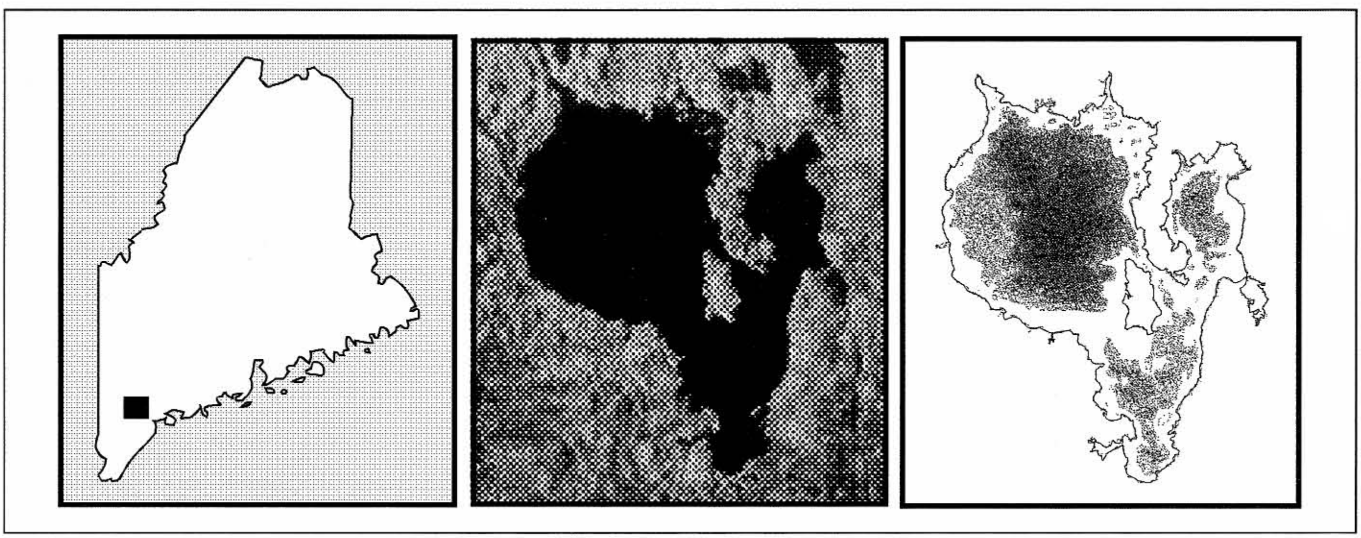
Sebago Lake State Park Beach Dynamics

A Report on Results of Beach Profiling



by Stephen M. Dickson and Robert A. Johnston

Maine Geological Survey
DEPARTMENT OF CONSERVATION
Walter A. Anderson, State Geologist

Open-File 94-4

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Table of Contents

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ABSTRACT

Sebago Lake State Park, located along the northern shore of Maine's second largest lake, is the site of this shoreline change study. To determine the extent of shoreline erosion and accretion at the state park, a beach profile network was established in late 1990. Beach profile data were collected at 10 stations set up in the state park and at two locations outside the park. Profiles were collected during all seasons for three years and were repeated more than 20 times at each park site. Eighteen profiles were analyzed at the two stations outside the park in Jordan Bay. Analysis of the data shows that: (1) winter ice pushes sand up the profile and leaves a ridge of sand at most locations in early spring; (2) spring high-water levels smooth over the ice-created ridge, and during rising lake levels, waves push sand up the beach; and (3) through summer and fall, during a period of falling lake levels, waves cause a temporary adjustment to the profile with accretion just above the water line and erosion below it.

The most notable and consistent erosion of almost all beaches occurred in the fall of 1992. Some condition (presumably storm waves) created two wave-cut scarps, or notches, in most beach profiles. Each notch was probably formed during a different stage in lake level in the month of September. This erosional feature was filled by the summer of 1993 and had no apparent lasting effect on the profile geometry. A similar behavior was not found in fall 1991 and there were insufficient data at the time of this report to evaluate fall 1993.

The greatest variability in profiles at any one location occurred on the spit at Songo Beach. Both erosion and accretion of as much as 10 feet (3 meters) horizontally occurred rapidly (in a period of a month or two) and then took almost a year to return to its prior condition. Vertical changes in the height of the spit were also recorded. During high water in 1992, the eastern part of the spit built upward several inches (centimeters) while the western part remained unchanged. In subsequent months the eastern part remained stable while the western part lowered several inches (centimeters). By summer 1993 conditions at both sites had returned close to those of early 1992.

The study period covers almost three years during which time the profiles indicate a generally stable position of the upper beach. While erosion and accretion were noted at all profile stations, no permanent shifts were seen in the position of the beaches. The greatest lasting change may be in the lowering of the offshore portion of a few profiles, although with only two years of underwater profiling it is difficult to be conclusive about offshore losses. The time for recovery from a short, but volumetrically significant, erosion period may take many months and can approach a year.

INTRODUCTION

Purpose

Sebago Lake is located approximately 20 miles (30 kilometers) northwest of Portland, Maine (Fig. 1). It is located along the boundary between the coastal lowland and the central highlands of New England (Denny, 1982). The lake covers 47.5 square miles (123 square kilometers) and is 316 feet (97 meters) deep. It is the deepest lake in Maine.

Shoreline erosion at Sebago Lake State Park became a concern to the Maine Department of Conservation in the late 1980s at the Songo Beach day-use area, where tree roots were exposed along the beach (Fig. 2). The presence of exposed roots implied sand loss from the upper part of the beach profile and suggested that the entire beach was eroding. At a number of areas around the lake, erosion of beaches has been reported during periods of high water levels and large waves.

The Maine Geological Survey was asked by the Bureau of Parks and Recreation (both in the Maine Department of Conservation) to assist in establishing beach profile stations to study the problem in the area of the state park. Late in 1990 a network of ten profile stations was established in the park (Fig. 3a) and in 1991 two more were started at Halls Beach south of Browns Point in Raymond (Fig. 3b). Periodic profiling has occurred at these 12 sites since then.

The purpose of this study is to evaluate beach profiles to determine if beach erosion or accretion occurred during the past three years. This report examines over 240 beach profiles for indications of permanent change to the beaches. Analysis of temporal and spatial trends is made with consideration of the lake level and ice action. Lake levels, partially controlled by a dam, fluctuated by as much as 5 feet (1.5 meters; Fig. 4) during the study and are important in determining where waves impact, and sometimes reshape, the beach profile. Ice forms over the lake and along the shore for a few months in winter. Sand can be frozen into the ice and redistributed by ice-push and ice-rafting. In this report it is assumed that the beaches will respond to lake levels (high, low, fast change, etc.) or ice action in similar ways and thus lead to a determination of the cause(s) of beach erosion at Sebago Lake State Park.

Geology of Sebago Lake

Topographic relief in the Sebago Lake region is low to moderate, with elevations ranging from 200 to 1300 feet (62 to 400 meters). The northern two-thirds of Sebago Lake is underlain by the Sebago batholith, a Carboniferous intrusion of granitic rock (Osberg et al., 1985). The southern one-third of the lake is underlain by the Waterville Formation, Devonian metamorphosed pelites and sandstones. The erosion of these two bedrock types developed a deeper and larger northerly basin in the area underlain by the less resistant granitic rocks and a shallow and smaller southerly basin in the area of the metamorphosed rocks.

The lake and surrounding area have been strongly affected by continental glaciation. The last glacial ice was in the area approximately 14,000 years before present. With the earth's crust depressed by the weight of ice, the ocean was in contact with the edge of the receding ice sheet in the vicinity of Sebago Lake. The lake, parts of its shoreline, and surrounding lands were submerged below sea level. The inland marine limit (or shoreline; Fig. 1) from this time has been mapped crossing Sebago Lake between Frye Island and the western shore of the lake (Thompson and Borns, 1985). This boundary is based on the exposure of marine clay (Presumpscot Formation) along the shoreline near Whites Bridge and at the northern end of Jordan Bay (Bolduc et al., 1994). No marine clay has been identified along the shoreline of the big basin or on land north of the mapped marine limit (Thompson, 1976; Thompson and Smith, 1977).

Geologic materials exposed along the Sebago Lake shoreline include swamp, glacial-marine, glacial-lacustrine, glacial-stream, end moraine, till, and bedrock (Bolduc et al., 1994; Thompson, 1976; Thompson and Smith, 1977). Some artificial fill, in the form of seawalls, is also found along the shoreline of the lake. Till- and bedrock-lined shorelines are the most resistant to erosion, while the less resistant sand, gravel, and mud shorelines are easily reworked by waves. The large volume of sediment available from glacial deposits and their subsequent erosion and reworking by fluvial and lacustrine processes has provided sand for beaches around the lake. The Songo River delta was built 2000 feet (600 meters) into the lake from sand carried down the river. Bloom (1959; Fig. 5) suggested that waves reworked the delta sand alongshore to create Cub Cove, Songo, Naples, and Witches Cove Beaches at the state park.

Shoreline Processes

This study focuses on the sand beaches of Sebago Lake State Park. In order to evaluate the roles of waves and ice action on sand transport at the beaches we will briefly examine each of these topics below. Several terms used in the text are illustrated in Figure 6a.

Waves - In this report we consider the beach environment as the zone of modern, unconsolidated granular sediment that extends from the uppermost limit of wave action to the deepest water depth agitated beneath waves or "wave base." Wave base is a depth equal to 25% of the deep water wavelength (Komar, 1976). Beach profiles measured in this study typically extend underwater, but not far enough offshore to reach wave base. We estimate wave base to be approximately 24 feet (7.2 meters, based on estimates below). Hence, sand exchange in the beach environment by waves can include the offshore lake bed beyond the limits profiled and illustrated in this report.

Wave action is known to be a primary influence on the movement of beach sand (Komar, 1976). Waves that approach the beach at an angle cause sand movement alongshore called longshore drift (Fig. 6b). The direction of wave approach is controlled by the wind direction and wave refraction in shallow water. In addition, there may be seasonality in the wind speed or direction that may determine the volume of sand transported by alongshore currents. In a study by Lorang et al. (1993) in a Montana lake, the redistribution of annual wave energy (from that experienced by a natural lake) due to regulated lake levels caused increased beach erosion. In Montana, erosion was caused by higher lake levels in the stormy fall season when wave energy was found to be greatest. Fall storms may play an important role

in moving sand onshore or offshore or along the beach at the state park.

In general, lake level restricted to one elevation (high or low) limits wave action to a relatively narrow part of the beach profile. A prolonged period of monochromatic (single period) wave action on a beach should produce a profile of "equilibrium." In reality, however, levels fluctuate due to precipitation, wind, barometric pressure, dams, etc. Fluctuating lake levels and wave heights will influence a wider range of the beach profile than a lake with a constant, or narrow range of levels. Idealized profile adjustments due to lake level changes are shown in Figure 7. Unlike this ideal situation, waves are of various heights and periods and can arrive from different directions. These conditions vary seasonally, further complicating predictions of profile variation to lake level changes. Consequently, an equilibrium profile, in the strictest sense, is never established. Instead, sand is always shifting in response to the existing conditions. Extreme conditions, such as storm waves, can cause large changes that may take weeks or months to erase. A beach profile then, is the complex result of past events and includes both erosional and depositional episodes.

Waves can be either constructive (depositional) or destructive (erosional) to a beach profile. Wave characteristics such as height and length as well as beach slope and grain size determine how sand will move under certain conditions. The process of landward movement of sand beneath shoaling waves is well understood and documented. The process called Stokes Drift (Komar, 1976) results from wave orbital friction and speed differences below wave crests and troughs. Sands on the outer part of the beach profile experience an oscillatory (onshore-offshore) motion below a passing wave. Smaller, constructive waves produce a stronger landward velocity which results in sand shifting landward beneath shoaling waves. Consequently, not all waves are detrimental to the beach. In fact, this landward motion of sand by Stokes Drift causes sand accumulation along the upper part of beach profiles and almost certainly helps maintain Sebago Lake beaches.

Sand can also be carried into deeper water where it would build up the offshore portion of a profile. This offshore shift in sand results in a lower-sloping profile with apparent erosion of the subaerial beach. The sand can be returned landward by a different wave type or by lowering the lake level. When lake level is lowered, sand can be reworked back ashore (even by small waves) onto the upper part of the beach profile. Sand carried ashore leads to a steeper beach profile. As a result of profile steepening, high waves can travel closer to shore before breaking. This condition allows for greater scour near the waterline and erosion back to a flatter profile. In short, the profile response to waves and lake level is continually changing.

Because no observational wave data were available for this study a specific investigation has not been made of wave height and periods at the Sebago Lake profile sites. Such a study would help determine which wave conditions are constructional and which are erosional. If lake levels remain high during periods of destructive waves, then it is possible that erosion could occur in the upper portion of the beach profile. If lake levels were low during periods of high waves, then the lower portion of a beach profile would be eroded.

Beaches exist because of a balance between sediment supply and loss in directions both parallel and perpendicular to the shore. Shallow waters with sandy lake beds can supply sand to beaches. The delta of the Songo River may be a sand source for Songo Beach. During periods of low lake level, the delta surface may be reworked more vigorously by waves and additional sand carried toward the beach. Similarly, deeper portions of the beach profile may be a source of sand to the beach. At times of low lake level, waves may rework the lower beach area and carry sand onshore or offshore.

In summary, wind-generated waves affect the shore, the swash zone, and the lake bed above wave base. Changing wave conditions and lake levels result in dynamic beach profiles that never reach a stable equilibrium. Wave size depends on fetch (distance of travel across the lake; Fig. 8), duration of wind, wind direction, wind speed, and water depth. Each of these five variables will be considered next.

Wind - Winds in Maine are influenced by the prevailing westerlies. The percent occurrence from different directions is shown in Table 1 and Figure 9. Winter has a strong northwesterly component in the wind (Fig. 10a) while spring winds add a southerly component not seen in the winter (Fig. 10b). Summer winds are strongly influenced by southerly winds (Fig. 10c) and fall winds show a distribution from north to south (Fig. 10d) similar to the annual average.

The strongest winds occur in the winter and spring (Table 2) and are calmest in the summer. As the preceding paragraph described, there is a possibility that the strong winds in the winter and spring will be from the west or north. Because the fetch to the state park beaches is small or nonexistent from these directions, these strong winds may not make waves that impact the state park beaches. Therefore, it is necessary to consider the occurrence of high winds with southwest to southeast fetches, those capable of sending waves to the state park.

Winds that were capable of generating waves of a foot (0.3 meters) or more were considered from the directions approaching the state park. Winds in excess of 8 miles per hour (13 kilometers per hour) were selected from Tables 1 and 2 and arranged by seasons in Tables 3-6. From these data the number of hours of waves approaching the state park beaches was estimated. Figure 11 summarizes the seasonal differences. Spring may generate the largest duration of waves approaching the park with the shortest duration in the winter. In addition, winter ice reduces the number of hours of wave attack.

There is a seasonality in wind which should affect waves at the state park beaches. Wind data can be further detailed by fetch direction. Figure 12 shows the cumulative directions of wind-generated waves in the overall column heights. The relative contribution of each season is also shown. The relative contributions of each season are shown in Figure 13. Southerly

winds dominate in spring and summer. In fall, strong winds approach from the south to southwest with about the same durations. In winter, strong westerly winds are likely to affect the beaches. The overall strength of winds and presumably wave approach increases to the west, showing the effect of the prevailing westerlies.

A second wind variable affecting wave heights is fetch. Fetch varies with direction from the state park beaches and ranges from 1.7 to 10.4 miles (2.8 to 16.7 kilometers; Table 1, Fig. 8). The longest fetch is to the south-southeast and the least is to the west. The remaining fetches range from 3 to 6 miles (4.8 to 9.7 km). Larger waves can be built over longer fetches so the largest waves impacting the state park should come from the south or south-southeast.

Using a theoretical approach, waves reaching the state park can be approximated. Wave heights can be estimated graphically from nomograms based on wind speed and fetch (U.S. Army Corps of Engineers, 1984, p. 3-50). These graphs yield a "significant wave height" which is the average height of the highest one-third of the waves for given conditions of wind and fetch (Komar, 1976). Different wave heights can be predicted using direction and fetch data from Table 1.

A "worst-case scenario" with SSE gale force winds approaching Songo Beach would result in a maximum significant wave height of 4.4 feet (1.3 m) with a period of 4.3 seconds. Shorter fetches are more common than the 10.4 mile (16.7 kilometers) south-southeast fetch and would result in smaller waves. For example, a gale would produce a 3.4 foot (1.0 meter) wave over a 6 mile (9.7 kilometer) fetch and a 2.4 foot (0.7 meter) wave over a 3 mile (4.8 kilometers) fetch. At Halls Beach the maximum significant wave height for a SSW gale would be 3.5 feet (1.1 m) with a period of 3.7 seconds.

In either the state park or Halls Beach case, fully-developed ("deep water") waves can be created in as little as two hours. For Sebago Lake, wind duration and water depth do not restrict the maximum size of waves. Wind speed and direction (and hence fetch) are the two factors controlling maximum wave heights at the state park beaches.

In short, winds generate one-foot or larger waves that impact the state park beaches for more than 25% of the year. Gale force winds last for only a few hours each year, but could create significant wave heights in excess of 4 feet (1 meter) at state park beaches. Waves will impact the beach in all seasons, but are reduced in importance in winter due to stronger northwesterly winds and ice cover.

Ice - Ice often covers Sebago Lake during two to three months of the winter when there are strong winds (Table 3). Since winter wave action is reduced by ice, beach erosion by waves at the state park should also be reduced in the winter. However, another process that affects sand transport is ice action. Wind stress on the ice causes it to move across the lake and pile up along the shore. On the Ohio shore of Lake Erie, ice is suspected of causing beach erosion (Barnes et al., 1993). In the St. Lawrence River estuary ice may deposit sand along the shoreline (Dionne, 1993). Consequently, ice can have both erosional and depositional effects on a beach.

Sebago Lake ice frequently incorporates and carries sand (Fig. 14). In addition, ice physically plows frozen sand onto the subaerial beach at the state park. In order to determine the role of ice on the beaches at Sebago Lake, profiles were compared from the late fall into the early spring and photographs were taken of the beach to document its impact on the sand budget.

METHODS

Selection of Beach Profile Sites

Five beaches were selected for measurement and analysis. The grain size of the beaches ranges from medium to coarse sand. Cub Cove Beach is a pocket beach about 500 feet (150 meters) long with a slope of about 1:10 (height:length; Fig. 3a). Songo Beach is a mainland beach located at the day-use area at the park, is about 2000 feet (600 meters) long, and has a slope of about 1:12. At the eastern end of Songo Beach the spit continues away from the mainland for a distance of about 2500 feet (760 meters). Slopes on the spit beach range from as steep as 1:7 to as low as 1:17. Naples Beach is the third beach. This beach is a 1500 foot (450 meters) mainland beach with a slope of 1:12. Witch Cove Beach, just west of Naples Beach, is also about 1500 feet (450 meters) long and has slopes of 1:11 to 1:13. The fifth beach is located in Jordan Bay, well away from the state park beaches (Fig. 3b). This mainland beach is 4000 feet (1200 meters) or more in length and at the profile sites, near the center of the beach, has slopes from 1:8 to 1:10.

Ten profiles were established at Sebago Lake State Park in the fall of 1990. Multiple profiles were established along each beach in order to evaluate longshore shifts in sand (e.g., erosion at one end and deposition at the other). Profile locations are shown in Figures 3a, b and are numbered from east to west in the park.

Two profiles (Nos. 1 and 2; Fig. 3a) were located at Cub Cove Beach. Three profiles were set up along Songo Beach (Nos. 3, 4, and 5; Fig. 15) and two farther west on the extension of sand called Songo Beach spit (Nos. 6 and 7; Fig. 16). Two profiles were established on Naples Beach (Nos. 8 and 9) and one on the smaller Witch Cove Beach (Nos. 10; Fig. 3a). Two additional profiles (Nos. 11 and 12) were located at Halls Beach in Jordan Bay (Fig. 1, 3b) in July 1991.

Emery Method of Beach Profiling

Beach profiles are lines surveyed perpendicular to the shoreline that record the shape of the beach at the time of measurement. In this report a series of profiles records changes in beach shape over a period of three years, providing insight into the processes that shape Sebago Lake beaches. The processes are determined by waves, currents, lake level, sediment size, ice

action, human activities, etc. From the time series of profiles, the erosional and accretional history of the beaches can be determined, and the coastal processes that shape the landforms can be studied.

The "visual method" of beach profiling was developed by K. O. Emery (1961) and involves measuring the vertical distance between the tops of two graduated poles of equal length by leveling on the horizon. The steps in measuring and recording profiles used in this study are outlined in Appendix I. Data were recorded on profile data sheets in the field. They were later entered into a computer spreadsheet program and cumulative horizontal distances and differences in elevation calculated. Data were edited to correct recording errors (see Data Analysis section below).

Plots of Beach Profiles

Beach profiles were plotted using Sigma Plot software. A large vertical exaggeration of approximately 20:1 was used in order to accentuate changes in the elevation of the beach. A plot of all the profiles at each location was used to define the vertical envelope that the beach occupied during the study period. The outermost points that delimit this envelope define a "sweep zone" (Barnes and King, 1955). Analysis of the sweep zone helps to define the overall variability of a given beach profile location which can then be compared to individual changes seen between months, seasons or years. Profiles were plotted as listed in Table 7.

Data Corrections

Several different types of corrections were made to some parts of the original field-collected data set. Corrections to the data were made when obvious recording errors (+/-) were noted in plots of profiles. Destruction of a control stake prevented full analysis of a continuous time series at Songo Spit Beach No. 6 between April and May 1991, and at Cub Cove Beach No. 2 in the summer of 1993. One period of high water covered a control stake at Songo Beach Spit No. 7 in May, 1993 so the profile was not measured. May 1992 data from Songo Beach No. 3 profile were not easily adjusted to fit within the sweep zone so it was not included in the analysis. Profile No. 8 at Naples Beach in May 1993 is suspected to have a recording error around -2 feet, but no correction was made to the data. Profile No. 11 at Halls Beach had two measurements (May and June 1993) that started a few feet away from the reference pin. No correction was made and the data were disregarded in the analysis of trends.

Data Analysis and Error Estimates

The twelve beach profile sites were analyzed independently. Trends in profile change were studied. The full data set from 1990-1993 was used to identify profile variability (as shown conceptually in Fig. 7). Profile trends by month and season were analyzed to evaluate monthly or seasonal changes. Interannual profiles were studied to compare change over a 12 month period. For example August 1991 was compared to August 1992, when any seasonal characteristics of the profile should be similar but net change over a year might be detected.

Plots show consistently reproducible geomorphology in the upper parts of the profiles where no significant change is expected due to water level, waves, or ice. Vertical precision is estimated to be less than 3 inches (6 centimeters) and horizontal precision to be 12 inches (30 centimeters) at any place along a profile. Systematic errors would tend to be cumulative and could cause greater imprecision on the outer portion of the profiles but we have not made a detailed error analysis.

Because the lake shoreline was used as a horizon for the Emery method, a minor systematic error was probably introduced to the vertical elevation data. The result of this error would be to slightly exaggerate beach slopes. Because the magnitude of exaggeration is common to all readings at a single location, the *relative* changes in profile elevation used to draw the conclusions will not be affected.

We focused on profile changes that are much larger than the estimated precision. In addition, where small vertical or horizontal changes were found to be systematic (consistently changing in one direction) over several months we have noted the trend. Consequently, the trends discussed in this report are expected to be free from measurement errors. The absolute vertical or horizontal change is approximate and subject to the errors mentioned above. However, the purpose of this report is to identify *trends* in profiles that may suggest beach erosion or accretion over the study period.

RESULTS

Analysis of Profiles

This section highlights characteristics of individual profiles from season to season, over the winter, from year to year, and over the entire study period. Profiles are ordered by number below and each series of profile plots are identified chronologically by letter. Seasonal sets of profiles are arranged sequentially for each beach in Appendix II.

Cub Cove No. 1 - This location showed relative stability over a two year period. The sweep zone is narrow. A small berm built from ice shove (April, 1991) was present in the spring 1992 profile (Fig. 17). Notches (small scarps, presumably from waves) were cut into the profile in the fall 1992 (Fig. 18) and subsequently smoothed out the following spring.

Cub Cove No. 2 - Over the study period the beach was stable (Fig. 19) despite the three-month-erosional perturbation in the fall of 1992. This profile has a narrow, sigmoidal (s-shaped) sweep zone. An erosional notch formed in fall of 1992 (below 4 feet on the profile elevation in Fig. 20) and persisted until smoothed out the following spring. This erosion resulted

in a horizontal loss of 5 - 10 feet in the vicinity of the water line. Sand returned to the profile in the spring of 1993 and restored it to its former shape (Fig. 20).

Songo Beach No. 3 - This beach showed both erosion and accretion during the study period. Both changes appeared to be related to water levels. In the spring of 1991 the lake level rose over 2 feet and sand moved in over the older profile to cause accretion of the upper beach (Fig. 21). The underwater profile was not measured. In the spring of 1992 a similar accretion occurred with rising levels and the underwater portion of the profile eroded (Fig. 22). Summer 1992 and 1993 sigmoidal (s-shaped) profiles shifted downward in response to lowering lake level. Consequently, the dry beach prograded as much as 6 feet horizontally and erosion occurred below the water line. Erosion events occurred in September 1992 and in November 1992 (Fig. 23). Sand returned to the beach in the spring and summer of 1993.

Songo Beach No. 4 - Overall, this location showed stability. There was no net loss in the upper part of this profile. There was no erosion of the dry beach in the summers of 1991 and 1992 (Fig. 24). Erosion of about 10 feet was found below -3 feet during the summer and fall of 1992 as lake levels fell. The profile became notched in the fall of 1992 (Fig. 25). During the spring and summer of 1993 the sigmoidal profile shifted offshore with falling lake levels and resulted in 4 feet of horizontal accretion above the water line and 6 feet of horizontal erosion below it.

Songo Beach No. 5 - This portion of the beach showed periods of erosion and accretion each of which lasted about a year. This profile line has a sweep zone that becomes wider with increasing depth. From the first profile in December 1990 to August 1992 the beach generally gained sand. After that time and until the most recent profile (October 1993) there was an overall loss of sand. Profile adjustment, due to changing lake level in the summers of 1992 and 1993, produced temporary accretion and erosion at different portions of the profile. Erosion in the fall of 1992 created a notch in the profile and the outermost portion of the profiles lowered (Fig. 26).

Songo Beach No. 6 - This and the next profile are located across a spit at the west end of Songo Beach near the mouth of the Songo River. This location showed considerable variability and change over periods of several months to a year, but no consistent gain or loss of sand over the entire survey period. A 5 inch vertical accretion (upbuilding) on the top of the spit began in May and June 1992 (Fig. 27) and coincided with a high lake level (265.5 feet above mean sea level; Fig. 4). This addition of sand persisted, showing net gain, with some gradual lowering by the summer of 1993. The beach also prograded 6 feet horizontally during the summer of 1992 (Fig. 28). However, this growth had disappeared by the summer of 1993. In the fall of 1992 cut and fill temporarily changed the higher profile and a notch was cut just below the water level. By spring 1993 the notch in the previous fall profile was smoothed out. No large changes were noted to the upper beach over any of the three winters of record (Fig. 29).

Songo Beach No. 7 - This outer spit profile showed instability, as the No. 6 profile did, that was mostly related to changes in water level. This profile has a large sweep zone throughout its length. Ridge and runnel morphology (Fig. 6a) within 1 foot of the water line is characteristic of this profile. In spring 1992 a rising water level caused horizontal progradation of 10 feet on the beachface (Fig. 30). The top of the spit was stable and unchanged by high water. Between June and July 1992 the ridge and runnel system and top of the spit were eroded landward 10 feet or more and down about half a foot. The spit rebuilt upward by August 1992 but did not regain lost sand from the beachface. A notch in the lower profile in the fall of 1992 was infilled by the following summer (1993) and 10 feet of progradation returned sand lost in the summer of 1992. Sand also widened the top of the spit in the summer of 1993.

Naples Beach No. 8 - The upper part of this profile was stable while the lower part showed minor erosion underwater during the survey period. This profile is fairly linear overall. The sweep zone shows the greatest variability around the water line. The summer profiles show stability and some shifting sand due to changing water levels. No large change occurred over the winters of 1990-91 or 1991-92. Notches were cut into the profile in the fall of 1992 and infilled by the spring of 1993. Between the summer of 1991 and 1993 horizontal erosion (below -2 foot elevation) of about 5 feet occurred (Fig. 31 and compare summer 1991 to summer 1993 in Appendix II).

Naples Beach No. 9 - The dry beach lost sand while the beachface remained relatively stable, but shifted with changing water levels. The subaerial beach lowered over the study period. Most of the vertical loss occurred in July 1991 (Fig. 32). A similar change was not recorded in the following two summers. In the spring of 1991 water level rose 2 feet in two months and led to 9 feet of accretion above the final water level (Fig. 33). Notches were cut into the profile in the fall of 1992 and infilled by the spring of 1993. The subaerial profile was unchanged during each winter. A high water level and stream incision across the beach in the spring of 1992 did not change the profile.

Witch Cove Beach No. 10 - The overall shape and slope of this profile was consistent and showed general stability during the survey period. The greatest profile variability was due to the fall 1992 notches (Fig. 34). Accretion and erosion in the summers of 1992 and 1993 is related to a shift in the sigmoidal shape of the profile relative to the water line as noted at other locations.

Halls Beach No. 11 - Profiles at this site showed stability. This beach has a shorter time series (only 2 profiles were measured in the summer of 1991). Little change occurred in 1992 and 1993 (Fig. 35). There were no pronounced fall notches in 1992.

Halls Beach No. 12 - This beach profile was also stable but had more variability than No. 11. The October 1992 profile had two small notches, but no change seen above or below the notch (Fig. 36). They were smoothed out over the next two months (Fig. 37). Over the winter of 1992-1993 up to 5 feet (horizontally) was eroded from the beach face. Accretion in May returned the profile to its original shape.

Long-term Trends, 1990 To 1993

During the three year study period, the profiles indicate a generally stable position of the subaerial beach. Erosion and accretion were noted at all profile stations but no permanent shifts were seen in the position of the beaches. The greatest lasting change may be in the lowering of the offshore portion of a few profiles, although with only two years of underwater profiling it is difficult to be conclusive about offshore losses. As noted below, the time for recovery from short, but volumetrically significant, erosional events may take many months and can approach a year.

Seasonal Trends

Spring - Spring profiles frequently show a small accumulation of sand at the position of the lake level (e.g., Figs. 14, 17). This accretion is caused by the ice-push when ice is piled against the shoreline, often creating ice ridges and slabs of frozen sand sliding landward over the beach profile. While notable, these sand accumulations are ephemeral and are reworked by rising lake levels in late spring (e.g., Fig. 18).

By late spring (usually in May) lake levels reach an annual maximum. Analysis of beach profiles around the period of high water found no significant erosion of the upper beach profiles. In fact, rising water levels approaching the high water level were found to bring sand onto the higher portion of the beach (Figs. 21, 22, 27, 30, 33). From these data it appears that wave action with a rising water level over a few months may bring sand ashore.

One area that showed a significant response to high water levels was on the Songo Beach spit (Profile No. 6). This is discussed below in the section Largest Profile Changes.

Summer - As lake levels fall during the summer (Fig. 4), there is a lakeward shift of the shoreline. Many profiles indicated a similar pattern of 5 to 10 feet of horizontal accretion above the water line as lake levels fell (e.g., see Profile No. 4 and 5, summer of 1992 and 1993, in Appendix II). Similarly, the underwater portions of the profiles were eroded. This combined response is simply an adjustment of the profile to lower levels. The beach profile is generally slightly sigmoidal (s-shaped) with an inflection point at the water line. A shift of the profile takes place in response to a lower lake level and results in the redistribution of sand along the profile. There does not appear to be any net loss or gain of sand from the profile as a whole during this process. If any temporary change occurs it is the addition of sand to the dry beach and a slight deepening of the water offshore.

Fall - By fall, lake levels are even lower and the summer trends continue. Of note, however, is a significant loss of sand during the month of September 1992 (Figs. 18, 19, 23, 25, 26, 34, 36). The profiles show two notches cut into most beaches. Both of these could be due to two high wave events that removed sand from the profiles. These notches persisted throughout the fall and, presumably, into the winter. A similar trend was not seen in the fall of 1991. That earlier year showed no significant changes to the beach. Consequently, the interannual variability in the fall (stormy) season may cause a large variability in the beach profiles and in the size of annual sweep zones in the lower portions of the profiles.

Winter - Ice cover prevented beach profiling during much of the winter. A comparison of latest fall profiles (November or December) with the first profiles in the spring (April or May) indicated stability of the beach above the lake levels. This can be seen by comparing fall and spring profiles in Appendix II. Winter ice action did not remove large amounts of sand from the profiles or create permanent sand loss.

Interannual Profile Change

Because of a relatively low lake level in August, the profiles are longer than those in spring and are well-suited for interannual comparison. By comparing the same month from subsequent years it was possible to examine the data for net changes in profile position. August to August comparisons show the stability of all beaches from one year to the next (Figs. 19, 24).

Largest Profile Changes

The greatest variability in profiles at any one location was found at Songo Beach spit. Both erosion and accretion can occur rapidly (in a period of a month or two) and then take almost a year to return to its prior condition (Figs. 27, 28, 29). As much as 10 feet of horizontal erosion or accretion can result in this short time span. Vertical changes in the height of the spit were also recorded. During high water in 1992, the eastern part of the spit built upward while the western part did not change. In subsequent months, elevation of the eastern part remained stable while elevation of the western part decreased. By 1993 conditions at both sites had returned close to those of early 1992.

DISCUSSION OF BEACH DYNAMICS

The upper, subaerial beach does not change significantly over the winter. However, wind-driven ice piles up along the shoreline and creates ice ridges. These ridges push sand up the beach profile and, in most locations, leave a small sand ridge (less than a foot in height at the time of profiling) on the shore in early spring after the ice melts. Less commonly, slabs of frozen beach sand, several inches (centimeters) in thickness are thrust shoreward over the subaerial beach profile and leave a tabular sand deposit on the beach.

Rising water levels in the spring smooth over ice-created ridges. As lake levels rise in the spring, waves transport sand shoreward raising the beach and shifting the shoreline 4 feet (1.2 meters) lakeward. This phenomenon has been noted in the upper St. Lawrence River estuary of Quebec (Dionne, 1993).

The most noticeable effect of high lake level on the profiles was found on Songo Beach spit. Sand was carried ashore by

waves and deposited onto the top of the spit when it became submerged. This upbuilding increased the height of the spit by about 6 inches (15 cm) during high water in 1992 (Fig. 27). The largest accretion during this study period was found in this area. The sand could have come from Songo Beach although net loss from Songo Beach was not pronounced. Alternatively, the sand could have come ashore from deeper portions of the profile or from the Songo River delta just offshore (Fig. 3a).

Through summer and fall lake levels drop without any permanent impact on the profile positions. The greatest erosion during the study period occurred in September 1992 (Figs. 18, 19, 23, 25, 26, 34, 36). This was most likely due to wind-generated waves although no wave data exists. Erosion lowered portions of many profiles, but did not affect the subaerial beach. By the following year erosion infilled at all locations and no significant long-term loss was measured.

Falling lake levels cause an adjustment to what appears be a short-term equilibrium beach profile. The normal profile is sigmoidal in shape. A downward shift in water level (and consequently offshore) results in 1 to 4 feet (0.3 to 1.2 meters) of horizontal accretion above the water line and about 2 to 4 feet (0.6 to 1.2 meters) of horizontal erosion below the water line (e.g., Fig. 31). This pattern of change is probably due to wave deposition in the upper swash zone and erosion just below the lake level. In the area where the profile slope flattens underwater the sand level may lower 4 inches (10 centimeters) in response to this shift. Consequently, lowering water levels have two impacts on dry beaches: (1) accretion extends the dry beach out into the lake a few feet (a meter) and (2) lower level creates a wider beach because of greater subaerial exposure of the beach. In general, slopes are about 1:7 to 1:17 so lowering the lake level one foot (meter) results in exposure of about 7 to 17 feet (meters) of beach above the water line. There doesn't seem to be any net loss of beach sand associated with falling levels during the study period.

CONCLUSIONS

Significant erosion occurred to almost all beaches in the fall of 1992. Some condition (presumably storm waves) created two wave-cut scarps, or notches, in most beach profiles. Each notch was probably formed by more than one wave event during falling lake levels in the month of September. This erosion was infilled by the summer of 1993 and had no apparent lasting effect on the profile geometry. A similar behavior was not found in fall 1991 and there are insufficient data at the time of this report to evaluate fall 1993.

The greatest variability in profiles at any one location was found at the Songo Beach spit. Both erosion and accretion of as much as 10 feet (3 meters) horizontally can occur rapidly (in a period of a month or two) and then take almost a year to return to its prior condition. Vertical changes in the height of the spit were also recorded. During high water in 1992, the eastern part of the spit built upward 5 inches (13 centimeters) while the western part did not change. In subsequent months the eastern part remained stable while the western part lowered about 5 inches (13 centimeters). By 1993 conditions at both sites had returned close to those of early 1992.

A high lake level in the late spring did not cause a vertical lowering or horizontal erosion of the beach in the time period studied. This finding is contrary to the long-term trend of erosion around the base of trees that have exposed roots. The long-term sand loss could be from a process not identified in this study. For example there could be longshore transport of sand from Songo Beach to the spit at times of high lake level. Sand from the spit may be washed over and deposited in the wetland on the north side of the spit.

The study period covers almost three years. The profiles indicate a generally stable position of the upper beach. While erosion and accretion were noted at all profile stations, no permanent shifts were seen in the position of the beaches. The greatest lasting change may be in the lowering of the offshore portion of a few profiles, although with only two years of underwater profiling it is difficult to be conclusive about offshore losses. The time for recovery from a short but volumetrically significant erosion period may take many months and can approach a year.

RECOMMENDATIONS

Several recommendations can be made from the results gathered so far. First, we recommend continuing the process of beach profiling. The interannual variability is high and three years of data have allowed analysis of rates of beach recovery following only one period of significant erosion. Furthermore, profiles are now being measured at other locations around the lake by other groups including lake associations. By continuing the profiles at the state park it will be possible to better define the role of constructive and destructive processes on shoreline erosion. A complete data archive should be assembled combining park data with data from other lake shorelines and made available for analysis by all contributors.

Second, we recommend that fall lake levels be kept below the annual maximum elevation, as they have been in the last few years. Large waves in the fall could be damaging to the upper beach and swash zone. By keeping levels low when waves are large, erosion is limited to the low- to middle-profile positions. Results have shown that erosion at this middle elevation is infilled during rising lake levels in the following spring and summer. Further analysis of seasonality in wave height should be considered. Wave heights could be hindcast from wind data and compared to profiles and lake levels. Field measurements of waves and currents could be made and correlated with wind data to better define the strength of Stokes Drift. If the shoreward transport is found to be important, then lowering the lake levels further could be beneficial to the beach.

Third, we recommend that March lake levels be kept as low as practical before rising in spring. During the rise, wave action

transports sand to the upper portion of the beach profiles. Rising levels can result in beach accretion. If lake levels were lowered (deepening wave base) below those in the study period it is possible that, with proper wave conditions, more sand might be transported shoreward from the deeper water by Stokes Drift. Extremely low lake levels, during droughts for example, may result in sand loss to the outer beach and delta surface, or perhaps off the delta into the deeper lake. Sand loss offshore during such times could be permanent. A combination of sediment samples and a grid of ground penetrating radar surveys over the delta when the lake is frozen could determine if sand is abundant offshore and might support this recommendation further.

Fourth, we recommend that the Songo Beach spit and adjacent wetland be studied as a possible sand sink. The dynamic changes measured on the spit suggest that this area may have the greatest sand exchange between offshore, alongshore, and perhaps over the spit into the wetland adjacent to the Songo River. Both wind and waves may modify the spit and could lead to shoreline adjustments. The wetland may act as a sand sink during times of landward transport. If sand reached the wetland it would be unlikely to be returned to the spit or beach by natural processes acting over a period of a few years. Only the more dramatic process of a new inlet forming across the spit could excavate sand in the wetland and carry it lakeward in river currents. Although the process of sand deposition in the wetland has not been documented nor the wetland investigated, it remains an area for further study. Investigation should include an analysis of the spit geometry in historical air photographs to help answer questions related to spit dynamics. Ground penetrating radar surveys of the spit and river delta complex could identify deposits of sand and provide information on sources and sinks of beach sand. This geologic information should be integrated with depth and elevation data in a geographic information system. Various lake levels should be analyzed and displayed as a 3-D map of the beach and delta to better understand the role of extreme high and low lake levels on sediment loss to wetlands and offshore.

ACKNOWLEDGMENTS

We gratefully acknowledge the diligent work of Steven Barden and G. Robert Webb, employees of the Bureau of Parks and Recreation at Sebago Lake State Park, who have regularly profiled and photographed beaches at Sebago Lake since late 1990. Cindy Bastey of the Augusta Parks and Recreation office compiled and updated the beach profile data files. We thank W. Dana Perkins, Jr. of the Portland Water District for providing water level and meteorological data. This report benefited from insightful reviews by Daniel F. Belknap, Donald E. Guy, Jr., Harold D. Nilsson, and Irwin D. Novak.

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Tables

Table 1

Lake Fetch from Sebago Lake State Park and Wind Directions from Portland, Maine

Direction	Distance (mi)	Distance (km)	Annual (% occurrence)	Wint.	Spr.	Sum.	Fall
				(% occurrence, 1951-1980)			
W	1.7	2.8	8.7	10.1	8.0	7.7	9.0
WSW	3.2	5.1	7.8	9.5	6.4	7.0	8.2
SW	4.7	7.5	7.3	8.3	5.3	7.4	8.3
SSW	5.6	9.0	6.4	4.6	5.5	8.9	6.7
S	6.0	9.7	8.7	3.0	9.1	13.8	8.6
SSE	10.4	16.7	3.8	1.6	4.4	5.7	3.4
SE	4.3	7.0	2.2	1.1	2.8	2.8	2.1
ESE	3.0	4.8	2.8	1.1	3.9	3.6	2.4
E	-	-	3.5	1.3	5.1	4.7	3.1
ENE	-	-	2.6	1.4	3.8	2.9	2.5
NE	-	-	3.3	3.3	4.0	2.7	3.1
NNE	-	-	4.8	6.6	5.1	2.6	4.8
N	-	-	9.2	13.2	8.8	5.4	9.6
Calm	-	-	5.5	5.0	4.0	6.8	6.3

Table 2

Wind Speed at Portland, Maine

Speed (mph)	Annual (%)	Winter	Spring	Summer	Fall
		(% occurrence, 1951-1980 average)			
1-3	7.6	6.9	5.9	9.1	8.4
4-8	29.7	28.6	25.2	33.8	31.3
9-12	32.1	31.0	32.7	32.7	31.9
13-18	20.4	21.9	25.6	16.1	18.1
19-24	3.6	4.9	5.0	1.3	3.1
25-31	0.9	1.5	1.3	0.2	0.7
Calm	5.7	5.2	4.3	6.8	6.5

Table 3

Winter Wind Speed and Direction

Direction	Annual Hrs. (all speeds)	9-12	13-18	19-24	25-31	32-38	Total (9-38mph)
		(mph classes, ave. annual hrs., 1951-1980)					
W	221	69	48	10.8	3.3	0.66	132
WSW	208	64	46	10.2	3.1	0.62	124
SW	182	56	40	8.9	2.7	0.55	108
SSW	101	31	22	4.9	1.5	0.30	60
S	66	20	14	3.2	1.0	0.20	38
SSE	35	11	8	1.7	0.5	0.11	21
SE	24	7	5	1.2	0.4	0.07	14
ESE	28	9	6	1.4	0.4	0.09	17
Total Hrs.	865	267	189	42.3	12.9	2.60	514
% All Dir.	39.5	12.2	8.6	1.9	0.6	0.1	23.5

Table 4

Spring Wind Speed and Direction

Direction	Annual Hrs. (all speeds)	9-12	13-18	19-24	25-31	32-38	Total (9-38mph)
		(mph classes, ave. annual hrs., 1951-1980)					
W	175	57	45	8.8	2.3	0.35	113
WSW	140	46	36	7.0	1.8	0.28	91
SW	116	38	30	5.8	1.5	0.23	76
SSW	120	39	31	6.0	1.6	0.24	78
S	199	65	51	10.0	2.6	0.40	129
SSE	96	31	25	4.8	1.3	0.19	62
SE	61	20	16	3.1	0.8	0.12	40
ESE	85	28	22	4.3	1.1	0.17	56
Total Hrs.	992	324	256	49.8	13.0	1.98	645
% All Dir.	45.3	14.8	11.7	2.3	0.6	0.0	29.5

Table 5

Summer Wind Speed and Direction

Direction	Annual Hrs. (all speeds)	9-12	13-18	19-24	25-31	32-38	Total (9-38mph)
		(mph classes, ave. annual hrs., 1951-1980)					
W	169	55	27	2.2	0.34	0.0	85
WSW	153	50	25	2.0	0.31	0.0	77
SW	162	53	26	2.1	0.32	0.0	81
SSW	195	64	31	2.5	0.39	0.0	98
S	302	99	49	3.9	0.60	0.0	152
SSE	125	41	20	1.6	0.25	0.0	63
SE	61	20	10	0.8	0.12	0.0	31
ESE	79	26	13	1.1	0.16	0.0	40
Total Hrs.	1246	408	201	16.2	2.49	0.0	627
% All Dir.	56.9	18.6	9.2	0.7	0.1	0.0	28.6

Table 6

Fall Wind Speed and Direction

Direction	Annual Hrs. (all speeds)	9-12	13-18	19-24	25-31	32-38	Total (9-38mph)
		(mph classes, ave. annual hrs., 1951-1980)					
W	197	64	35	6.0	1.4	0.2	107
WSW	180	57	33	5.6	1.3	0.2	97
SW	182	58	33	5.6	1.3	0.2	98
SSW	147	47	27	4.5	1.0	0.2	80
S	188	60	34	5.8	1.3	0.2	101
SSE	74	24	13	2.3	0.5	0.1	40
SE	46	15	8	1.4	0.3	0.1	25
ESE	53	17	10	1.6	0.4	0.1	28
Total Hrs.	1067	342	193	33	7.5	1.3	576
% All Dir.	48.7	15.6	8.8	1.5	0.3	0.06	26.3

Table 7

Profile Plots and Analysis

Sweep Zone	All the profile data collected (December 1990-October 1993).
Over Winter	The last data collected in one year and the first data collected in the following year. Three separate cycles plotted (1990-91, 1991-92, 1992-93).
Spring	Plot of data from the spring months of each year (1991, 1992, 1993).
Summer	Plot of data from the summer months of each year (1991, 1992, 1993).
Fall	Plot of data from the fall months of each year (1991, 1992, 1993).
Interannual	Plot of data from the same month in consecutive years (e.g., April 1991, 1992, 1993; July 1991, 1992, 1993).

Figures

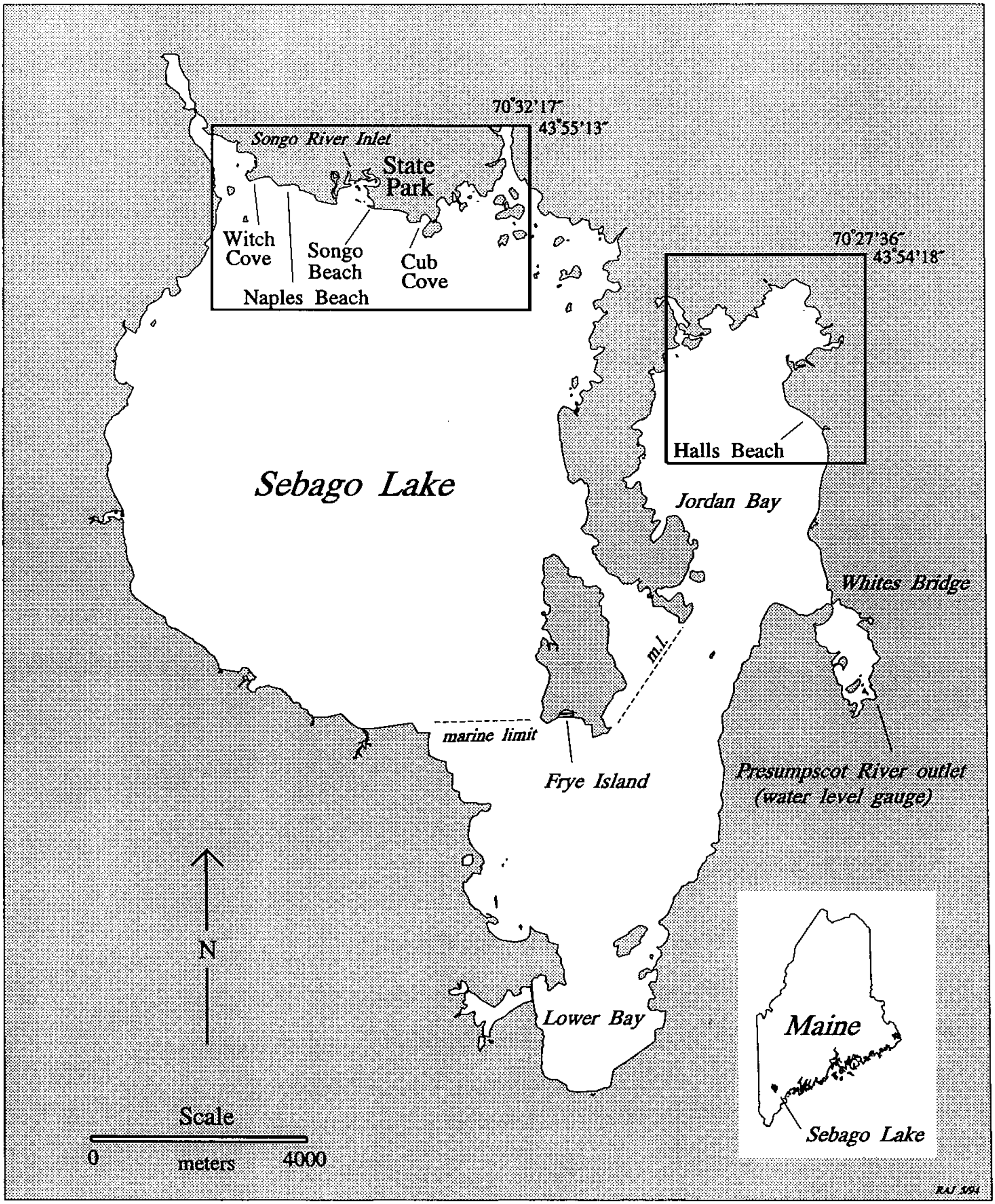
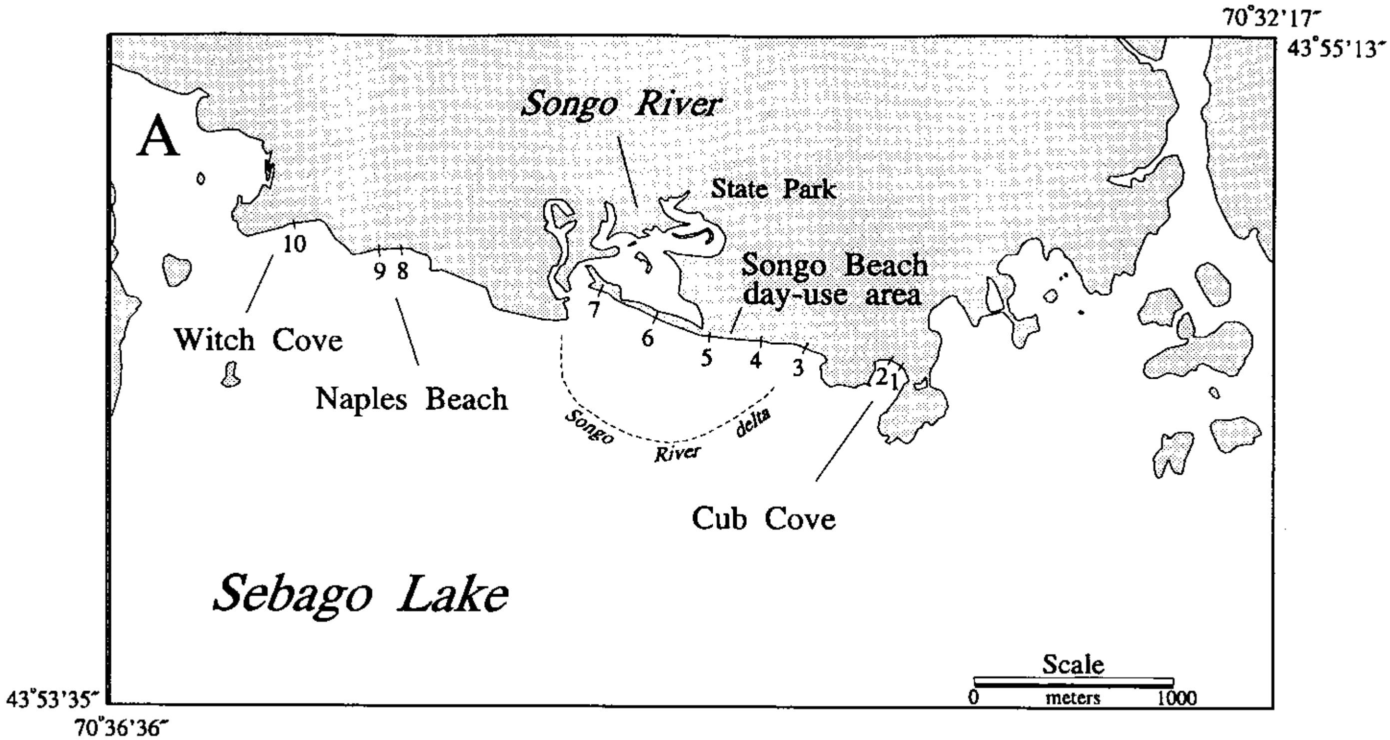


Figure 1. General location map of Sebago Lake. Profile locations are at the northern end of the lake in the inset boxes and are shown in more detail in Figure 3.

Figure 2. Photographs of Songo Beach with exposed tree roots indicating sand loss. Photos by C. S. Bastey, Bureau of Parks and Recreation on 5 April 1993.



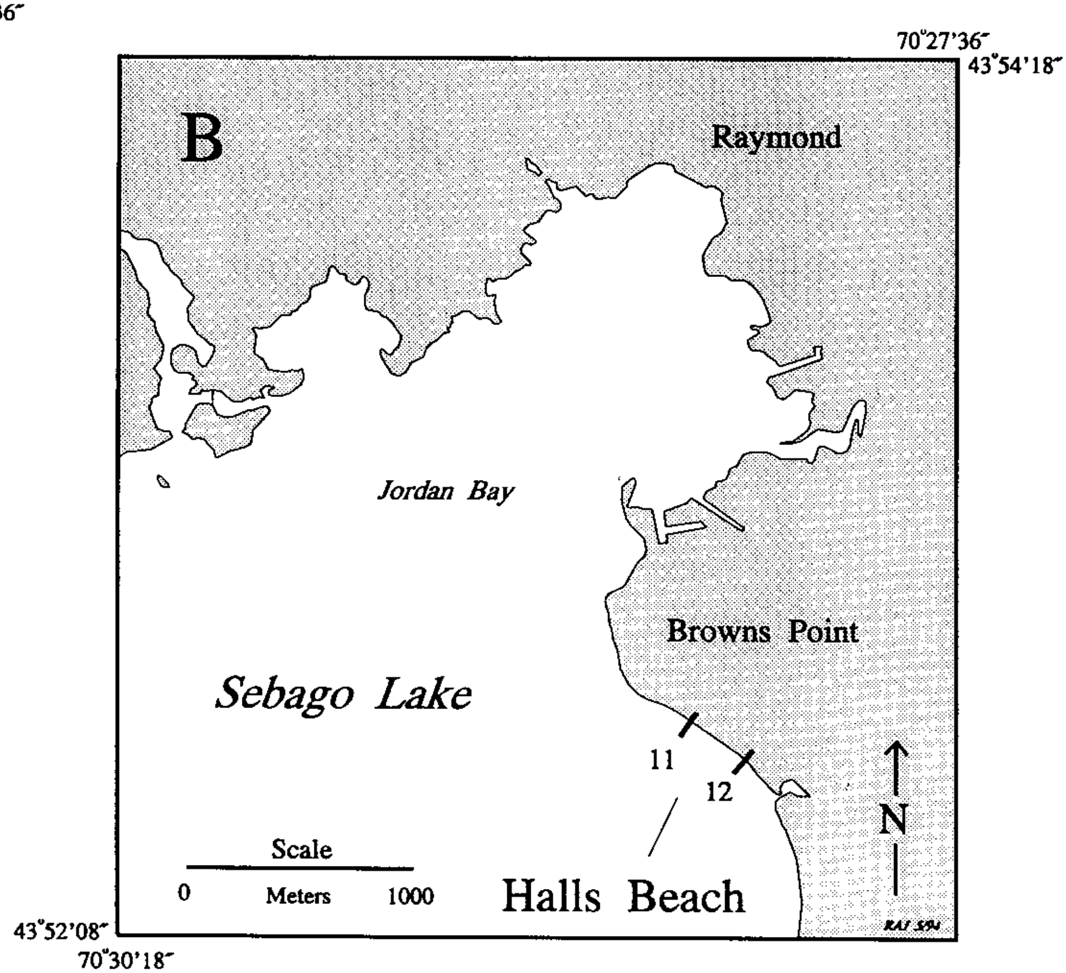
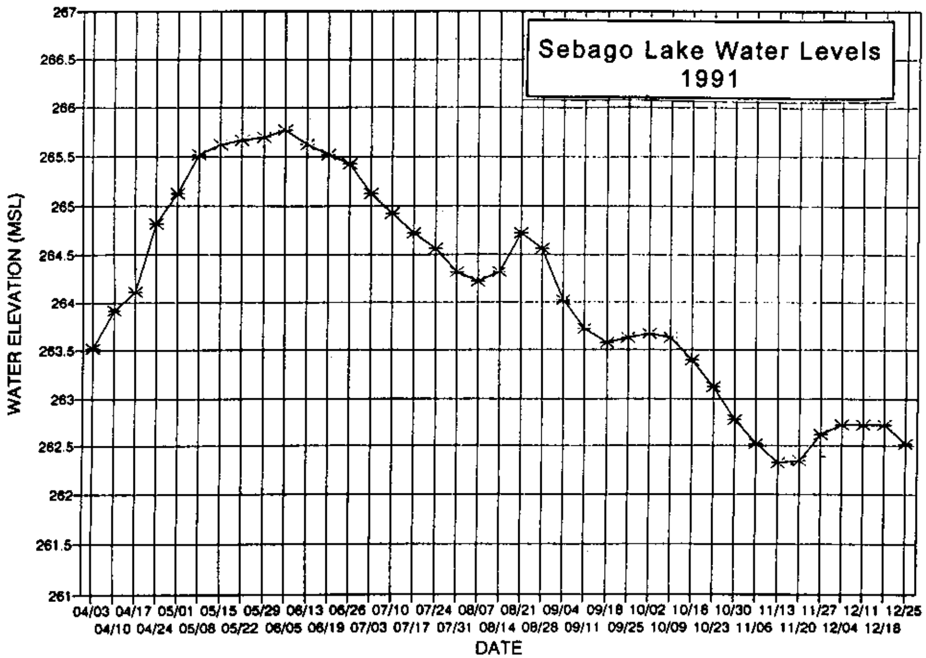
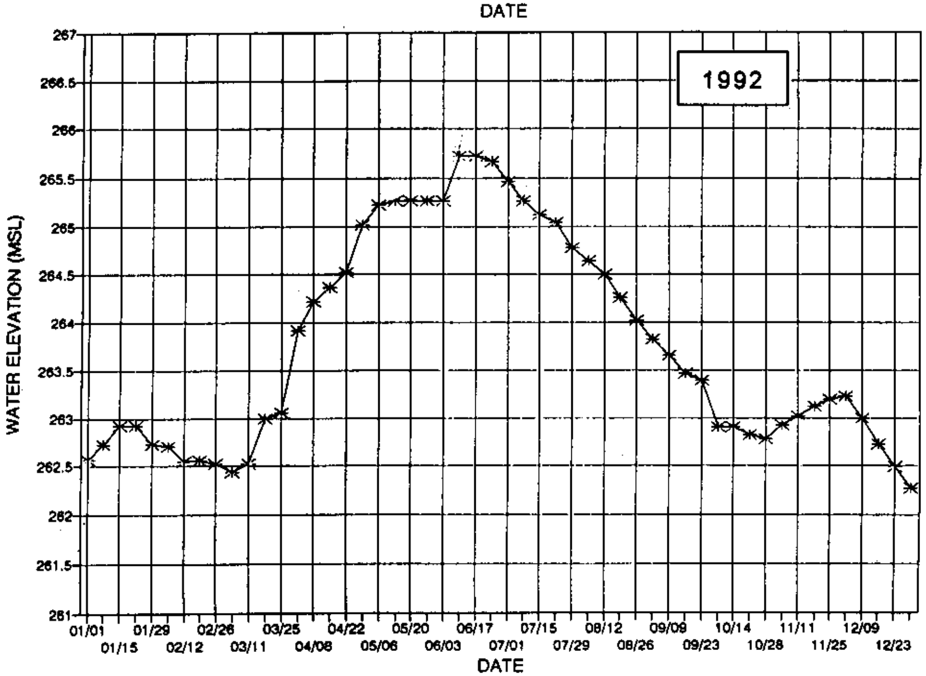


Figure 3. Beach profile stations 1-10 at Sebago Lake State Park (a) and 11 and 12 at Halls Beach (b).





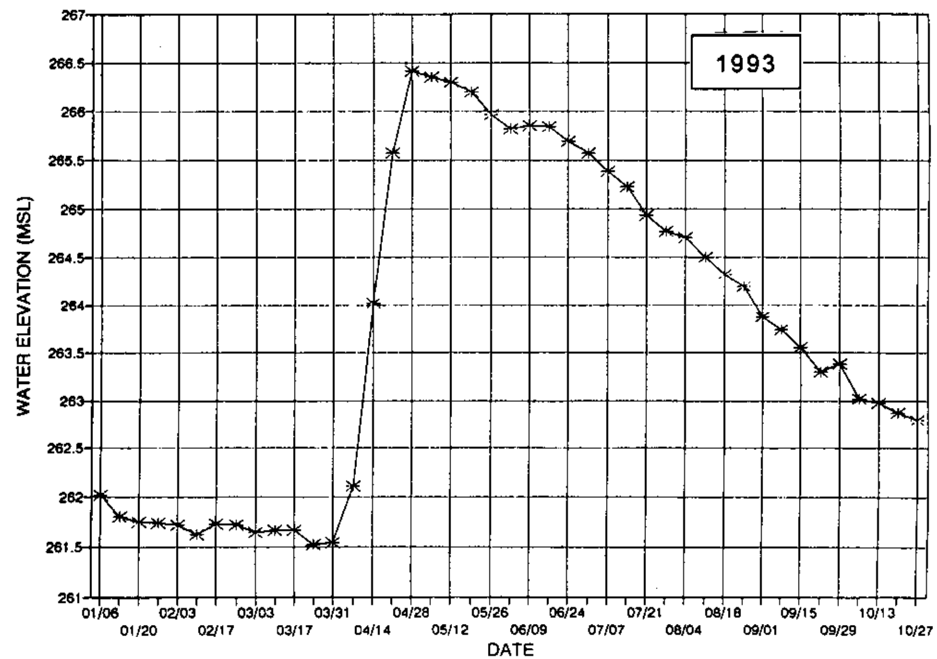


Figure 4. Sebago Lake level from April 1991 through October 1993. Levels in this reservoir are controlled by precipitation and releases from a dam at the outlet to the Presumpscot River near Whites Bridge (Fig. 1). Weekly level readings are shown by date along the bottom of the graph. Elevations are in feet above mean sea level (MSL) as recorded at a gauge at the dam. Illustration courtesy of C.S. Bastey, Bureau of Parks and Recreation. Data from the S. D. Warren Company, Westbrook, Maine.

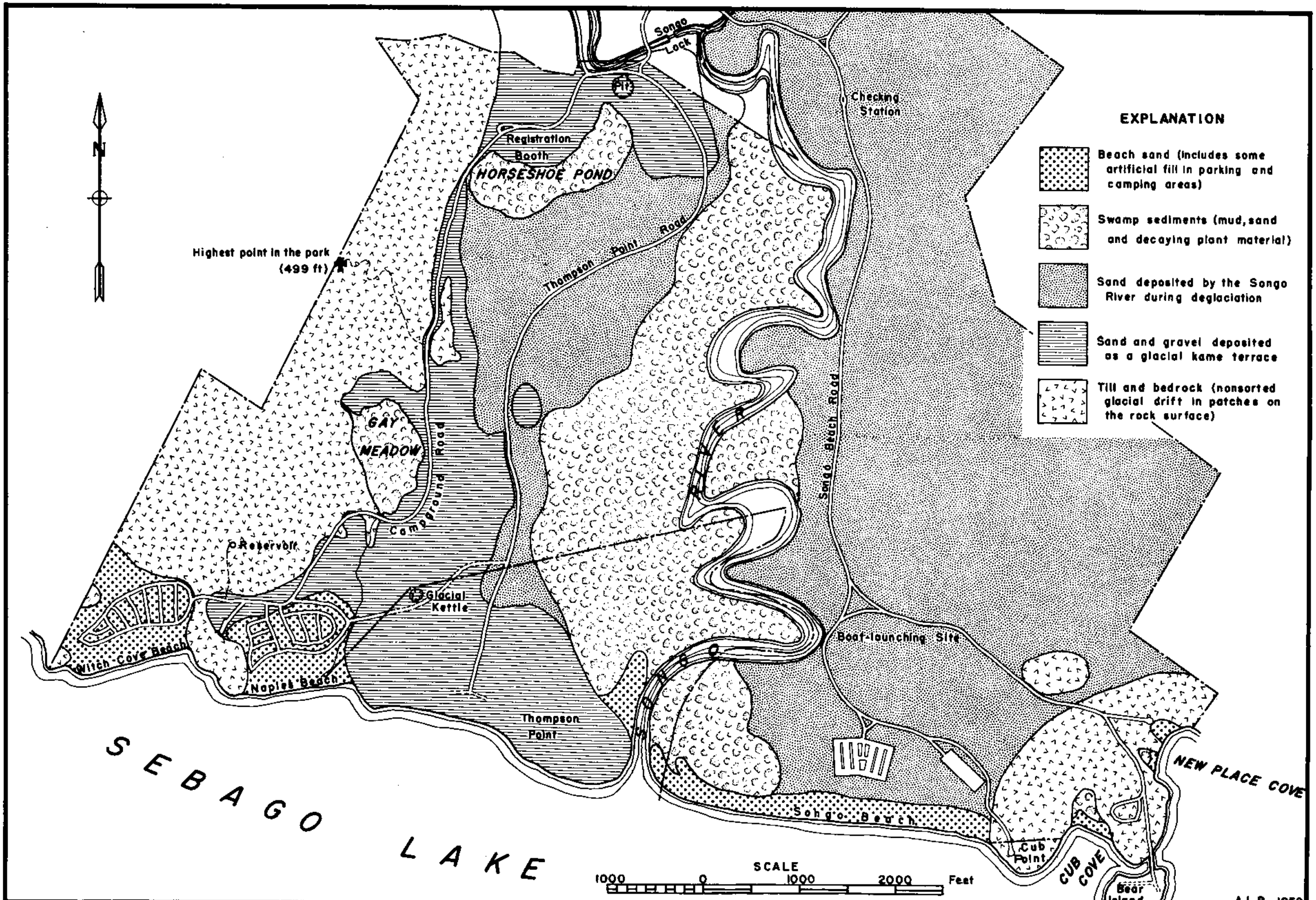
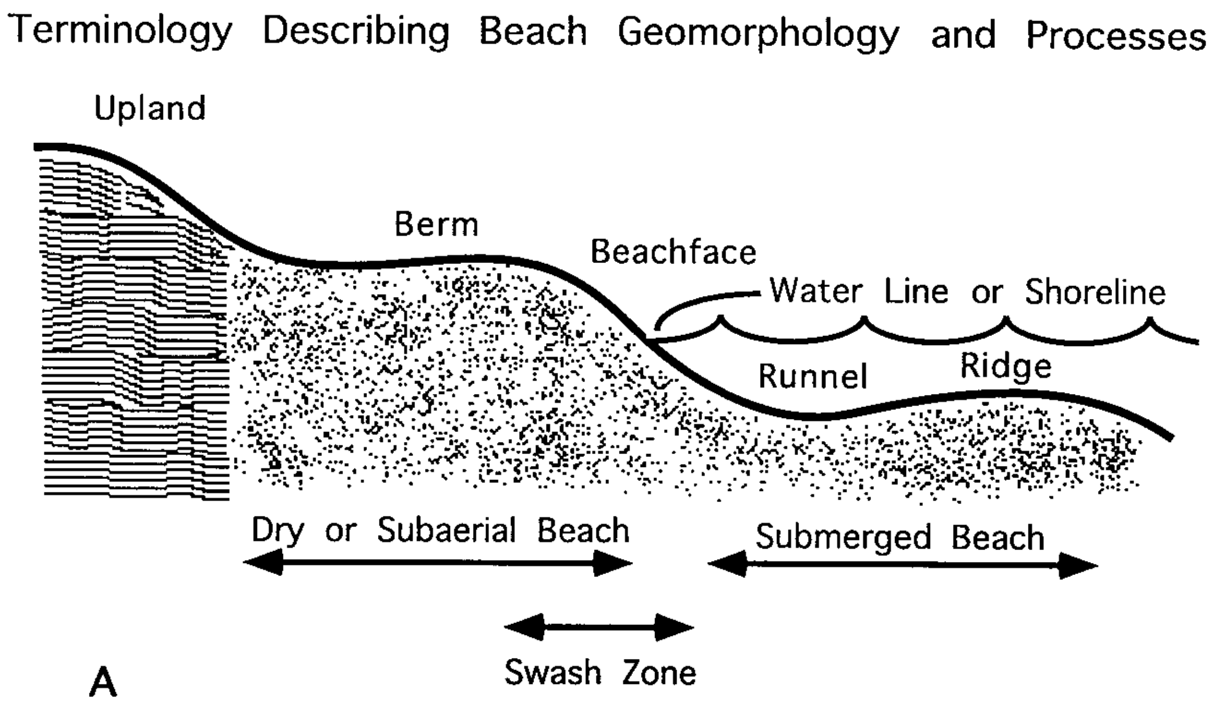


Figure 5. Geologic map of Sebago Lake State Park from Bloom (1959, Plate III).



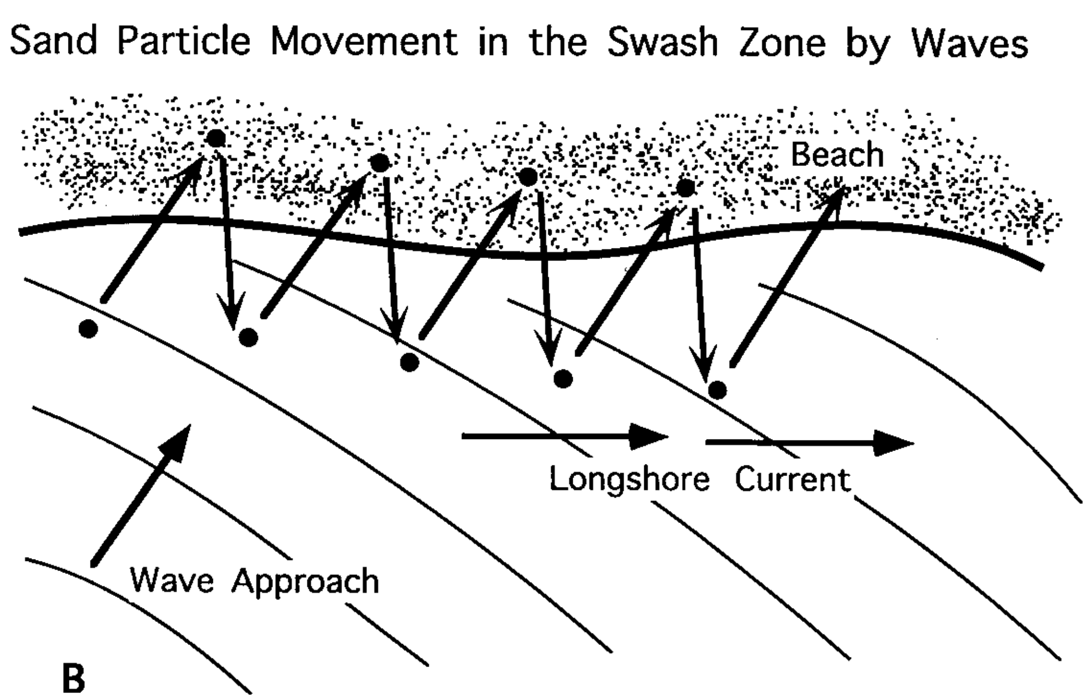


Figure 6. Top diagram showing a typical beach profile with terminology found in the text (a). Bottom diagram (b) showing sand particle movement along the shoreline due to onshore - offshore movement in the swash zone due to oblique wave approach (plan view). The waves also create a shore parallel current, the longshore current. The river of sand moving alongshore is called the longshore drift.

Beach Profile Adjustment to Lake Level Changes

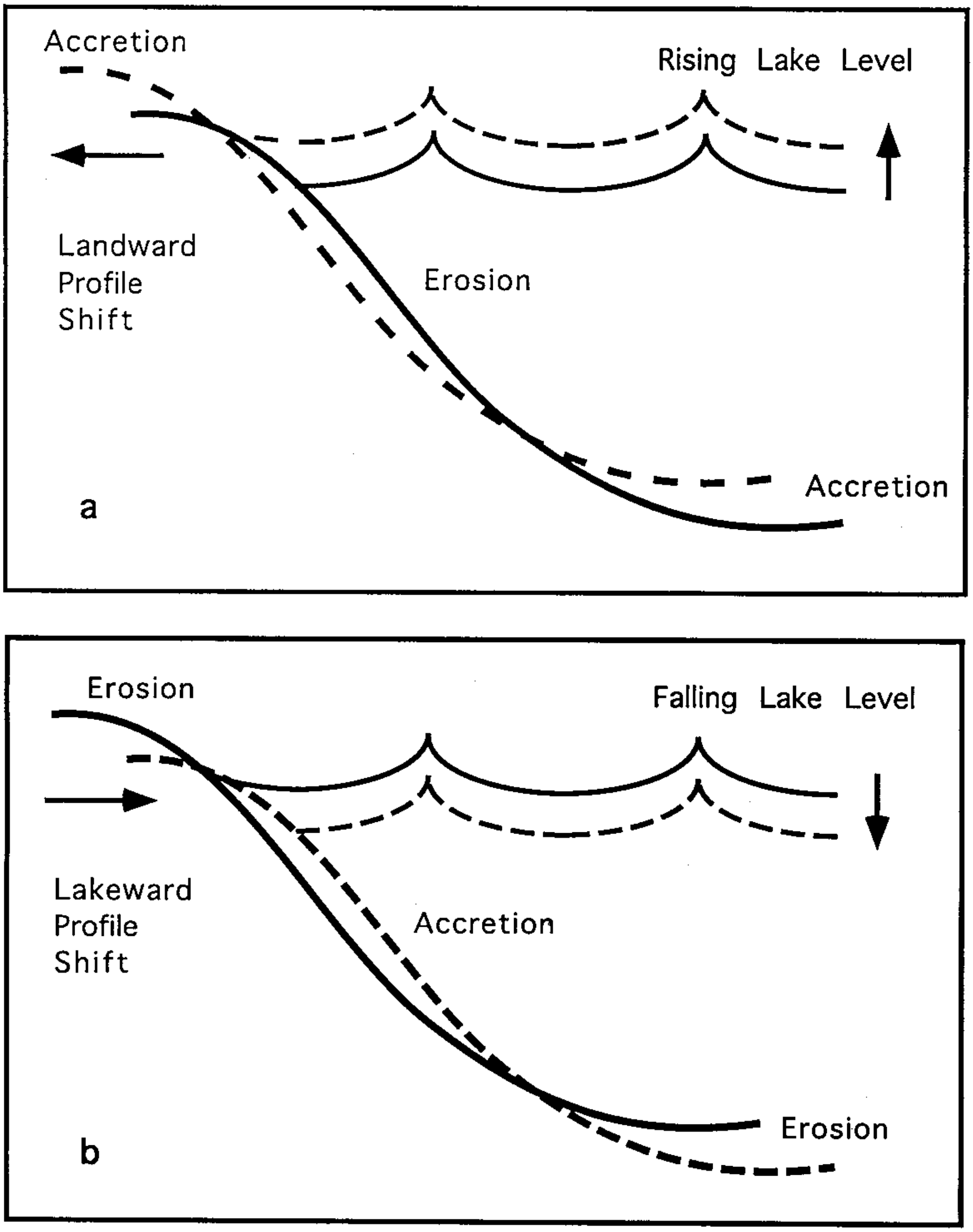


Figure 7. A schematic example of profile change from one "equilibrium" configuration (solid line) to another (dashed line). In (a) the original lake level is low (solid line) and rises to a new position (dashed line). The profile adjusts upward and landward. The upper and lower portions of the profile show accretion while the middle, submerged portion shows erosion. In (b) the lake level falls from a high level (solid line) to a lower level (dashed line). The profile adjusts downward and lakeward. The upper and lower portions of the profile show erosion while the middle, submerged portion shows accretion. The extremes of all the profiles define the outer envelope of variation called the "sweep zone."

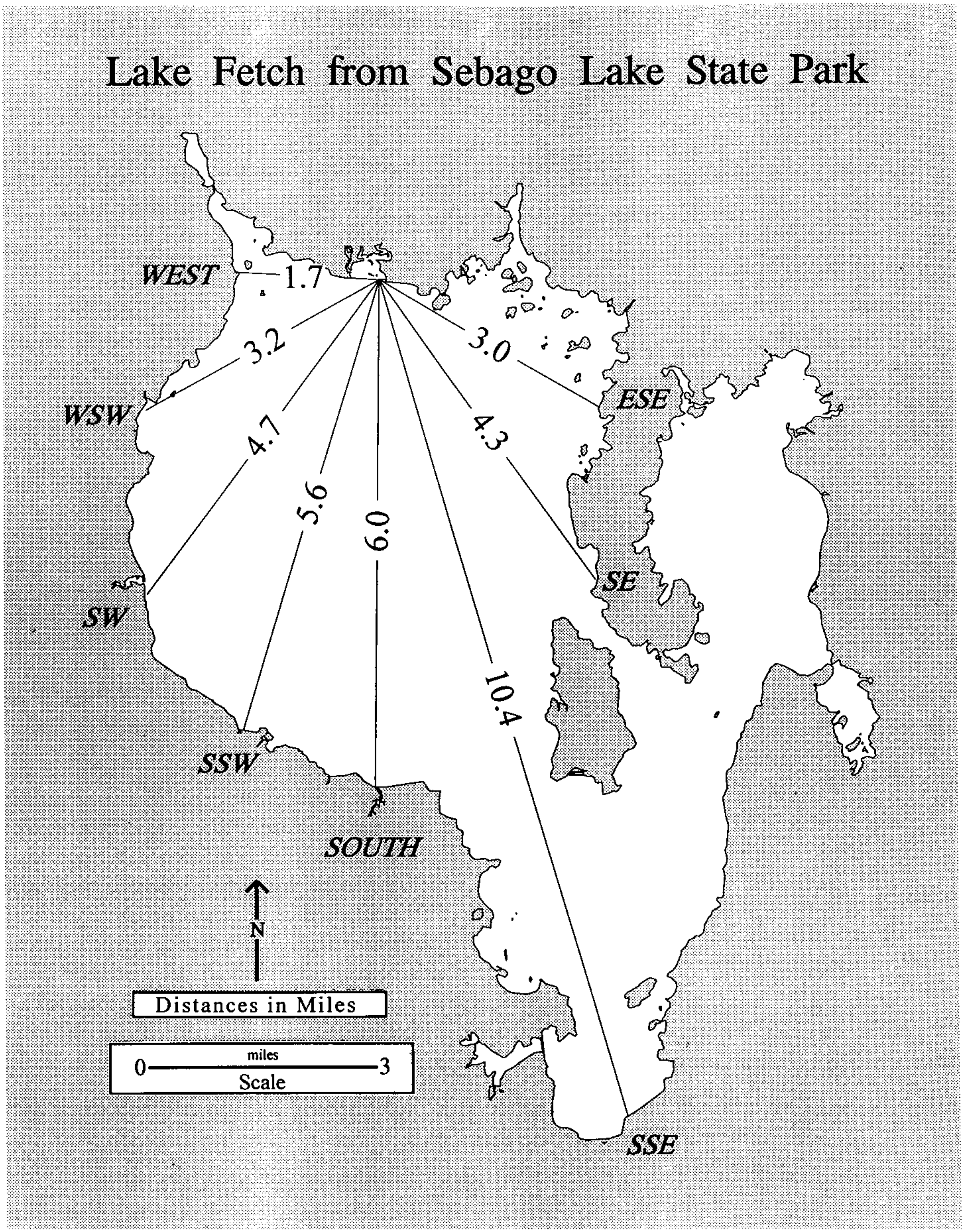


Figure 8. Fetch distances and directions from Sebago Lake State Park beaches.

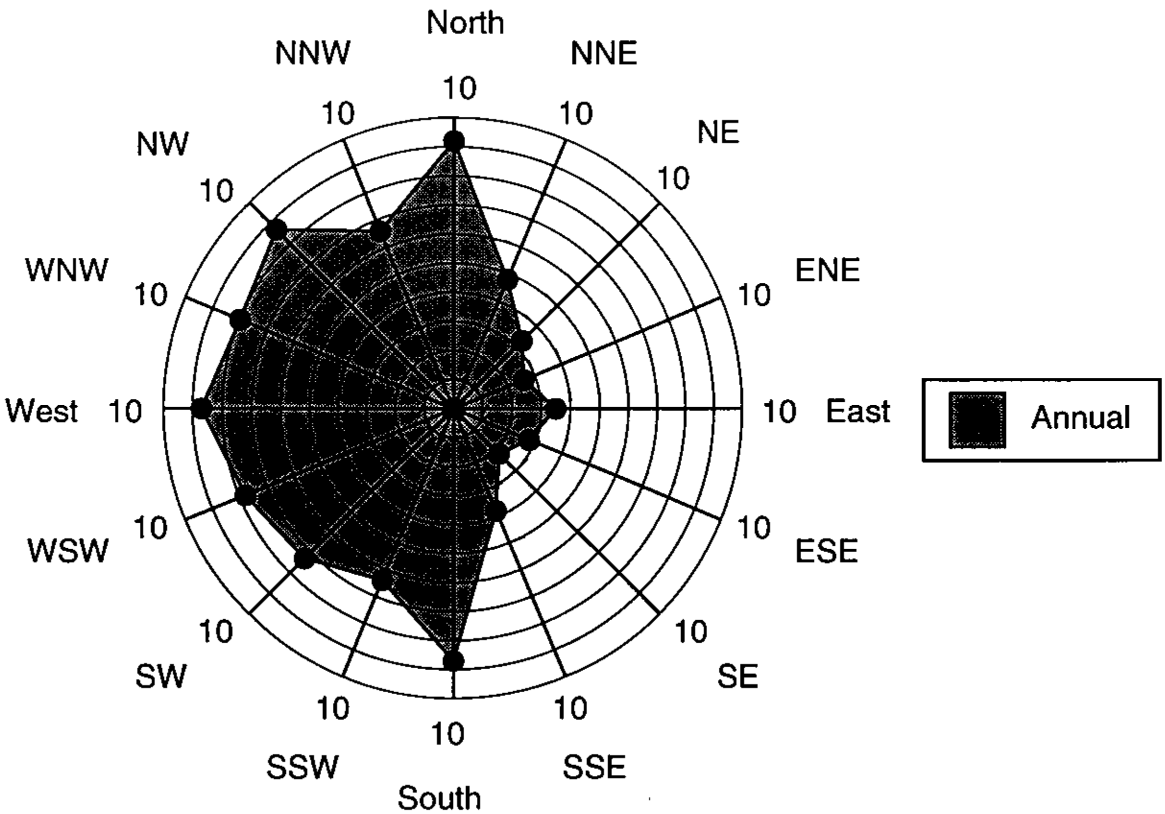


Figure 9. Annual Wind rose for Portland, Maine. Percent occurrences indicated by rings. Each ring represents 10%. Data shown in Table 1.

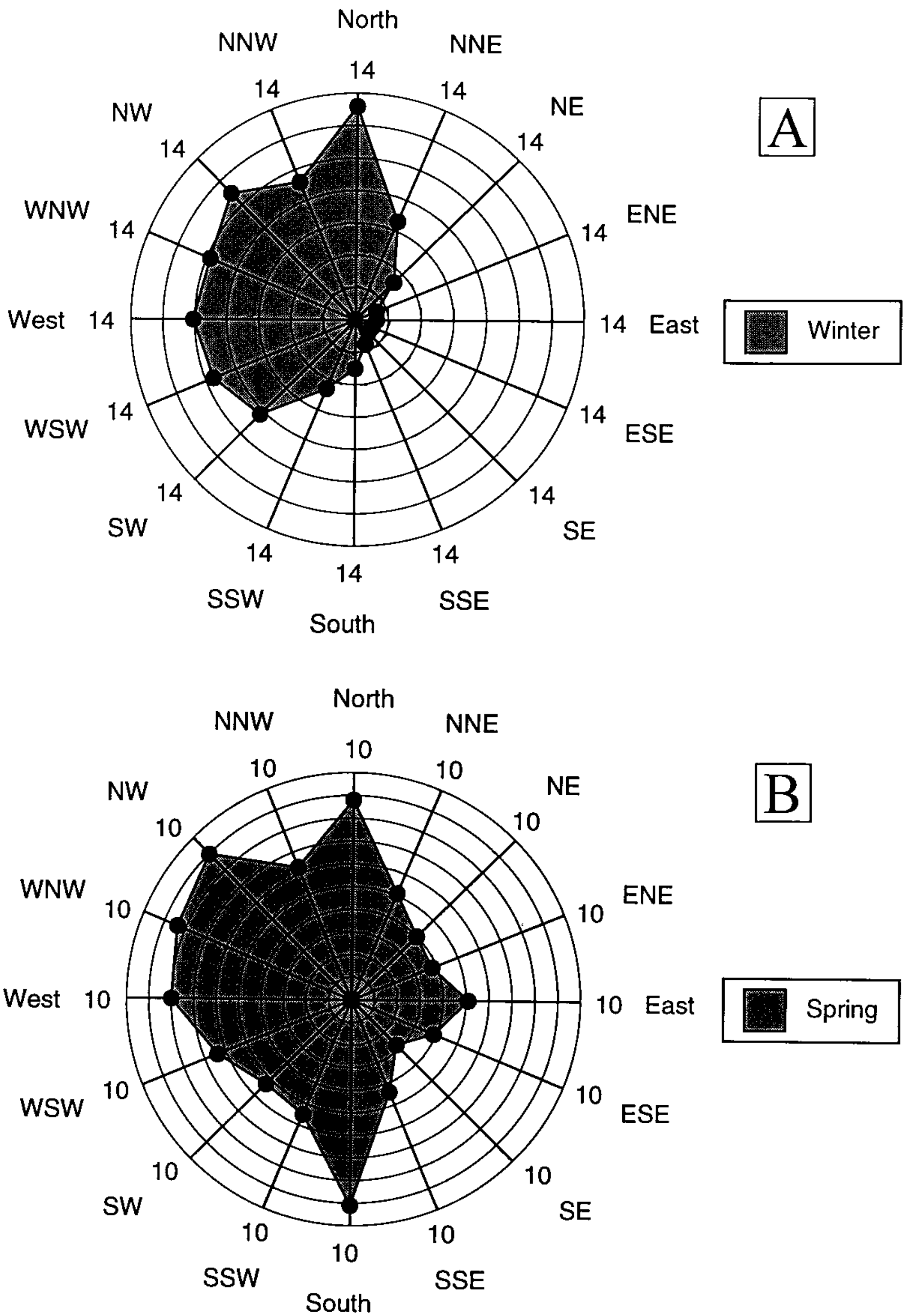
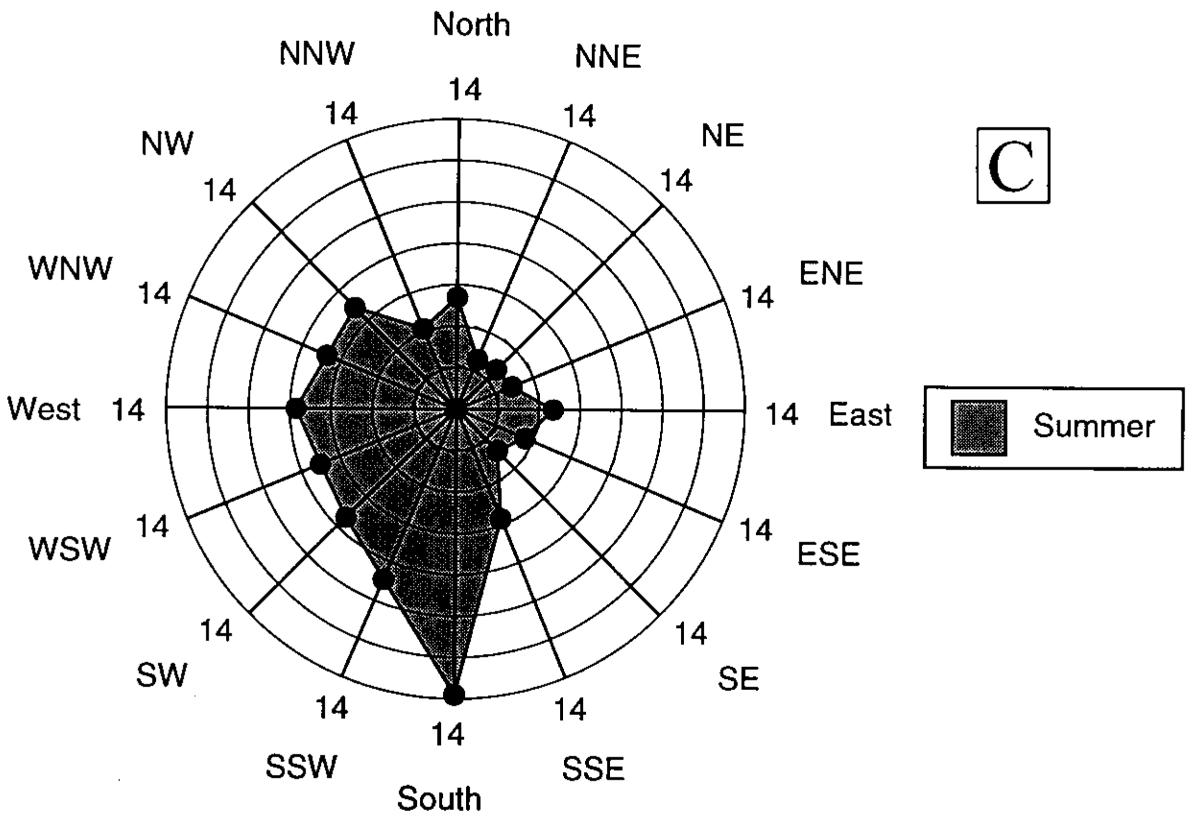


Figure 10. Seasonal wind roses for Portland, Maine. Data shown in Table 1.



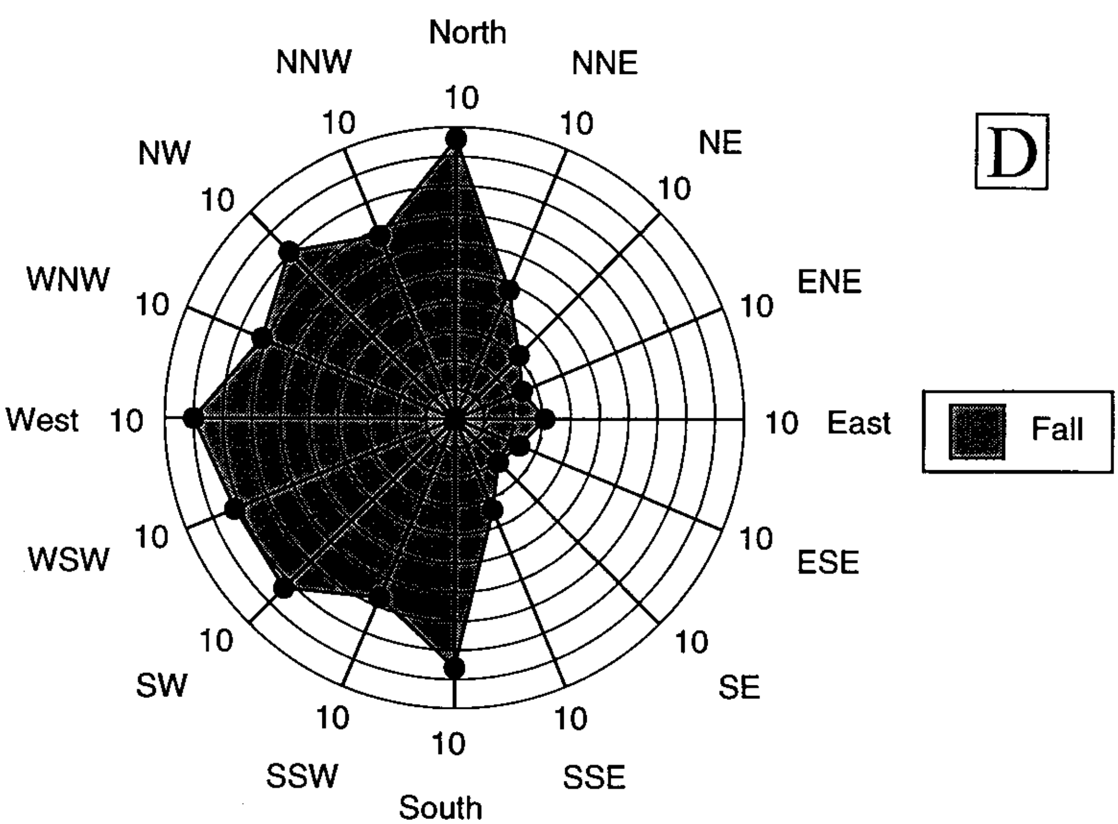


Figure 10. (continued) Seasonal wind roses for Portland, Maine. Data shown in Table 1.

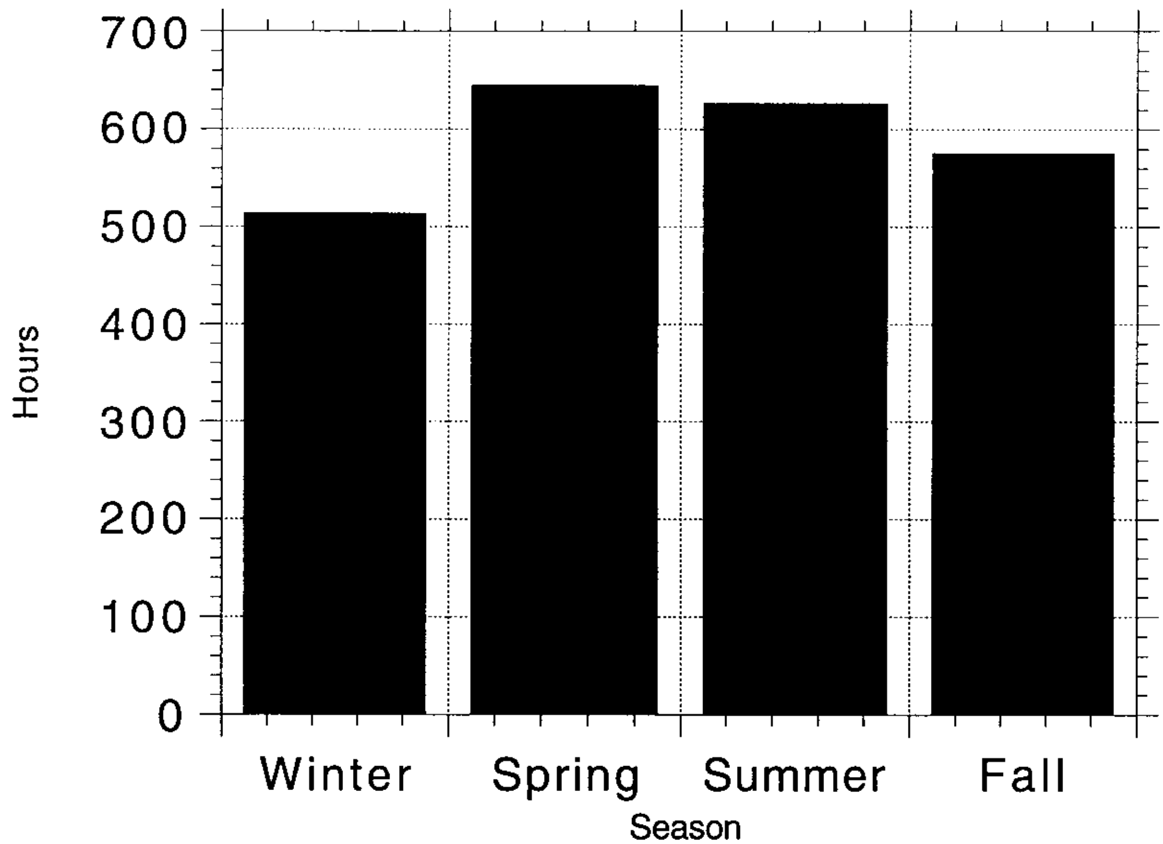


Figure 11. Histogram of hours of wave-generating winds approaching the state park beaches by season. Data are from Tables 3-6.

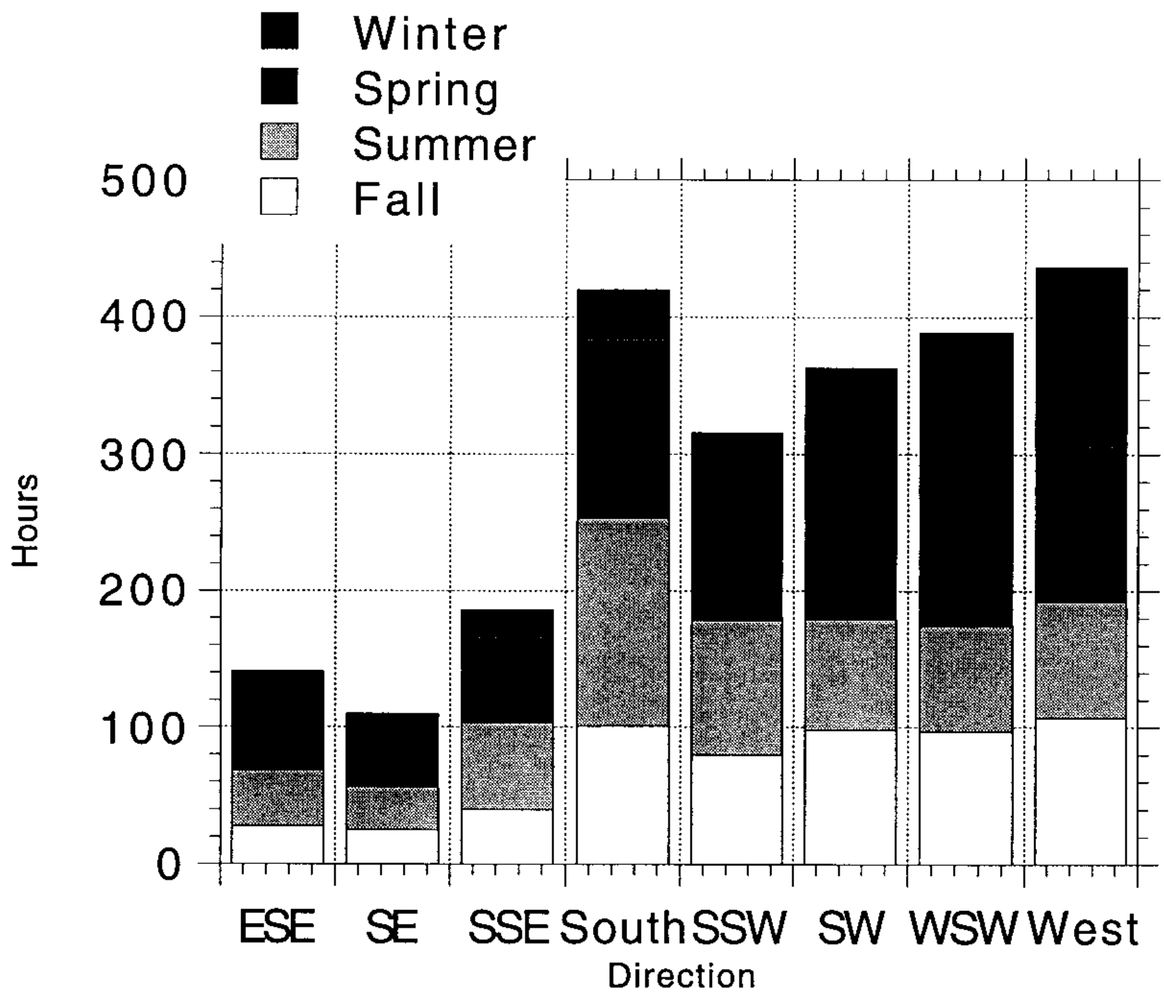


Figure 12. Cumulative histogram of hours of wave-generating winds by season and direction. South to west directions are most prevalent. Note the the southerly dominance if winter wind data are removed. Data are from Tables 3-6.

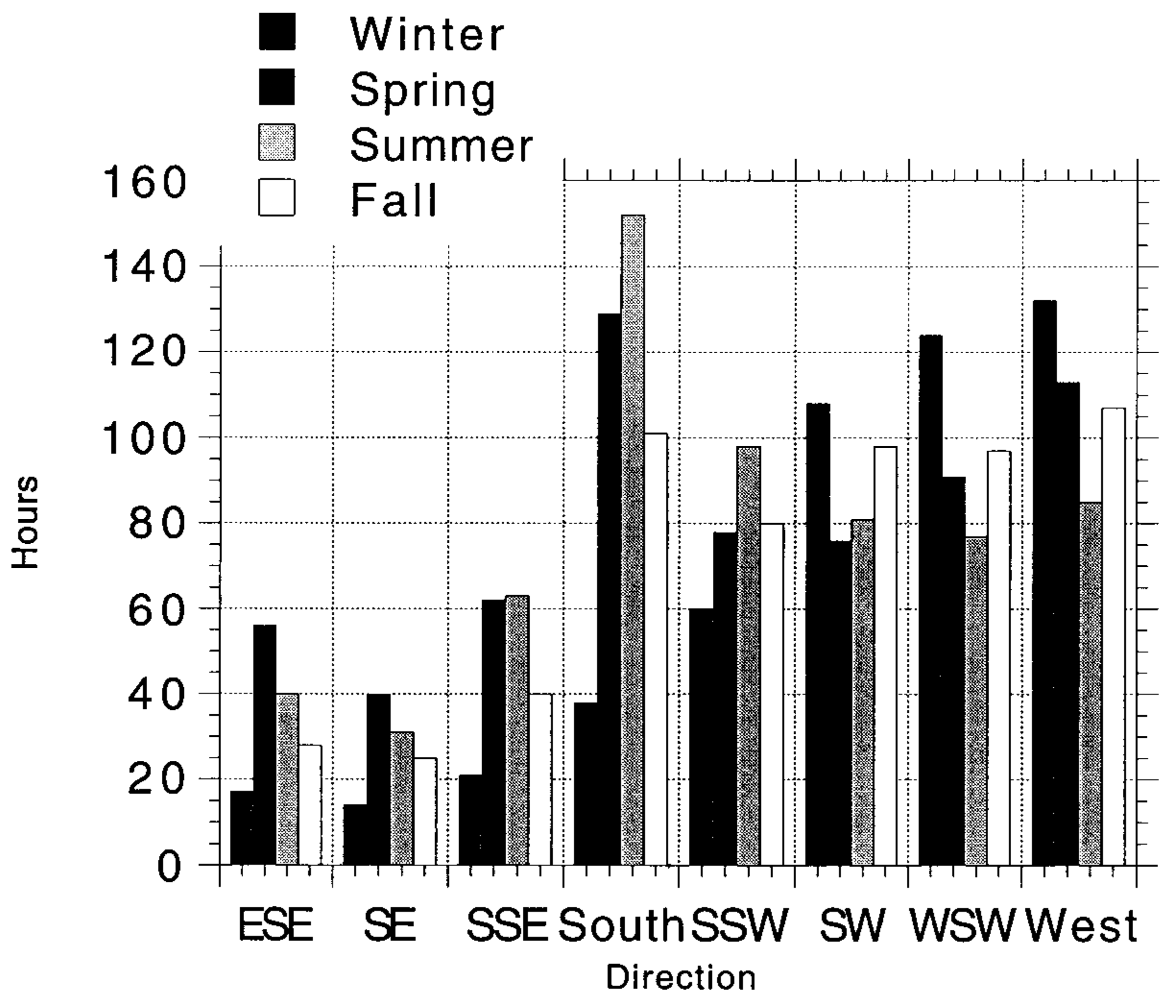


Figure 13. Histogram of hours of wave-generating winds by season and direction. Data are from Tables 3-6.

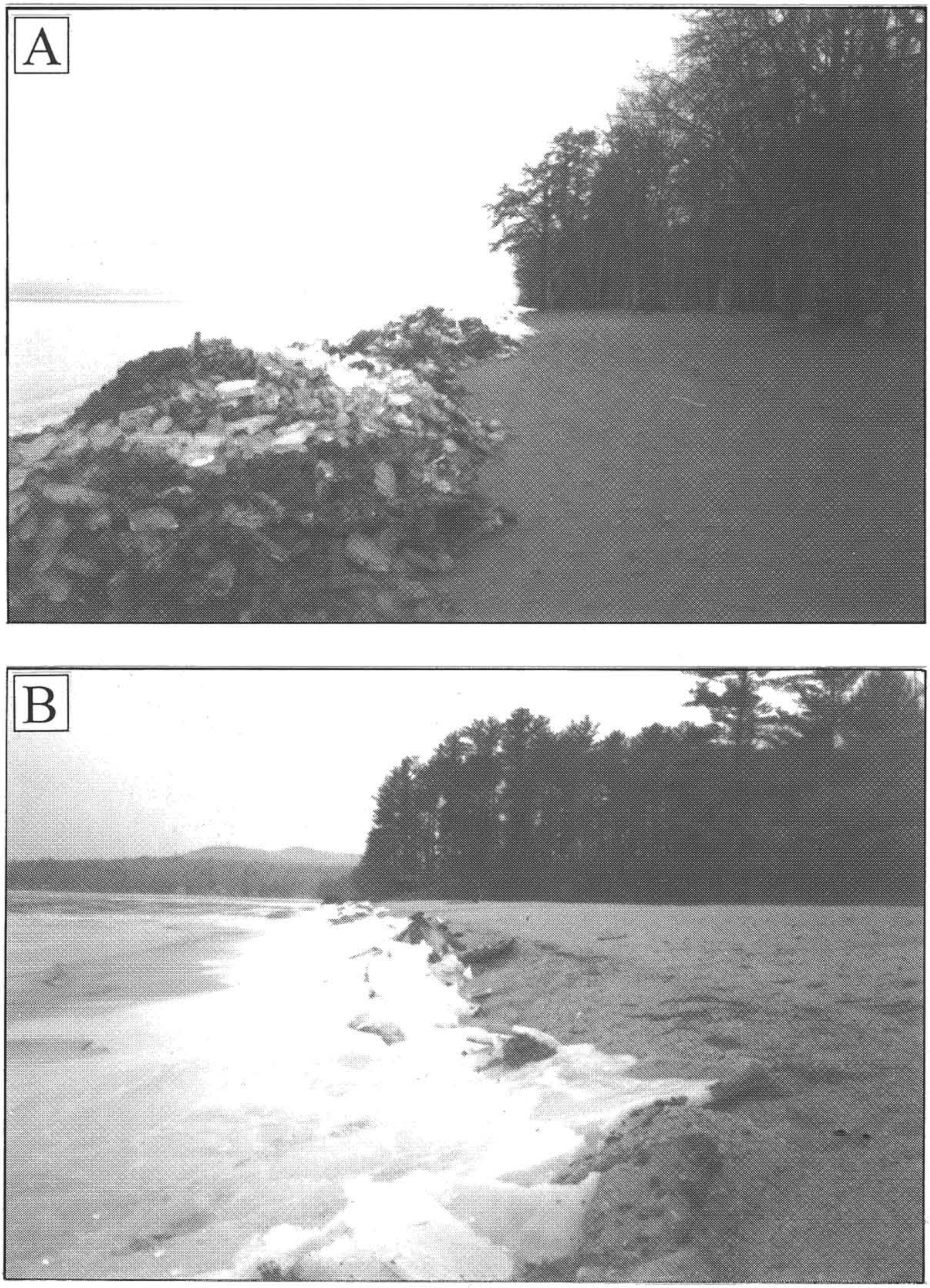


Figure 14. Photograph of an ice-push ridges of sand and ice. Songo Beach (a) near Profile No. 4 on 27 March 1992 looking toward Profile No. 5. Ridges may reach 6 feet (2 meters) in height. Naples Beach (b) near Profile 8 looking toward Profile 9 on 27 March 1992. Photo courtesy of Bureau of Parks and Recreation, DOC.

Figure 15. Photograph of Songo Beach near Profile No. 3 on 2 December 1993. The beach has low relief. At periods of high lake levels the shoreline reaches the base of some trees along the upland edge of the beach. Photo courtesy of Bureau of Parks and Recreation, DOC.

Figure 16. Photograph of Songo Beach spit on 11 June 1992 looking west toward the Songo River. The lake is on the left and wetland on the right. Photo courtesy of Bureau of Parks and Recreation, DOC.

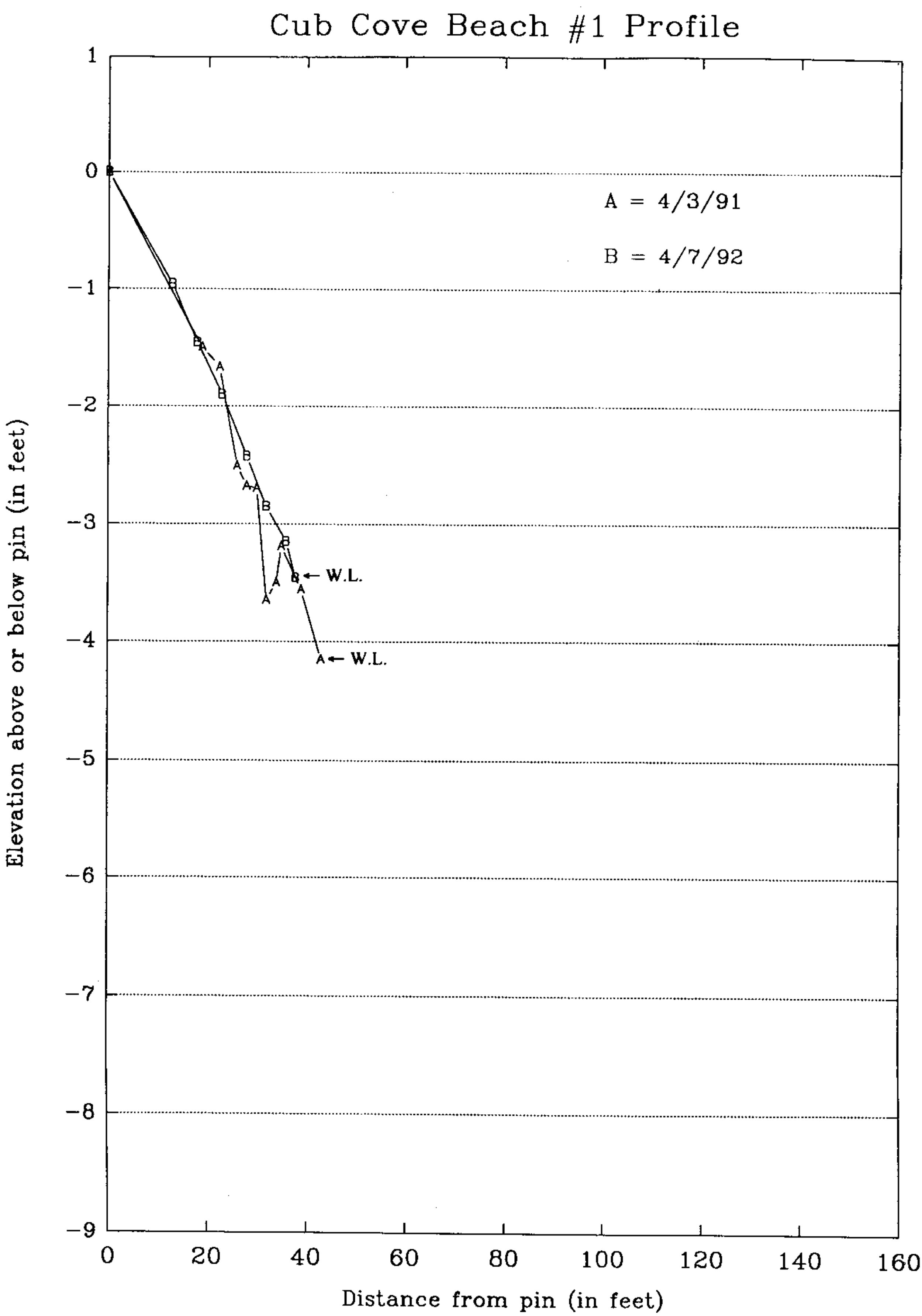


Figure 17. Ice action prior to 3 April 1991 leaves ridge and runnel topography in the Cub Cove Beach No. 1 profile. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

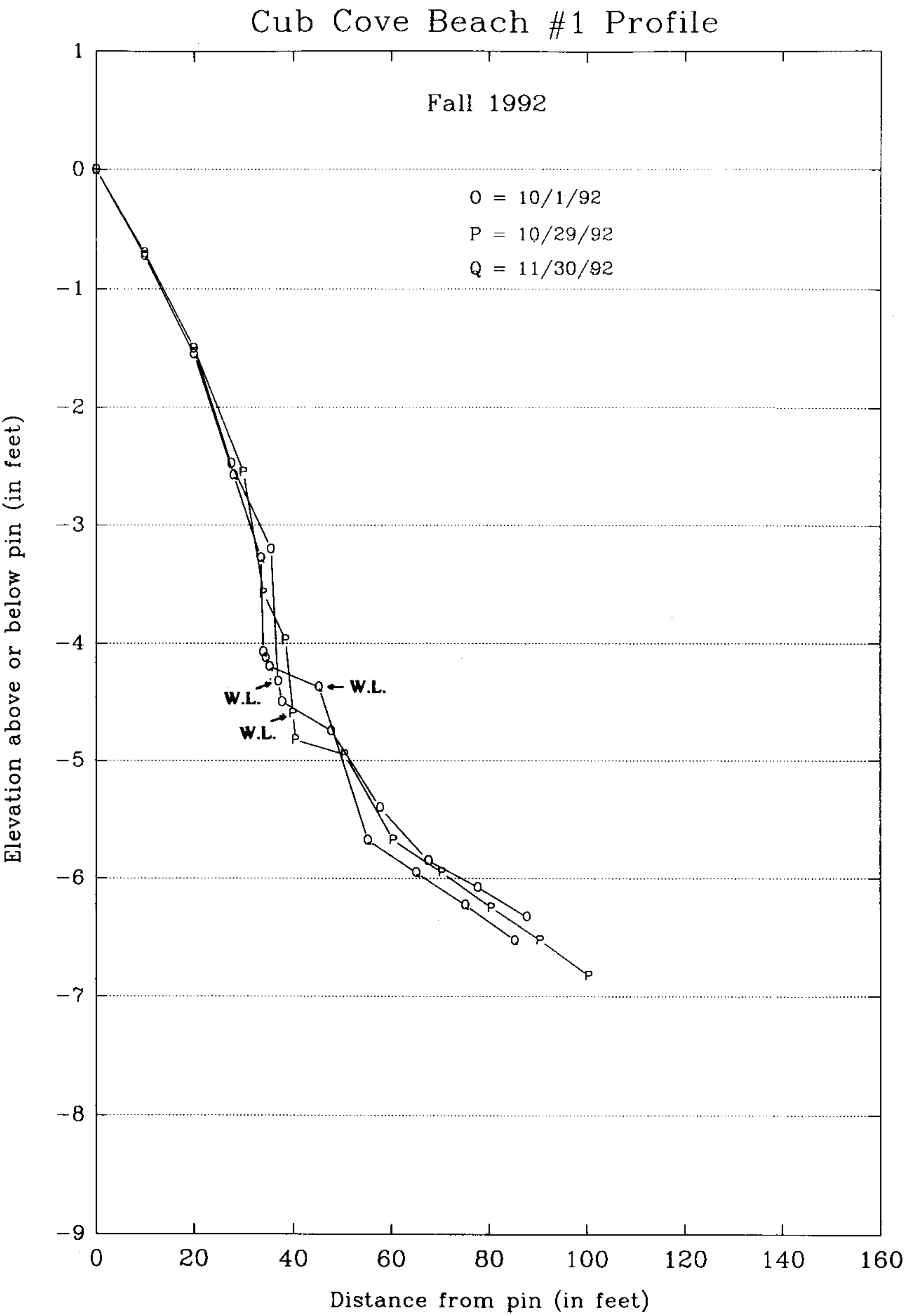


Figure 18. Erosional notches cut in the fall 1992 at Cub Cove Beach No. 1 profile. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

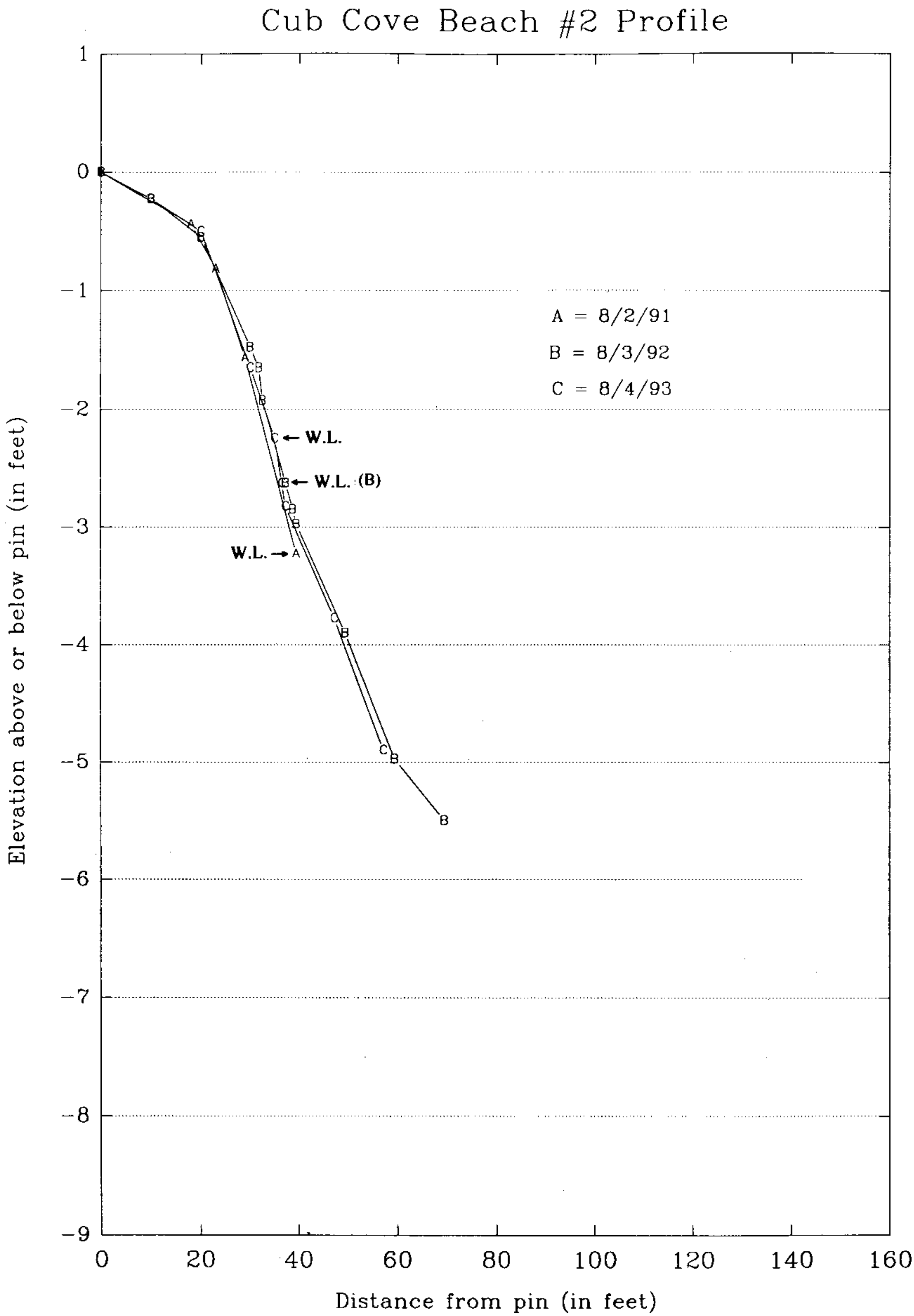


Figure 19. Summer 1991 through 1993 Cub Cove Beach No. 2 profiles. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

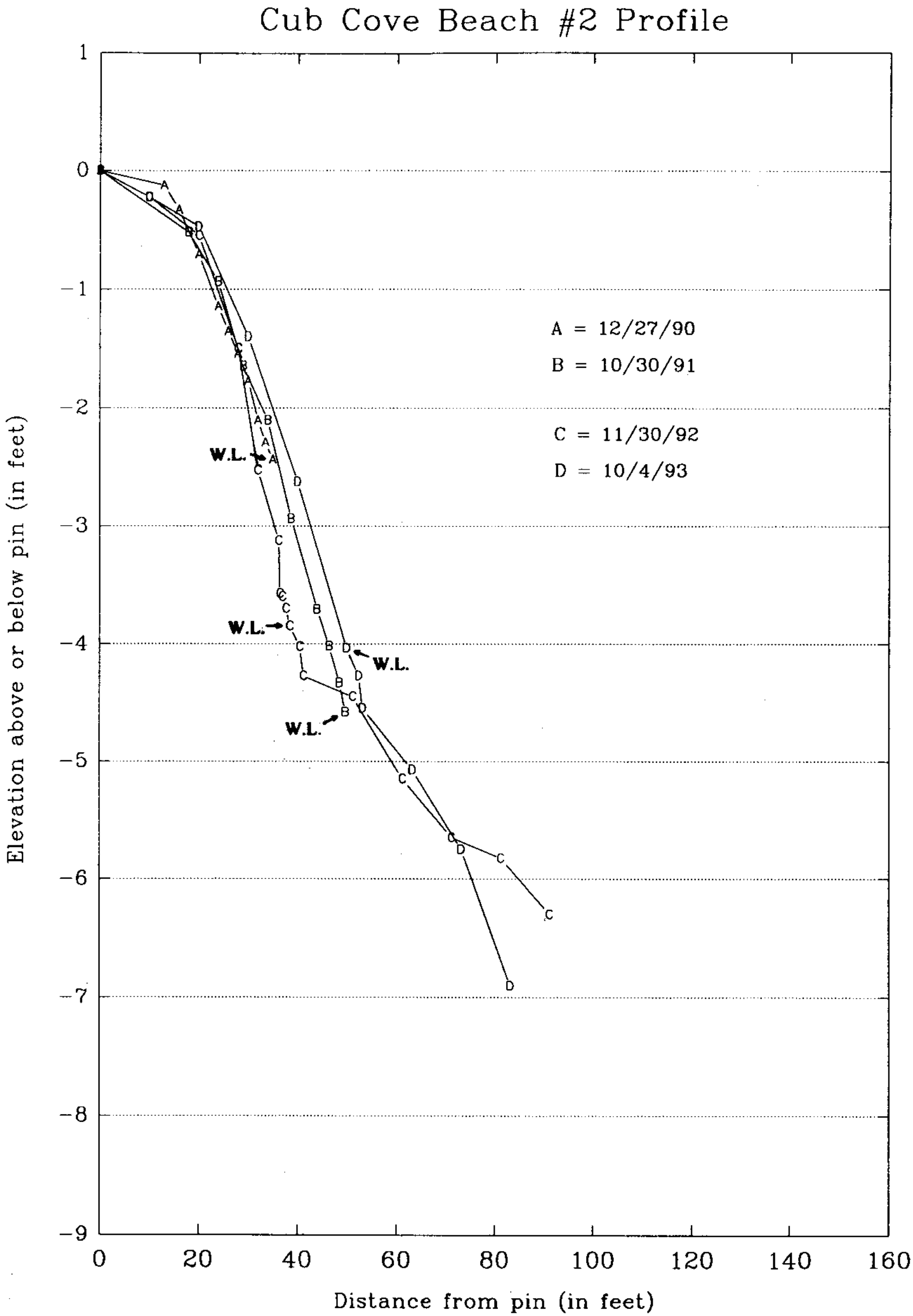


Figure 20. Fall 1992 notches cut in Cub Cove Beach No. 2 profile are refilled by fall of 1993 between -4 and -5 feet elevation. No notches were found in the fall of 1991. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

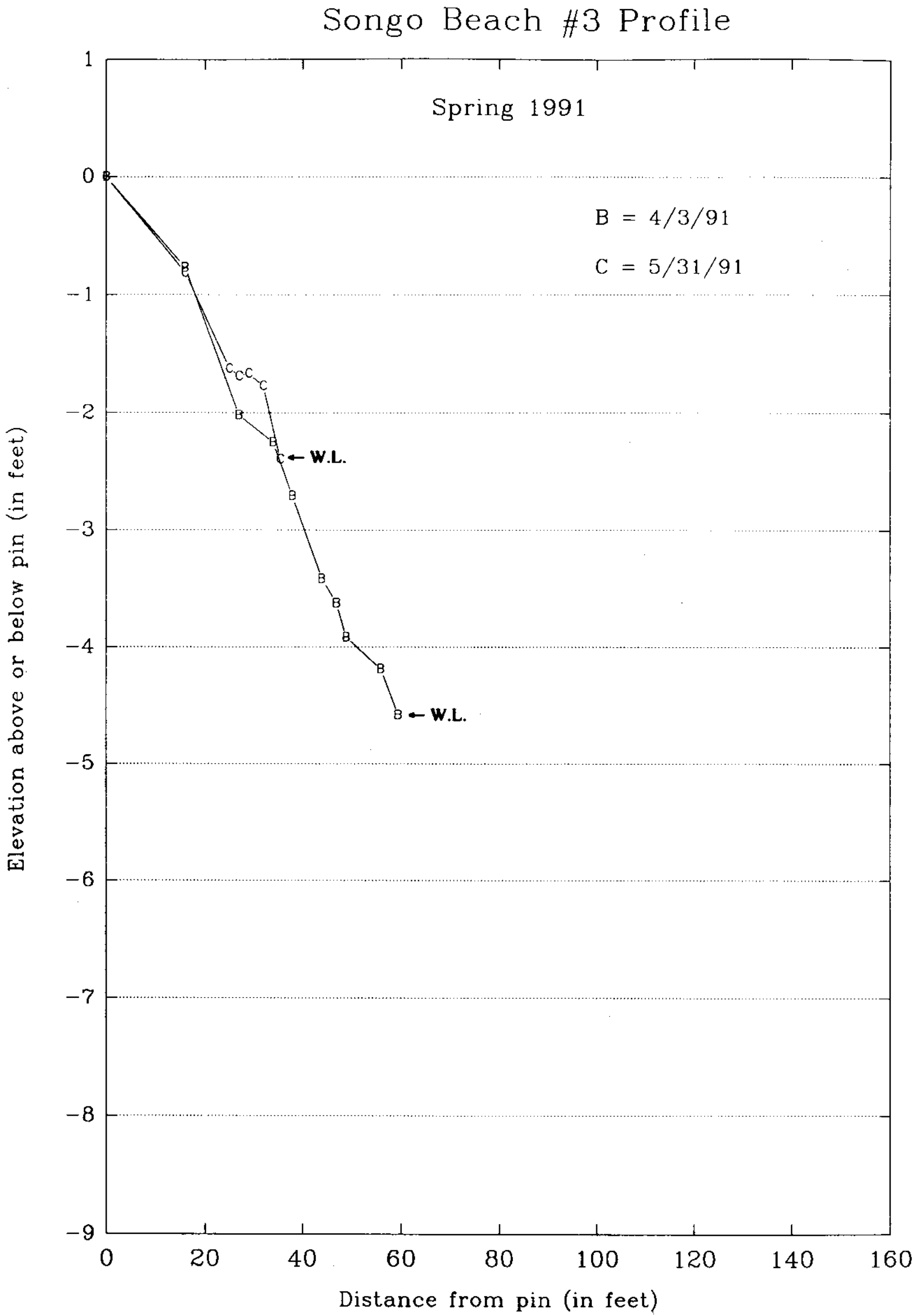


Figure 21. Effect of rising water level on the Songo Beach No. 3 profile in spring. Sand accumulates at -1.5 to -2.2 feet elevations above the water line. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

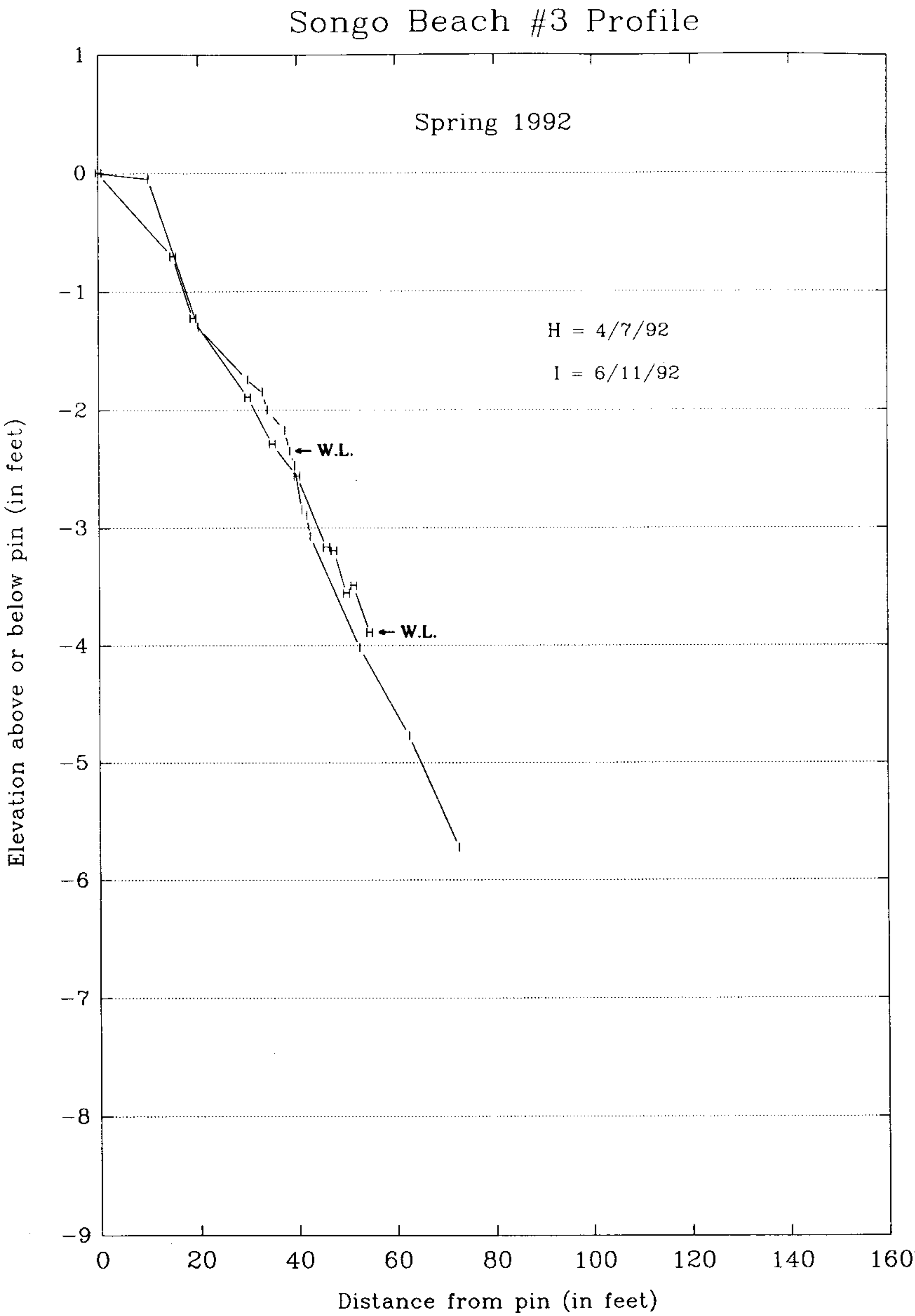


Figure 22. Sand brought onto the upper beach was eroded from the lower beach on the Songo Beach No. 3 profile during a rising water level. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

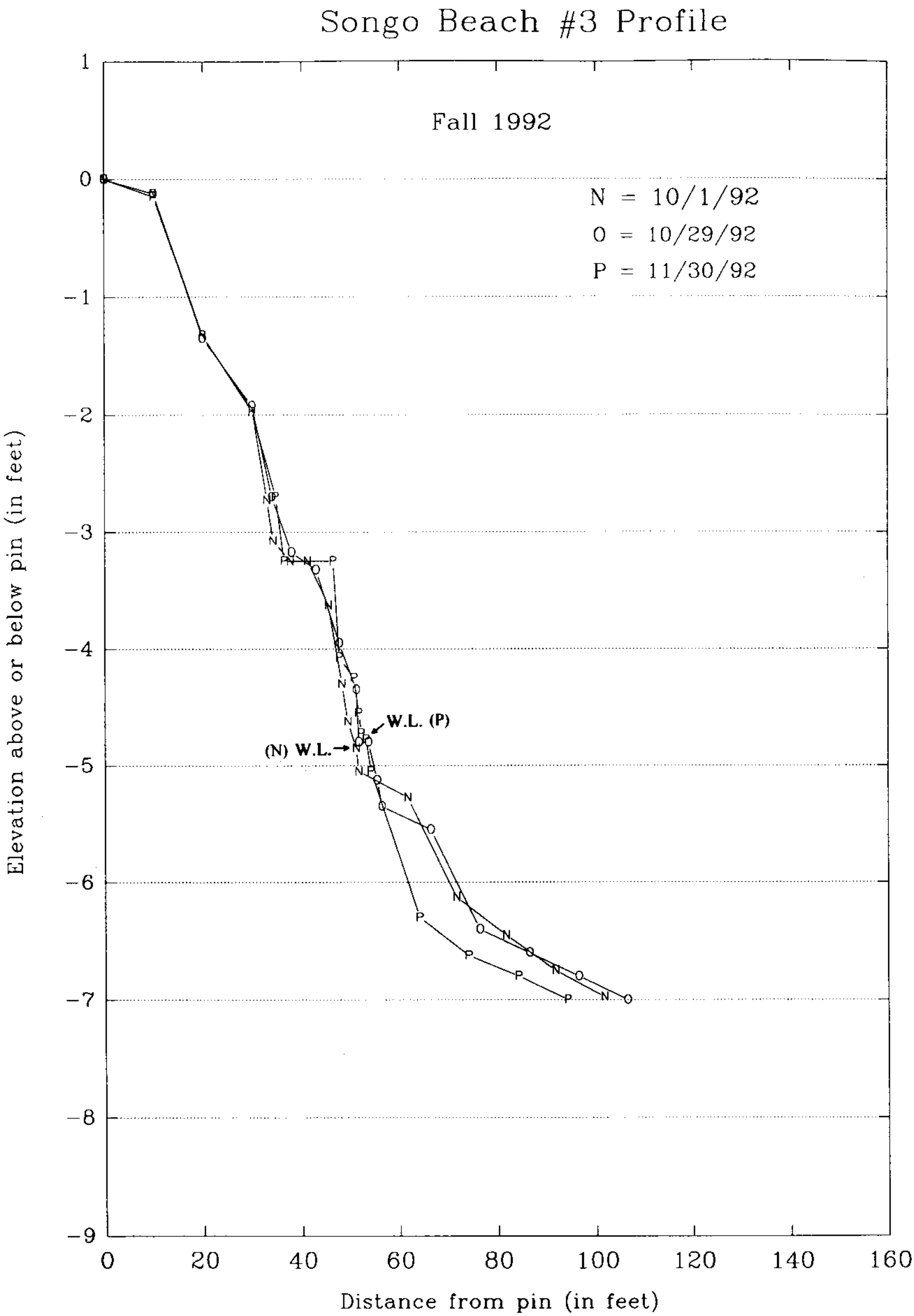


Figure 23. Erosion of the lower profile below -5 feet elevation on the Songo Beach No. 3 profile in the late fall. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

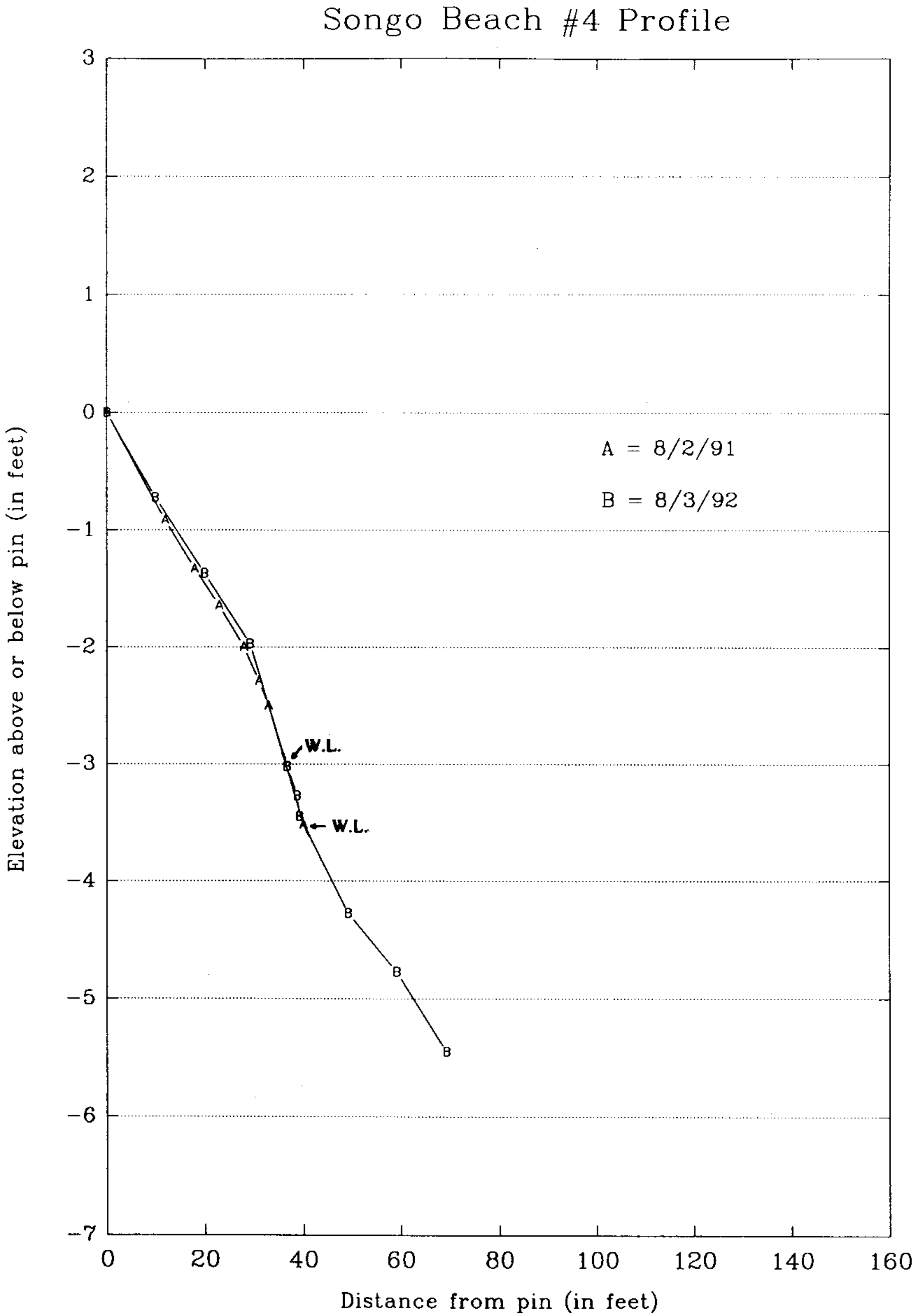


Figure 24. Songo Beach No. 4 profile illustrating no loss of dry beach from the summer of 1991 to the summer of 1992. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

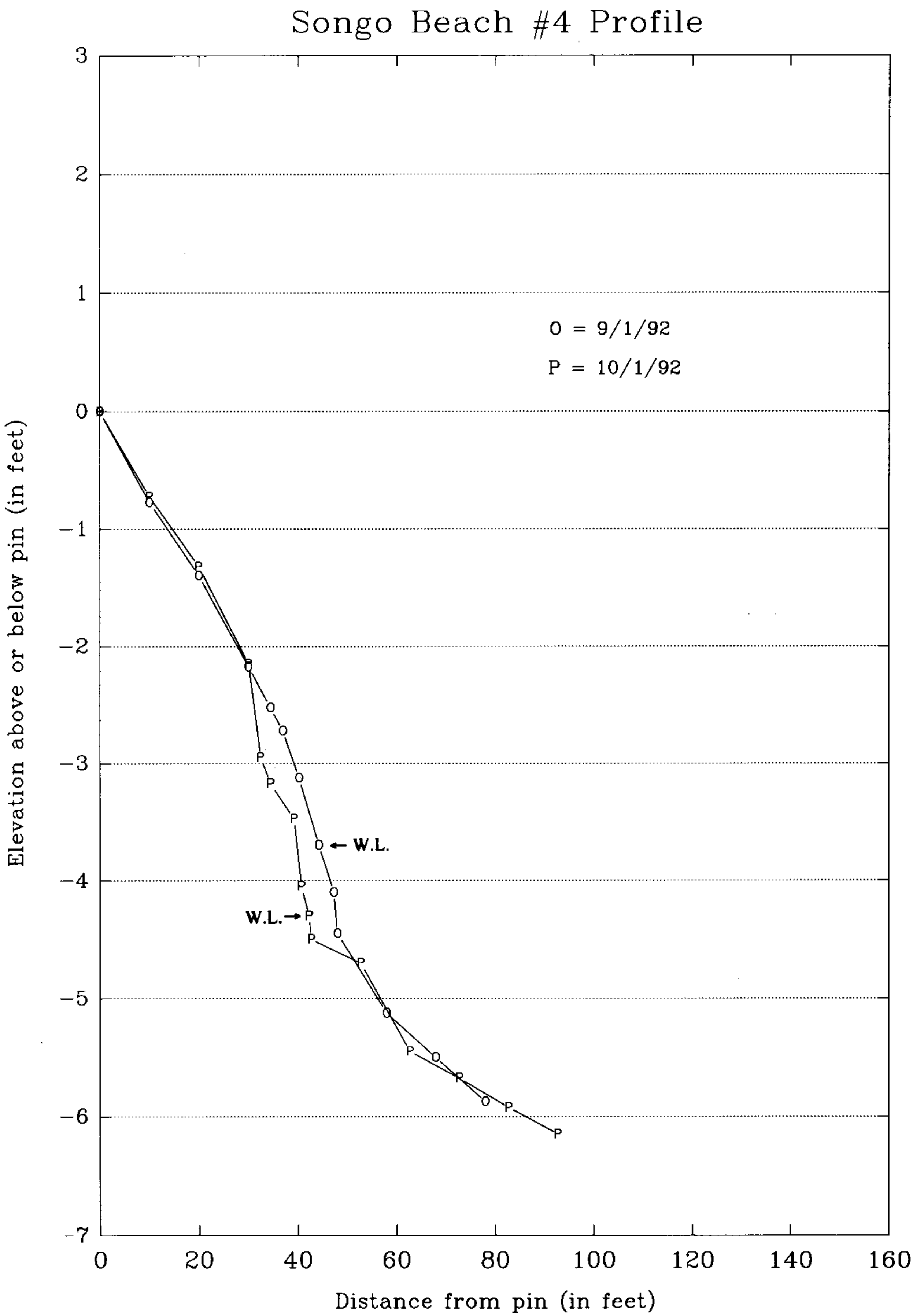


Figure 25. Songo Beach No. 4 profile showing the onset of fall 1992 erosion in the month of September. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

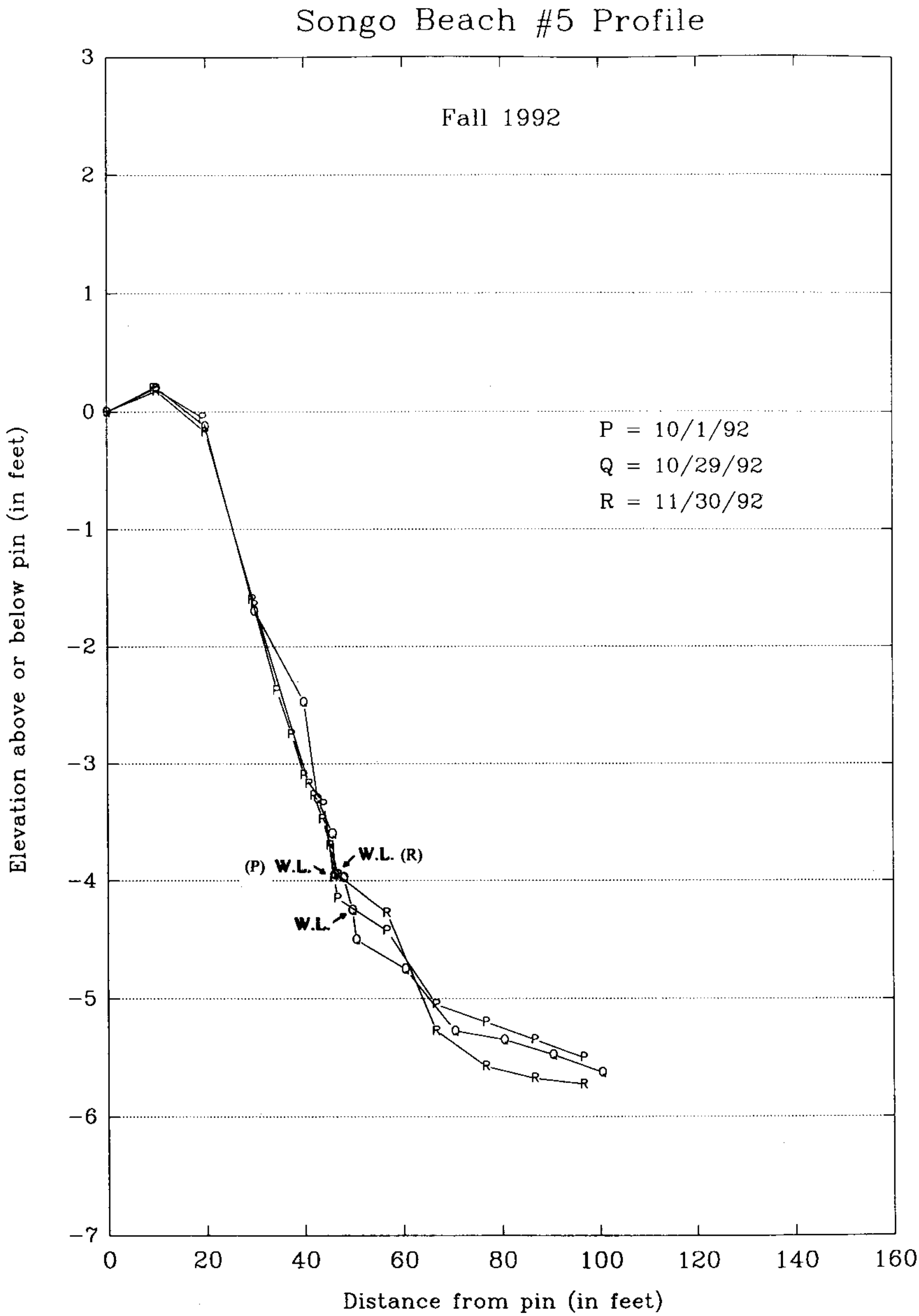


Figure 26. Songo Beach No. 5 profile implying wave scour and beach lowering in the months of October and November. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

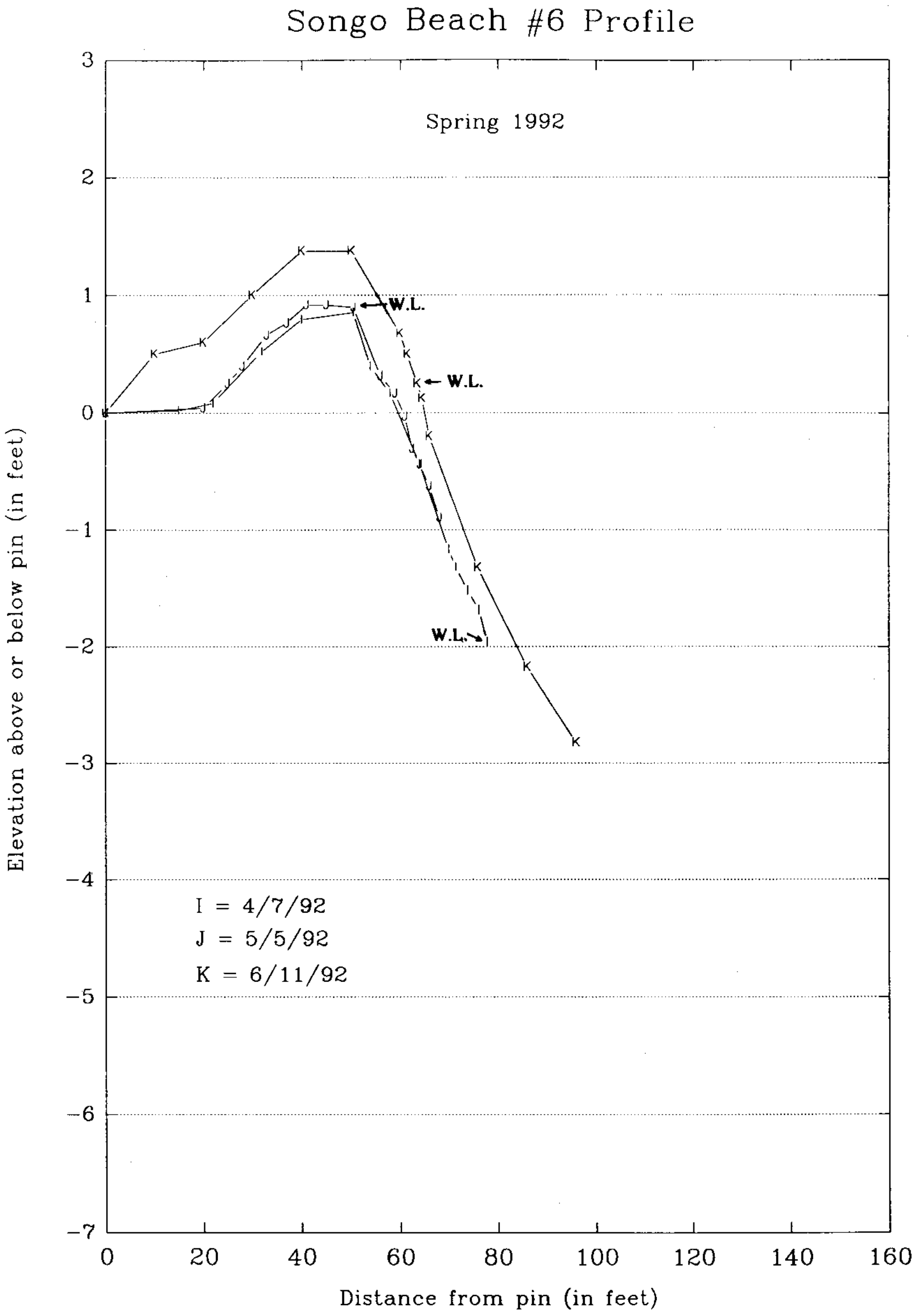


Figure 27. Songo Beach No. 6 profile showing an upbuilding sequence on the spit between early May and mid June 1992. Upbilding, possibly from longshore drift since the lower profile accreted also. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

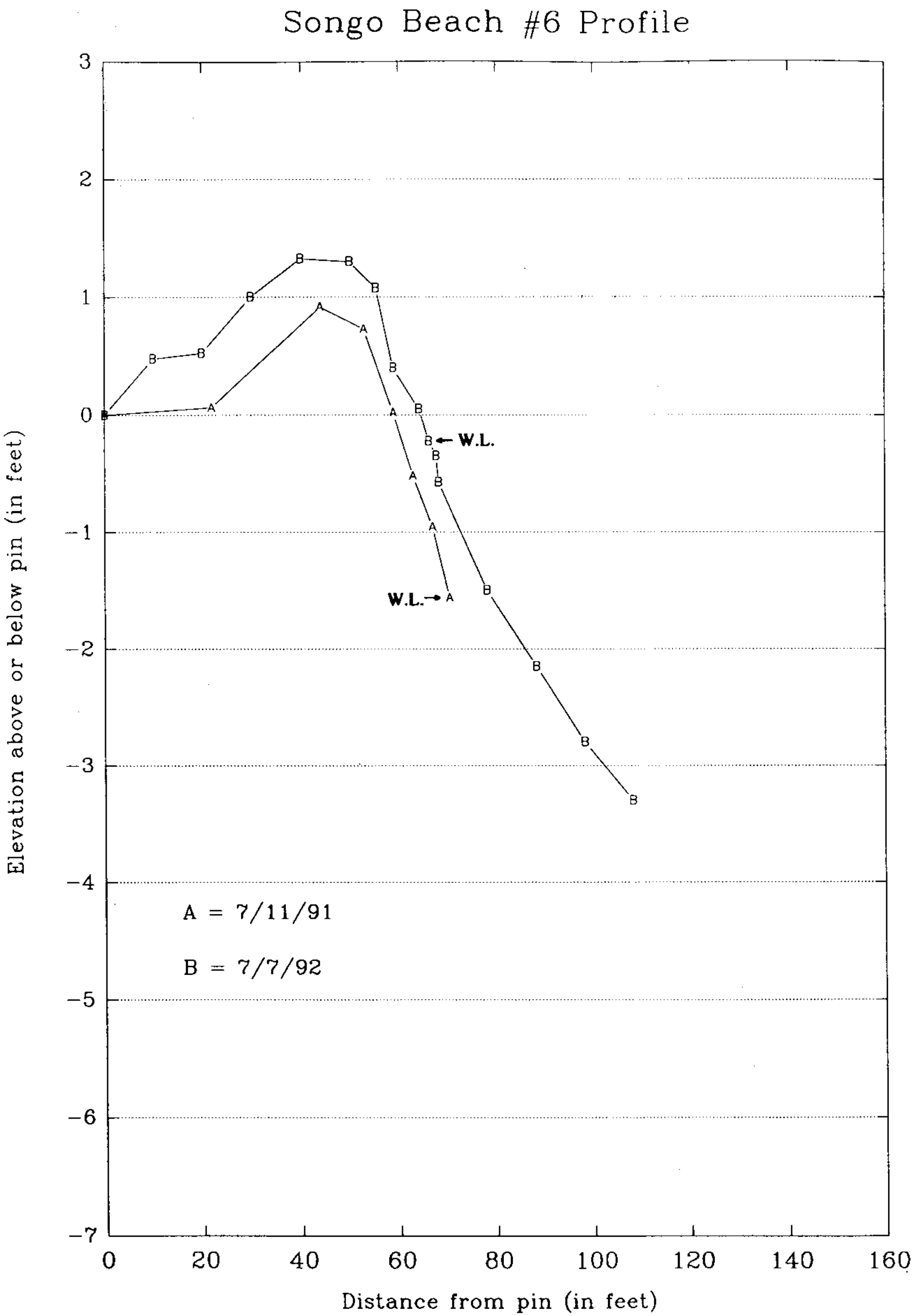


Figure 28. Songo Beach No. 6 profile showing horizontal and vertical accretion from the summer of 1991 to the summer of 1992 (same accretion as in Fig. 27). (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

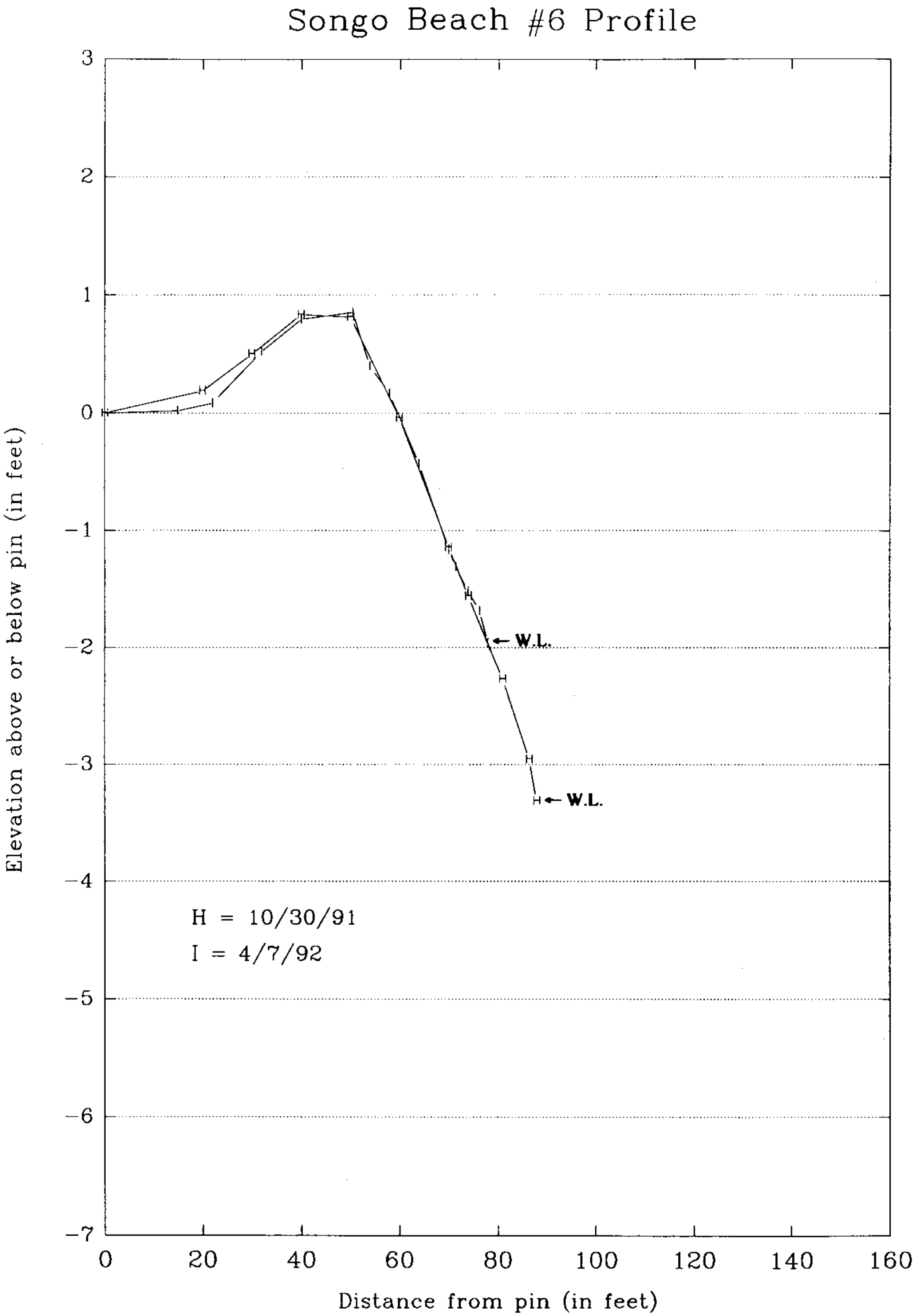


Figure 29. Songo Beach No. 6 profile showing an example of over-winter stability (1991-1992) on the spit portion of the beach. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

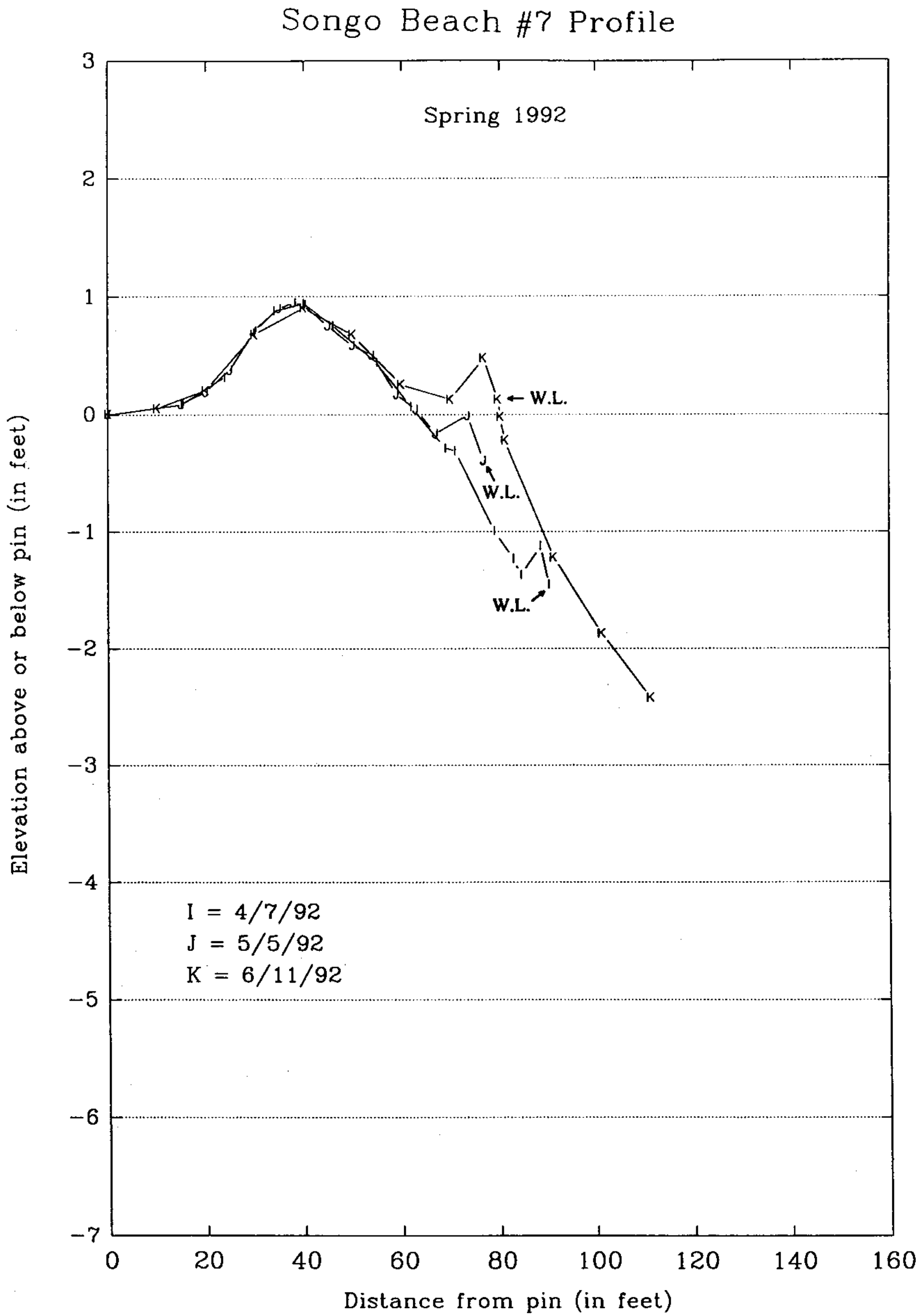


Figure 30. Songo Beach No. 7 profile showing spit progradation and migration of ridge and runnel topography as the water level rose in the spring of 1992. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

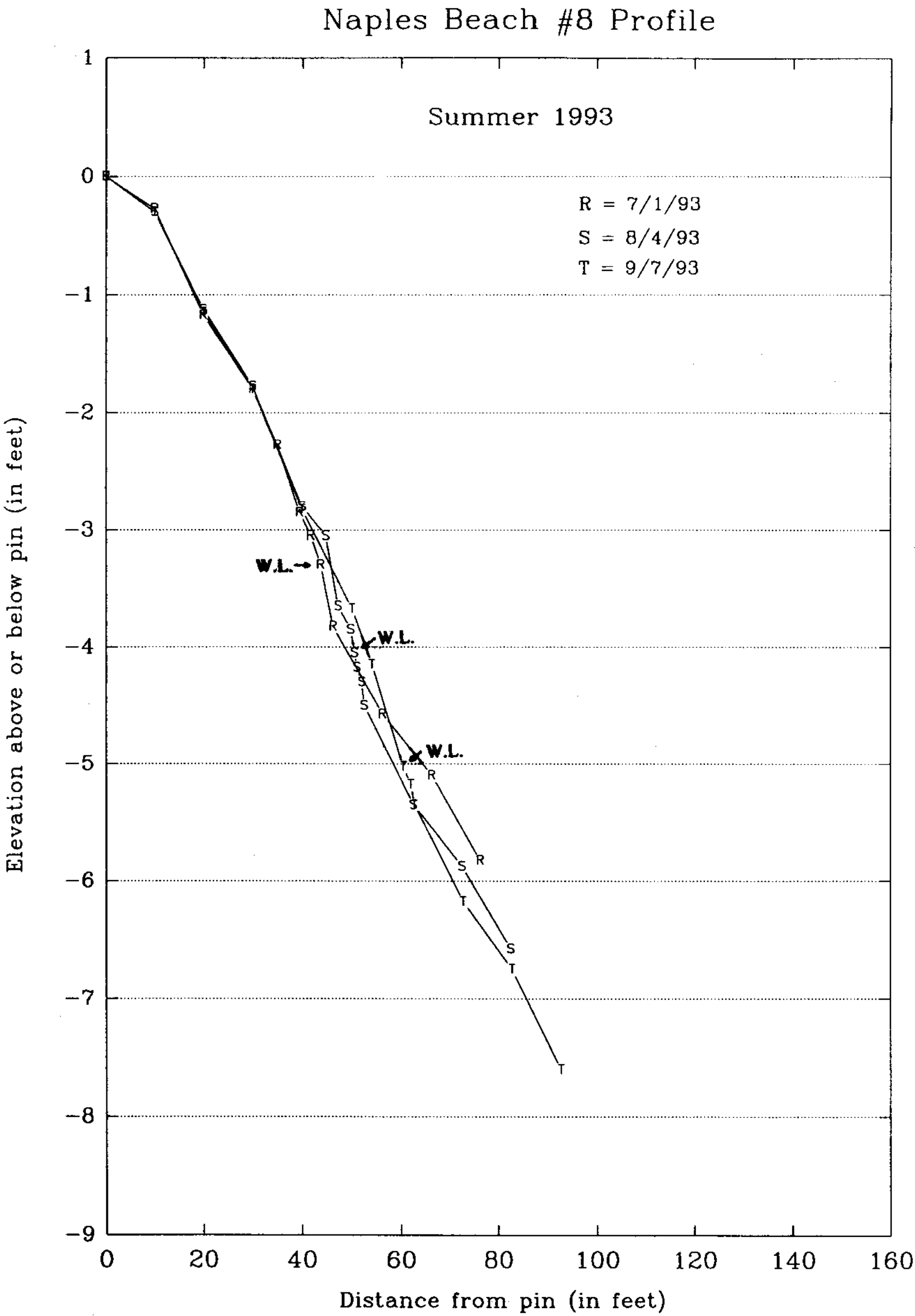


Figure 31. Naples Beach No. 8 profile, summer 1993, showing fluctuations near the water line, erosion below -5 feet, and accretion between -3 and -5 feet elevation. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

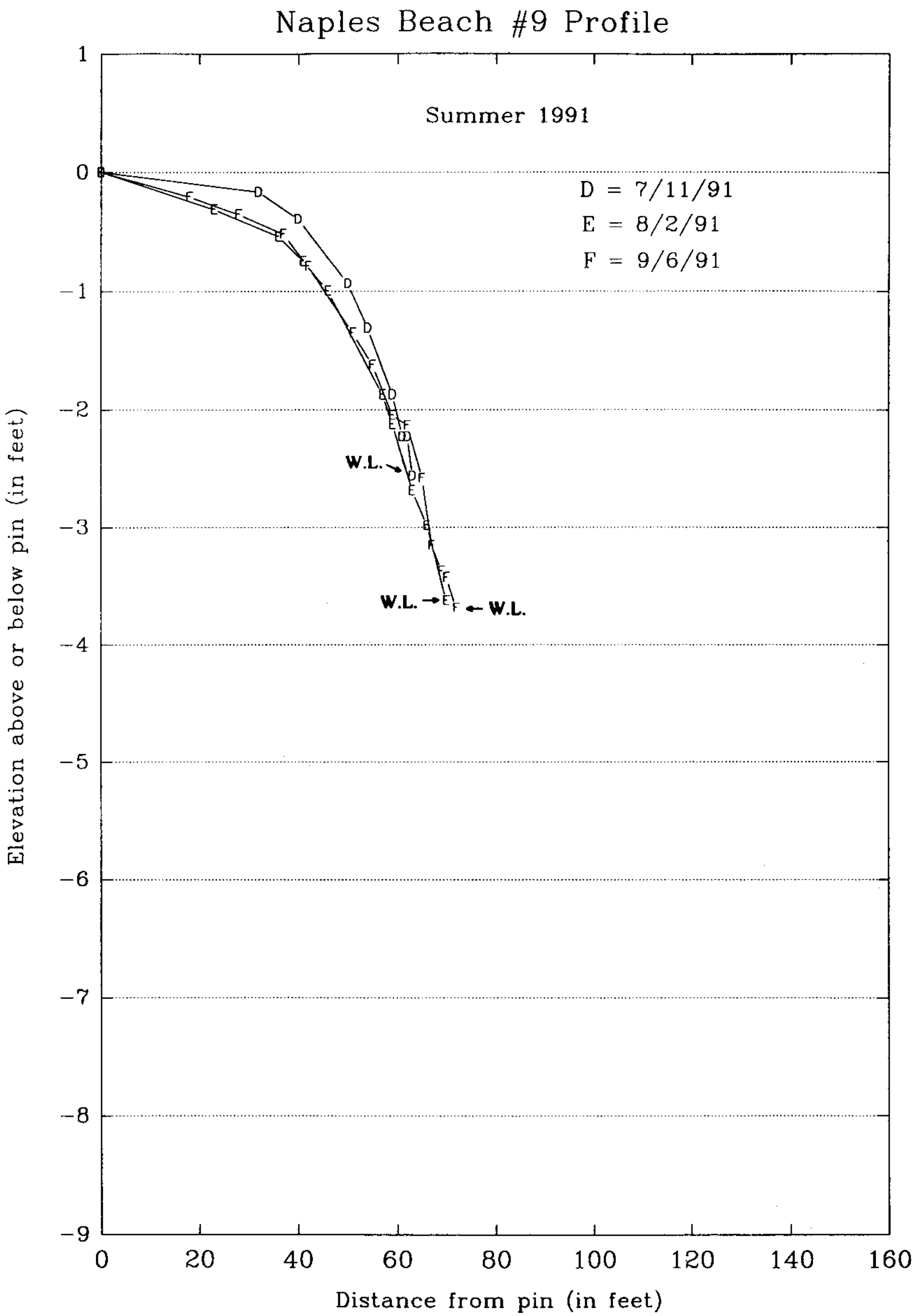


Figure 32. Naples Beach No. 9 profile, summer 1991, showing falling lake level and a lowering of the dry beach. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

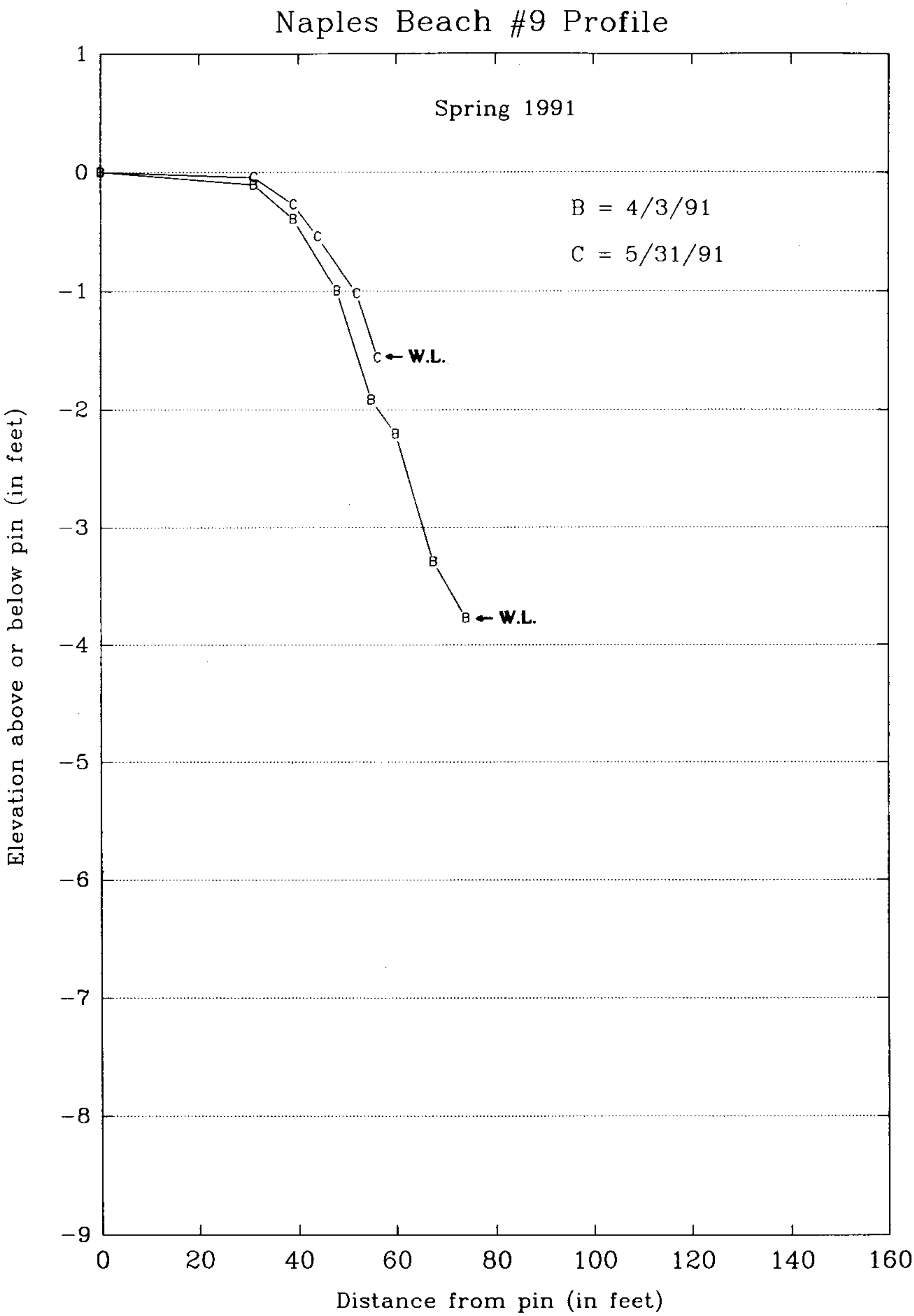


Figure 33. Naples Beach No. 9 profile, spring 1991, showing rising lake level and profile accretion. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

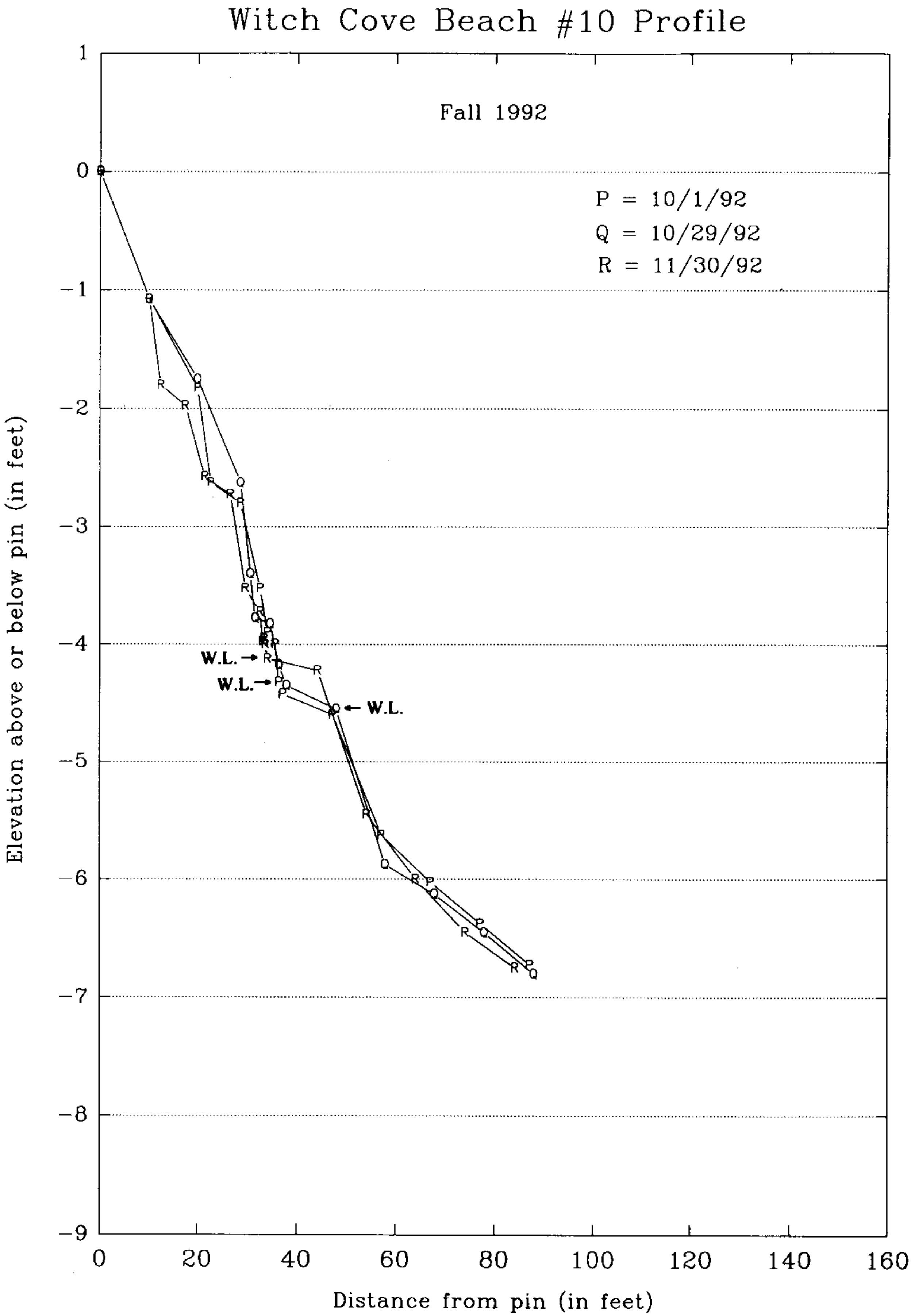


Figure 34. Witch Cove Beach No. 10 profile, fall 1992, showing erosional notches below -4 feet elevation. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

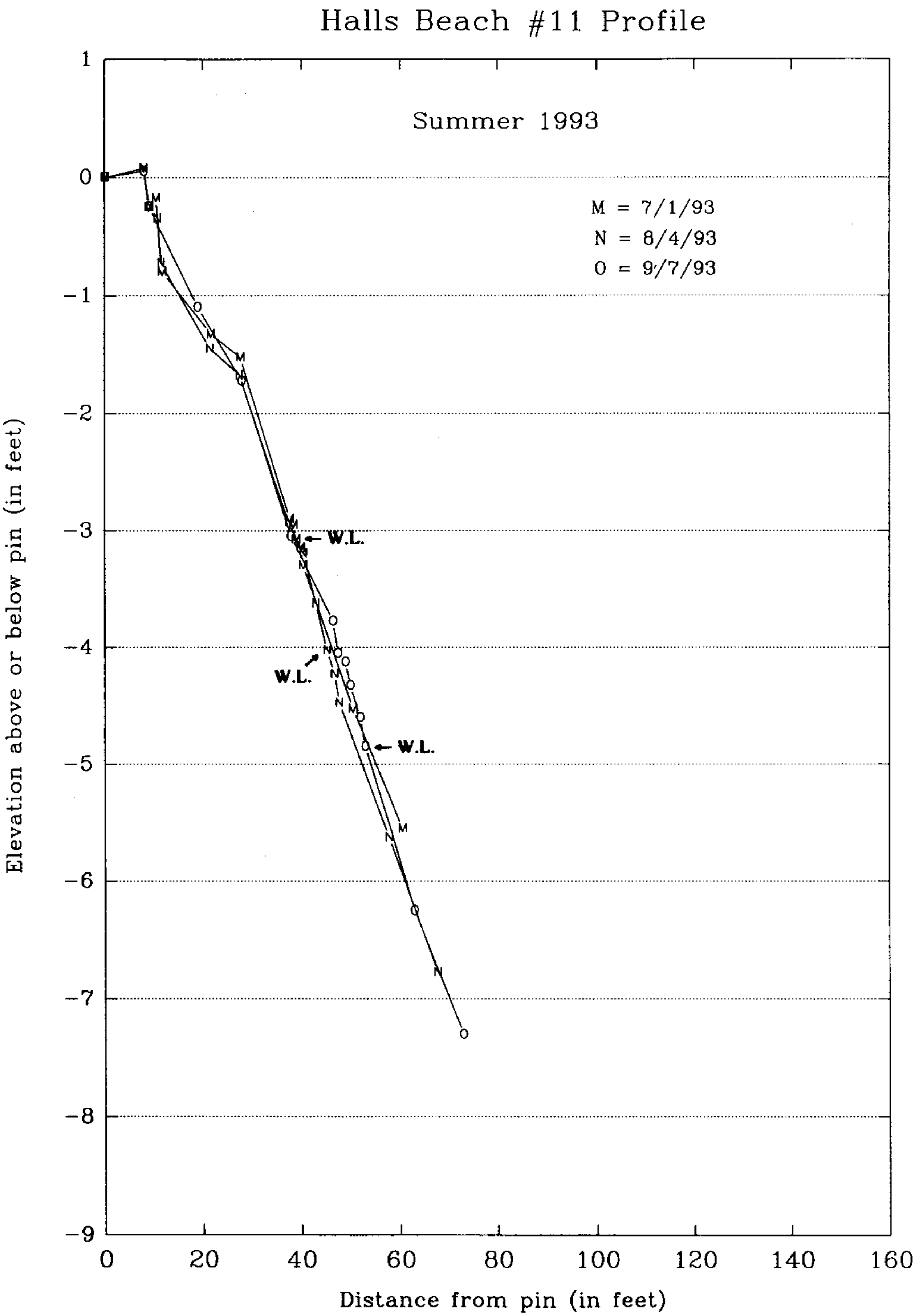


Figure 35. Halls Beach No. 11 profile, summer 1993, showing summer stability during a falling lake level. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

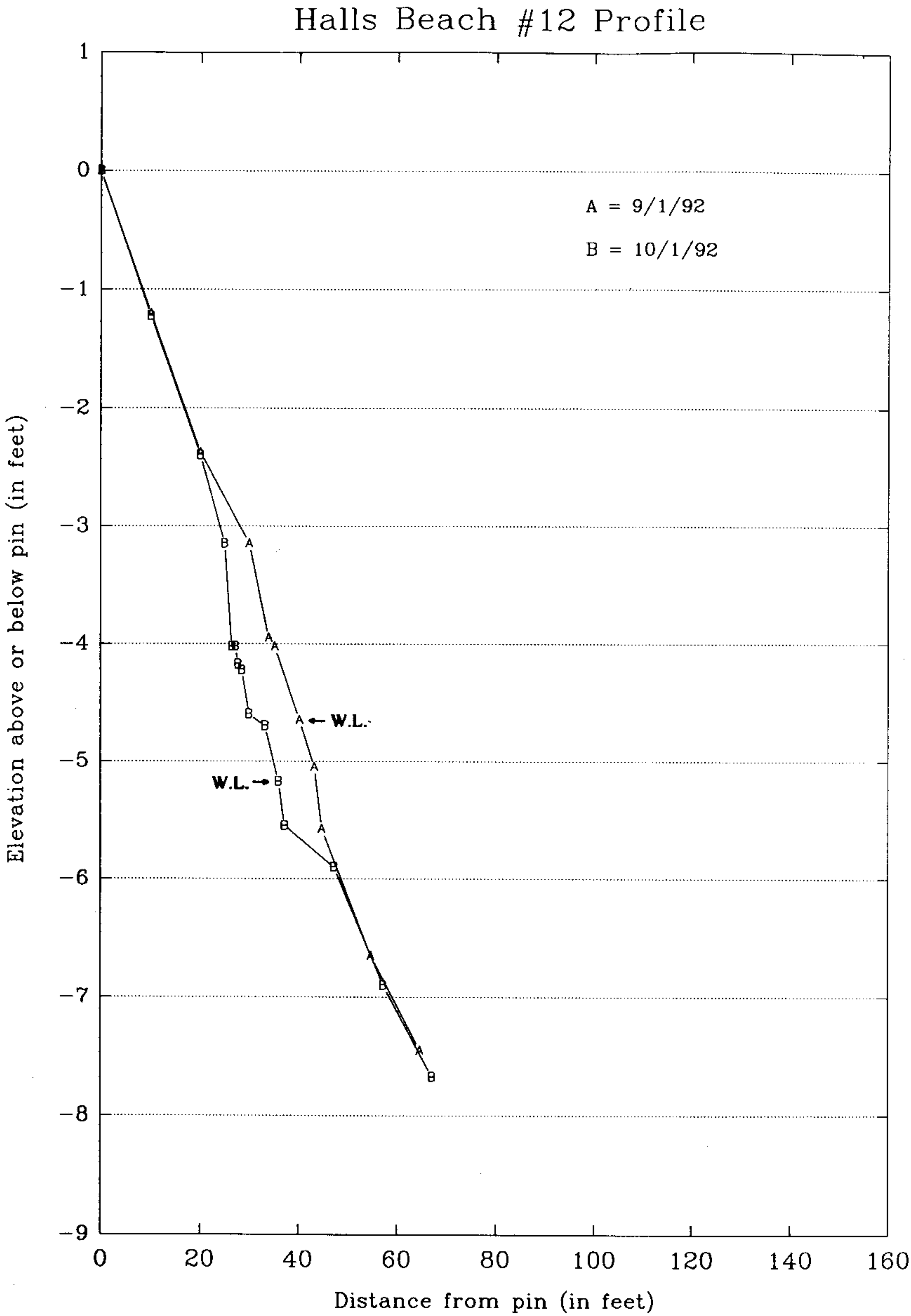


Figure 36. Halls Beach No. 12 profile showing significant erosion in September 1992. (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

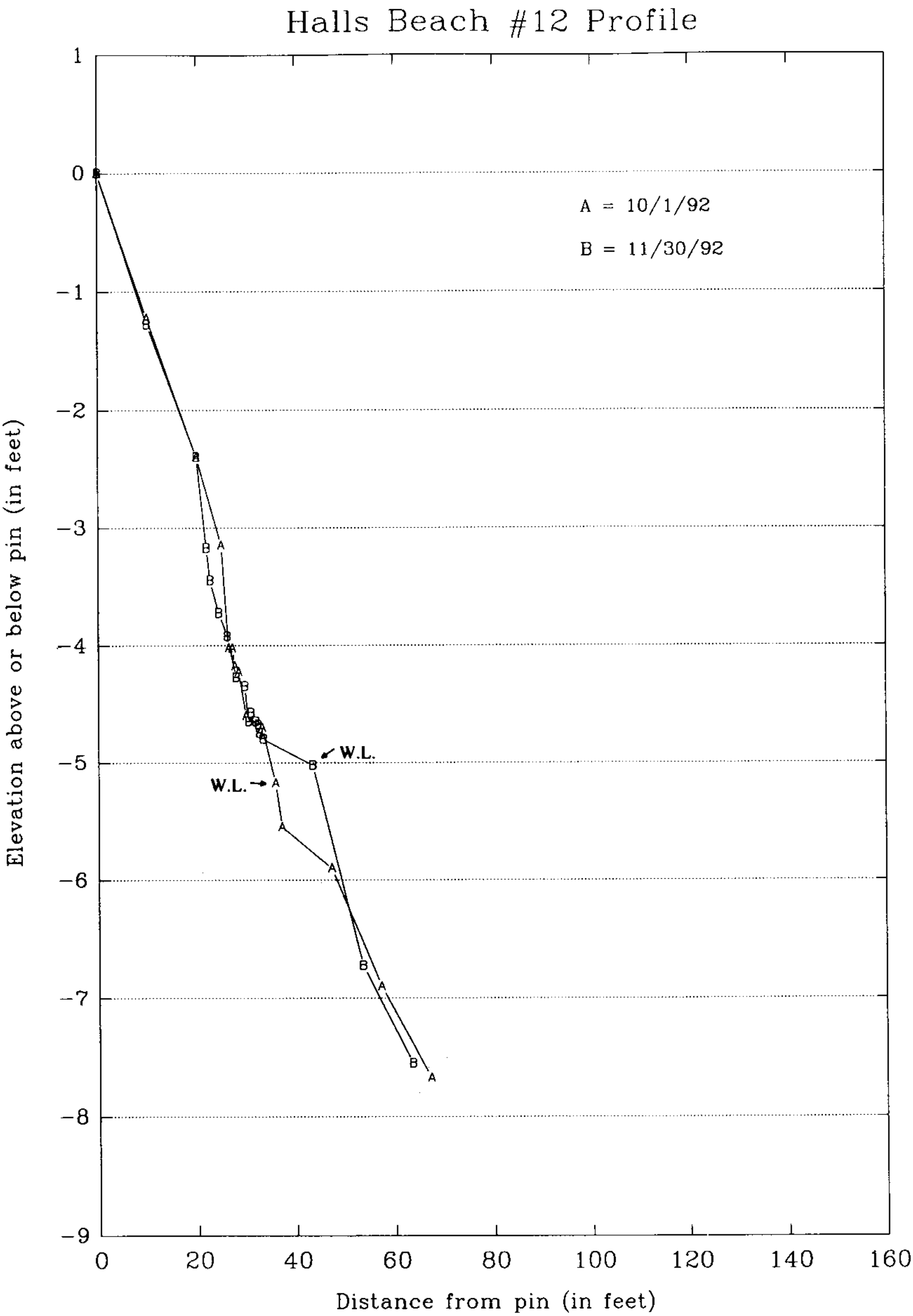


Figure 37. Halls Beach No. 12 profile with October to late November beach accretion during a slowly rising lake level (see Fig. 4 for levels). (Vertical exaggeration is 20:1. W.L. is lake water level at the time of profiling.)

Appendix I

Description of the Emery Method of Beach Profiling

1. Set a control point (a reference stake) in the ground. A second, previously chosen and more landward reference point or stake is usually used. If necessary, place temporary vertical marker poles at both stake positions. Fill in basic data such as who is surveying, recording, the date, time, profile number beach location, etc. on the log sheet.

2. Measure the height of the ground in relation to the control point. If the ground is lower than the control point, make the height difference negative. If the ground is higher, make the height difference positive. Record the height difference on the log sheet.

3. Stand an end of Rod 1 on the ground next to the control point.

4. Take a visual heading (or compass bearing) from the control point toward the water and stand Rod 2 on the ground 5 feet (or a shorter distance) horizontally from Rod 1 along this bearing. Sometimes two poles are placed in the ground and used for back-sighting. One pole is driven in at the control point and another landward at least 10 feet (3 meters) at a known, and repeatedly used, location. The horizontal distance is measured by either a graduated chain or pole. Hold both rods vertically while standing to one side of the bearing line between them. The horizontal distance is recorded on the log sheet paired with a vertical measurement described in the next section.

5. When the ground *slopes down*, the person holding Rod 1 sights (levels) the distant shoreline "horizon" with the top of Rod 2 while standing next to Rod 1. This person reads the sight line intersection with the scale on Rod 1. The intersection, a vertical distance, is customarily recorded as negative on the log sheet to the nearest quarter inch (or centimeter).
When the ground *slopes up*, the person holding Rod 1 sights across the top of Rod 1 to the horizon and reads the vertical distance down from the top of Rod 2. The vertical height difference is recorded on the log sheet as a positive number.

6. After the elevation change is recorded, Rod 1 is picked up and moved to the Rod 2 position and Rod 2 is moved further along the profile line. The distance moved is five feet unless there is a topographic feature to measure at a shorter distance. In either case, Rod 2 must be precisely aligned along the same bearing as the earlier measurement. This is easily accomplished by backsighting along the line by the lead person. Repeat Steps 4 and 5 progressively moving down the beach toward the water. Small changes in slope are measured as are any features of interest. This may necessitate a close horizontal spacing between the rods.

7. At the waterline a pair of distance/elevation measurements is made and the time of day recorded in the notes.

8. Measurements in the water should be made as far offshore as possible while maintaining safety precautions. Commonly this is to a depth up to 3 feet (1 meter).

9. Photograph the beach in both directions looking alongshore with the profile line in the foreground. Make general observations in the notes about profile configuration, such as "water line," "concave up" or "irregular along the shore" which may help in data compilation and analysis.

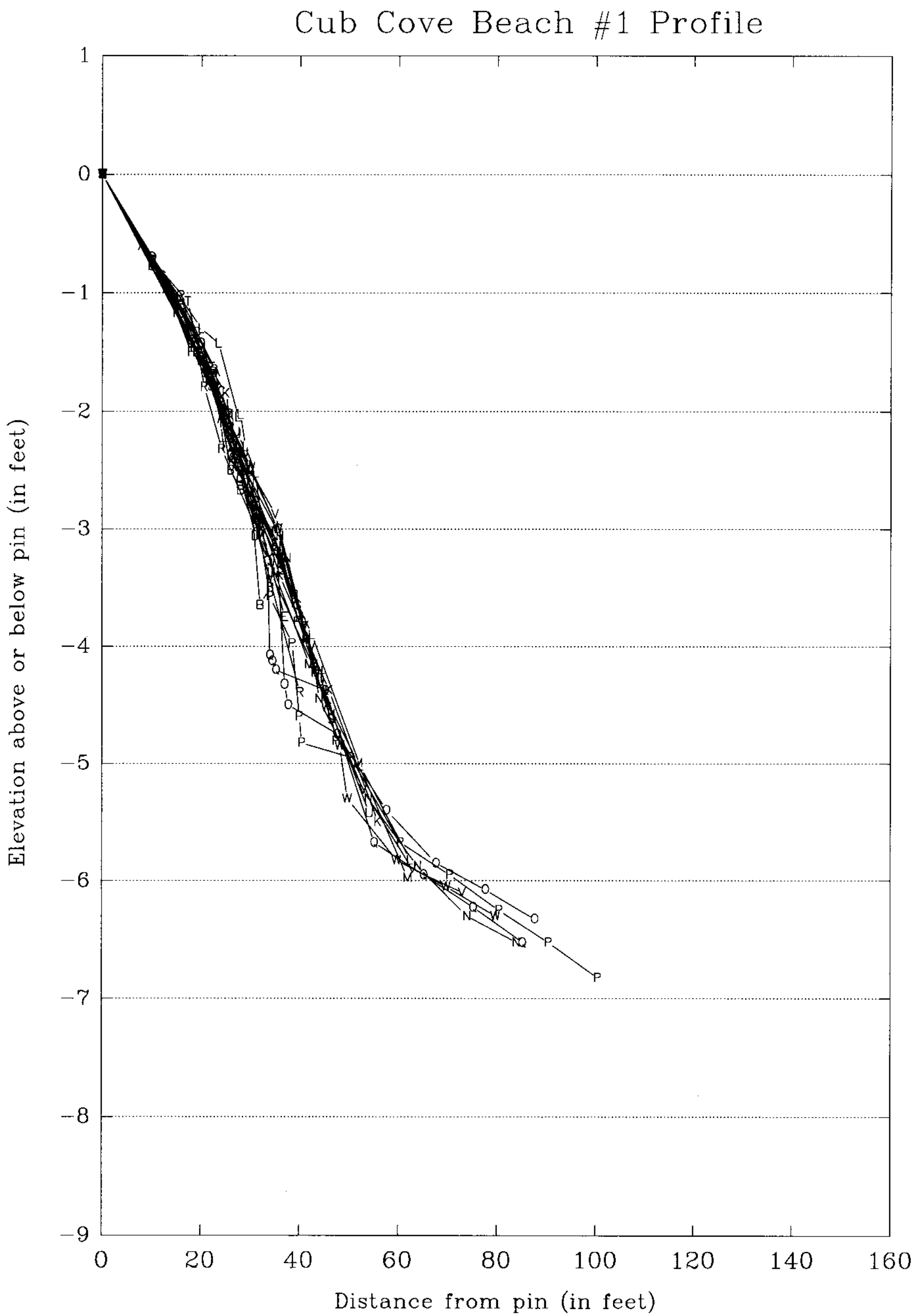
Appendix II

Beach Profiles

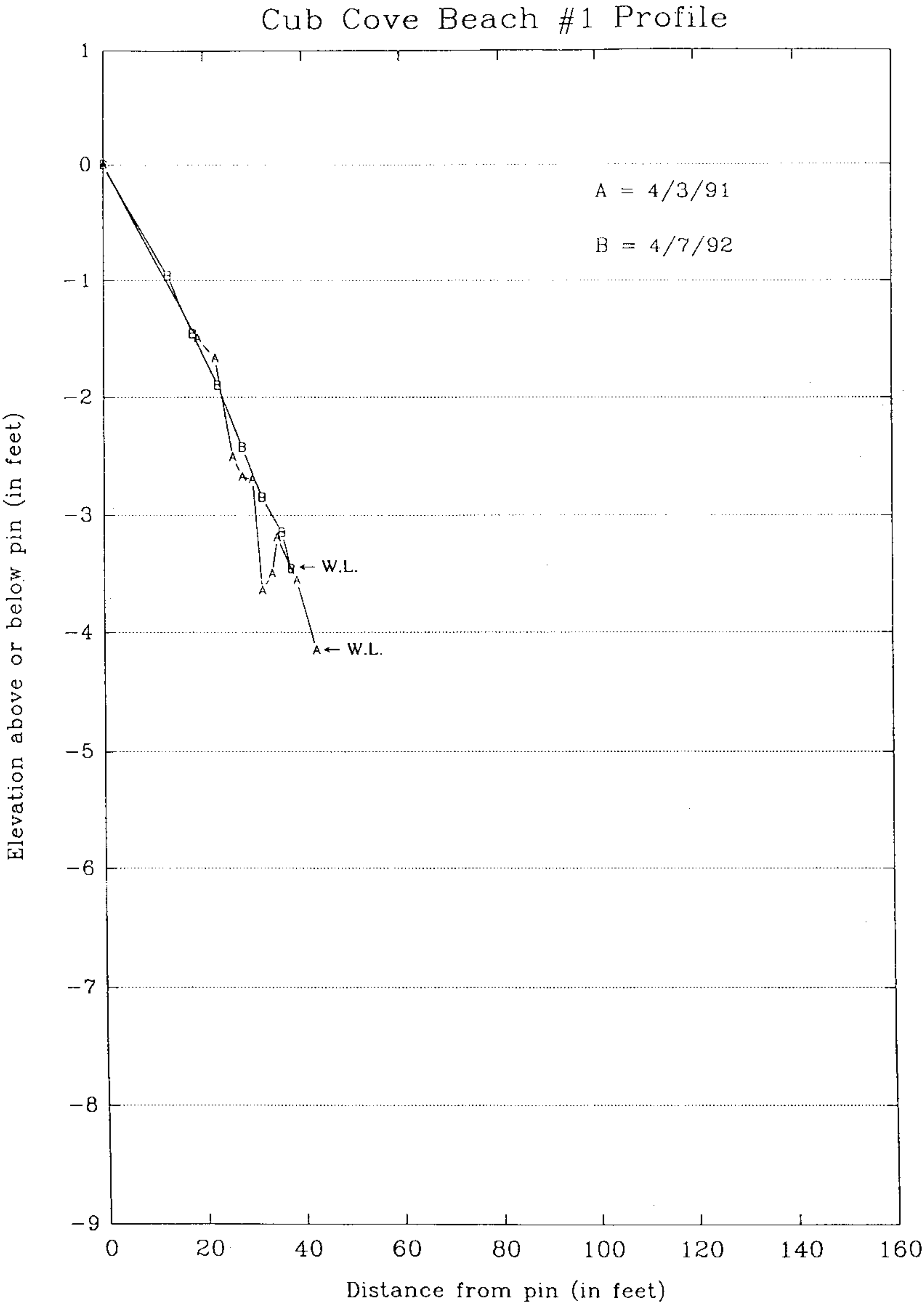
Plot Series:

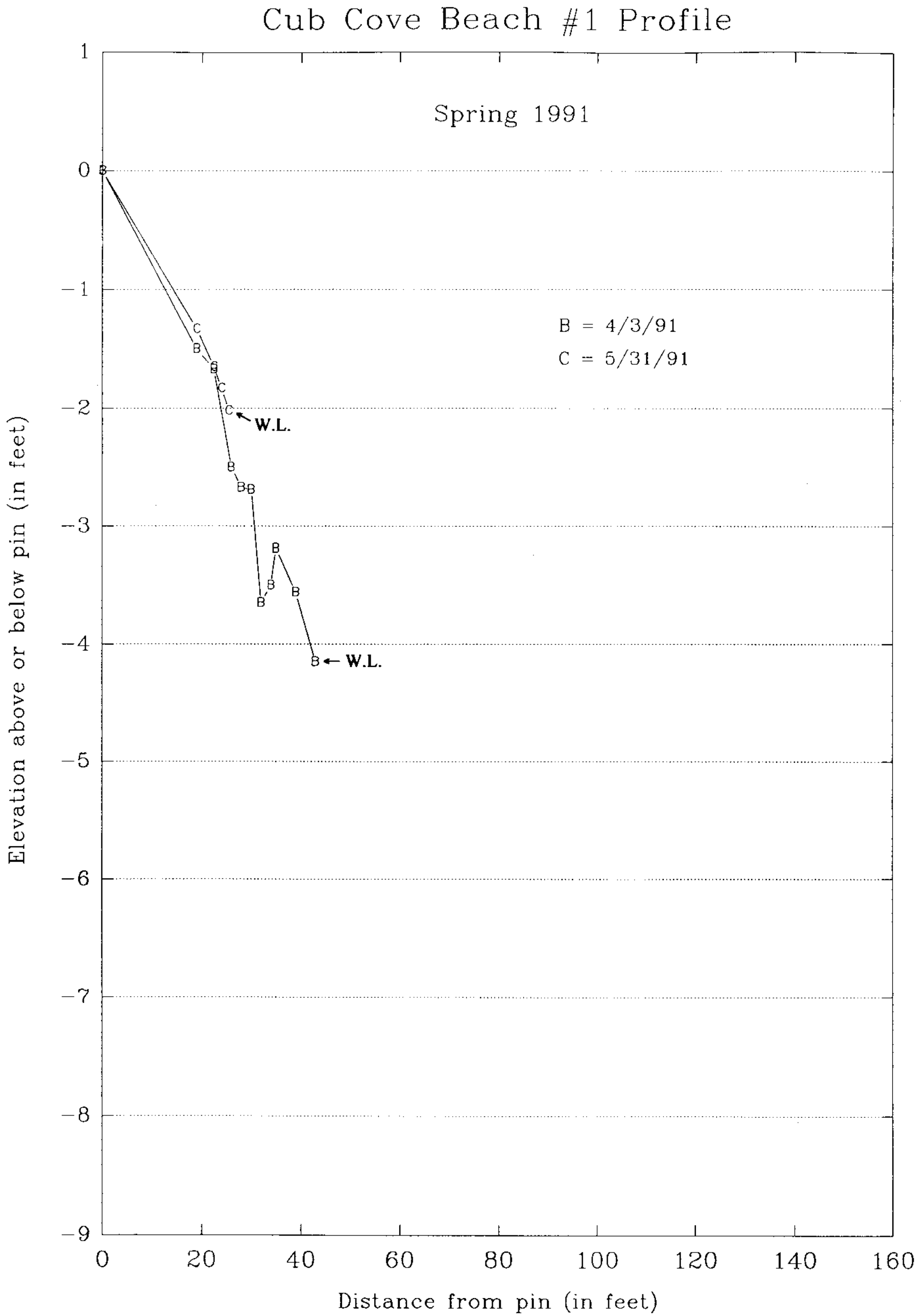
Sweep Zone, Spring 1991, Summer 1991, Fall 1991, Spring 1992, Summer 1992, Fall 1992, Spring 1993, Summer 1993, and Fall 1993

Profile Lines:

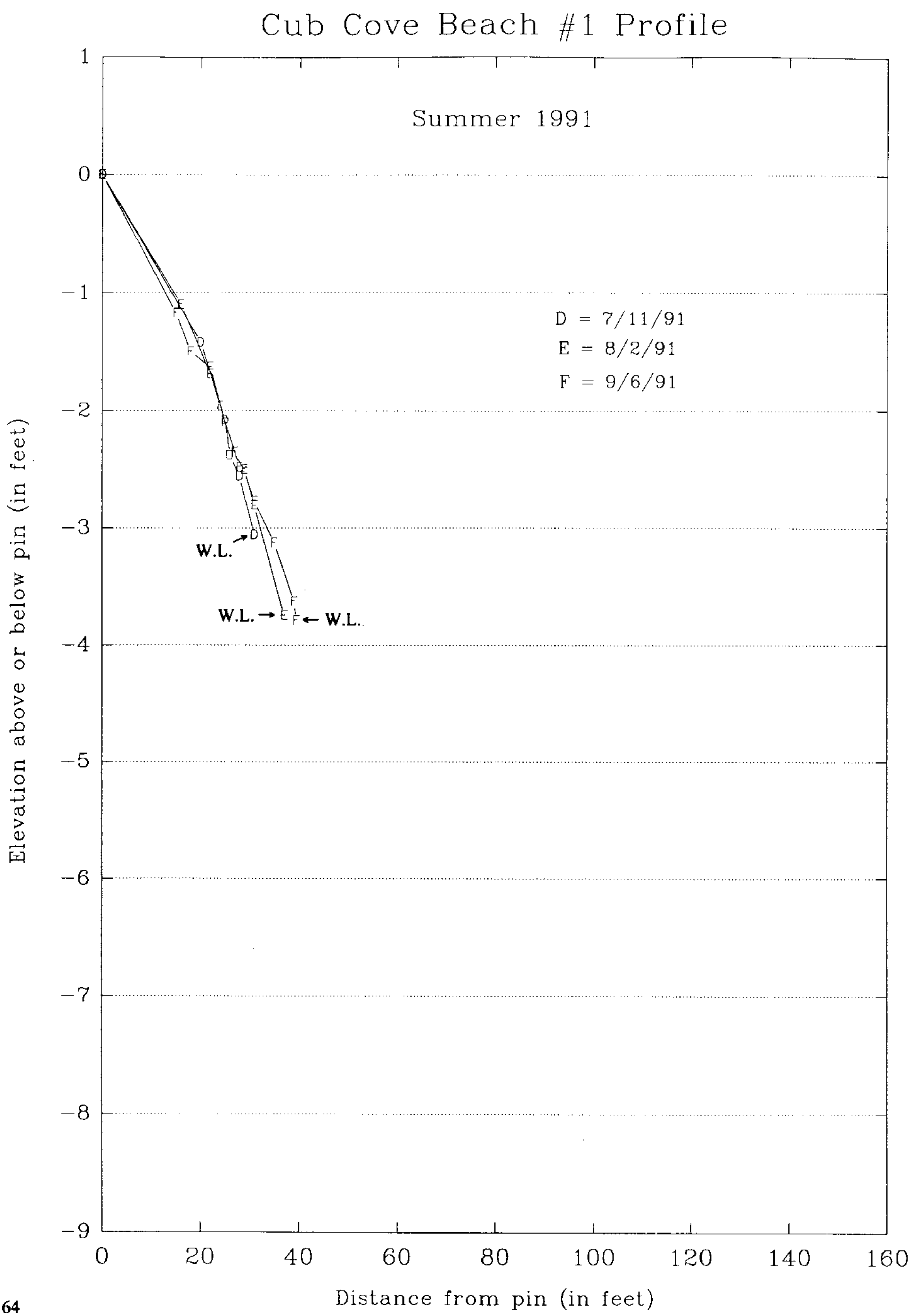


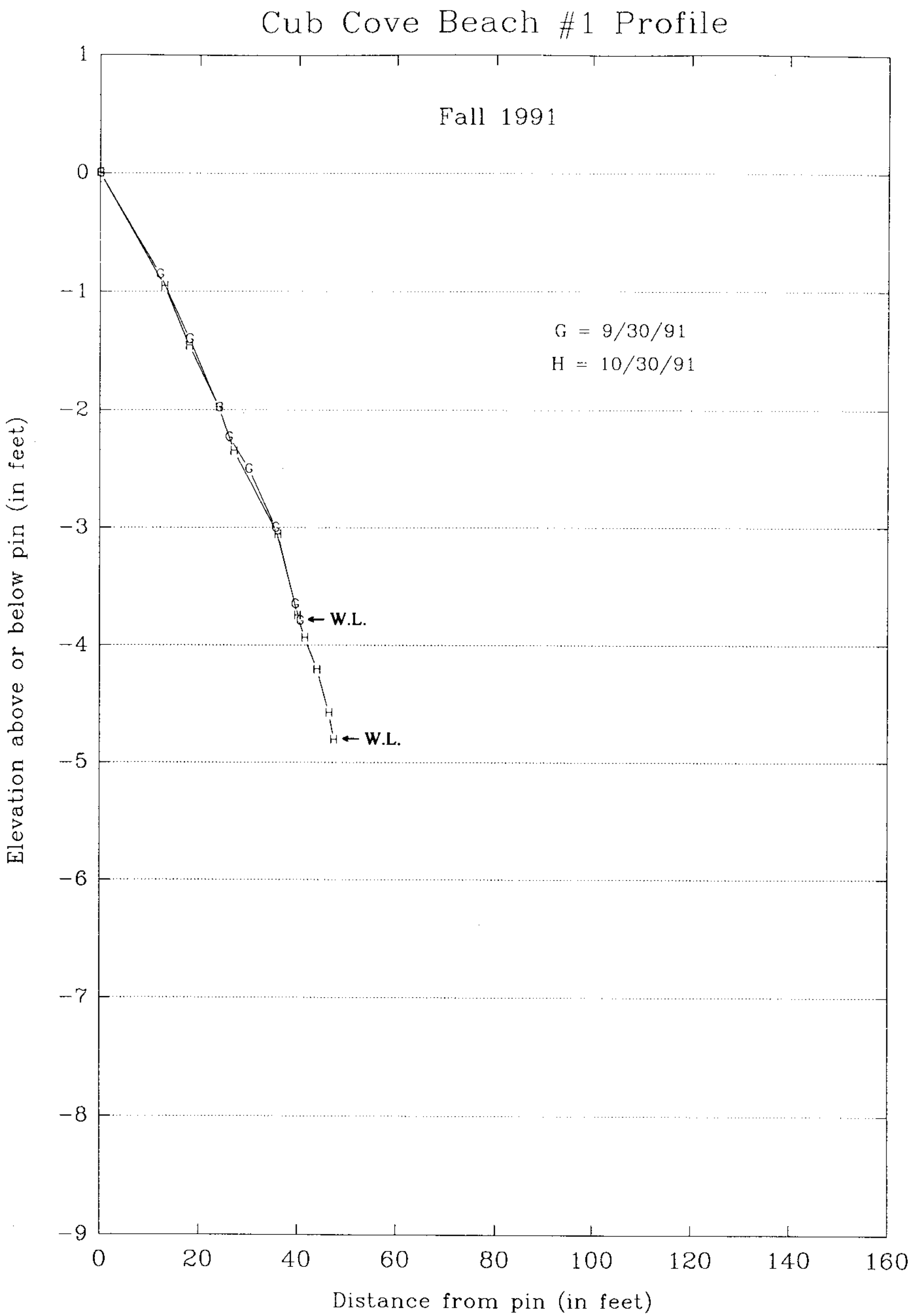
Cub Cove Beach #1 Profile
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Cub Cove Beach #1 Profile
A = 4/3/91
B = 4/7/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

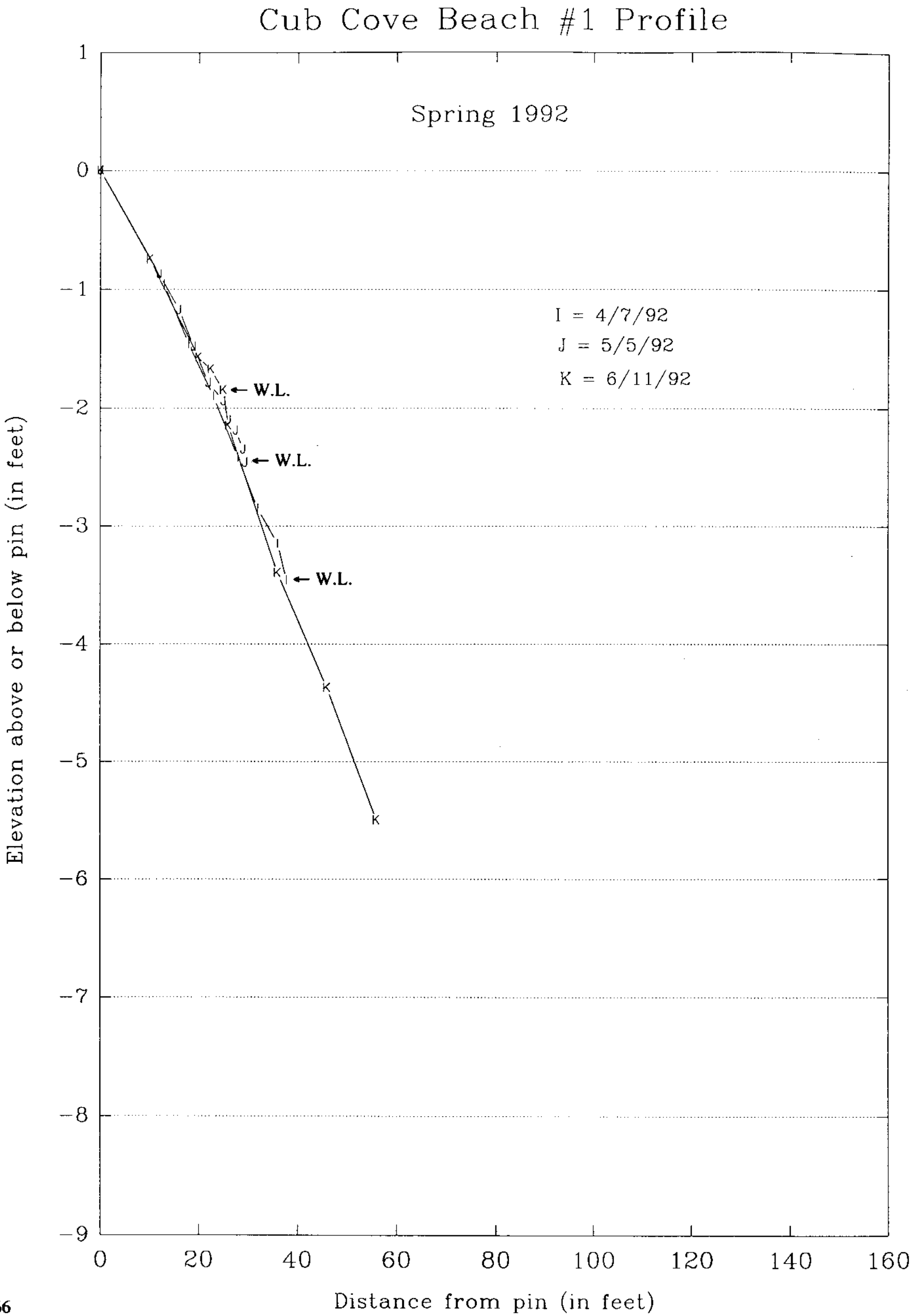


Cub Cove Beach #1 Profile
Spring 1991
B = 4/3/91
C = 5/31/91
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

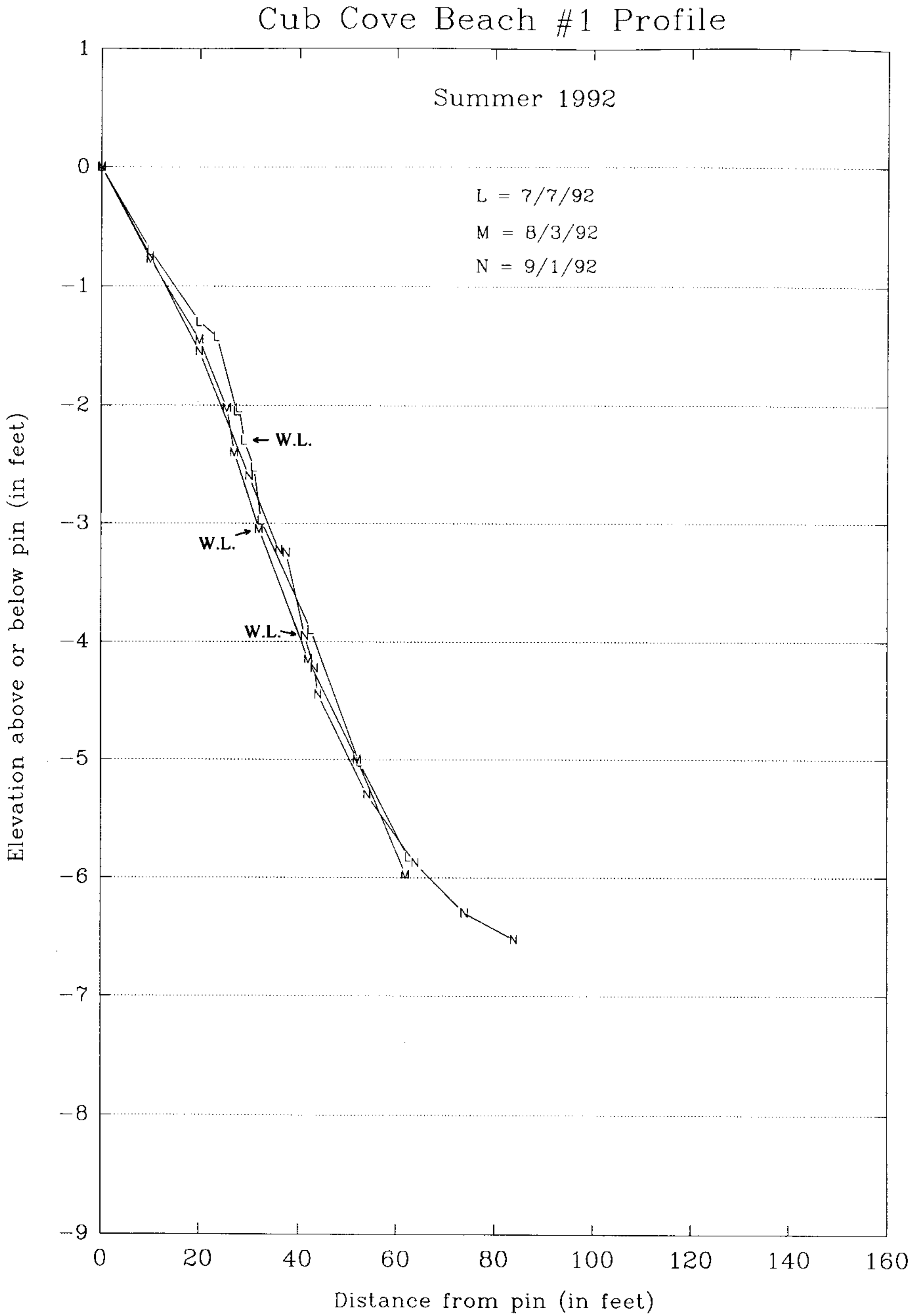

Cub Cove Beach #1 Profile
Summer 1991
D = 7/11/91
E = 8/2/91
F = 9/6/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

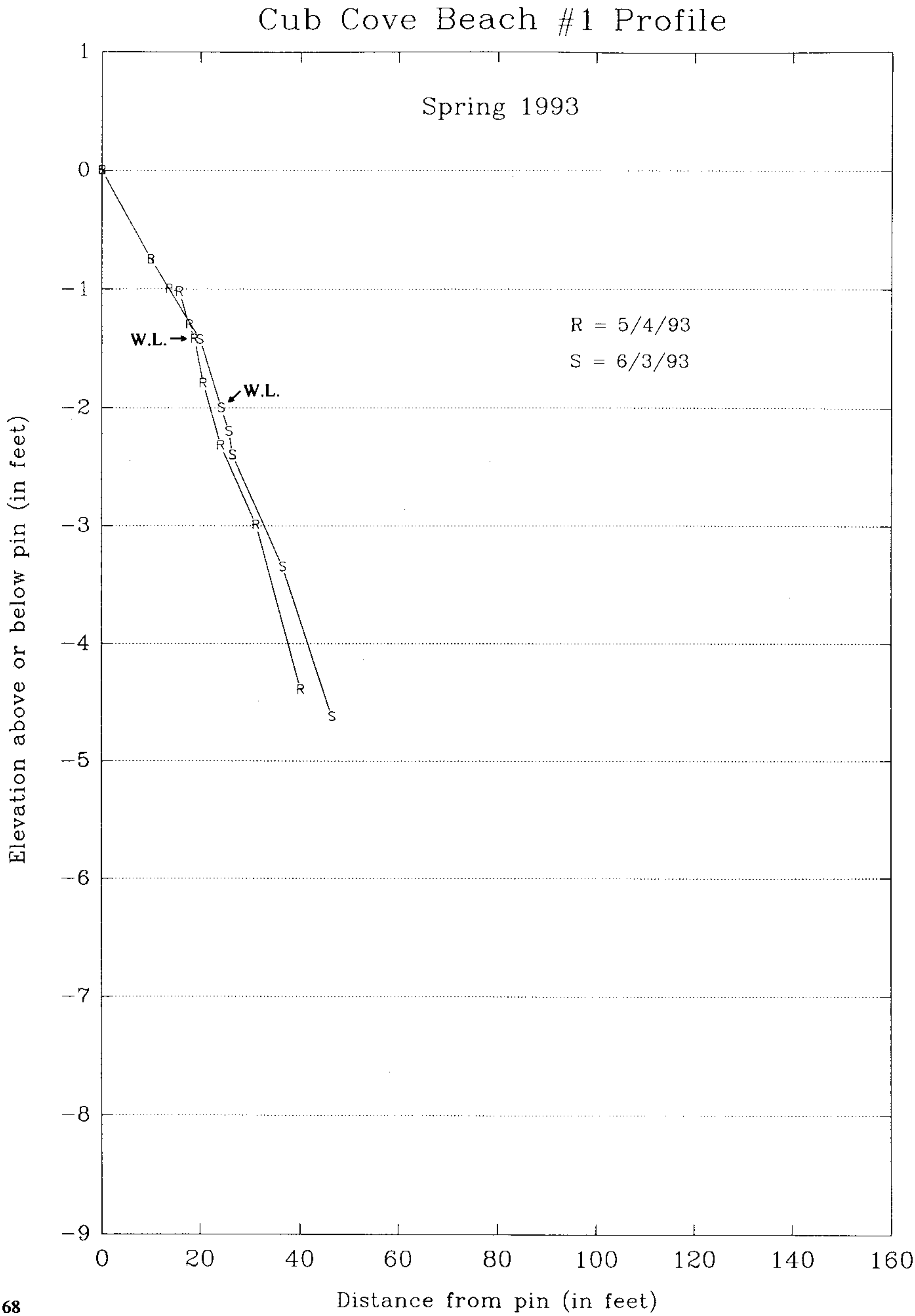


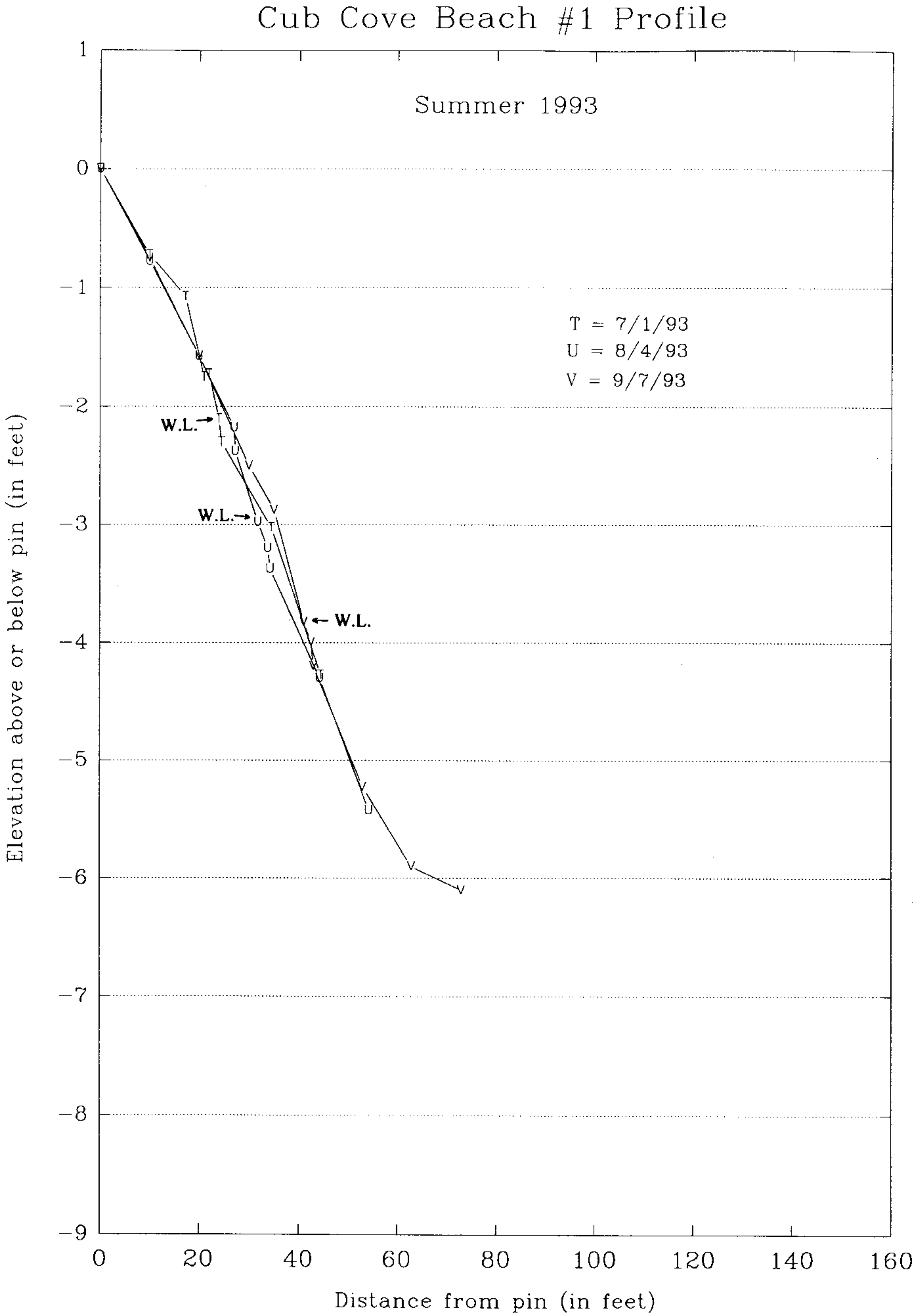
Cub Cove Beach #1 Profile
Fall 1991
G = 9/30/91
H = 10/30/91
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

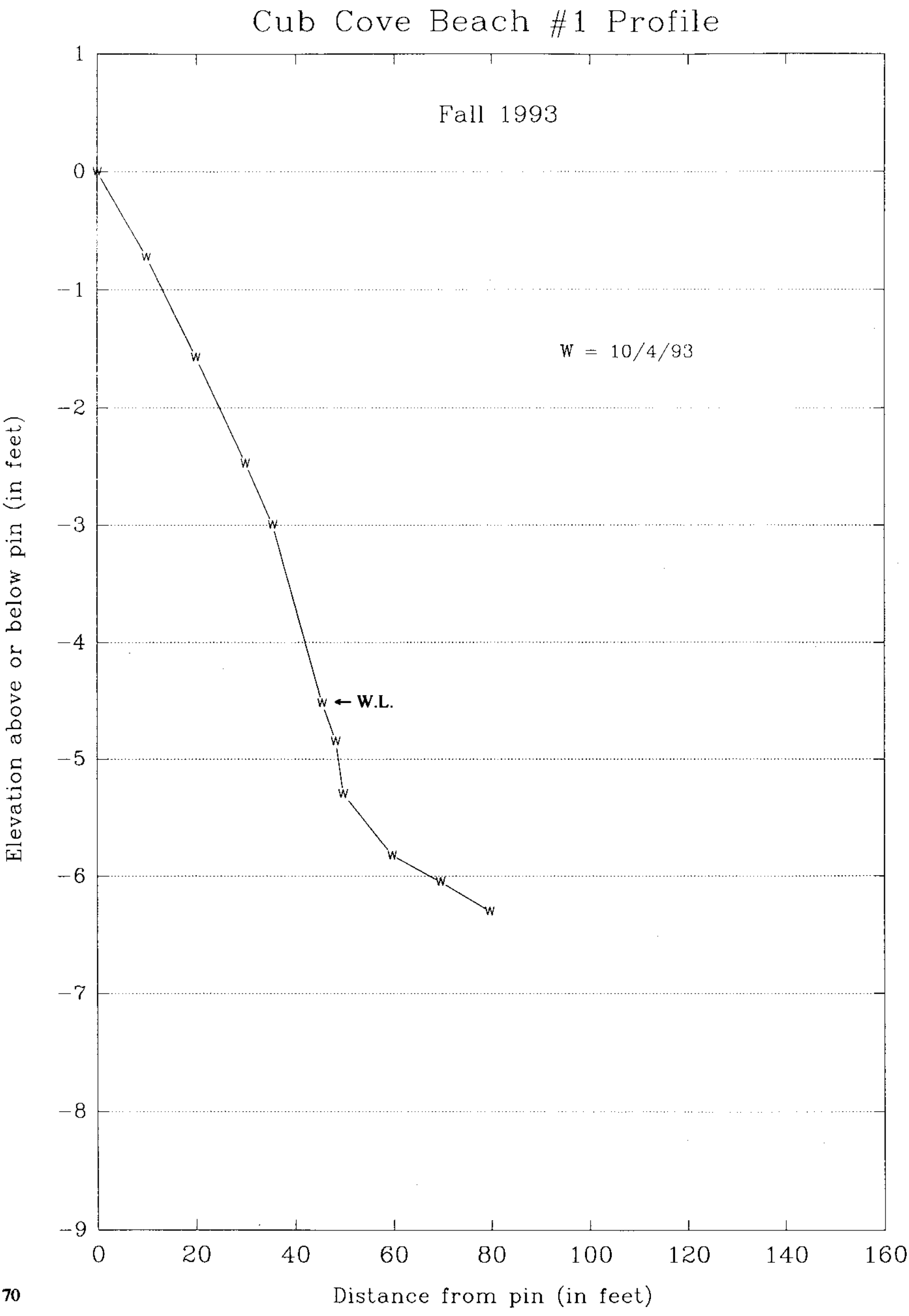


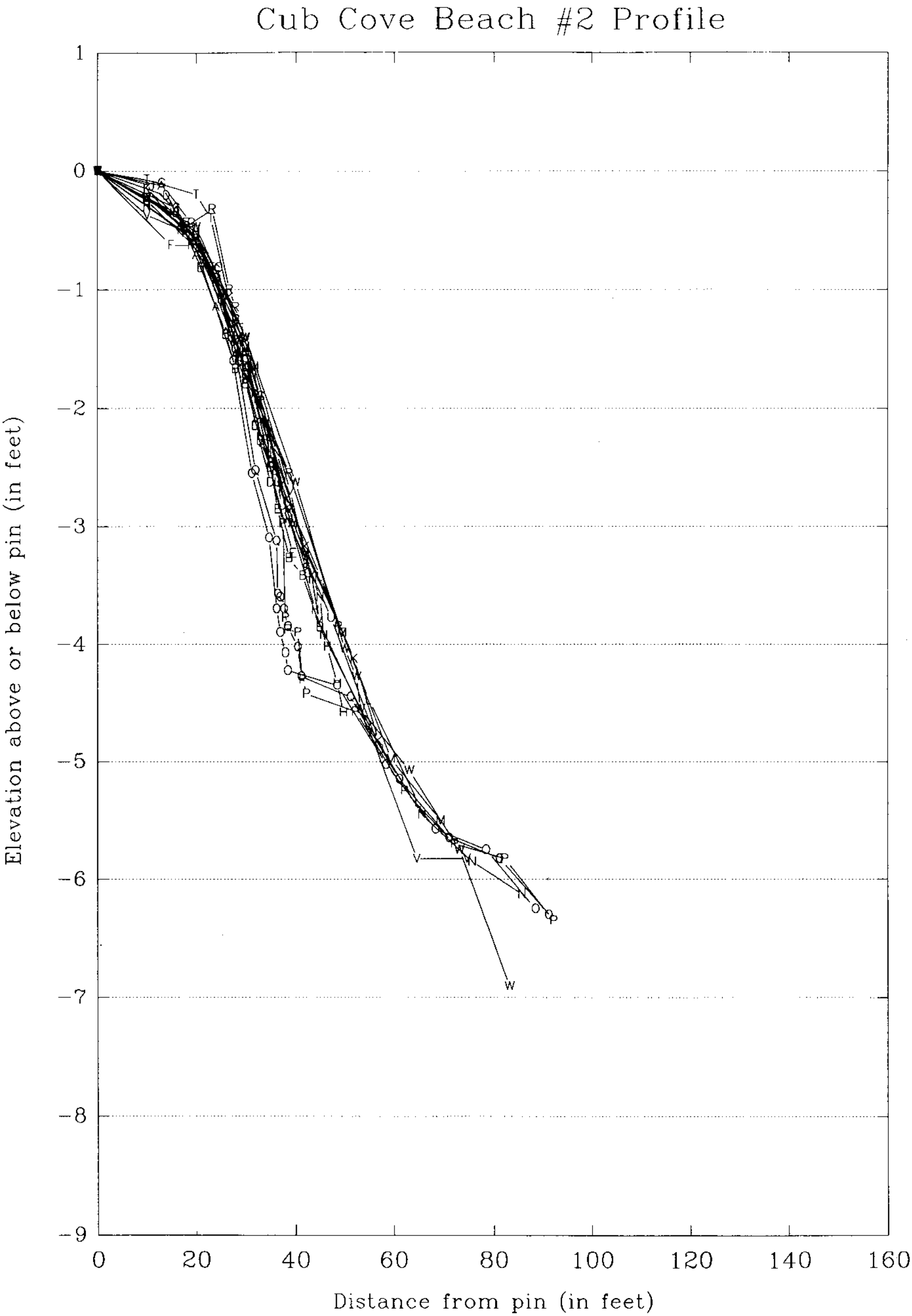
Cub Cove Beach #1 Profile
Spring 1992
I = 4/7/92
J = 5/5/92
K = 6/11/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)

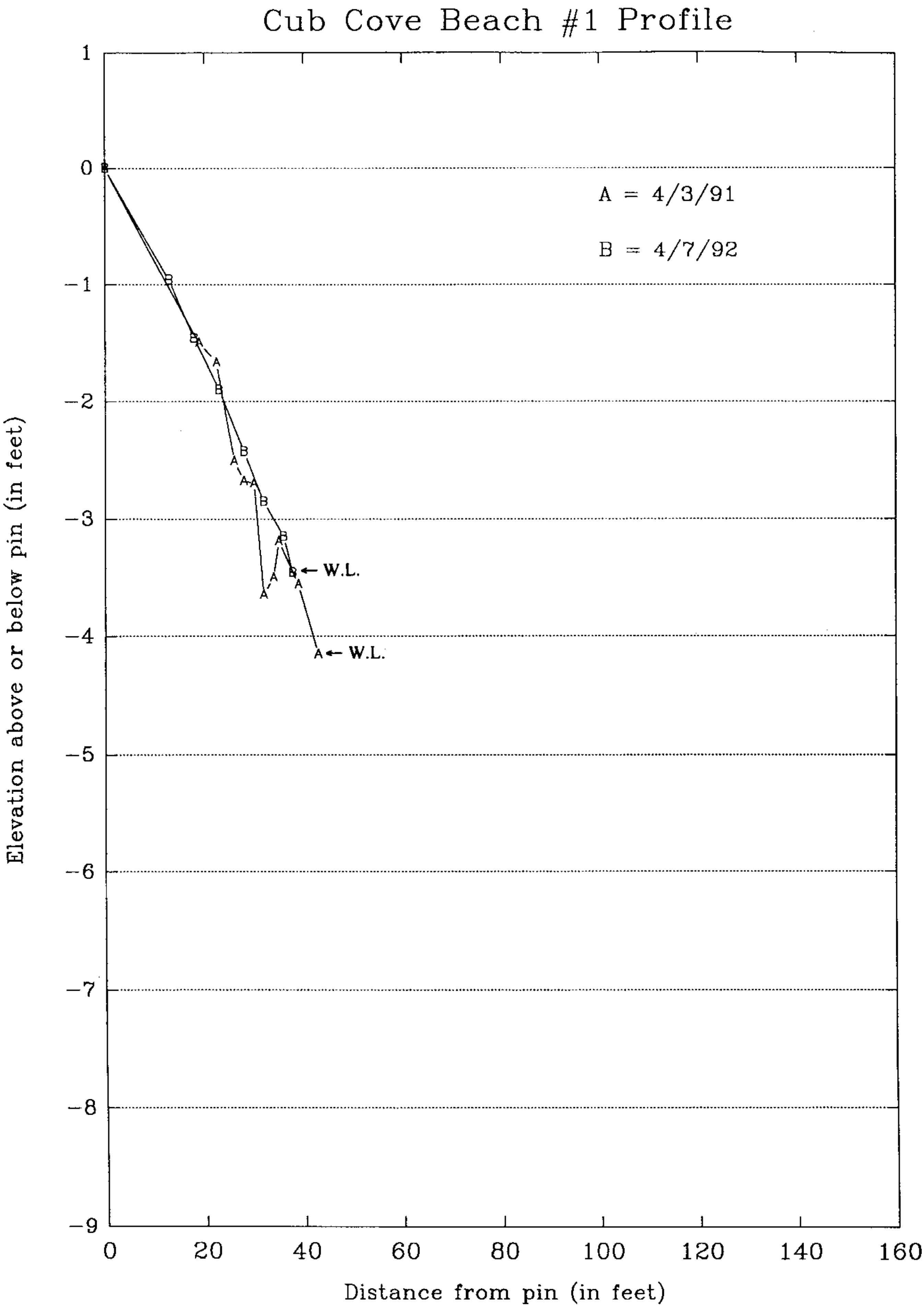

Cub Cove Beach #1 Profile
Summer 1992
L = 7/7/92
M = 8/3/92
N = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

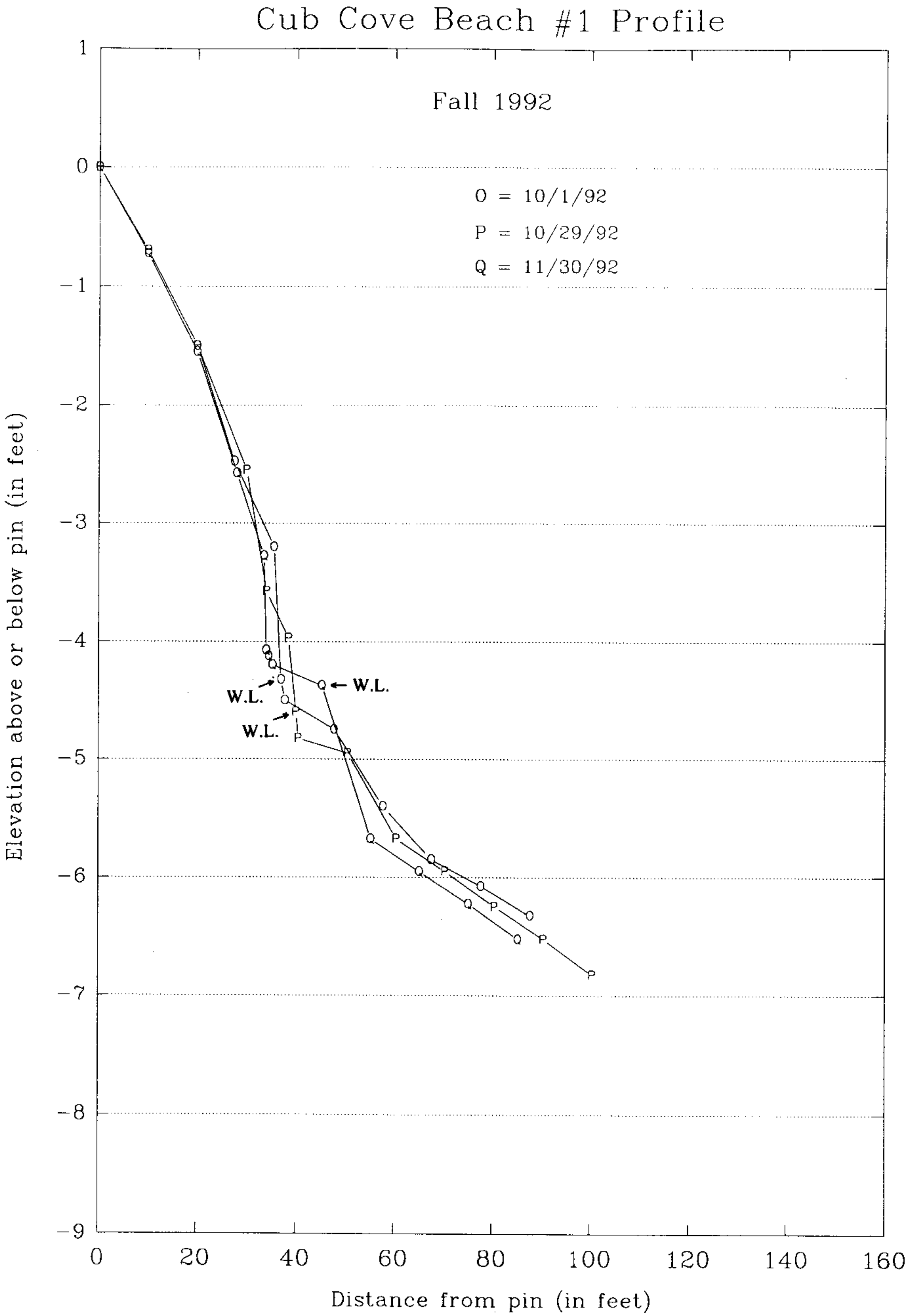

Cub Cove Beach #1 Profile
Spring 1993
R = 5/4/93
S = 6/3/93
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Cub Cove Beach #1 Profile
Summer 1993
T = 7/1/93
U = 8/4/93
V = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

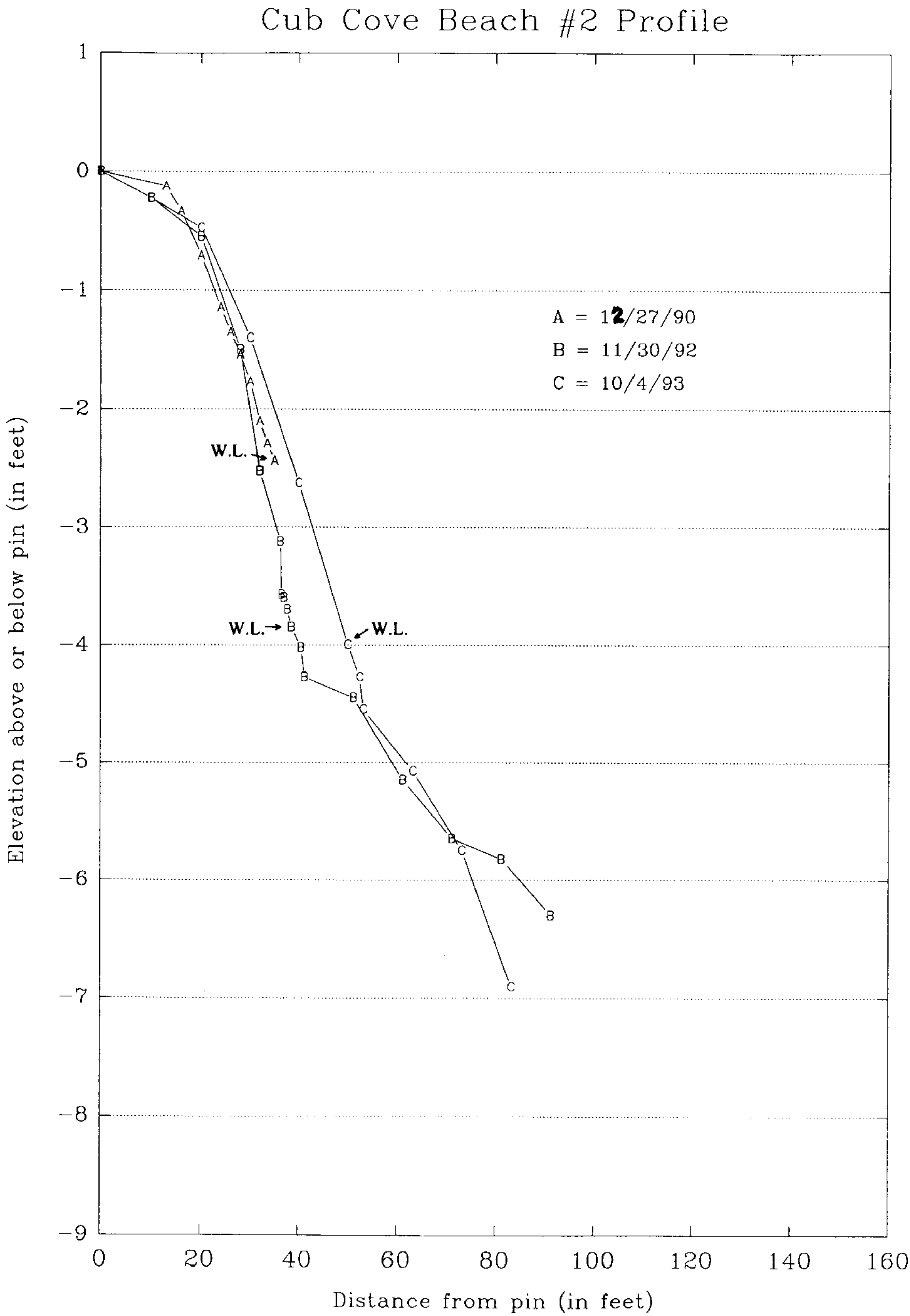

Cub Cove Beach #1 Profile
Fall 1993
W = 10/4/93
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Cub Cove Beach #2 Profile
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

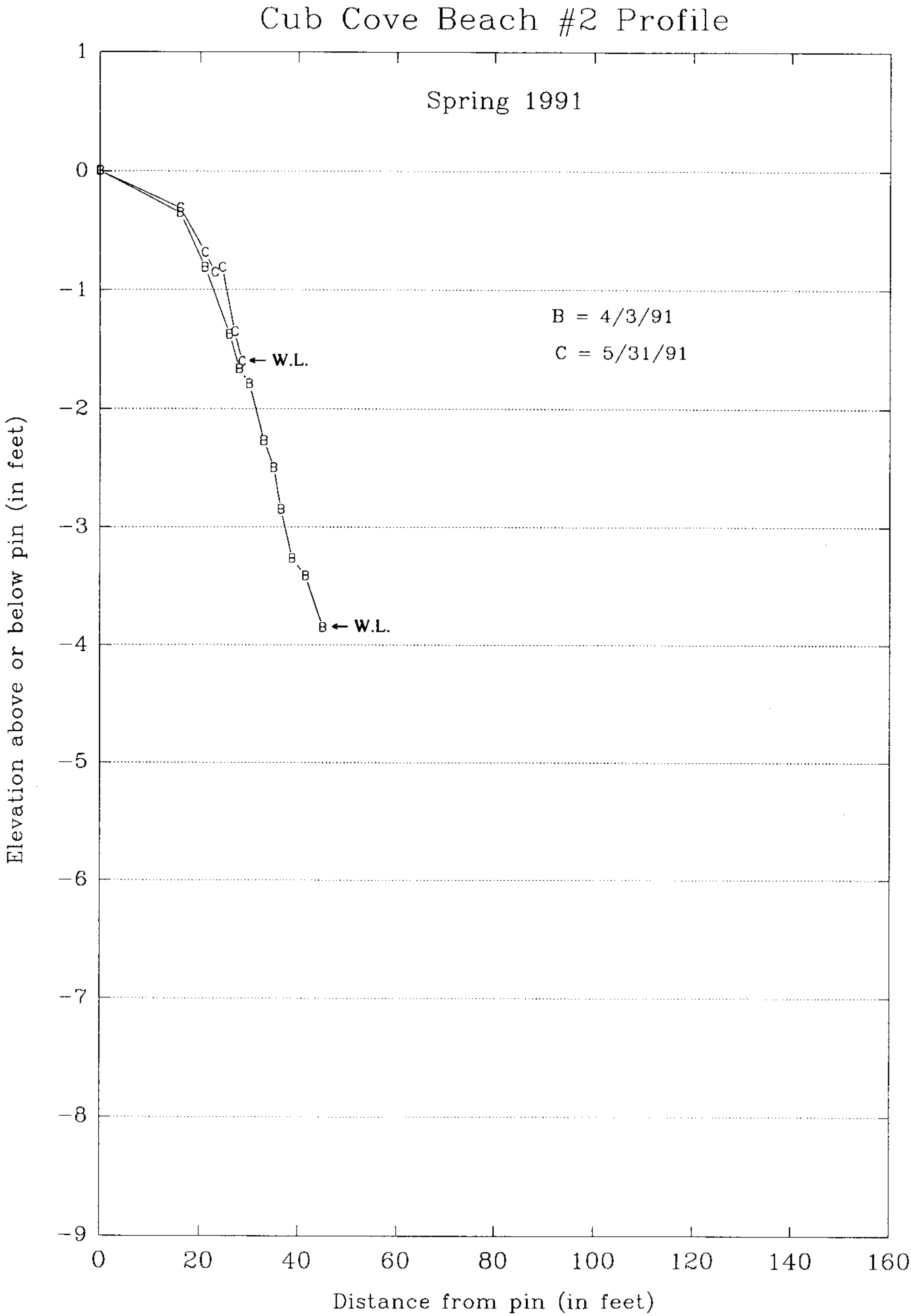

Cub Cove Beach #1 Profile
A = 4/3/91
B = 4/7/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160



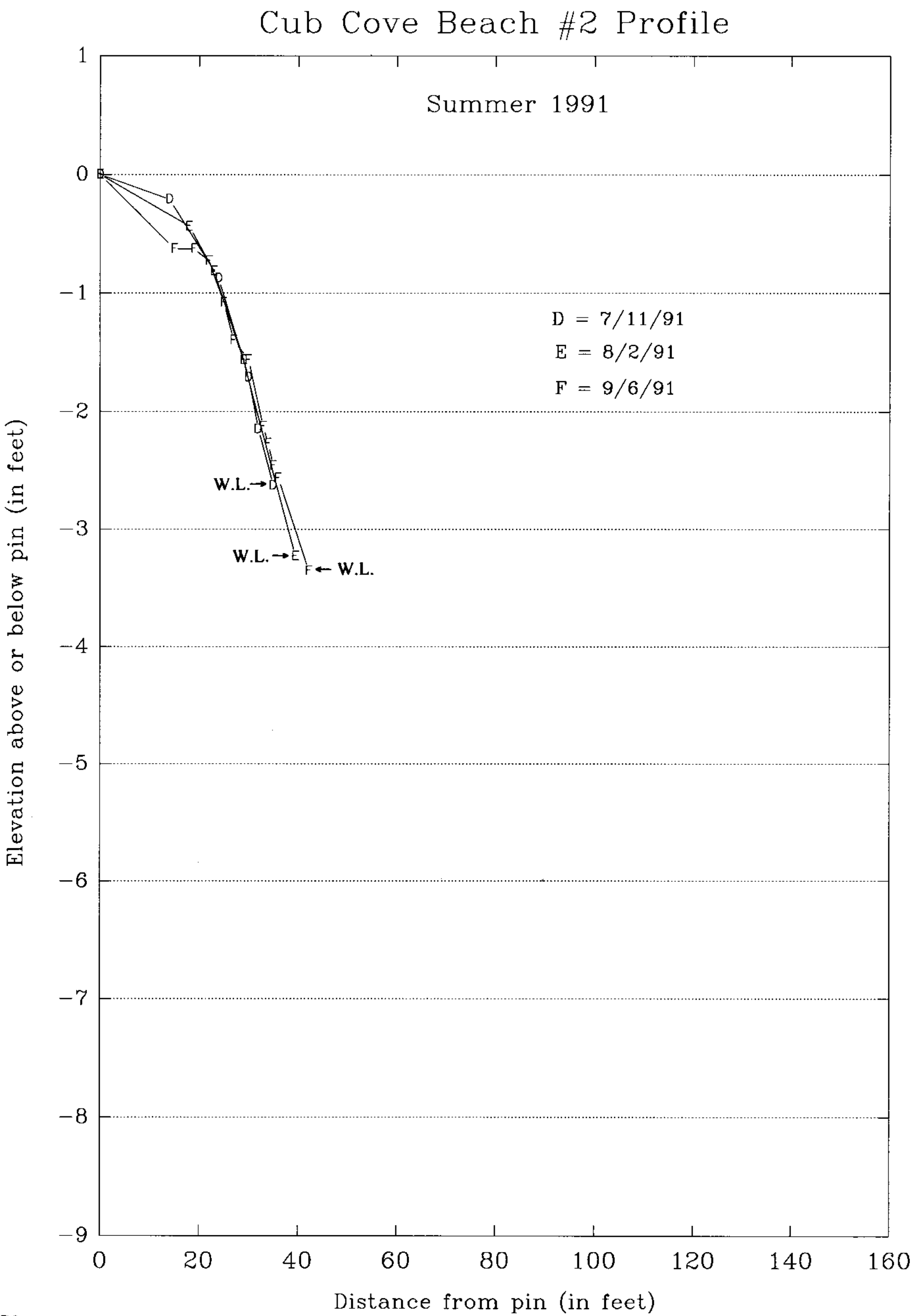
Cub Cove Beach #1 Profile
Fall 1992
O = 10/1/92
P = 10/29/92
Q = 11/30/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

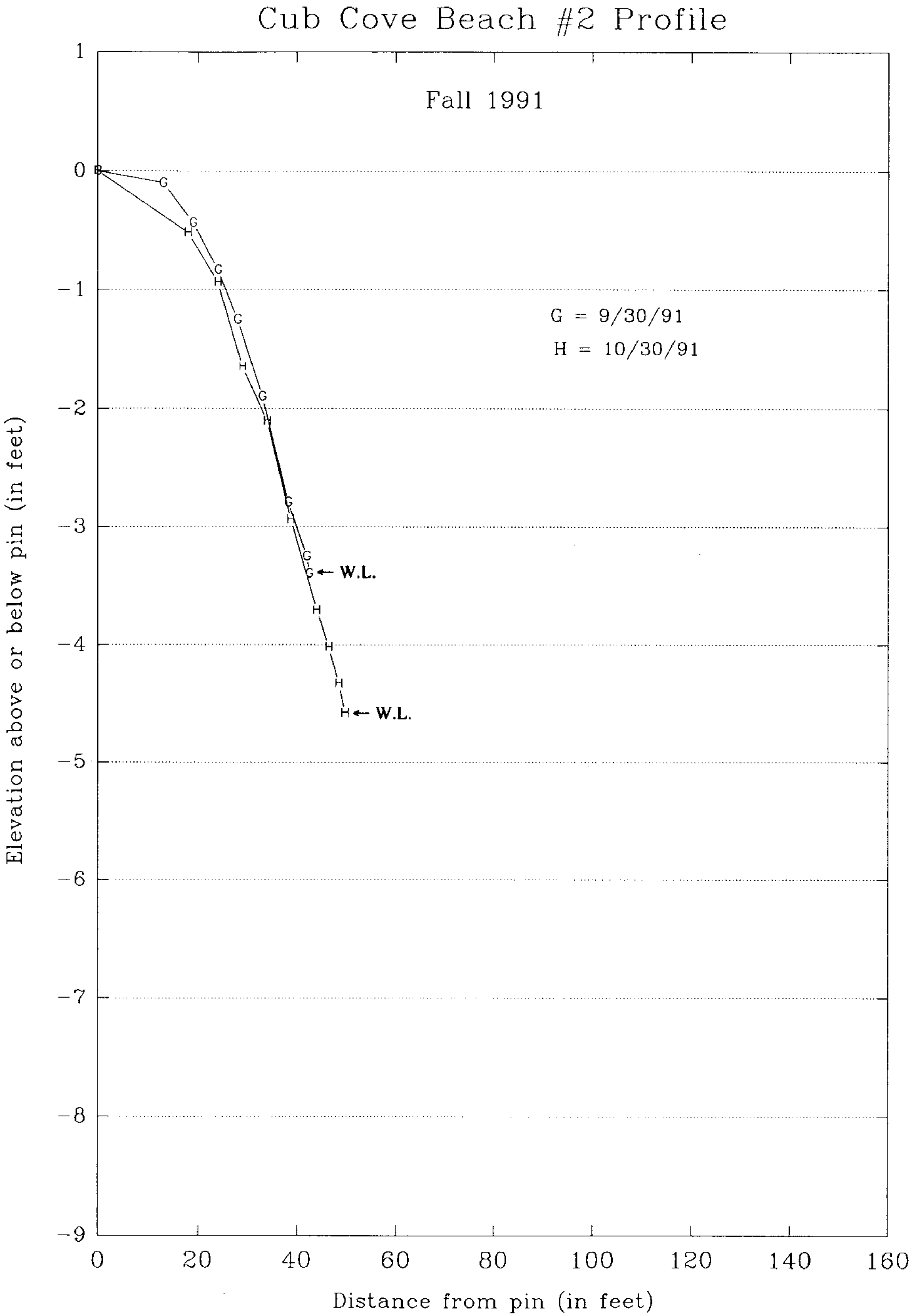


Cub Cove Beach #2 Profile
A = 12/27/90
B = 11/30/92
C = 10/4/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

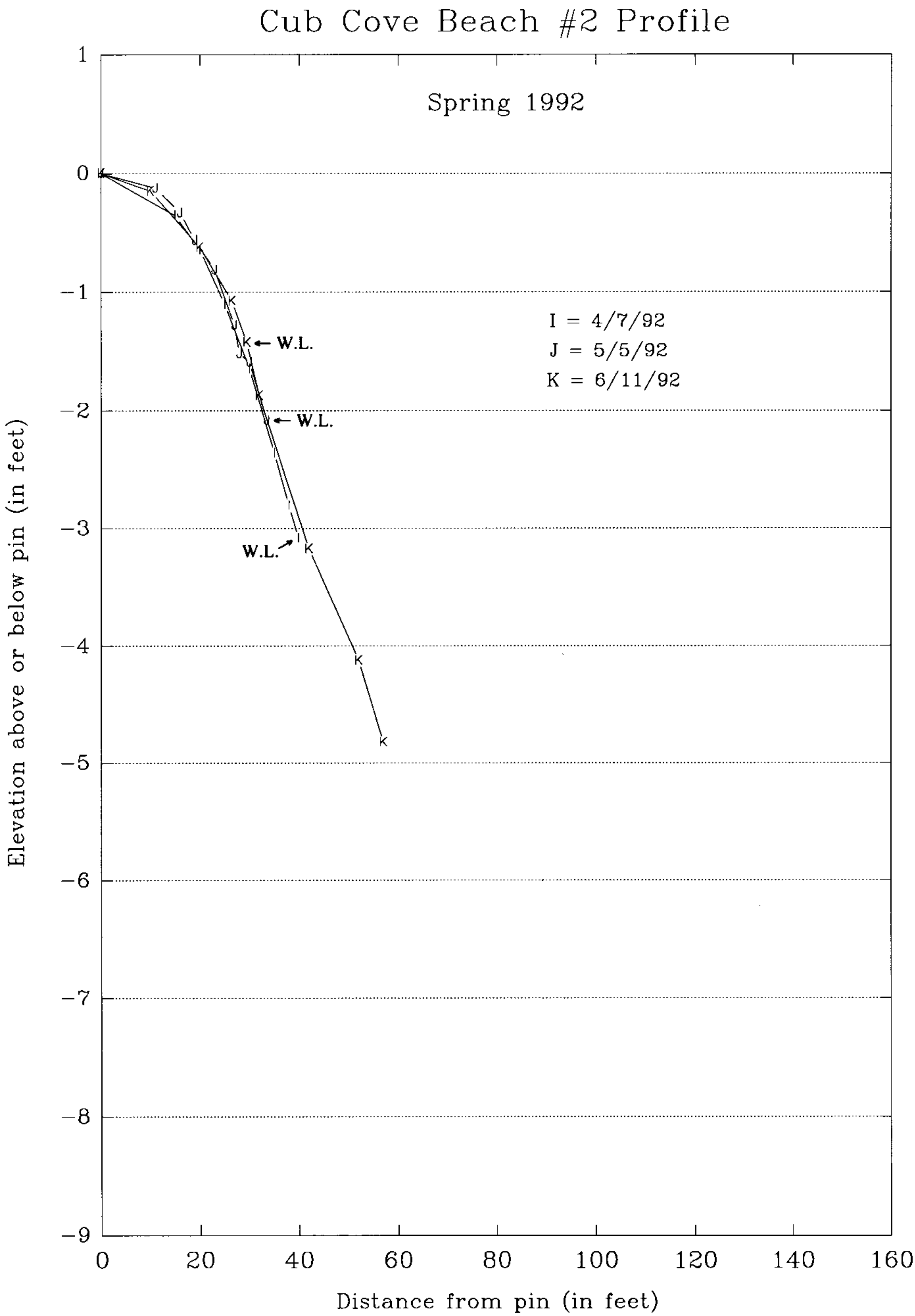


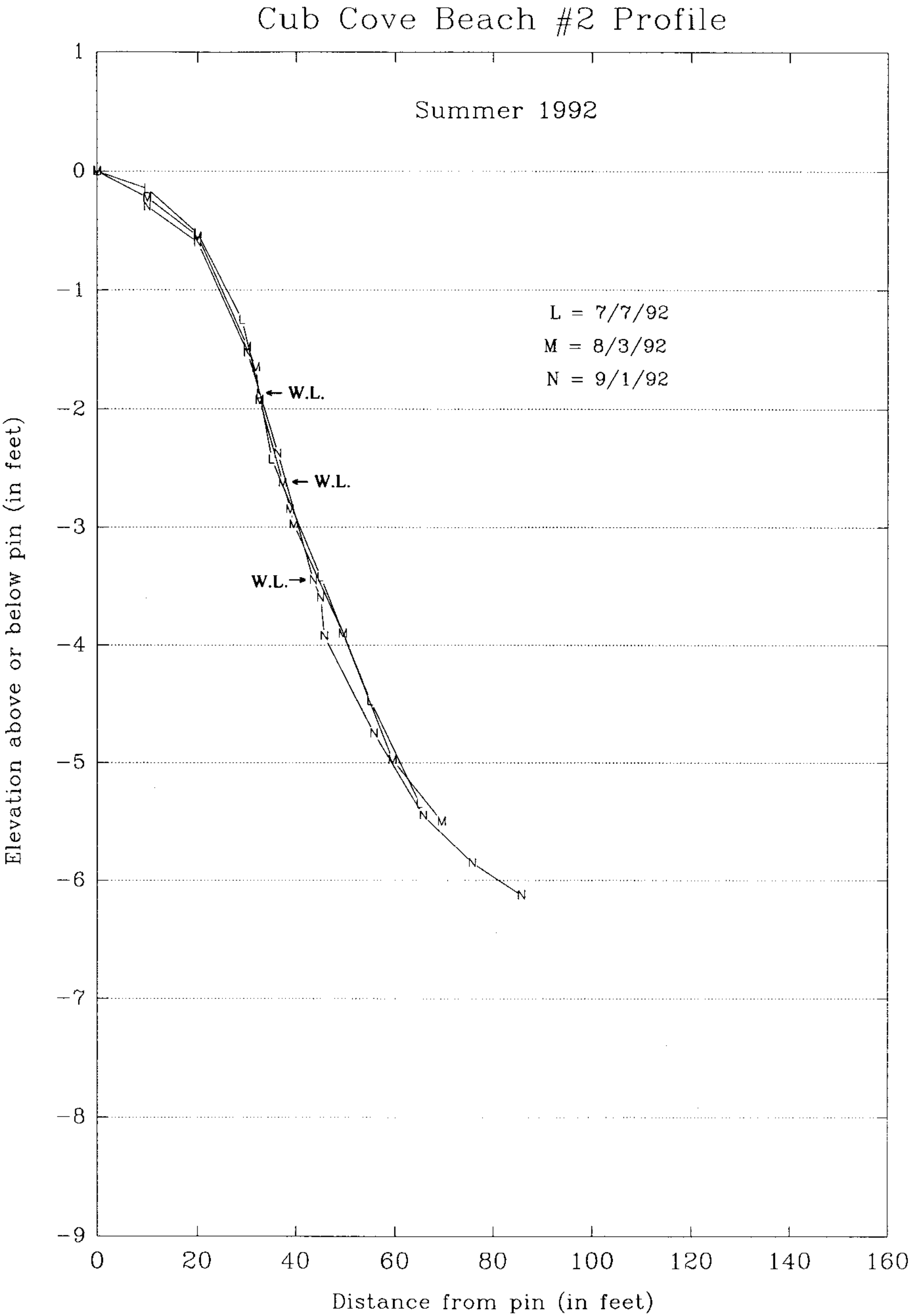
Cub Cove Beach #2 Profile
Spring 1991
B = 4/3/91
C = 5/31/91
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

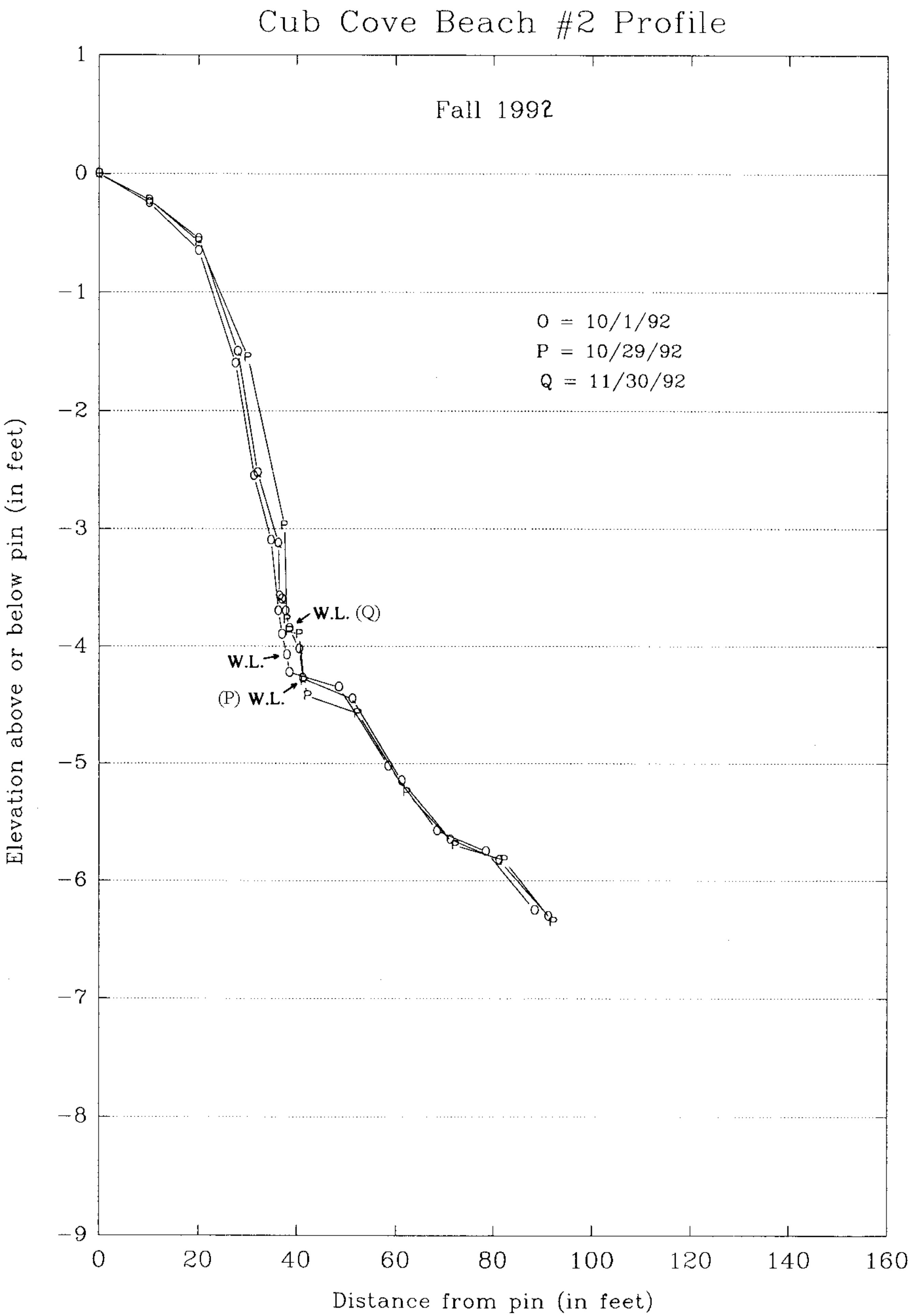

Cub Cove Beach #2 Profile
Summer 1991
D = 7/11/91
E = 8/2/91
F = 9/6/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

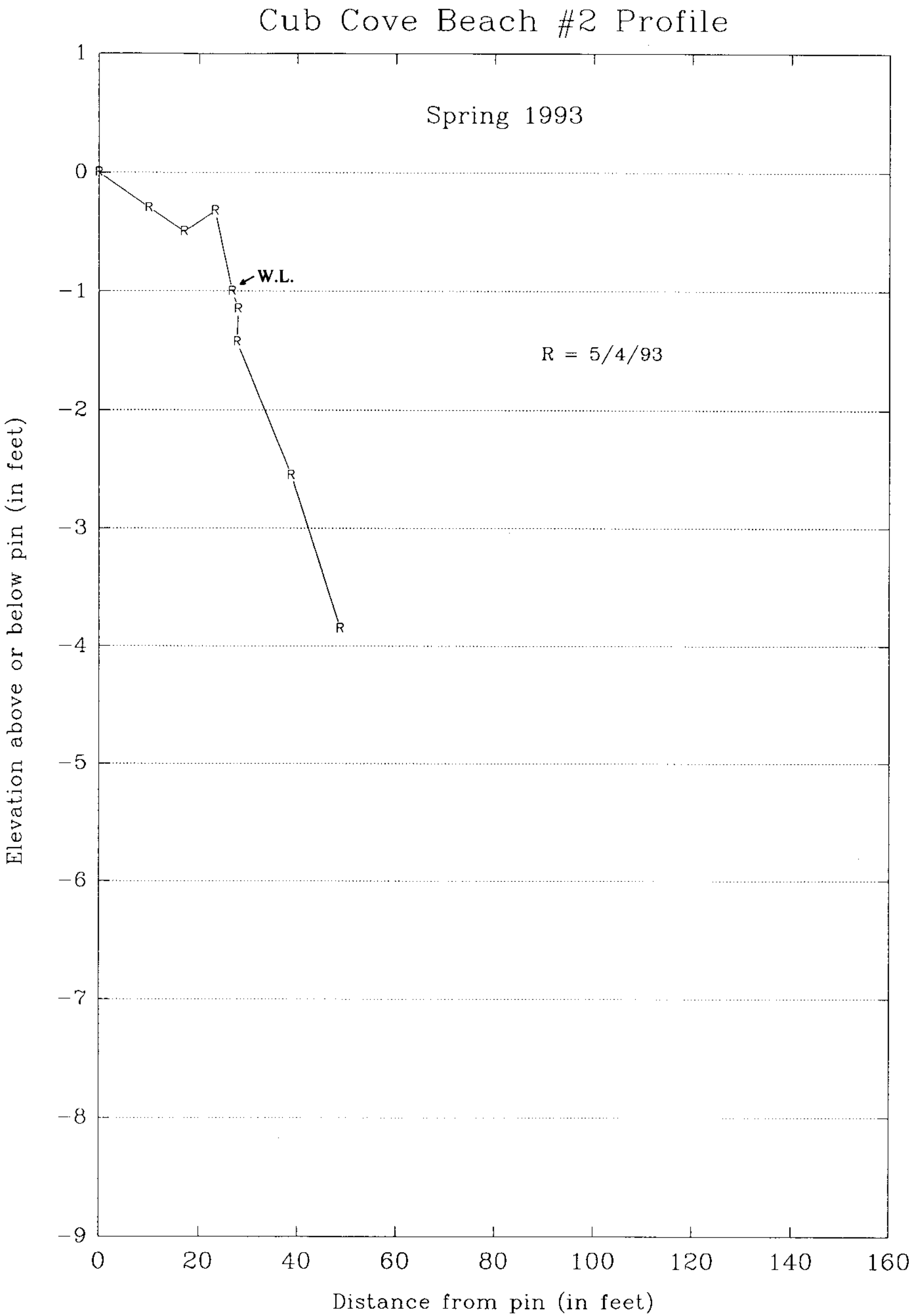


Cub Cove Beach #2 Profile
Fall 1991
G = 9/30/91
H = 10/30/91
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

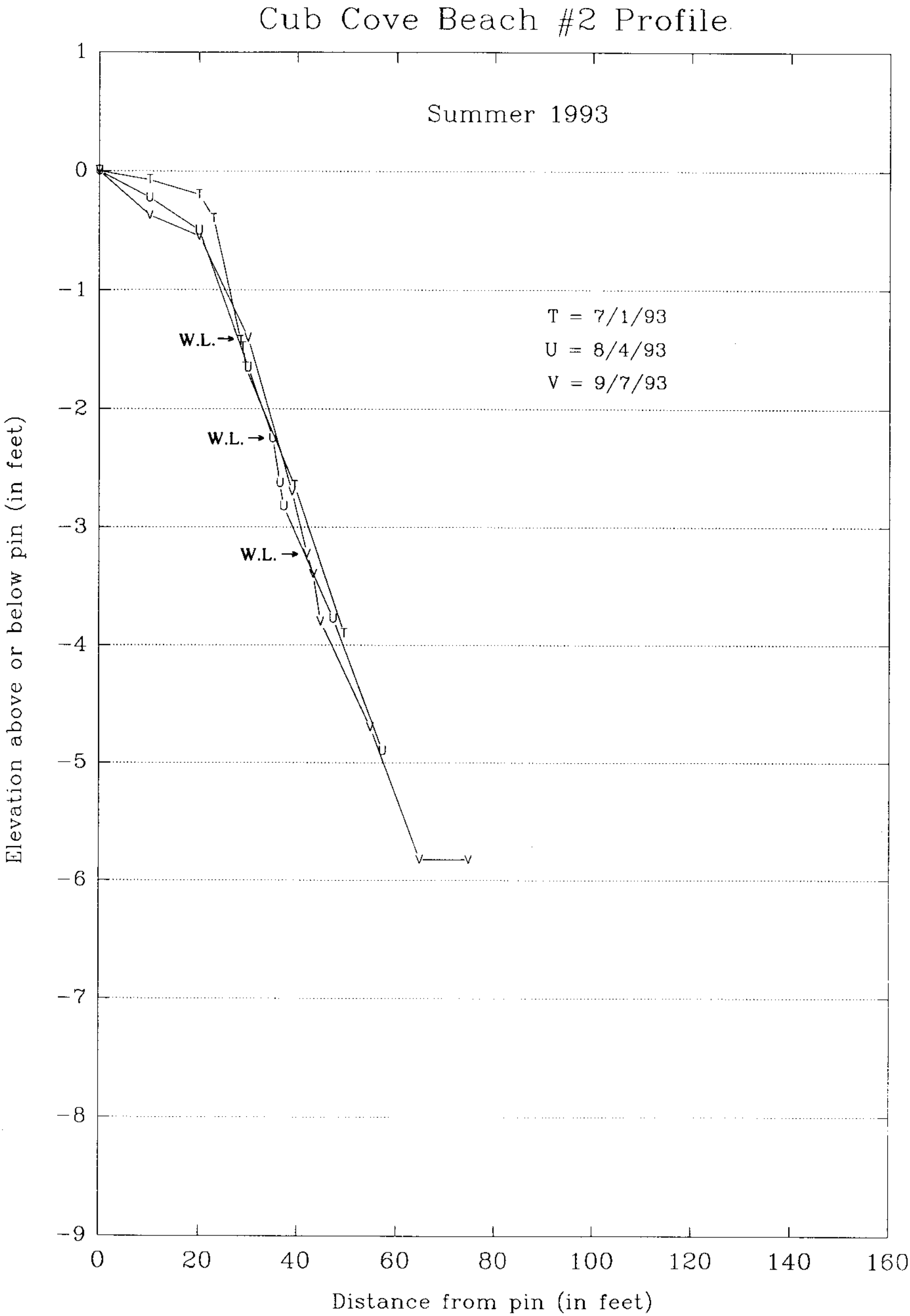

Cub Cove Beach #2 Profile
Spring 1992
I = 4/7/92
J = 5/5/92
K = 6/11/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Cub Cove Beach #2 Profile
Summer 1992
L = 7/7/92
M = 8/3/92
N = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

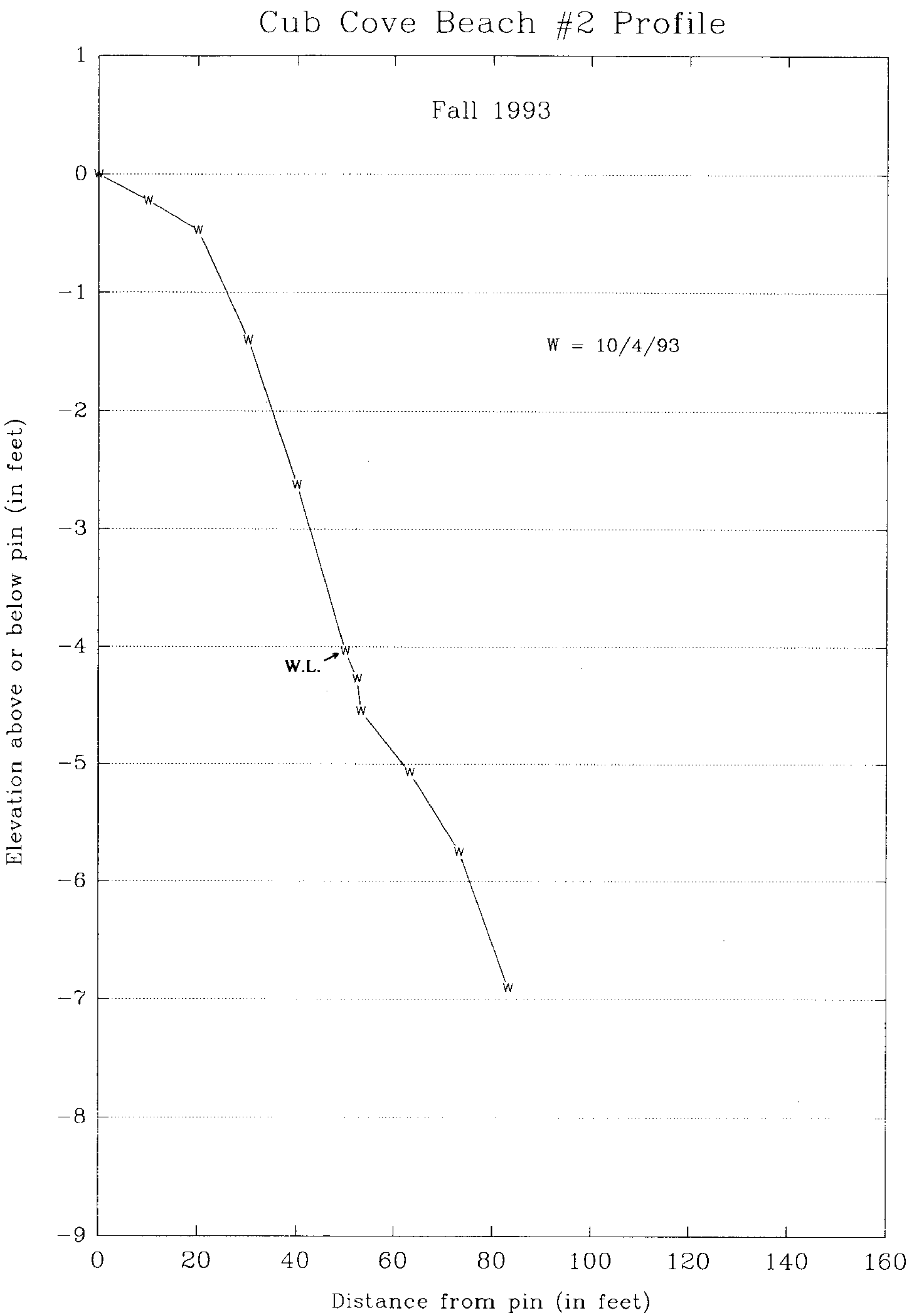

Cub Cove Beach #2 Profile
Fall 1992
O = 10/1/92
P = 10/29/92
Q = 11/30/92
W.L. (Q)
W.L.
(P) W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160



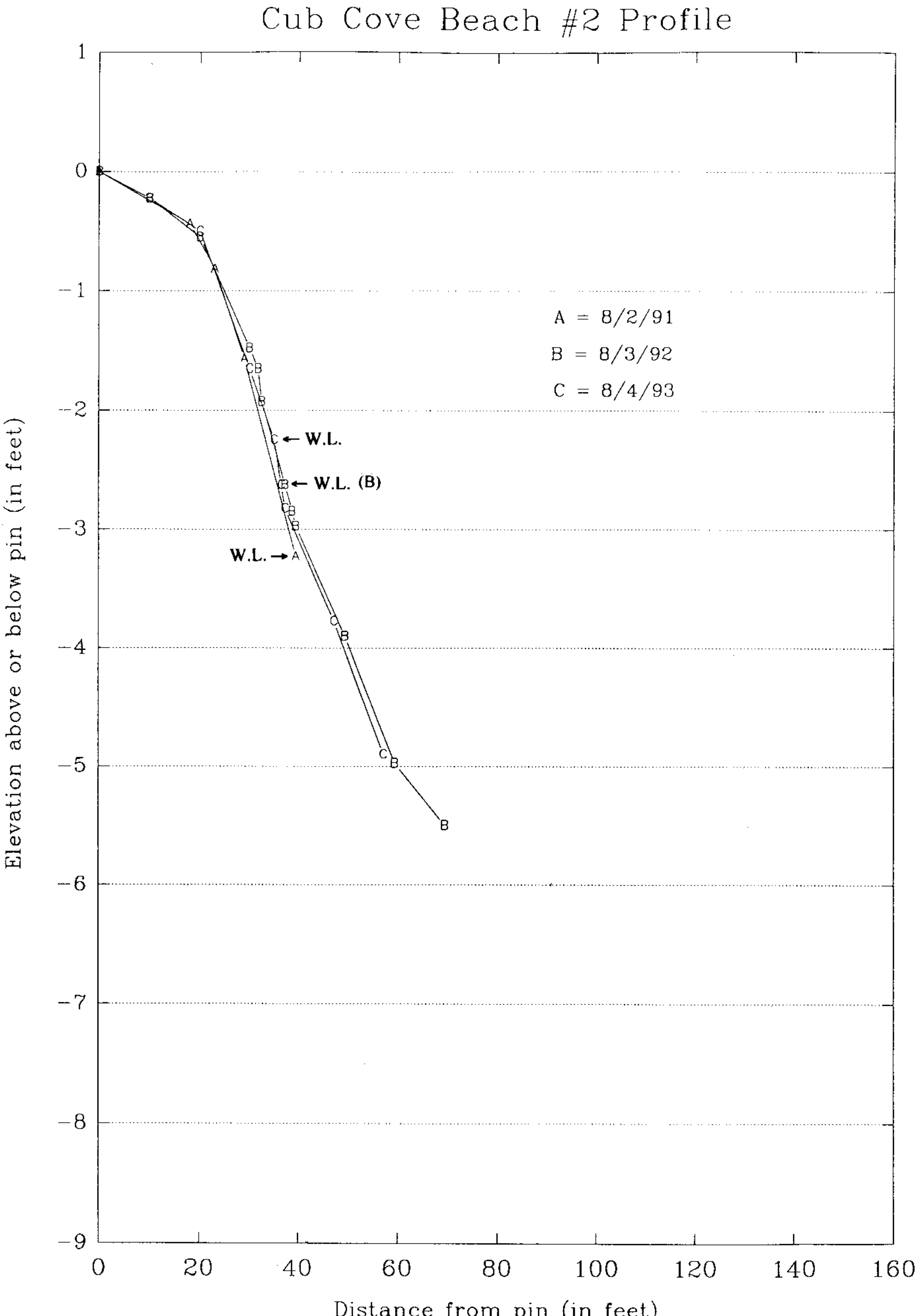
Cub Cove Beach #2 Profile
Spring 1993
W.L.
R = 5/4/93
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

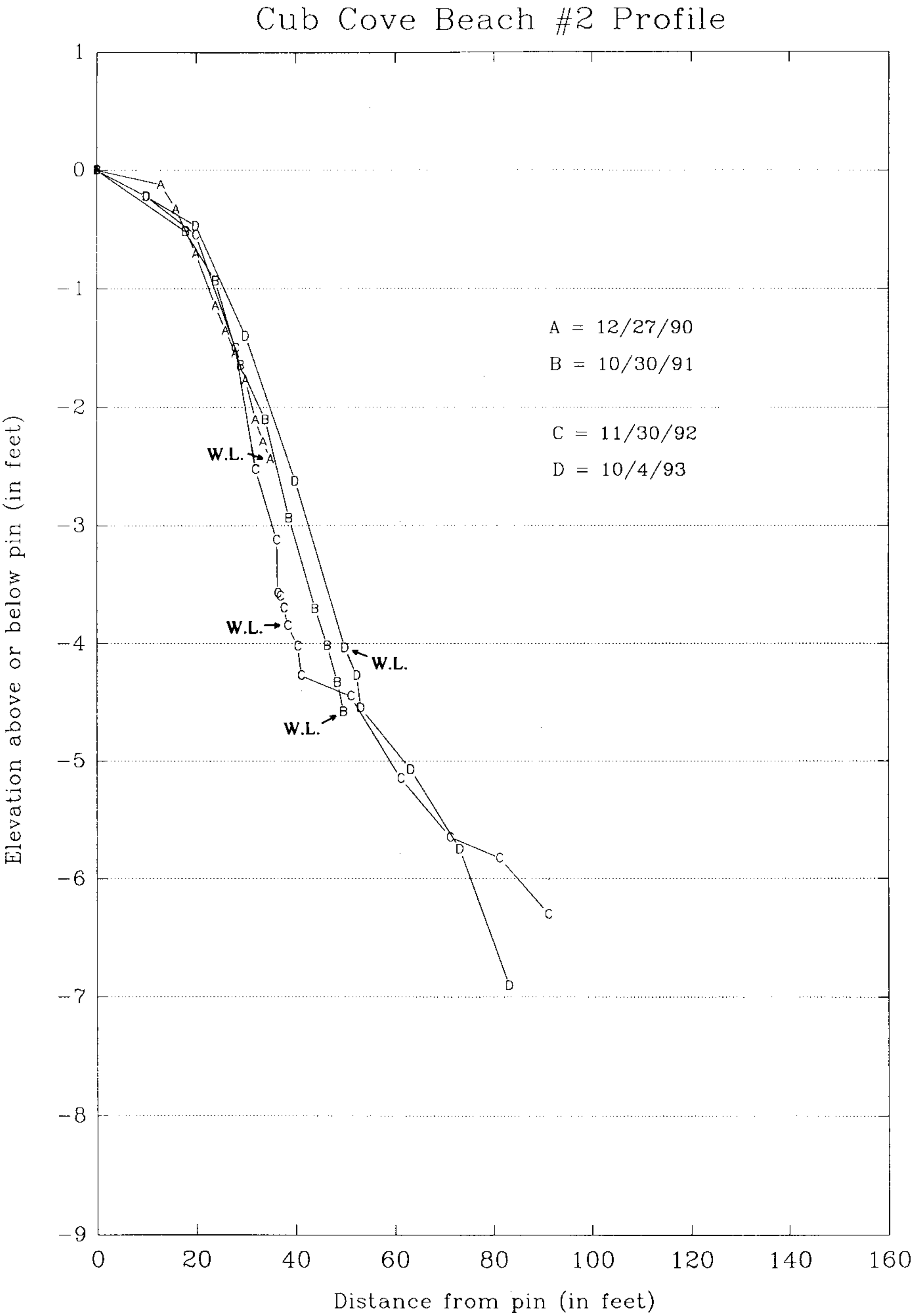


Cub Cove Beach #2 Profile
Summer 1993
T = 7/1/93
U = 8/4/93
V = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

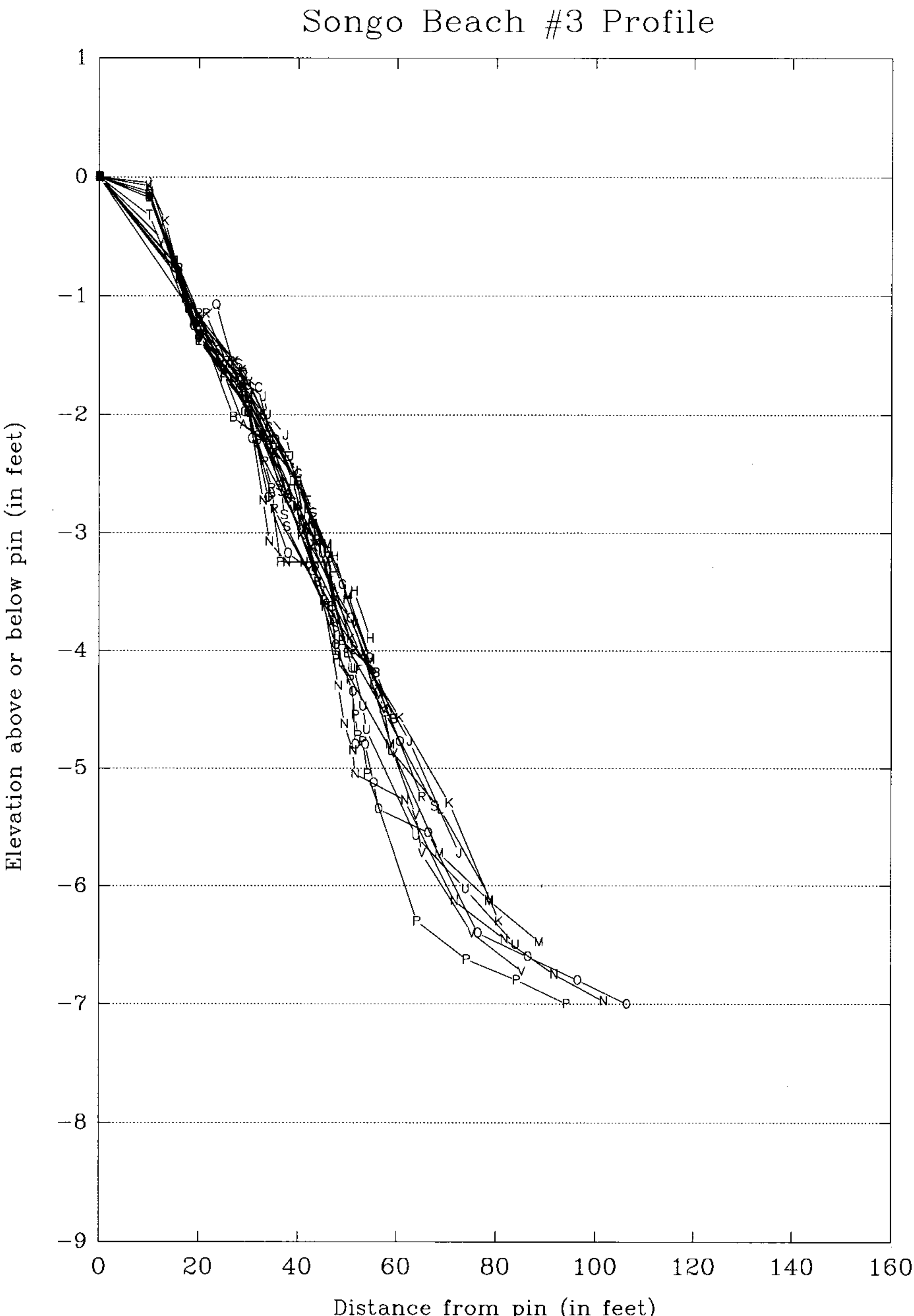


Cub Cove Beach #2 Profile
Fall 1993
W = 10/4/93
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

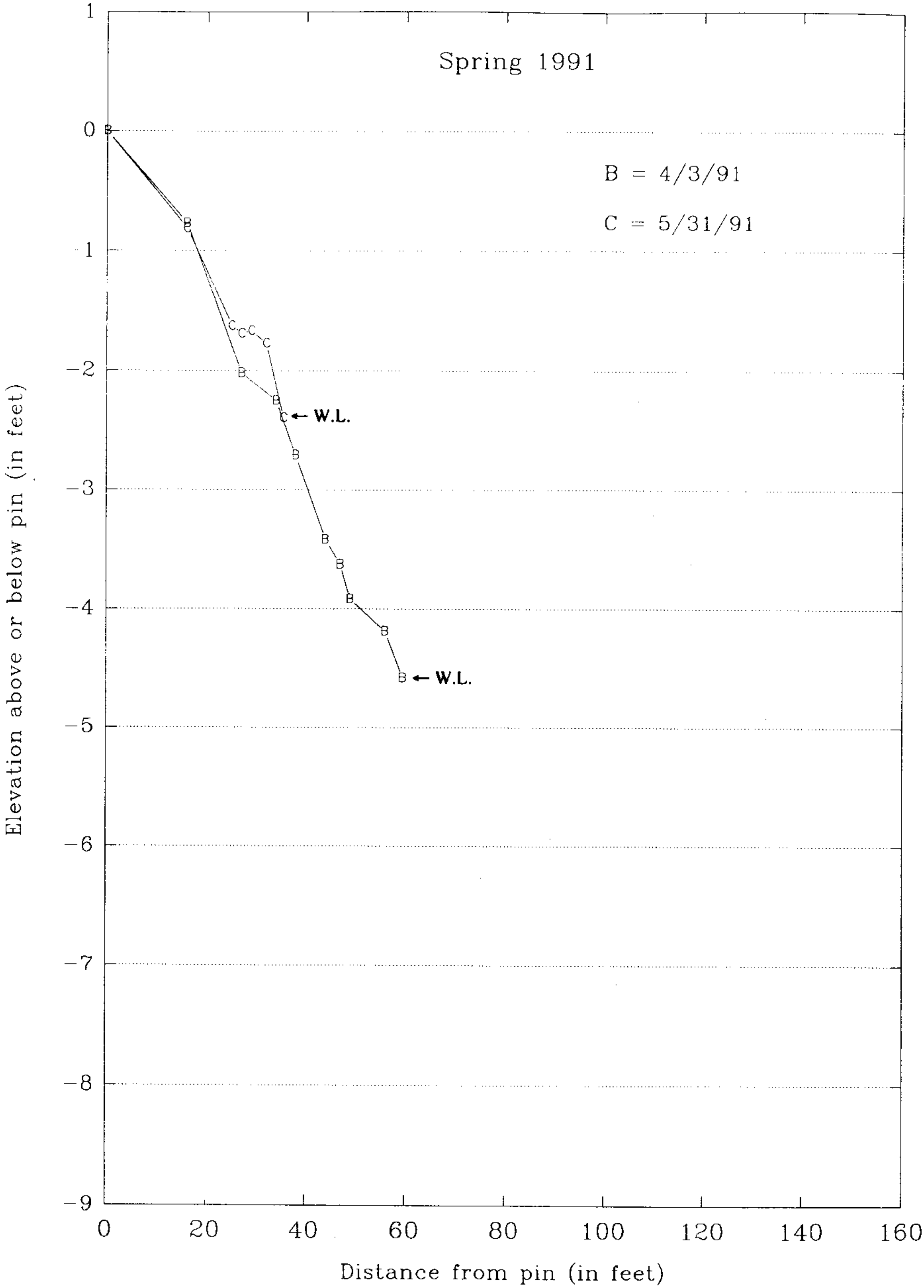

Cub Cove Beach #2 Profile
A = 8/2/91
B = 8/3/92
C = 8/4/93
W.L.
W.L. (B)
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

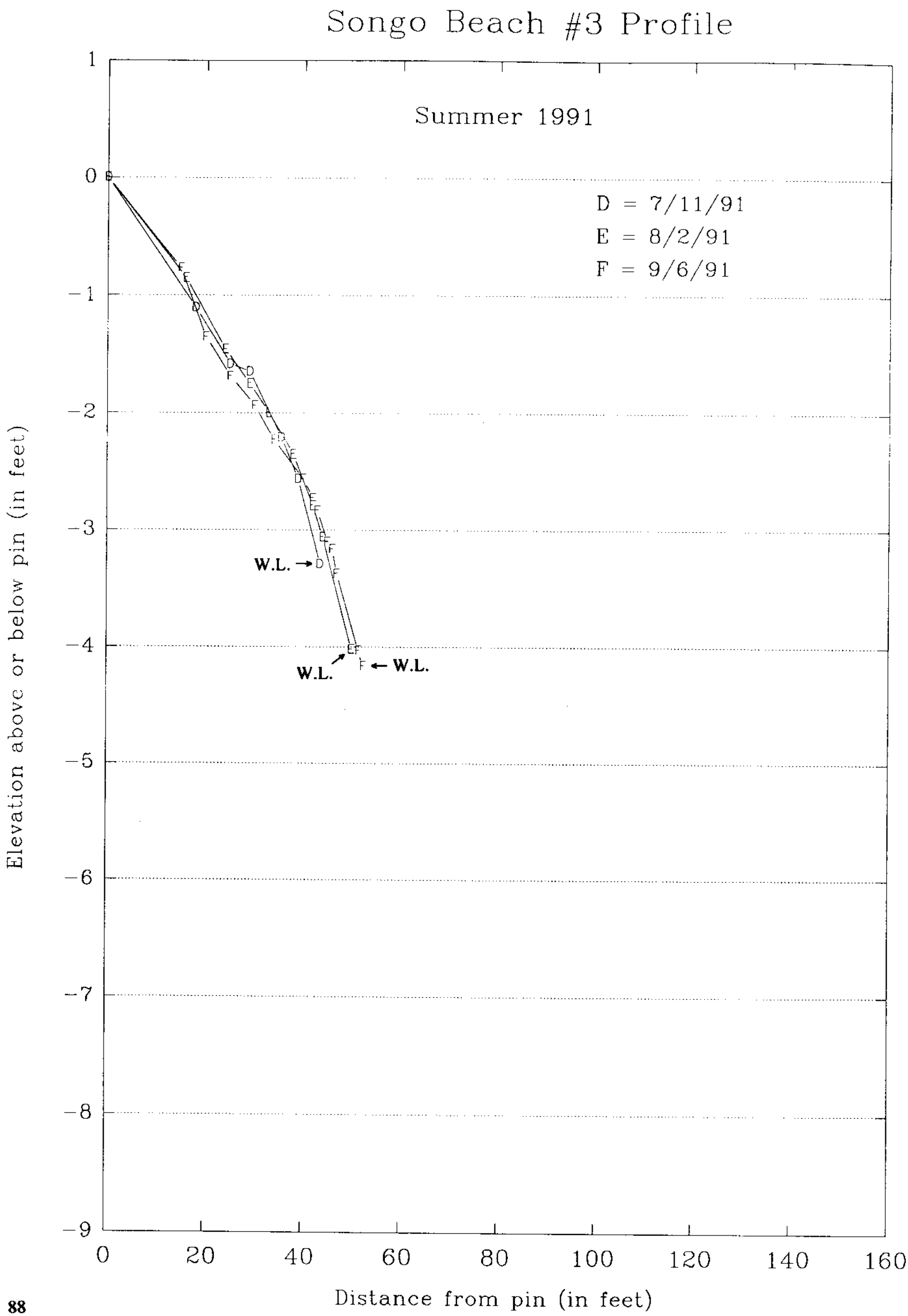


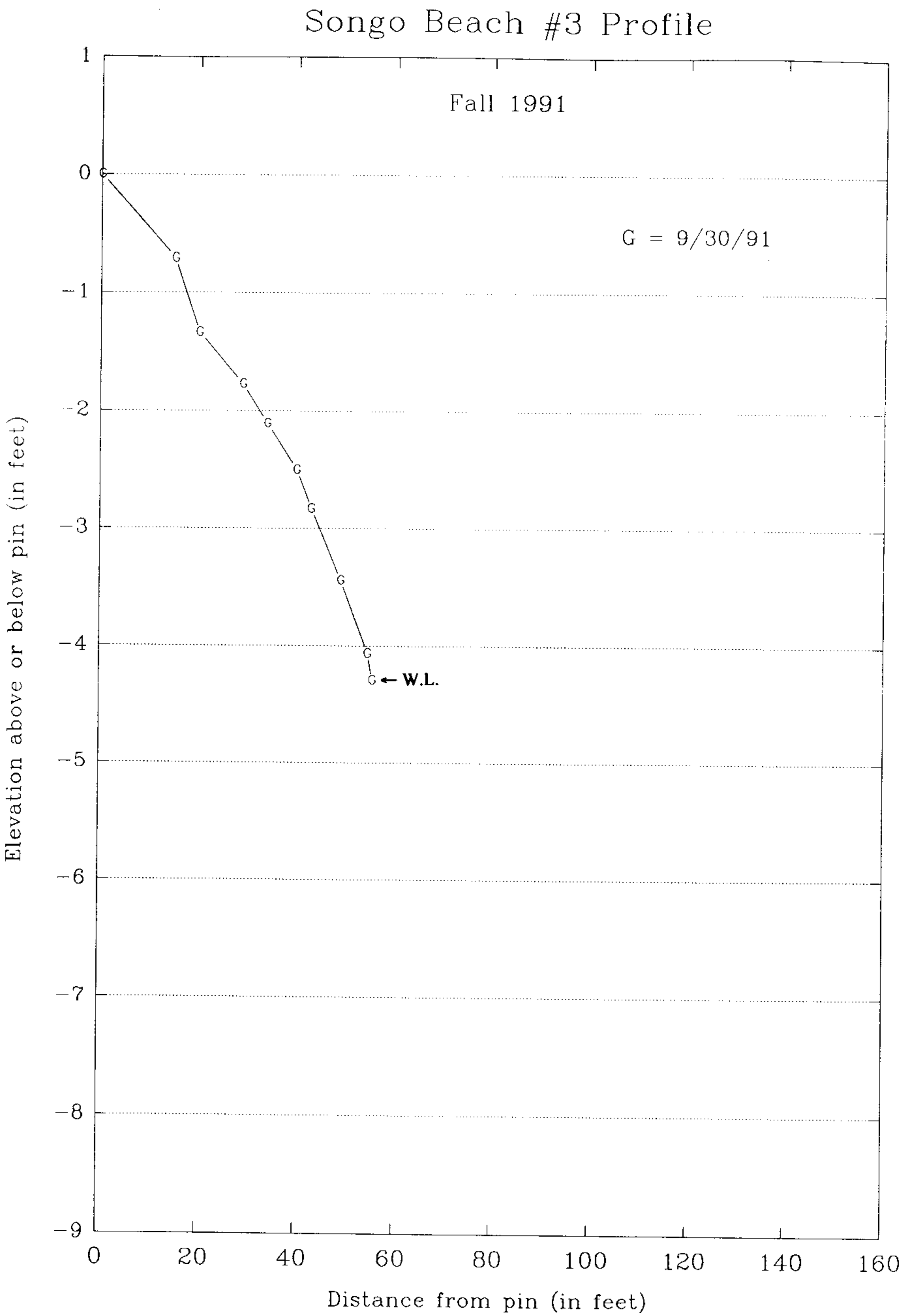
Cub Cove Beach #2 Profile
Elevation above or below pin (in feet)
Distance from pin (in feet)
A = 12/27/90
B = 10/30/91
C = 11/30/92
D = 10/4/93
W.L.
W.L.
W.L.
W.L.
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

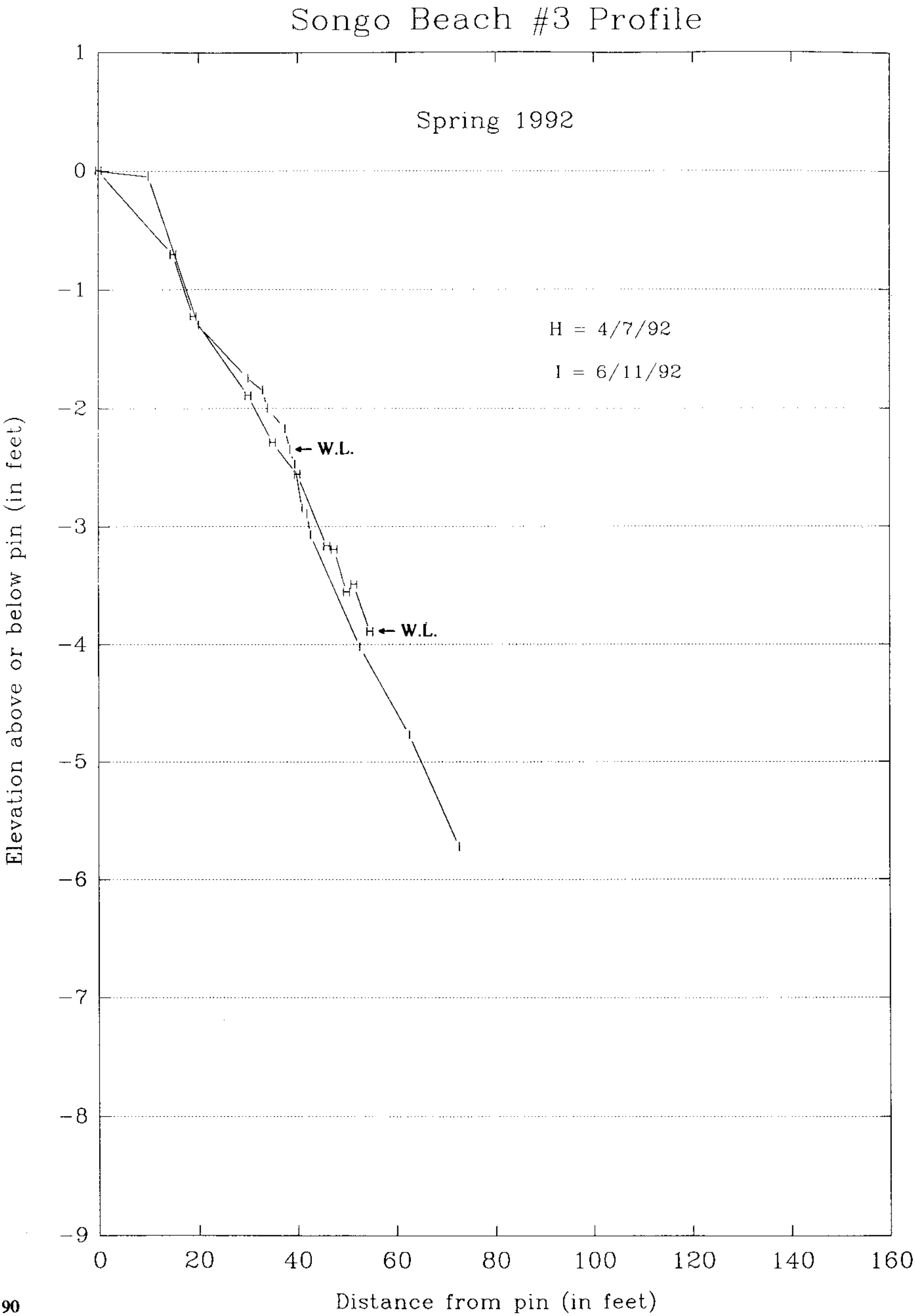

Songo Beach #3 Profile
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

Songo Beach #3 Profile

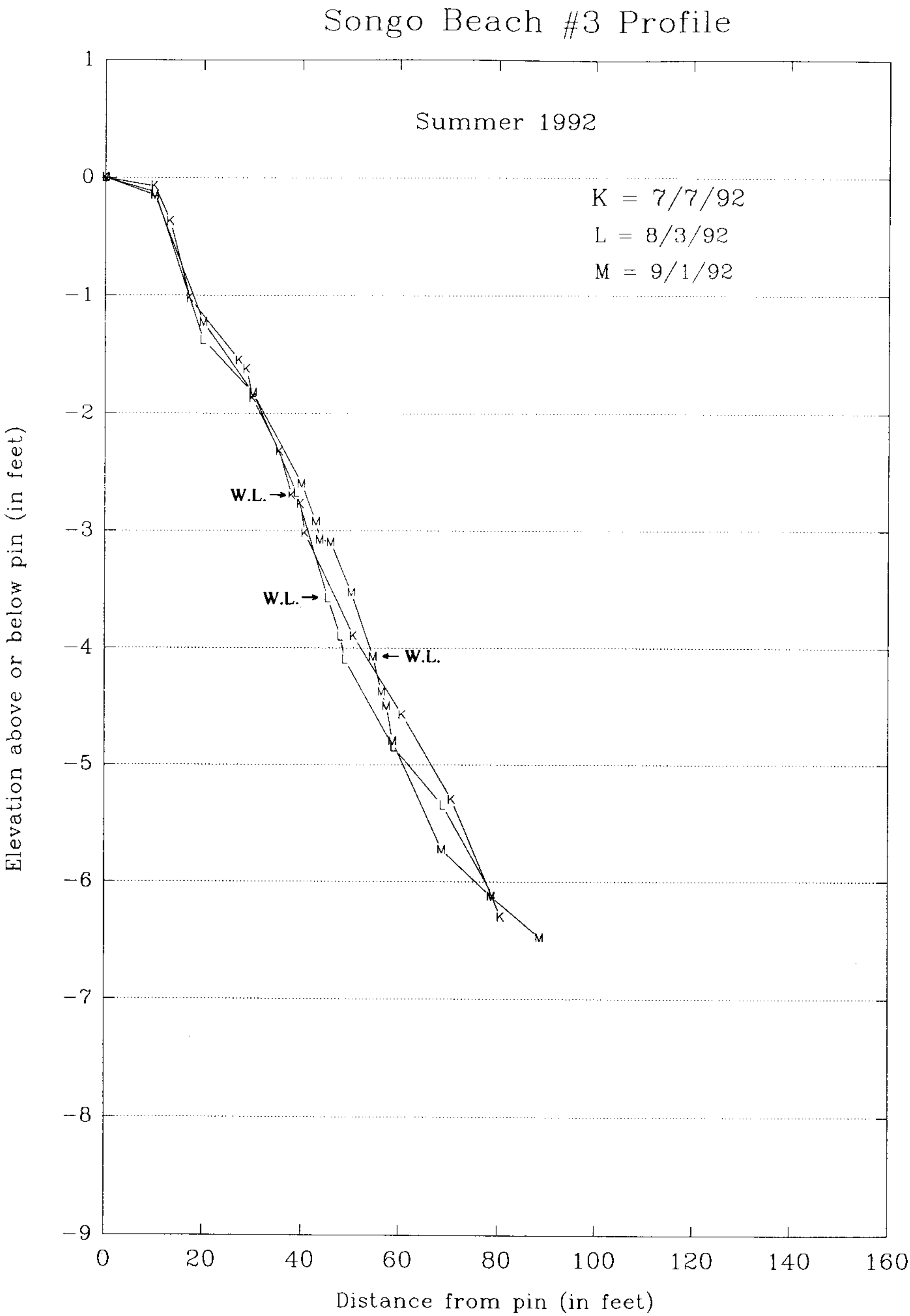


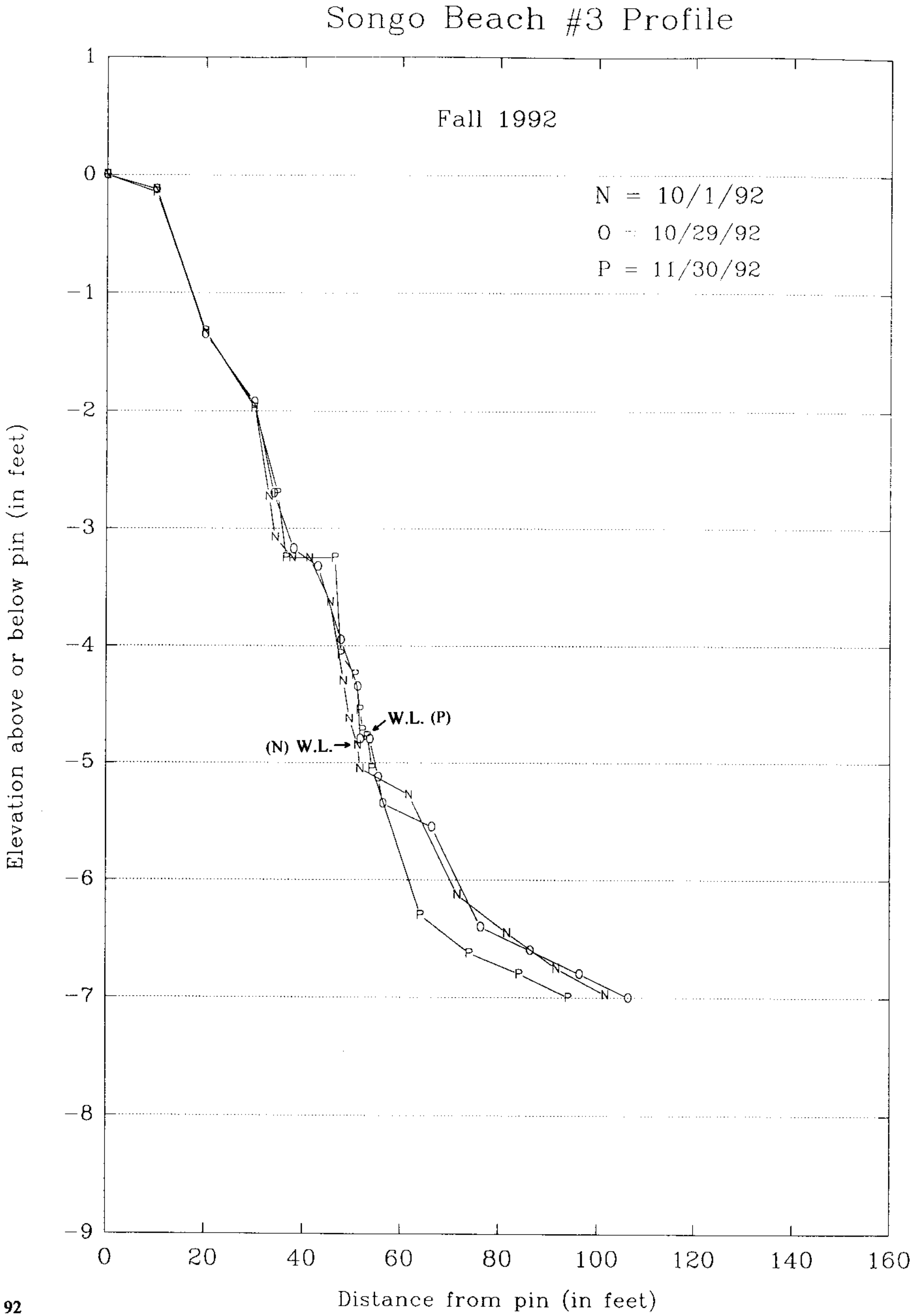

Songo Beach #3 Profile
Summer 1991
D = 7/11/91
E = 8/2/91
F = 9/6/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

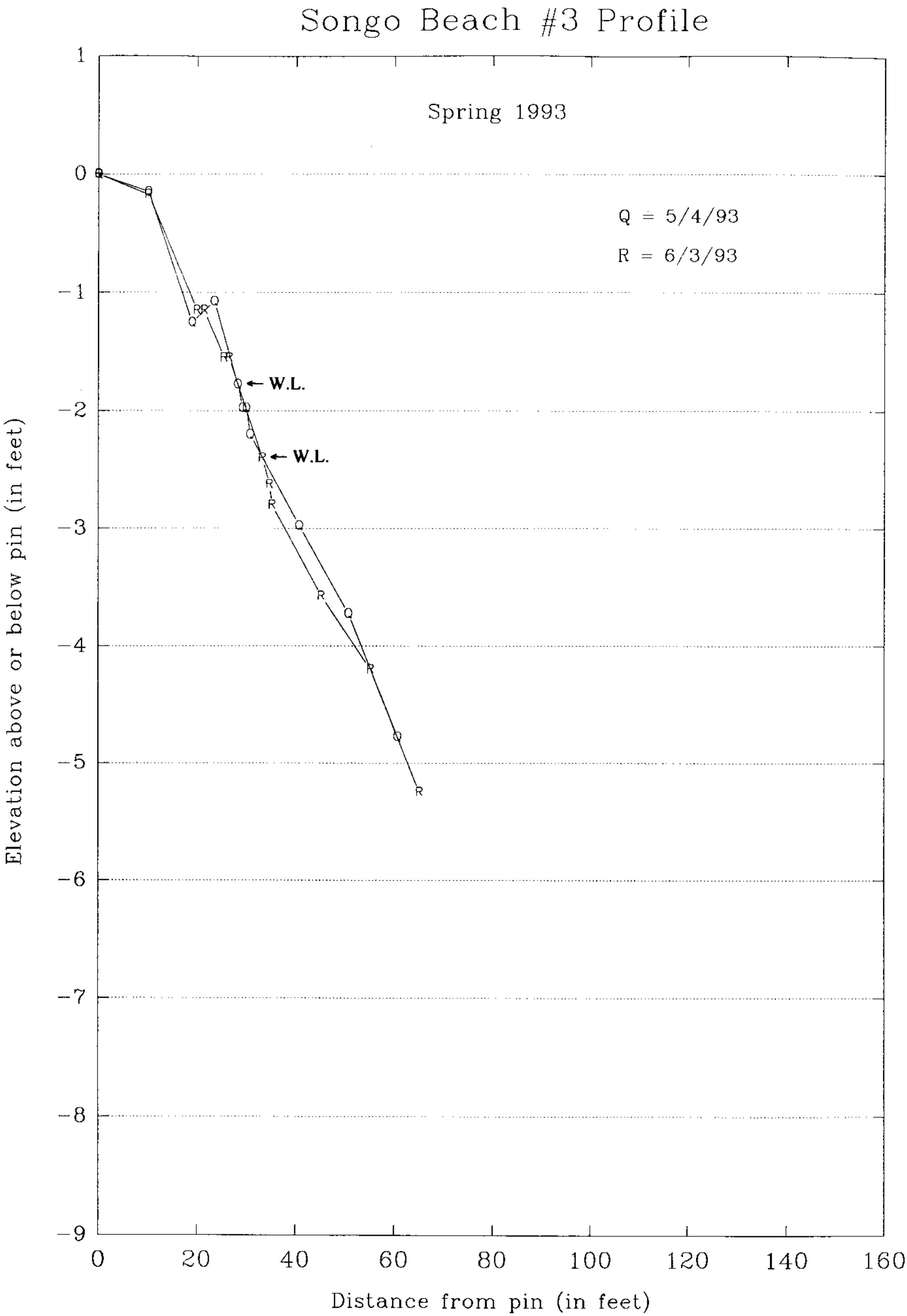

Songo Beach #3 Profile
Fall 1991
G = 9/30/91
W.L.
Elevation above or below pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
Distance from pin (in feet)
0
20
40
60
80
100
120
140
160



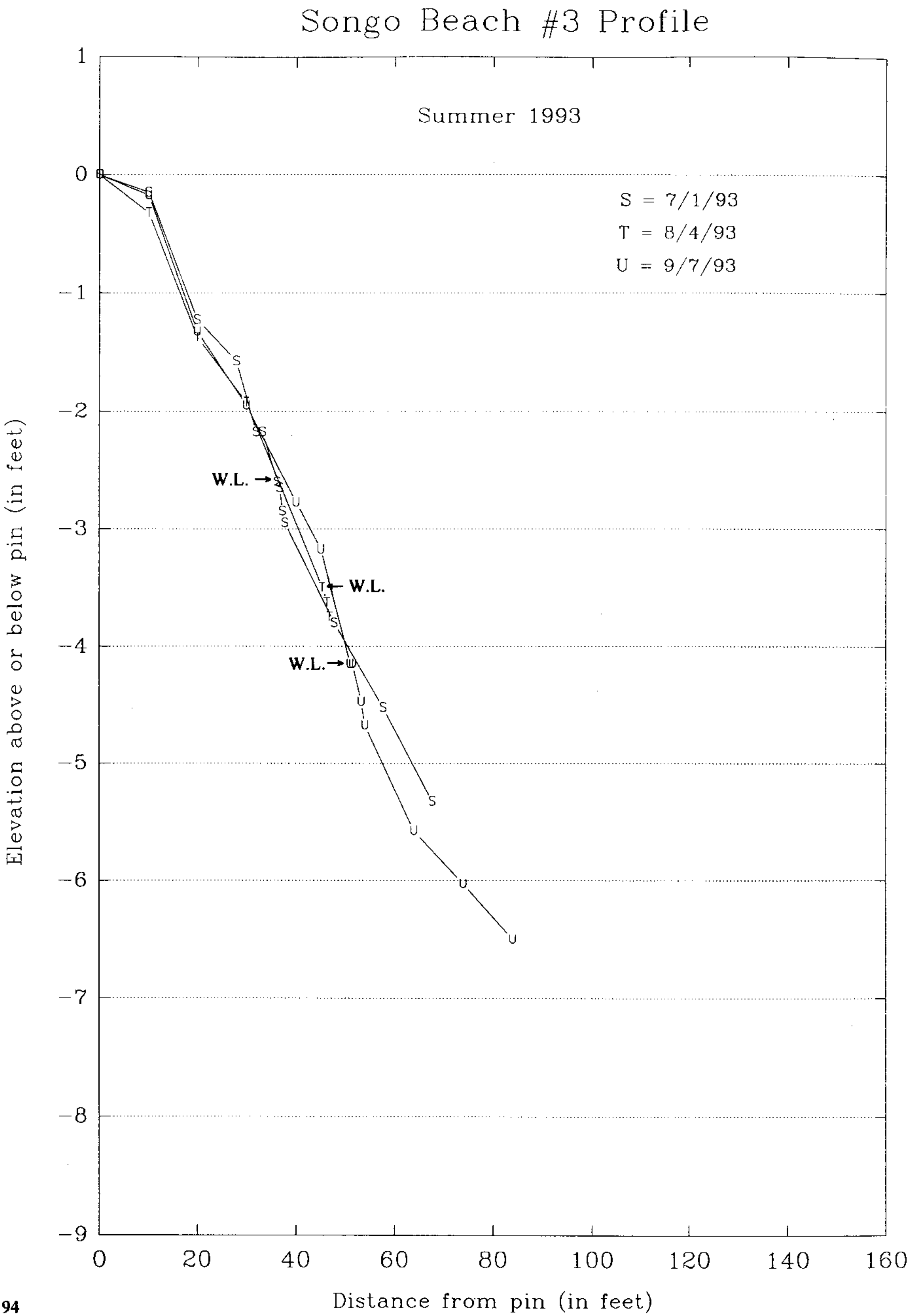
Songo Beach #3 Profile
Spring 1992
H = 4/7/92
I = 6/11/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

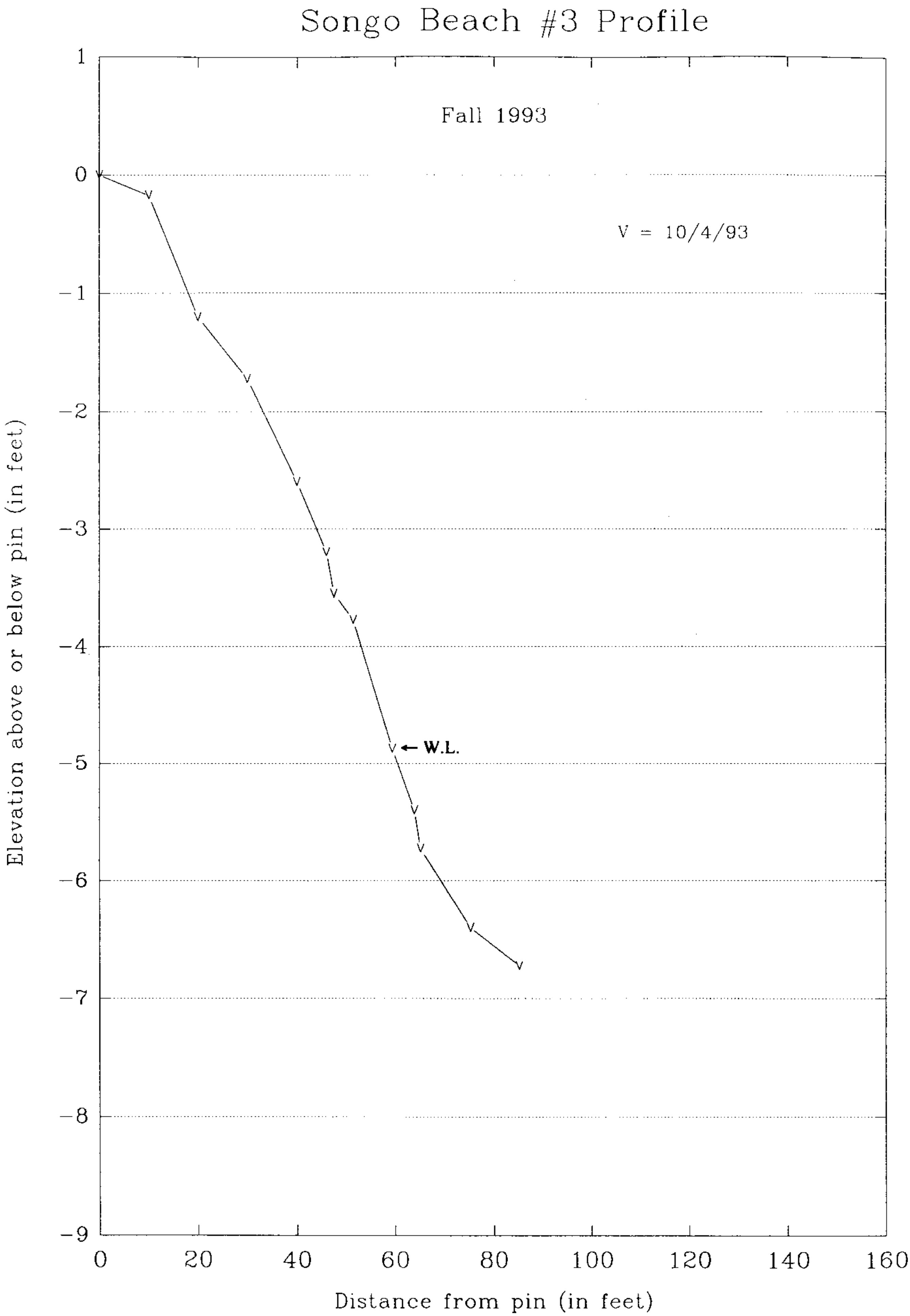

Songo Beach #3 Profile
Summer 1992
K = 7/7/92
L = 8/3/92
M = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Songo Beach #3 Profile
Fall 1992
N = 10/1/92
O = 10/29/92
P = 11/30/92
W.L. (P)
(N) W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

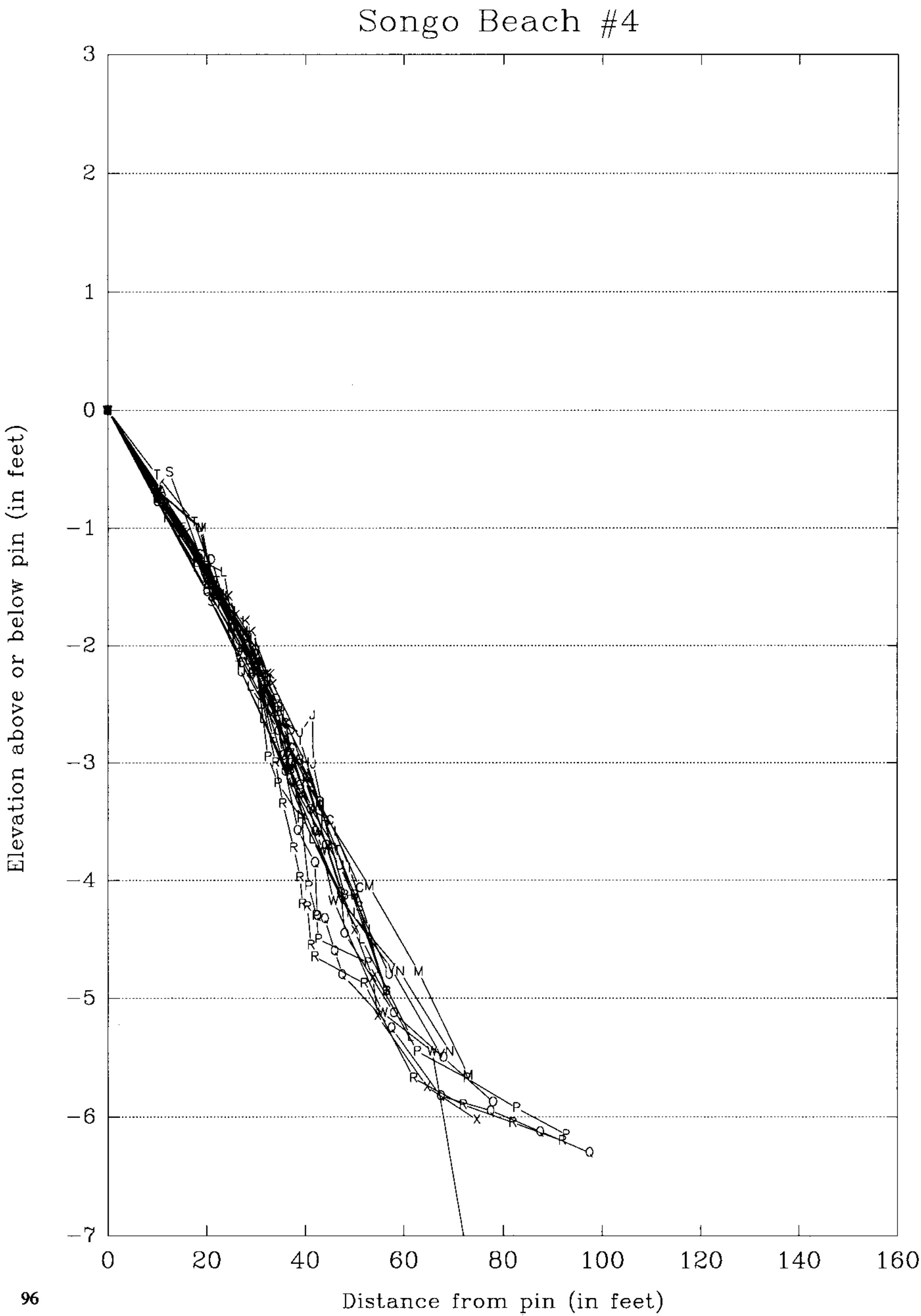


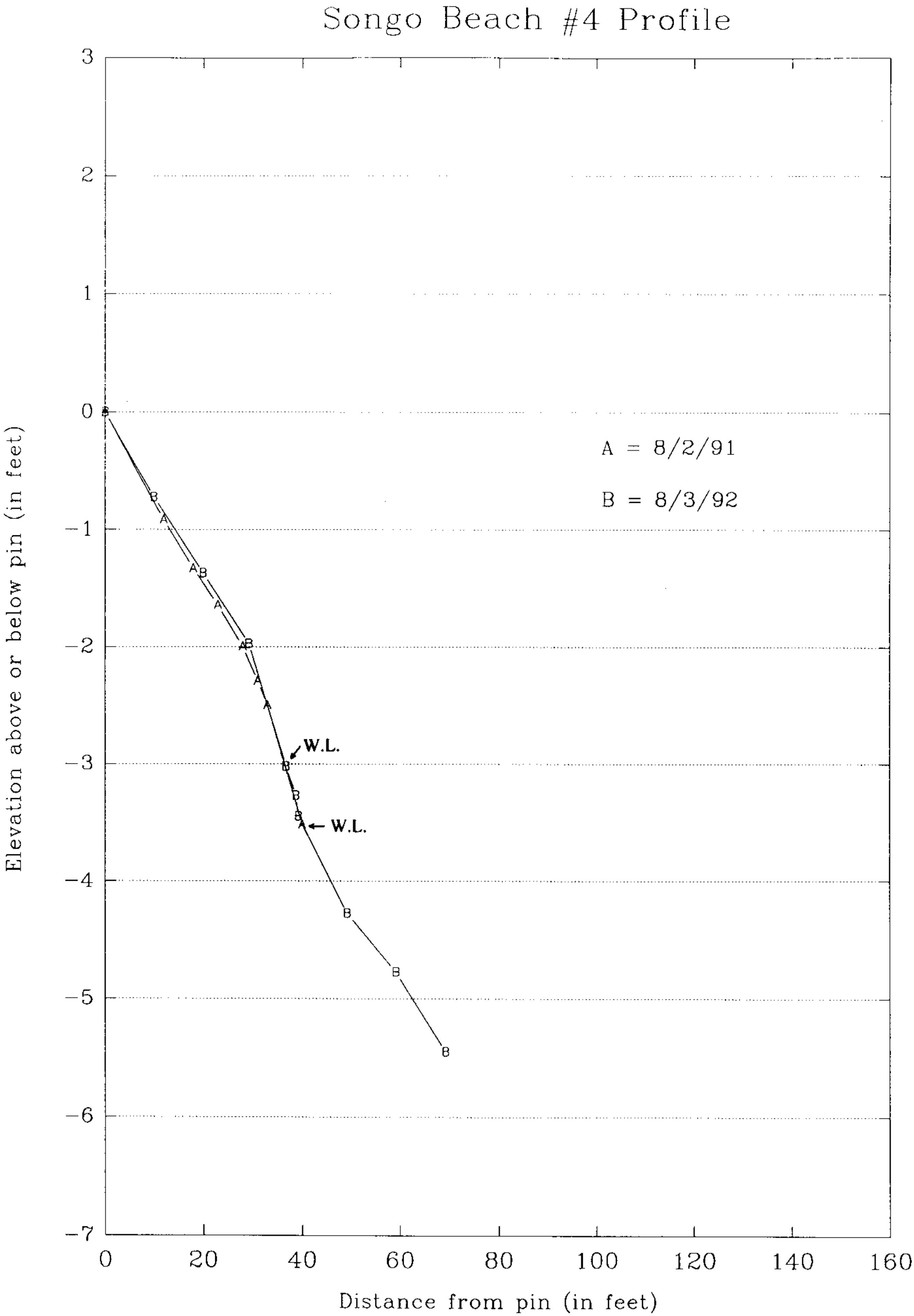
Songo Beach #3 Profile
Spring 1993
Q = 5/4/93
R = 6/3/93
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

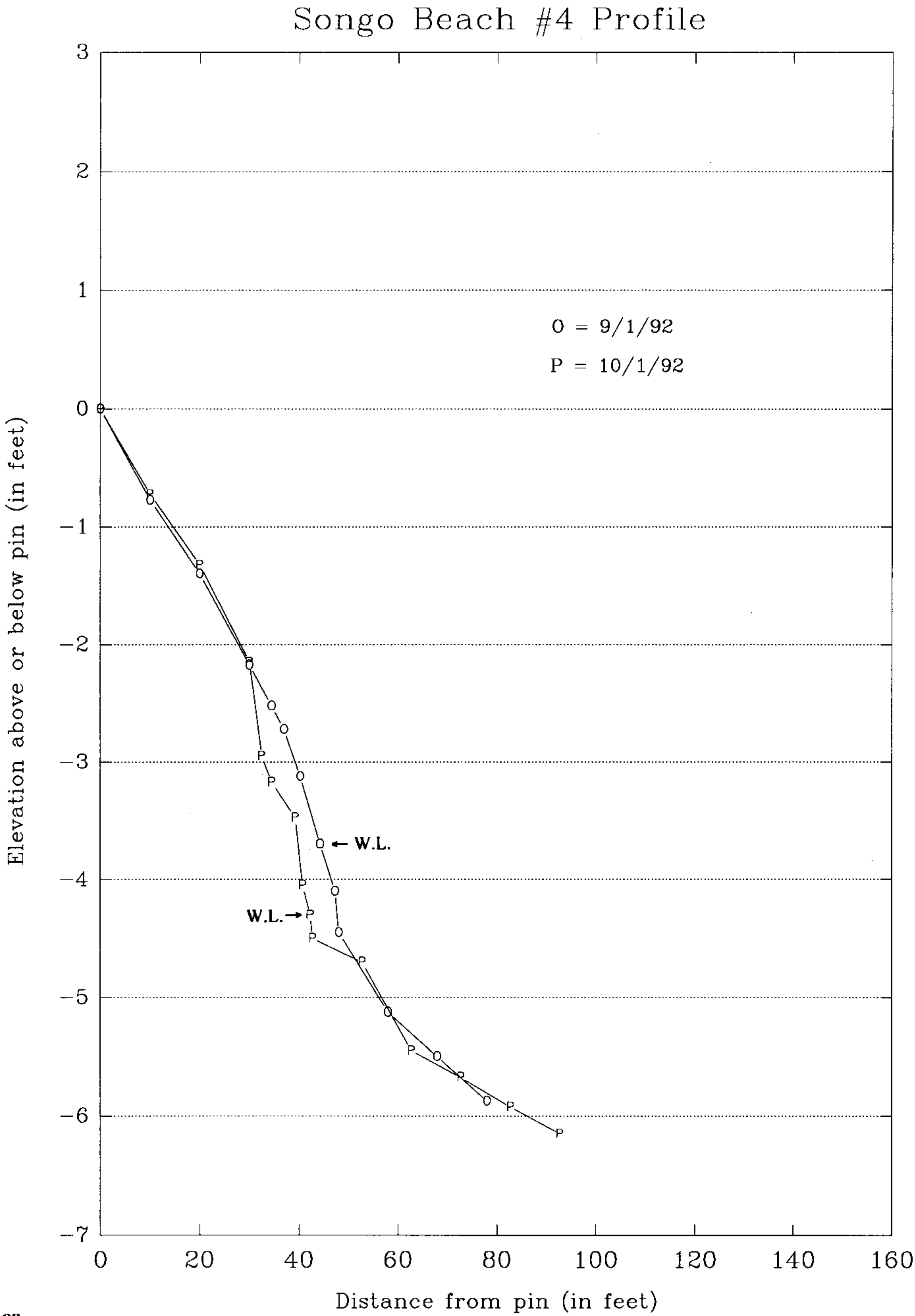

Songo Beach #3 Profile
Summer 1993
S = 7/1/93
T = 8/4/93
U = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160
Distance from pin (in feet)



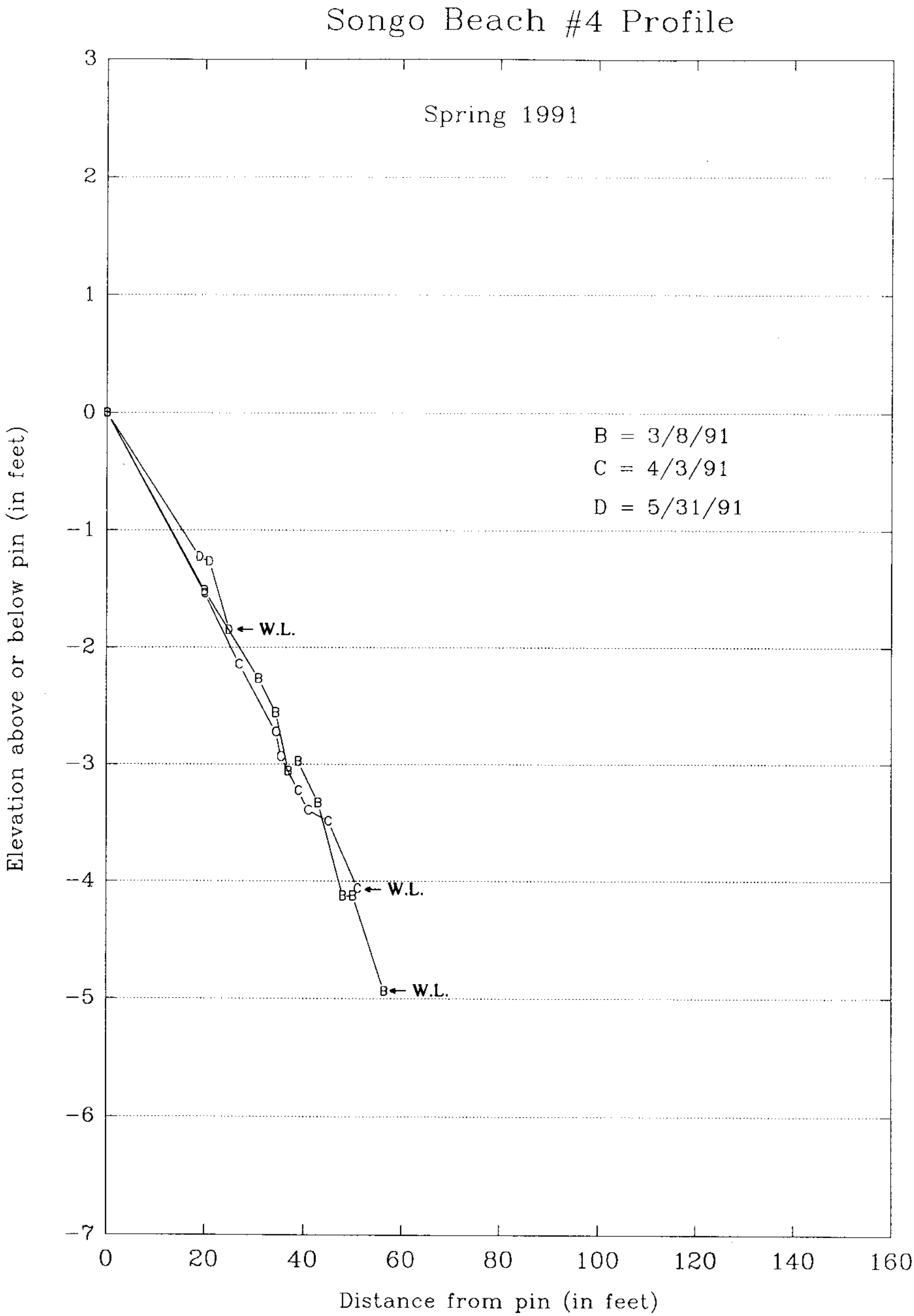
Songo Beach #3 Profile
Fall 1993
V = 10/4/93
← W.L.
Elevation above or below pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160
Distance from pin (in feet)

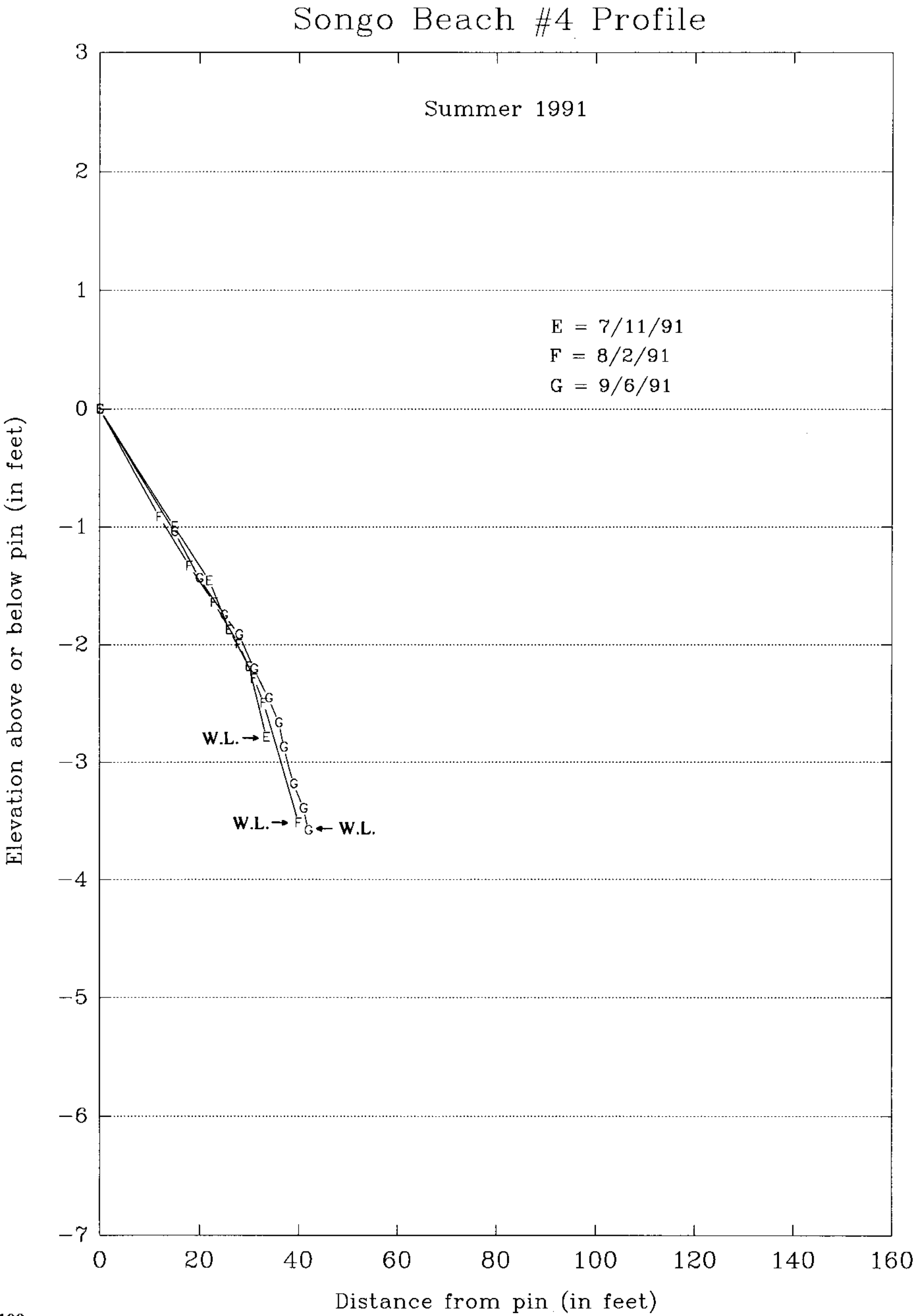

Songo Beach #4
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160


Songo Beach #4 Profile
A = 8/2/91
B = 8/3/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160



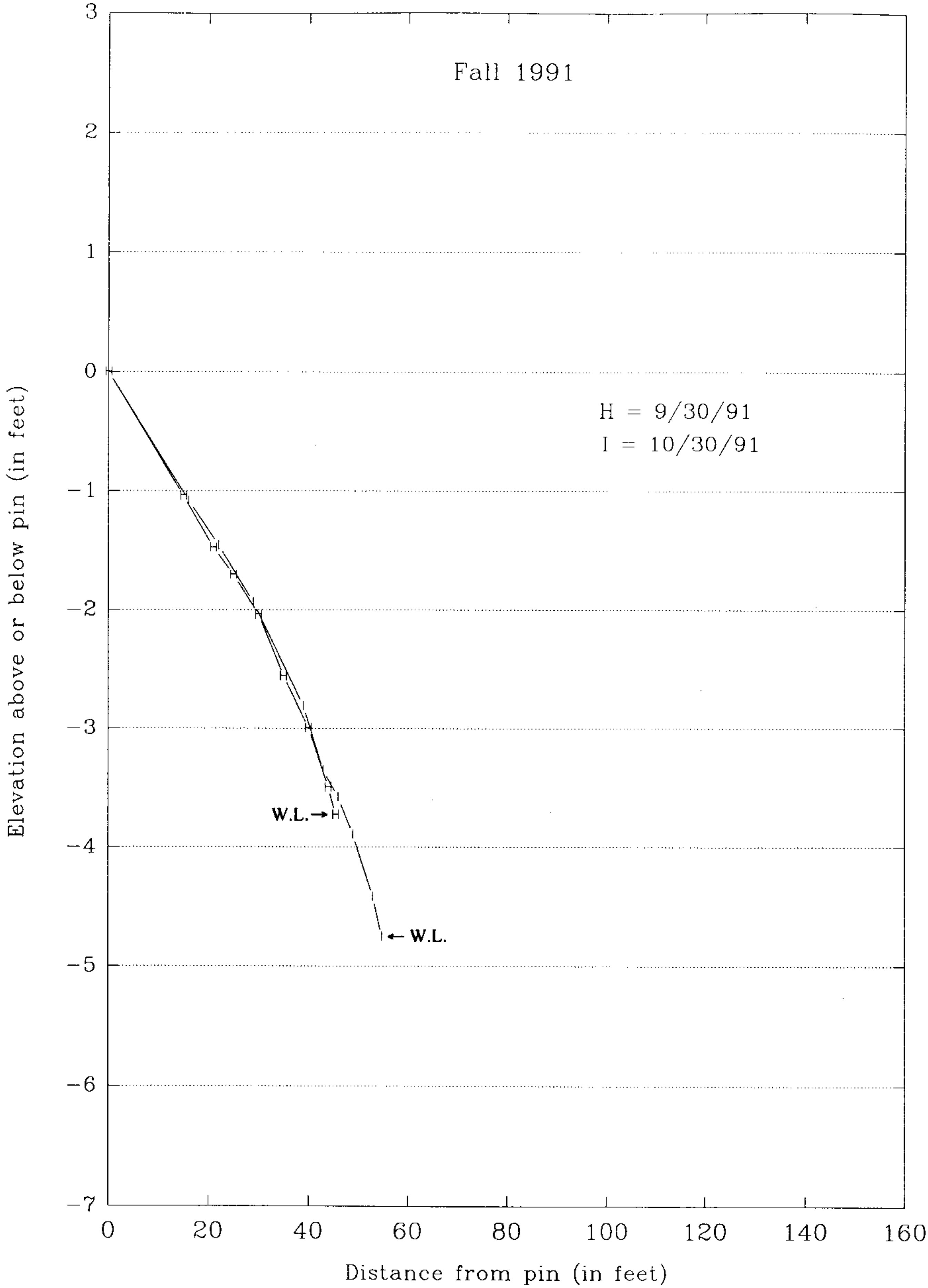
Songo Beach #4 Profile
O = 9/1/92
P = 10/1/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

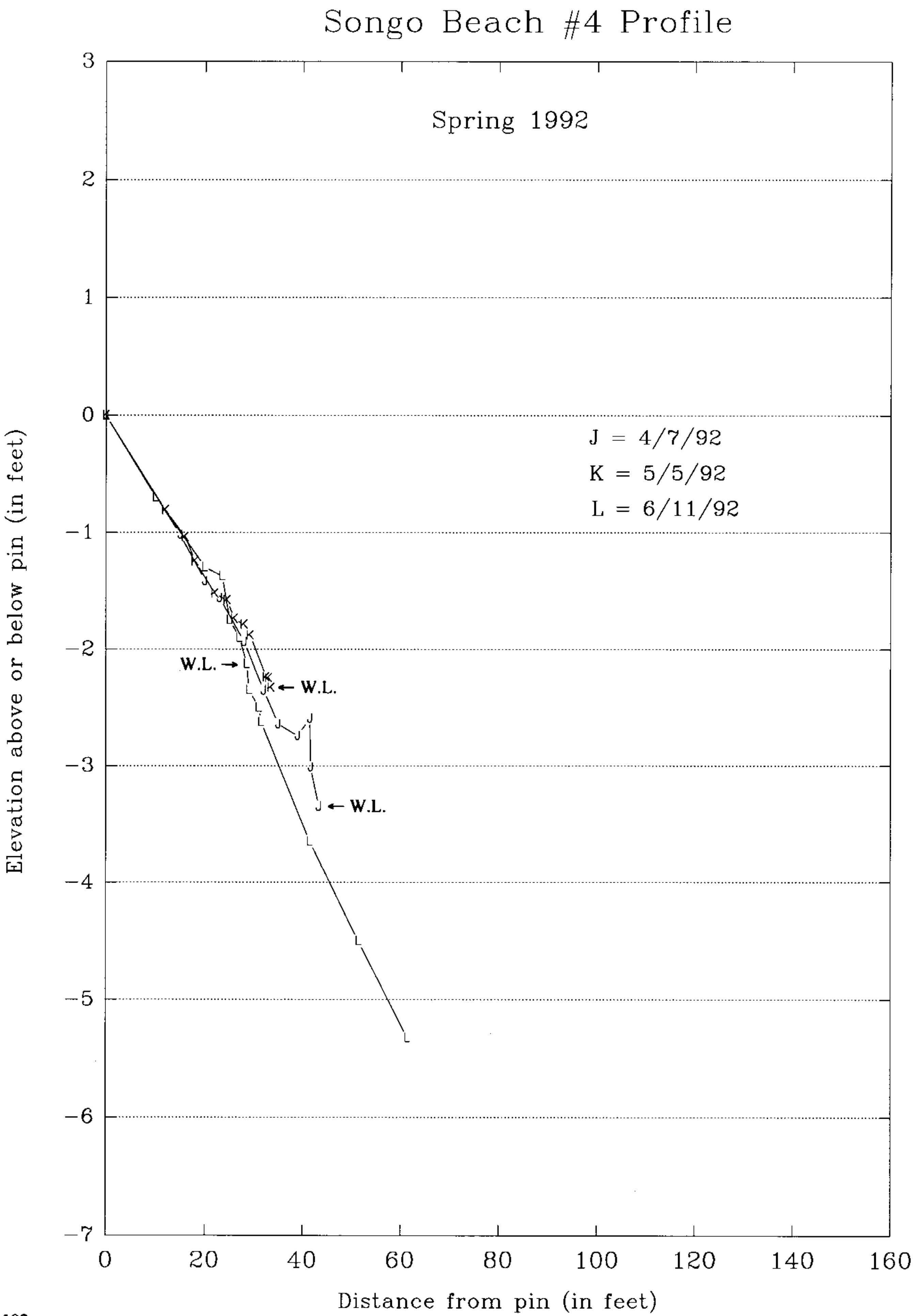

Songo Beach #4 Profile
Spring 1991
B = 3/8/91
C = 4/3/91
D = 5/31/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

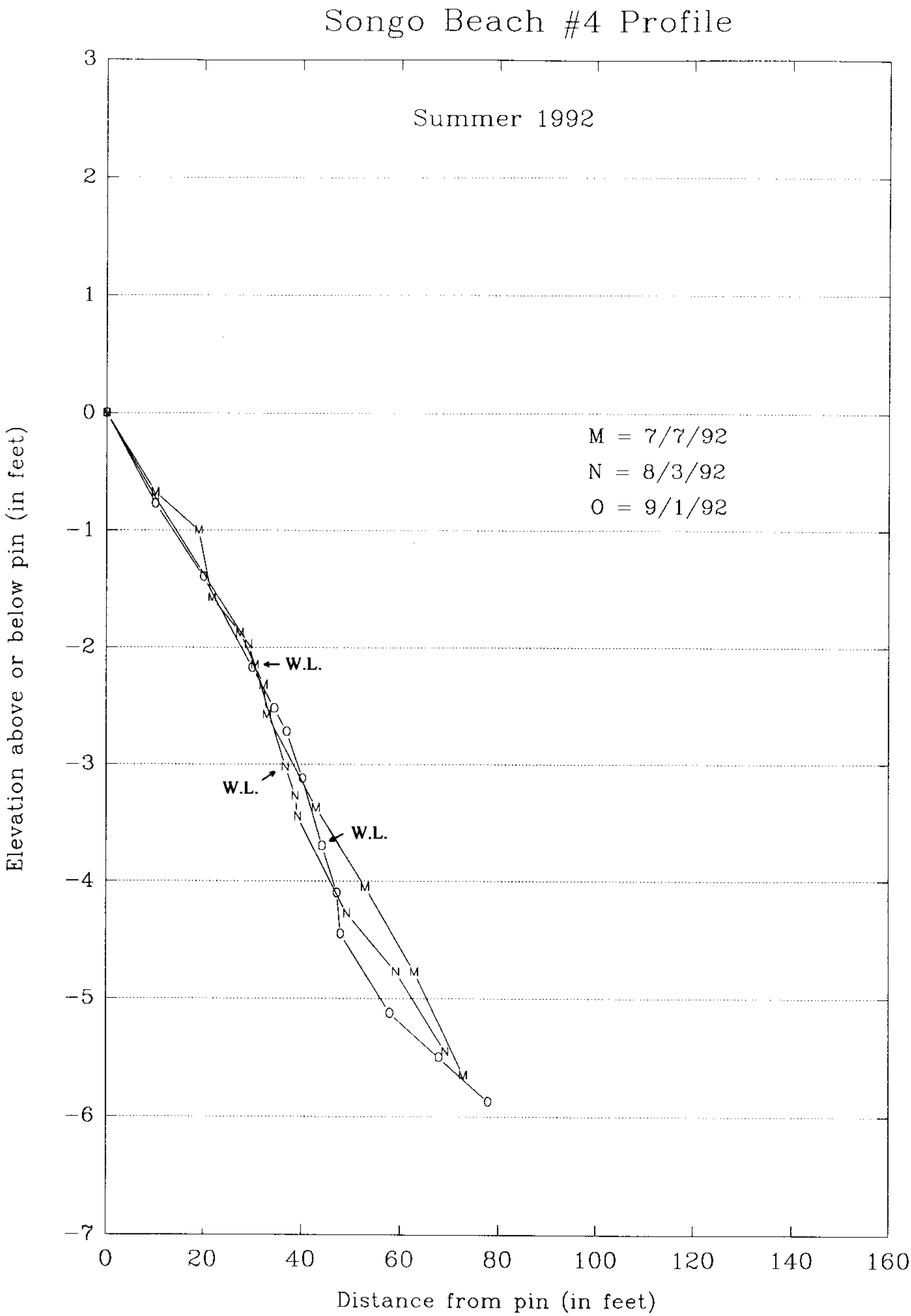


Songo Beach #4 Profile
Summer 1991
E = 7/11/91
F = 8/2/91
G = 9/6/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

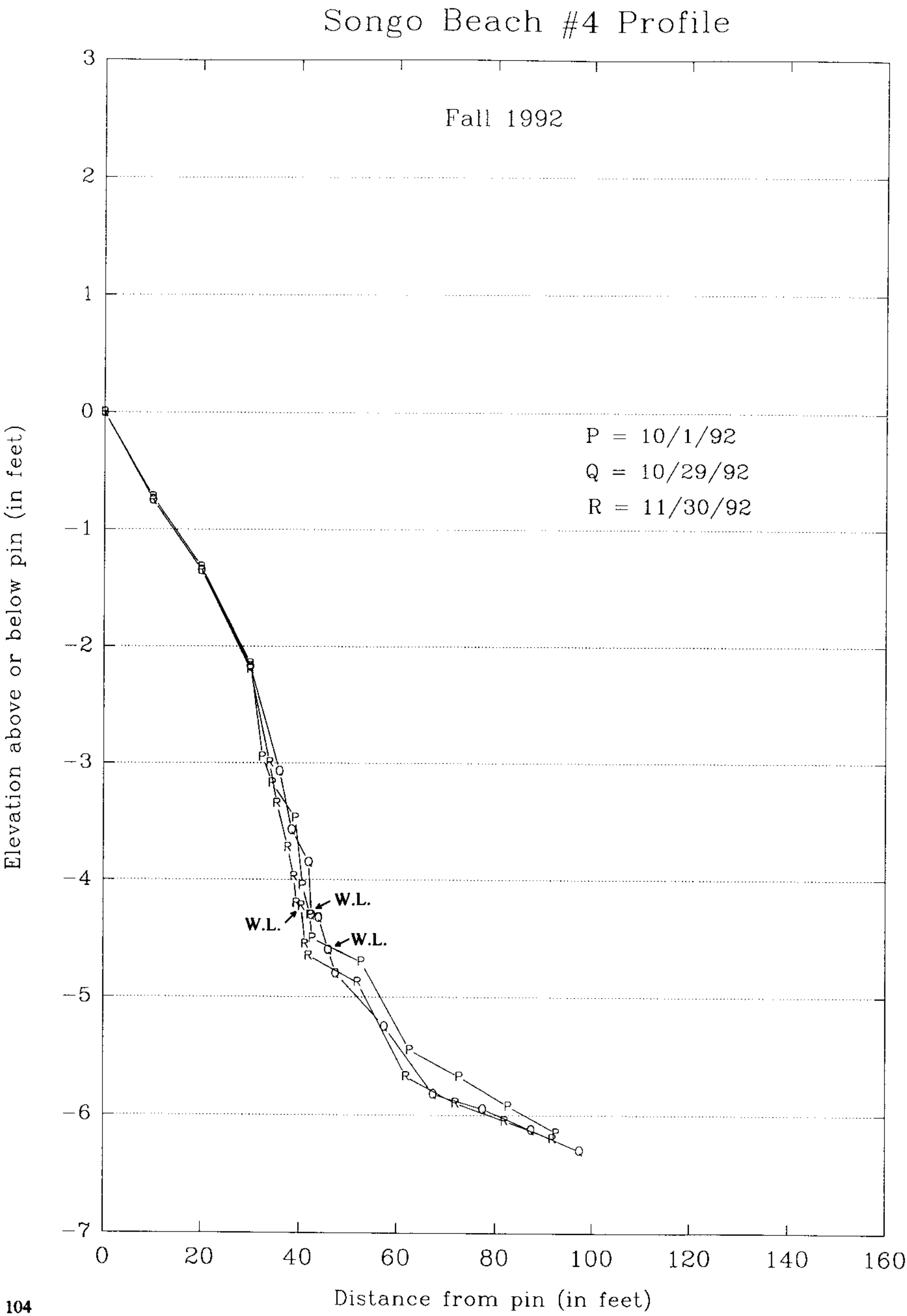
Songo Beach #4 Profile




Songo Beach #4 Profile
Spring 1992
J = 4/7/92
K = 5/5/92
L = 6/11/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

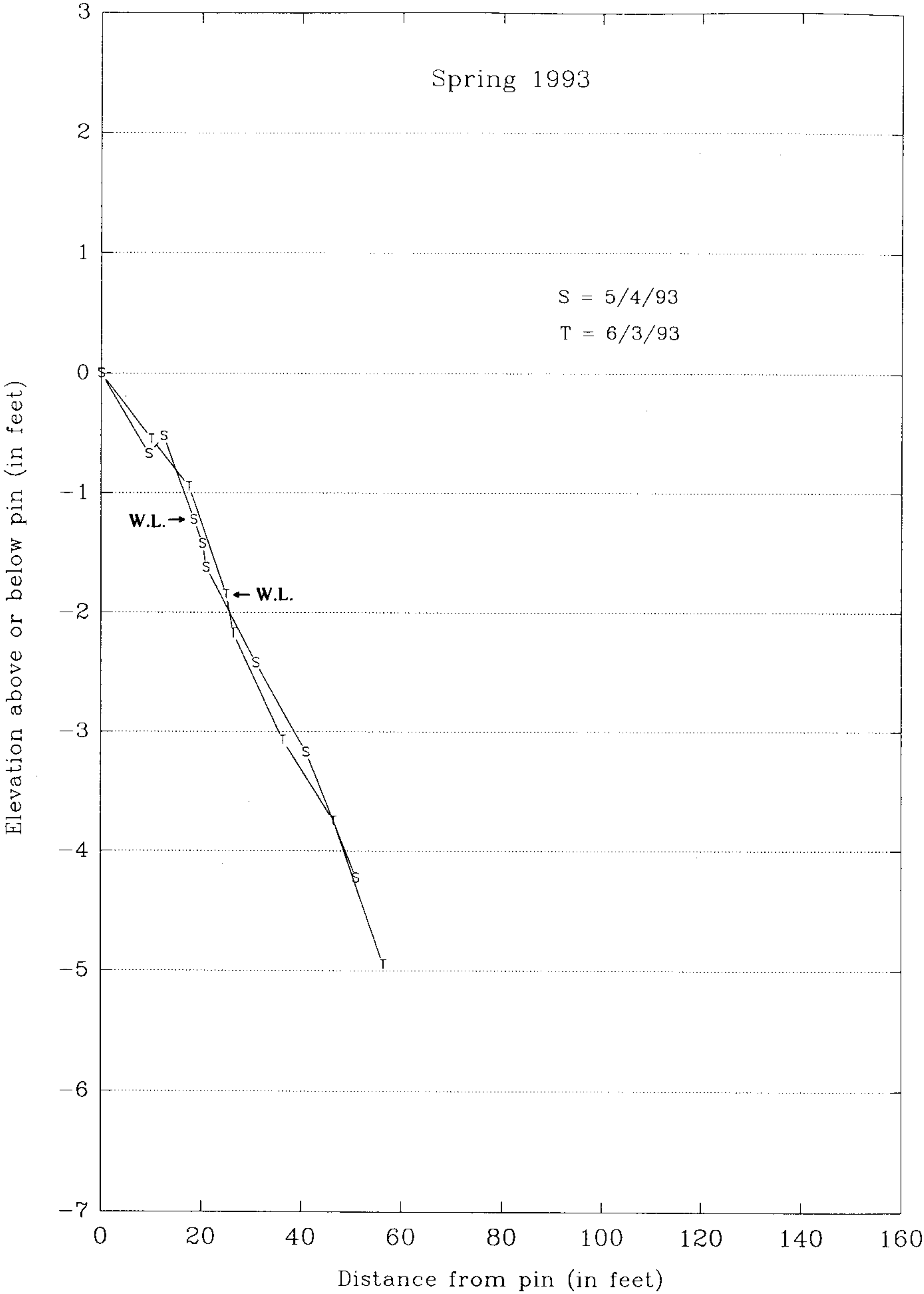


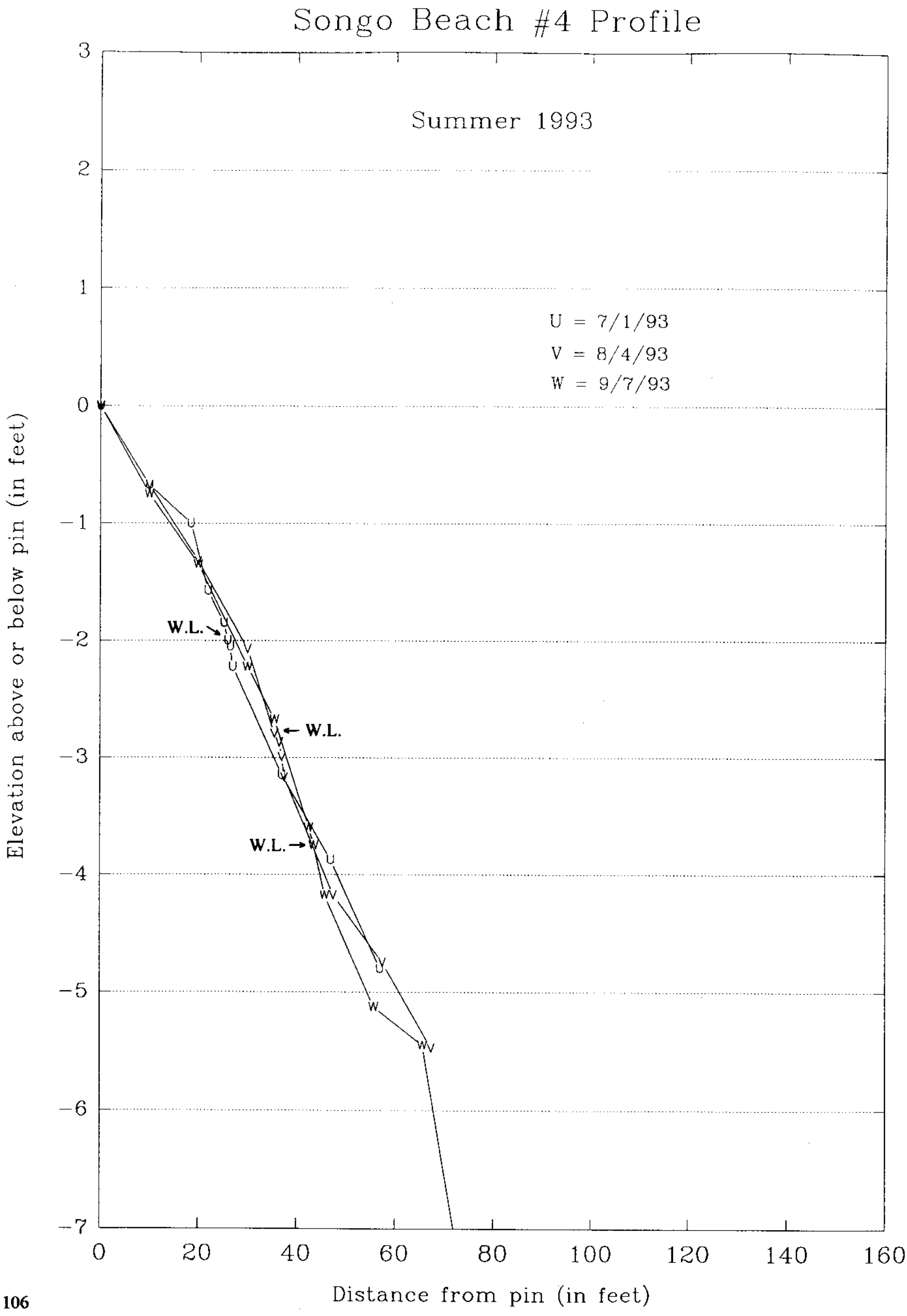
Songo Beach #4 Profile
Summer 1992
M = 7/7/92
N = 8/3/92
O = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
0
20
40
60
80
100
120
140
160



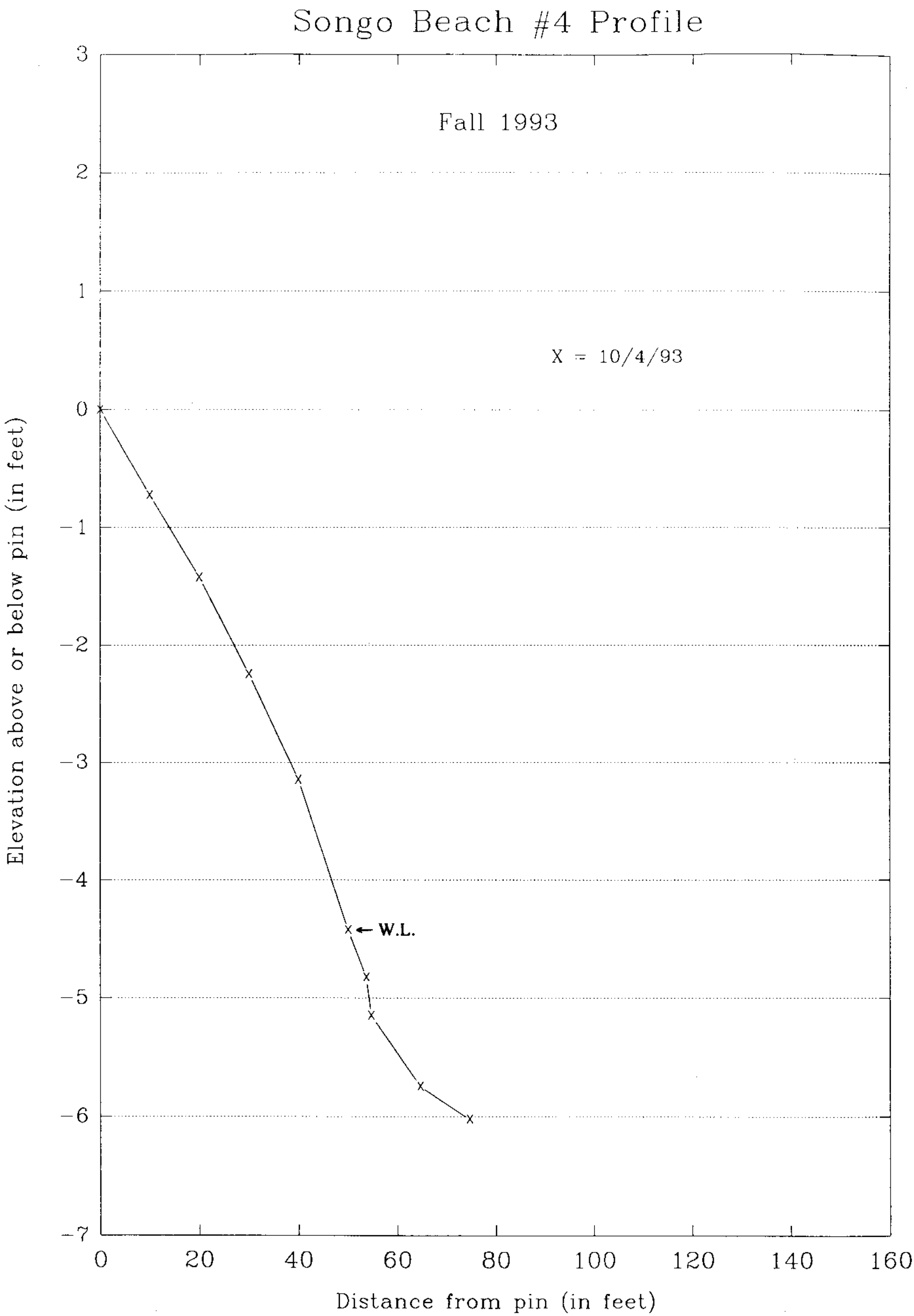
Songo Beach #4 Profile
Fall 1992
P = 10/1/92
Q = 10/29/92
R = 11/30/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

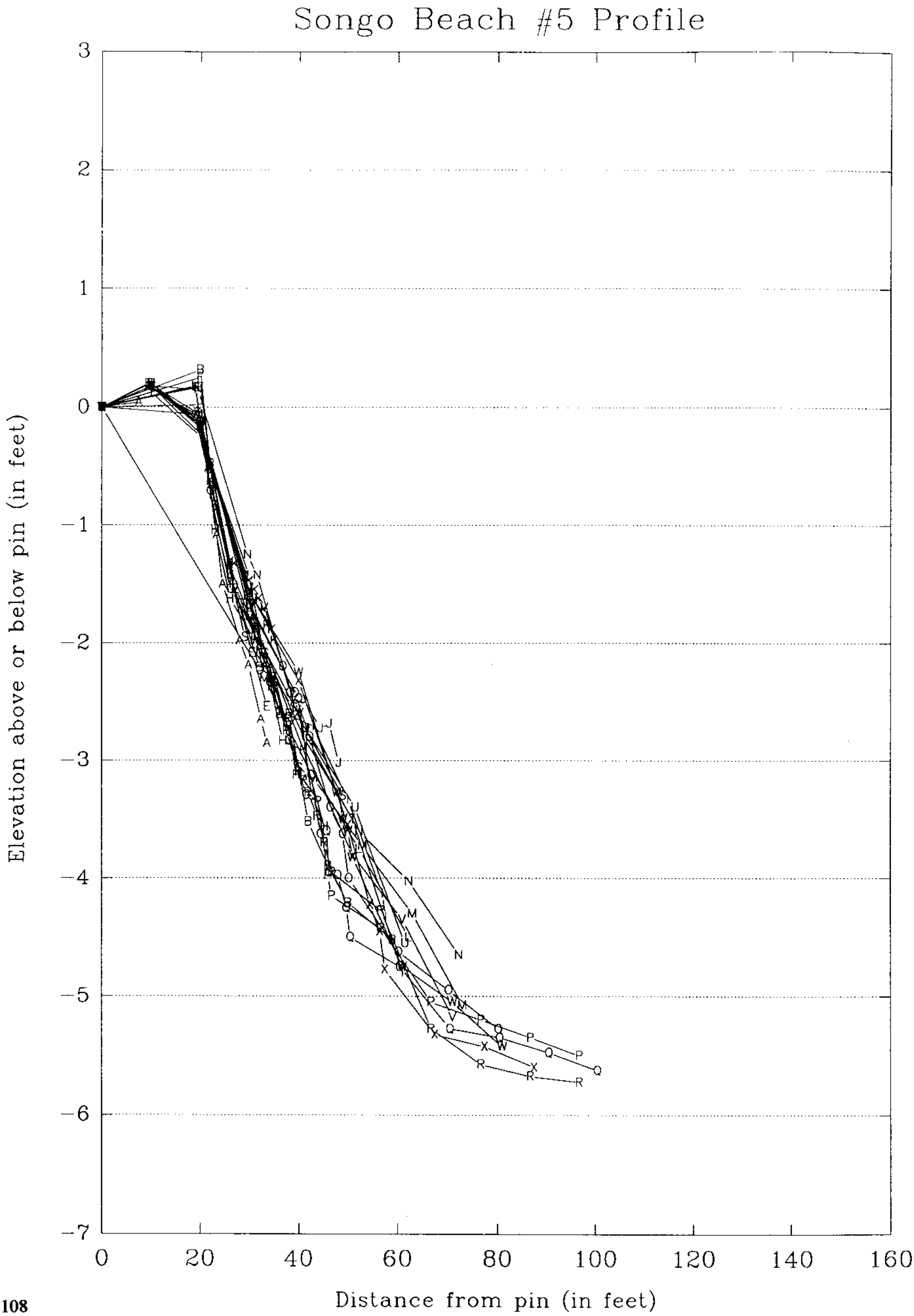
Songo Beach #4 Profile



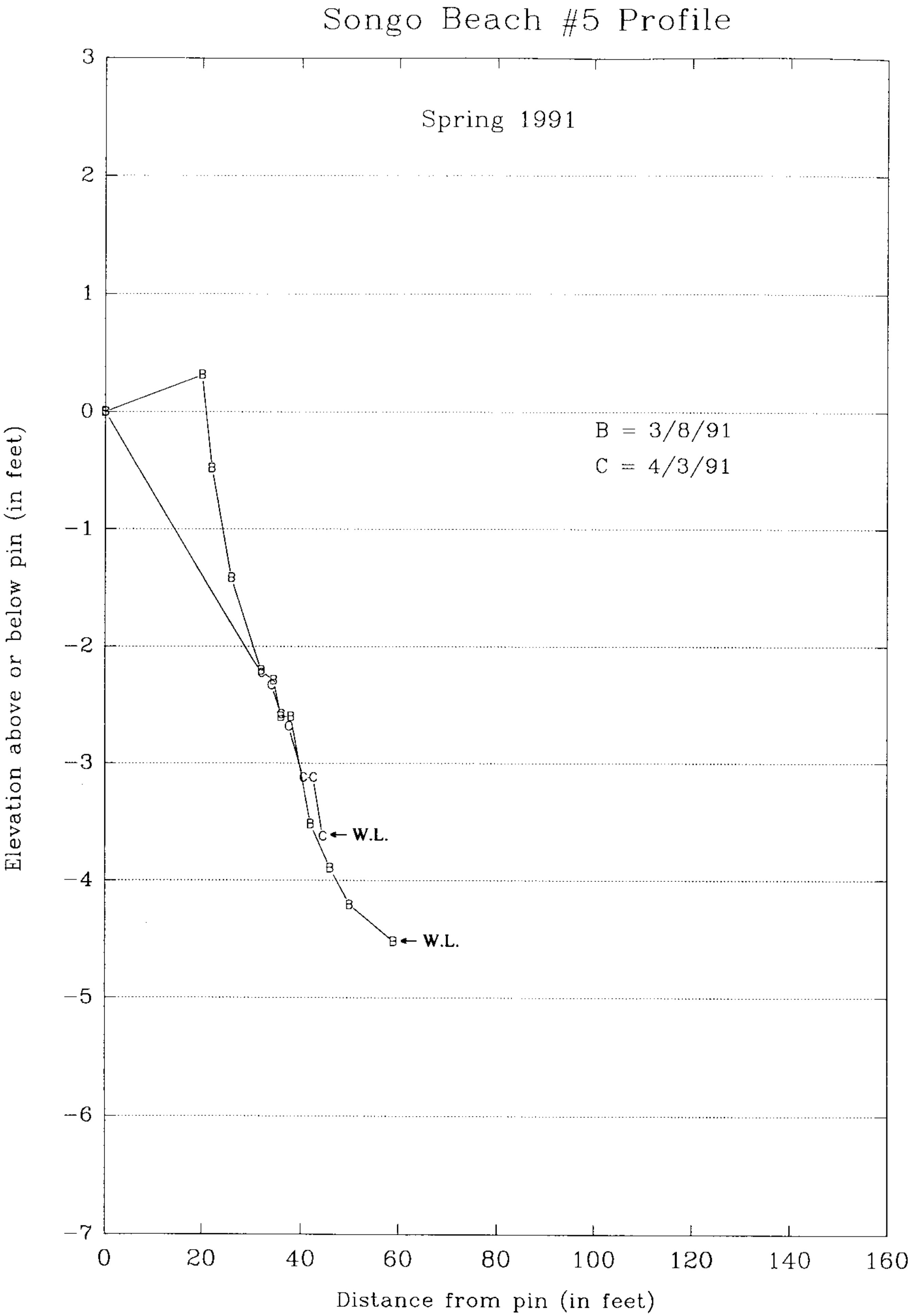


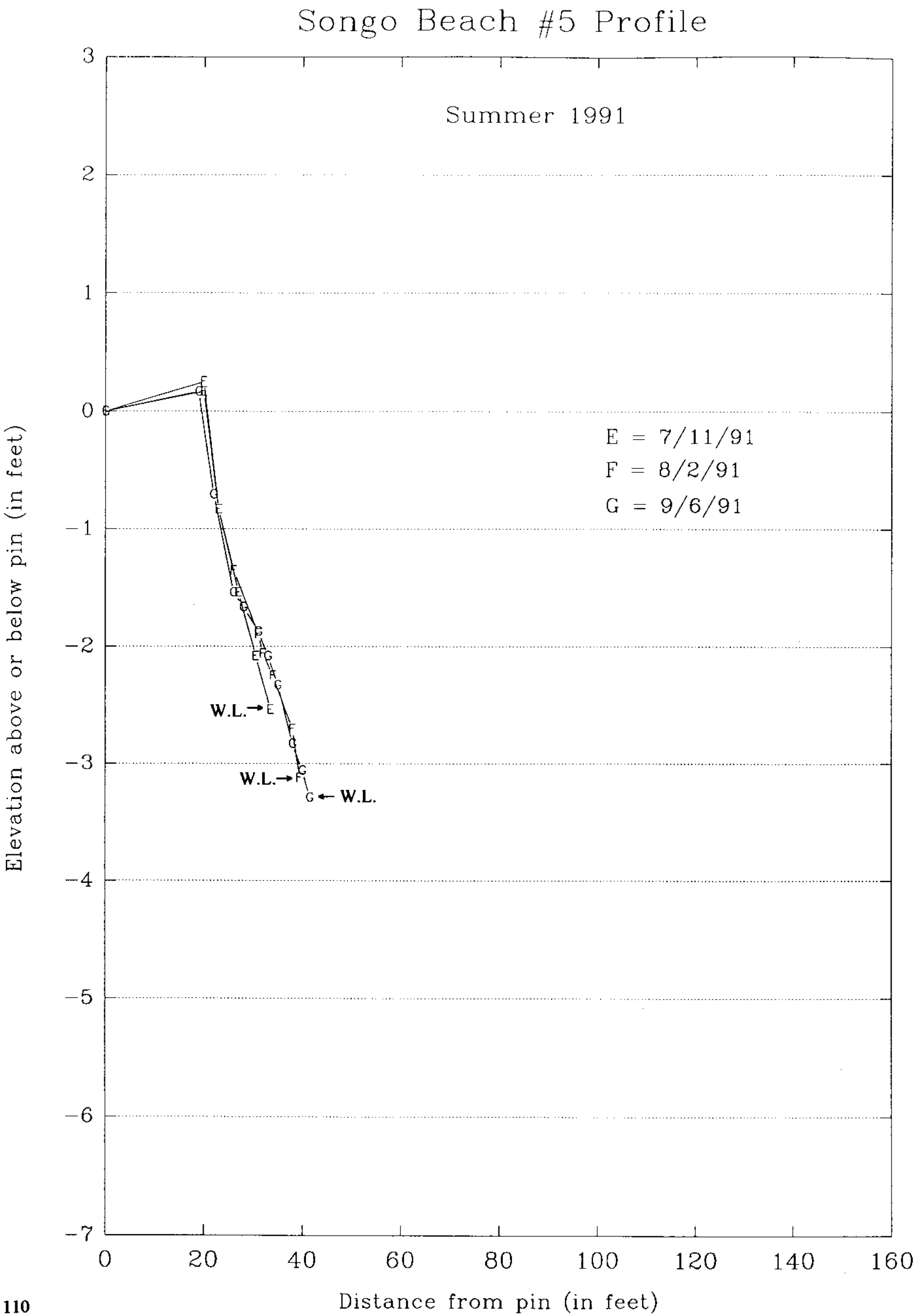
Songo Beach #4 Profile
Summer 1993
U = 7/1/93
V = 8/4/93
W = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

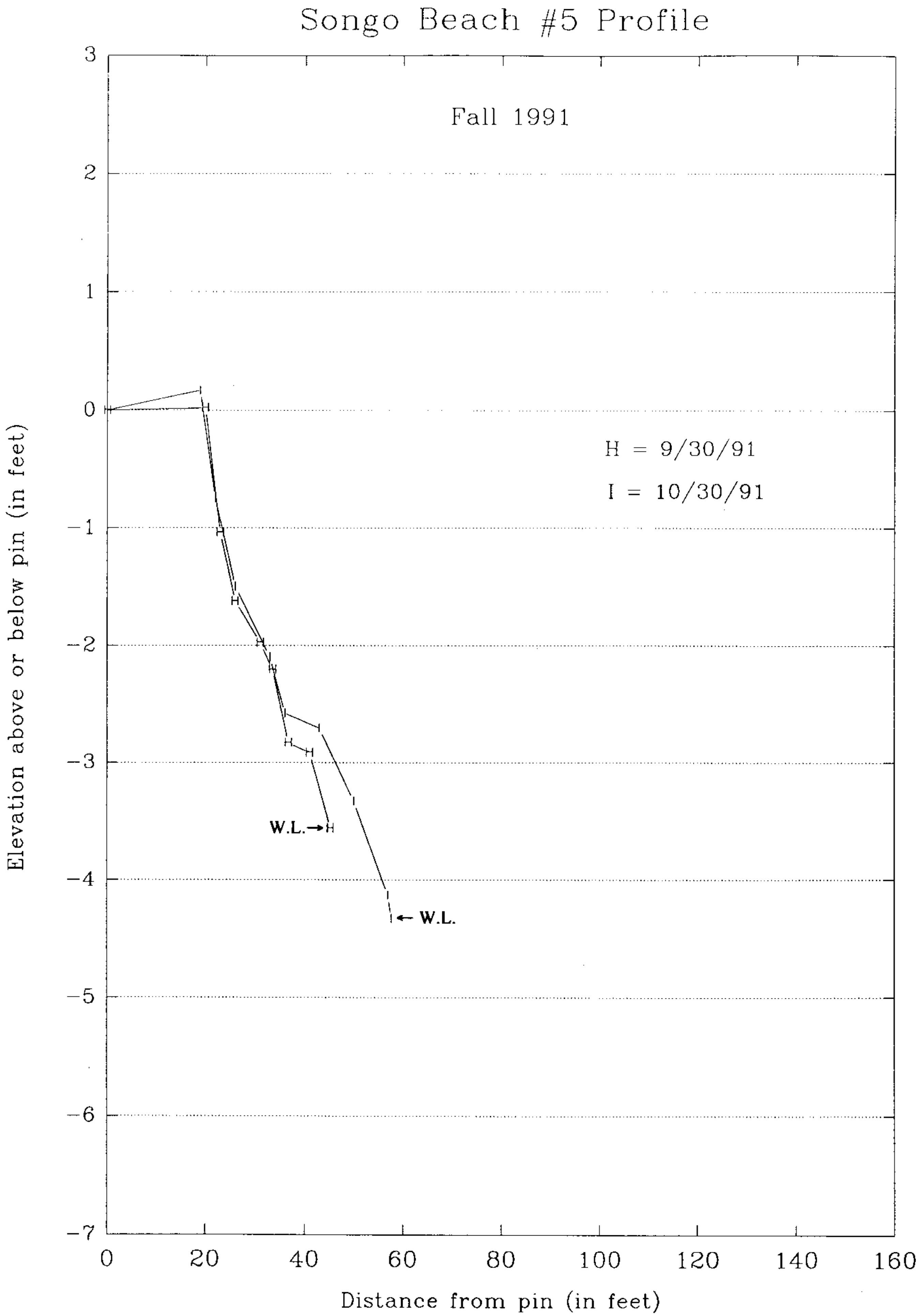

Songo Beach #4 Profile
Fall 1993
X = 10/4/93
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
0
20
40
60
80
100
120
140
160

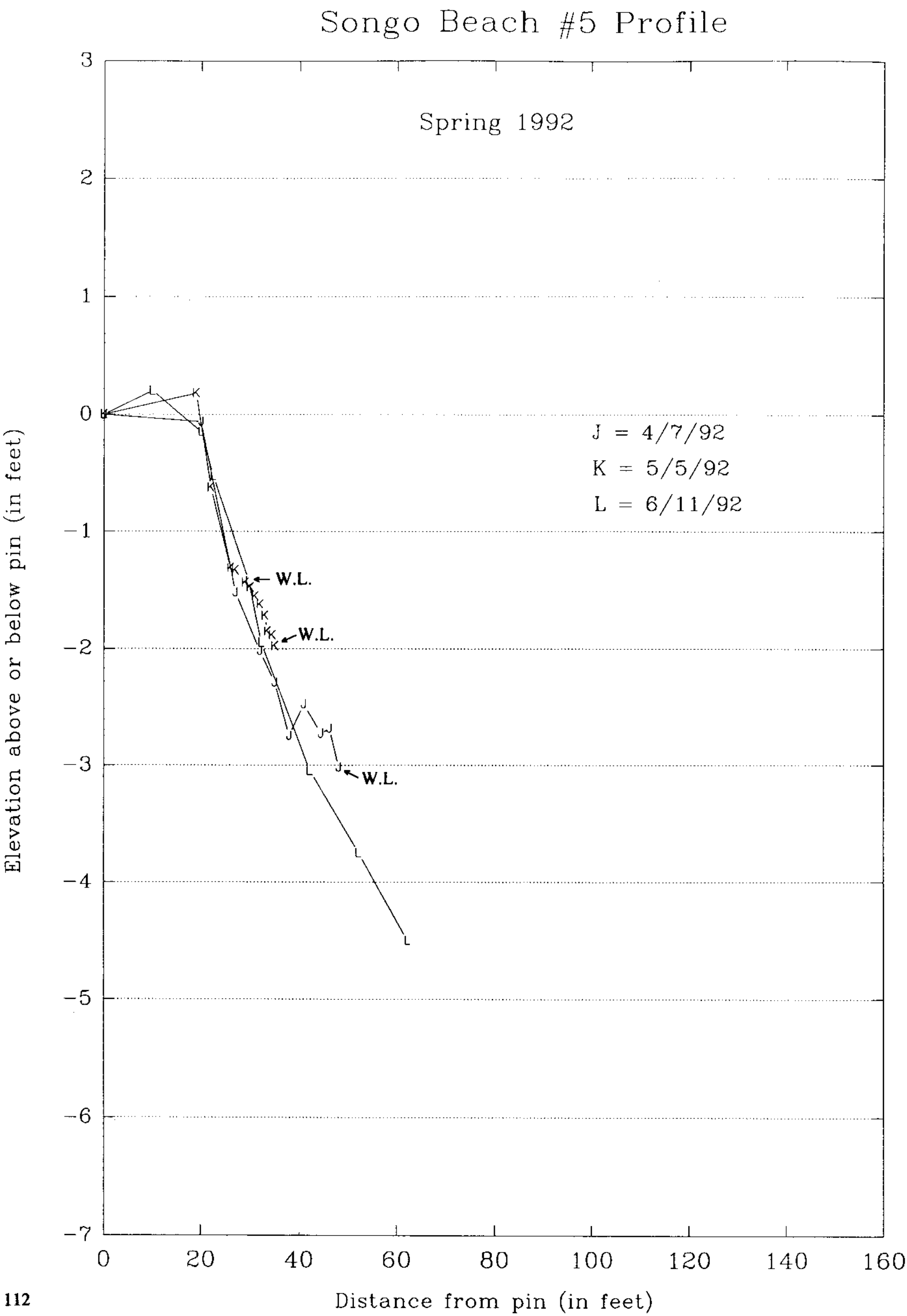


Songo Beach #5 Profile
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

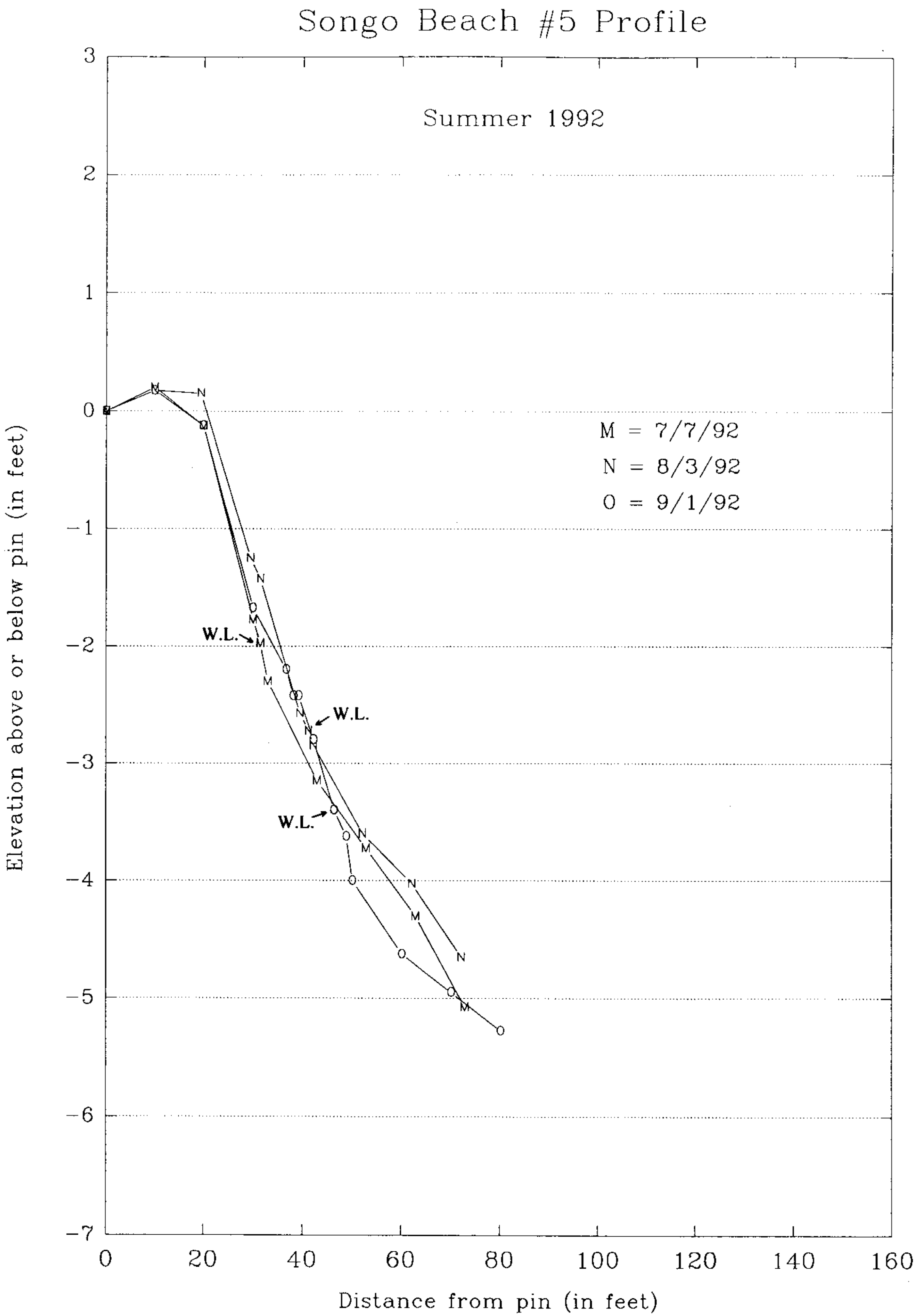

Songo Beach #5 Profile
Spring 1991
B = 3/8/91
C = 4/3/91
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160


Songo Beach #5 Profile
Summer 1991
E = 7/11/91
F = 8/2/91
G = 9/6/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

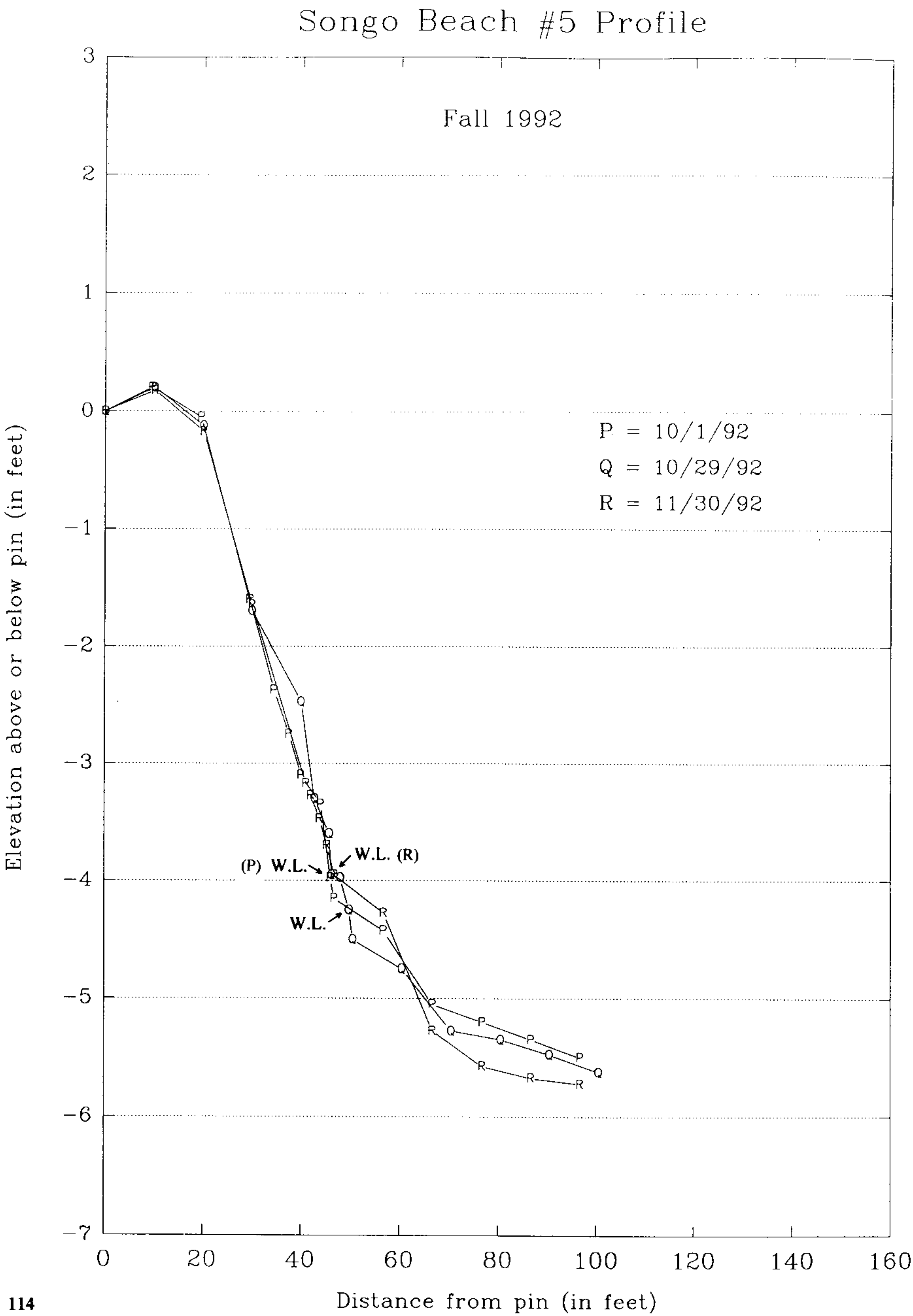

Songo Beach #5 Profile
Fall 1991
H = 9/30/91
I = 10/30/91
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160



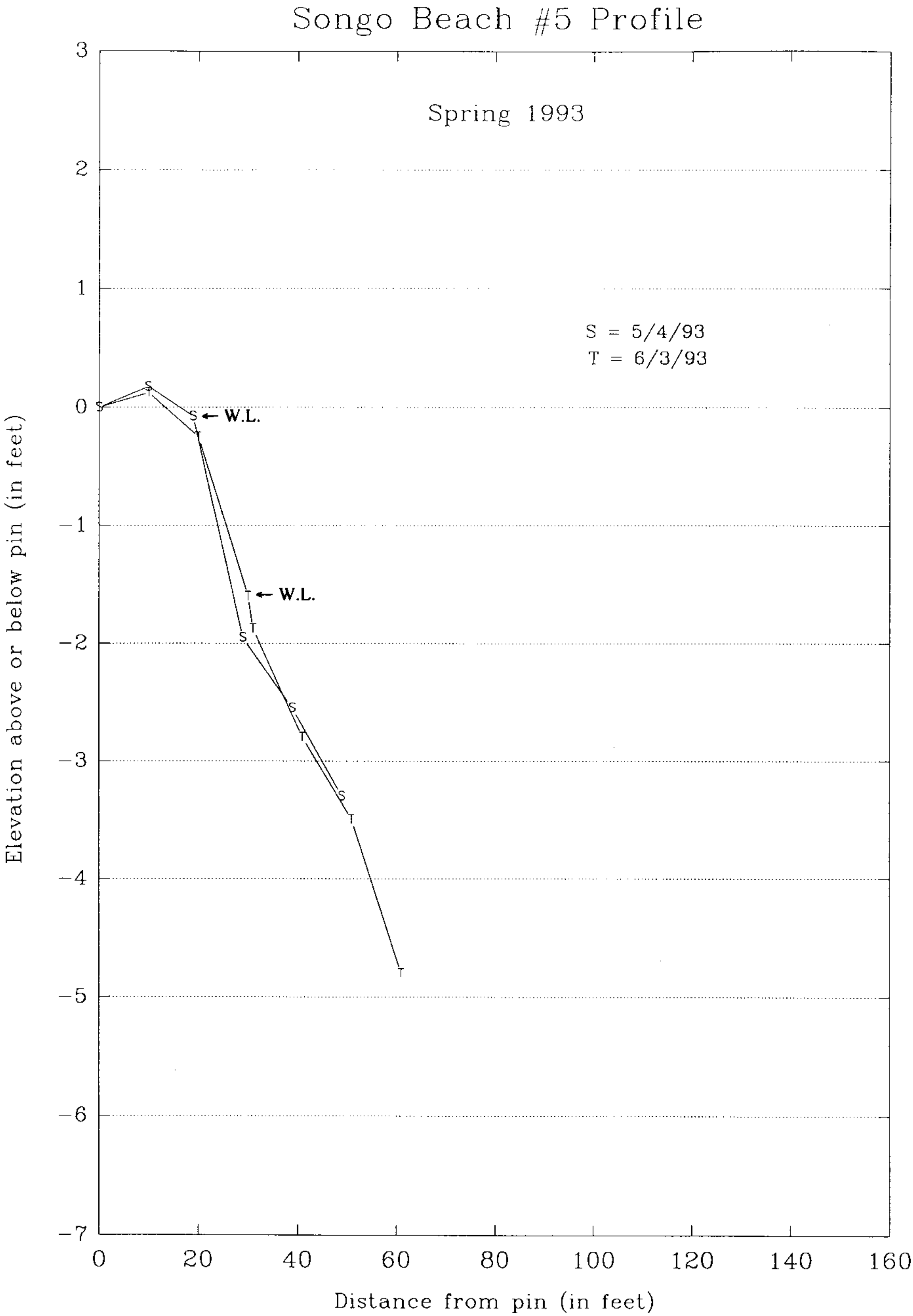
Songo Beach #5 Profile
Spring 1992
J = 4/7/92
K = 5/5/92
L = 6/11/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

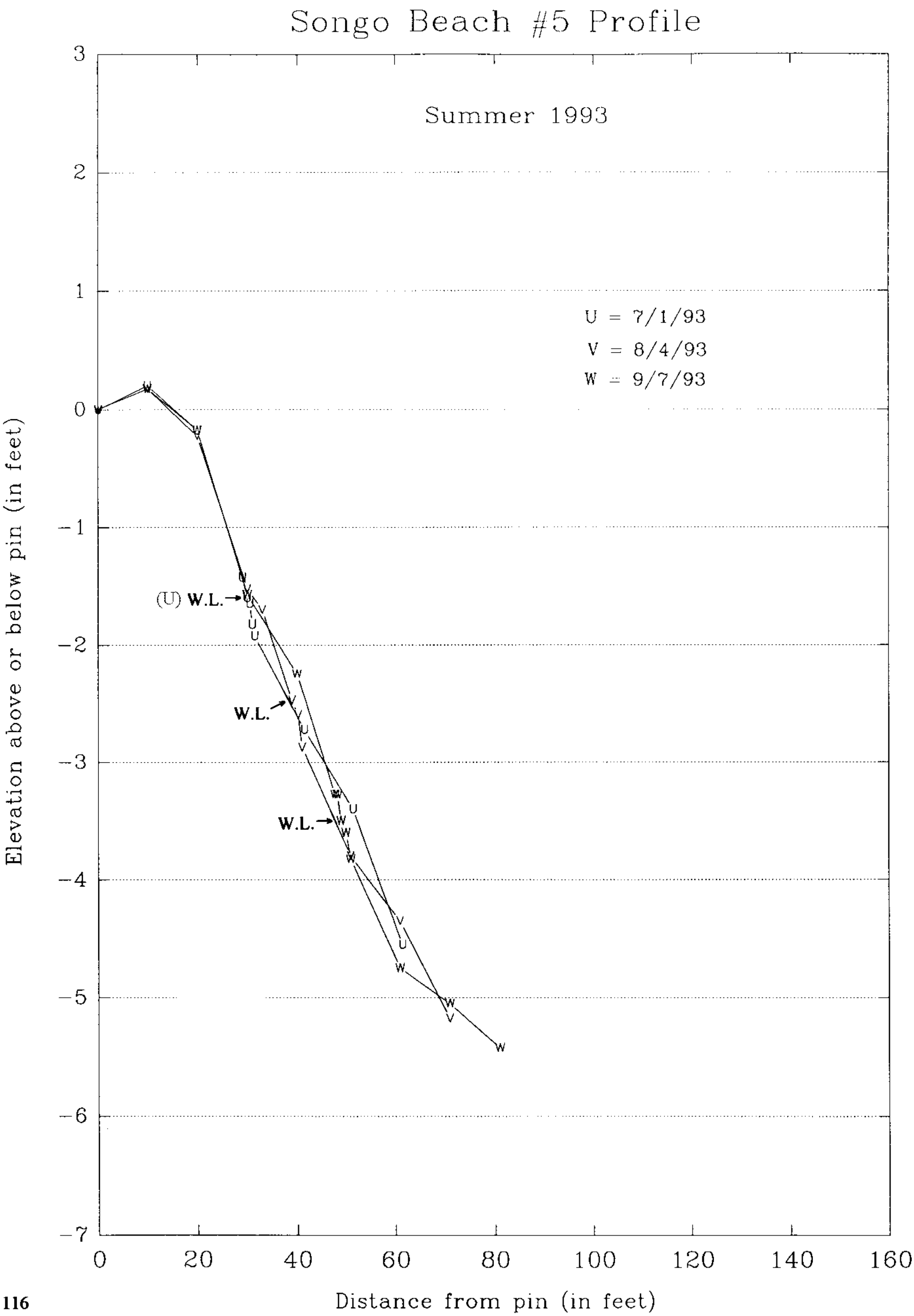


Songo Beach #5 Profile
Summer 1992
M = 7/7/92
N = 8/3/92
O = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

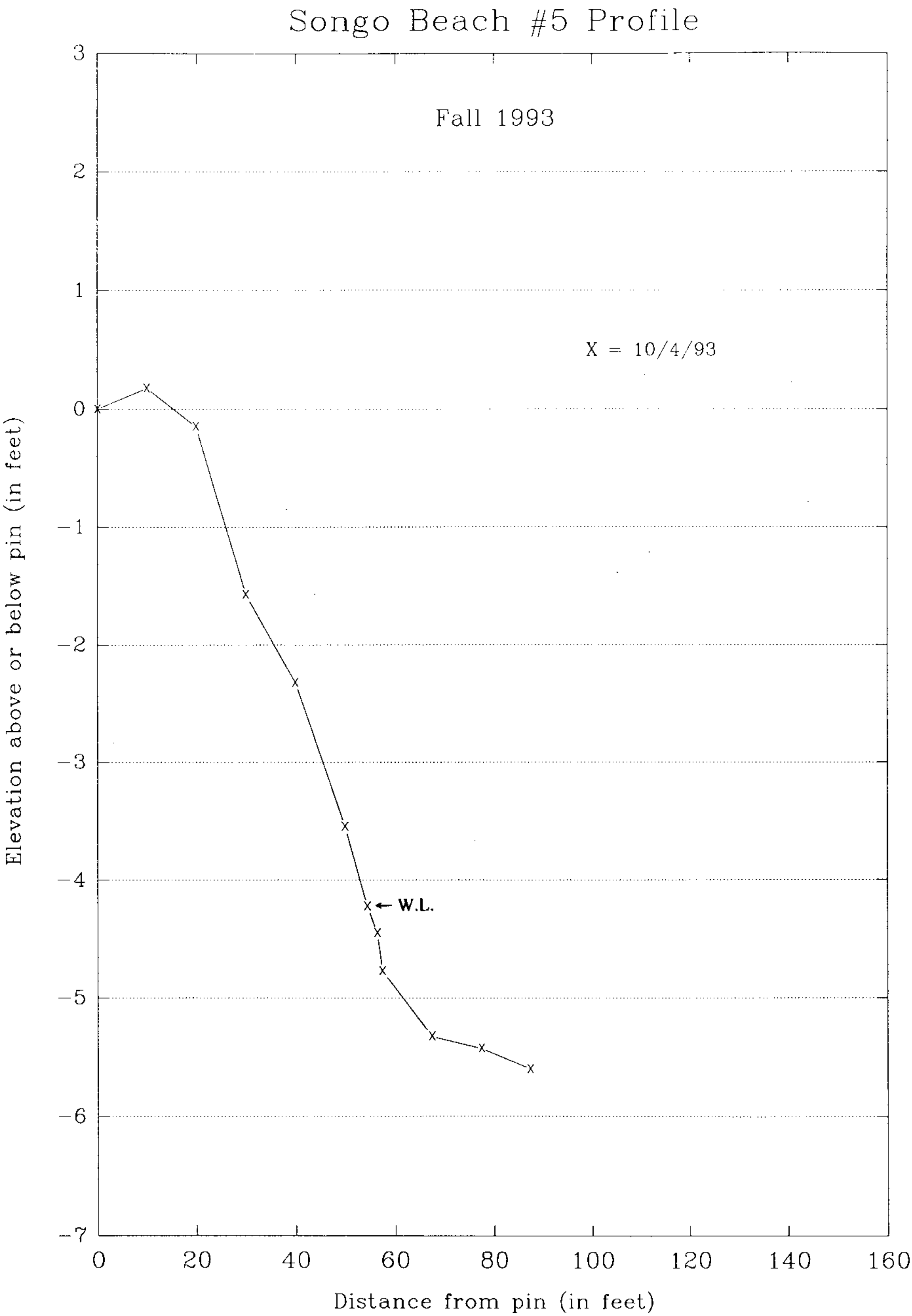


Songo Beach #5 Profile
Fall 1992
P = 10/1/92
Q = 10/29/92
R = 11/30/92
(P) W.L.
W.L. (R)
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
0
20
40
60
80
100
120
140
160


Songo Beach #5 Profile
Spring 1993
S = 5/4/93
T = 6/3/93
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

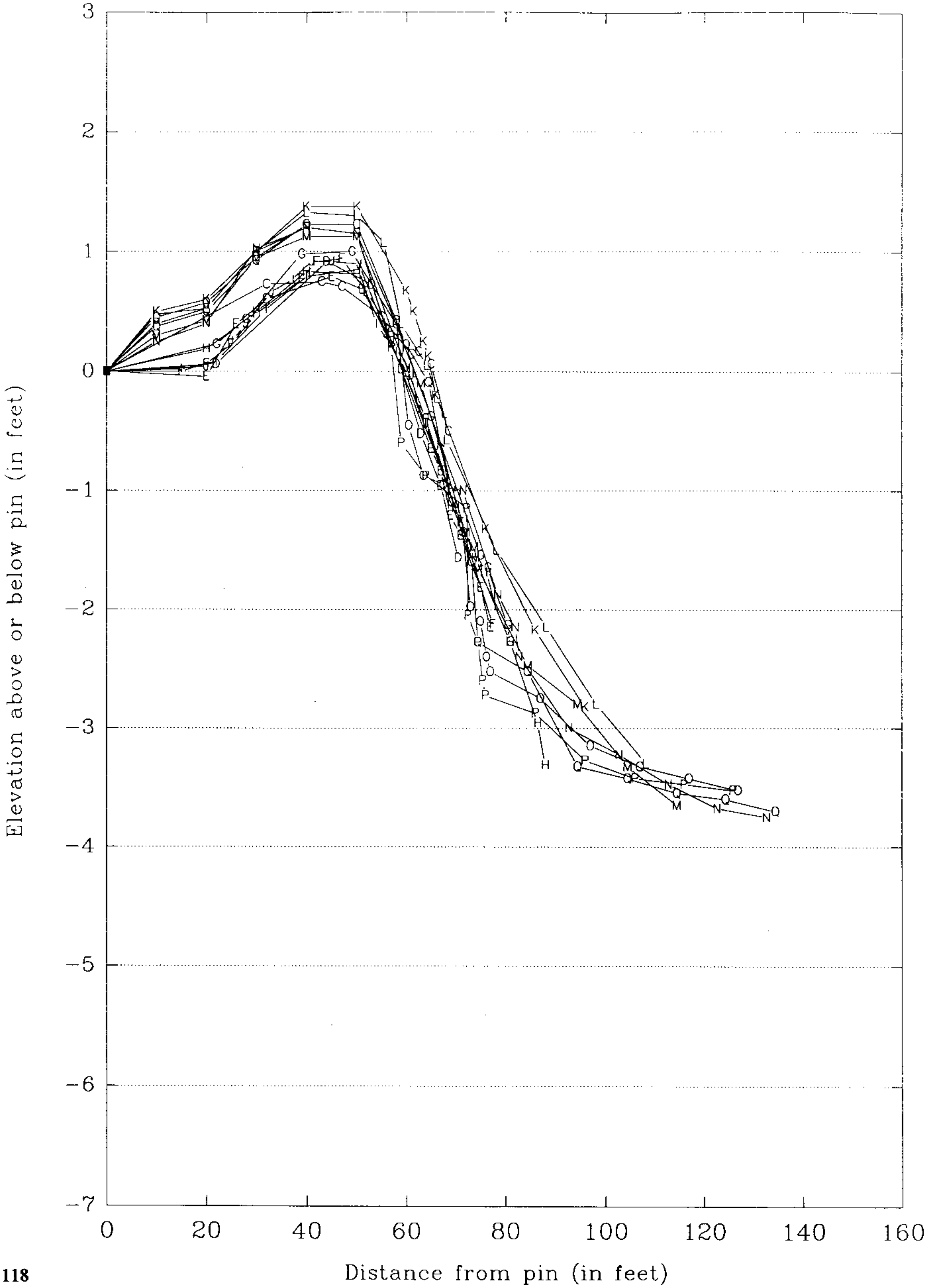


Songo Beach #5 Profile
Summer 1993
U = 7/1/93
V = 8/4/93
W = 9/7/93
(U) W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

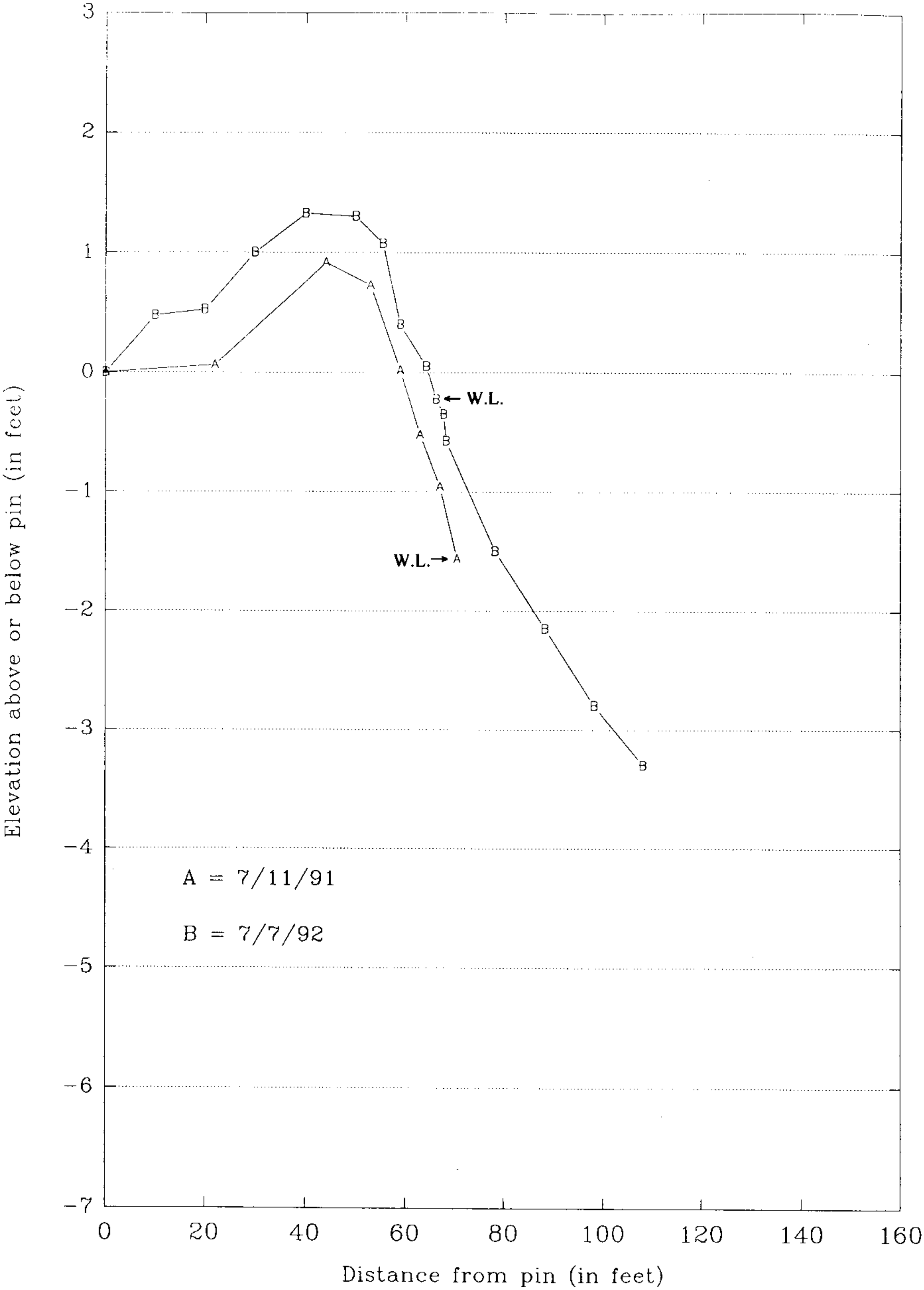


Songo Beach #5 Profile
Fall 1993
X = 10/4/93
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
0
20
40
60
80
100
120
140
160

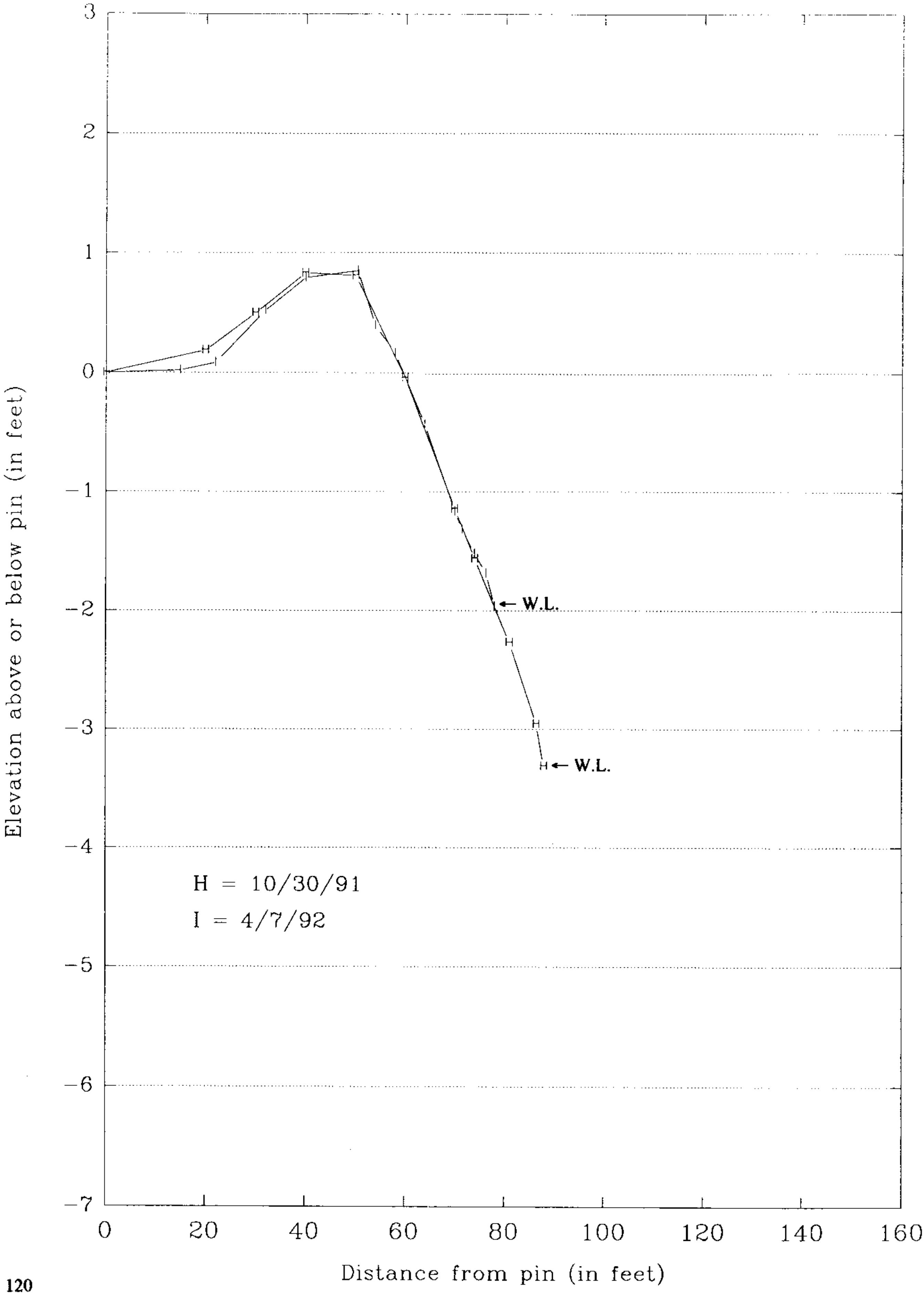
Songo Beach #6 Profile



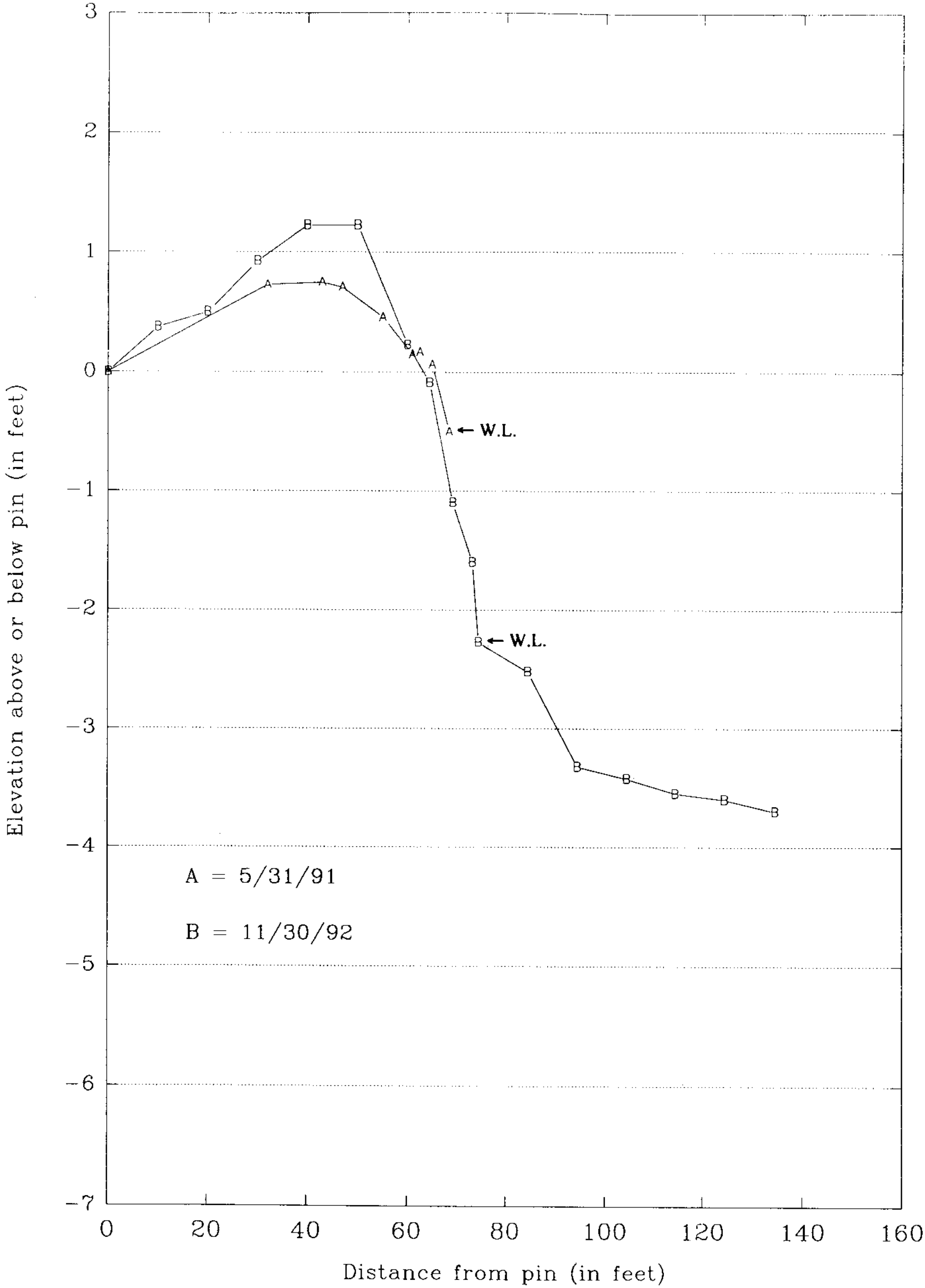
Songo Beach #6 Profile



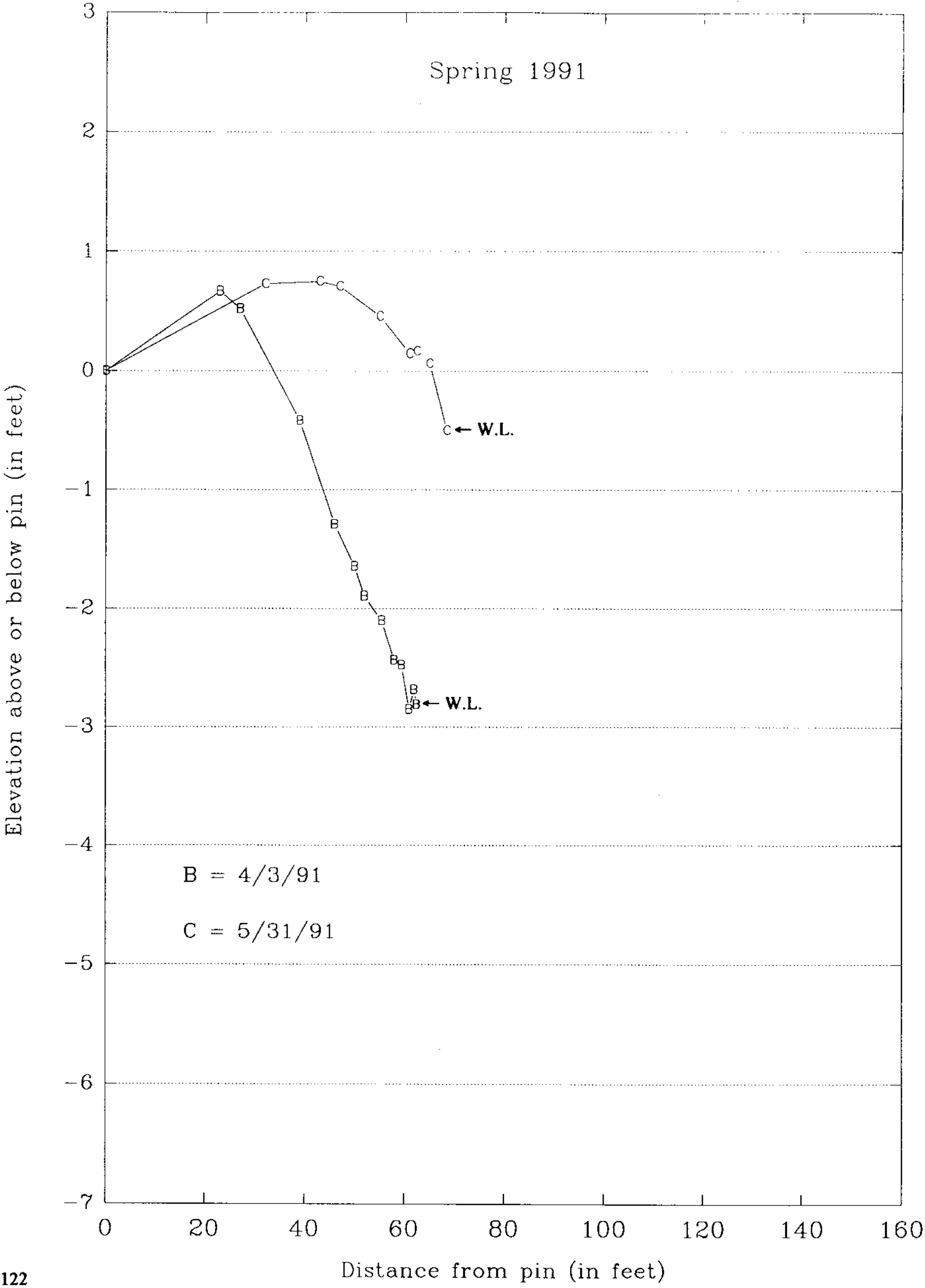
Songo Beach #6 Profile



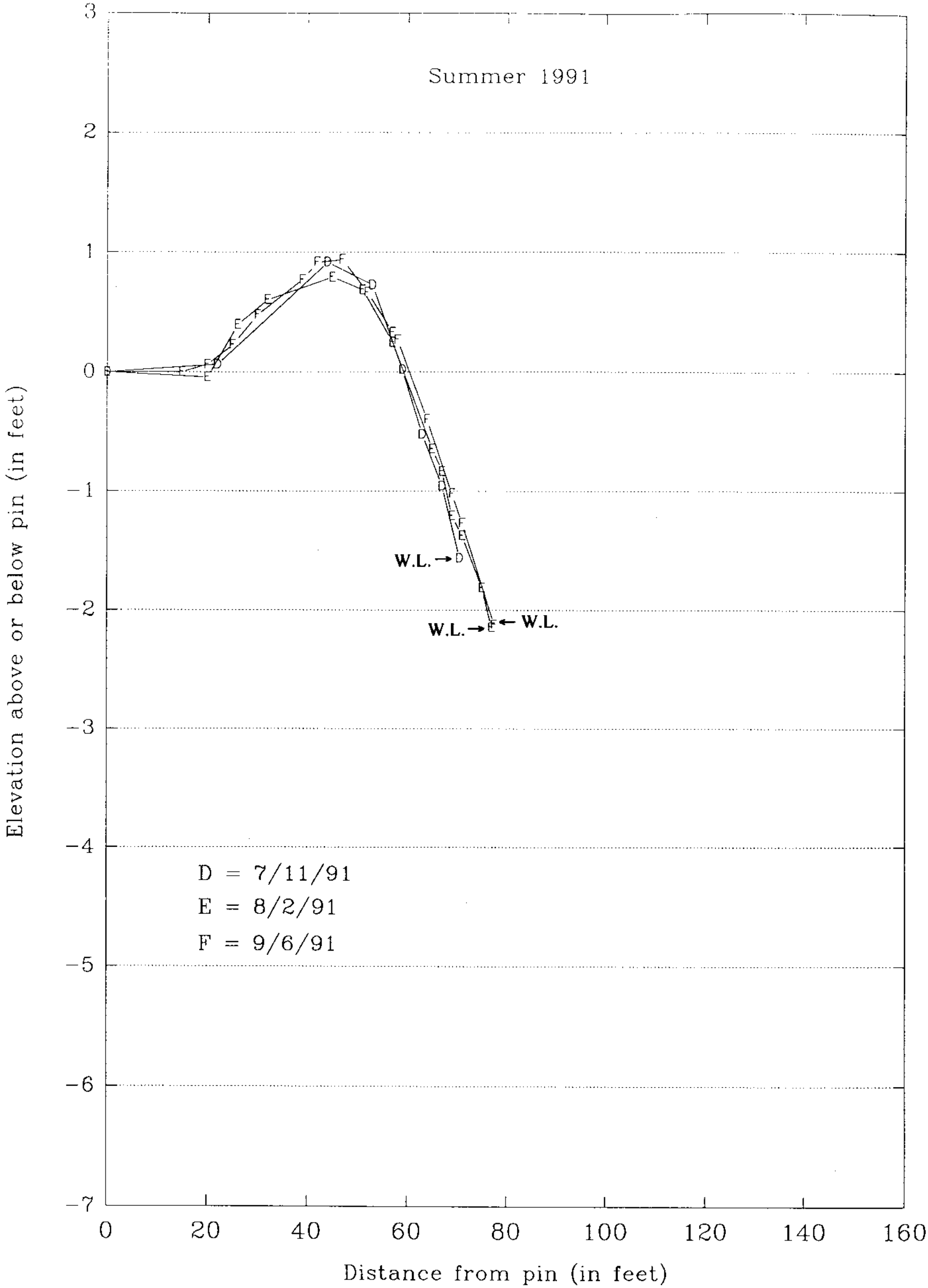
Songo Beach #6 Profile



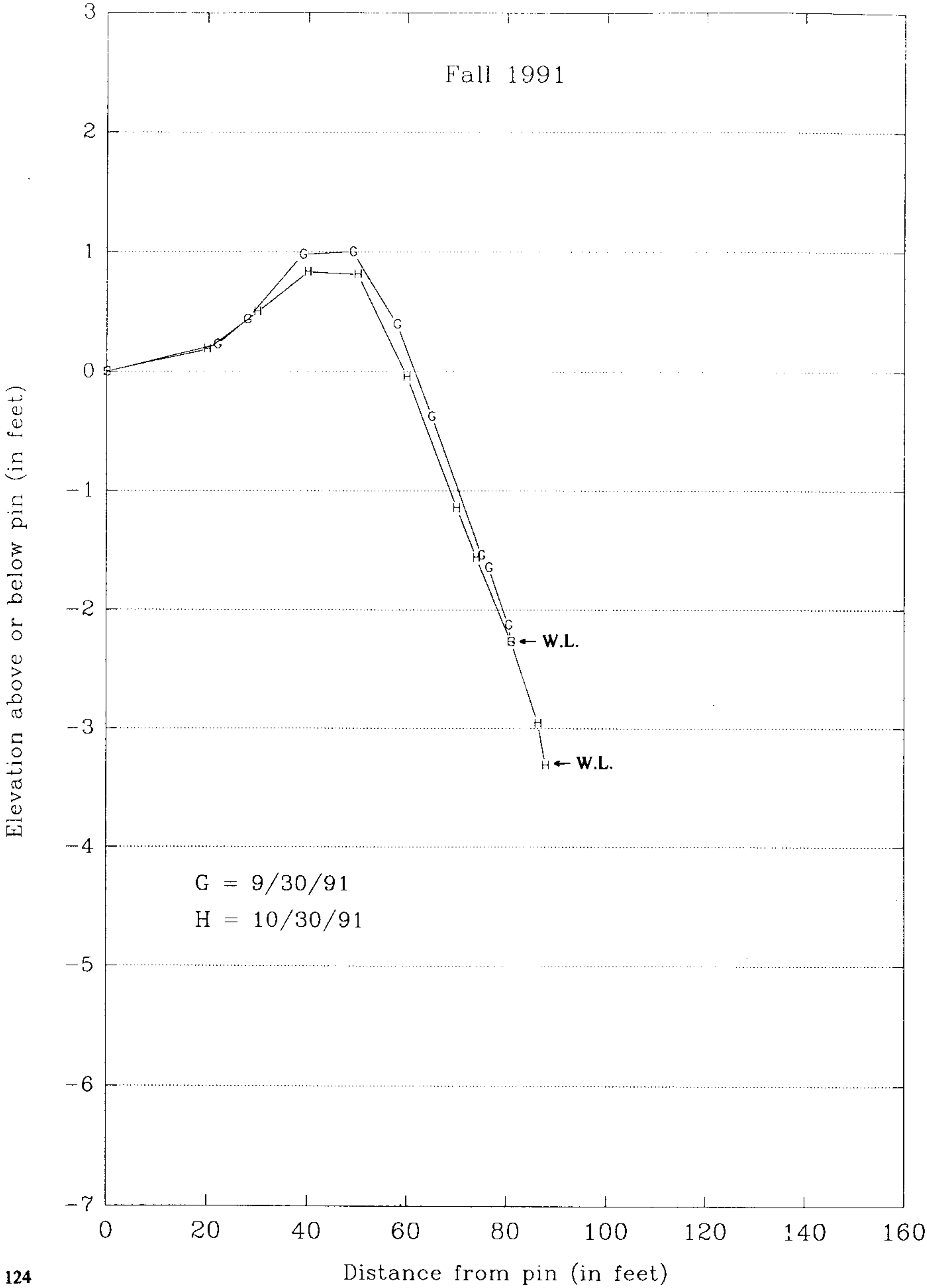
Songo Beach #6 Profile



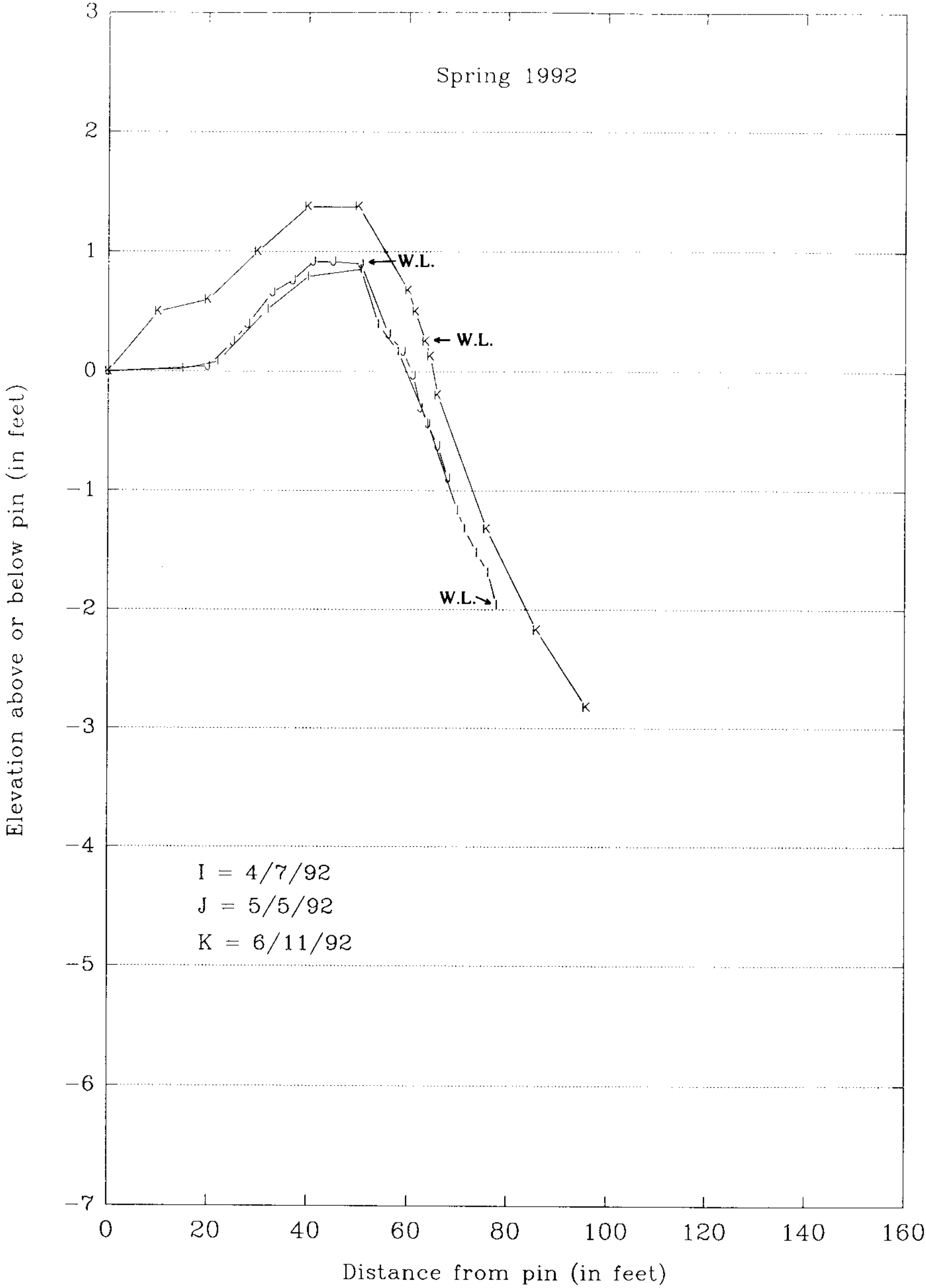
Songo Beach #6 Profile



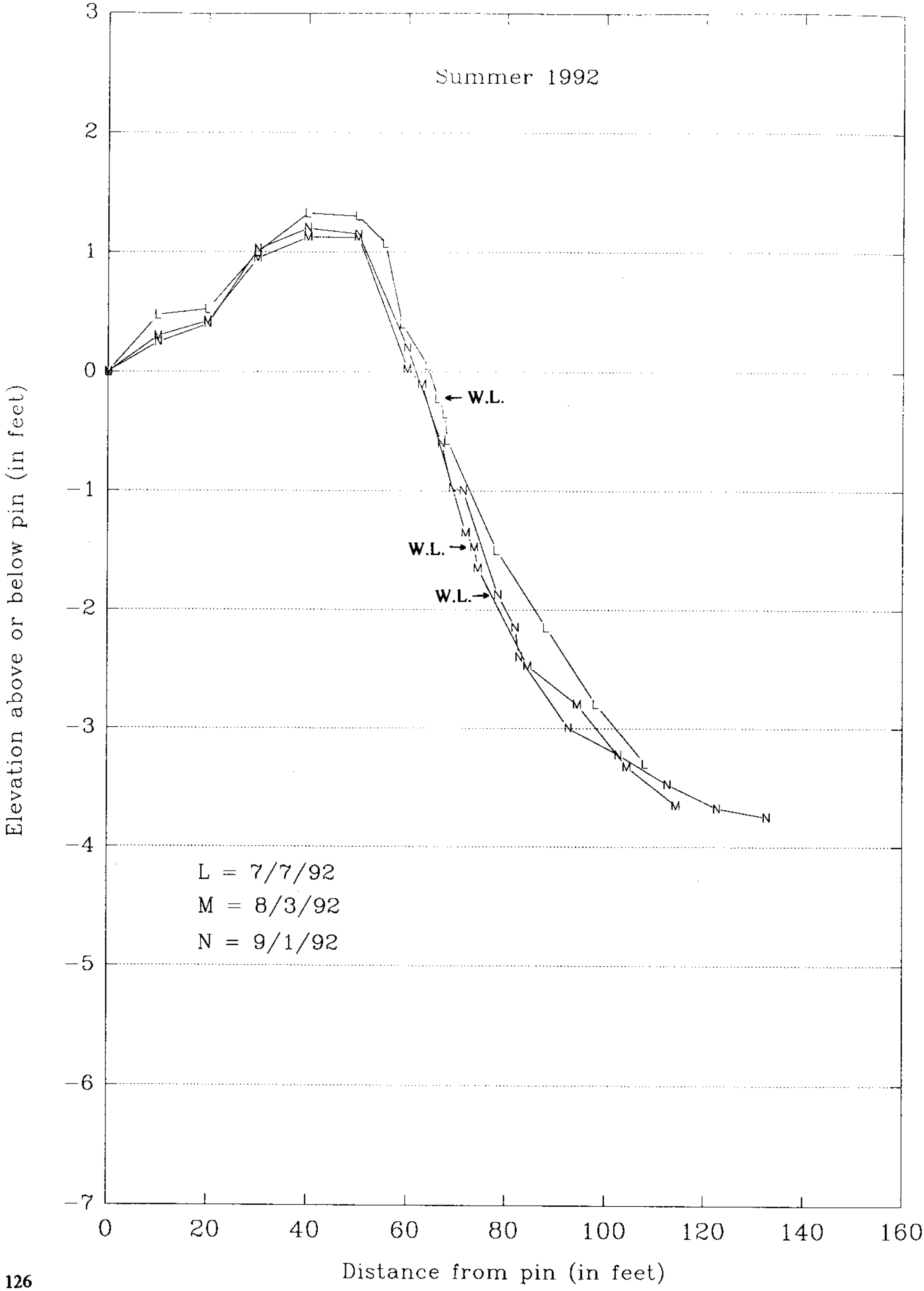
Songo Beach #6 Profile



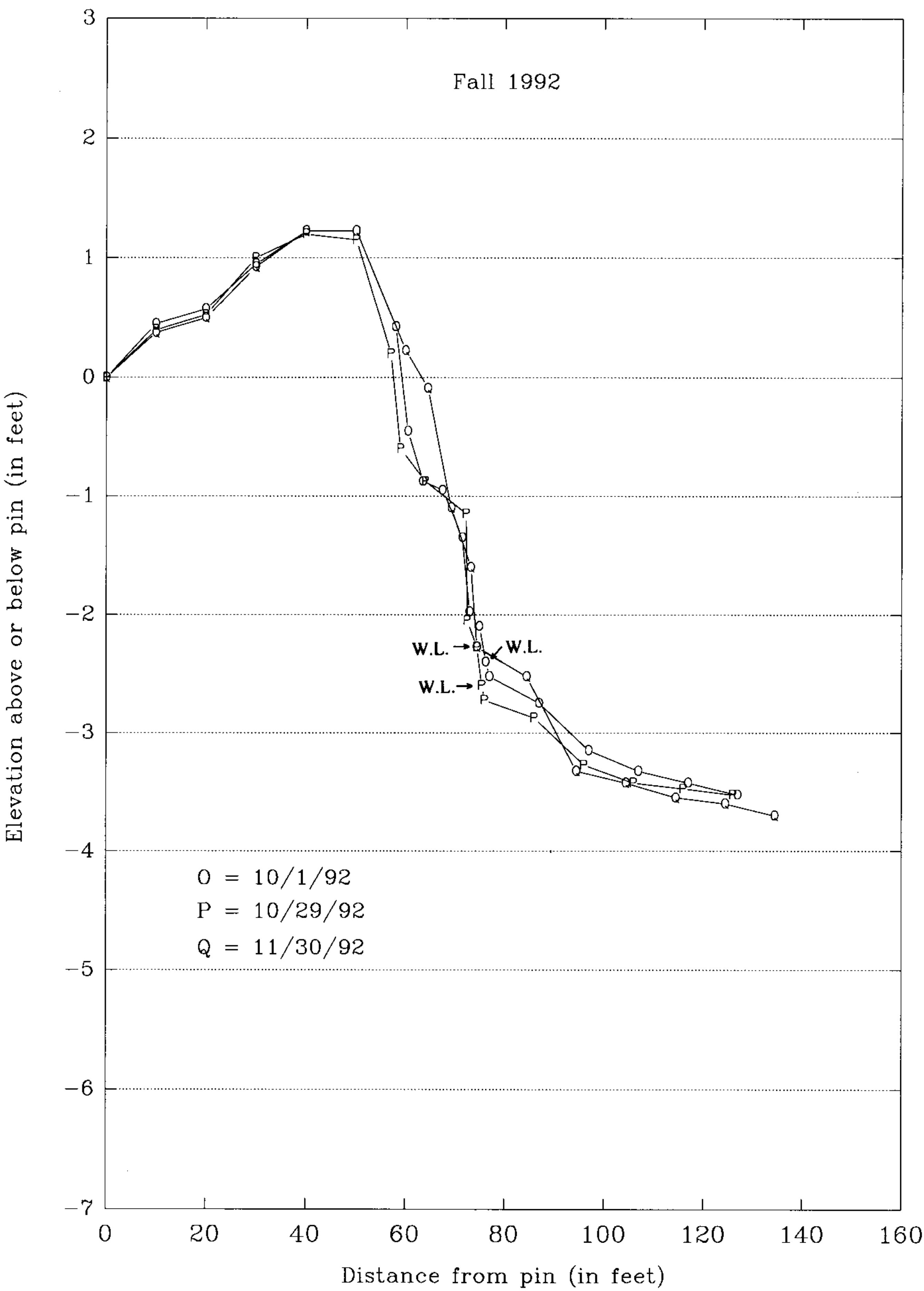
Songo Beach #6 Profile



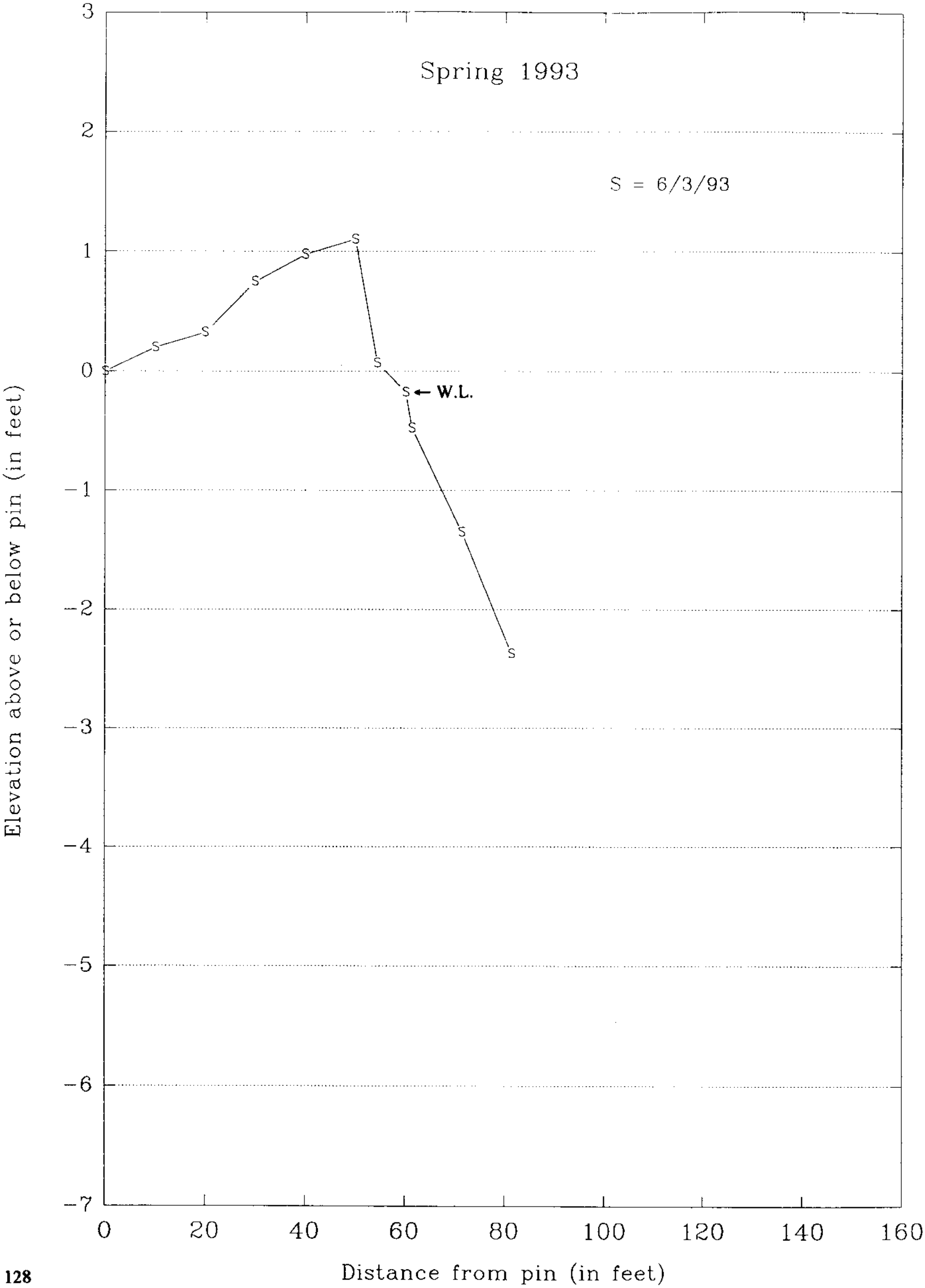
Songo Beach #6 Profile



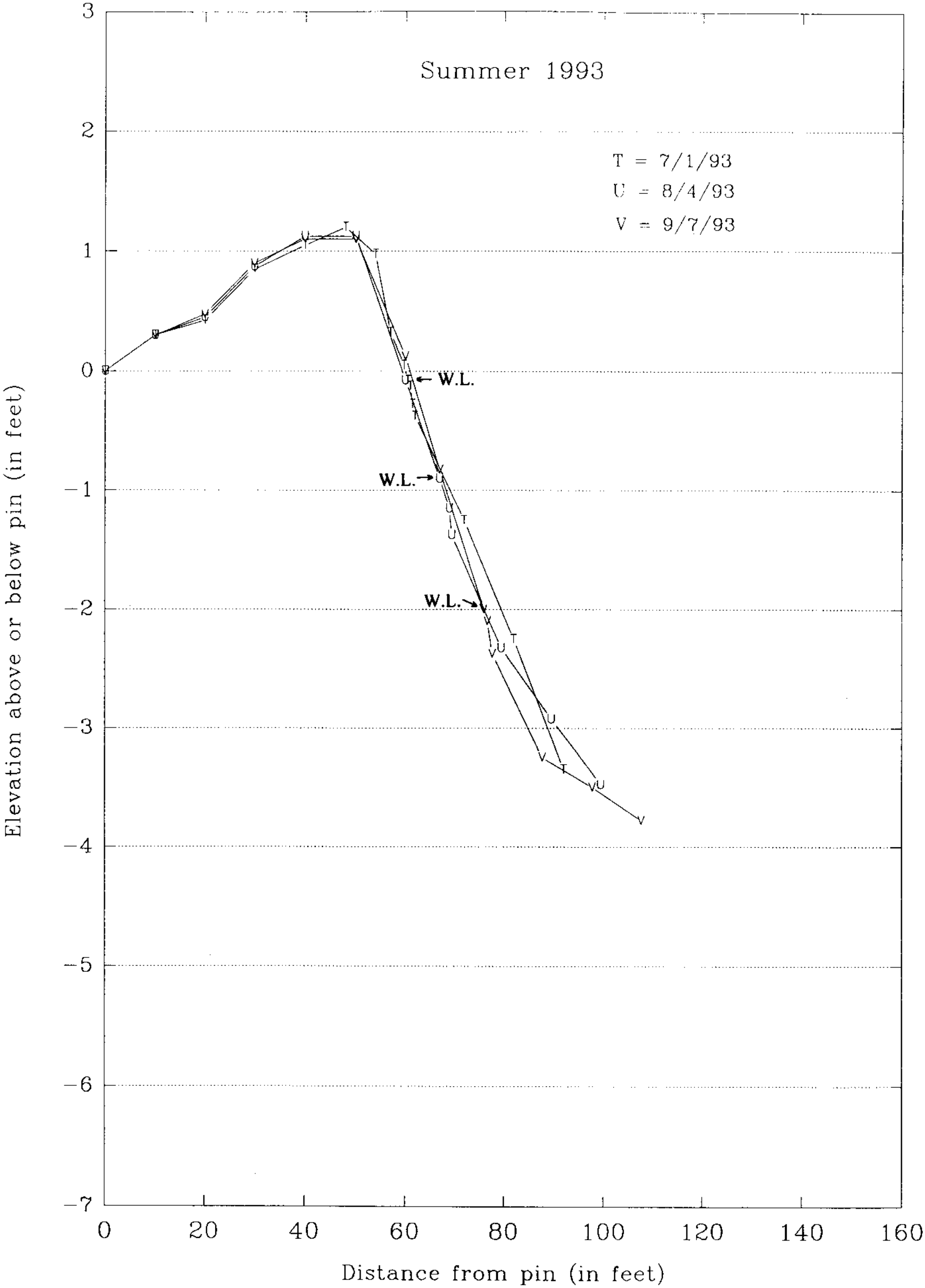
Songo Beach #6 Profile



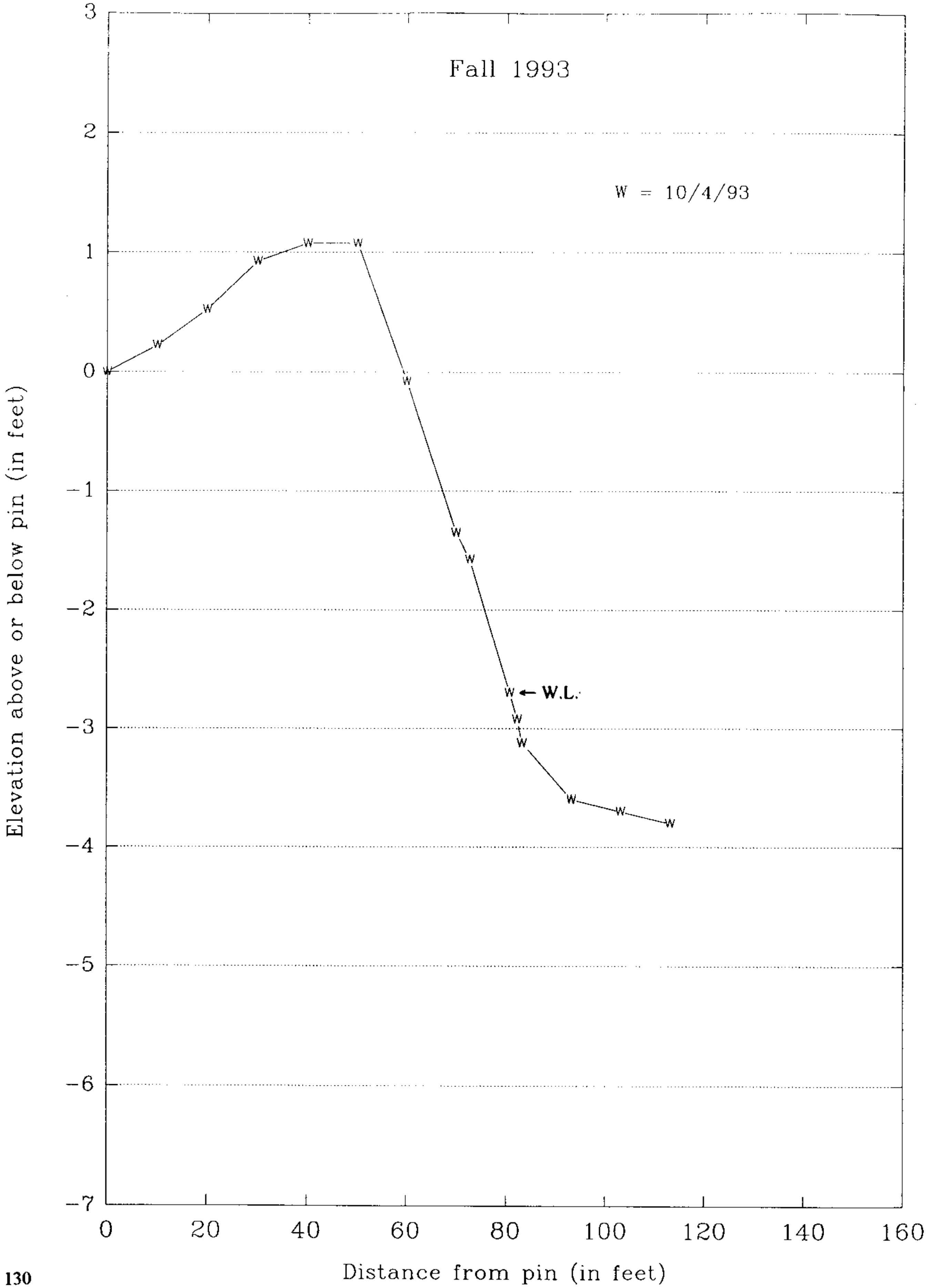
Songo Beach #6 Profile



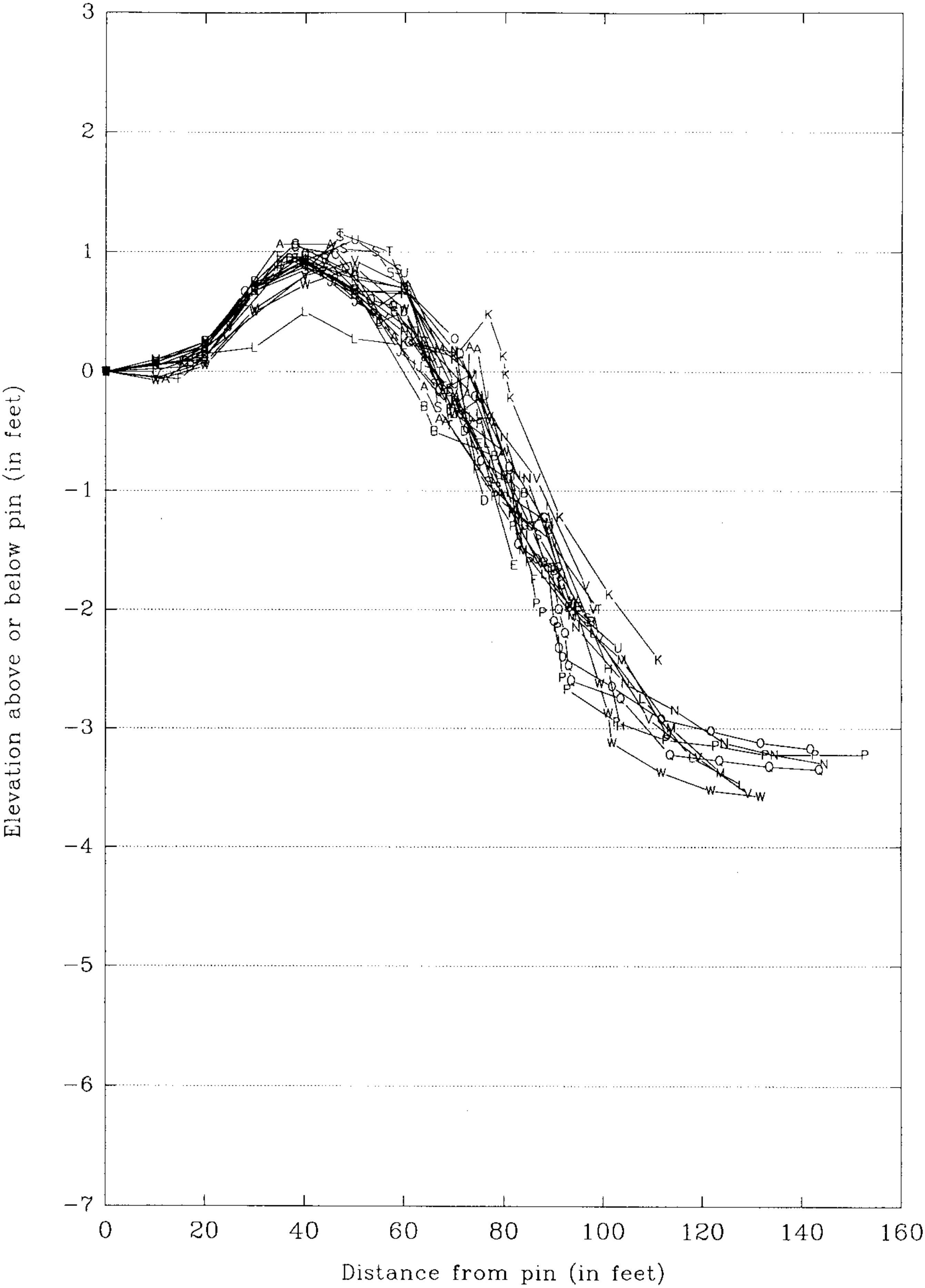
Songo Beach #6 Profile



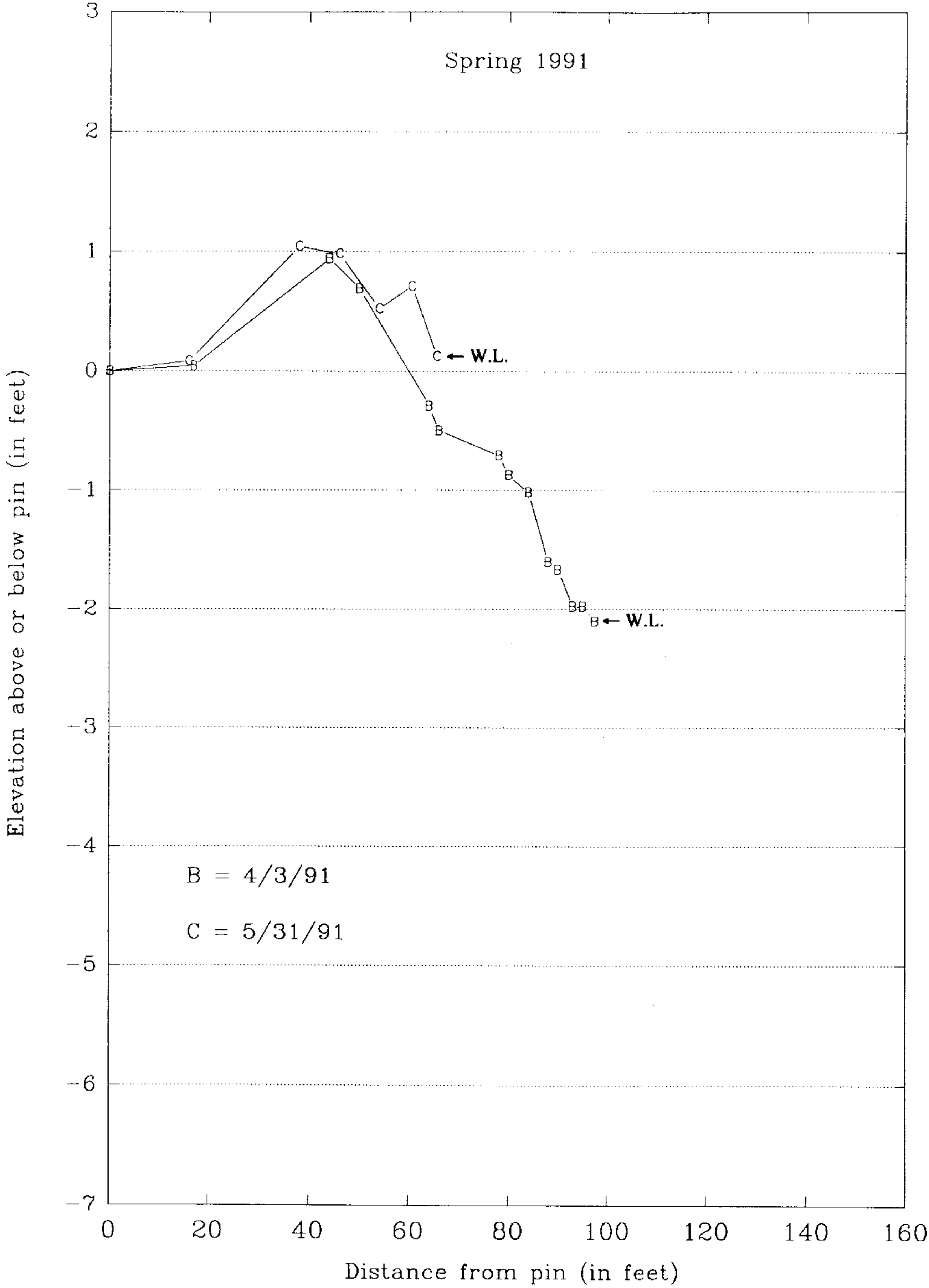
Songo Beach #6 Profile



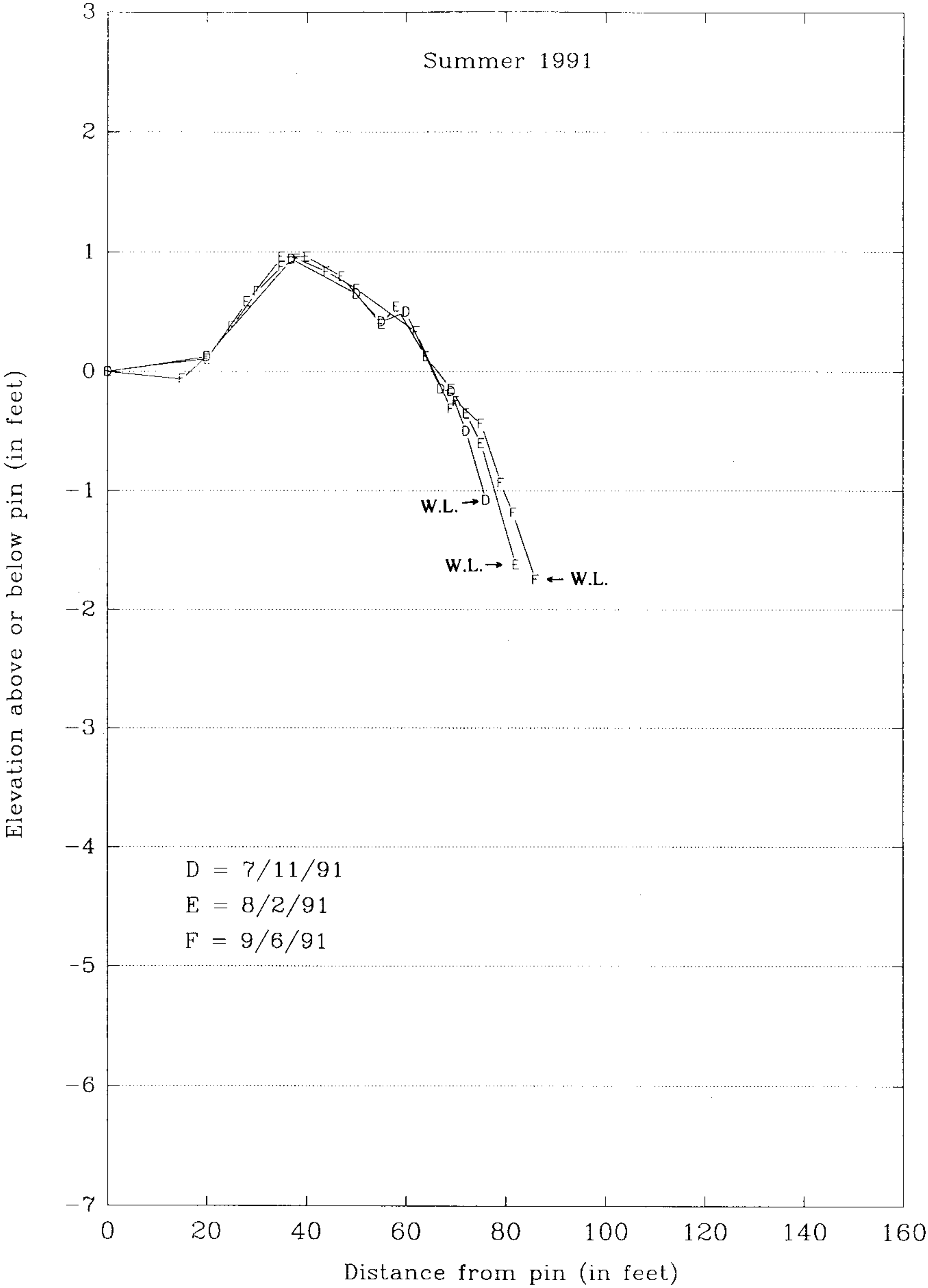
Songo Beach #7 Profile



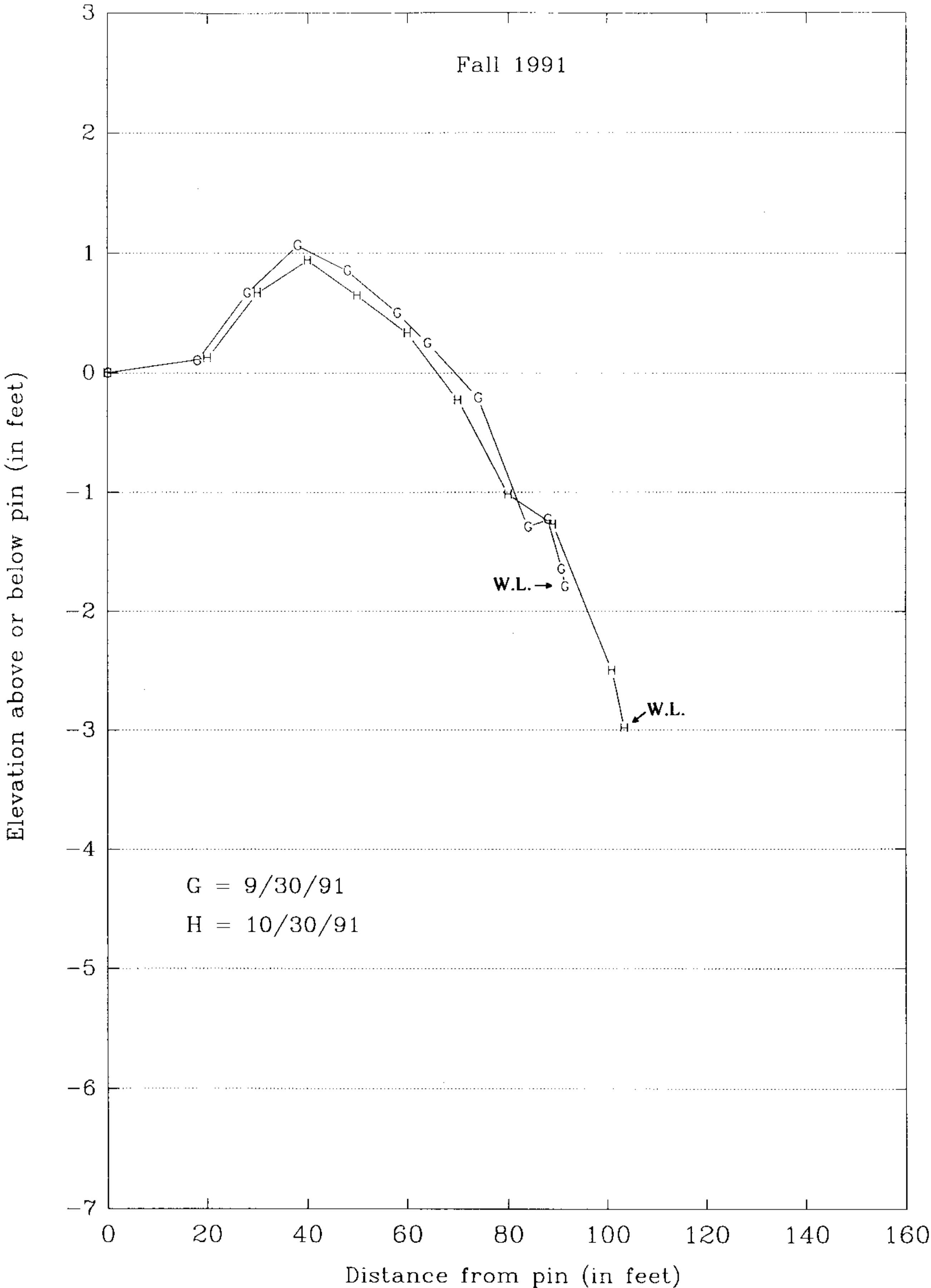
Songo Beach #7 Profile



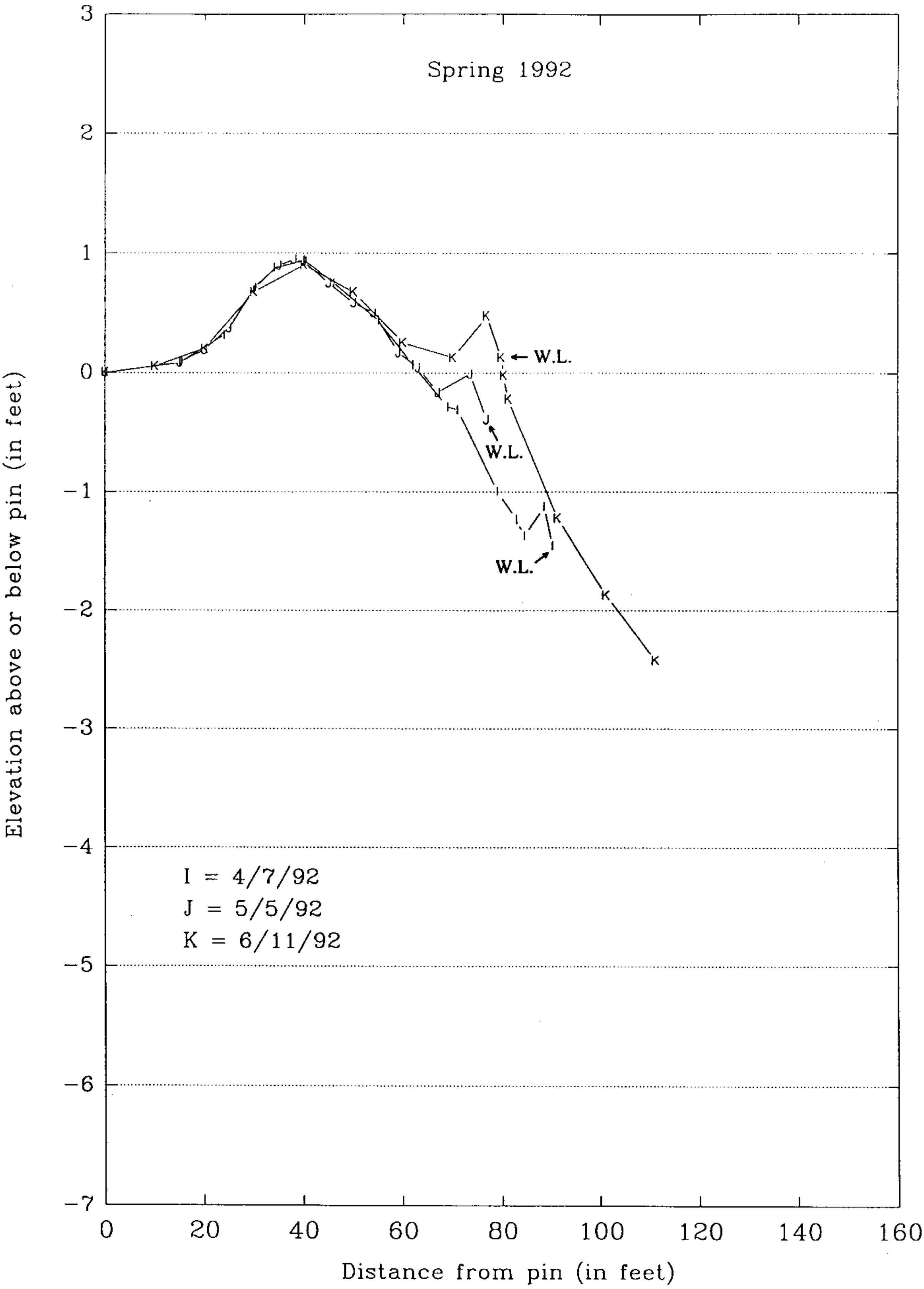
Songo Beach #7 Profile



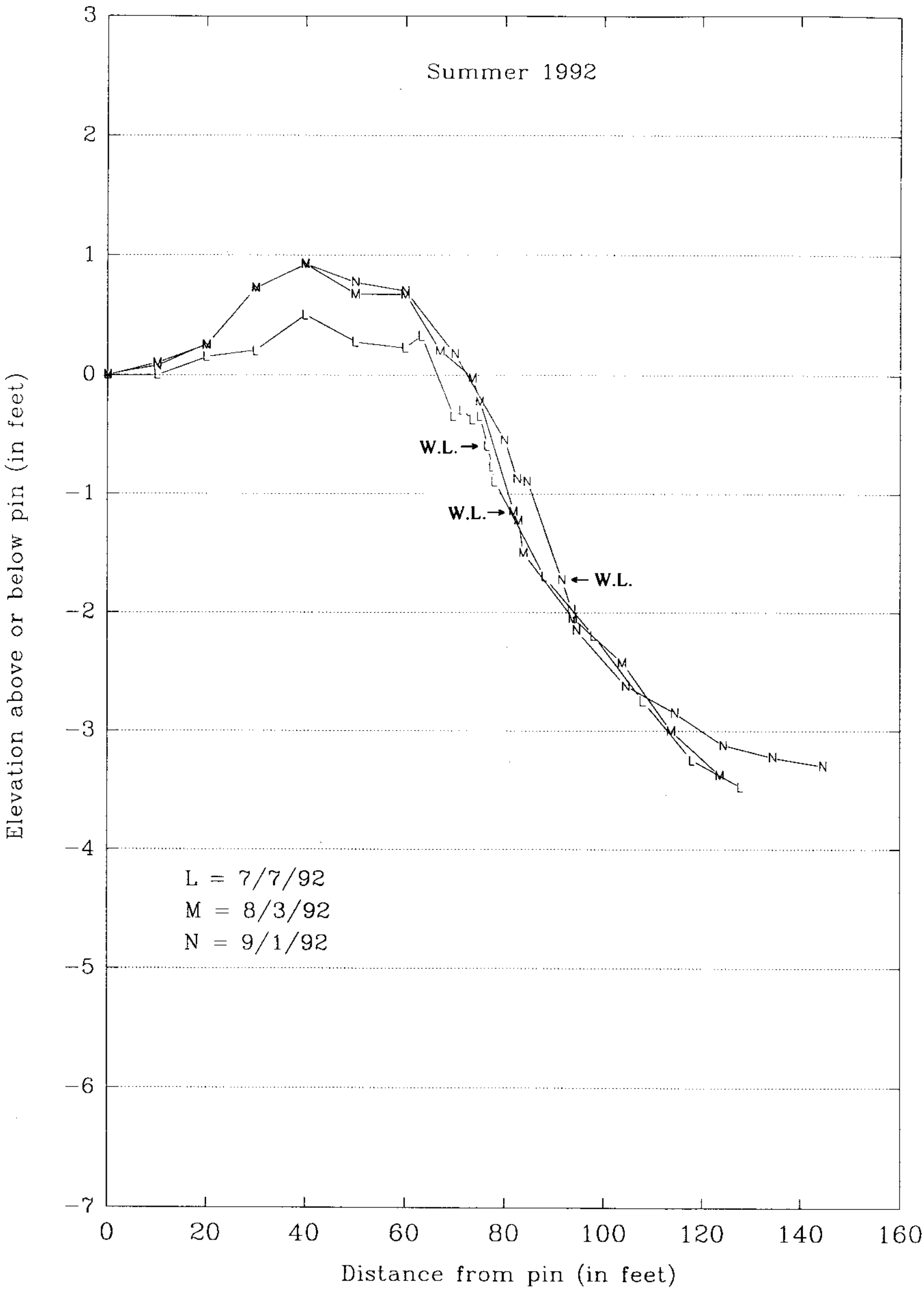
Songo Beach #7 Profile



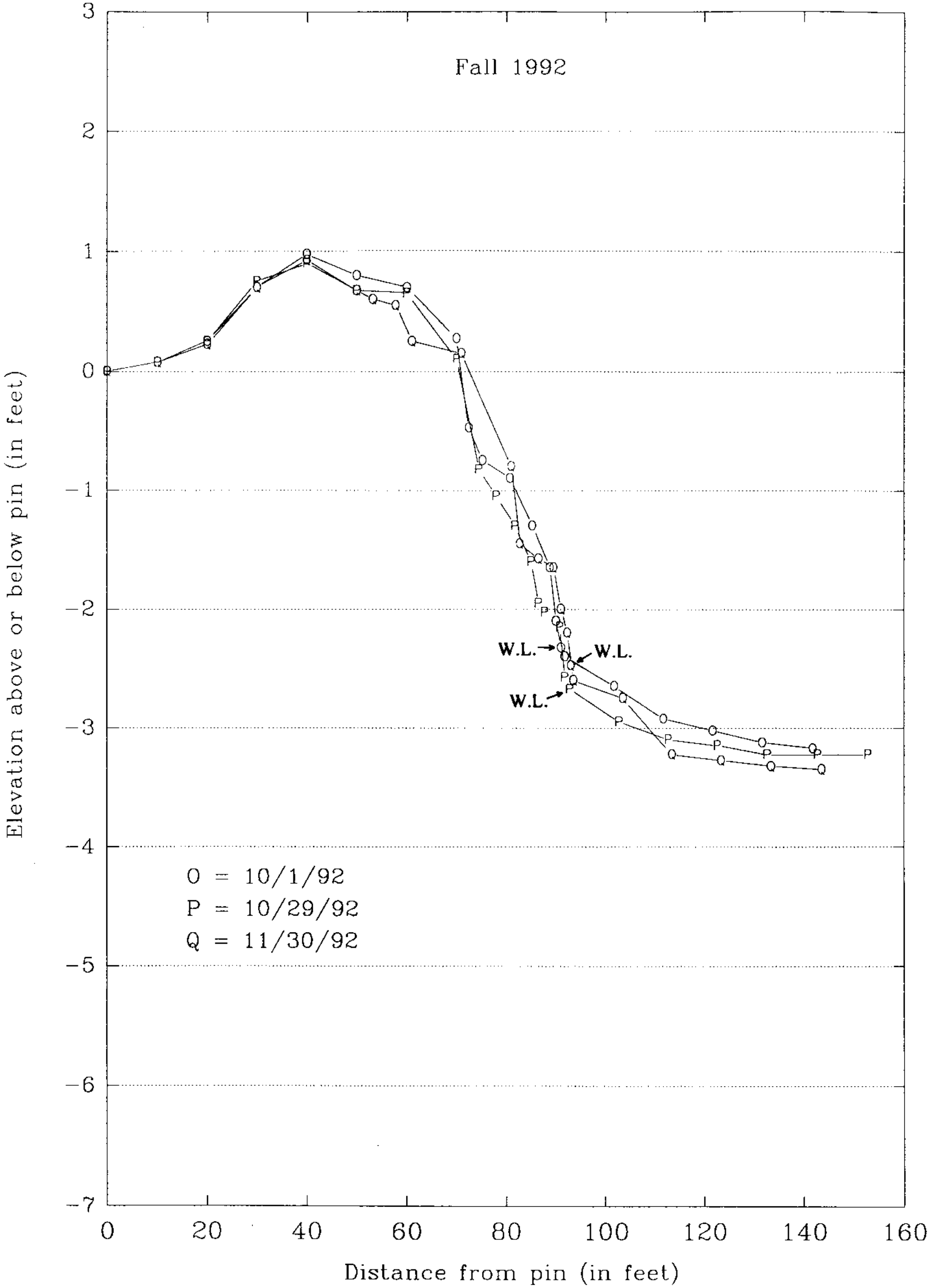
Songo Beach #7 Profile



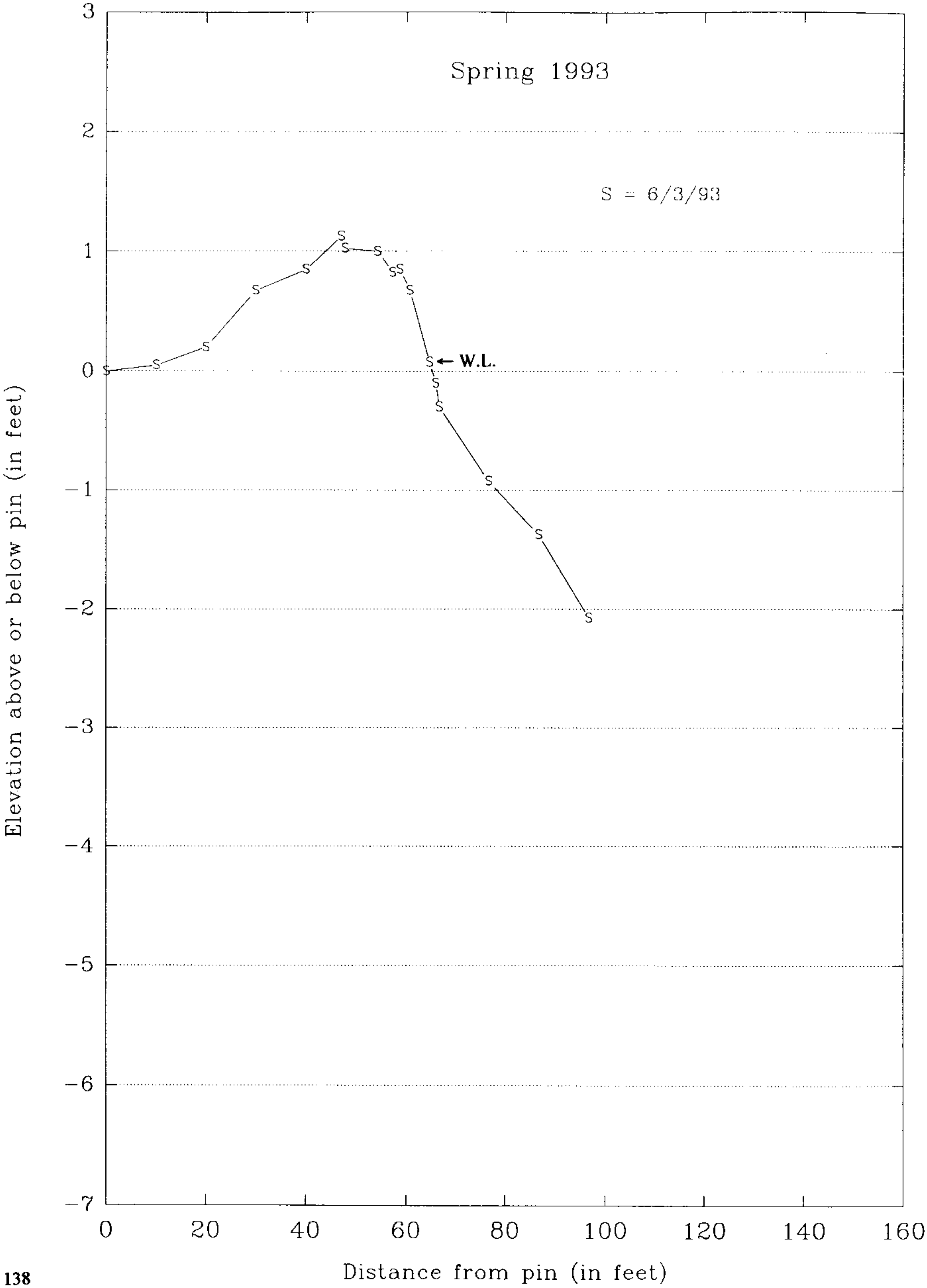
Songo Beach #7 Profile



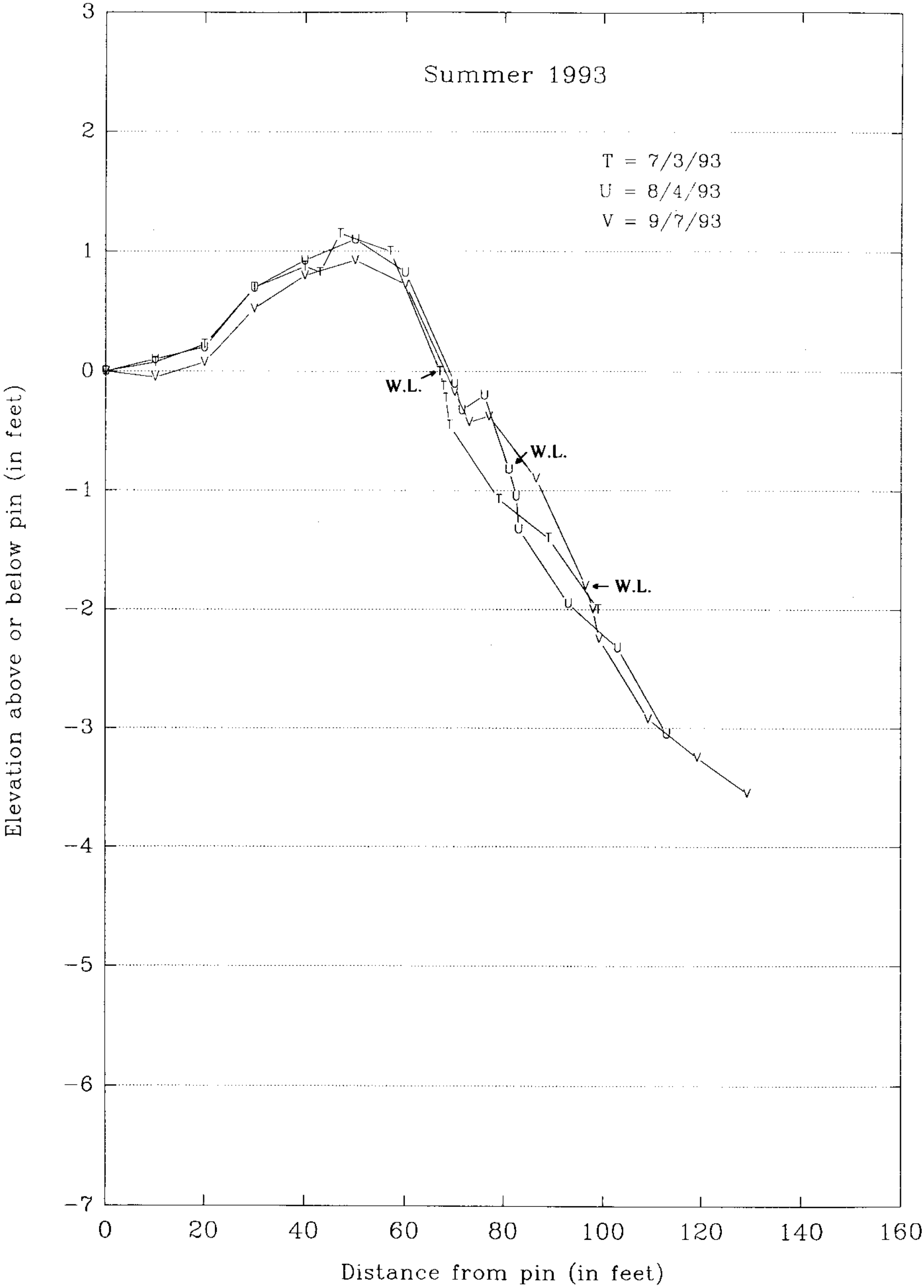
Songo Beach #7 Profile



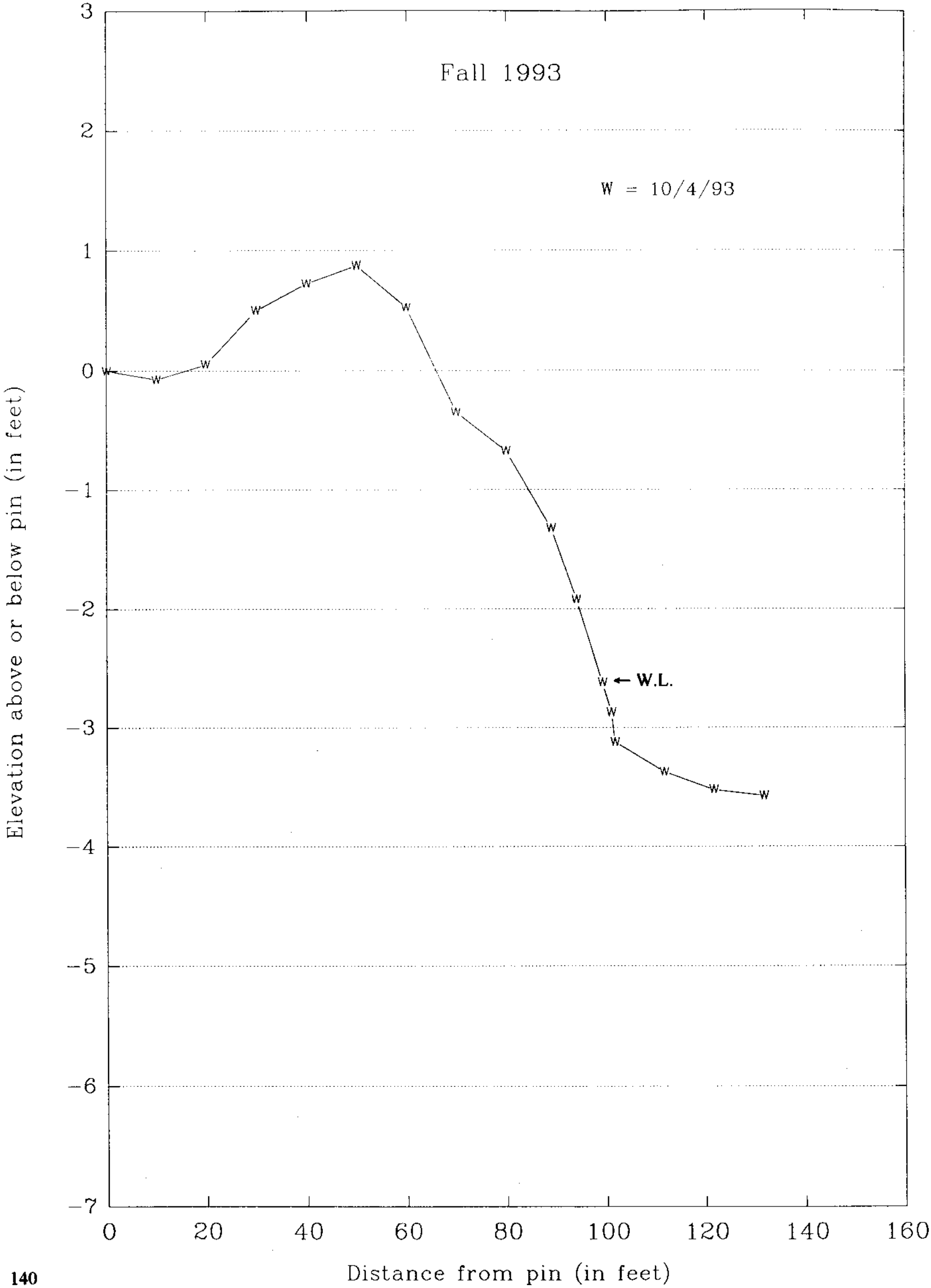
Songo Beach #7 Profile

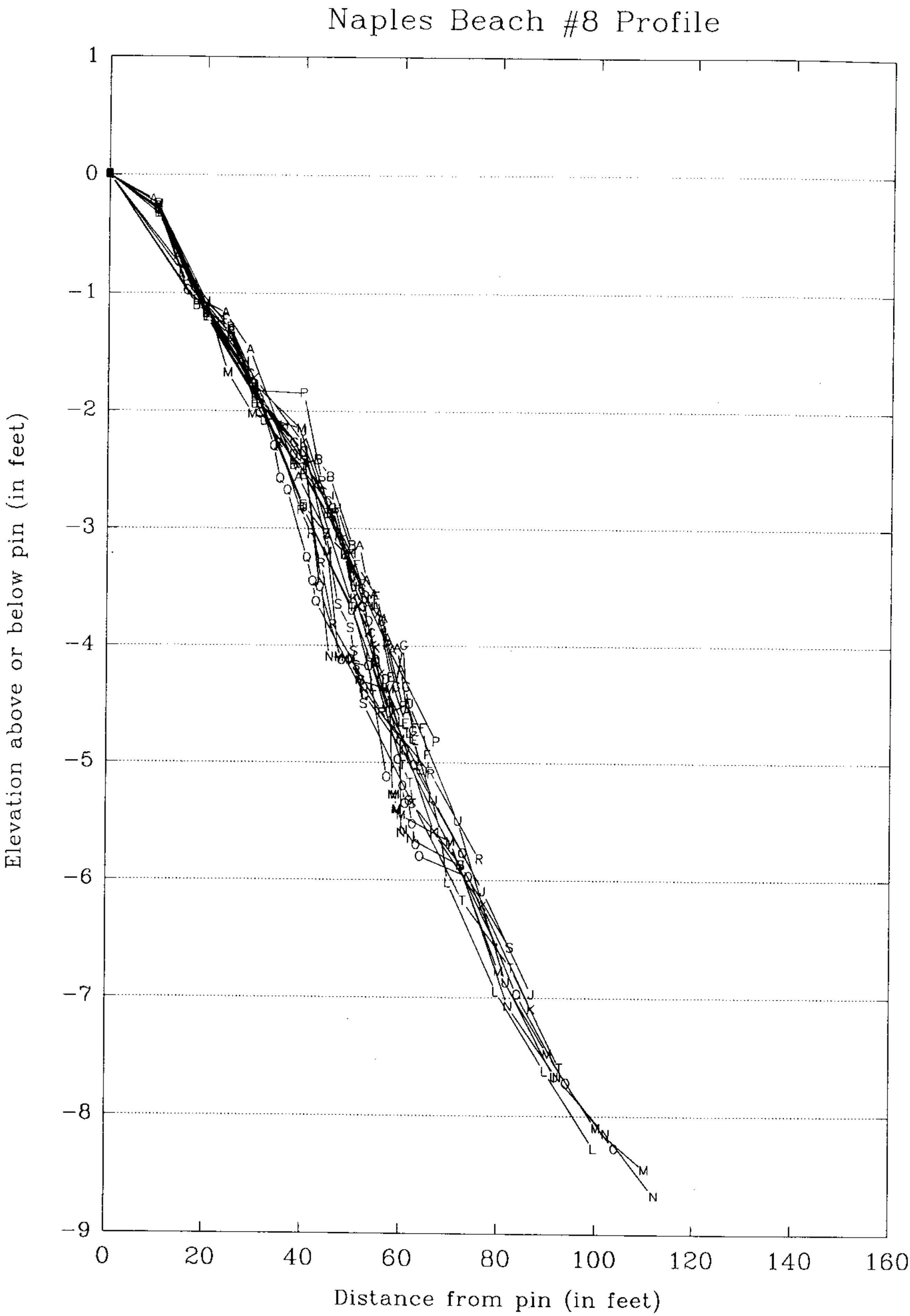


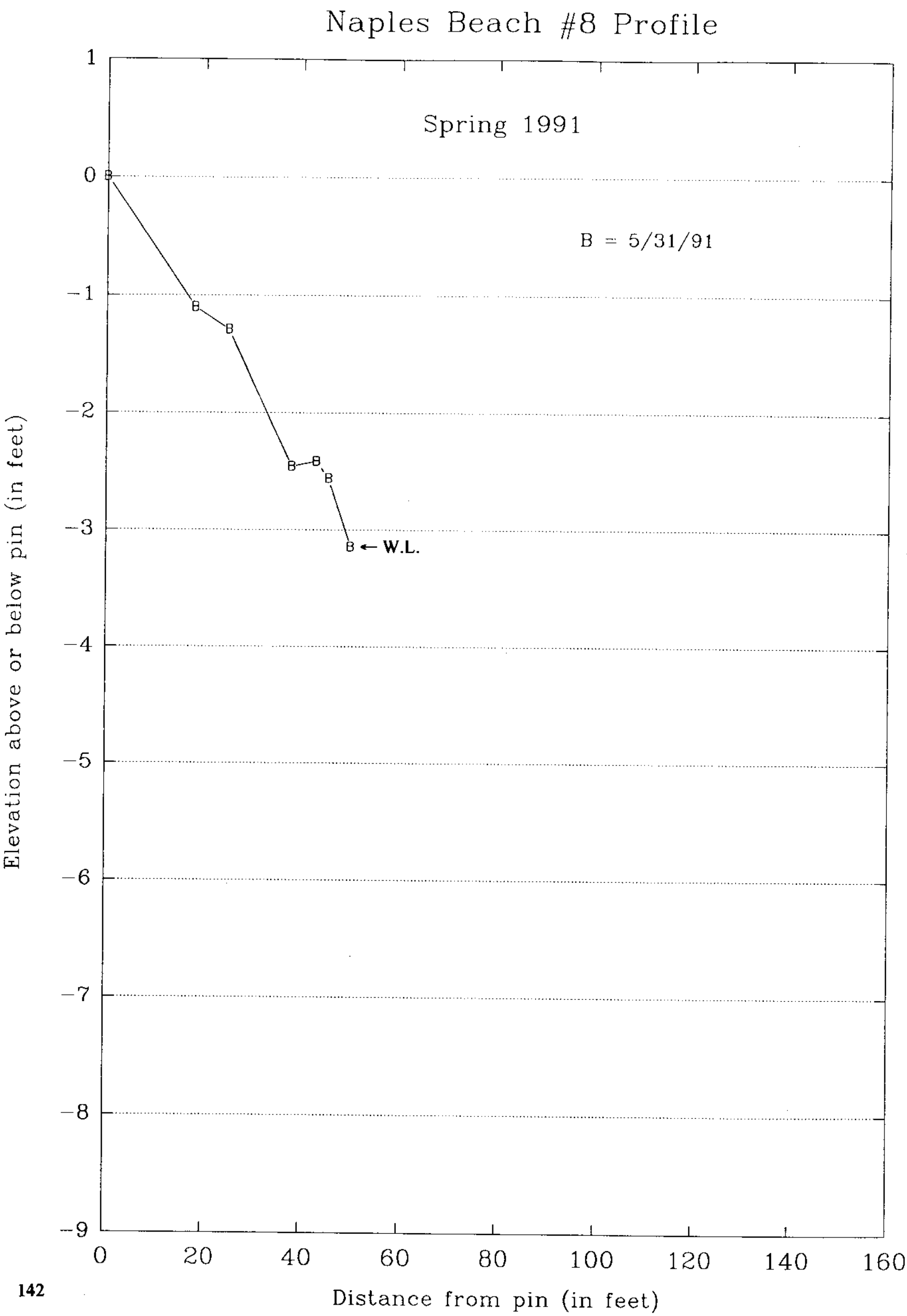
Songo Beach #7 Profile

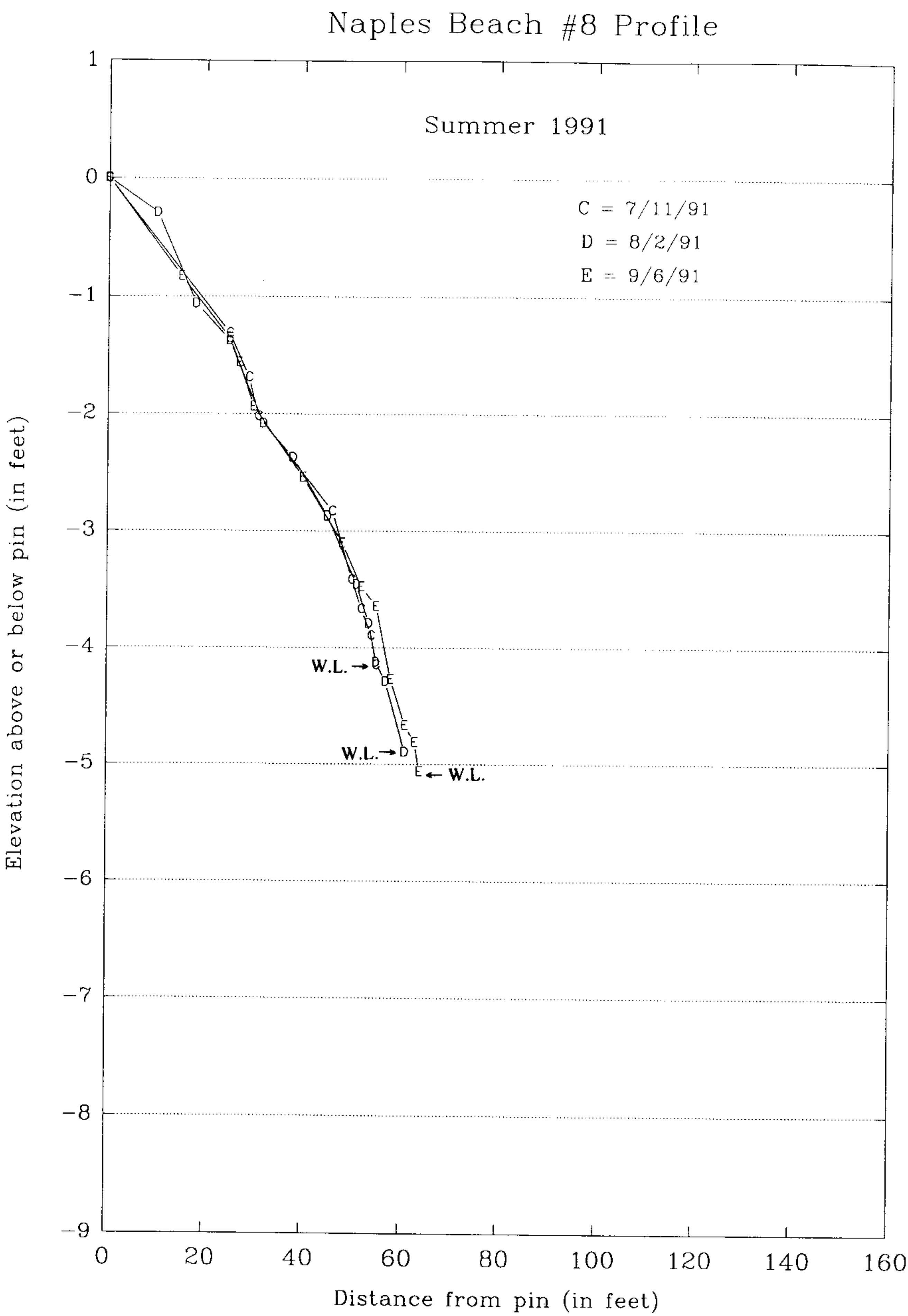


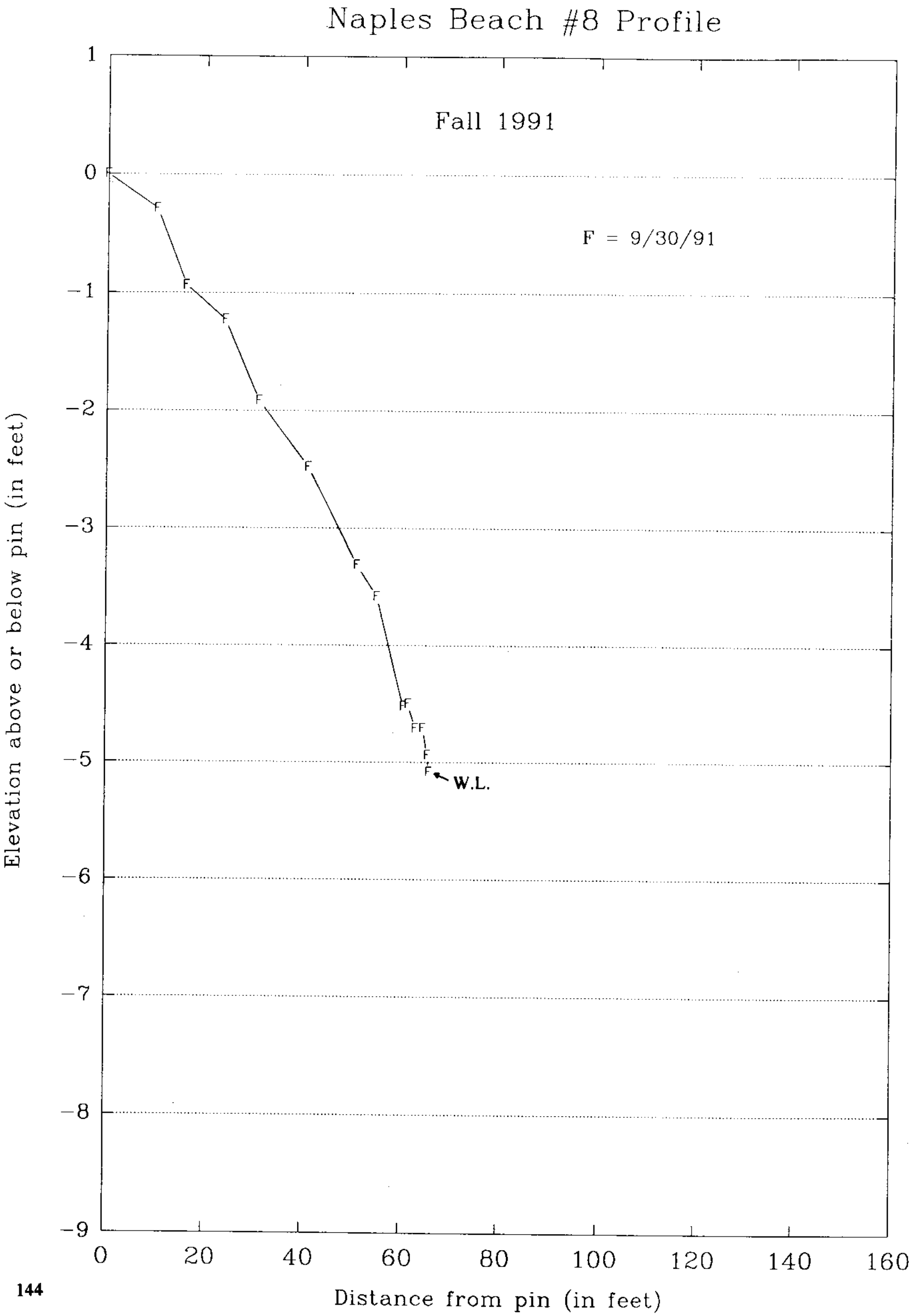
Songo Beach #7 Profile

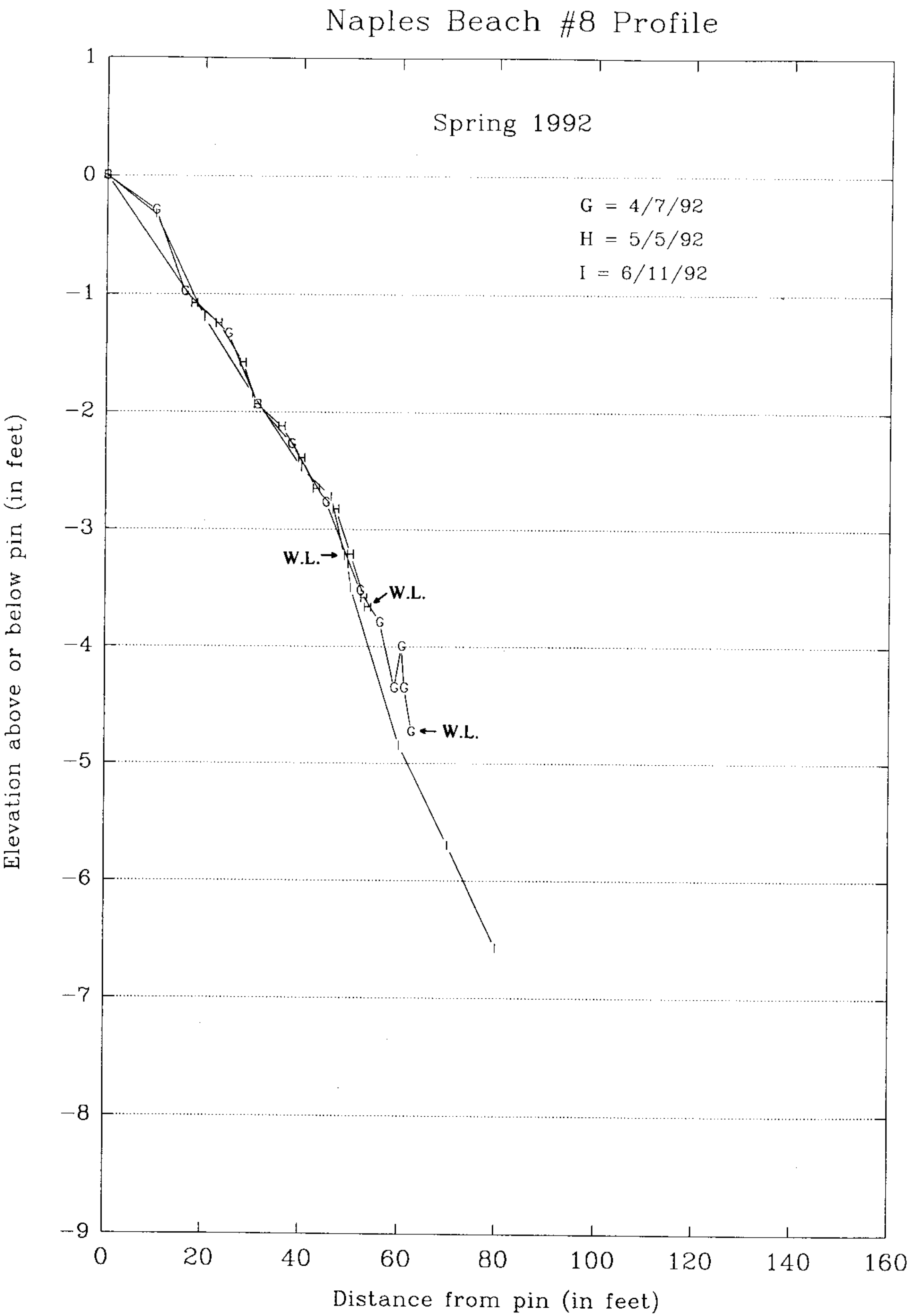



Naples Beach #8 Profile
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

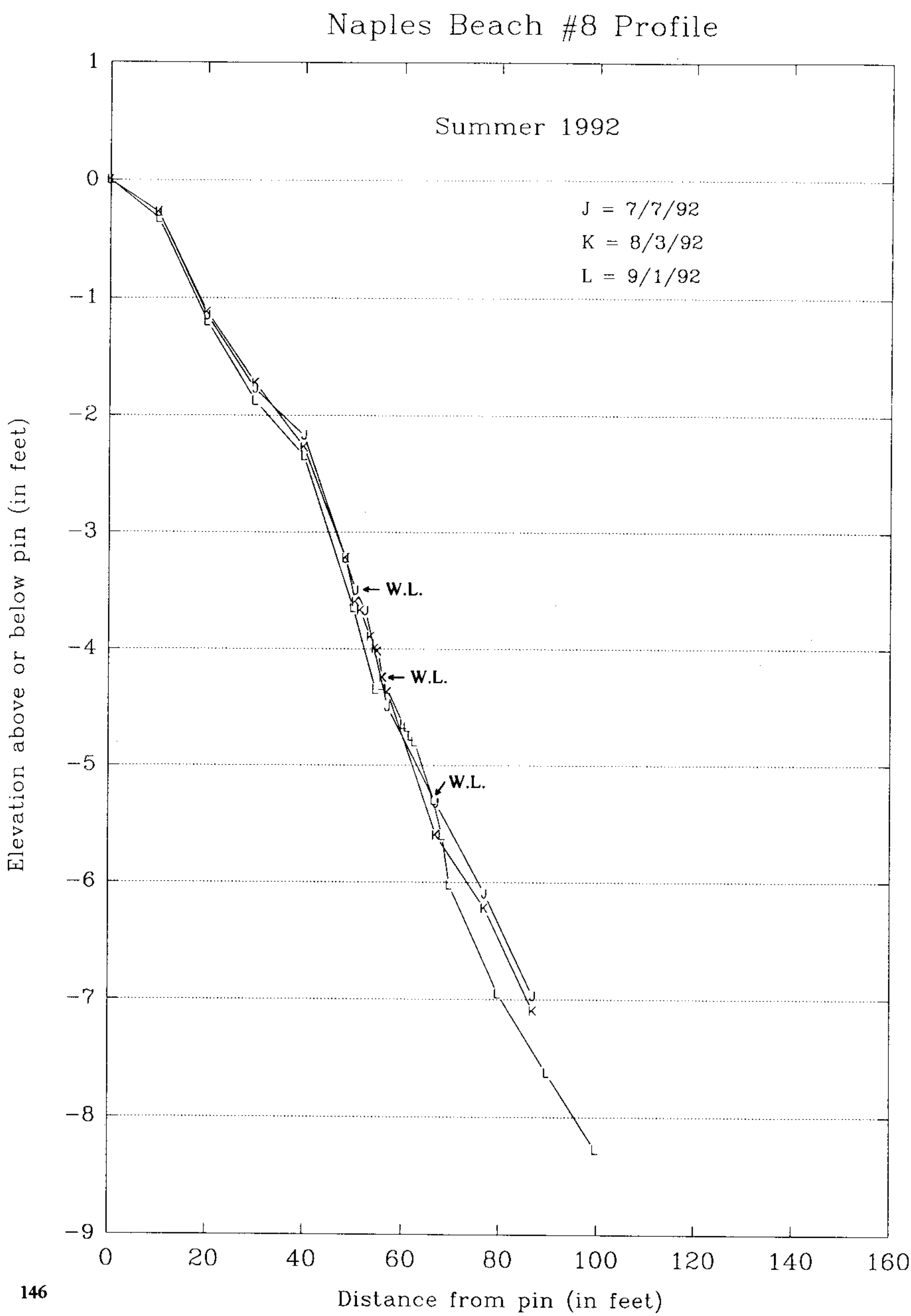

Naples Beach #8 Profile
Spring 1991
B = 5/31/91
W.L.
Elevation above or below pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160
Distance from pin (in feet)

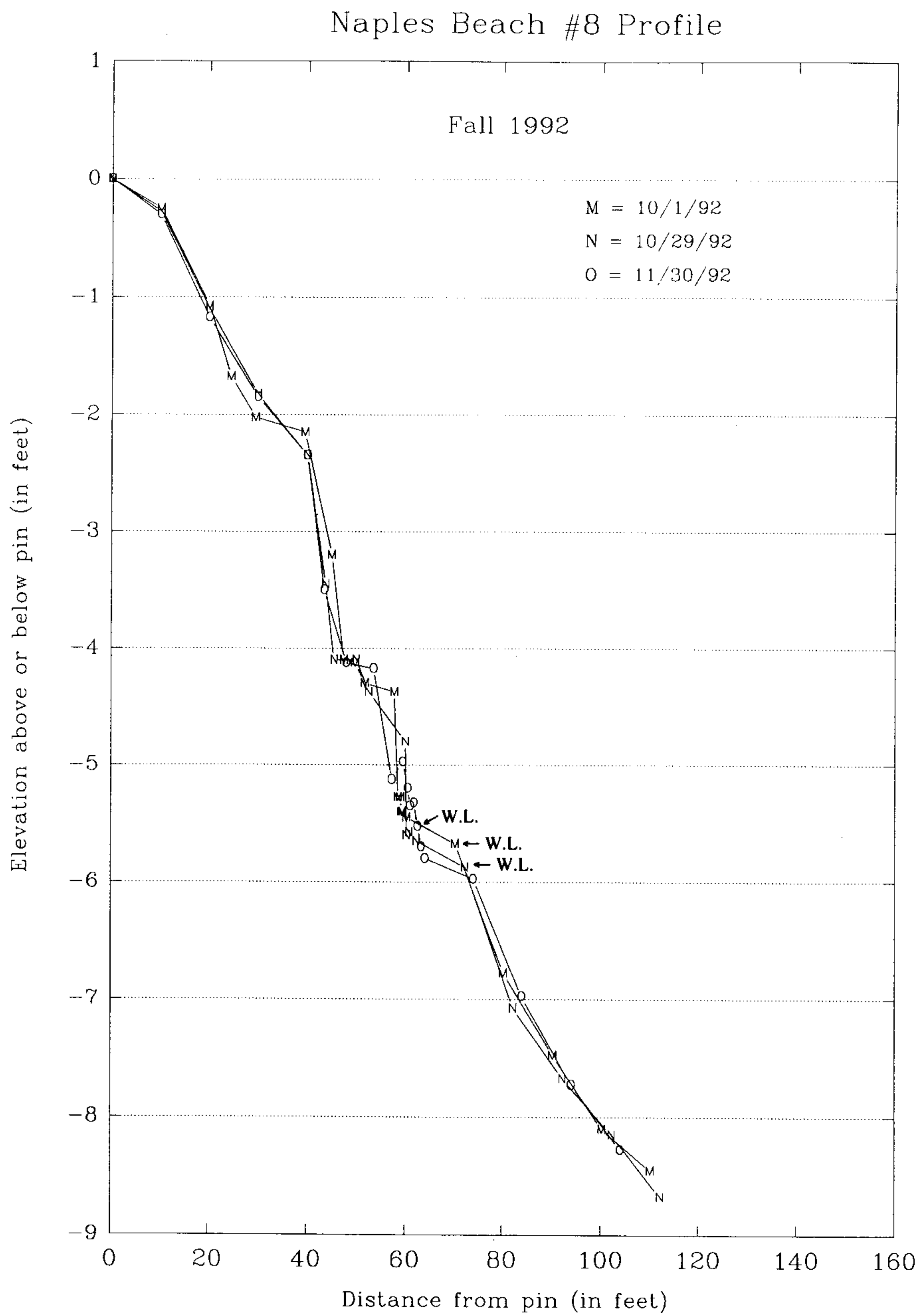

Naples Beach #8 Profile
Summer 1991
C = 7/11/91
D = 8/2/91
E = 9/6/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

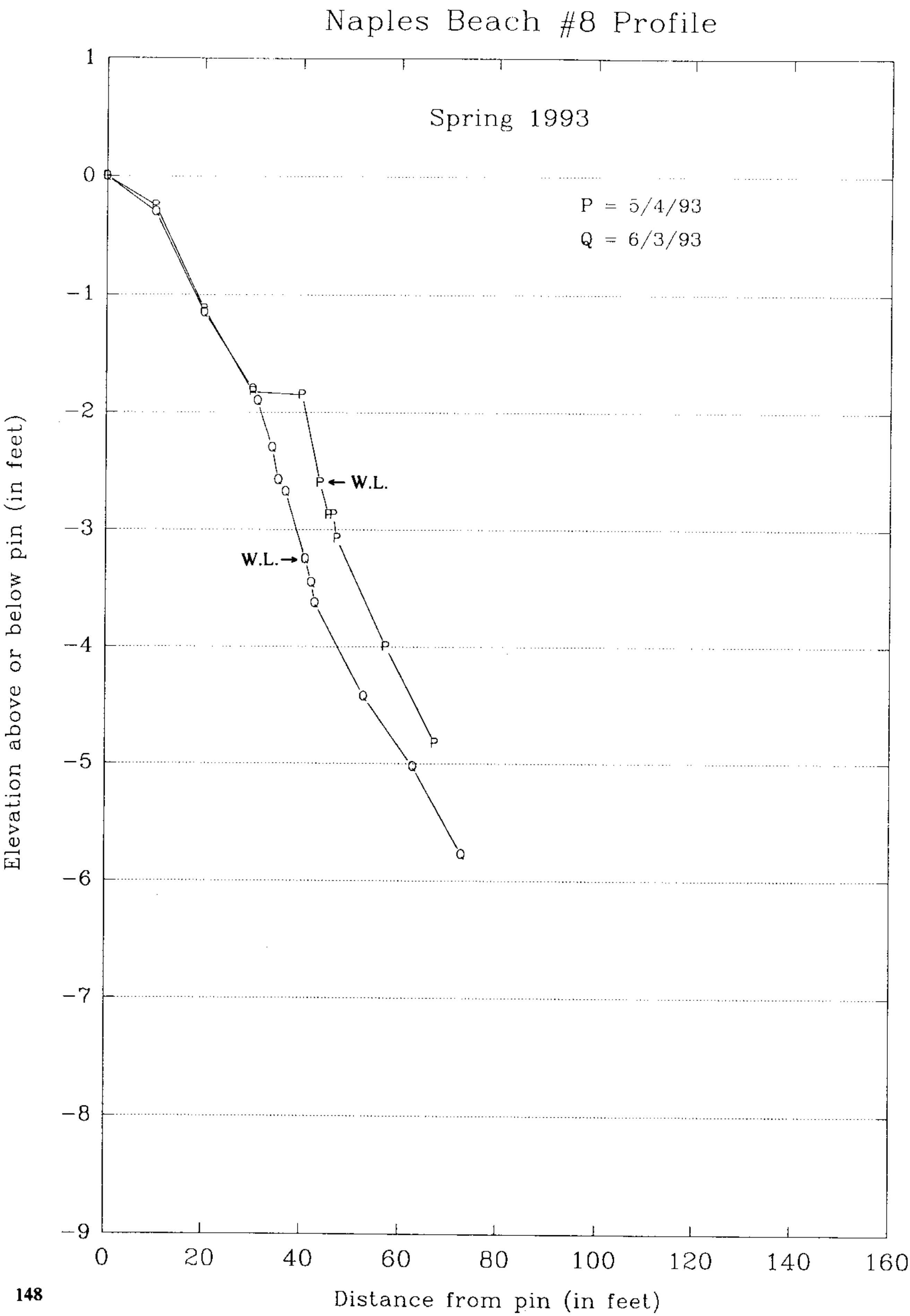

Naples Beach #8 Profile
Fall 1991
F = 9/30/91
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

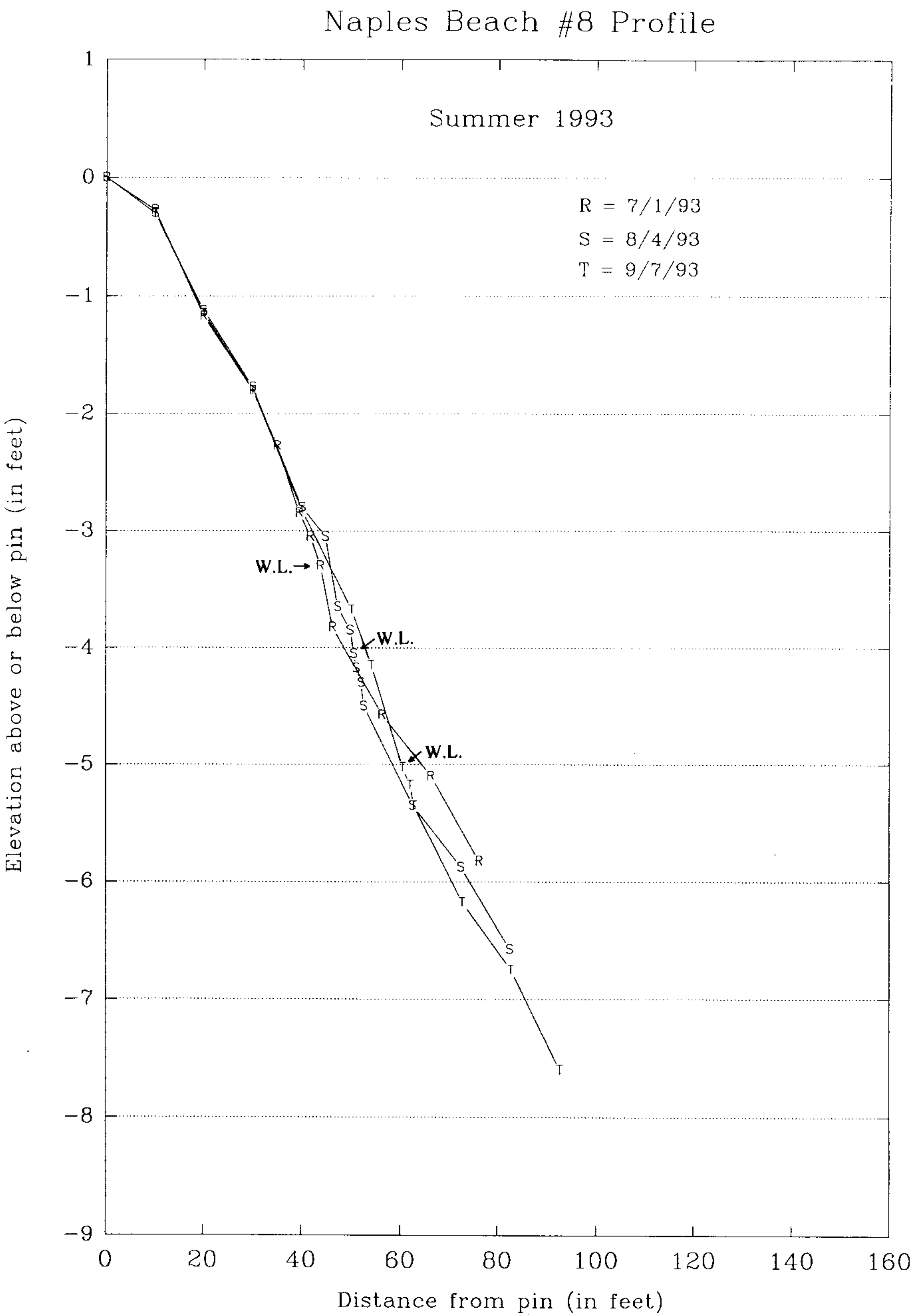


Naples Beach #8 Profile
Spring 1992
G = 4/7/92
H = 5/5/92
I = 6/11/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160
Distance from pin (in feet)

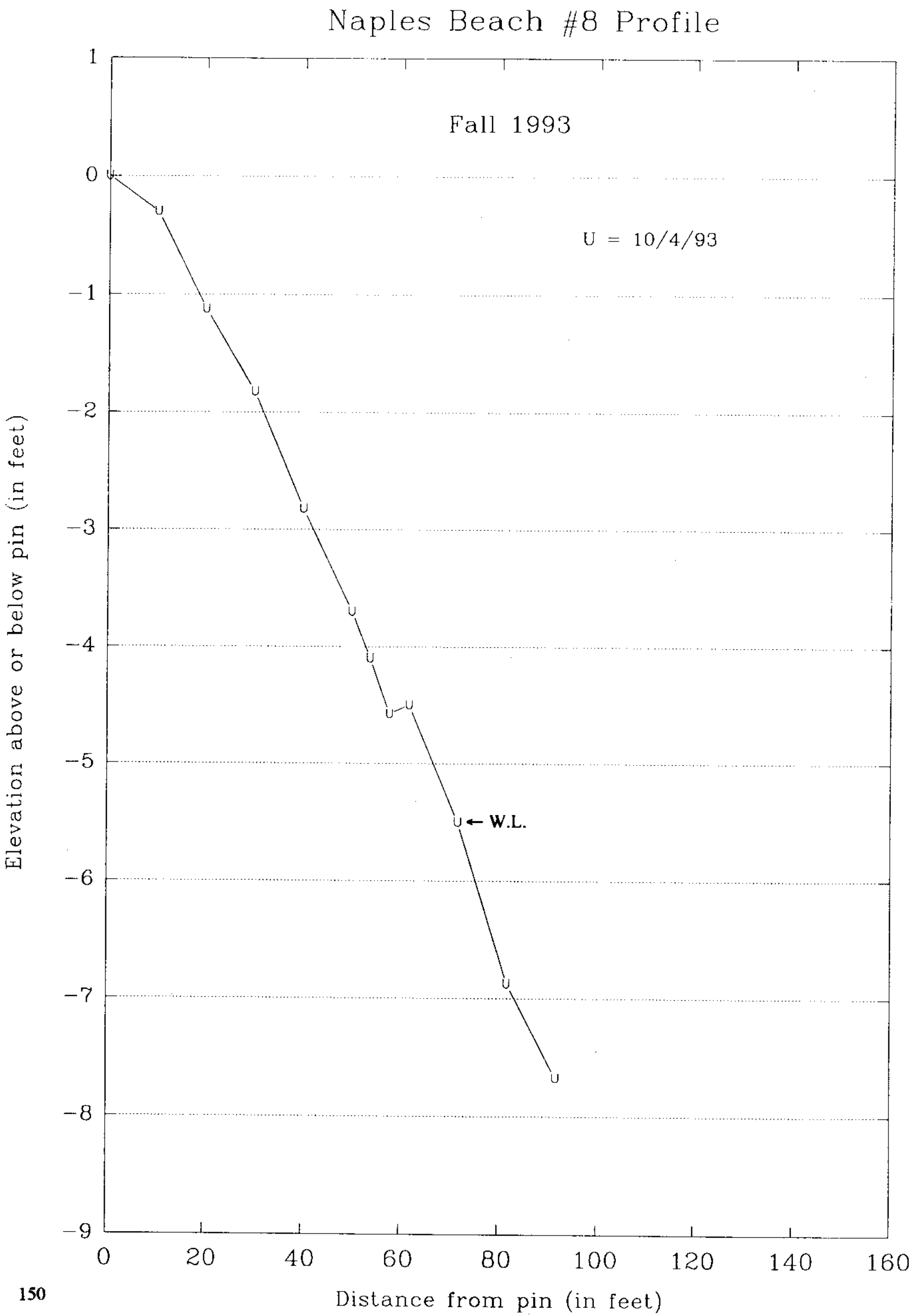

Naples Beach #8 Profile
Summer 1992
J = 7/7/92
K = 8/3/92
L = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

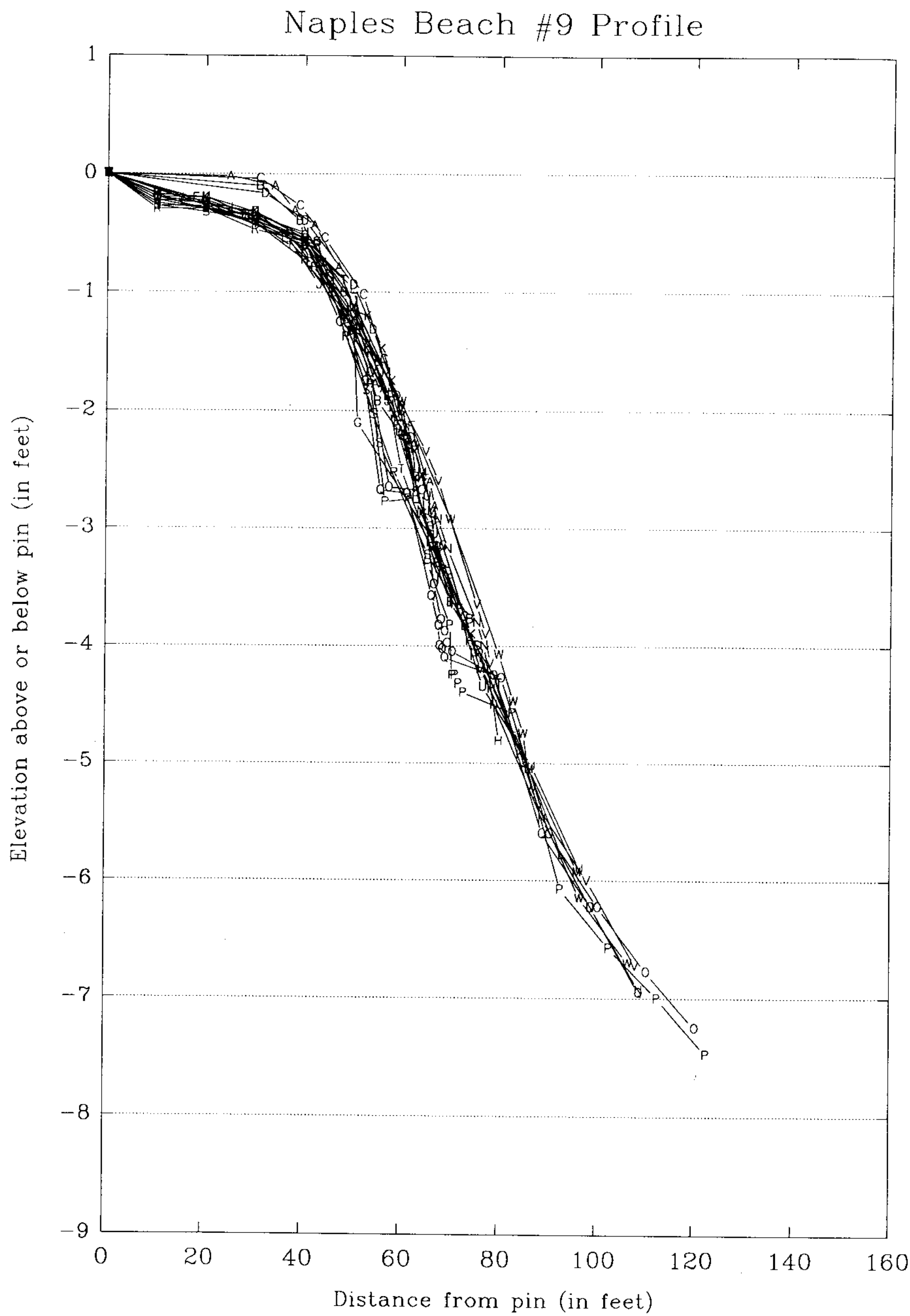

Naples Beach #8 Profile
Fall 1992
M = 10/1/92
N = 10/29/92
O = 11/30/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Naples Beach #8 Profile
Spring 1993
P = 5/4/93
Q = 6/3/93
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

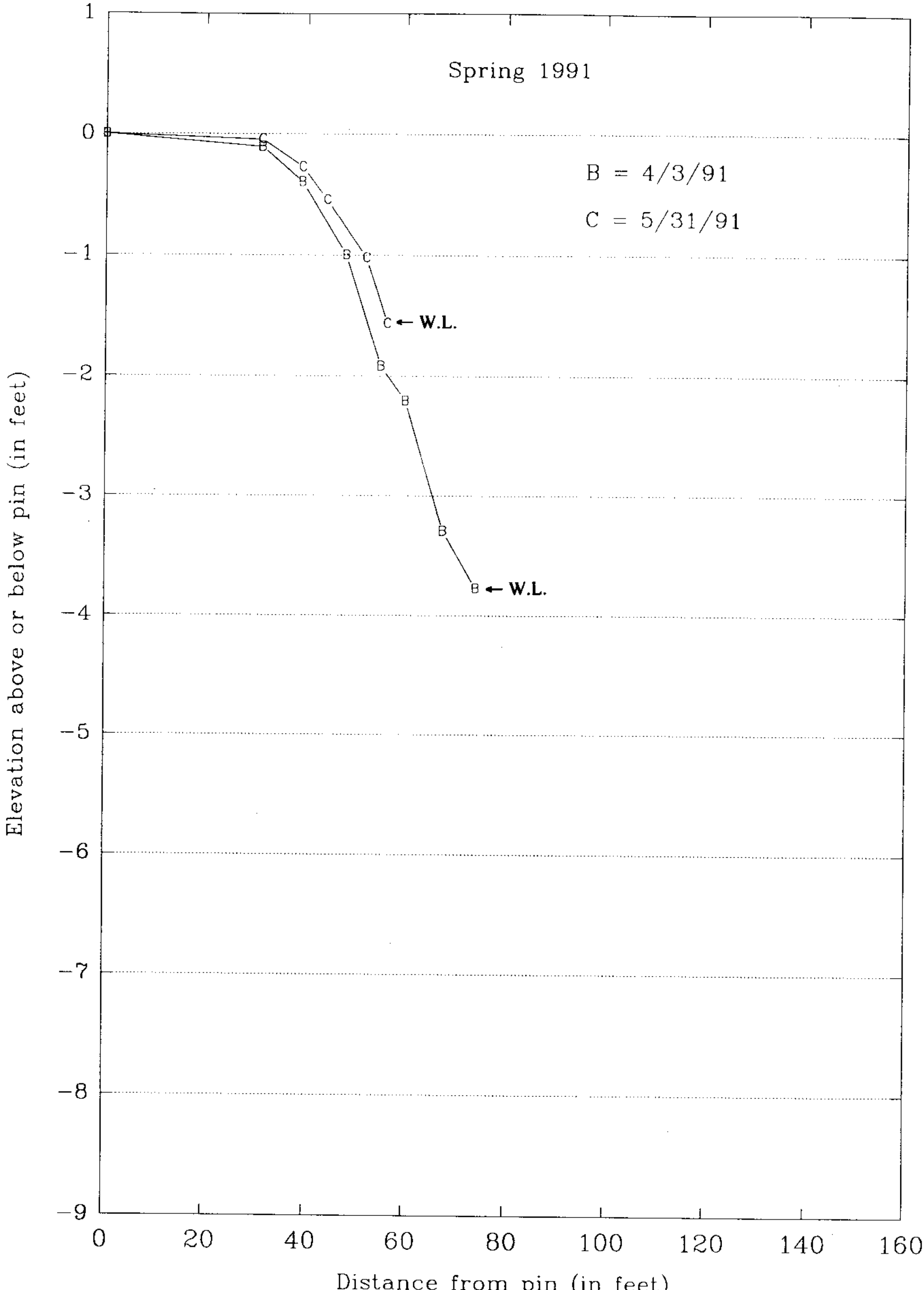


Naples Beach #8 Profile
Summer 1993
R = 7/1/93
S = 8/4/93
T = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

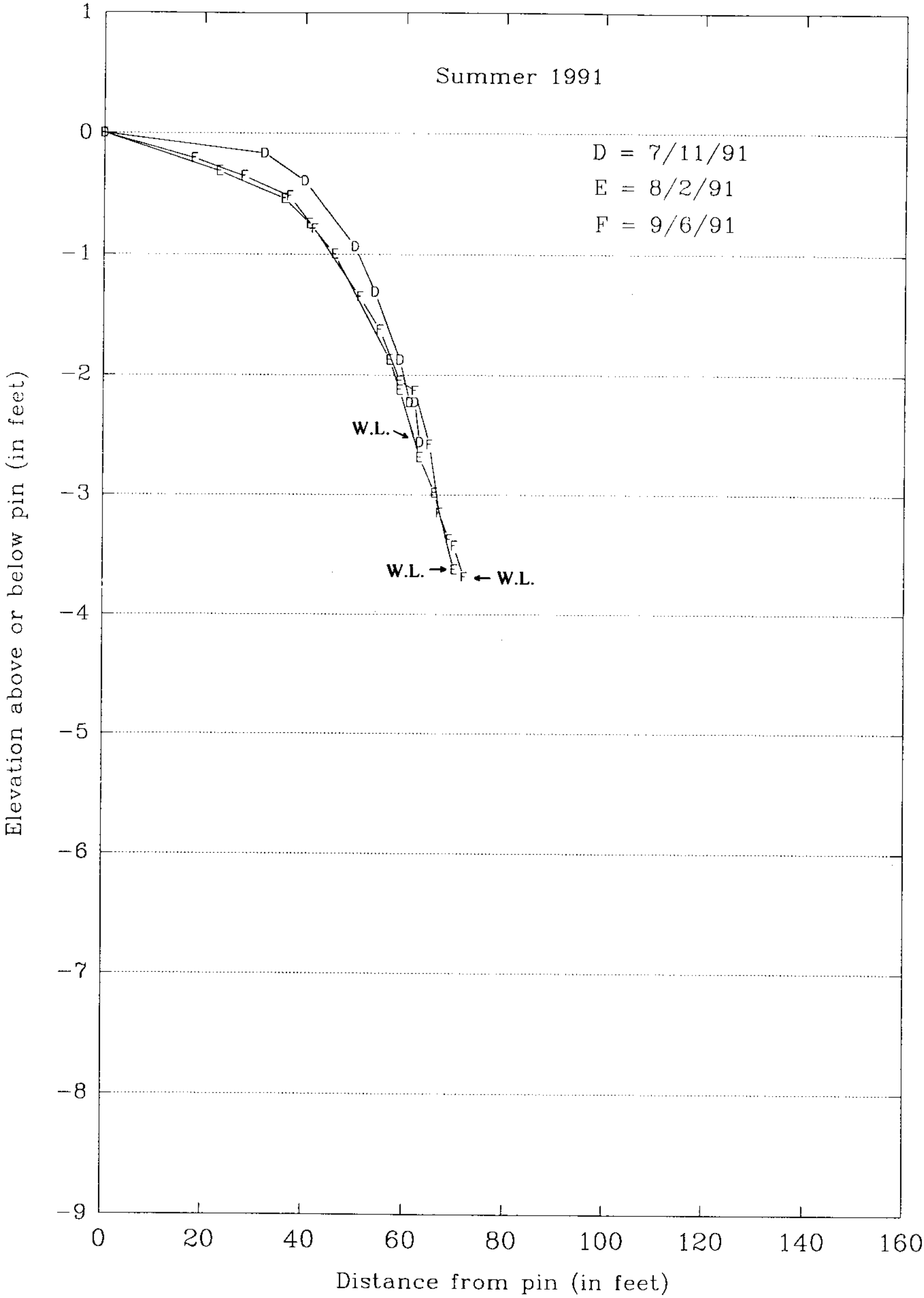

Naples Beach #8 Profile
Fall 1993
U = 10/4/93
← W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Naples Beach #9 Profile
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

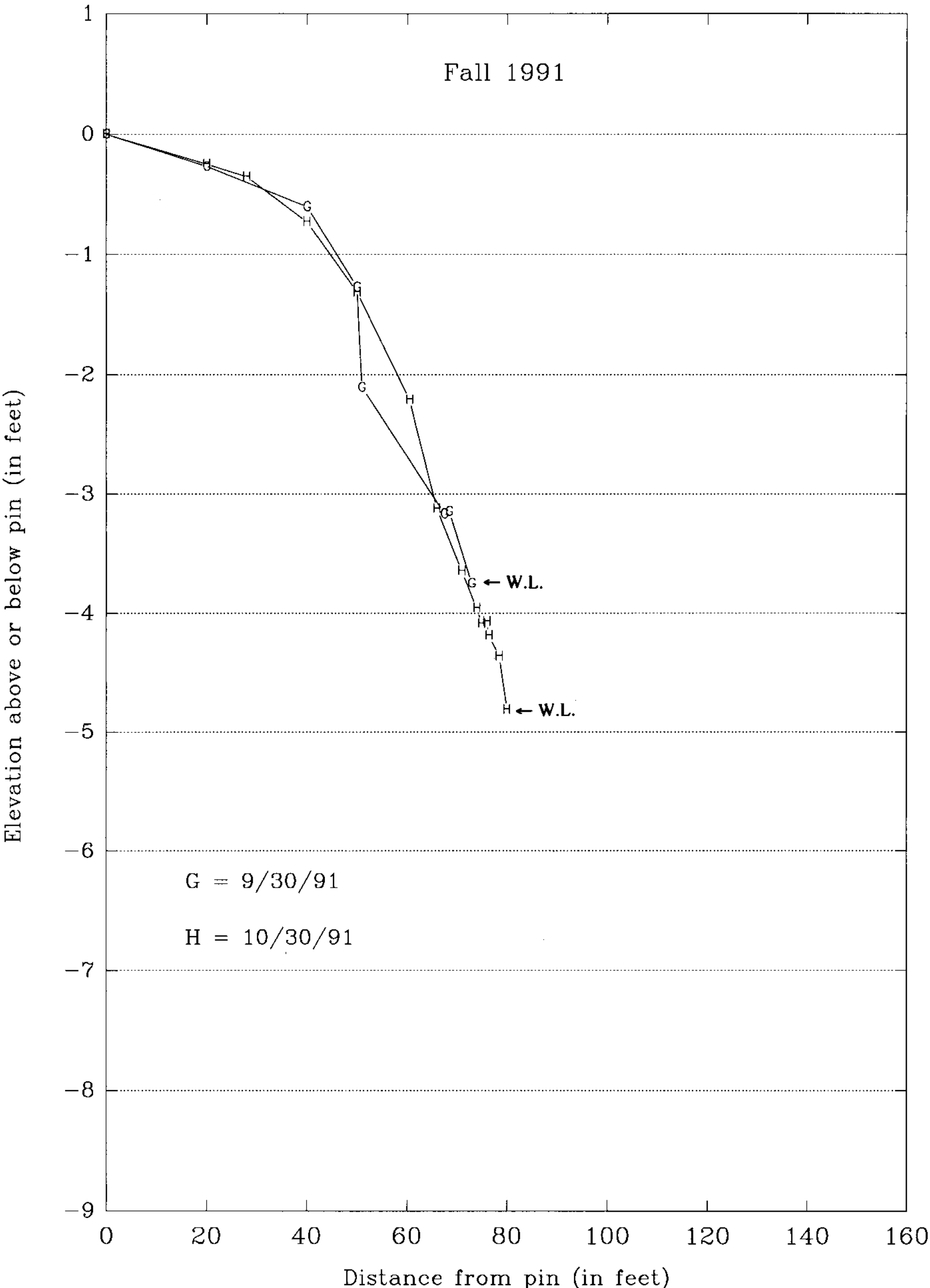
Naples Beach #9 Profile



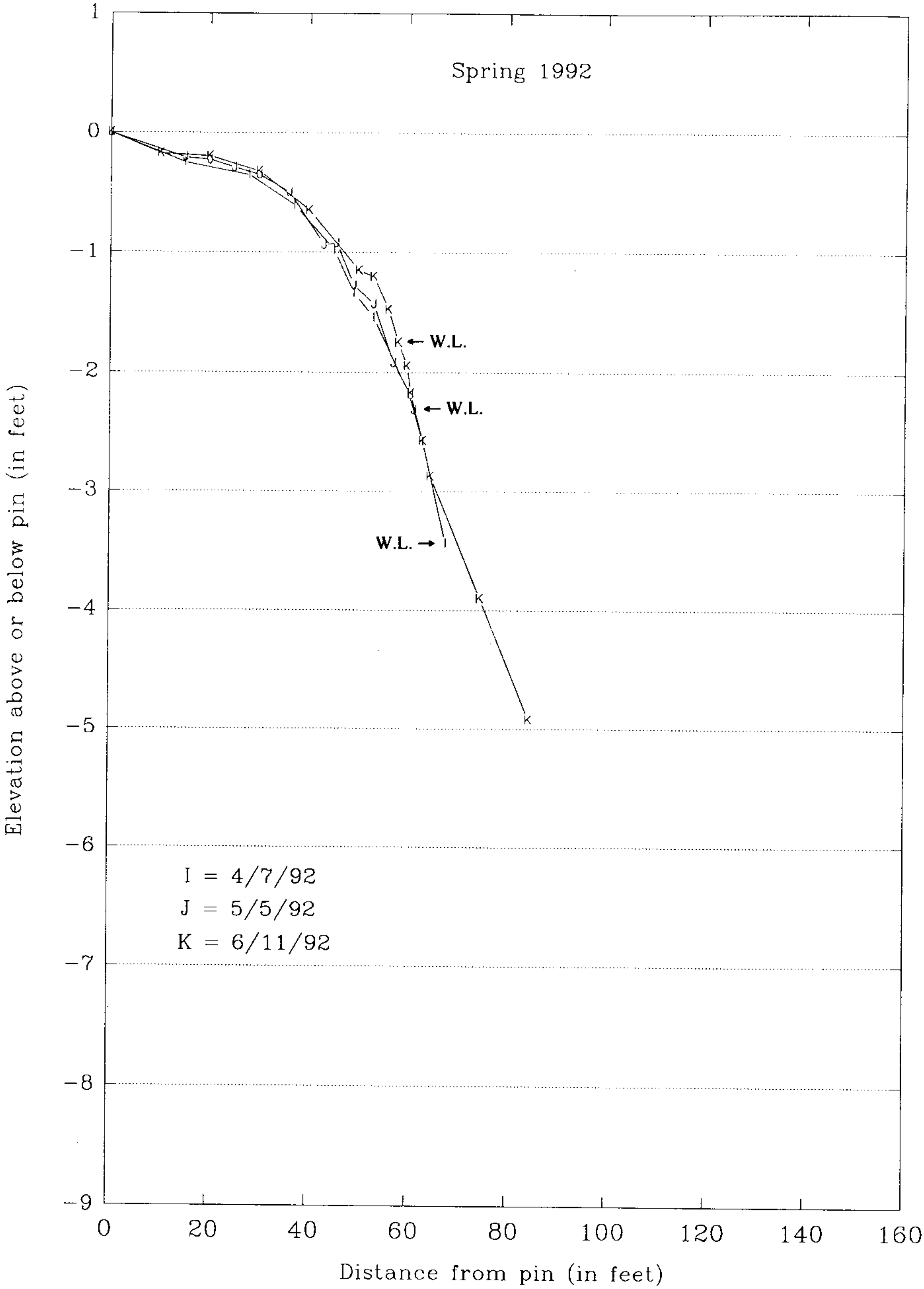
Naples Beach #9 Profile



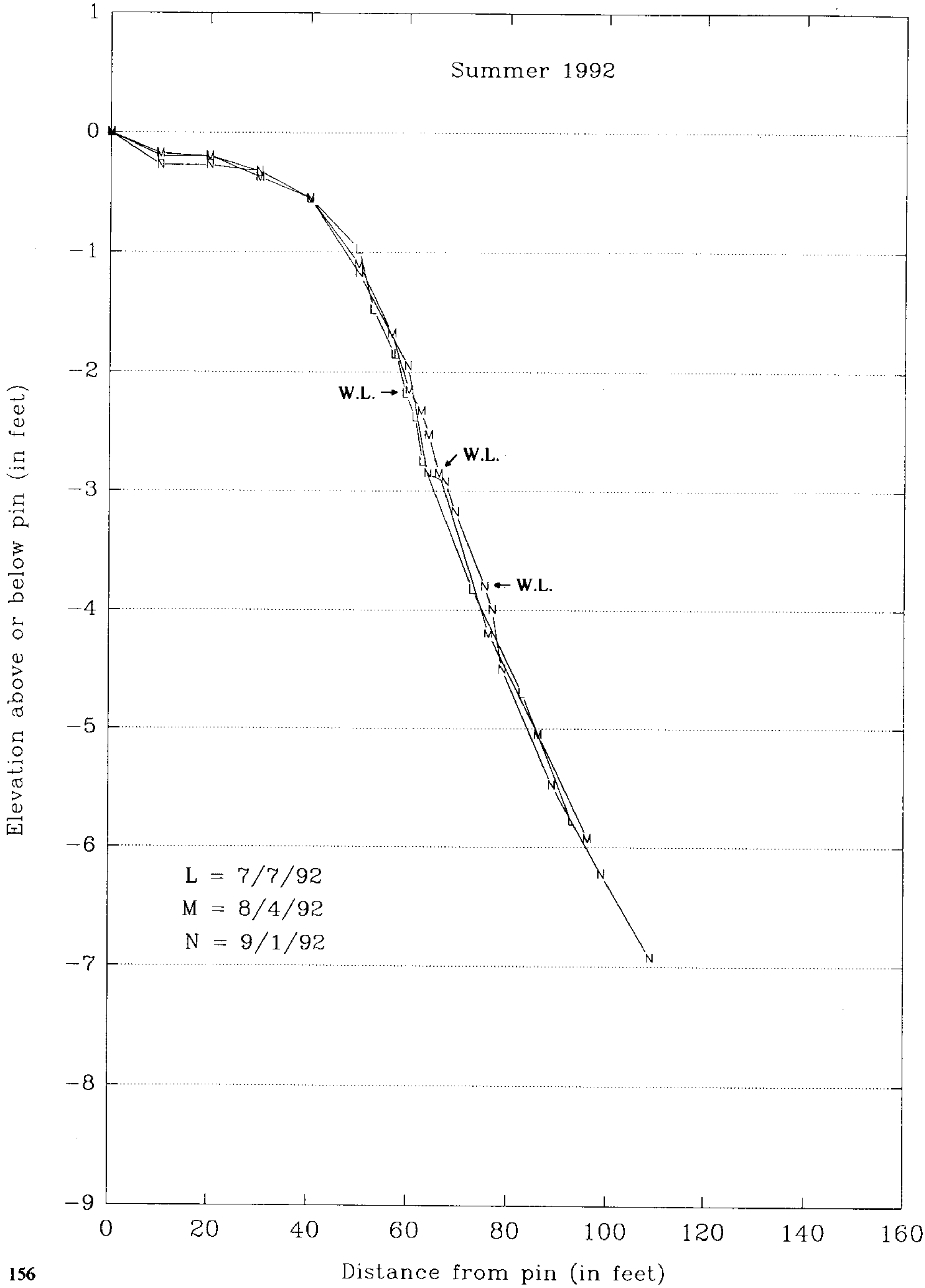
Naples Beach #9 Profile



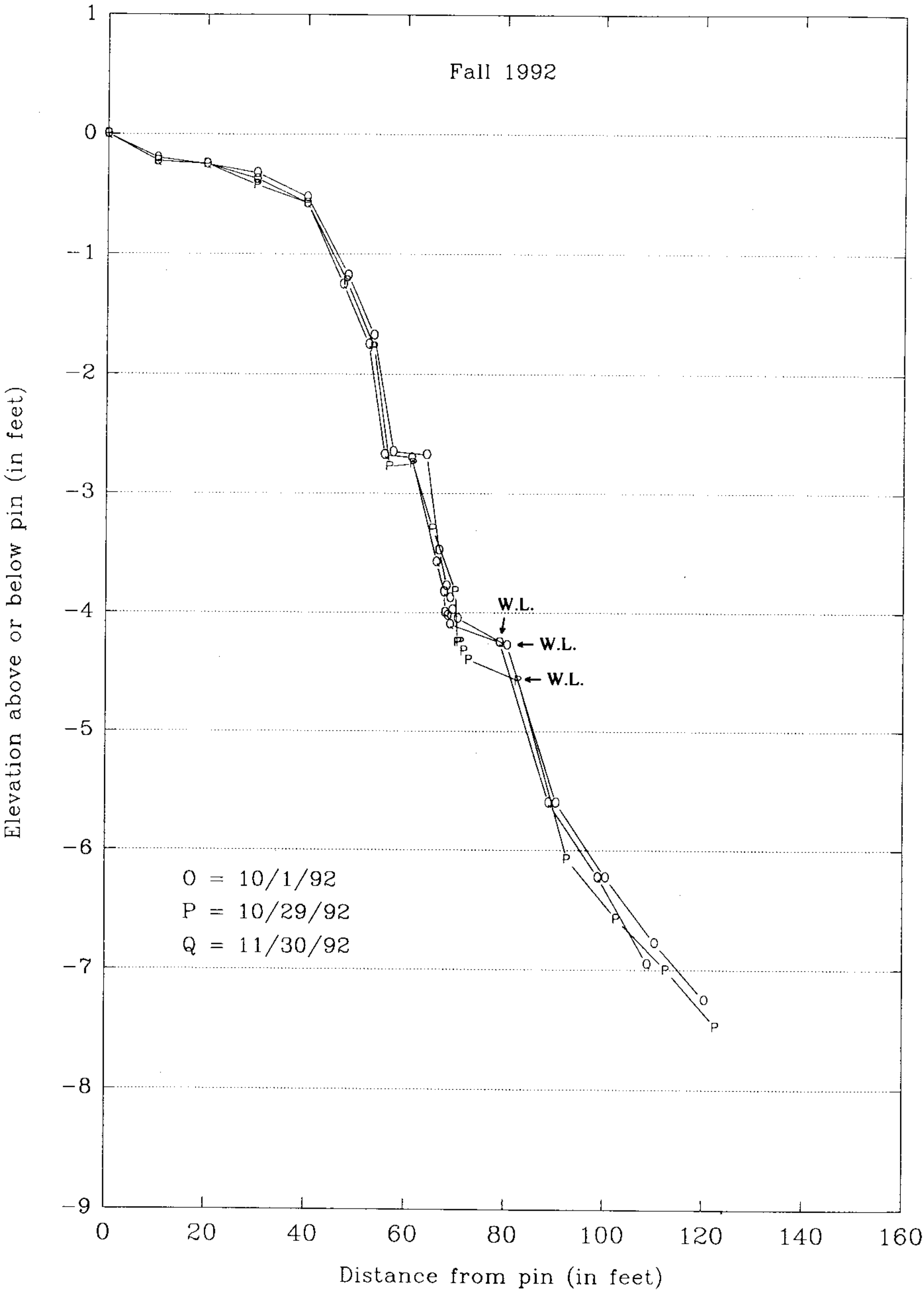
Naples Beach #9 Profile

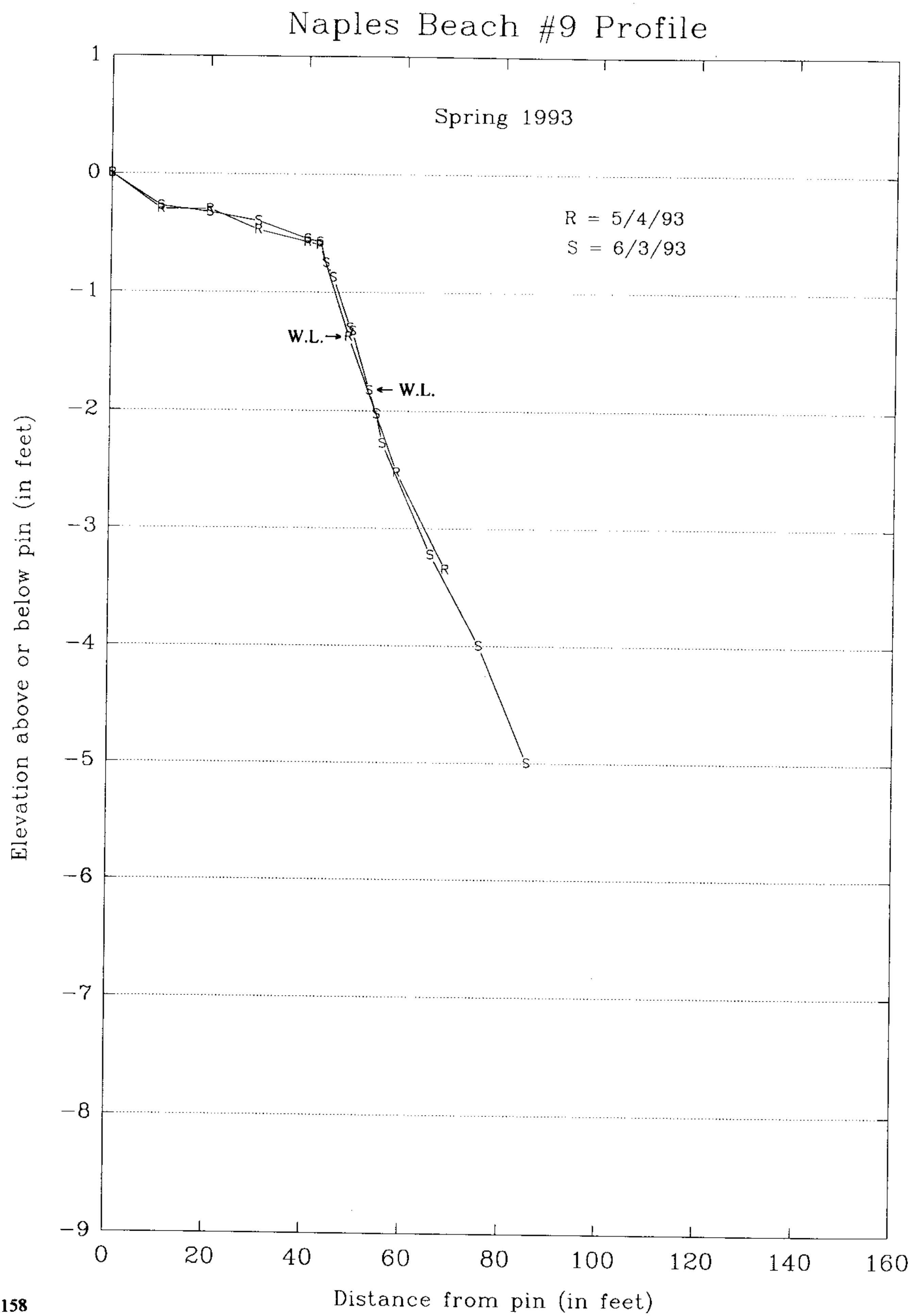


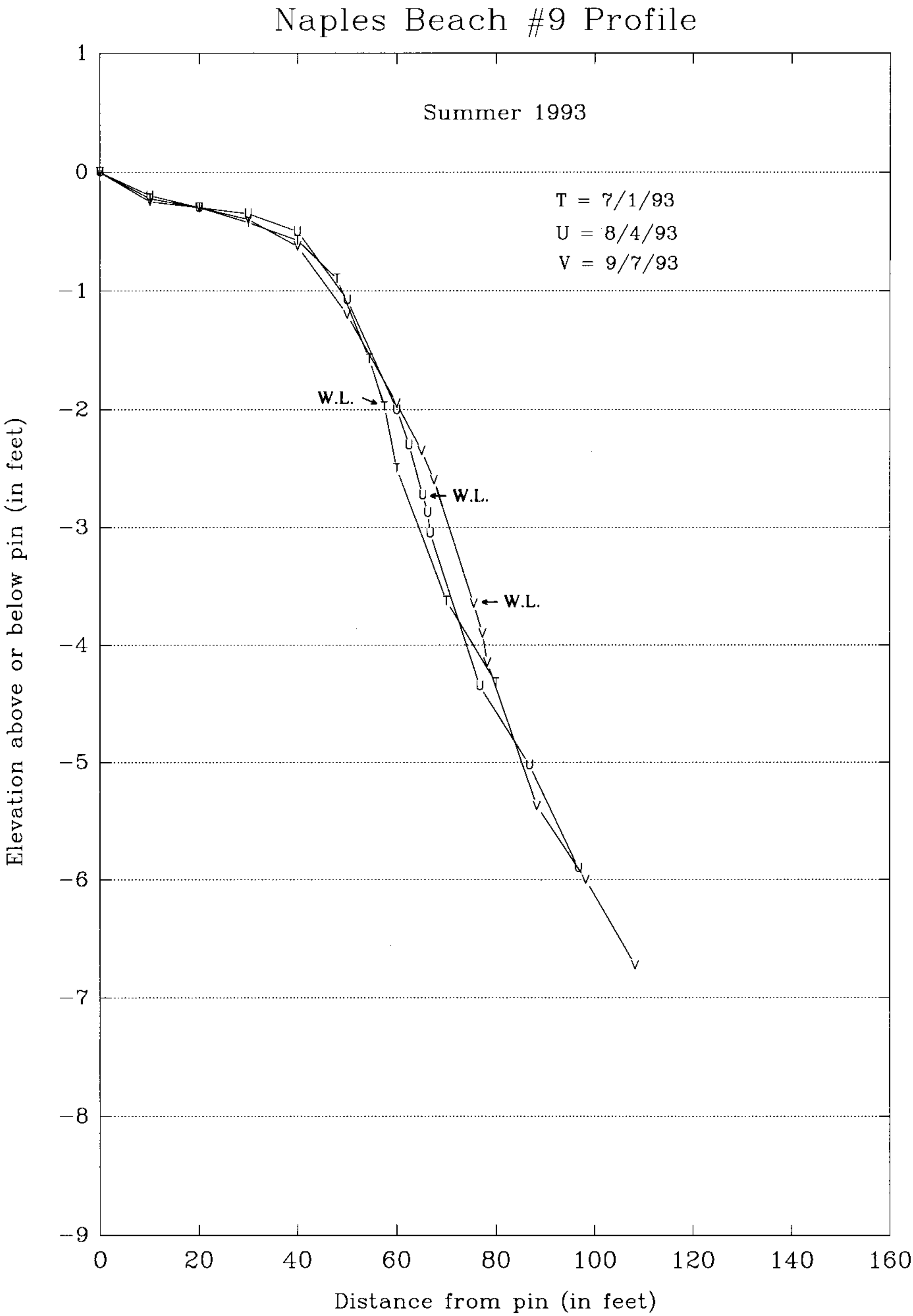
Naples Beach #9 Profile

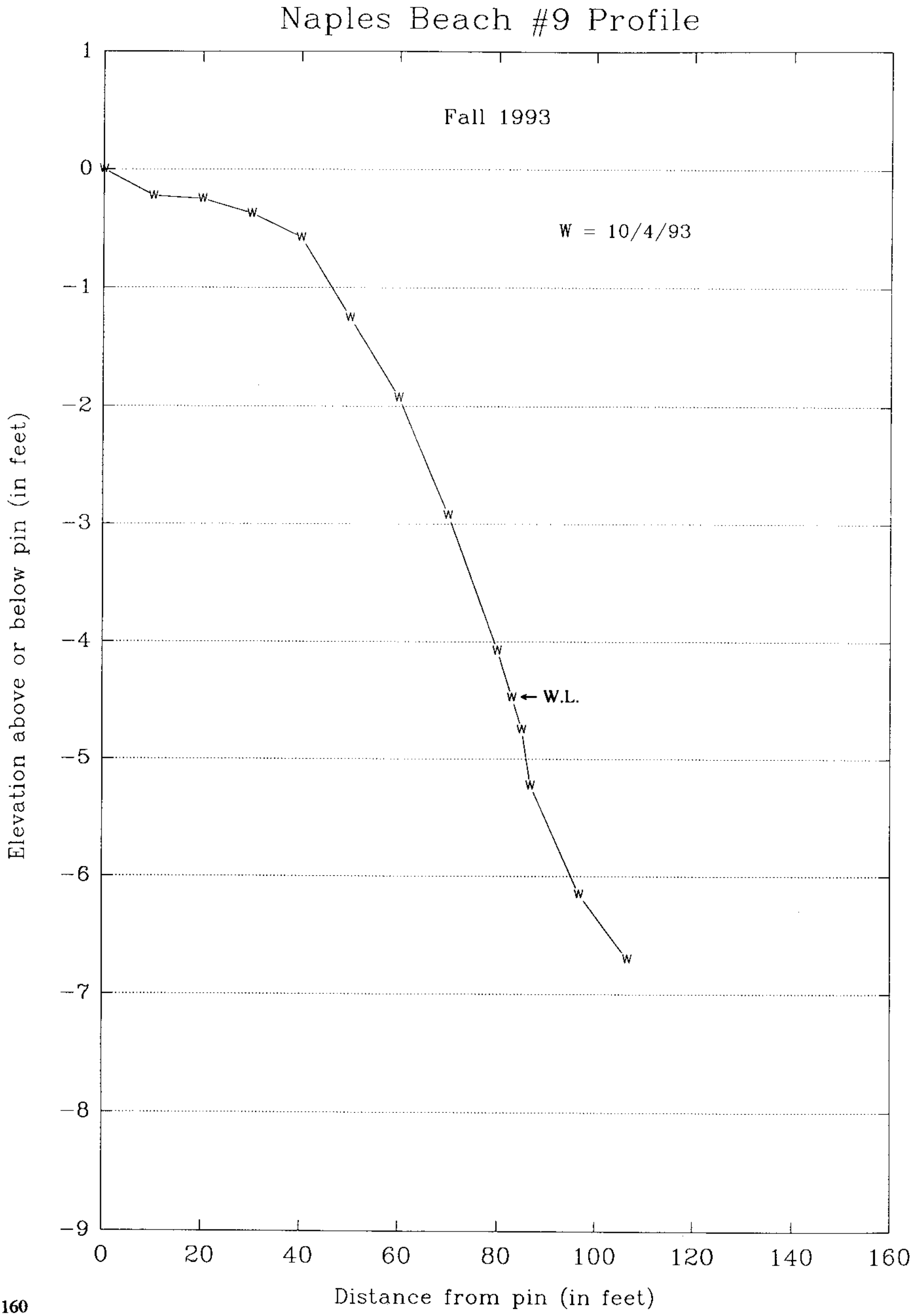


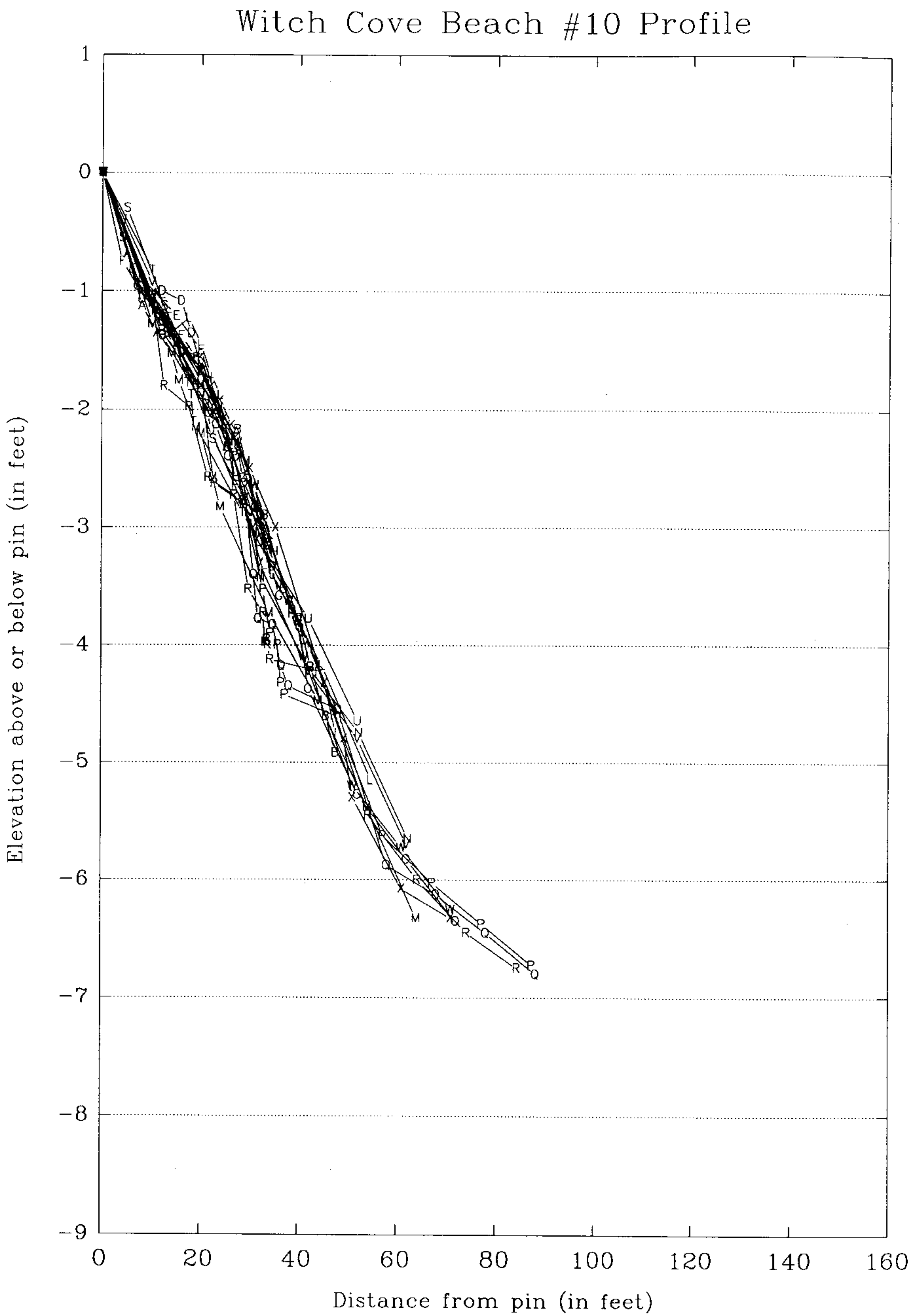
Naples Beach #9 Profile



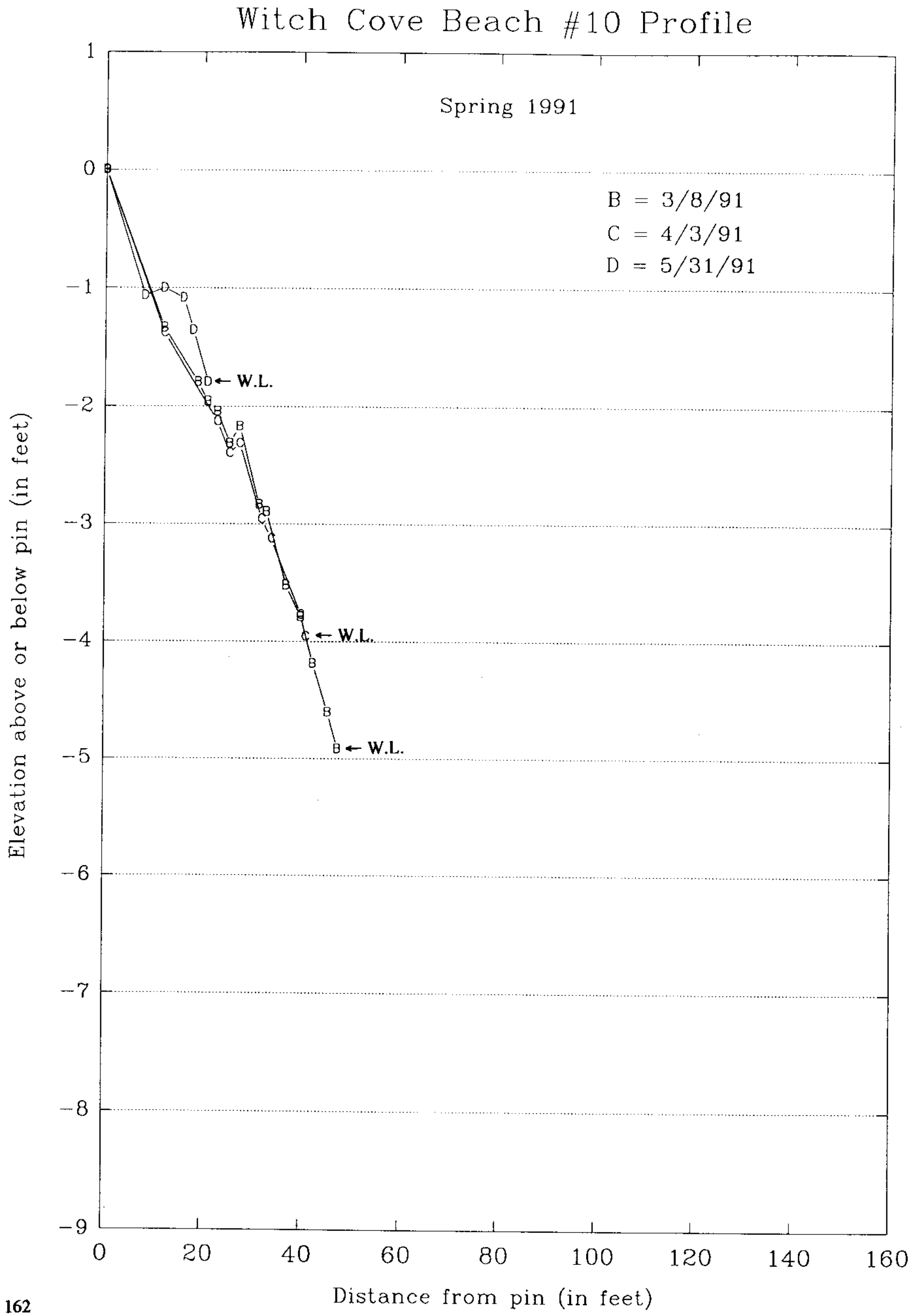

Naples Beach #9 Profile
Spring 1993
R = 5/4/93
S = 6/3/93
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

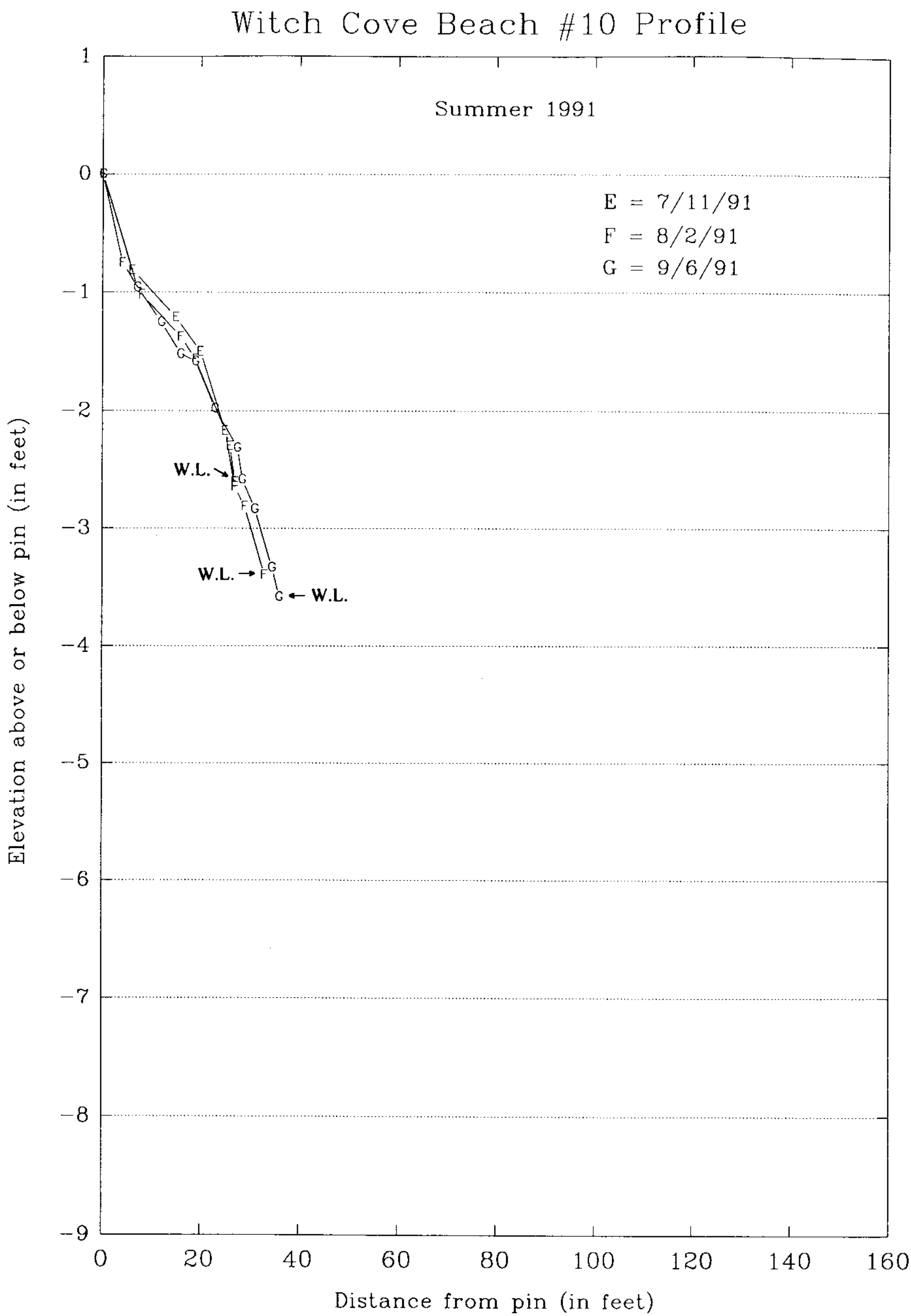

Naples Beach #9 Profile
Summer 1993
T = 7/1/93
U = 8/4/93
V = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Naples Beach #9 Profile
Fall 1993
W = 10/4/93
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

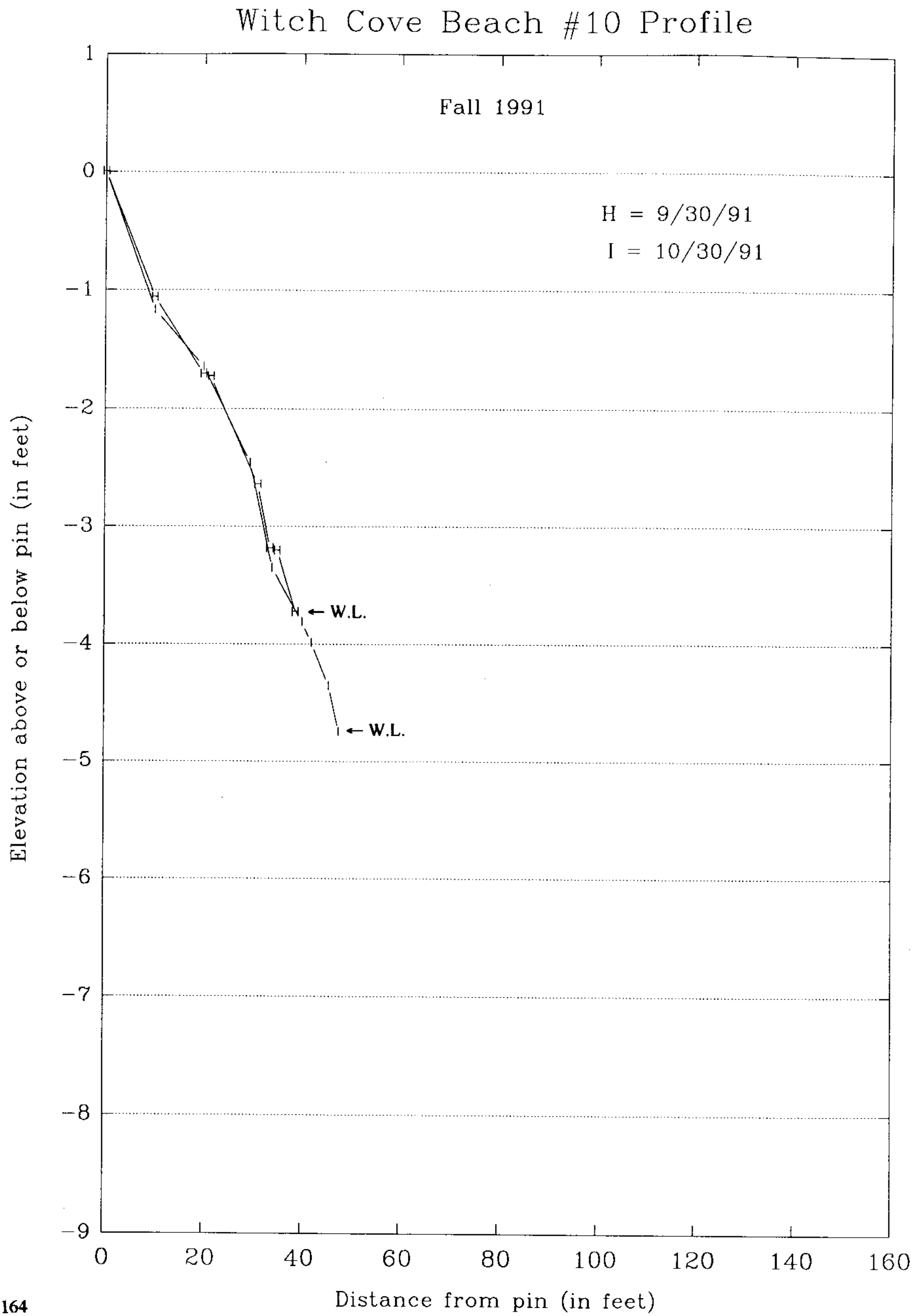


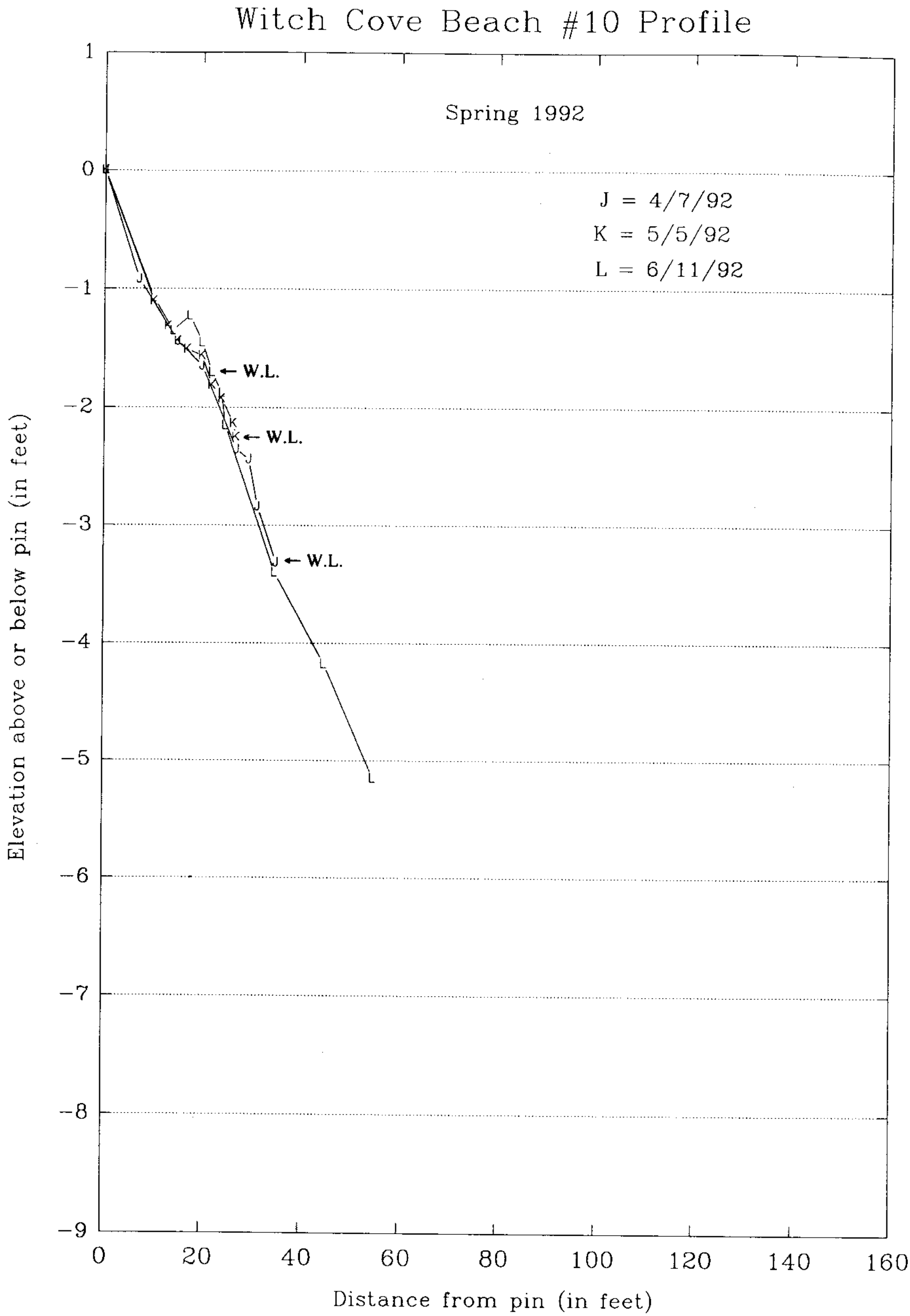
Witch Cove Beach #10 Profile
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

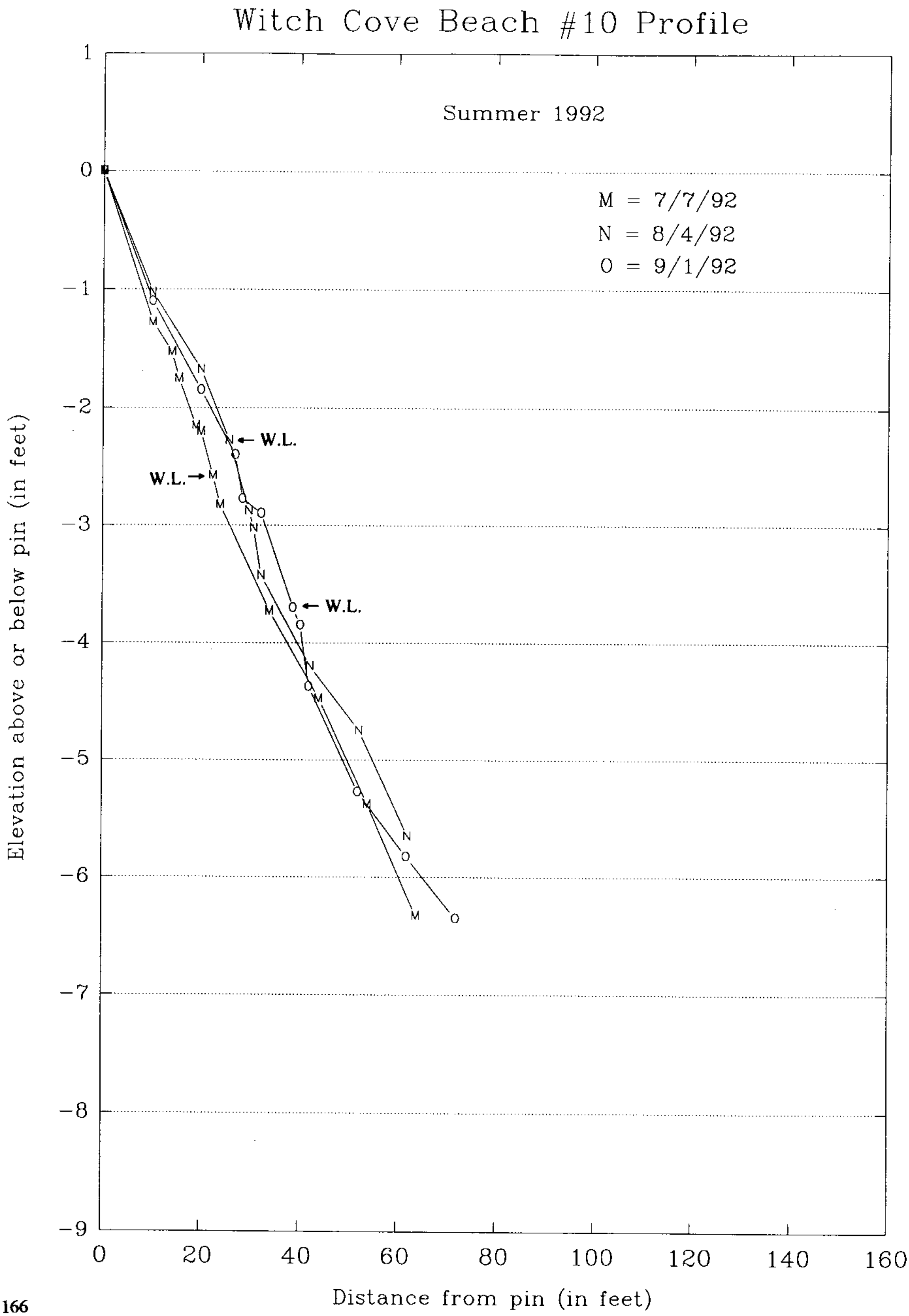

Witch Cove Beach #10 Profile
Spring 1991
B = 3/8/91
C = 4/3/91
D = 5/31/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

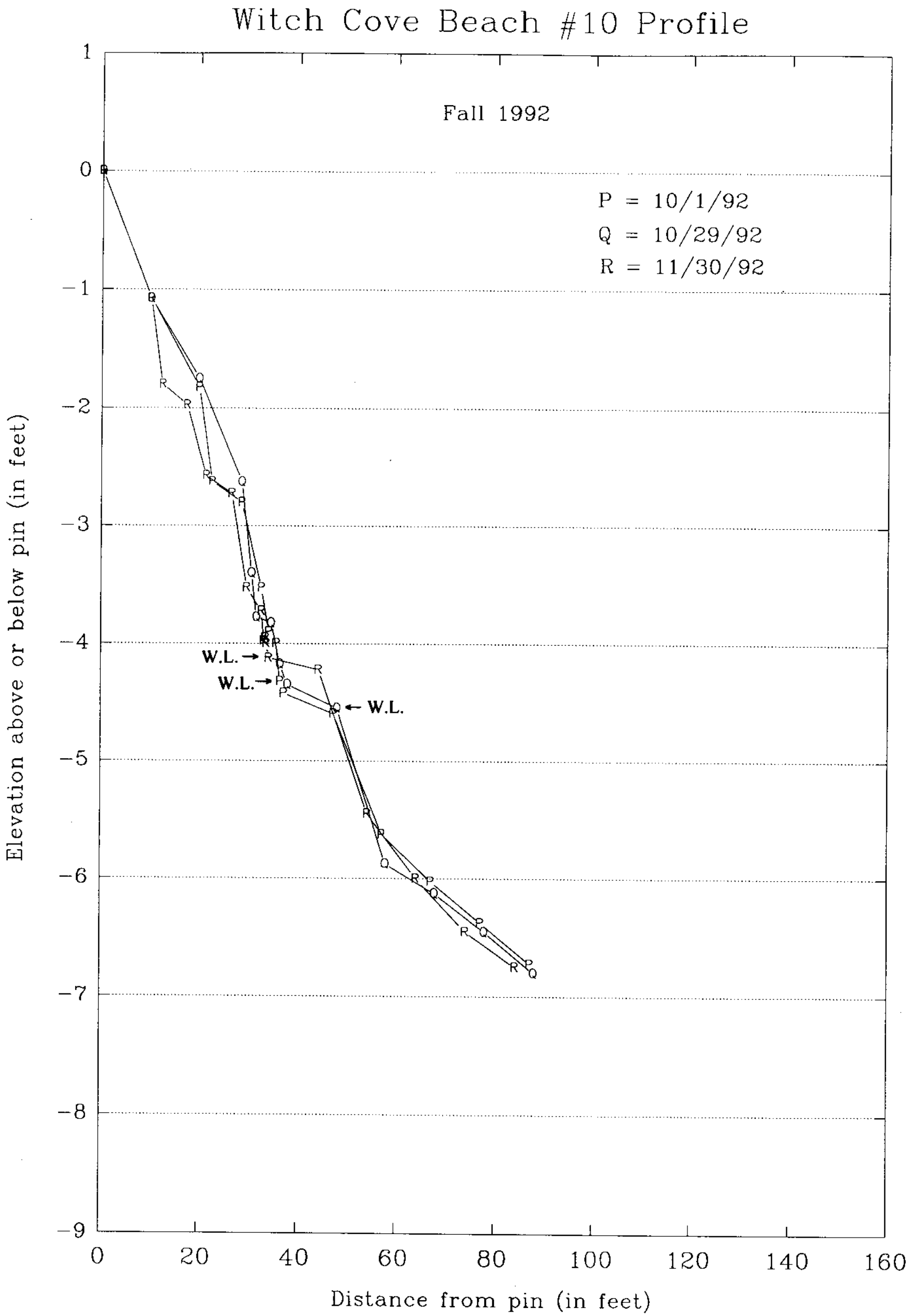


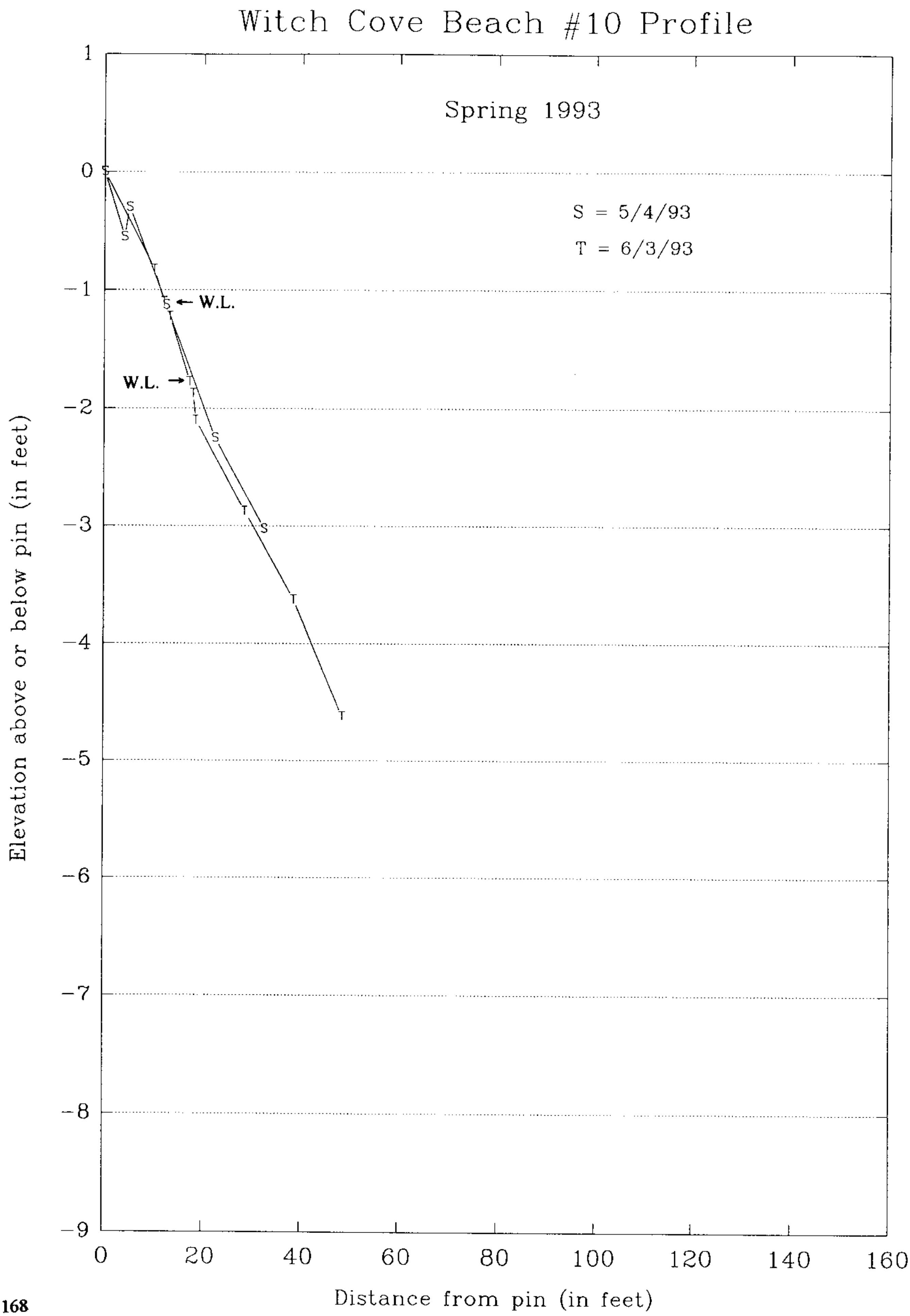
Witch Cove Beach #10 Profile
Summer 1991
E = 7/11/91
F = 8/2/91
G = 9/6/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Witch Cove Beach #10 Profile
Fall 1991
H = 9/30/91
I = 10/30/91
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

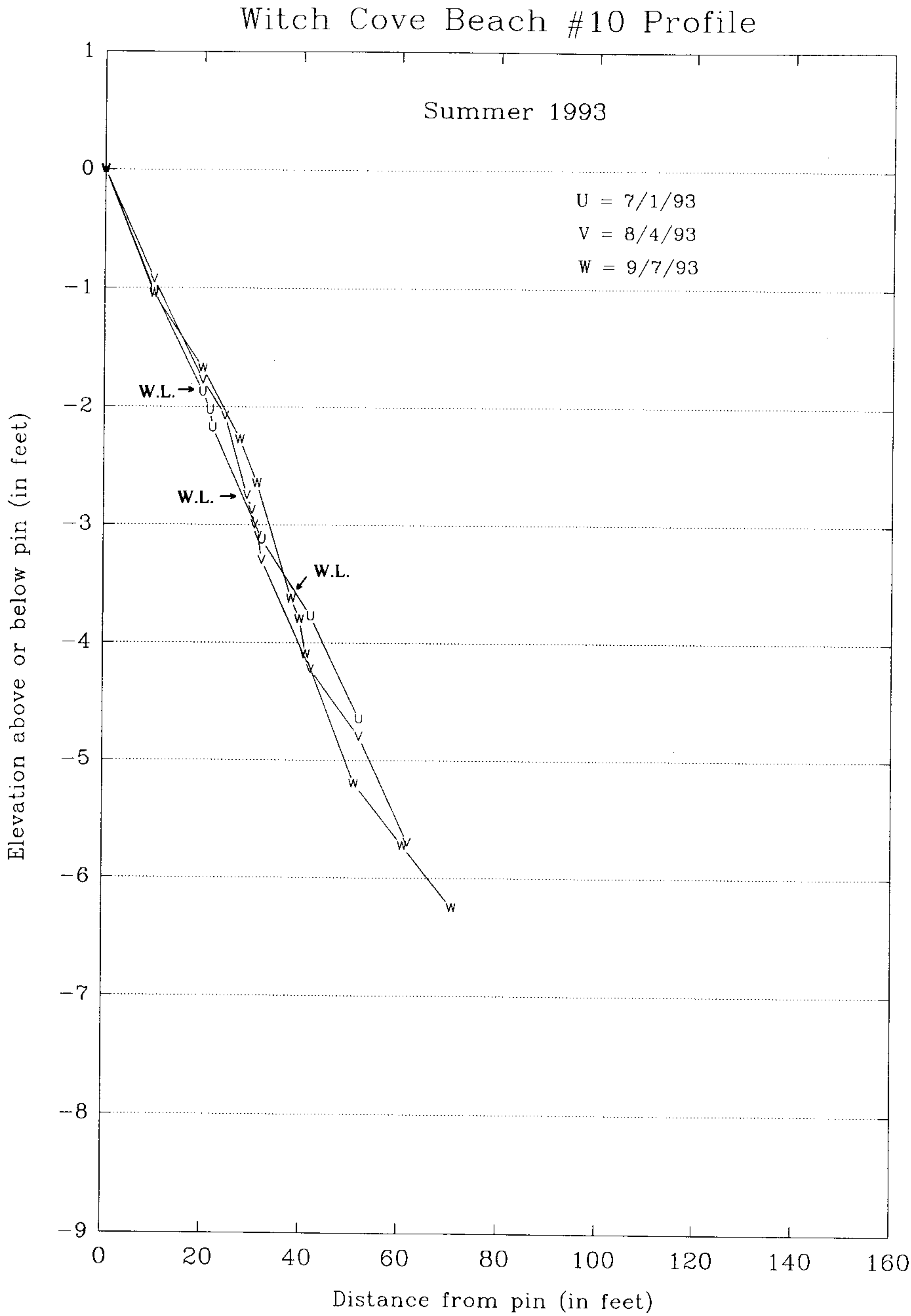

Witch Cove Beach #10 Profile
Spring 1992
J = 4/7/92
K = 5/5/92
L = 6/11/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

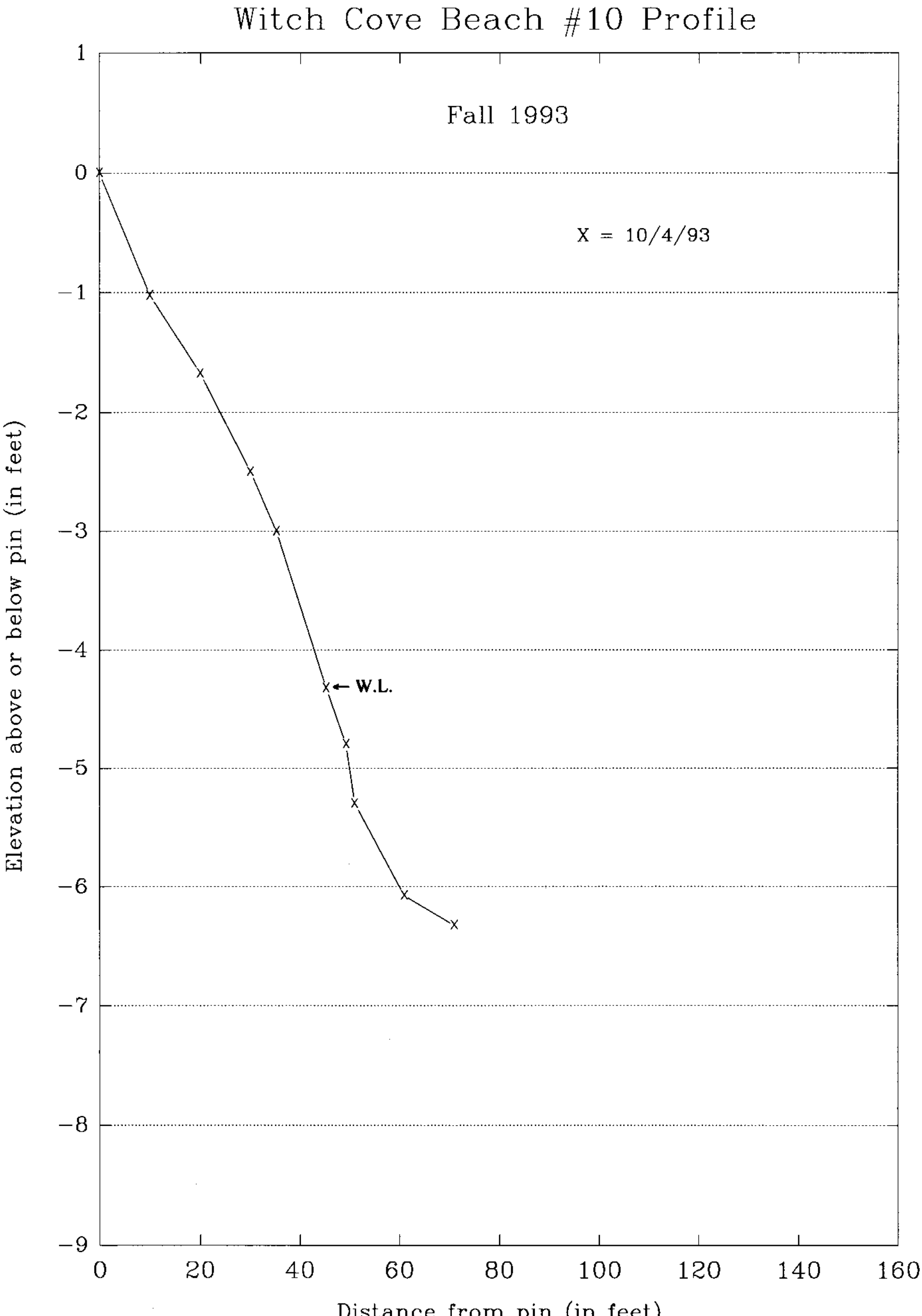

Witch Cove Beach #10 Profile
Summer 1992
M = 7/7/92
N = 8/4/92
O = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

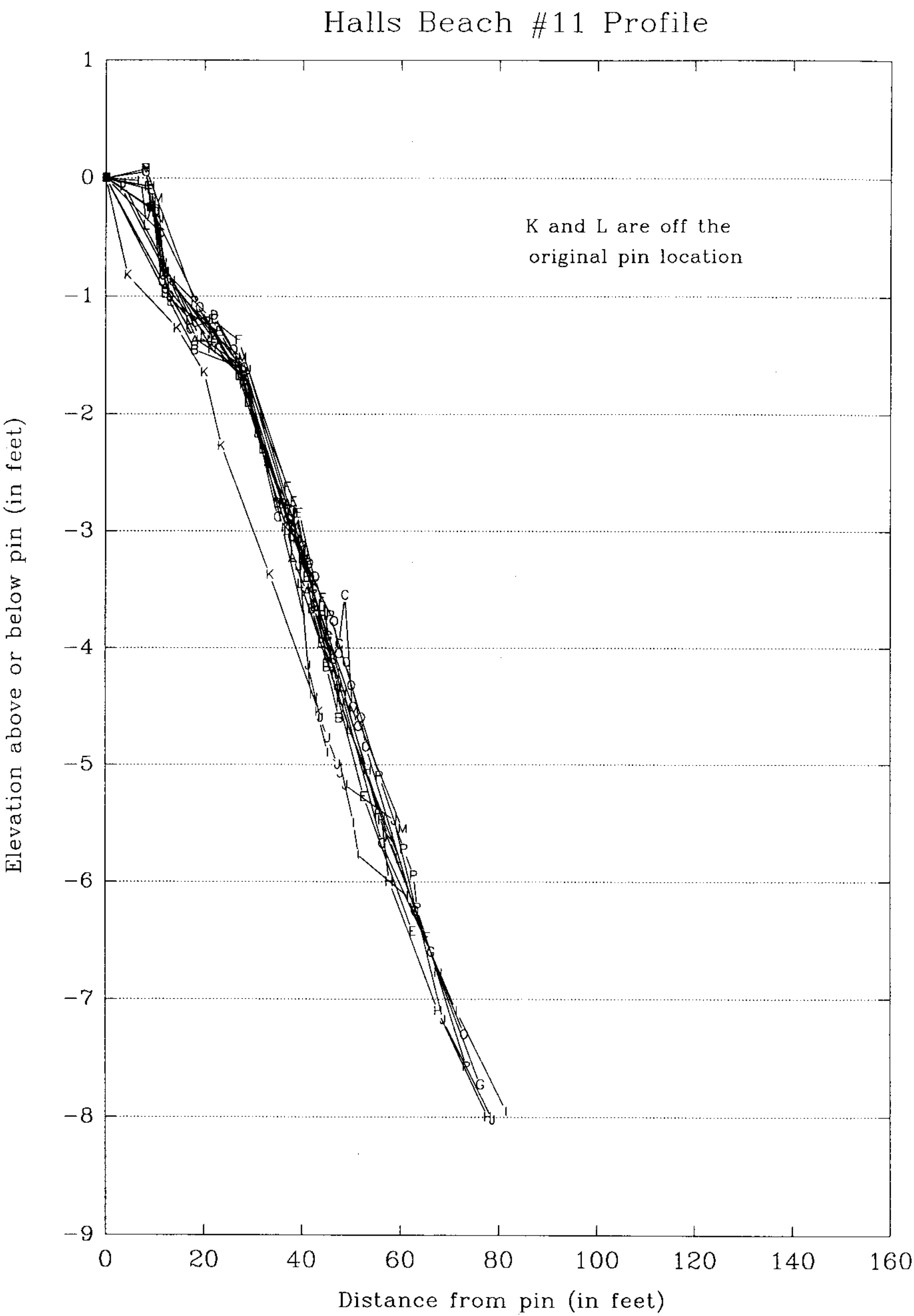

Witch Cove Beach #10 Profile
Fall 1992
P = 10/1/92
Q = 10/29/92
R = 11/30/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160



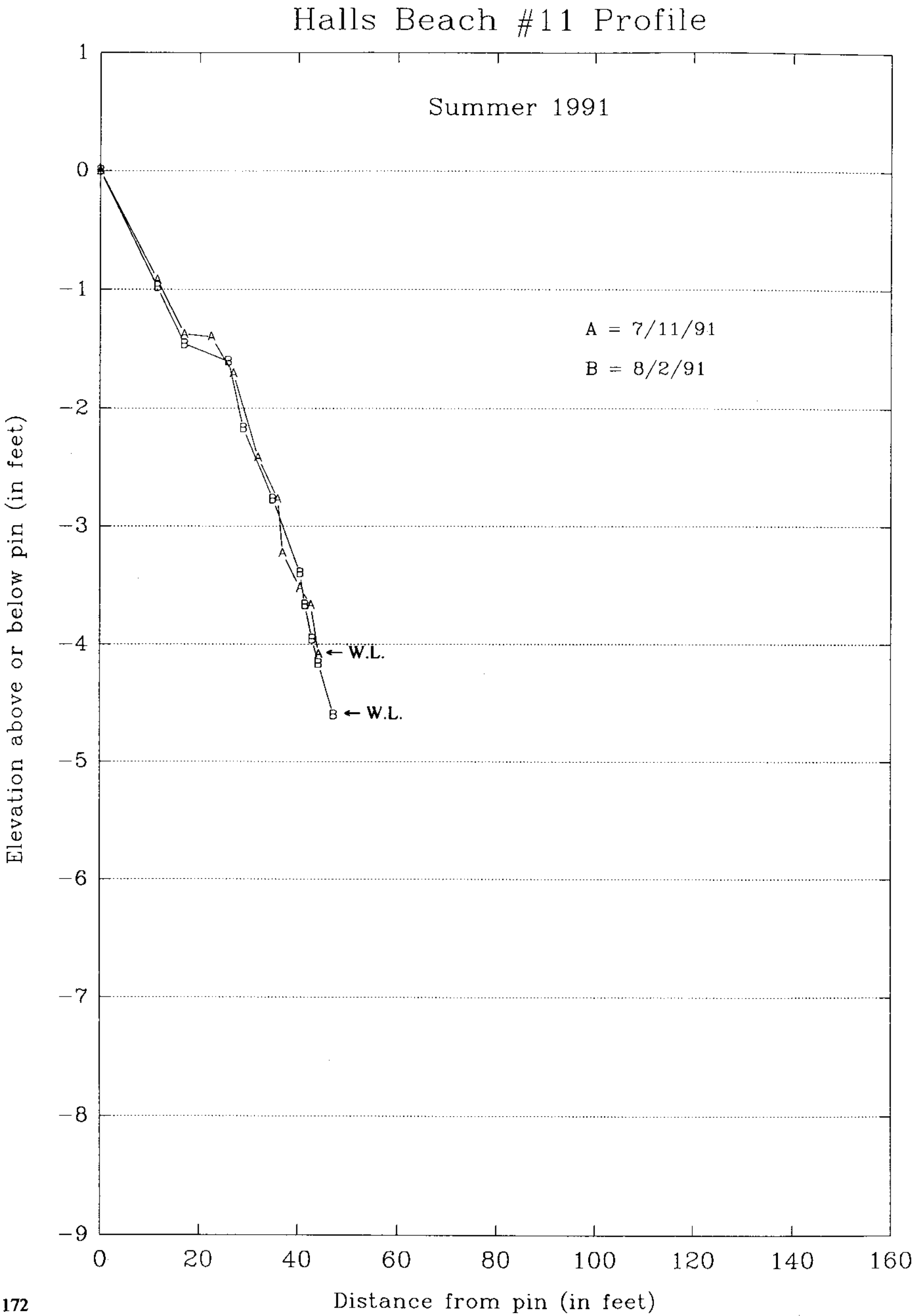
Witch Cove Beach #10 Profile
Spring 1993
S = 5/4/93
T = 6/3/93
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Witch Cove Beach #10 Profile
Summer 1993
U = 7/1/93
V = 8/4/93
W = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

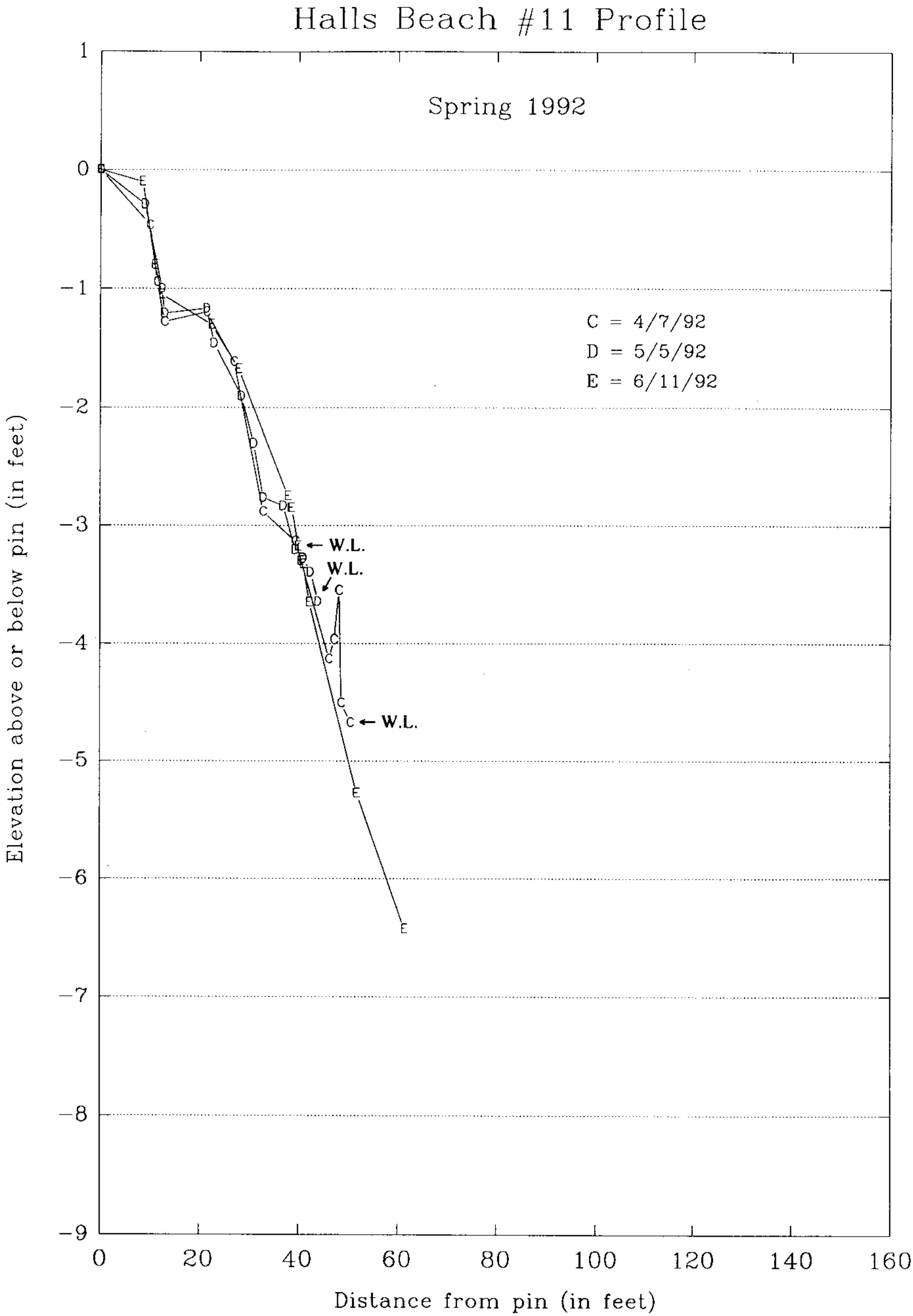

Witch Cove Beach #10 Profile
Fall 1993
X = 10/4/93
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

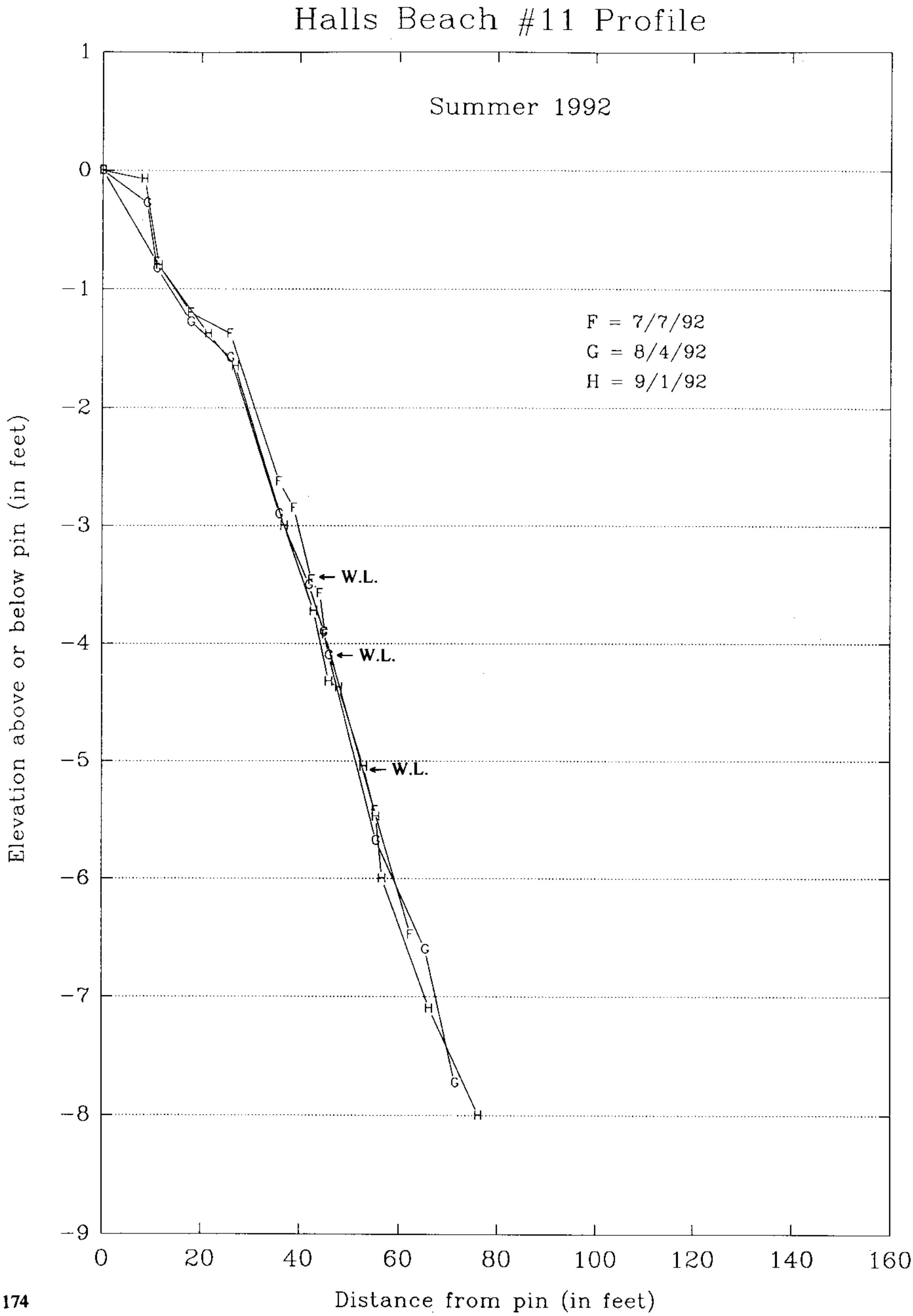


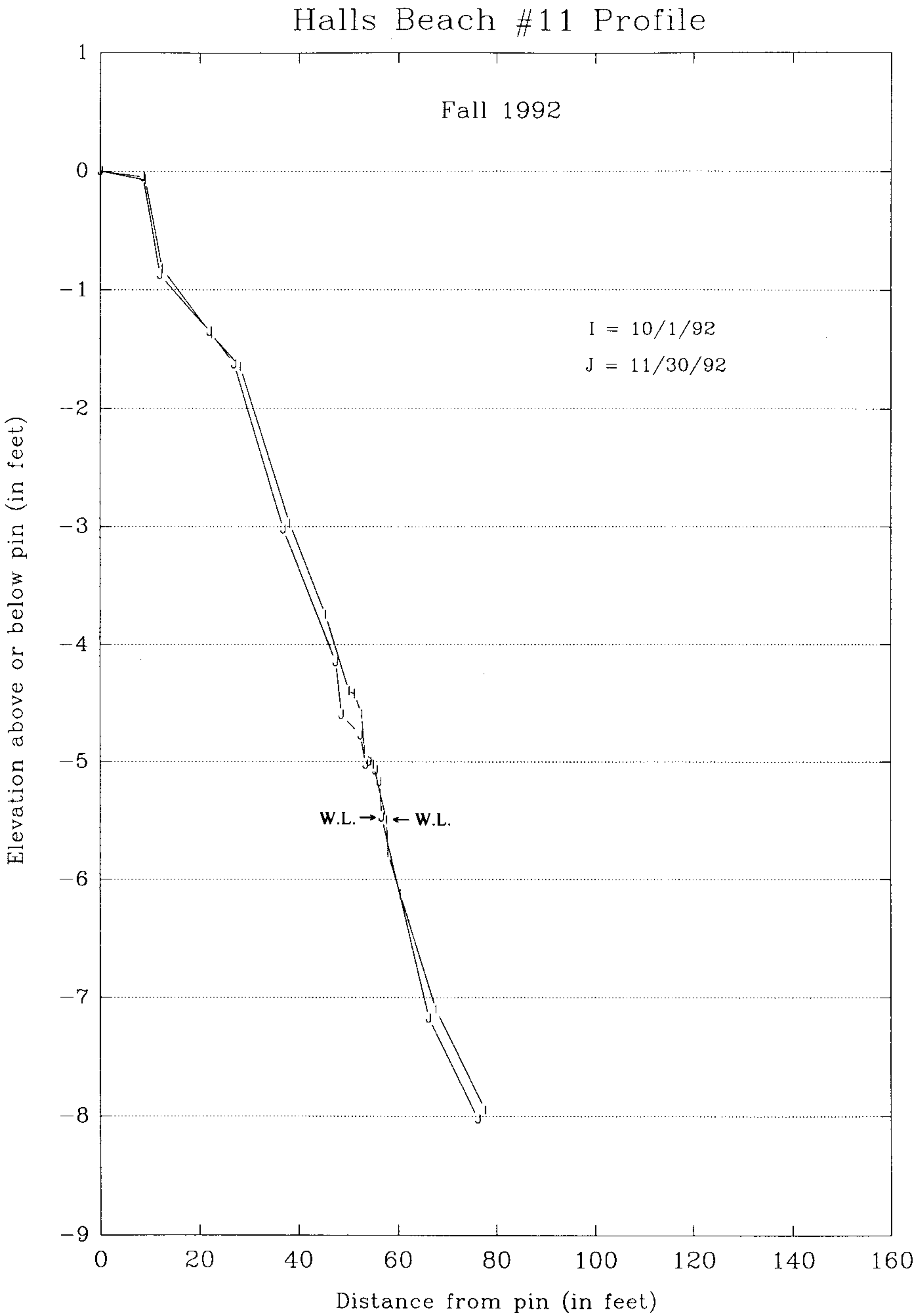
Halls Beach #11 Profile
K and L are off the original pin location
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

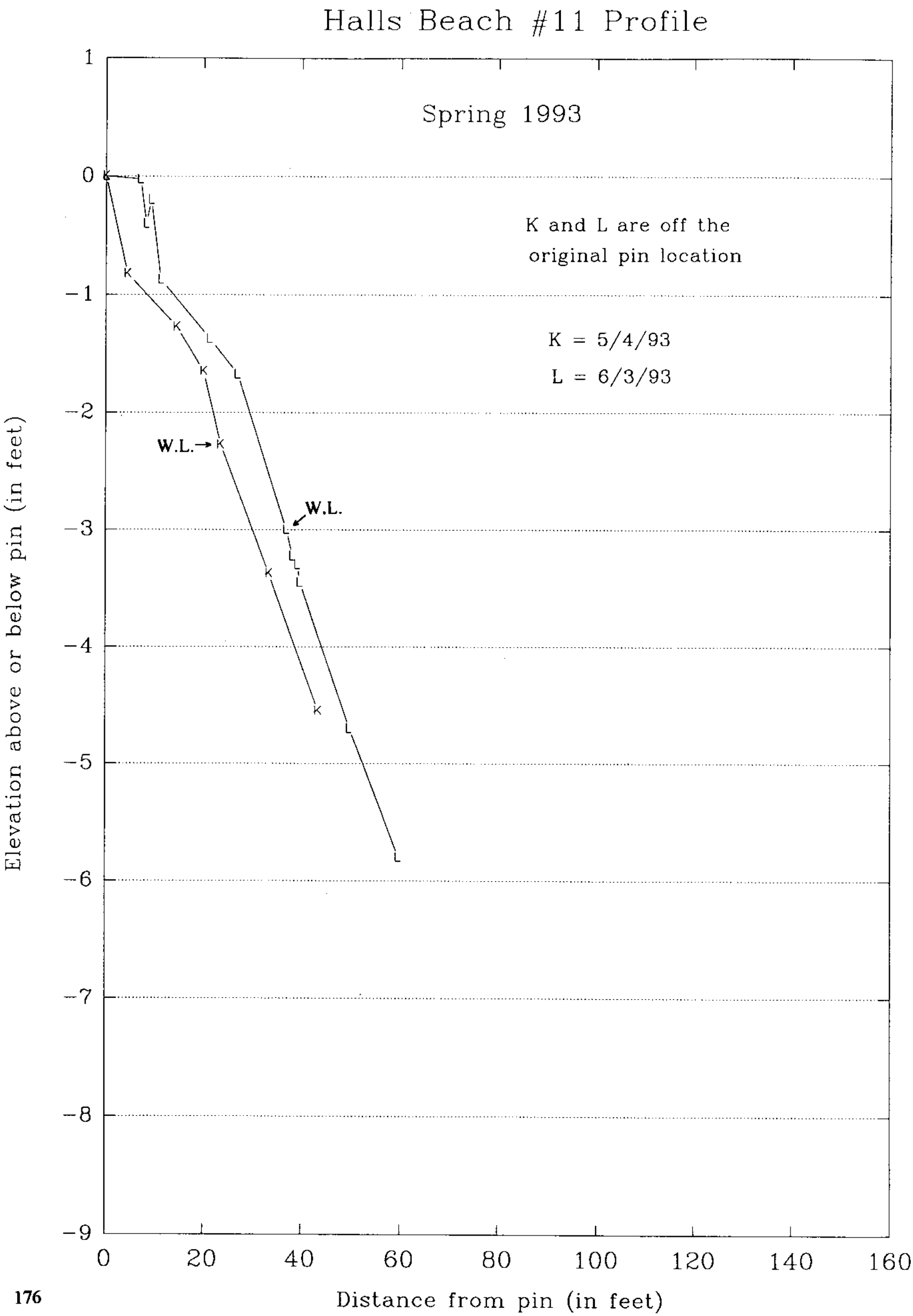


Halls Beach #11 Profile
Summer 1991
A = 7/11/91
B = 8/2/91
← W.L.
← W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

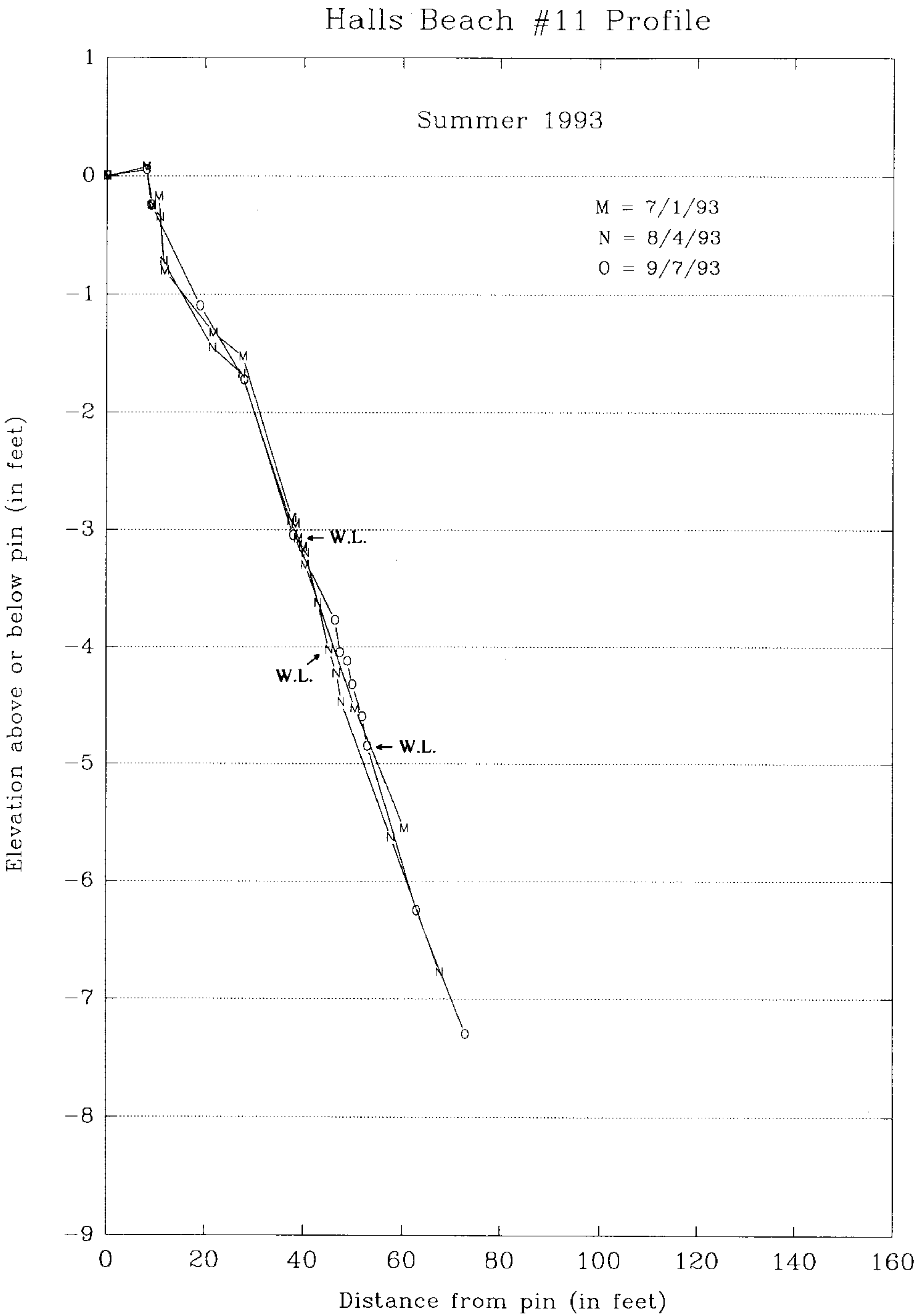

Halls Beach #11 Profile
Spring 1992
C = 4/7/92
D = 5/5/92
E = 6/11/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

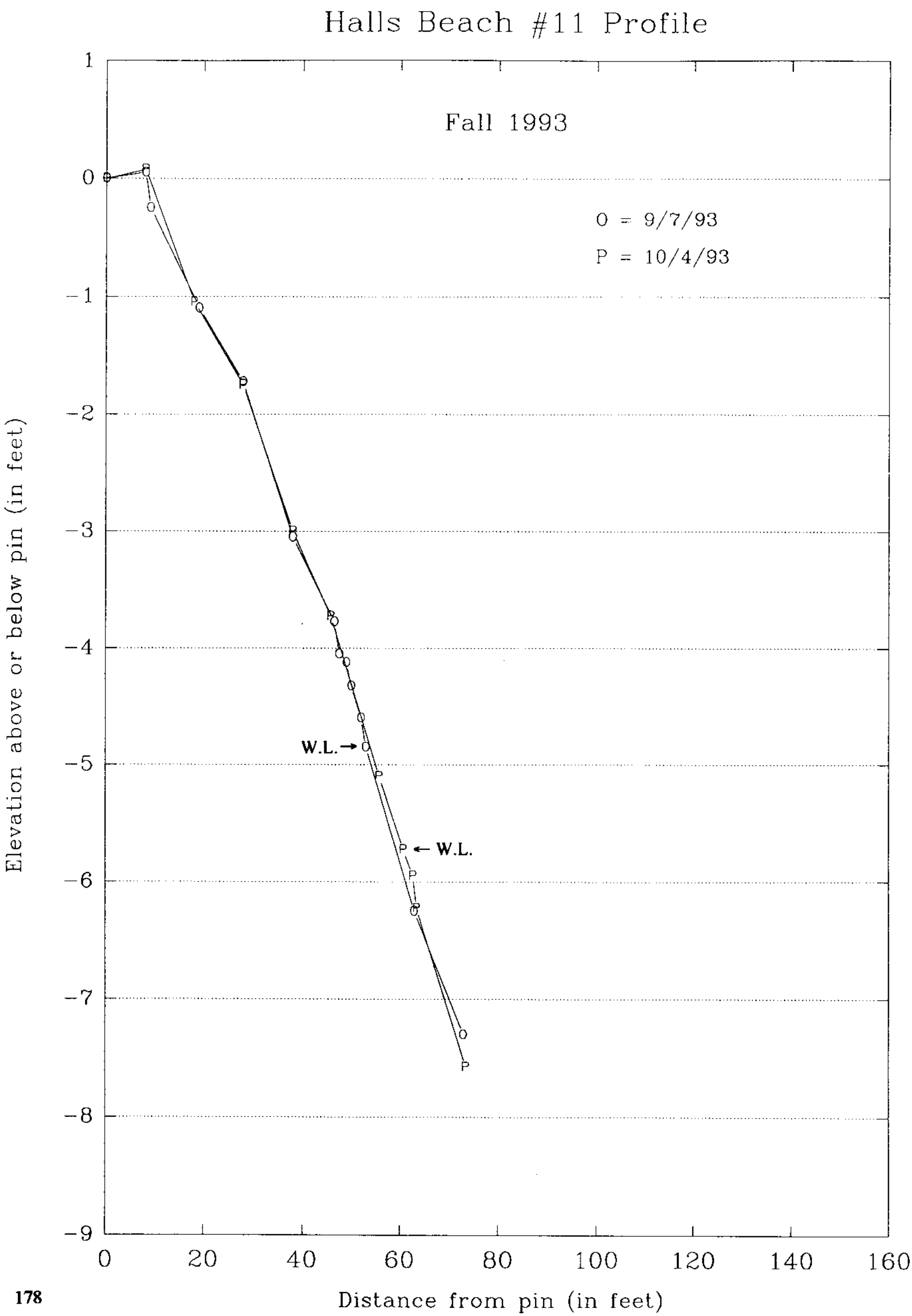

Halls Beach #11 Profile
Summer 1992
F = 7/7/92
G = 8/4/92
H = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Halls Beach #11 Profile
Fall 1992
I = 10/1/92
J = 11/30/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

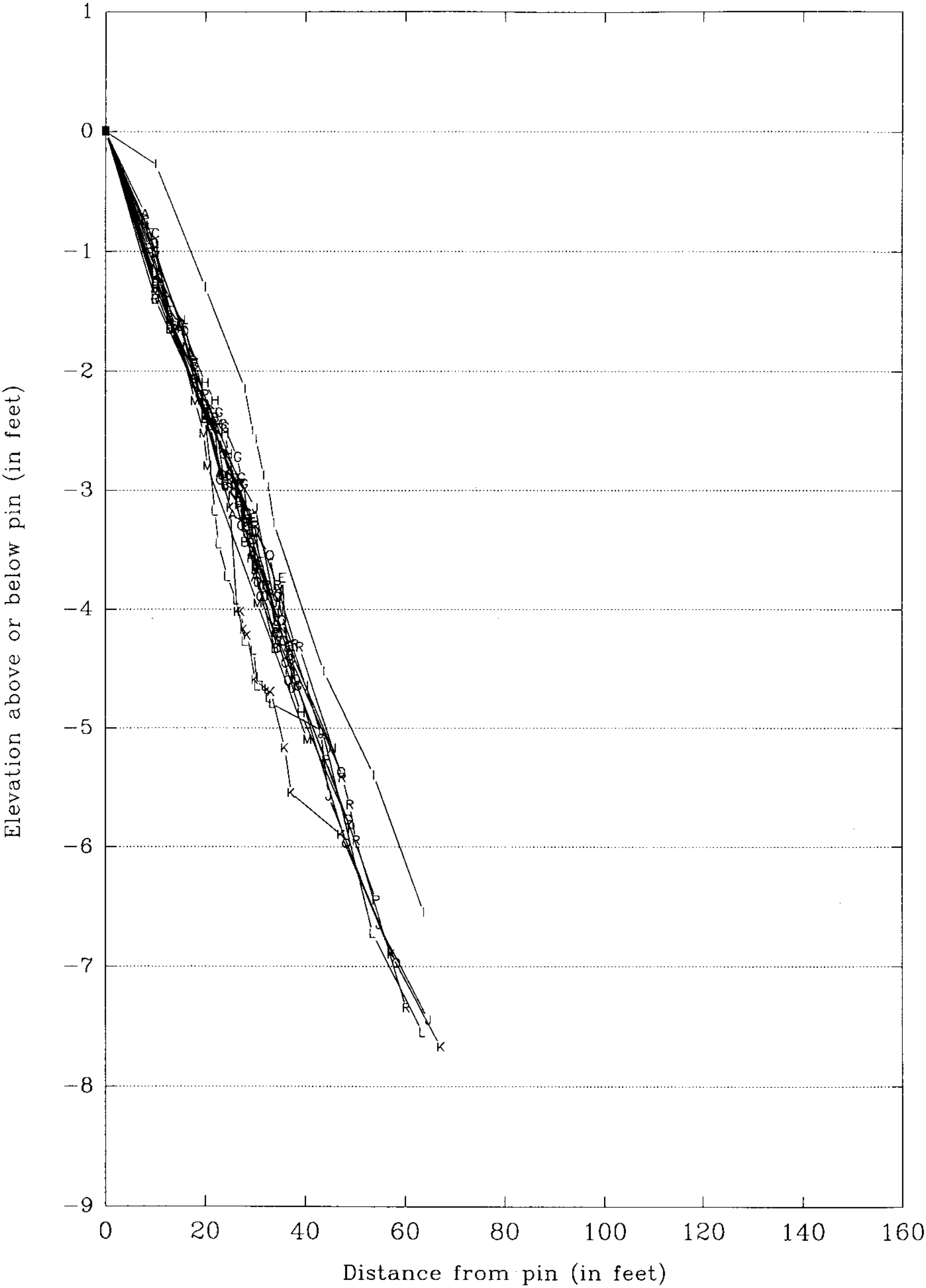


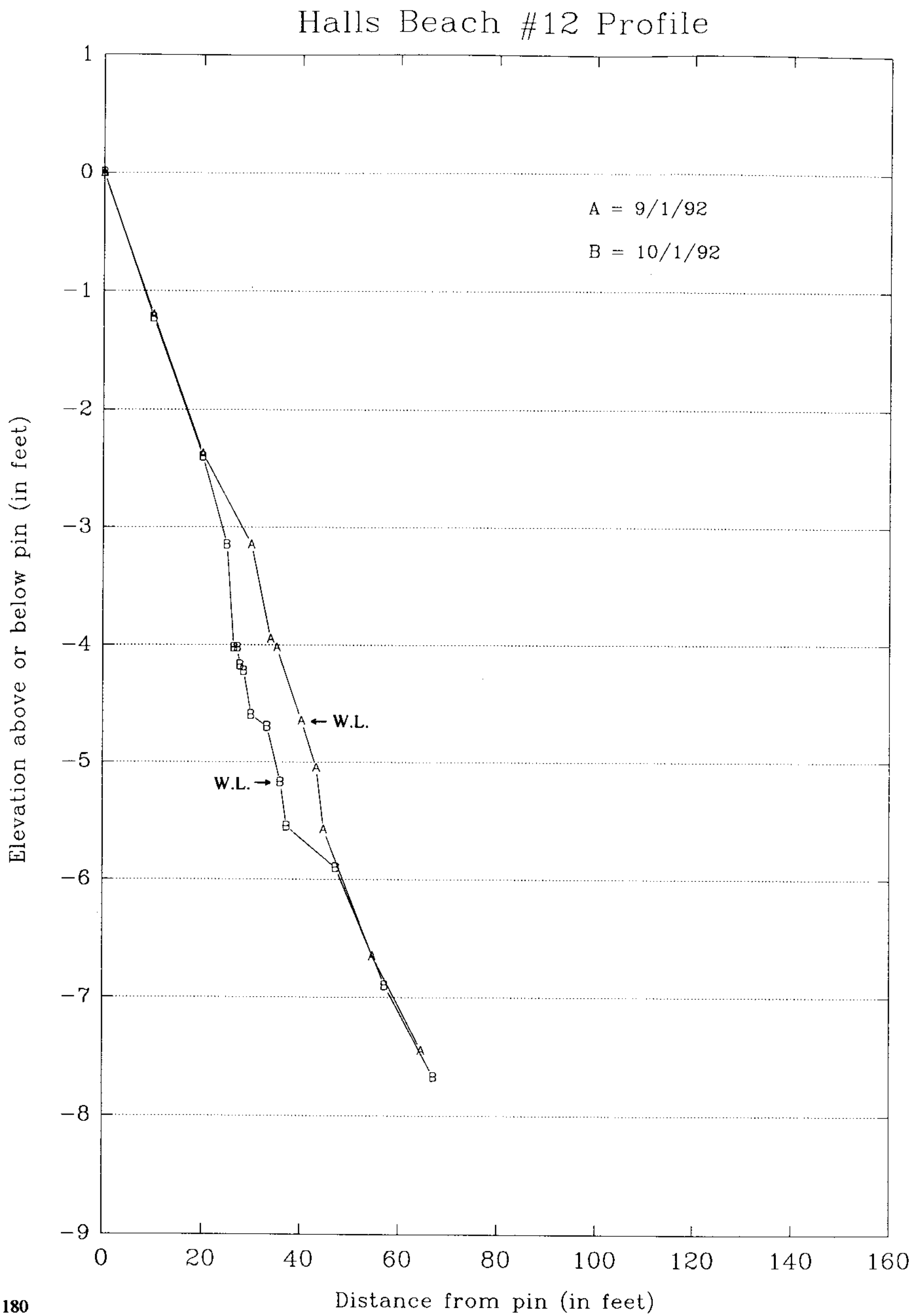
Halls Beach #11 Profile
Spring 1993
K and L are off the original pin location
K = 5/4/93
L = 6/3/93
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

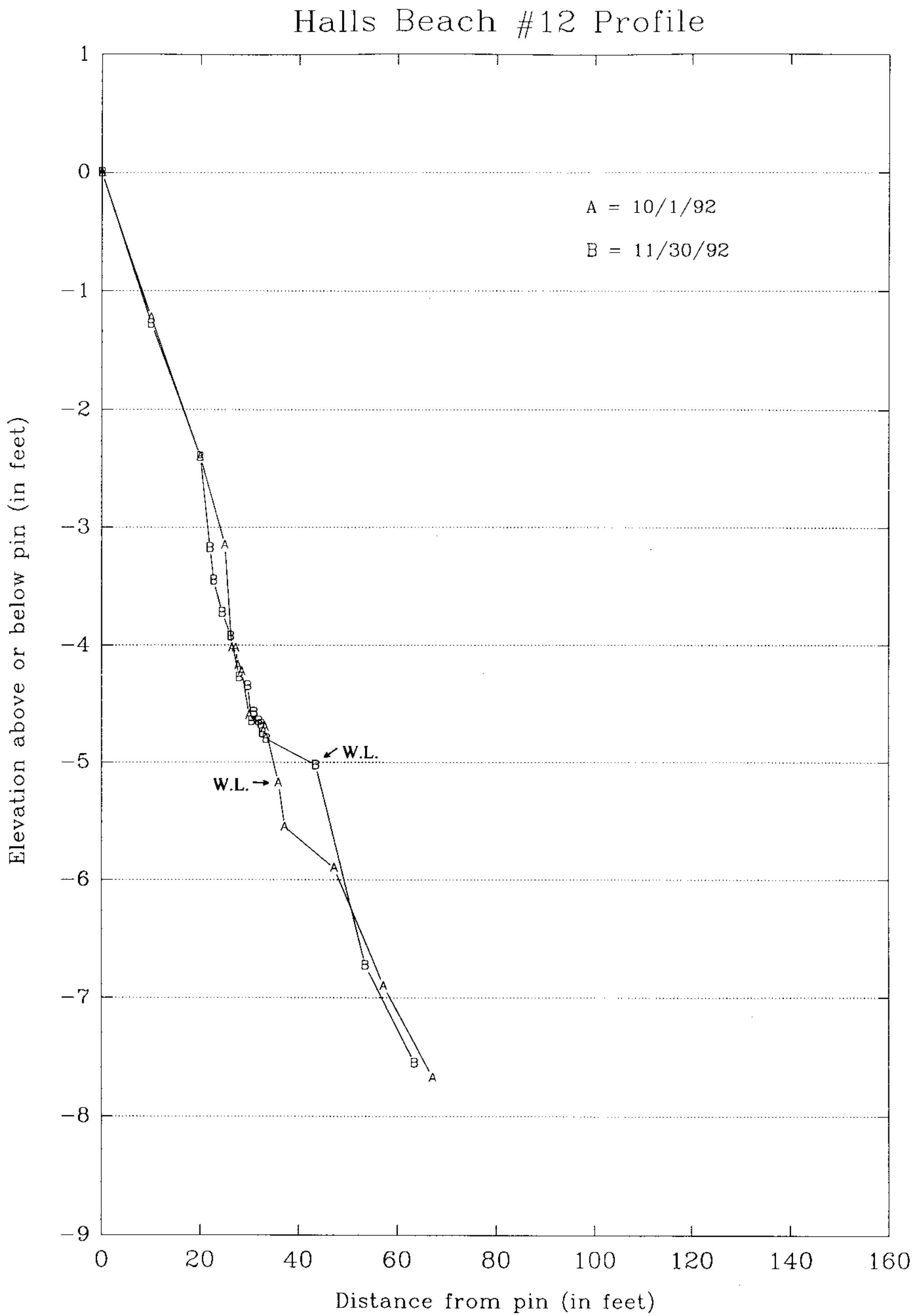

Halls Beach #11 Profile
Summer 1993
M = 7/1/93
N = 8/4/93
O = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

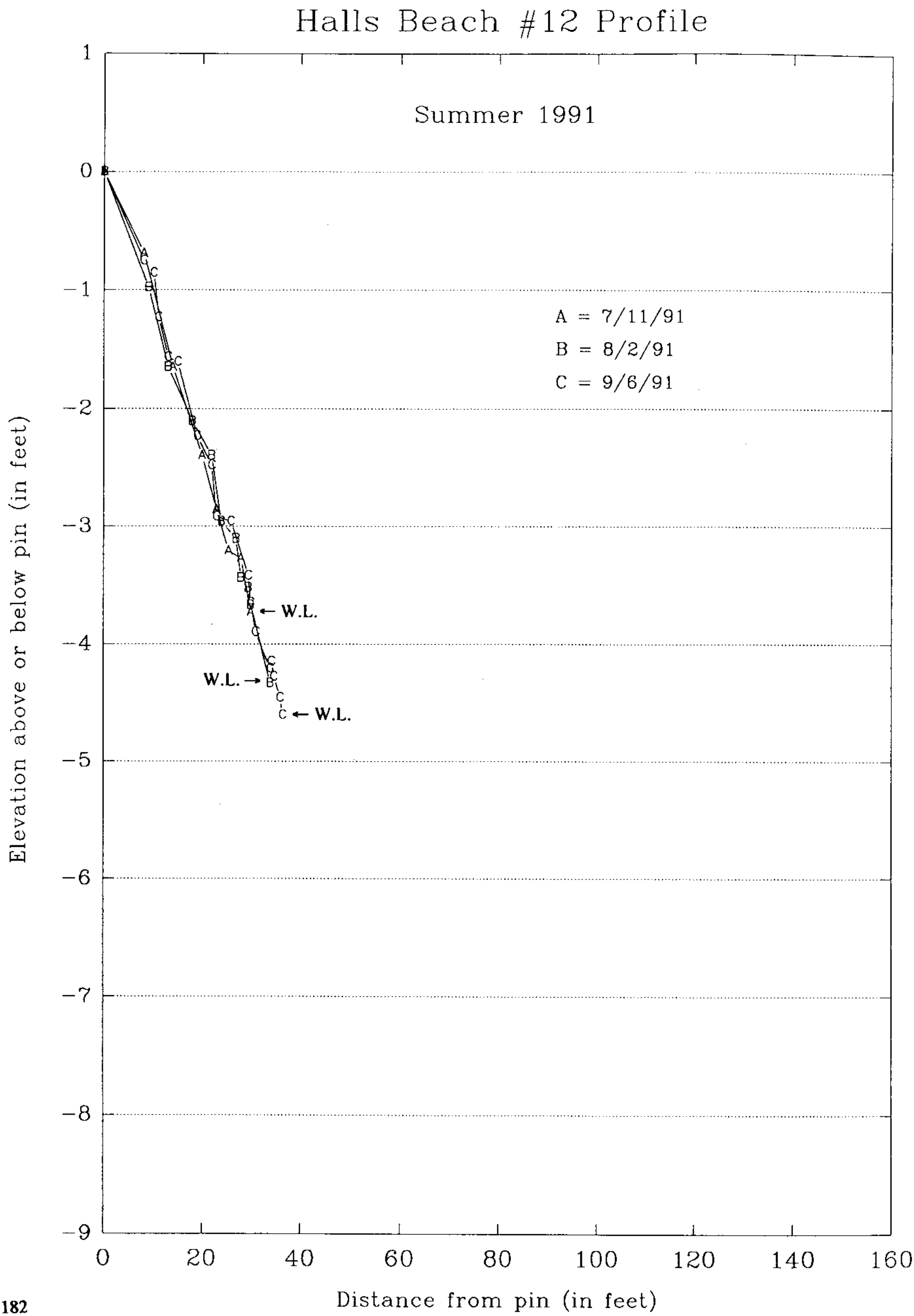

Halls Beach #11 Profile
Fall 1993
O = 9/7/93
P = 10/4/93
W.L.
W.L.
Elevation above or below pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160
Distance from pin (in feet)

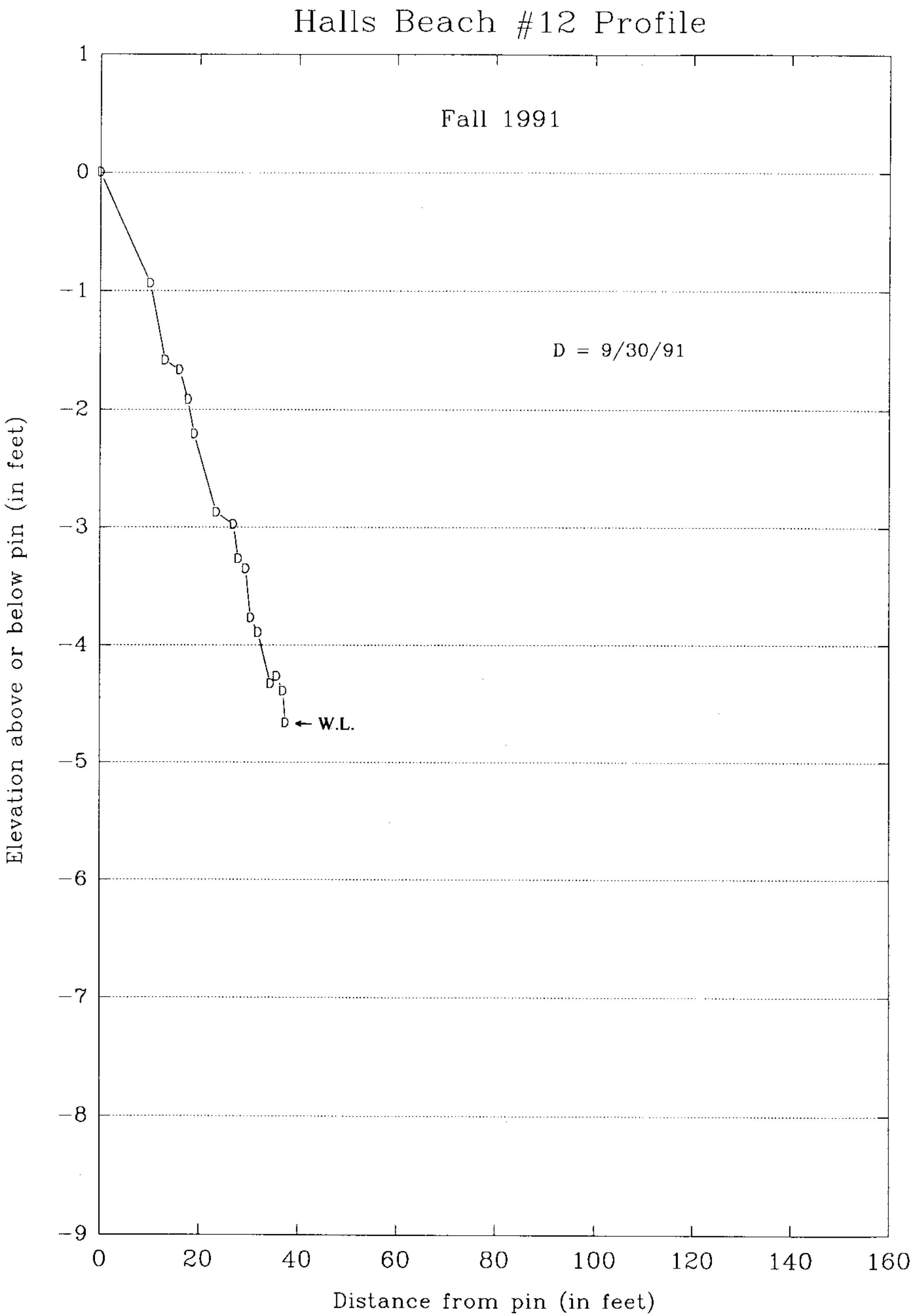
Halls Beach #12 Profile



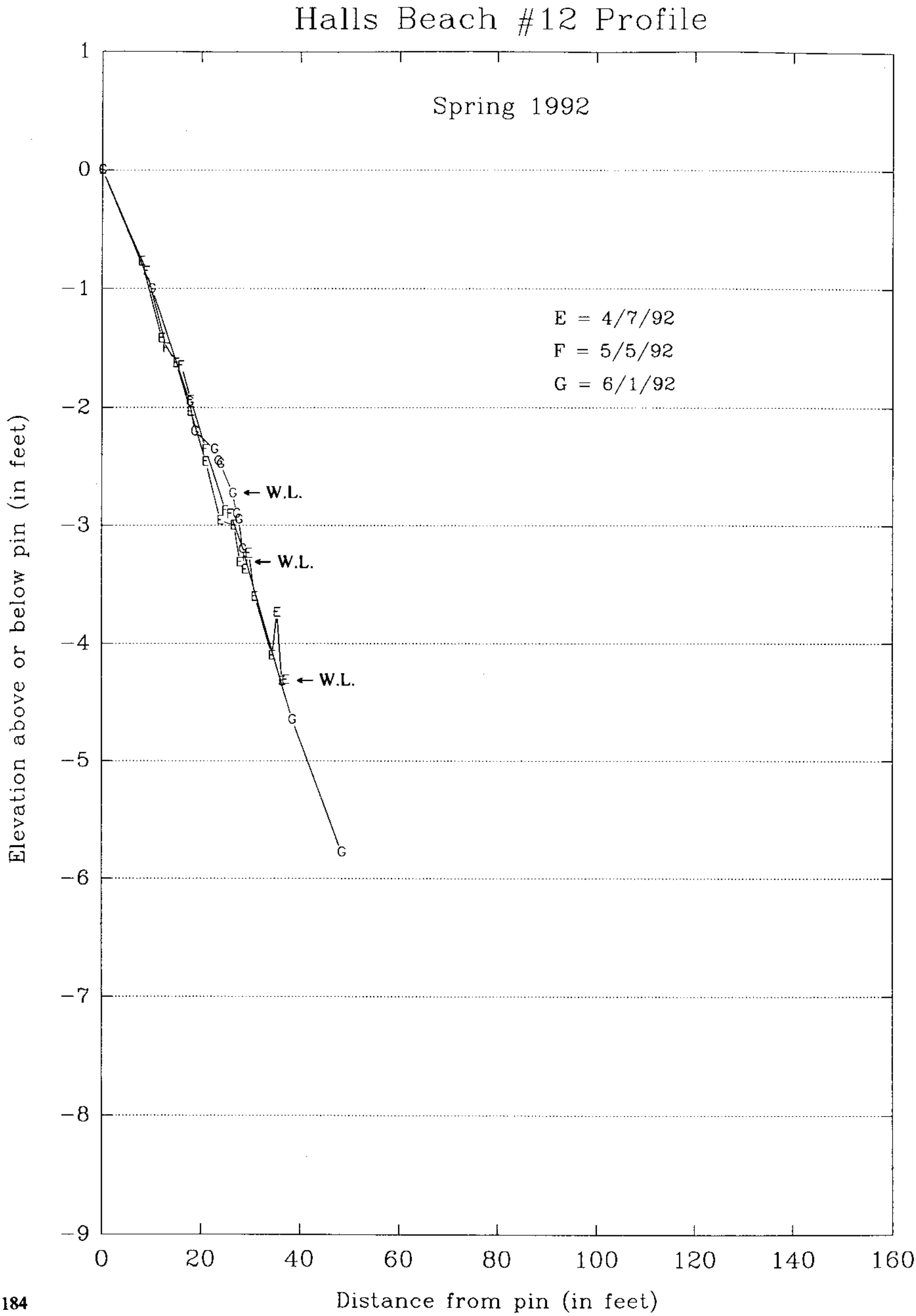

Halls Beach #12 Profile
A = 9/1/92
B = 10/1/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

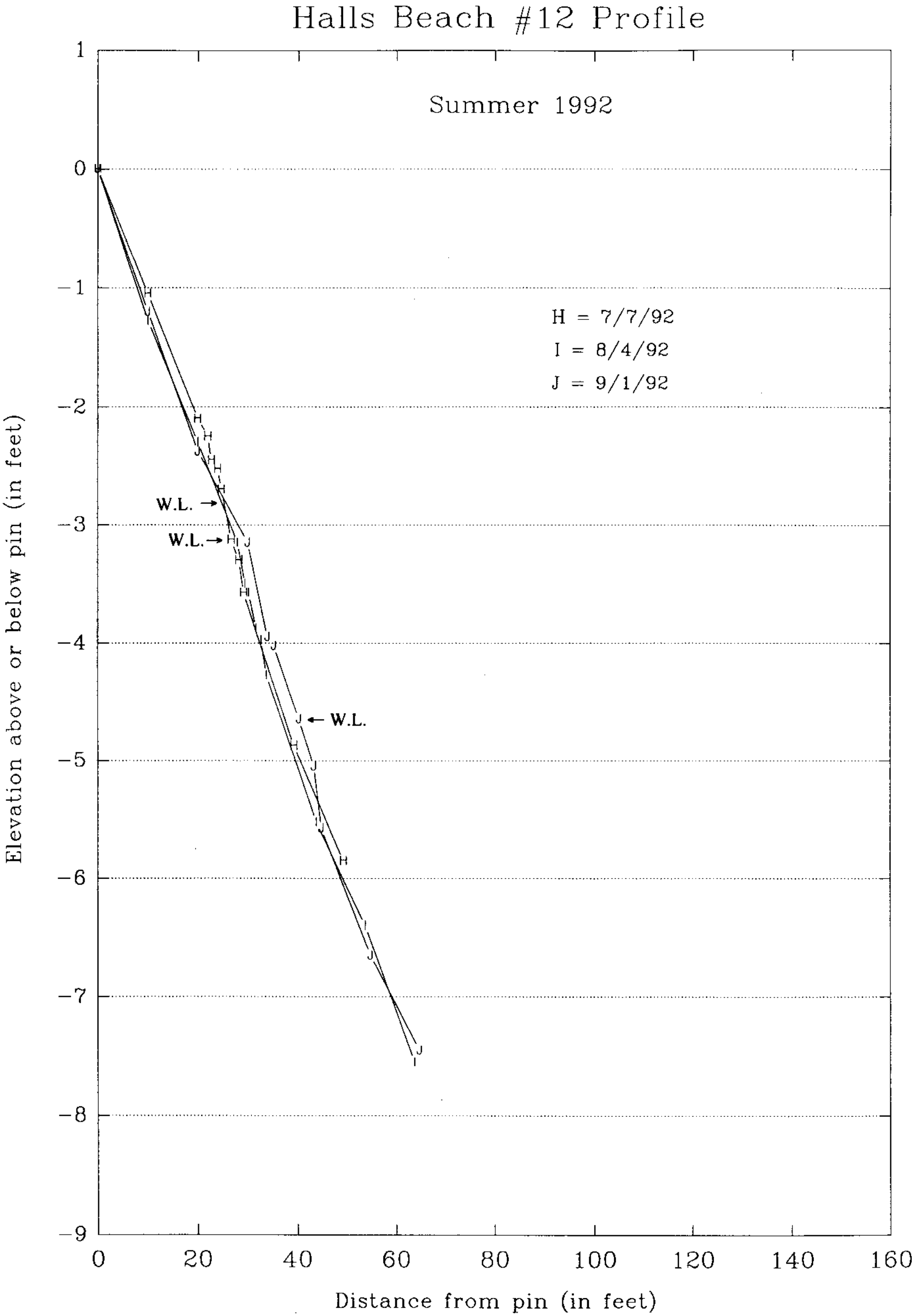

Halls Beach #12 Profile
A = 10/1/92
B = 11/30/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

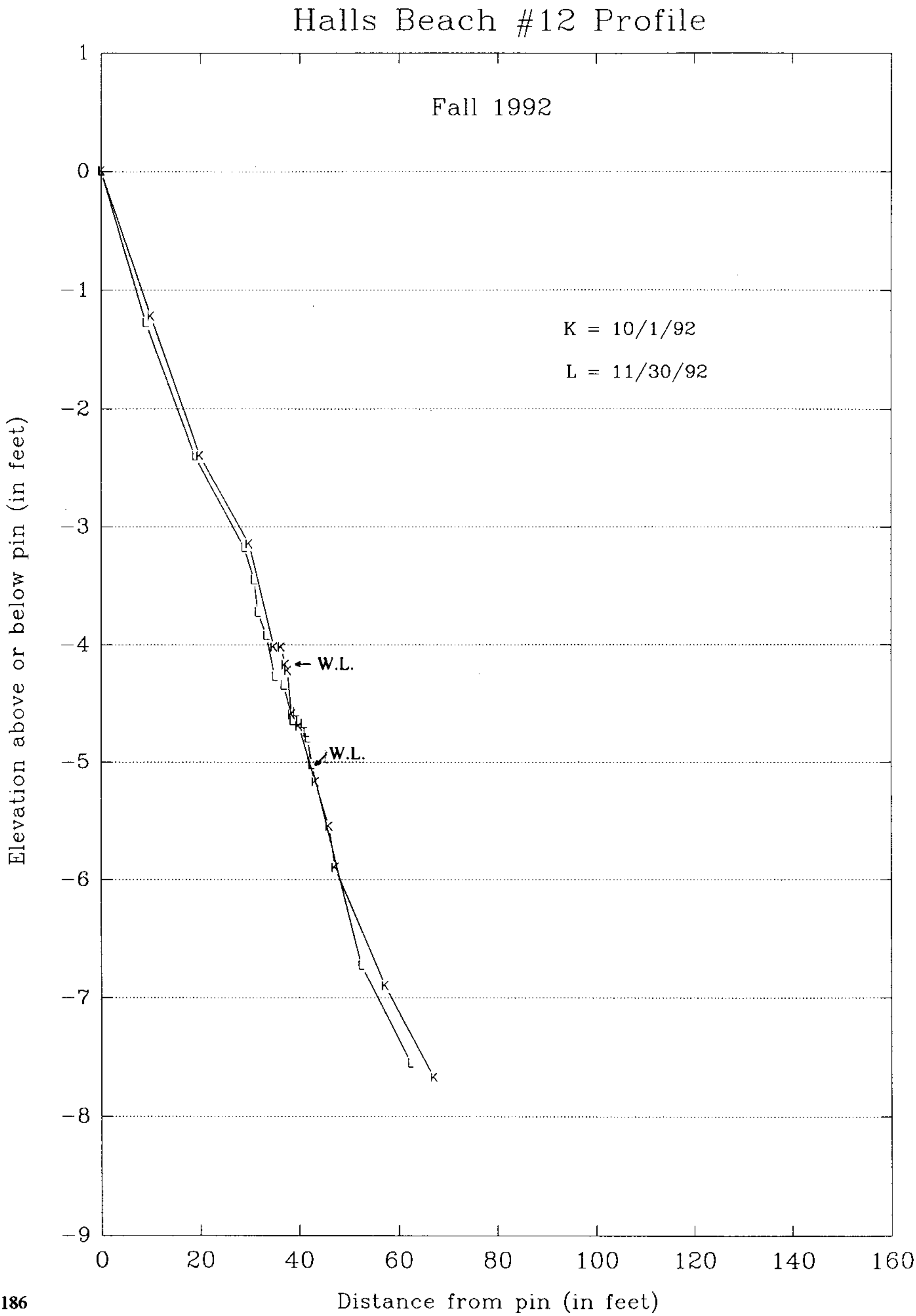

Halls Beach #12 Profile
Summer 1991
A = 7/11/91
B = 8/2/91
C = 9/6/91
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160



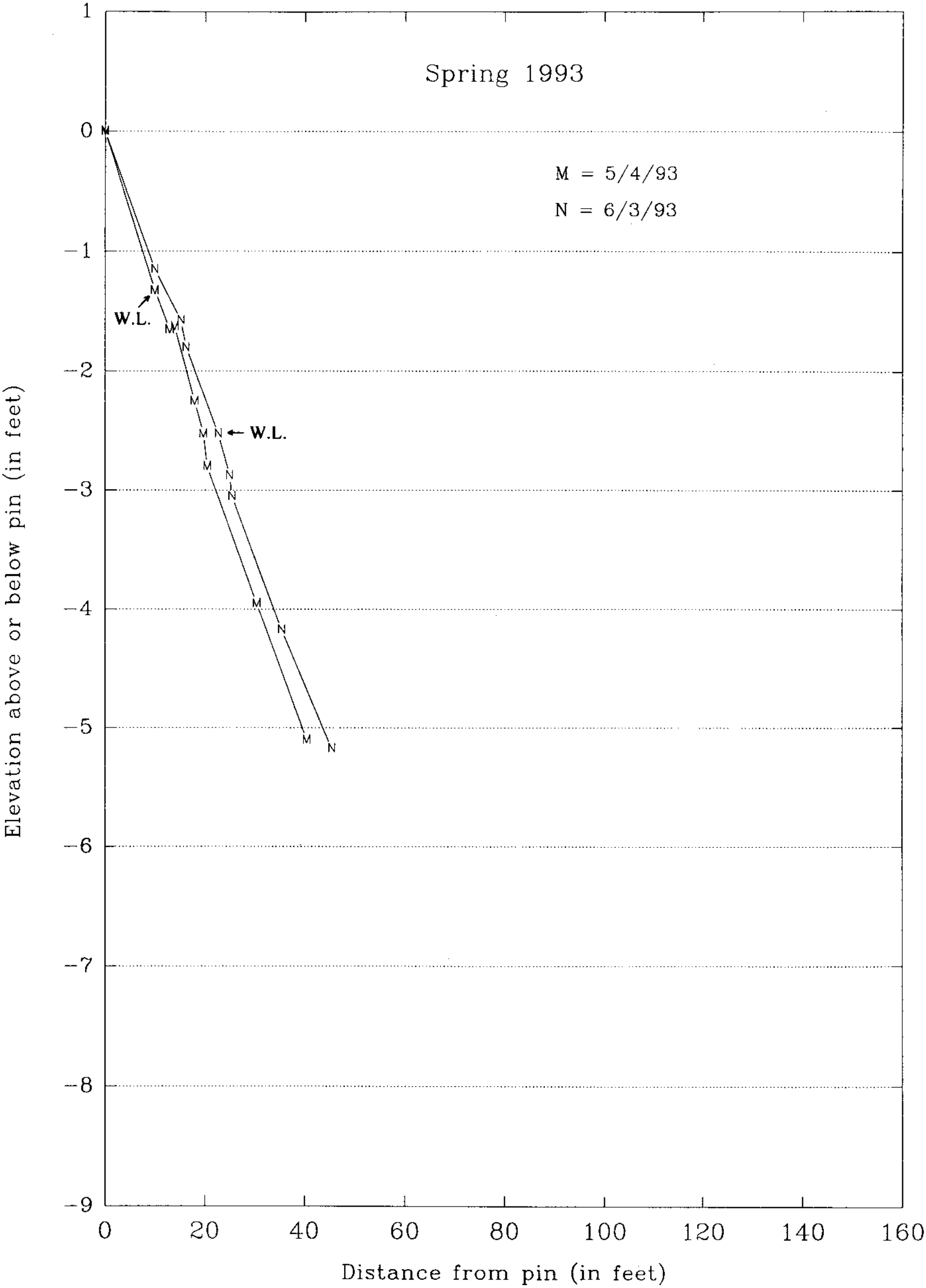
Halls Beach #12 Profile
Fall 1991
D = 9/30/91
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

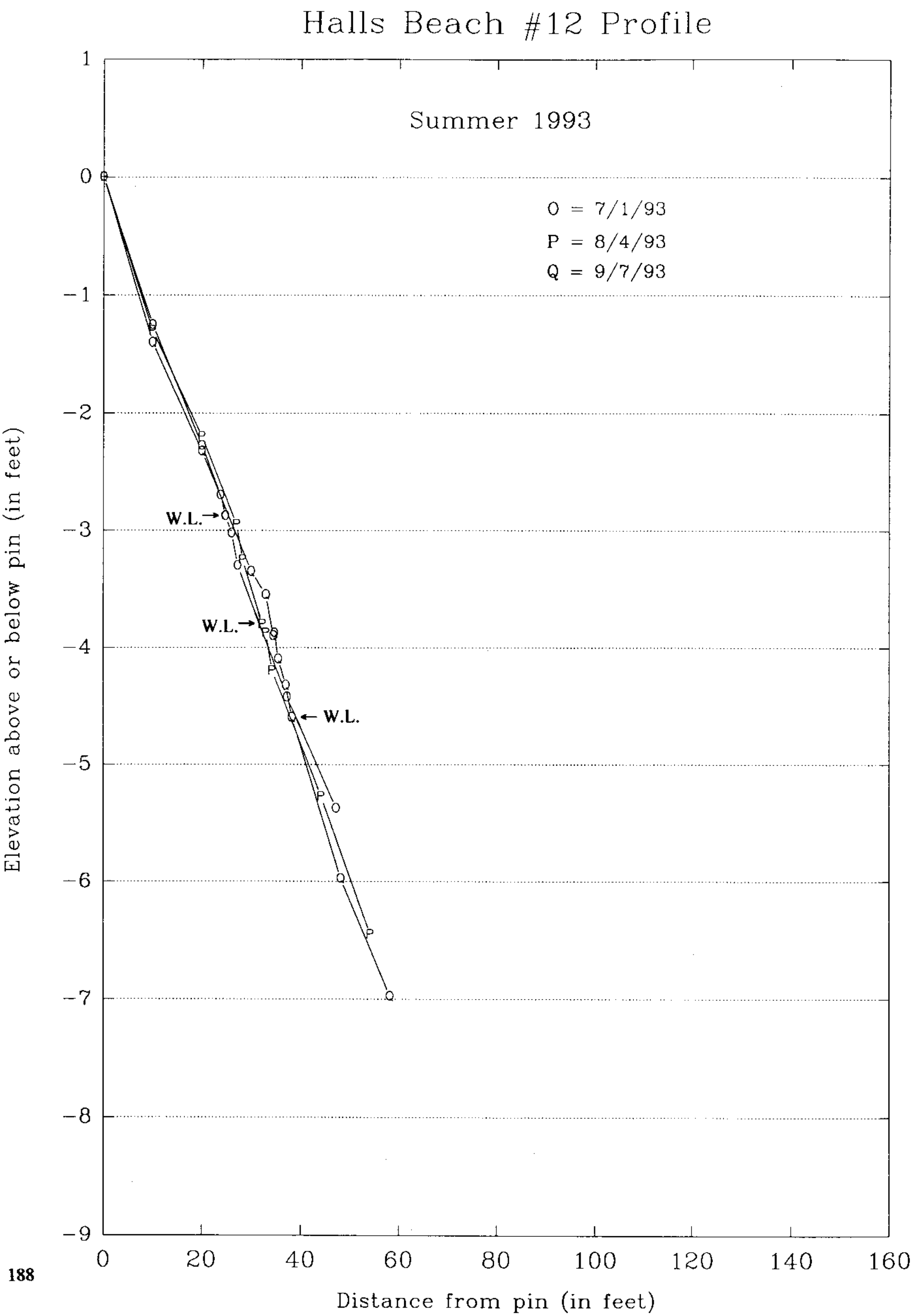

Halls Beach #12 Profile
Spring 1992
E = 4/7/92
F = 5/5/92
G = 6/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Halls Beach #12 Profile
Summer 1992
H = 7/7/92
I = 8/4/92
J = 9/1/92
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160

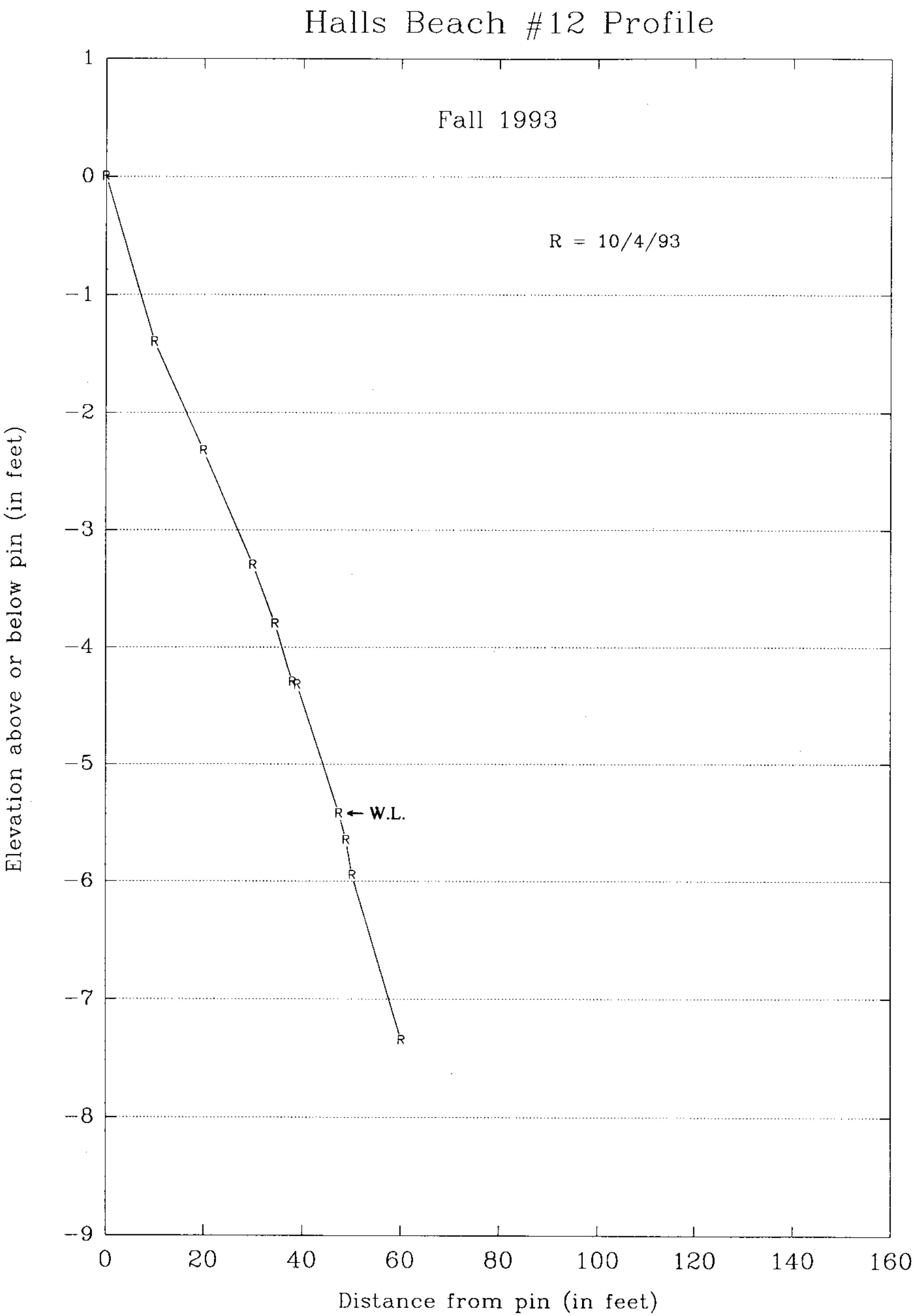

Halls Beach #12 Profile
Fall 1992
K = 10/1/92
L = 11/30/92
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160

Halls Beach #12 Profile





Halls Beach #12 Profile
Summer 1993
O = 7/1/93
P = 8/4/93
Q = 9/7/93
W.L.
W.L.
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160


Halls Beach #12 Profile
Fall 1993
R = 10/4/93
W.L.
Elevation above or below pin (in feet)
Distance from pin (in feet)
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
0
20
40
60
80
100
120
140
160