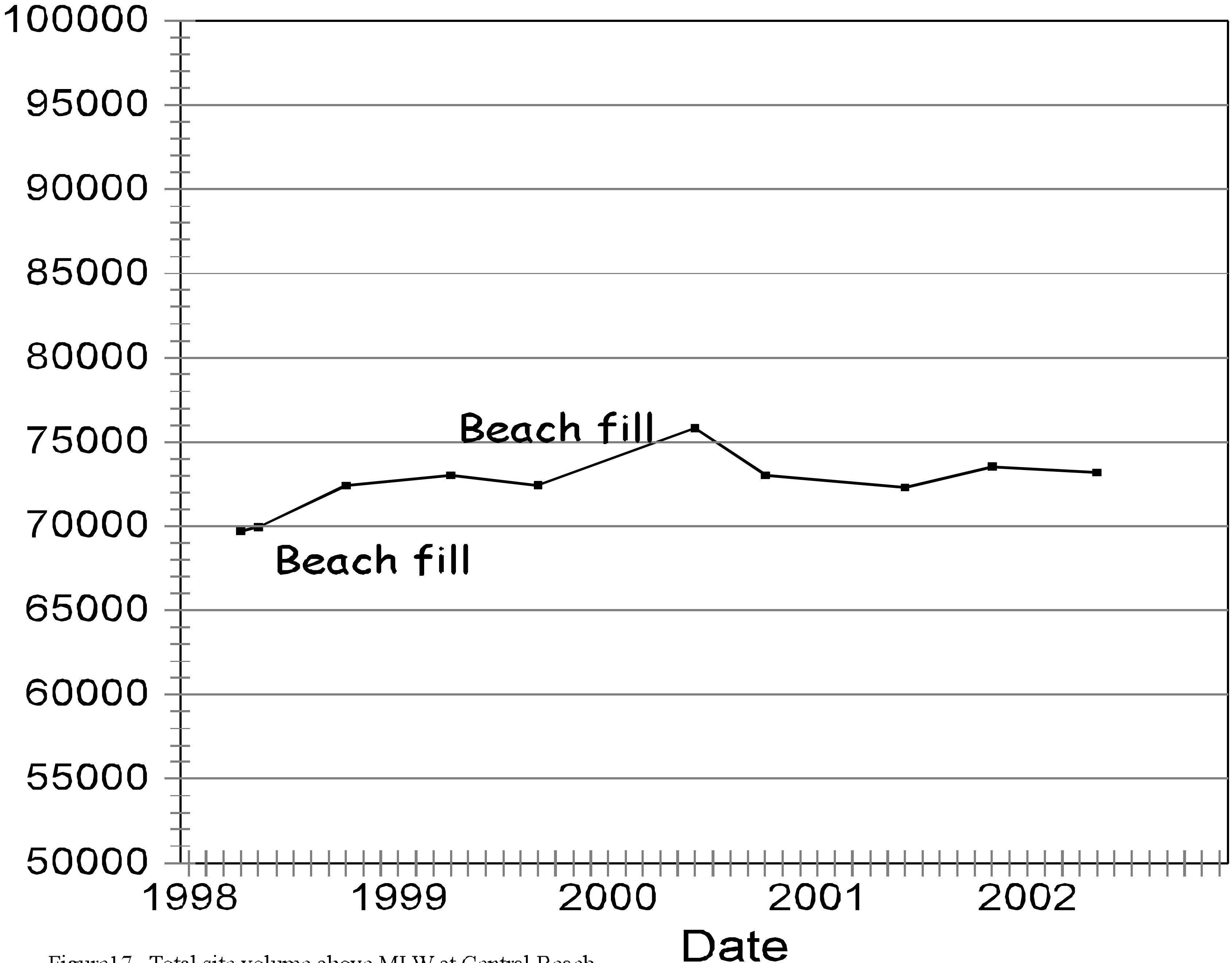


Figure17. Total site volume above MLW at Central Beach.

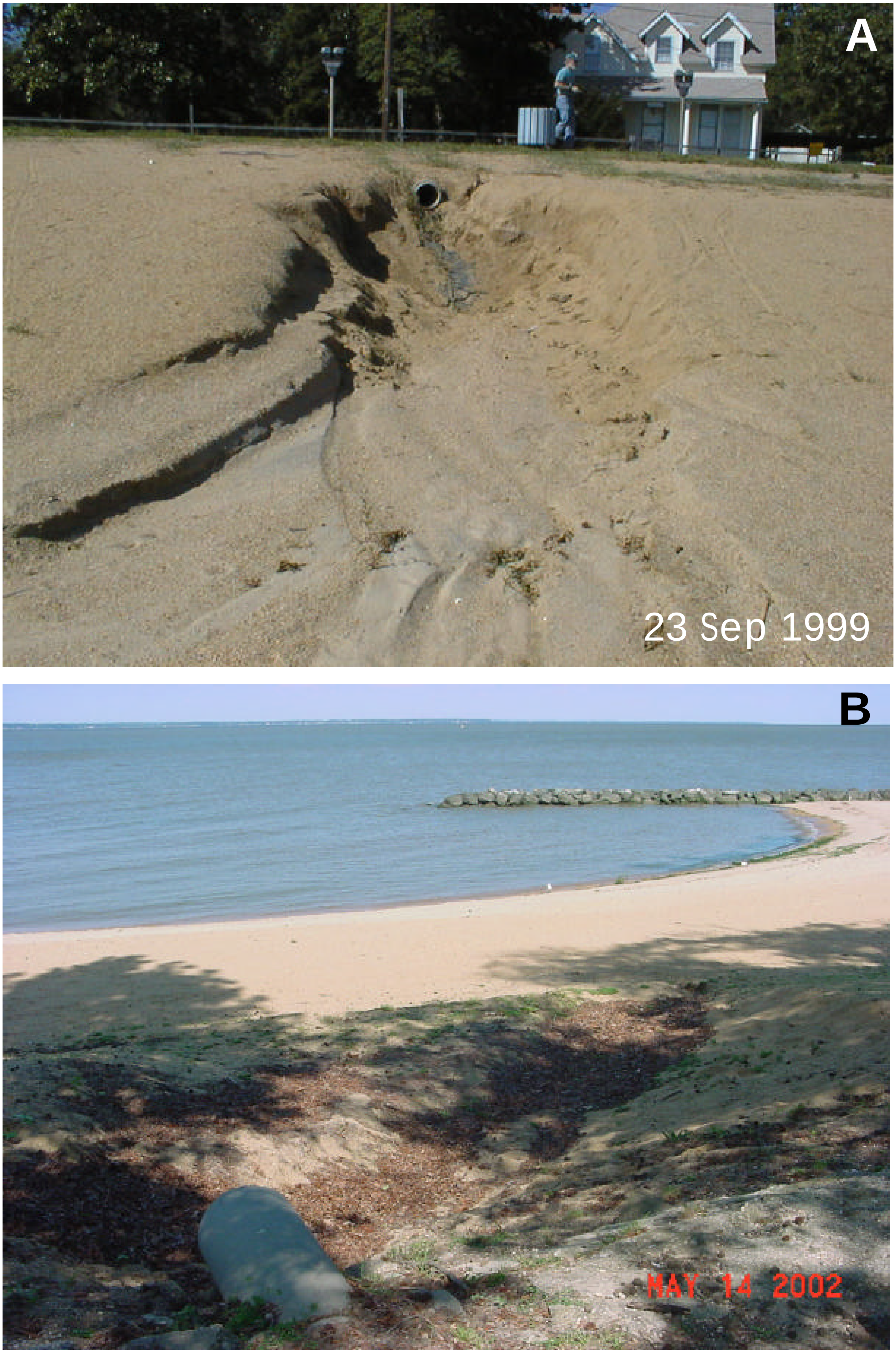


Figure 18. Central Beach storm water outfall pipe associated beach erosion A) after Hurricane Floyd in 1999 and B) in 2002.

IV. SUMMARY AND CONCLUSIONS

The change in the state of the beach at both Central Beach and Castlewood beach has been marked (Figures 19 and 20). Wide, usable, protective, stable recreational beaches have been created. In addition, Castlewood Beach acts to reduce shoaling at the entrance to Monroe Bay by allowing sand to accumulate behind the breakwaters. On the northern end, Central Beach also reduces the loss of sand to the system. The town shoreline north of Central Beach, the proposed area of redevelopment by the Town has been relatively stable in recent years thanks in part to the stability created by the breakwaters and beach fill at Central Beach and the structures placed along the shore. The breakwater system has "pinned" its south boundary and prevented sand loss down river. However, the area is subject to increased wave activity under northeast wind/wave conditions, particularly during northeast storm events.

Through time, much of the shoreline at Colonial Beach has been hardened with a rock revetment. Both the revetment and the breakwater systems replace a myriad of smaller, less efficient shore protection structures. However while the revetment abates erosion and protects infrastructure, it has halted the supply of native materials to the sediment transport system. Should sand be lost from the beaches during storm events, it is unlikely that it will return naturally. The native sediment type along this shore is relatively coarse due to the underlying geology. However, Central Beach's median grain size has been decreasing due to the beach fills that have taken place.

Measured shore change is occurring behind the breakwaters at Central Beach. The breakwaters are relatively low in comparison with the elevation of the beach. They provide a very stable beach but do not allow complete attachment of the sand behind the breakwaters due to their permeability. Still the beach is able to maintain its total sand volume. Sand shifts within the overall system in response to the wave climate.

The storm drains empty onto the beach and cause local erosion in the upper beach. These losses are not accounted for in the beach profile data. During storm events with a great deal of rainfall, severe erosion of the upper beach can occur. This situation can be rectified by directing the storm drains under the beach and through the breakwaters.

Figure 19. Central Beach in 1977 and 2001.

Figure 20. Castlewood Beach in 1977 and 2002.

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Appendix I
Data report on sand elevations at Central Beach

I. Data Information

Beach profile data came from several sources. The February 1981 beach profile and the beach fill template came from the U.S. Army Corps of Engineers Baltimore District's Preliminary Beach Erosion Control - Colonial Beach, Virginia plans. The April 3, 1986 data were measured from plots of profiles taken by R. Peel Dillard, Certified Land Surveyor, Tappahannock, Virginia. The June 25, 2001 data is from VIMS's database of semi-annual profiles. However, all 18 profiles were not surveyed each date.

VIMS's baseline is generally parallel and behind the Corps baseline at Central Beach (Figure I-1). VIMS profiles were placed to measure changes at the ends of the breakwaters, across the center of the breakwaters, and mid-bay. The Corps cross-sections are based on the design of the system. Since cross-sectional profiles are not directly comparable because the profiles are not located directly on top on another, adjustments were made to the Corps and Dillard surveys (both used the same baseline) to make the data comparable to VIMS data (Table I-1). The northernmost section of the beach is difficult to compare since the Corps baseline angled at VIMS profile 3. Also note that a revetment was installed at the southern end of Central Beach and profile 18 crosses it.

Table I-1. Adjustment data for Corps data to VIMS baseline. VIMS profiles 4 and 15 were not used in the analysis.

VIMS Profile No.	Corps Profile No.	Change West (ft)	Change North (ft)
1	15+78	11	8
2	15+00	11	-48
3	14+00	11	48
5	12+00	10	-9
6	11+00	10	15
7	10+00	10	16
8	9+00	9	-9
9	8+00	8	31
10	7+50	8	25
11	6+50	8	9
12	5+50	8	2
13	5+00	8	-21
14	4+00	8	13
16	2+50	7	-41
17	1+00	7	75
18	0+00	8	25

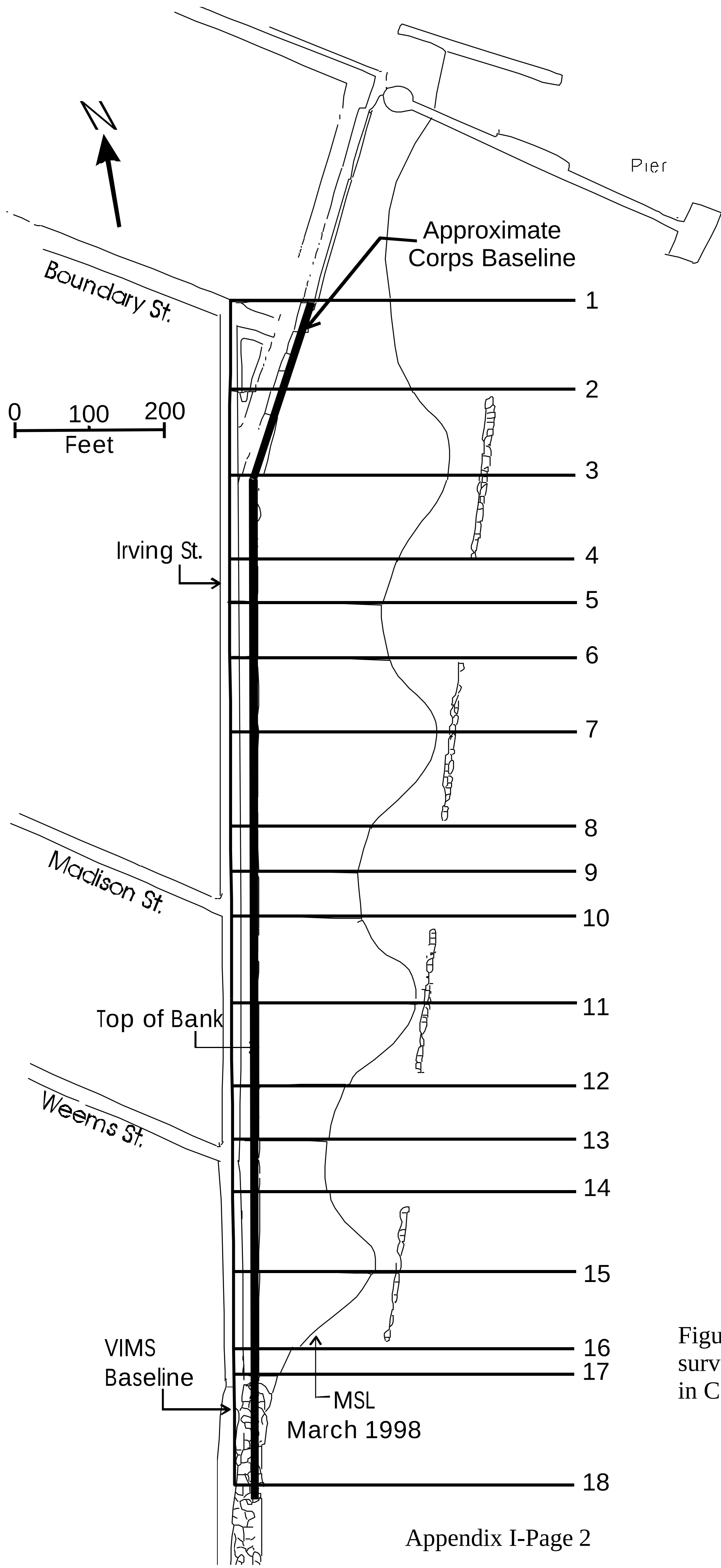

Figure I-1. VIMS and Corps survey baseline for Central Beach in Colonial Beach.

I. Data Information

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8	9+00	9	-9
9	8+00	8	31
10	7+50	8	25
11	6+50	8	9
12	5+50	8	2
13	5+00	8	-21
14	4+00	8	13
16	2+50	7	-41
17	1+00	7	75
18	0+00	8	25

II. Calculations

The four profile dates were plotted (Appendix IA) and volume calculations made. In order to determine the accuracy of the profiles, volume calculations of the fill template were made and compared to information on the plans. Total volume of the fill was calculated to be 49,910 cy by the Corps. VIMS calculated 49,691 cy (Table I-2).

Two sets of volume calculations were made. The first set was volume within the template region and above the template depth (Table I-3). These regions are depicted on Figure I-2. The Xon and Xoff indicate the distance from the baseline where the volume calculations start and stop and is based on the region where the beach fill template was place. The depth is where the beach fill meets the original bathymetry (Feb 1981). Table I-4 shows the volume in fill region for each profile and the net change between the post-fill template (1981) and June 2001. Table I-5 shows the total volume above the template depth (Table I-3).

Additional profiles were plotted against the beach fill template. These are shown in Appendix I-B.

Table I-2. Total fill volume.

	1981 Beach Fill Template		
Profile	**Fill Volume (cy/ft)**	**Length (ft)**	**Fill Volume (cy)**
1	25.696	63.5	1,632
2	37.367	119	4,447
3	39.281	137.5	5,401
5	49.761	118	5,872
6	42.146	86.5	3,646
7	39.37	112.5	4,429
8	37.326	91.5	3,415
9	33.478	59.5	1,992
10	27.883	87.5	2,440
11	24.209	113	2,736
12	26.304	90.5	2,381
13	30.296	68.5	2,075
14	23.017	136	3,130
16	22.893	120	2,747
17	13.052	92.5	1,207
18	8.817	75	661
		Sum	48,211
north of profile 1*			1,480
		Total	**49,691**

*From Preliminary Plans

Table I-3. Total volume above template depth.

Volume Regions & Depth				Alternative	
Profile	Xon (ft)	Xoff (ft)	Depth (ft MLW)	Xon (ft)	Xoff (ft)
1	181.00	424.00	-6		
2	133.00	341.00	-4.9		
3	108.00	329.00	-4.6	108.00	315.00
5	79.00	404.00	-6		
6	65.00	292.00	-4.7		
7	56.00	283.00	-3.7		
8	59.00	271.00	-3.7		
9	56.00	310.00	-4		
10	63.00	255.00	-3.2		
11	61.00	240.00	-2.5	61.00	252.00
12	54.00	233.00	-3.4		
13	49.00	278.00	-3.8		
14	57.00	218.00	-3.4		
16	44.00	202.00	-2.7		
17	35.00	168.00	-2.2		
18	36.00	152.00	-2		

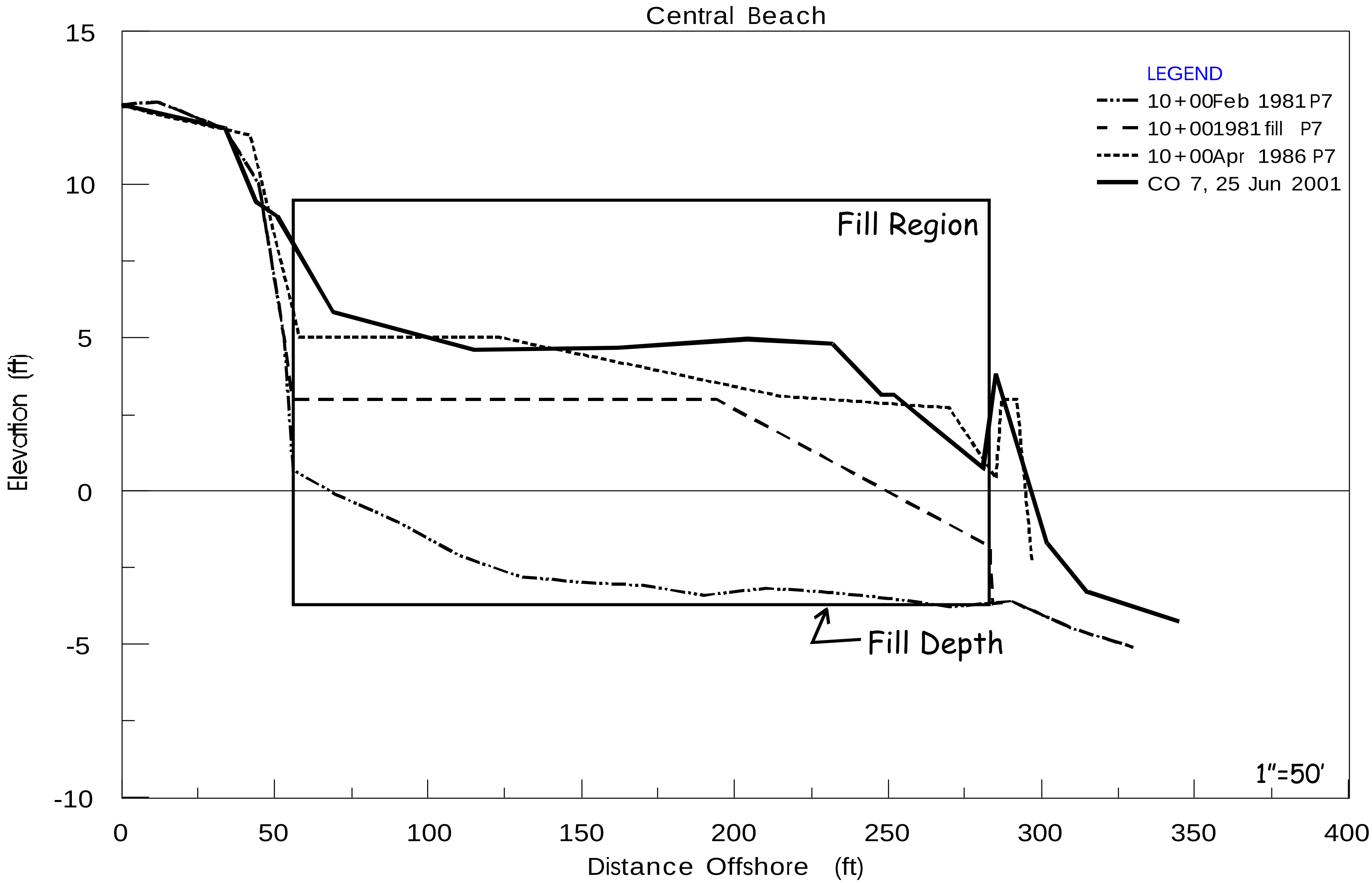


Figure I-2A. Fill region and depth considered in volume calculations.

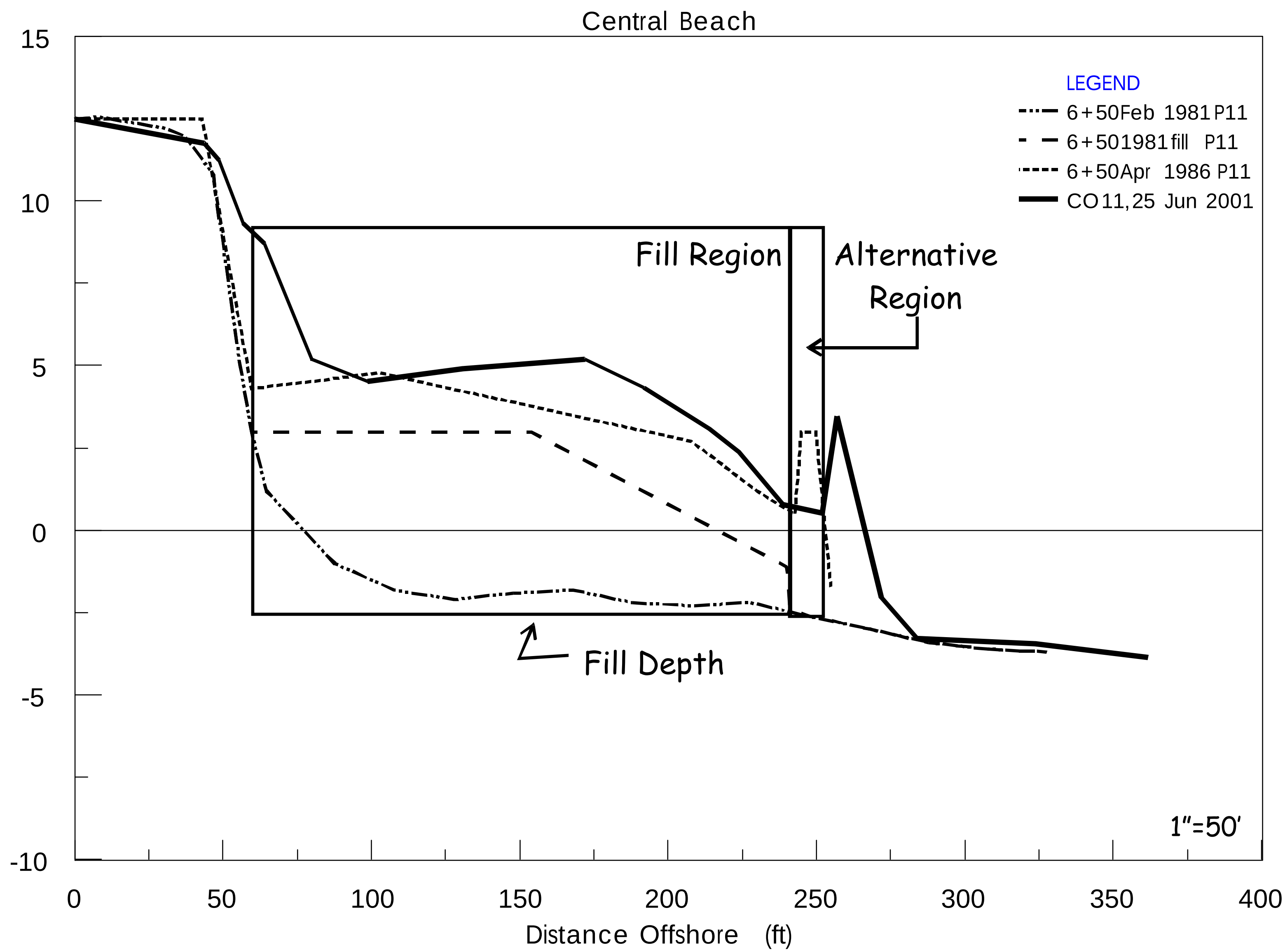


Figure I-2B. Fill region and depth considered in volume calculations with the alternative region demonstrated.

Table I-4. Volume in fill region.

Profile	Feb 1981 (cy/ft)	Fill 1981 (cy/ft)	Apr 1986 (cy/ft)	Jun 2001 (cy/ft)	Length (ft)	Feb 1981 (cy)	Fill 1981 (cy)	Apr 1986 (cy)	Jun 2001 (cy)	Net Change (cy) between Fill 1981 & Jun 2001
Volume in Fill Region Variable Widths and Elevations*										
1	26.137	51.833	37.538	31.830	63.5	1,660	3,291	2,384	2,021	(1,270)
2	16.123	53.444	48.814	44.895	119	1,919	6,360	5,809	5,343	(1,017)
3^	15.628	54.707	59.523	66.044	137.5	2,149	7,522	8,184	9,081	**1,559**
5	26.753	76.667	76.231	64.647	118	3,157	9,047	8,995	7,628	(1,418)
6	15.930	57.730	60.954	53.397	86.5	1,378	4,994	5,273	4,619	(375)
7	9.236	48.419	64.073	68.896	112.5	1,039	5,447	7,208	7,751	**2,304**
8	8.202	45.437	43.530	45.880	91.5	750	4,157	3,983	4,198	**41**
9	13.833	47.574	46.848	44.830	59.5	823	2,831	2,787	2,667	(163)
10	8.466	36.256	37.224	37.657	87.5	741	3,172	3,257	3,295	**123**
11^	5.764	29.933	40.178	46.854	113	651	3,382	4,540	5,295	**1,912**
12	9.245	35.341	32.982	34.242	90.5	837	3,198	2,985	3,099	(99)
13	10.199	40.170	35.574	29.878	68.5	699	2,752	2,437	2,047	(705)
14	7.972	30.913	28.134	24.954	136	1,084	4,204	3,826	3,394	(810)
16	4.273	26.305	28.867	15.853	120	513	3,157	3,464	1,902	(1,254)
17	3.285	16.370	6.575	9.549	92.5	304	1,514	608	883	(631)
18	2.569	11.296	4.100	3.604	75	193	847	308	270	(577)
Total	**183.62**	**662.40**	**651.15**	**623.01**	**1,571**	**17,895**	**65,876**	**66,048**	**63,493**	**(2,383)**
^Profiles 3 and 11 are breakwater profiles whose Fill Regions do not match.										
3	15.601	52.919	56.603	63.285	137.5	2,145	7,276	7,783	8,702	**1,425**
11	5.768	29.968	42.191	48.254	113	652	3,386	4,768	5,453	**2,066**
Alternative Total	**183.592**	**660.642**	**650.238**	**621.651**	**1,571**	**17,892**	**65,634**	**65,874**	**63,272**	**(2,362)**

*See Volume data for detailed widths and elevation

Total Gain	**5,938**
Total Gain Alternative	**5,958**

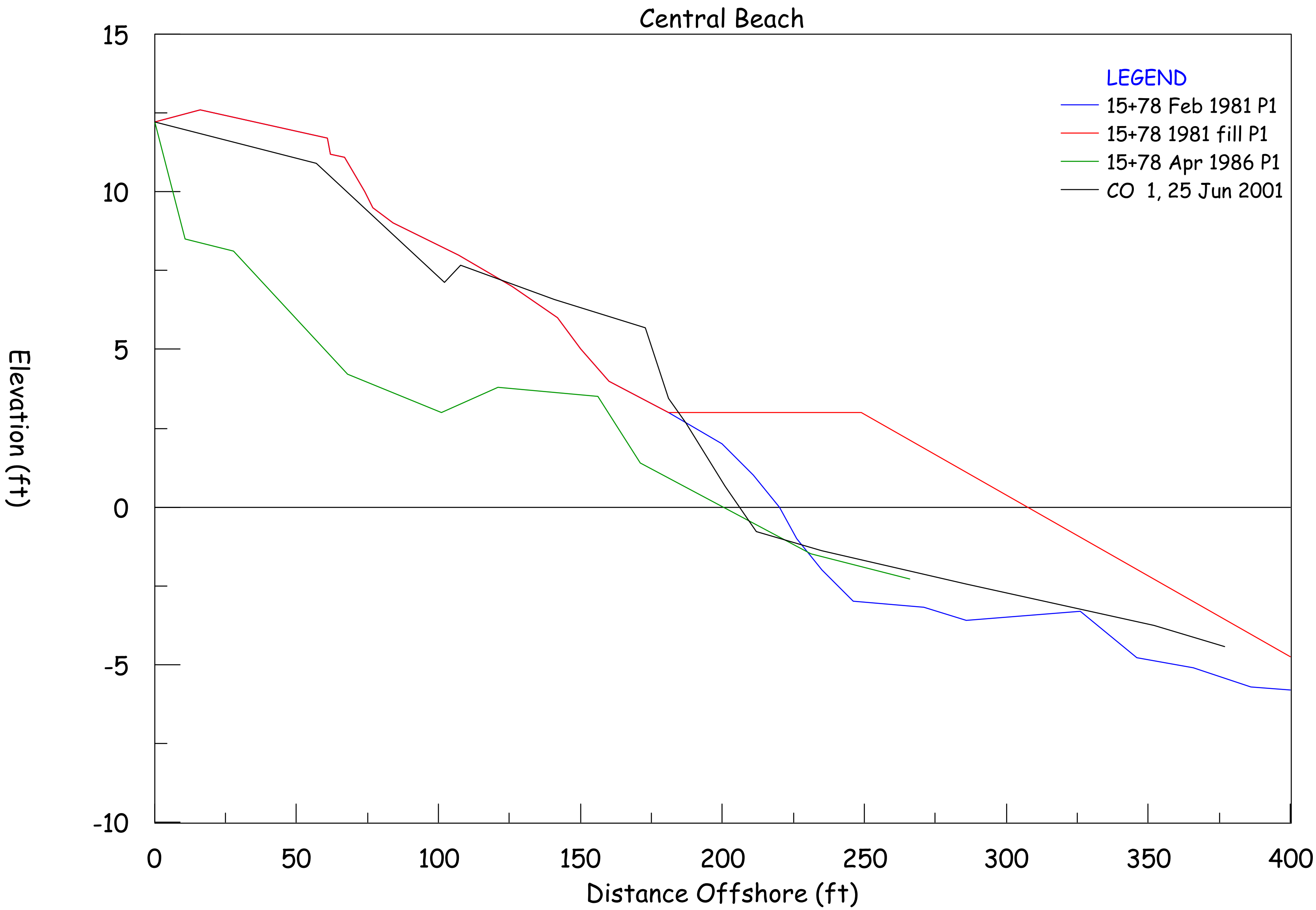
Table I-5. Volume above fill depth.

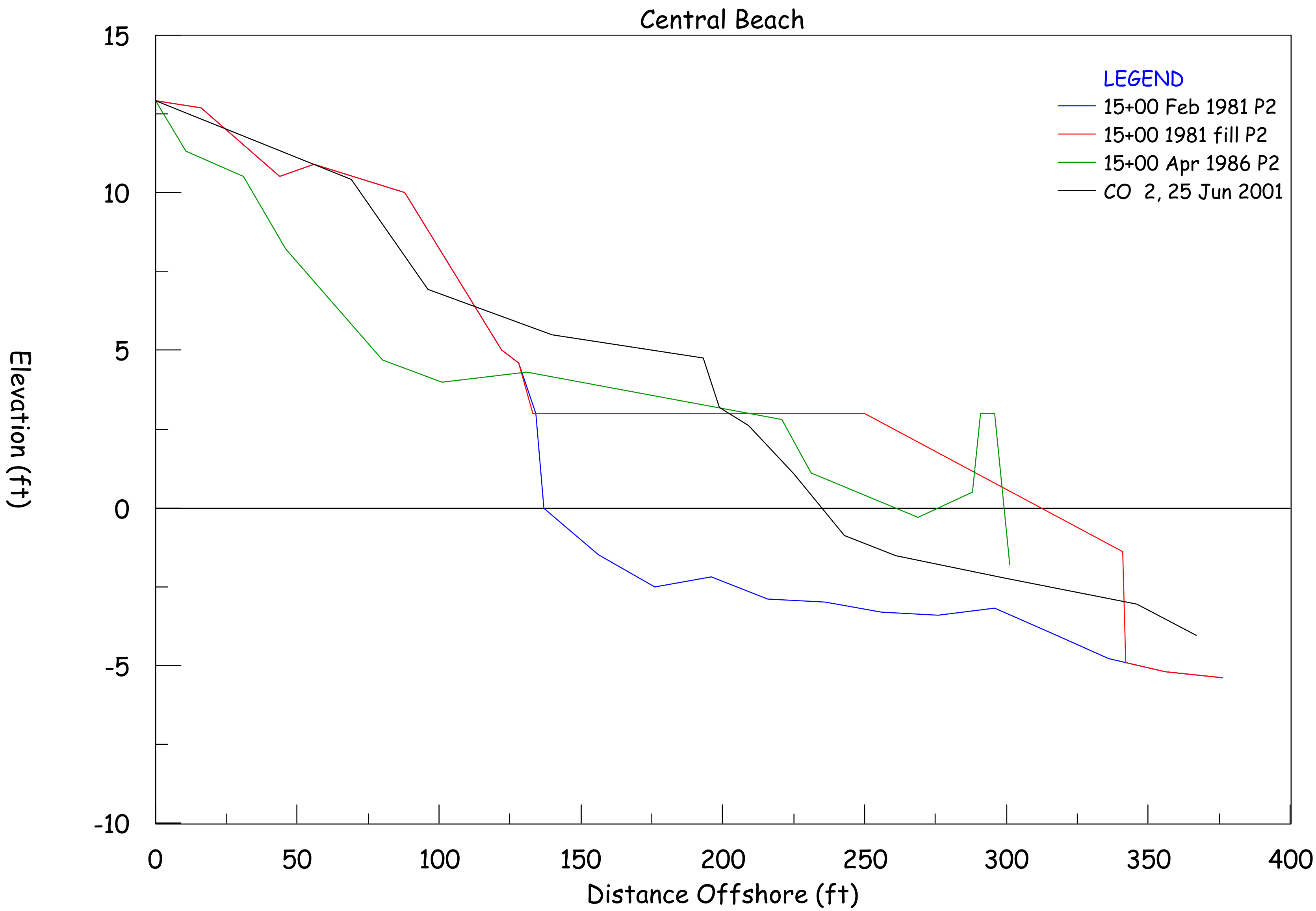
Volume Above Fill Depth Variable Widths and Elevations*										Net Change (cy) between
Profile	Feb 1981 (cy/ft)	Fill 1981 (cy/ft)	Apr 1986 (cy/ft)	Jun 2001 (cy/ft)	Length (ft)	Feb 1981 (cy)	Fill 1981 (cy)	Apr 1986 (cy)	Jun 2001 (cy)	Fill 1981 & Jun 2001
1	125.052	150.748	88.102	127.681	63.5	7,941	9,572	5,594	8,108	(1,465)
2	88.247	125.609	102.991	117.569	119	10,501	14,947	12,256	13,991	(957)
3	73.123	112.260	112.370	124.089	137.5	10,054	15,436	15,451	17,062	**1,626**
5	69.683	119.444	104.148	106.922	118	8,223	14,094	12,289	12,617	(1,478)
6	49.715	91.823	98.893	92.436	86.5	4,300	7,943	8,554	7,996	**53**
7	39.502	78.842	97.744	104.000	112.5	4,444	8,870	10,996	11,700	**2,830**
8	40.138	77.416	75.906	79.769	91.5	3,673	7,084	6,945	7,299	**215**
9	45.158	78.636	75.340	77.326	59.5	2,687	4,679	4,483	4,601	(78)
10	40.270	68.142	72.419	72.081	87.5	3,524	5,962	6,337	6,307	**345**
11	35.900	60.106	73.439	82.845	113	4,057	6,792	8,299	9,361	**2,570**
12	37.776	64.087	61.957	65.095	90.5	3,419	5,800	5,607	5,891	**91**
13	37.302	67.316	60.155	57.100	68.5	2,555	4,611	4,121	3,911	(700)
14	36.531	59.507	59.440	55.204	136	4,968	8,093	8,084	7,508	(585)
16	24.614	47.373	52.259	35.183	120	2,954	5,685	6,271	4,222	(1,463)
17	17.011	30.061	20.601	24.266	92.5	1,574	2,781	1,906	2,245	(536)
18	15.202	23.930	18.094	17.896	75	1,140	1,795	1,357	1,342	(453)
Total	**775.22**	**1,255.30**	**1,173.86**	**1,239.46**	**1,571**	**76,013**	**124,143**	**118,550**	**124,160**	**17**

*See Volume data for detailed widths and elevations

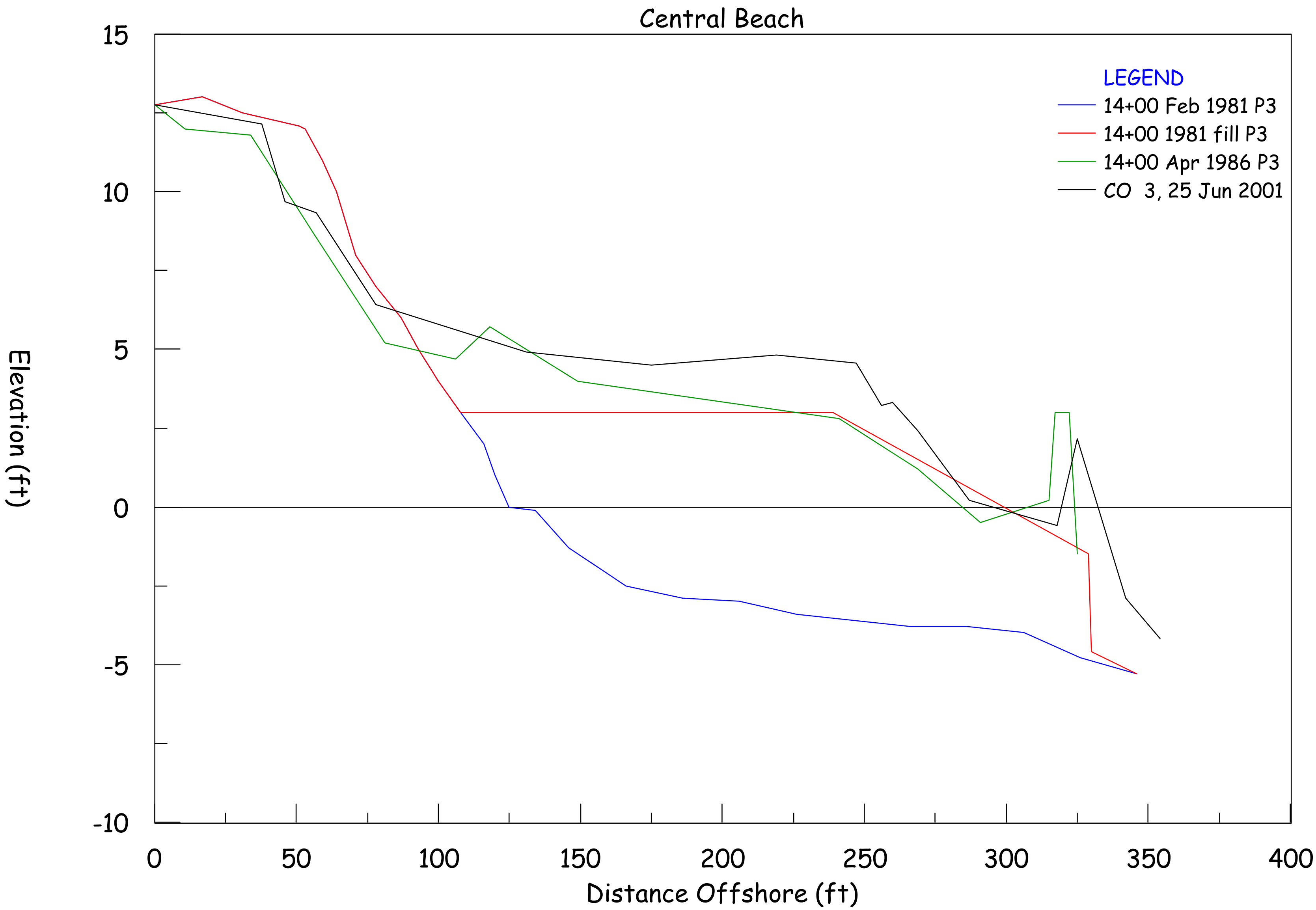
Total Gain	**7,730**

Appendix I-A

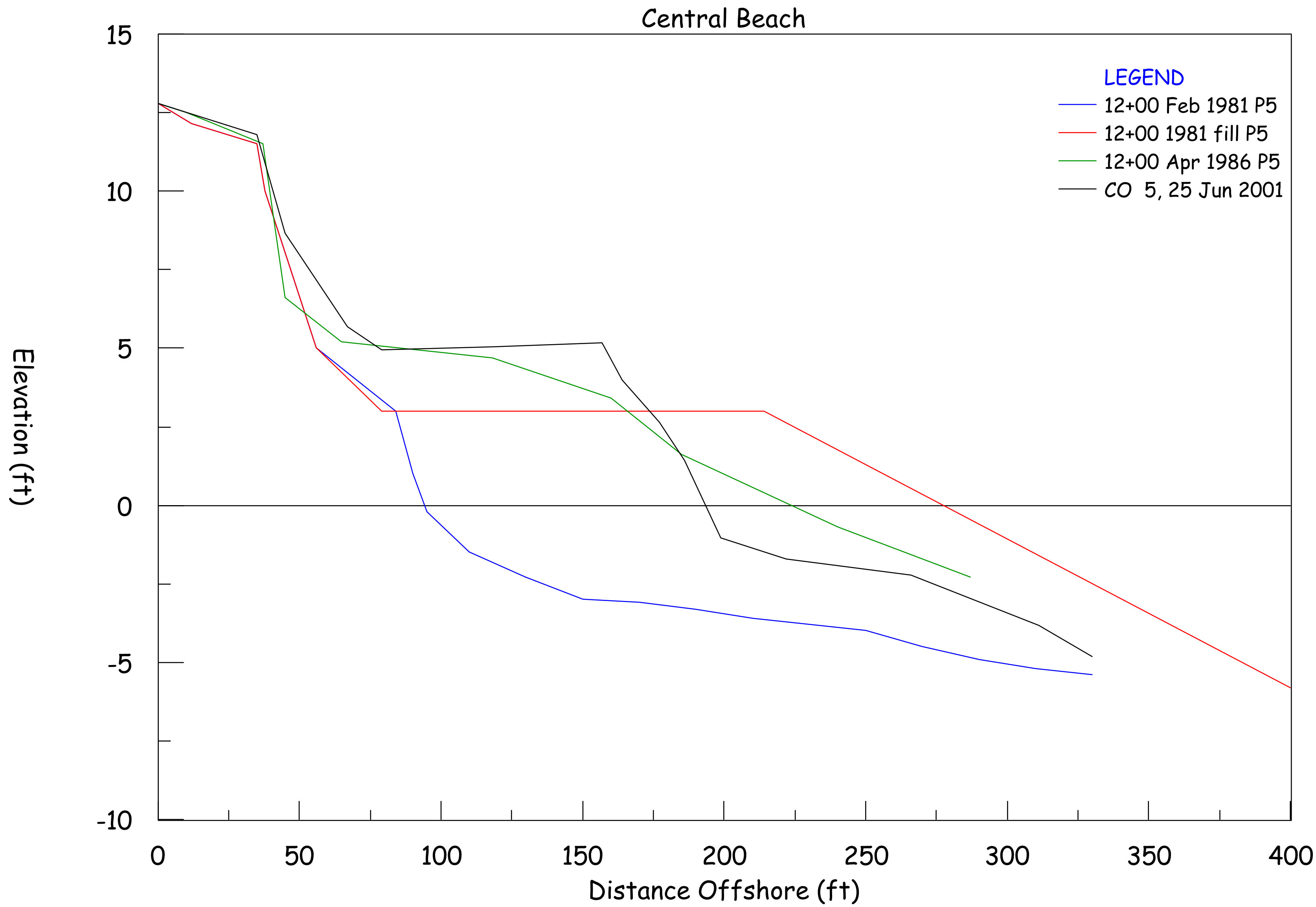

Central Beach
LEGEND
15+78 Feb 1981 P1
15+78 1981 fill P1
15+78 Apr 1986 P1
CO 1, 25 Jun 2001
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)



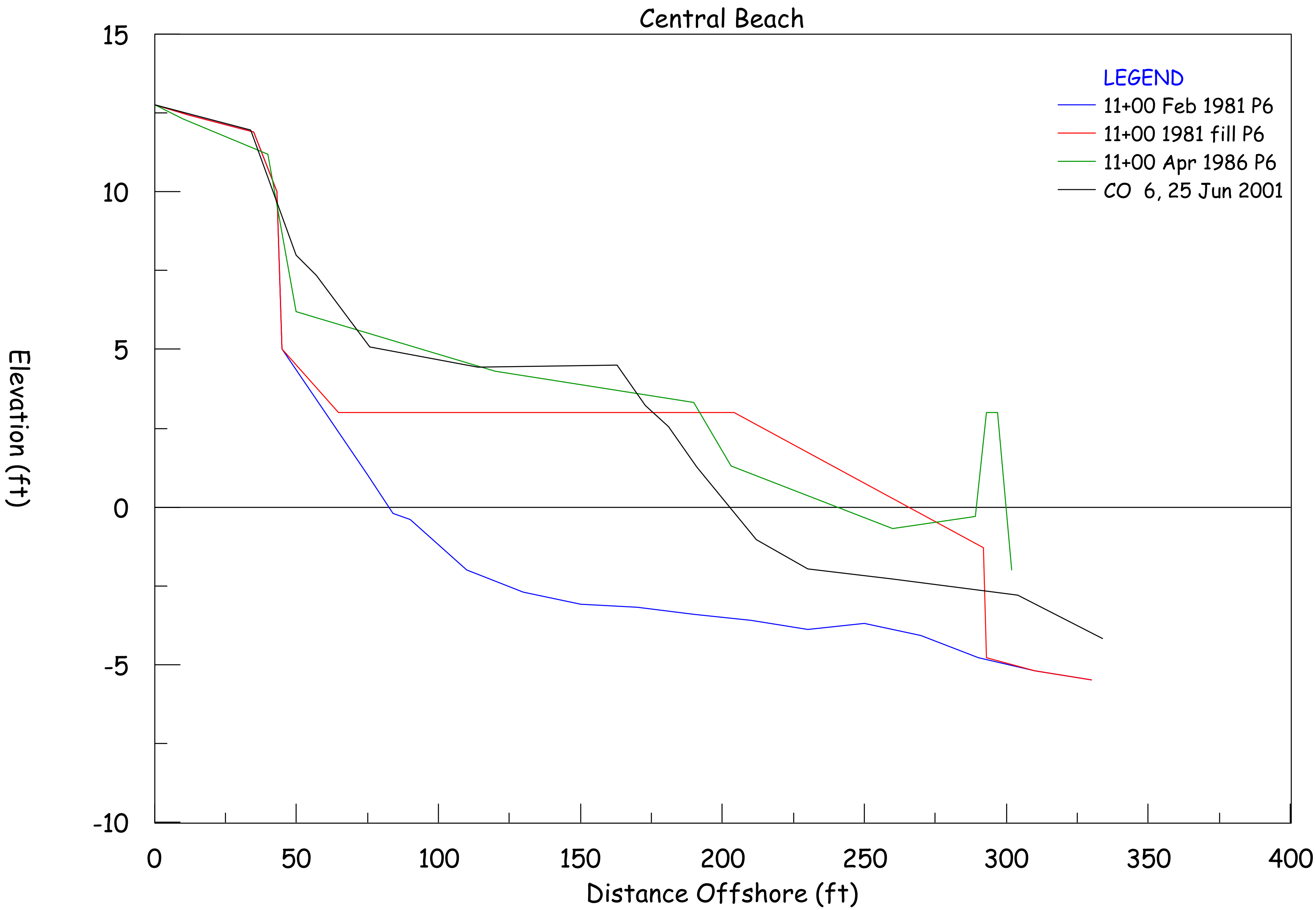
Central Beach
LEGEND
15+00 Feb 1981 P2
15+00 1981 fill P2
15+00 Apr 1986 P2
CO 2, 25 Jun 2001
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

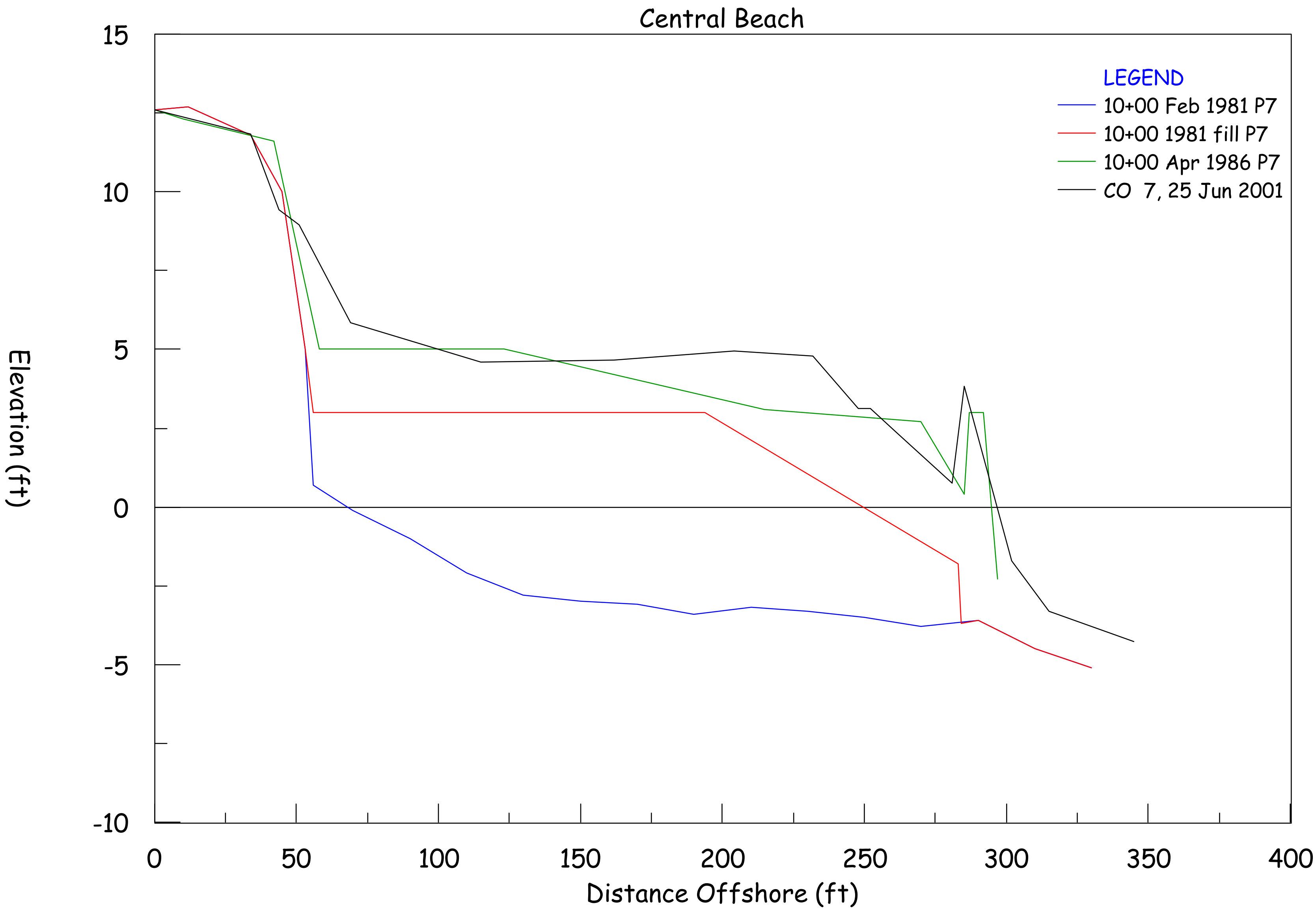


Central Beach
LEGEND
14+00 Feb 1981 P3
14+00 1981 fill P3
14+00 Apr 1986 P3
CO 3, 25 Jun 2001
15
10
5
0
-5
-10
Elevation (ft)
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

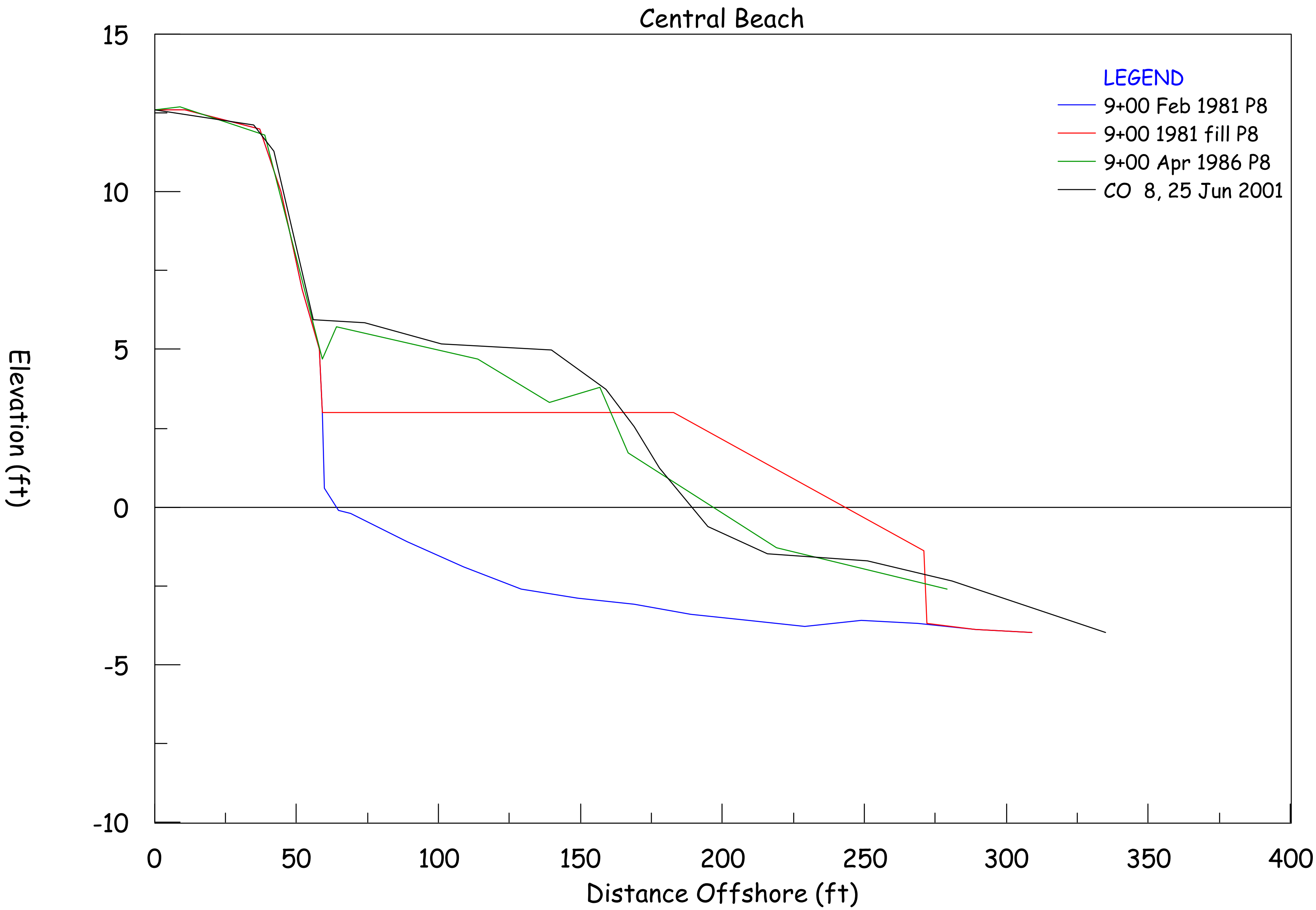


Central Beach
LEGEND
12+00 Feb 1981 P5
12+00 1981 fill P5
12+00 Apr 1986 P5
CO 5, 25 Jun 2001
15
10
5
0
-5
-10
Elevation (ft)
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

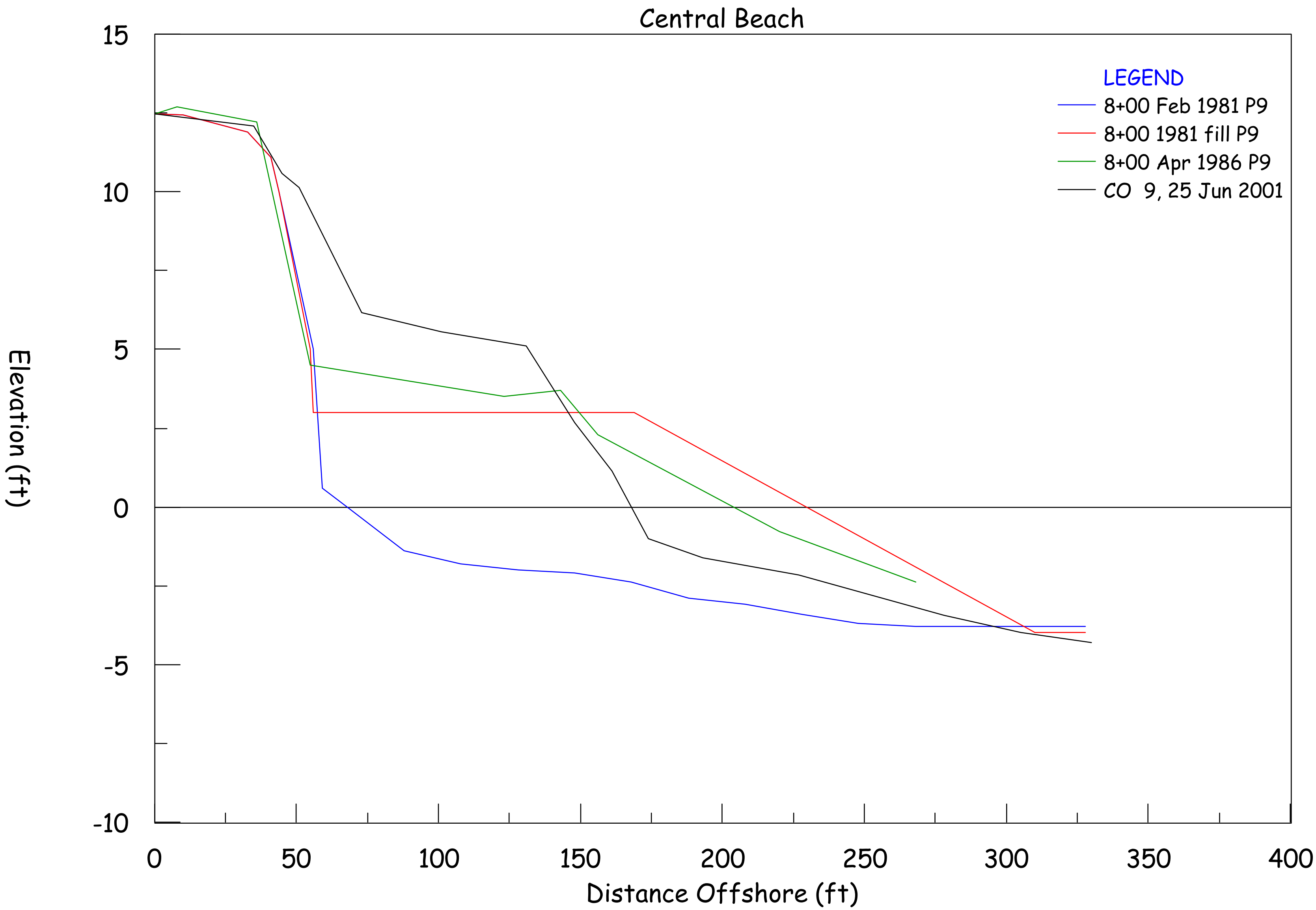

Central Beach
LEGEND
11+00 Feb 1981 P6
11+00 1981 fill P6
11+00 Apr 1986 P6
CO 6, 25 Jun 2001
Elevation (ft)
Distance Offshore (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400



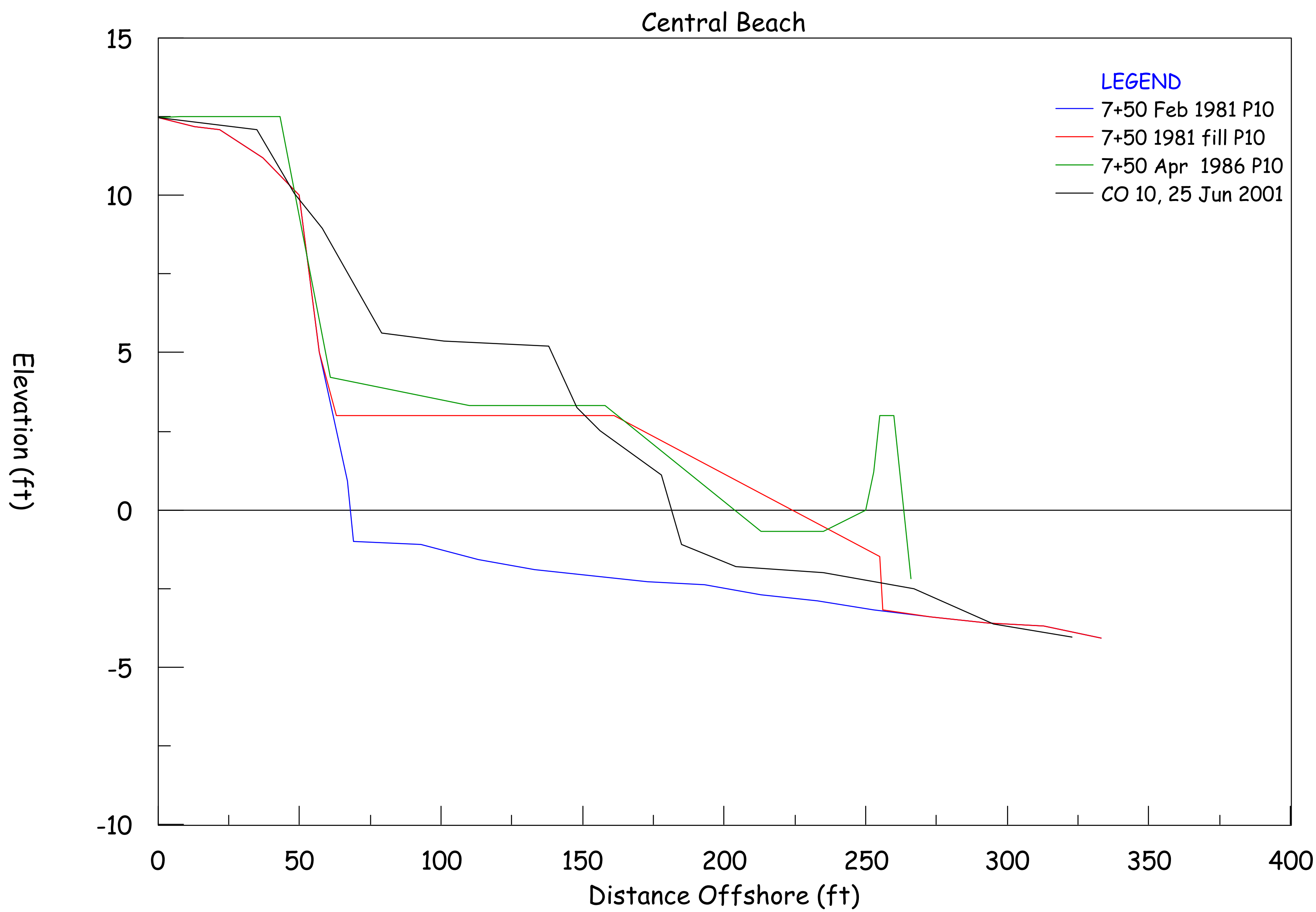
Central Beach
LEGEND
10+00 Feb 1981 P7
10+00 1981 fill P7
10+00 Apr 1986 P7
CO 7, 25 Jun 2001
15
10
5
0
-5
-10
Elevation (ft)
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)



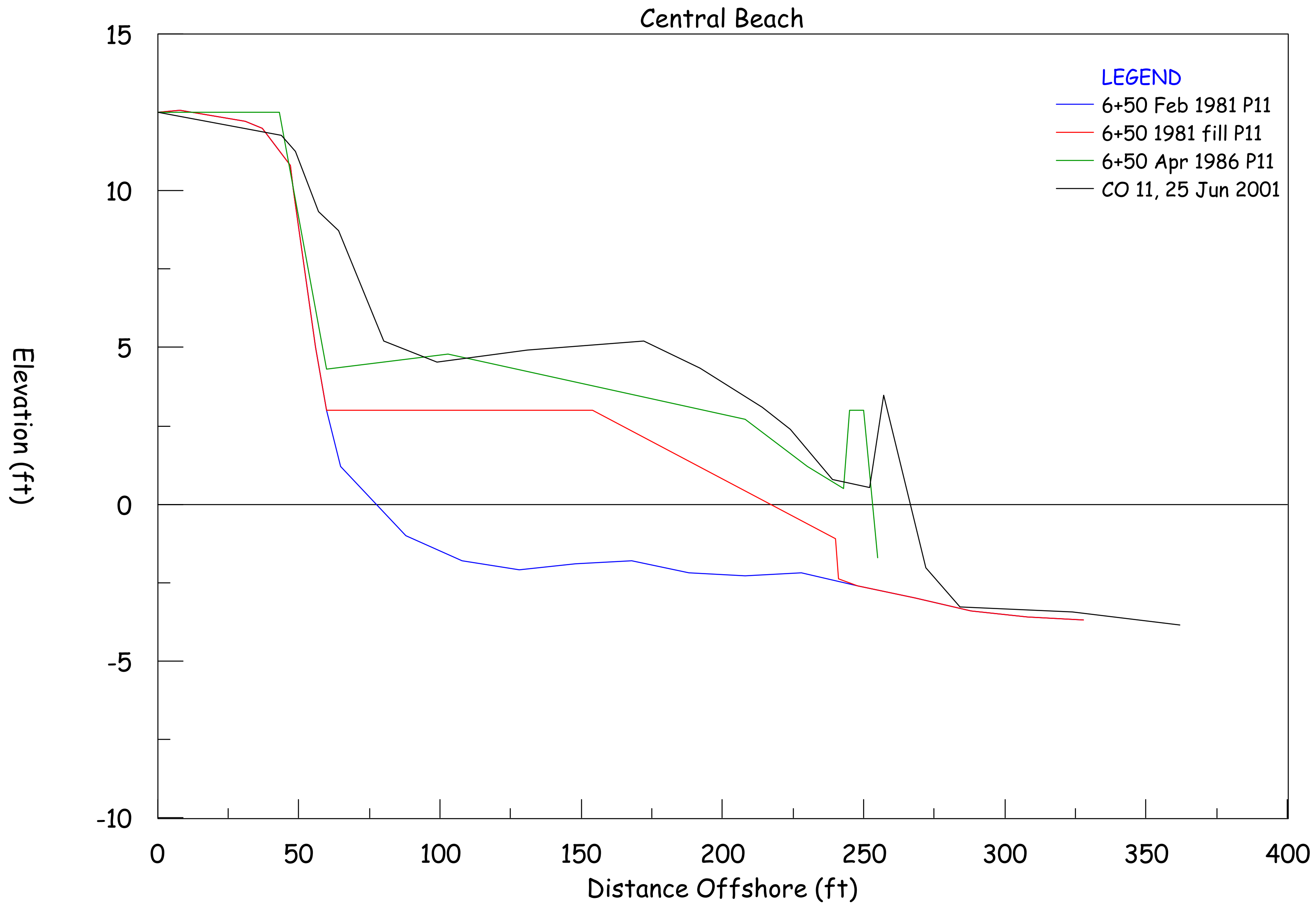
Central Beach
LEGEND
9+00 Feb 1981 P8
9+00 1981 fill P8
9+00 Apr 1986 P8
CO 8, 25 Jun 2001
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

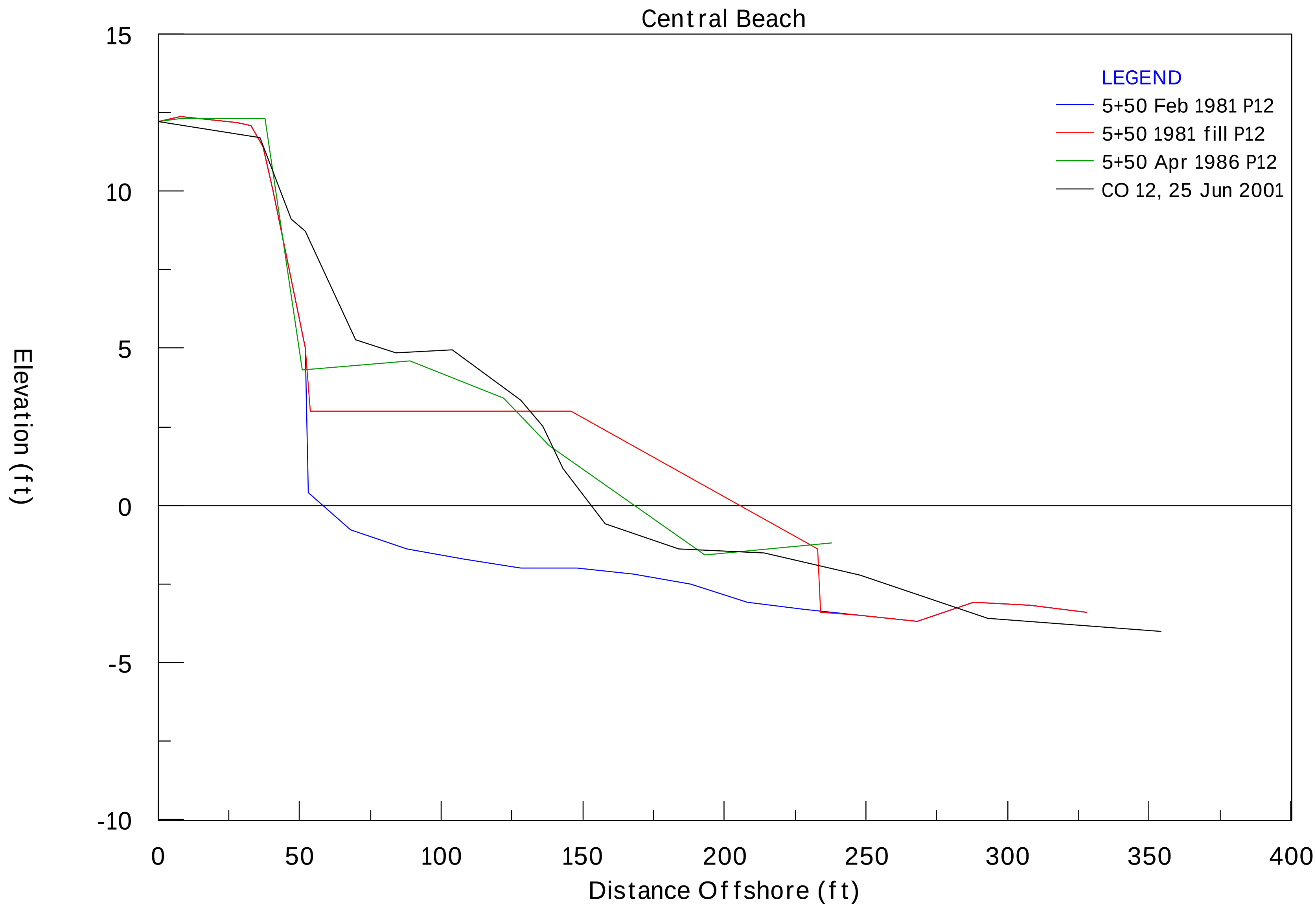


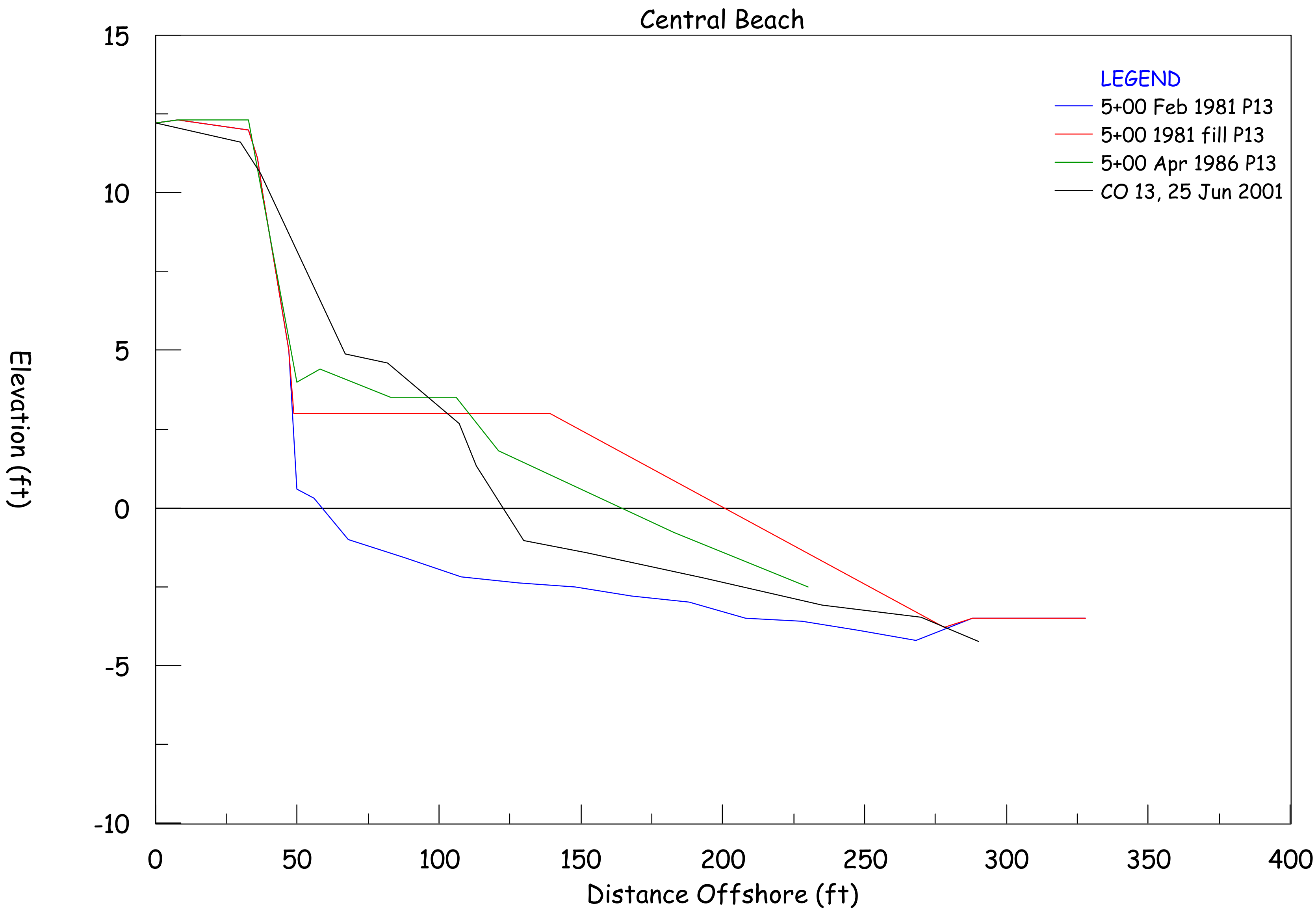
Central Beach
LEGEND
8+00 Feb 1981 P9
8+00 1981 fill P9
8+00 Apr 1986 P9
CO 9, 25 Jun 2001
Elevation (ft)
Distance Offshore (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400



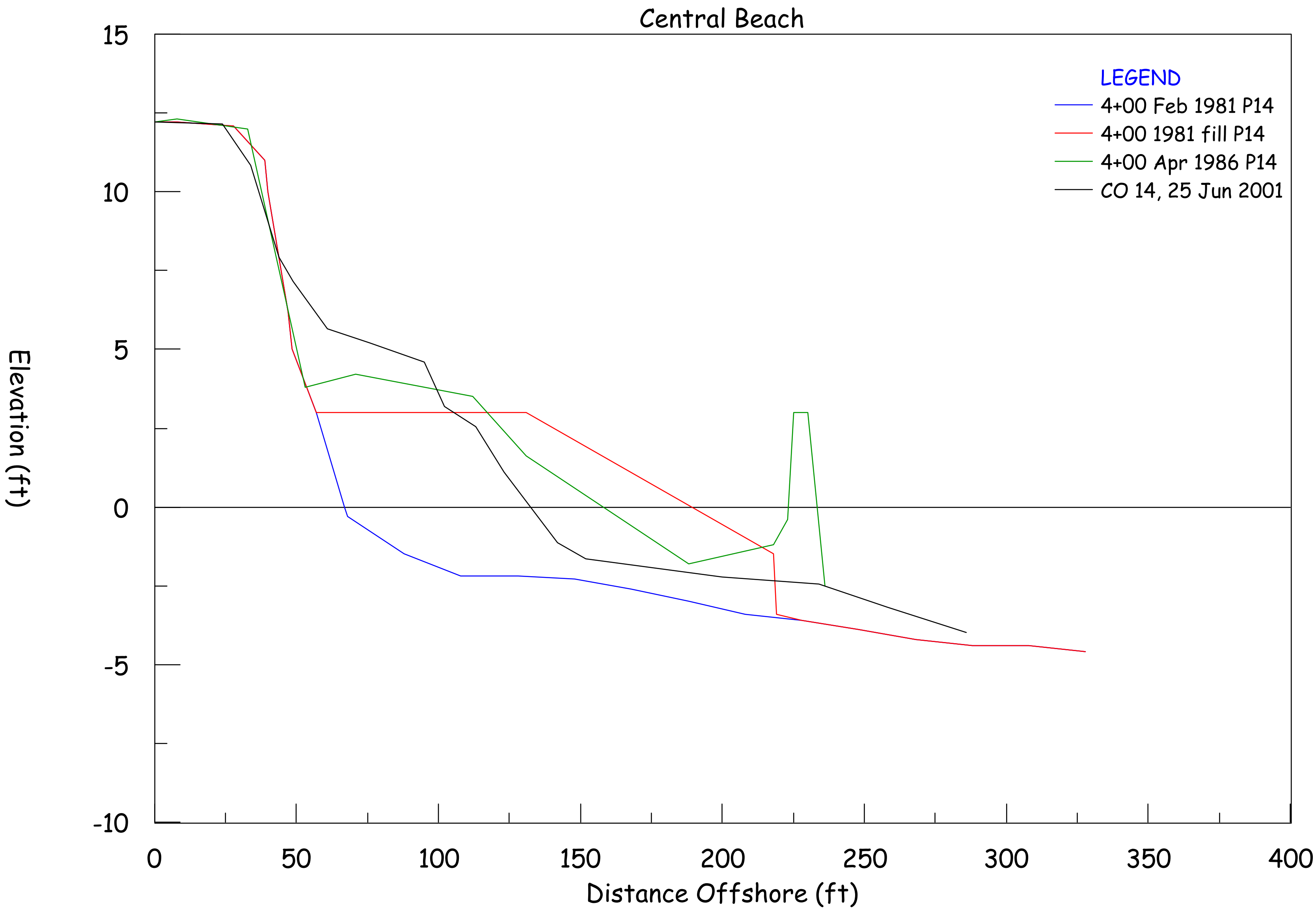
Central Beach
LEGEND
7+50 Feb 1981 P10
7+50 1981 fill P10
7+50 Apr 1986 P10
CO 10, 25 Jun 2001
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

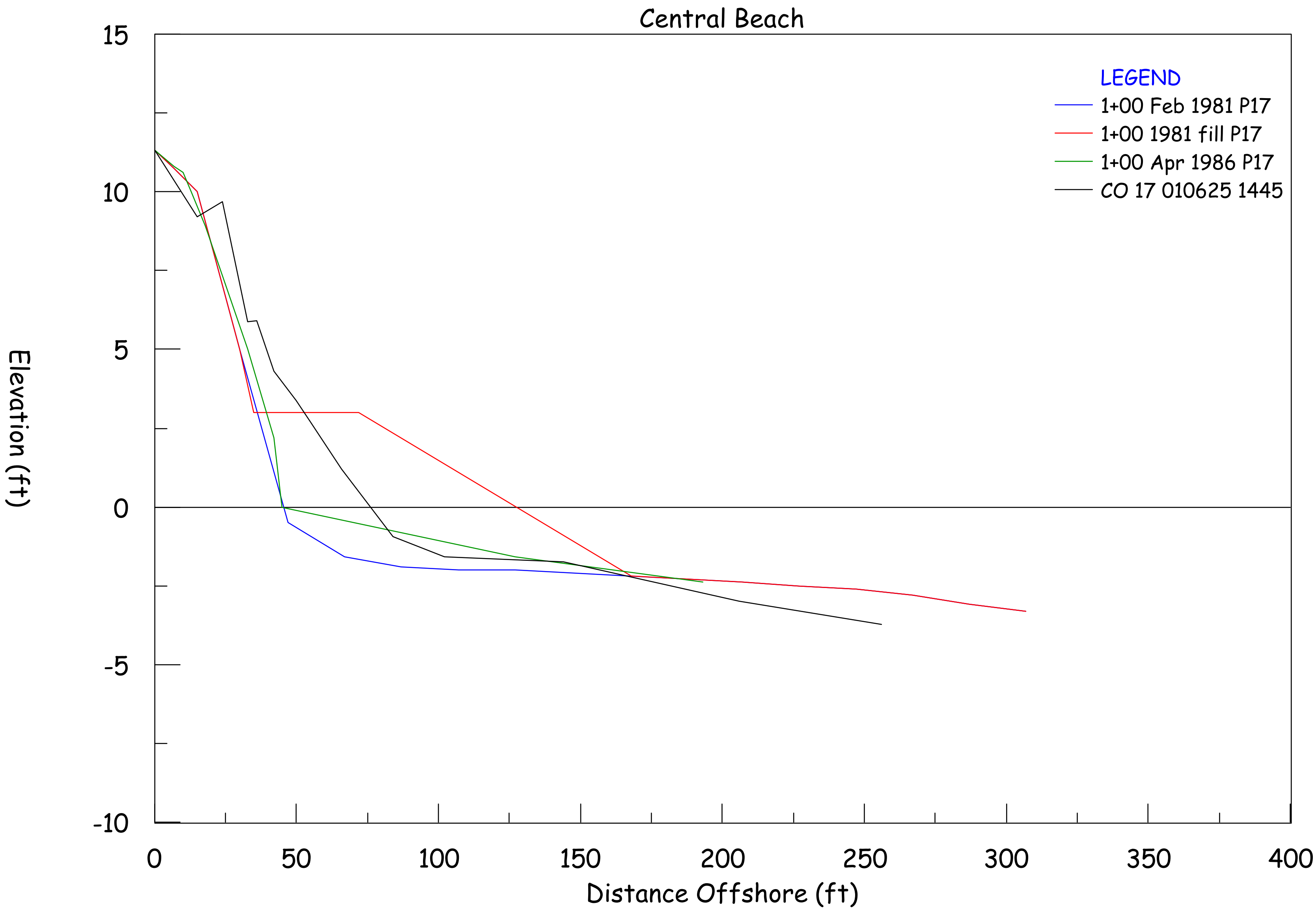

Central Beach
LEGEND
6+50 Feb 1981 P11
6+50 1981 fill P11
6+50 Apr 1986 P11
CO 11, 25 Jun 2001
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Elevation (ft)
Distance Offshore (ft)


Central Beach
LEGEND
5+50 Feb 1981 P12
5+50 1981 fill P12
5+50 Apr 1986 P12
CO 12, 25 Jun 2001
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Elevation (ft)
Distance Offshore (ft)

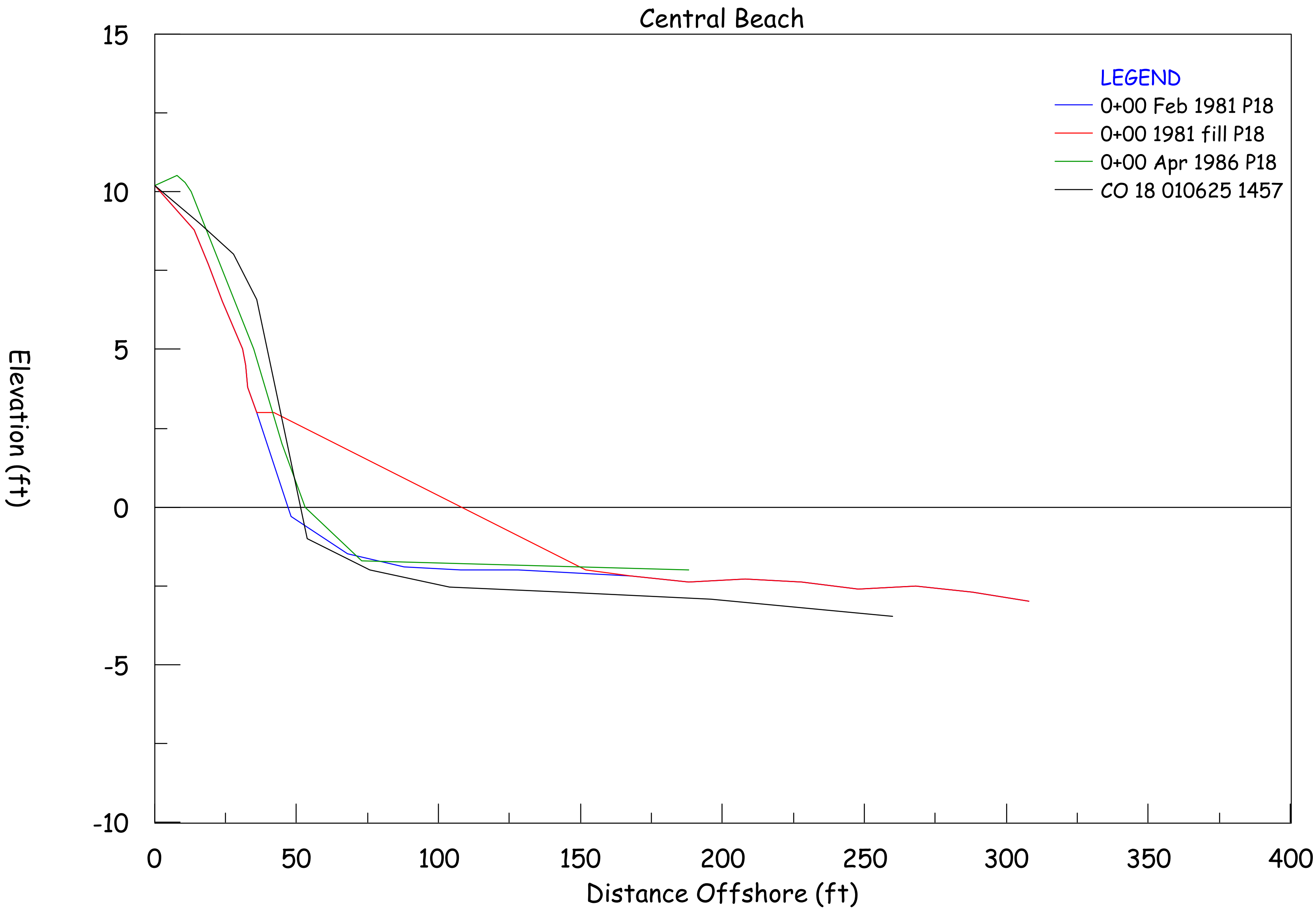


Central Beach
LEGEND
5+00 Feb 1981 P13
5+00 1981 fill P13
5+00 Apr 1986 P13
CO 13, 25 Jun 2001
Elevation (ft)
Distance Offshore (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400


Central Beach
LEGEND
4+00 Feb 1981 P14
4+00 1981 fill P14
4+00 Apr 1986 P14
CO 14, 25 Jun 2001
15
10
5
0
-5
-10
Elevation (ft)
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

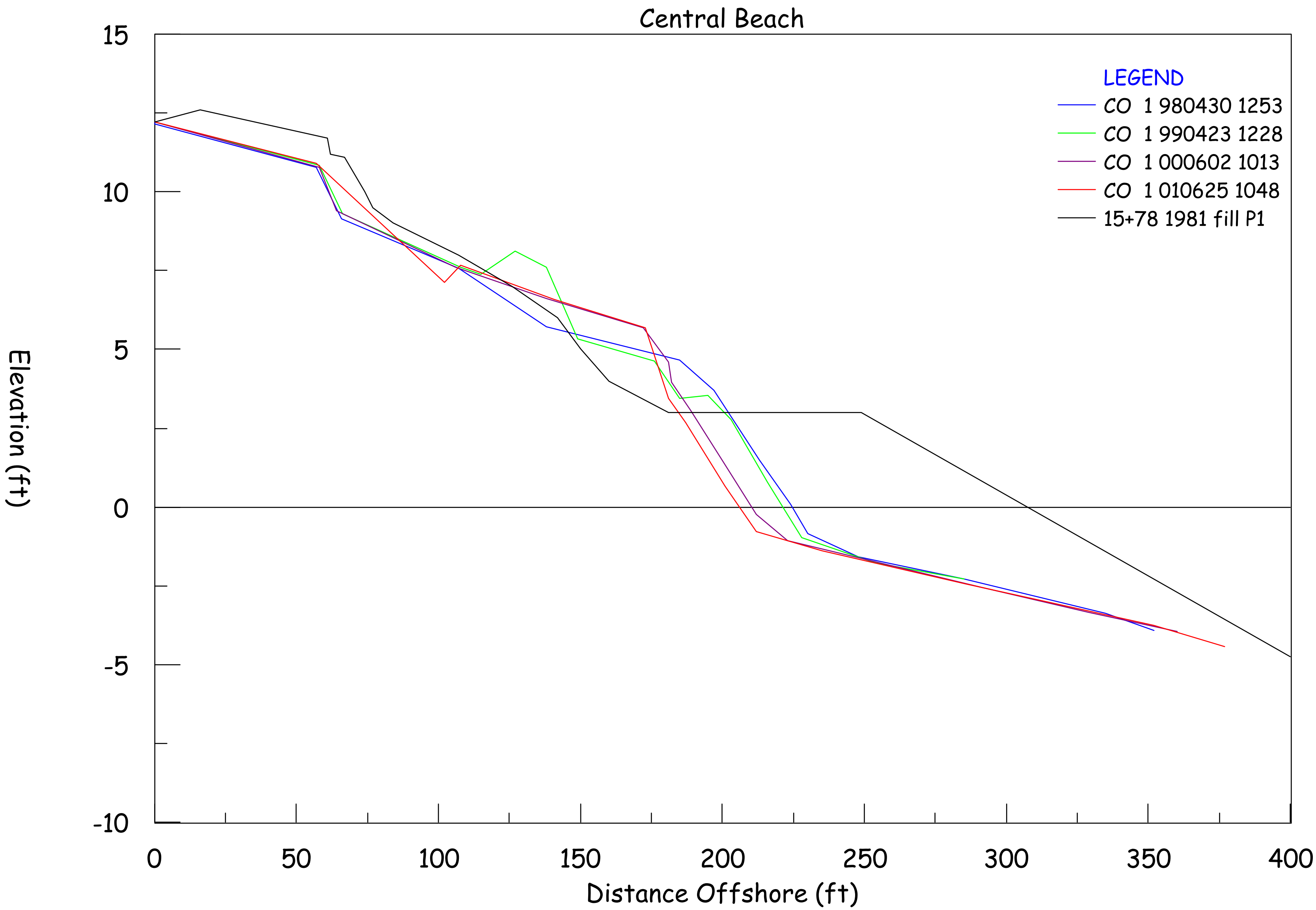


Central Beach
LEGEND
1+00 Feb 1981 P17
1+00 1981 fill P17
1+00 Apr 1986 P17
CO 17 010625 1445
15
10
5
0
-5
-10
Elevation (ft)
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

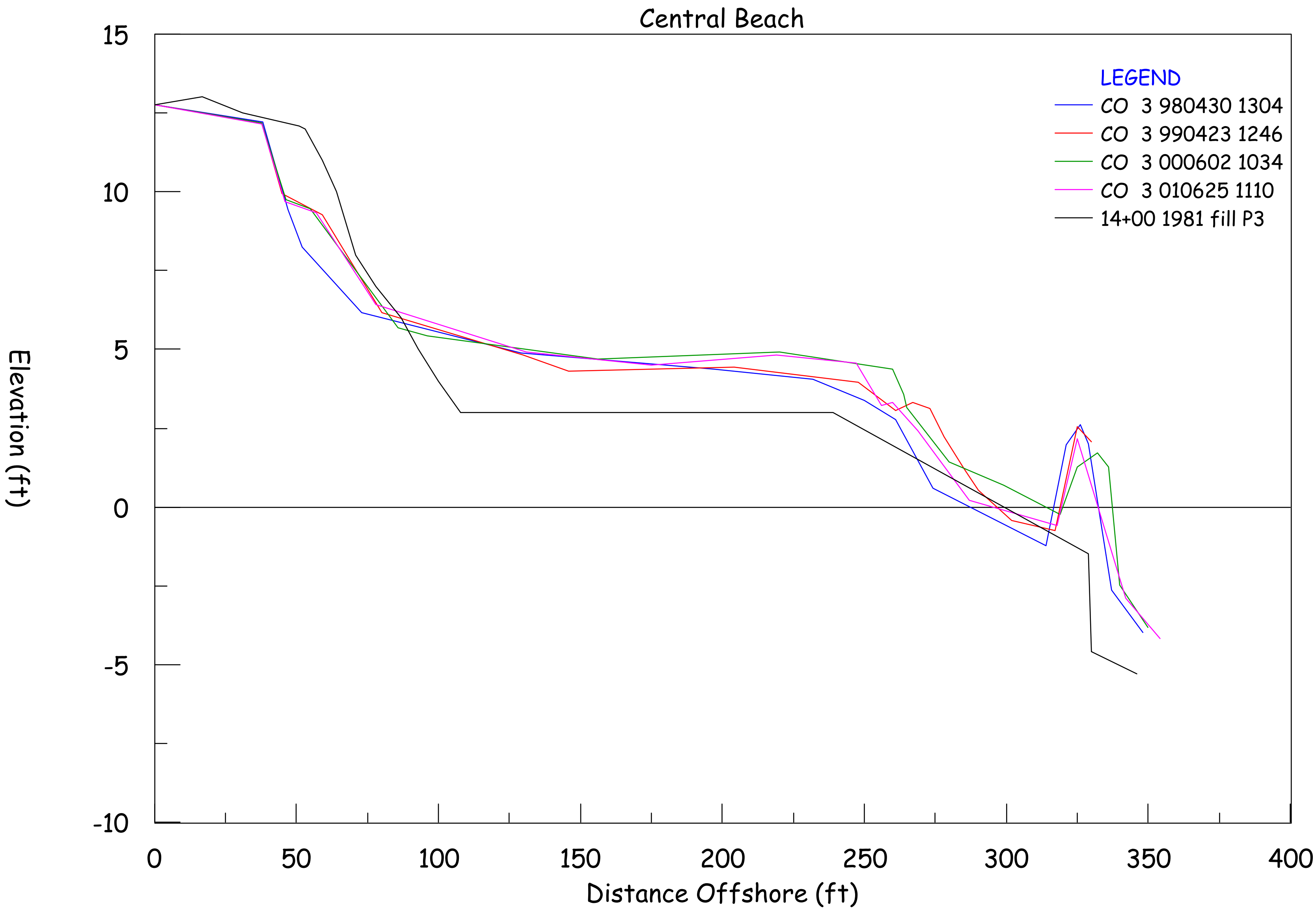


Central Beach
LEGEND
0+00 Feb 1981 P18
0+00 1981 fill P18
0+00 Apr 1986 P18
CO 18 010625 1457
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

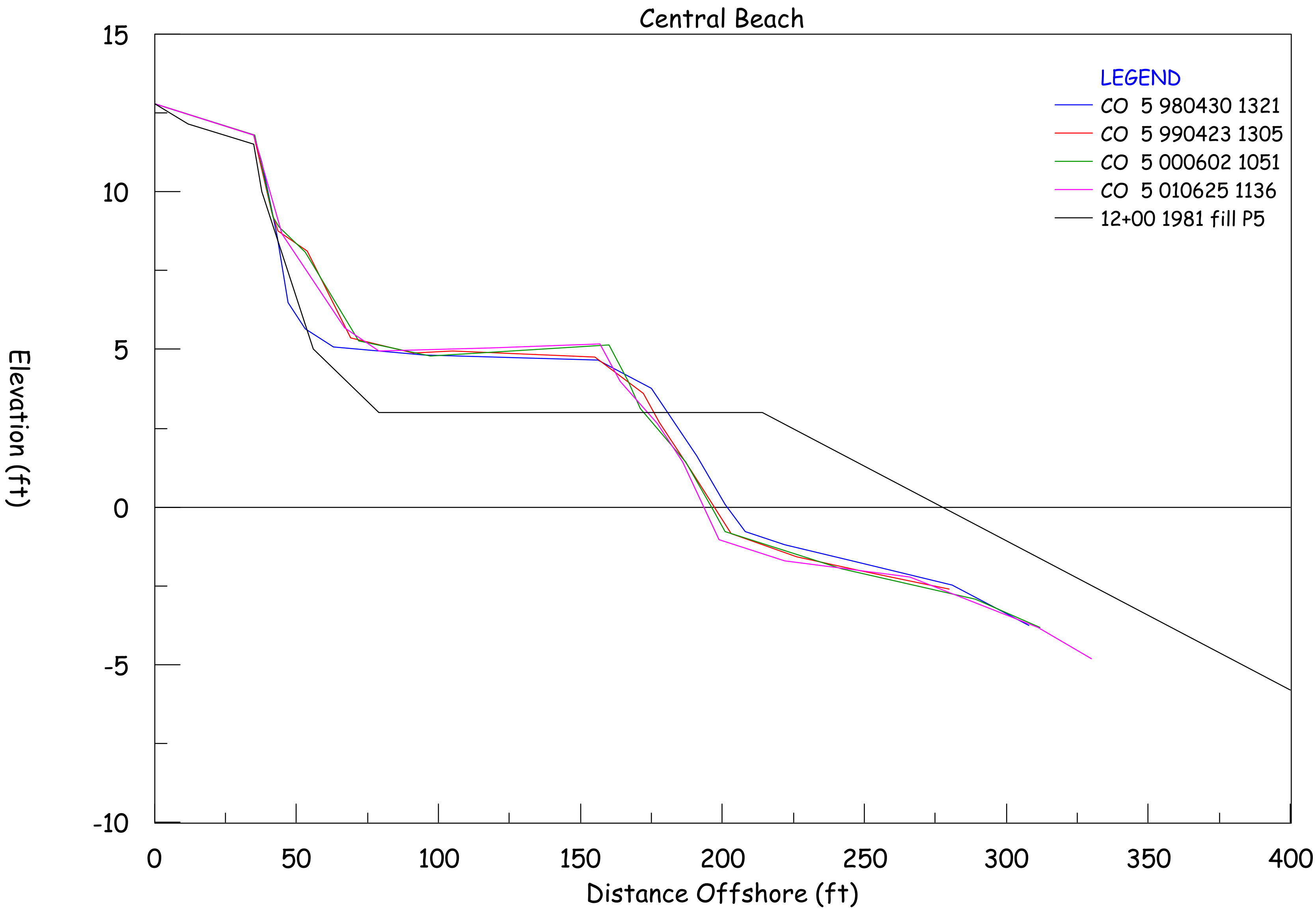
Appendix I-B



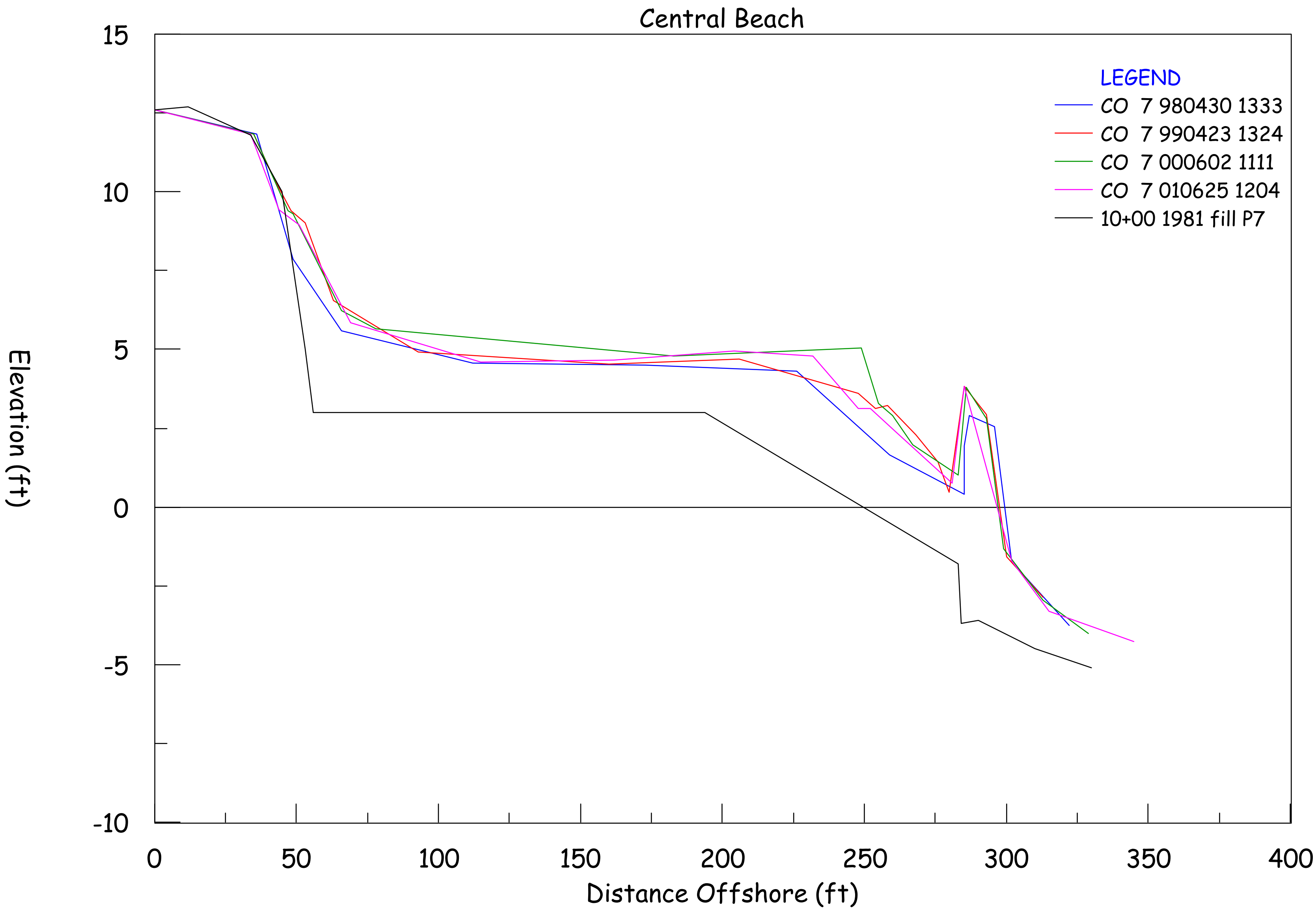
Central Beach
LEGEND
CO 1 980430 1253
CO 1 990423 1228
CO 1 000602 1013
CO 1 010625 1048
15+78 1981 fill P1
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

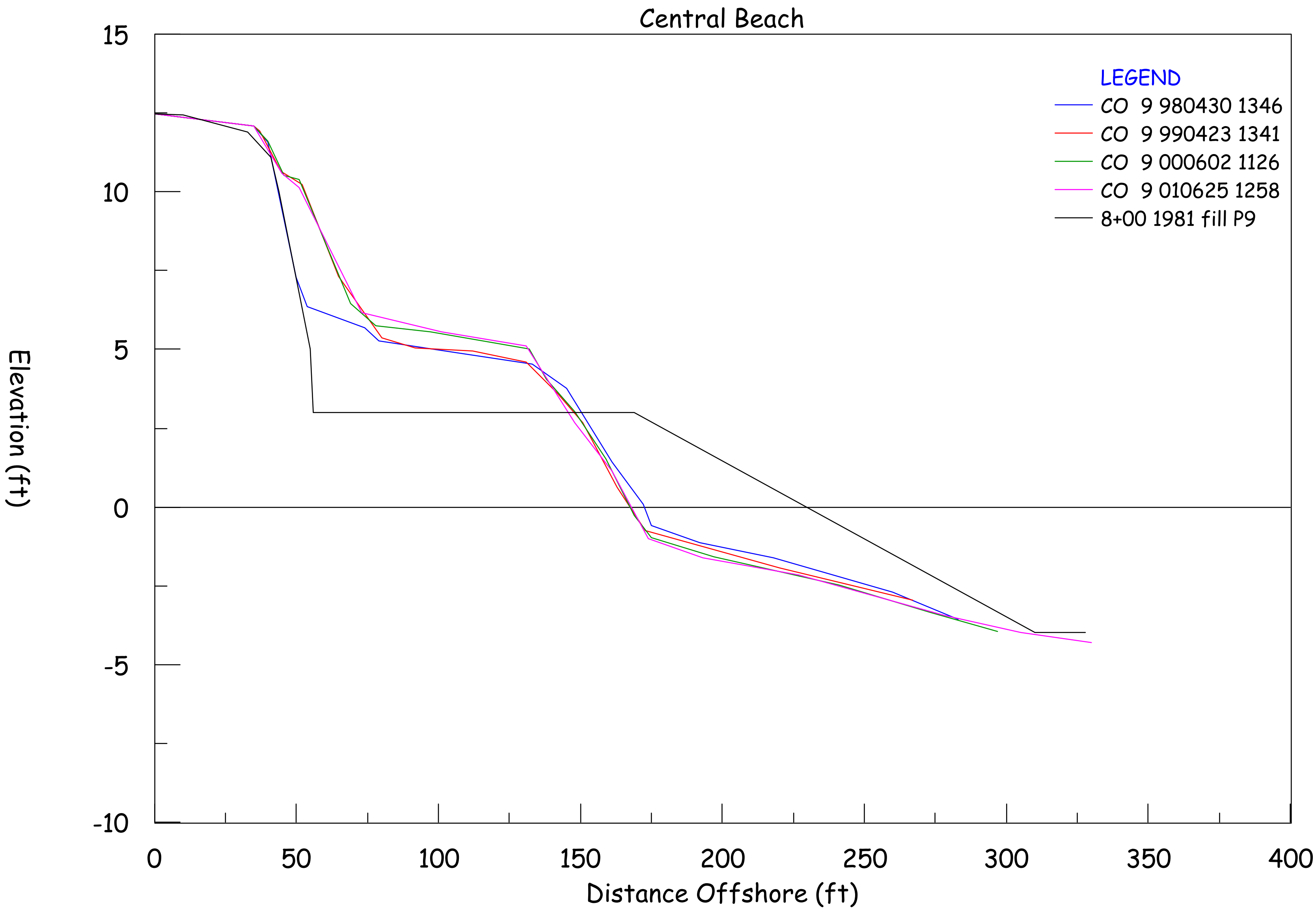


Central Beach
LEGEND
CO 3 980430 1304
CO 3 990423 1246
CO 3 000602 1034
CO 3 010625 1110
14+00 1981 fill P3
15
10
5
0
-5
-10
Elevation (ft)
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)

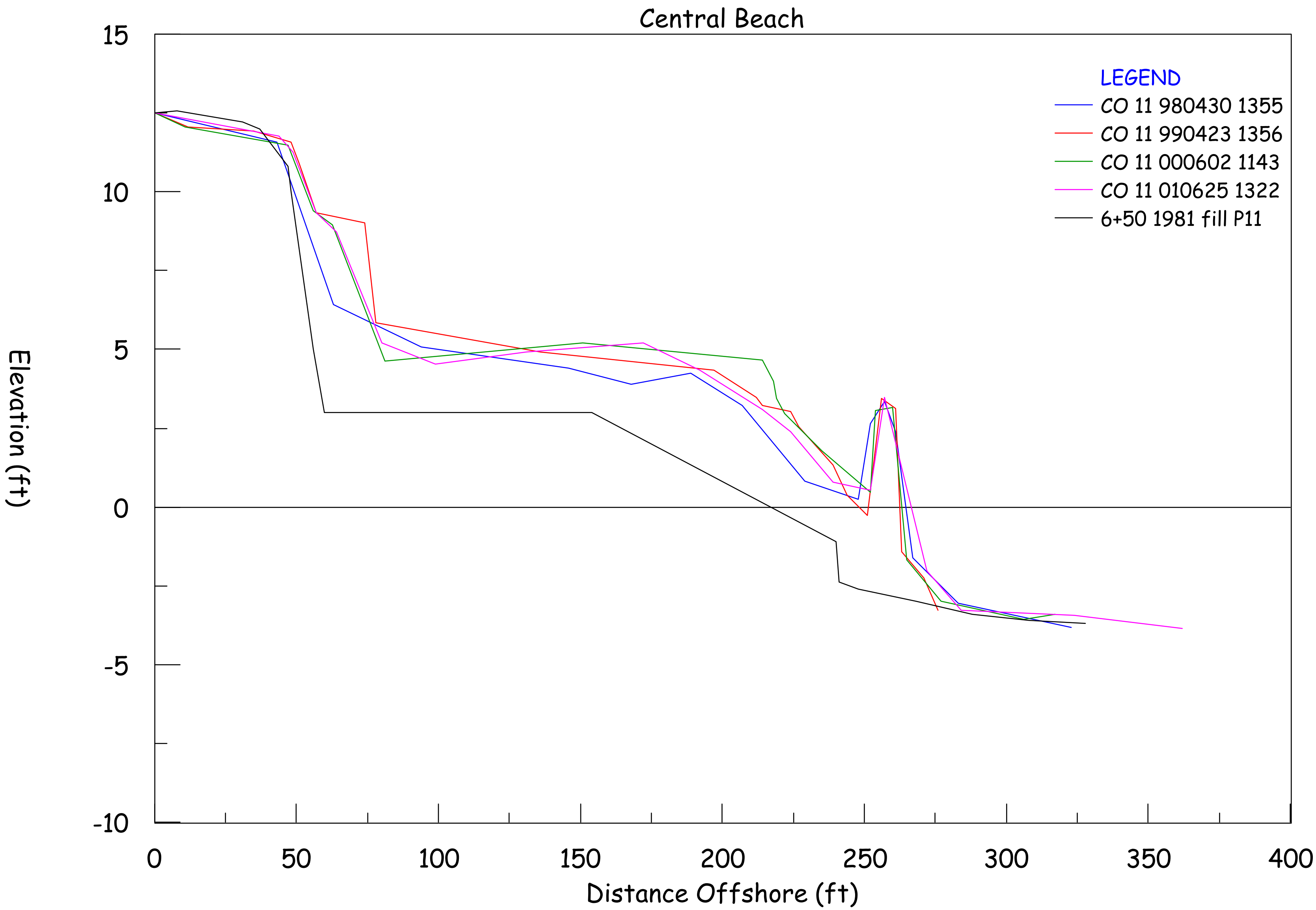


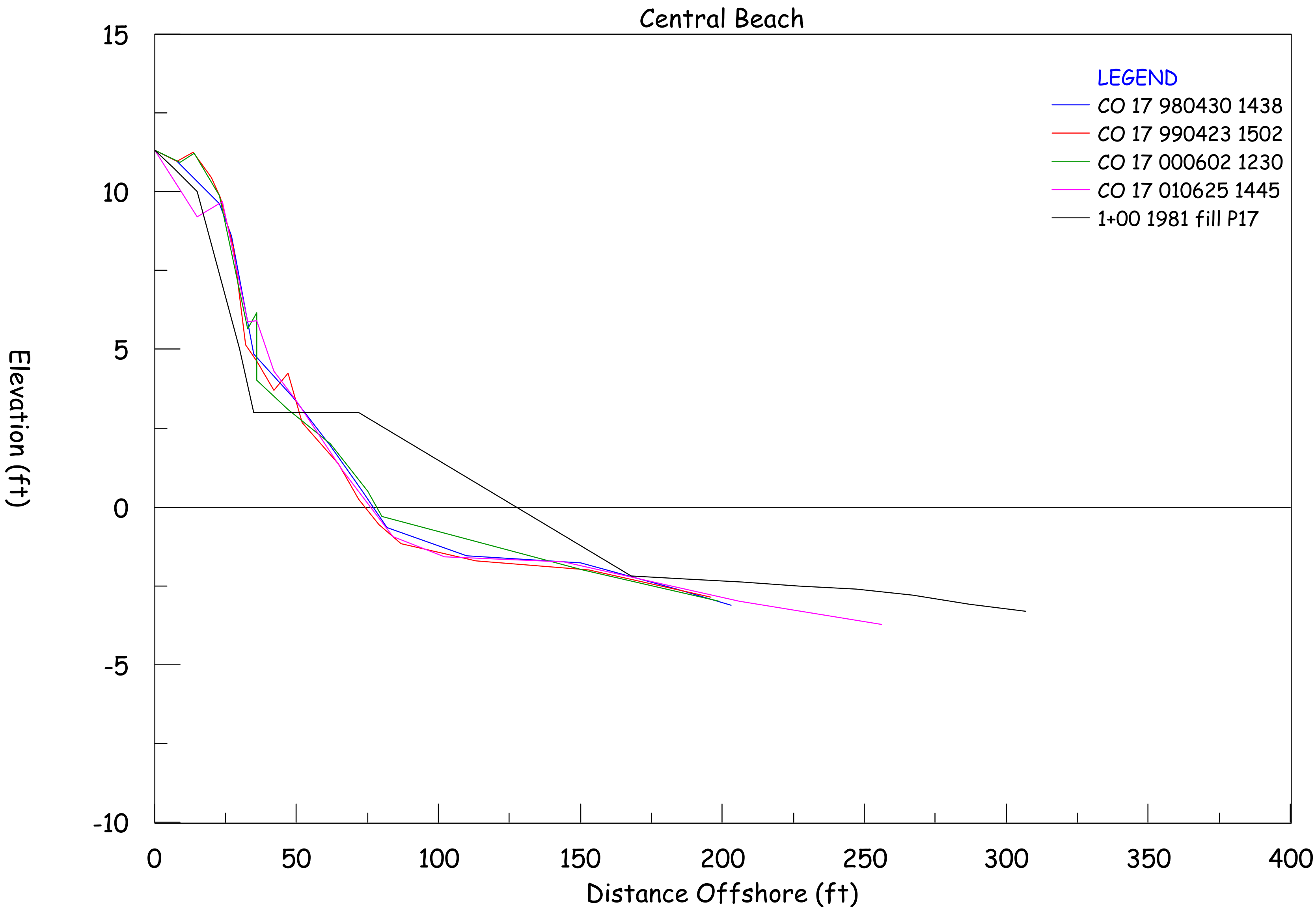
Central Beach
LEGEND
CO 5 980430 1321
CO 5 990423 1305
CO 5 000602 1051
CO 5 010625 1136
12+00 1981 fill P5
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)
Elevation (ft)


Central Beach
LEGEND
CO 7 980430 1333
CO 7 990423 1324
CO 7 000602 1111
CO 7 010625 1204
10+00 1981 fill P7
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)



Central Beach
LEGEND
CO 9 980430 1346
CO 9 990423 1341
CO 9 000602 1126
CO 9 010625 1258
8+00 1981 fill P9
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)


Central Beach
LEGEND
CO 11 980430 1355
CO 11 990423 1356
CO 11 000602 1143
CO 11 010625 1322
6+50 1981 fill P11
15
10
5
0
-5
-10
Elevation (ft)
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)



Central Beach
LEGEND
CO 17 980430 1438
CO 17 990423 1502
CO 17 000602 1230
CO 17 010625 1445
1+00 1981 fill P17
Elevation (ft)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
350
400
Distance Offshore (ft)