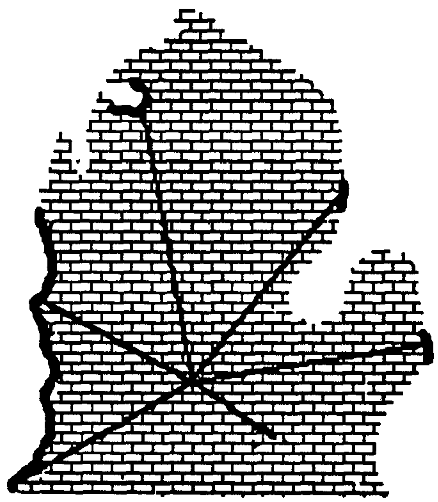
The University of Michigan
Ocean Engineering Laboratory

Department of Naval Architecture and Marine Engineering
College of Engineering

COASTAL MONITORING PROGRAM
AND
SHORELINE EVOLUTION MODEL
YEAR TWO: REPORT
TO THE
STATE OF MICHIGAN
DEPARTMENT OF NATURAL RESOURCES



Coastal Monitoring Program

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M.Wise, and T. Bromwell

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to:

The State of Michigan
Department of Natural Resources

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Introduction

The coastlines of the United States are projected to suffer increased population pressure in the near future, resulting in the need for an accurate and reliable predictive capability to assess the impact of physical processes and coastal engineering structures on shoreline properties. The Great Lakes encompass over 9000 miles of coastline, providing a home to approximately 15 percent of the U.S. population and 50 percent of Canada's. Of the Great Lakes coastline (U.S. and Canada) about 83 percent is privately owned land valued between $105,000 per linear foot, yielding a conservative resource value estimate of $20 billion.

The dominant processes controlling coastal erosion and sediment transport are waves and wave-generated currents, particularly during the passage of storms. Wave generated processes are the primary control on erosion of the bluff and sandy shorelines, while water level changes provide a secondary effect by modifying the vertical distance over which the wave processes may operate (Davidson-Arnott and Law, 1989). Coupling of high water levels and severe storm conditions may result in concentrated periods of economic loss, such as those of 1951-52, 1972-76 and the early 1980's. However, nearshore losses can continue throughout fluctuating and low water periods with lower vertical impact.

Therefore, assessment of the impact of both long and short term physical processes on the coastline is required to gain a true understanding of the evolution of the Great Lakes shorelines. In his review of nearshore research, Hails (1974) states that the largest problem facing a study of this nature is the collection of data for a sufficiently long time period to gain a representative picture of the changes taking place in the coastal zone.

It was, therefore, proposed that, through a multi-agency cooperative effort, numerical predictive models of shoreline evolution be developed accompanied by a comprehensive and thorough investigation of long term beach profile response.

The specific purpose of the coastal monitoring program described herein is to initiate and maintain field data collection activities for the establishment of a beach and nearshore survey grid and to obtain the necessary hydrographic survey data for an evaluation of shoreline response to changes in water levels and storm activity. The Ocean Engineering Laboratory is actively involved in utilizing this data to improve shoreline response forecasting capabilities. The latter portions of the total work effort are being pursued through research grants and cooperative efforts with the Coastal

Engineering Research Center (CERC), the National Oceanic and Atmospheric Administration (NOAA), and the Michigan Sea Grant College Program.

The purpose of this report is to summarize the results of the first two years of the coastal monitoring program funded by MDNR, Division of Land and Water Management through the Coastal Zone Management Program.

Purpose and Goals

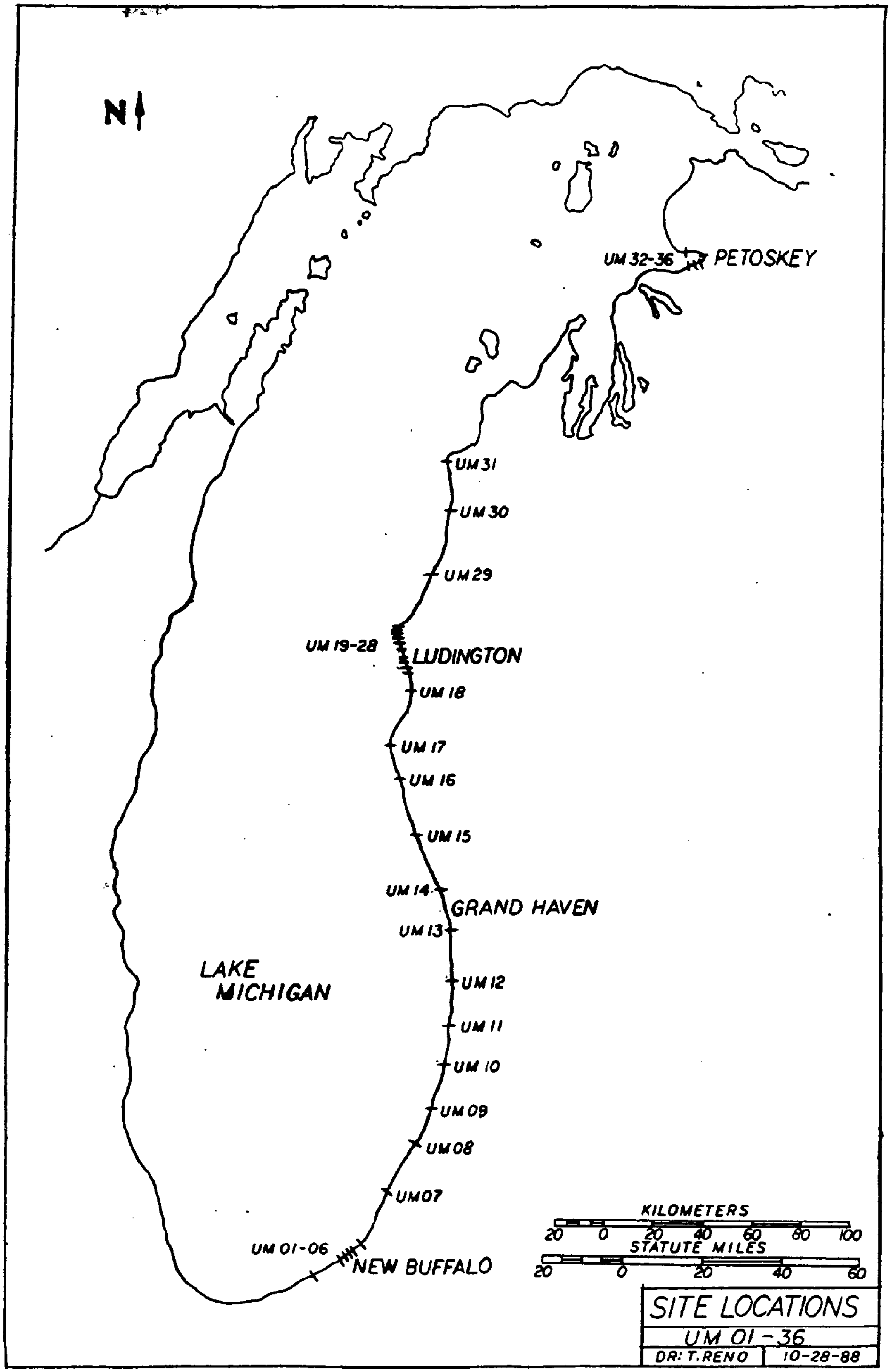
As described in the Year One Report for this project, in February, 1988, The University of Michigan's Department of Naval Architecture and Marine Engineering's Ocean Engineering Laboratory (OEL) proposed to the State of Michigan Department of Natural Resources (MDNR) a program to conduct a series of precision hydrographic surveys along the Lakes Michigan and Huron coastlines of the State of Michigan. The purpose of this research effort is to initiate a long term monitoring program aimed at establishing the current state of the shoreline and to provide valuable information on the rates of shoreline change in response to individual storms as well as seasonal and long term climatic variations. The ultimate goal of this research activity is to provide the data necessary to substantially advance our knowledge of Great Lakes coastal erosion processes and to support the development of a predictive shoreline evolution model. This effort will consider natural and man-impacted coasts in response to wind, waves, and Great Lakes water level changes.

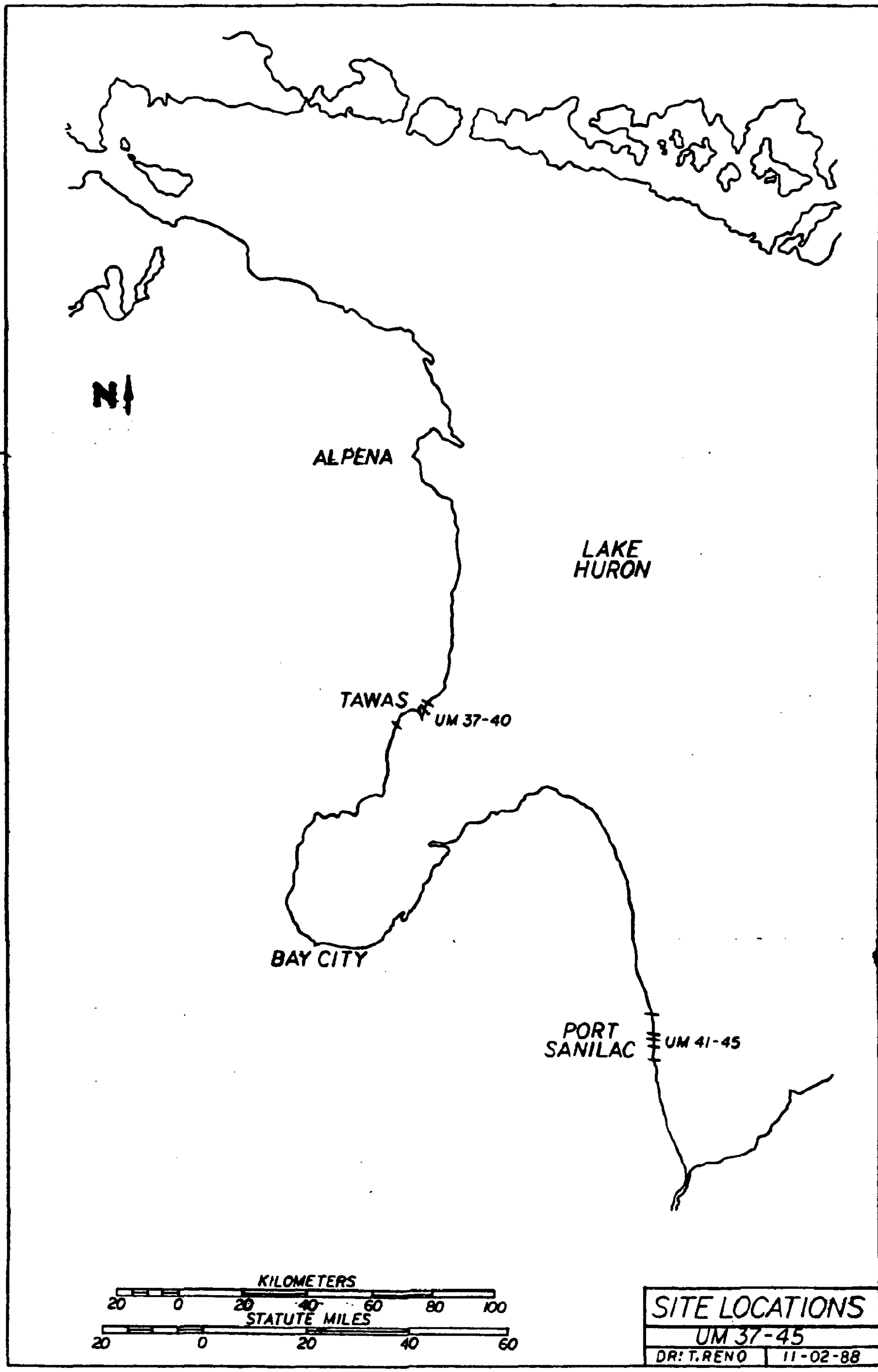
The proposed research plan consisted of precision hydrographic surveys conducted at 45 permanent survey sites. These sites were chosen to provide long term data on the rate of shoreline change over a wide range of both structurally impacted and naturally occurring beaches along the Lakes Michigan and Huron shorelines of the Lower Peninsula of Michigan (Figure 1). The 45 survey lines have been chosen to coincide, whenever possible, with historical survey data previously obtained by the U.S. Army Corps of Engineers as well as other research efforts reported in scientific literature (see Table I). Additional areas of particular scientific interest to both the MDNR and to The University of Michigan's coastal erosion research program have also been included.

It was recommended that surveys be conducted twice yearly (each Spring and Fall) commencing with Spring 1988. This monitoring scheme is similar to that in place for the past twelve years along the Indiana coastline of Lake Michigan and is designed to adequately identify both the seasonal and long term variations (on/off-shore changes) in the beach profiles. To adequately assess the short term variability of the beach and nearshore region of the Michigan shoreline, it was proposed that at least 15 of the original 45 lines be resampled each year on a short time scale.

The combination of short and long term beach response data will be an extremely valuable addition to this data set and will provide necessary direct insight for the development of numerical predictive models of shoreline evolution both for natural as well as man-influenced beach regions. Toward this goal, the two year precision hydrographic survey dataset has been analyzed for gross morphological changes, annual

Figure 1. Map of UM survey sites (from OEL 1989).




N
ALPENA
LAKE HURON
TAWAS
UM 37-40
BAY CITY
PORT SANILAC
UM 41-45
KILOMETERS
20 0 20 40 60 80 100
STATUTE MILES
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SITE LOCATIONS
UM 37-45
DR: T. RENO
11-02-88

Table I. MDNR Coastal Monitoring Program Permanent Survey Sites

Reference No.	Location	Description	County	Section,T,R	Historical Reference	SPRING Date	SPRING Time	POST-STORM Date	POST-STORM Time	FALL Date	FALL Time
UM01	NEW BUFFALO	IN/MI State Line	Berrien	24,T08S,R22W	H&J 26	5-04	13:00			8-09	08:00
UM02	NEW BUFFALO	Grand Beach	Berrien	17,T08S,R21W	H&J 29	5-04	11:45			8-09	09:20
UM03	NEW BUFFALO	Dunewood Condominiums	Berrien	09,T08S,R21W	H&J 35	5-04	09:00			8-09	10:30
UM04	NEW BUFFALO	City Waterfront Park	Berrien	03,T08S,R21W	H&J 42	5-03	16:10			8-08	11:45
UM05	NEW BUFFALO	11059 Riviera Dr.	Berrien	35,T07S,R21W	H&J 44	5-08	15:45			8-09	14:00
UM06	CHIKAMING	Township Park	Berrien	19,T07S,R20W	D 17	5-09	09:30			8-09	15:15
UM07	STEPHENSVILLE	Chalet-on-the-Lake	Berrien	20,T05S,R19W	D 16,B A1	5-22	08:25			8-09	17:00
UM08	HAGAR TOWNSHIP	Township Park	Berrien	15,T03S,R18W	D 15	5-22	10:05			8-10	07:40
UM09	VAN BUREN ST PK	Beach Access	VanBuren	32,T01S,R17W	D 14	5-22	12:15			8-10	10:35
UM10	GLENN	Public Road Easement	Allegan	31,T02N,R16W	D 13	5-22	15:00			8-10	12:30
UM11	DOUGLAS VILLAGE	Public Beach	Allegan	17,T03N,R16W	D 12	5-22	16:40			8-10	15:00
UM12	HOLLAND	James St. Beach Access	Ottawa	21,T05N,R16W	D 11	5-22	18:30			8-10	18:20
UM13	GRAND HAVEN	Buchanan St. Bch Acc	Ottawa	17,T07N,R16W	D 10	5-23	09:15			8-15	07:35
UM14	HOFFMASTER ST PK	Beach Access	Muskegon	36,T09N,R17W	D 09	5-23	11:15			8-15	09:40
UM15	WHITEHALL	Duck Lake Outlet	Muskegon	24,T11N,R18W	D 08	5-23	13:00			8-15	11:30
UM16	CLAYBANKS	Township Park	Oceana	16,T13N,R18W	D 07,H 24	5-23	15:30			8-15	13:00
UM17	LITTLE SABLE POINT	USCG Lighthouse	Oceana	35,T15N,R19W	D 06,H 17	5-23	17:30			8-15	17:25
UM18	SUMMIT TOWNSHIP	Township Park	Mason	23,T17N,R18W	D 05,H 32	5-24	09:45			8-17	16:00
UM19	LUDINGTON	Buttersville Park	Mason	22,T18N,R18W		5-24	11:20			8-17	13:20
UM20	LUDINGTON	Buttersville	Mason	22,T18N,R18W		5-24	12:00			8-17	14:30
UM21	LUDINGTON	Stearns Park	Mason	16,T18N,R18W		5-24	14:55			8-17	10:30
UM22	LUDINGTON	Juanita Rd.	Mason	09,T18N,R18W		6-06	08:08			8-17	09:30
UM23	LUDINGTON ST PK	Checkin Station	Mason	29,T19N,R18W		6-06	09:24			8-17	08:25
UM24	LUDINGTON ST PK	Beach House	Mason	19,T19N,R18W		6-06	10:51			8-16	17:20
UM25	LUDINGTON ST PK	N of Outpost Camp	Mason	18,T19N,R18W		6-06	11:48			8-16	16:20
UM26	BIG SABLE POINT	USCG Lighthouse	Mason	07,T19N,R18W	D 04	6-05	13:00			8-16	14:07
UM27	LUDINGTON ST PK	Wilderness Area	Mason	06,T19N,R18W		6-05	16:00			8-16	15:00
UM28	LUDINGTON ST PK	N. Boundary	Mason	05,T19N,R18W		6-05	14:30			8-16	09:05
UM29	MANISTEE	Bar Lake Outlet	Manistee	24,T22N,R17W	D 03	6-06	14:59			8-18	10:20
UM30	BENMAN CNTY LINE	Sunset Valley Resort	Manistee	03,T24N,R16W	D 02	6-06	16:39			8-21	18:30
UM31	POINT BESTIE	USCG Lighthouse	Benzie	04,T26N,R16W	D 01	6-06	18:07			8-22	11:00
UM32	PETOSKEY	Magnus Municipal Park	Emmet	06,T34N,R05W		6-07	16:18	7-19	12:30	8-23	07:00
UM33	PETOSKEY	Bayfront Park	Emmet	32,T35N,R05W		6-07	15:30	7-19	13:40	8-23	08:20
UM34	PETOSKEY	Bayview Association	Emmet	33,T35N,R05W		6-07	12:46	7-19	14:40	8-23	09:15
UM35	PETOSKEY ST PK	Beach Access	Emmet	27,T35N,R05W		6-07	11:00	7-19	17:00	8-23	10:00
UM36	PETOSKEY	Harbor Springs	Emmet	13,T35N,R06W		6-07	10:43	7-19	18:25	8-23	11:07

Historical References: H&J: Hawley and Judge (1969), D: Davis (1976) and Birkemeier (1981), B: Birkemeier (1980), H: Hands (1979).

Table I. MDNR Coastal Monitoring Program Permanent Survey Sites

Reference No.	Location	Description	County	Section,T,R	Historical Reference	SPRING Date	SPRING Time	POST-STORM Date	POST-STORM Time	FALL Date	FALL Time
UM37	TAWAS	Aster St.	Iosco	05,T22N,R09E		6-26	12:00	7-18	12:40	8-23	16:49
UM38	TAWAS	E. Birch Dr.	Iosco	26,T22N,R08E		6-26	10:10	7-18	11:25	8-23	18:27
UM39	TAWAS POINT ST PK	Beach Access	Iosco	34,T22N,R08E		6-26	09:15	7-18	10:10	8-23	19:21
UM40	TAWAS	Harbor Pier	Iosco	20,T21N,R08E		6-26	07:15	7-18	08:15	8-23	15:30
UM41	PORT SANILAC	Murphy Dr.	Sanilac	35,T13N,R16E		6-29	10:00	7-17	11:35	8-25	07:00
UM42	PORT SANILAC	349 S. Lake Rd.	Sanilac	02,T11N,R16E		7-06	08:00	7-17	12:35	8-25	08:30
UM43	PORT SANILAC	Goldman Ave.	Sanilac	02,T11N,R16E		7-06	10:00	7-17	13:35	8-25	09:45
UM44	PORT SANILAC	Roadside Park	Sanilac	11,T11N,R16E		7-06	12:00	7-17	15:05	8-25	10:40
UM45	PORT SANILAC	Walker Rd.	Sanilac	14,T11N,R16E		7-06	14:00	7-17	16:00	8-25	11:30

Historical References: H&J: Hawley and Judge (1969), D: Davis (1976) and Birkemeier (1981), B: Birkemeier (1980), H: Hands (1979).

volume change, and conformation of the coastal bathymetry to an equilibrium profile. Results of these analyses will be presented in this report.

Summary of Year One Findings

The success of the first year of this study was predicated upon the accuracy of the data collection and analysis techniques, the use of appropriate time and length scales over which data was collected, the incorporation of past data and insight, when available, into the planning and analysis scheme, and the ability of future researchers to use and build upon the database. The OEL employed the most reliable and accurate surveying technique available for hydrographic survey and sedimentological data collection. Data reduction and analysis was performed with nationally accepted programming and database management which was only slightly modified for streamlining in Year Two. Historical data was consulted for insight to process time and length scales, field and laboratory techniques, as well as comparison with present data collection.

Examination of historical literature revealed that there exists a need for further study of coastal evolution, particularly during falling lake levels. The first field season of data indicated that processes in action during the 1988 summer served to inflate the beach profile in most cases, as expected. Based upon previous studies of Great Lakes shoreline response to water level variation and storm waves, a decrease in mean lake level should cause a lowering of the effective wave base, thus increasing the amount of wave energy impinging the bottom at any depth. In response to this increase in energy, increasing sediment transport may result in offshore migration of the outer bars. The 1988 dataset displays about a 50 percent agreement with this hypothesis, reflecting the need for longer term monitoring during falling water levels.

The year one dataset also provided a first look at the response of the nearshore region to the passage of storm fronts in a southern and northern Lake Michigan regime. In order to characterize the long term response of the shoreline to falling annual lake levels, it was found necessary to compare the 1989 and 1988 datasets.

Re-Establishment of Permanent Beach and Nearshore Precision Hydrographic Survey Lines

During the 1988 field season, the OEL established a total of 45 survey lines along the Lower Peninsula's Lakes Michigan and Huron coastlines (see Figure 1). Previously existing nearshore survey lines along the Lake Michigan shoreline, and in particular, those reported by Hawley and Judge (1969), Davis (1976), Hands (1979), and Birkemeier (1980, 1981), were re-established and precisely relocated wherever possible. Due to recent, rapid changes in shoreline topography as a result of record high lake levels, it was only possible, in some cases, to establish survey lines in the same general vicinity as the previously existing lines. The Year One Report summarizes the site selection and initial bench mark establishment procedure

During April of 1989, a small shore-based survey crew visited all forty-five sites for a temporary bench mark (TBM) reconnaissance study. The main purpose of this endeavor was to take inventory of the TBM survival over the past winter. At this time, all of the 1988 TBM's were recovered, however, at ten sites the TBM's were buried and particularly difficult to salvage. At these burial sites it was found useful to place a higher TBM adjacent to the concealed pipe. The elevation difference between the two TBM's was precisely measured. Nine fall surveys were conducted from this adjacent benchmark. As a precautionary measure, we placed back-up bench marks on the dune or bluff at eight of the most dynamic sites. Each of these back-up bench marks was precisely surveyed and measured in order to maintain continuity between successive surveys which may rely upon them. One survey in the spring and four surveys in the fall were conducted from these back-up benchmarks due to large seasonal changes in the beach. It should be noted that north of UM23 (Ludington) and on Lake Huron, the TBM's were quite easy to relocate and no adjacent or back-up bench marks were necessary.

Precision Hydrographic Survey Data Collection

The survey activity consisted of conventional hydrographic survey techniques as described in the Year One Report. Consistency between successive surveys was of utmost importance. Since 1989 brought the use of a new survey fathometer, care was taken to run the new and old unit side by side to evaluate the interchangability of the tool and assure reproducibility of results. Otherwise, no modifications were made to the successful surveying technique as employed in 1988.

Table I provides a listing of survey site locations as well as survey dates and times. As in Year One, the entire study area was sampled during the spring and fall surveys. However, the post storm survey for 1989 was conducted at UM site 32 through 45. The Year One Report provides justification for the survey interval selection. Following is a summary of the site descriptions logged in the field notebooks 1988 and 1989.

NEW BUFFALO:

UM01 is located adjacent to a public road easement at the Michigan/Indiana state line. The TBM is positioned adjacent to the rubble mound structures at the base of a steep bluff protect the road from washout. Approximately 150 ft north of the survey line, a dilapidated seawall structure remains and 100 ft to the north is a sand bag groin.
1988-Some boulder movement was evident due to a slight tilting of the TBM pipe prior to the post-storm survey.
1989-A large amount of sand has accumulated at the base of the revetment. During the spring survey, a 10 ft gravel band appeared at the water line which narrowed to a 4 ft width in the fall. Tire tracks exist at this site.

UM02 is below a private dwelling construction site in Grand Beach. It is characterized by a steep dune face above a natural beach. The site is just north of a blowout in the dune.
1988-The blowout had been plowed throughout prior to the post-storm survey.
1989-As in UM01, a gravel band exists at the waterline. New large boulders to the south of the TBM have been dumped over the bluff from the southern side of the blow out to the southern end of the development. A clay horizon appears on the edge of the blow out to the south, approximately 4 ft above the TBM. To the north, a gravel bar appears to be welding to the shore during the spring survey. The shoreline is mildly undulating, exhibiting a 500 ft wavelength, with the TBM stationed at the crest of the cusp. The sandbar appears welded during the fall survey. In the fall, a ridge of water exists just inside the berm and dune grass has grown along bluff.

UM03 is a construction site just north of the Dunewood condominium development and just south of the harbor jetties at New Buffalo.
1988-A small vegetated bluff and cuspate beach forms were present at the fall survey. This site experienced beach nourishment during the late Fall 1988.
1989-The beach has grown larger. Large rocks lie along the base of the bluff at the edge of the tall beach grass. Pebbles lie along the swash line.

UM04 is located within the New Buffalo City Park north of harbor jetties. It is a heavily vegetated bluff with walkways and stairways for erosion control.
1988-The site is characterized by a broad beach. There was a large amount of boat traffic and beach use during post-storm and fall surveys.
1989-Cobbles exist on the backbeach while course gravel covers the midbeach. A snow/sand fence winds three-fourths of the way up the bluff.

UM05 is a private residence in New Buffalo. The bluff is high with riprap at the bottom (placed when the area was declared a national disaster in 1973). Otherwise the site is a natural beach.
1988-A large shallow bar was evident during the spring survey and cuspate shoreline features were present at the fall survey.
1989-The till bluff near the TBM has been built up and a berm has been formed. The undulating shoreline has a 300 ft cusp. Tire tracks appear on the beach. The rocky nearshore bottom turns to sand at around a 75 ft distance.

DAVIS SITES:

UM06 is located in Chikaming Township Park at the end of a road bed. It is characterized by a very steep till bluff. A water outlet is to the south of the TBM.
1988-During the spring survey, there was no beach present, however, approximately 45 ft of beach was exposed and a new staircase was built prior to fall survey.
1989-The beach has grown to be quite large with tree foliage growing in front of the TBM. No evidence of bluff slumping. A small amount of soil drainage occurs from the till bluff through a drainage pipe. A bar has welded to shore and ridge of water runs 7 ft from the water's edge, parallel to the shoreline. A 1 ft berm appears above the swash level and the migrating sandbar is almost fully welded to the shore in the fall.

UM07 is a private residence north of Chalet on the Lake near Stevensville. It is a pocket beach with a rubble mound structure to the south and undercut concrete slabs to north.
1988-It was necessary to move this site at the request of owner to the north boundary of Chalet on the Lake at the fall survey. This site covers a steel sheet pile with rubble mound toe protection.
1989-Nearly 20-30 ft of beach has accumulated since the last survey. Waves lap at the base of the rubble to the south. A small berm appears above the swash line. A snow/sand fence winds down northern side of the line to the end of the beach, however, no evidence of sand accretion appears.

UM08 is located within Hagar Township Park. There is a steep till bluff with rubble at the base shoreward of an otherwise natural beach. The site is immediately seaward of rubble at the base of the bluff.
1988-Some slumping of bluff behind the TBM was evident at the fall survey.
1989-The broad beach's high berm has a gentle slope on the seaward side. Some ground water runoff occurs to the north of the site and a large slump region to the south may have occurred. No cusps appear at the spring survey. In the fall, the beach has become slightly cusped.

UM09 is located at the beach access in Van Buren State Park. This is a region of large active sand dunes.
1988-There is a broad natural beach and the park has posted an erosion control area sign on the vegetated dune.

1989-The broad beach has a gentle seaward sloping berm and 500-750 ft wavelength cusps. The TBM is located between a trough to the south and a peak to the north. Well-rounded gravel material exists at the water line and the rocks at the knee sample are 1-2 in diameter. A deep trough occurs before the first bar. Black sand lies at the dune, base of dune, and midbeach.

UM10 is adjacent to a public road easement in Glenn. The site is a severely eroding till bluff. Gravel material appears at the water line and a small stream outflow runs to the north. Large concrete blocks form a revetment on the shore.
1988-There is evidence of recent slumping at the spring survey.
1989-The small stream has almost disappeared. A slumping of the bluff has occurred to the south of the TBM. The beach has a cusp wavelength of about 250 ft.

UM11 is located at the Douglas Village Public Beach, a residentially developed area. The bluff is thickly vegetated over a natural beach.
1988-There was evidence of slumping activity at the base of bluff at the spring survey.
1989-The stairway of the park has been buried to the first landing. A bluff has slumped just north of the site behind the staircase. Three feet north of the TBM, a maple tree's roots have been exposed. Sand has also been lost at the base of the tree which lies behind the TBM. A large rock lies in the southern nearshore water. In the fall survey, the stairs to the parking lot are still buried and no evidence exists of new slumping.

UM12 is the James St. public beach access north of Holland. This area is heavily populated. A vegetated trail over a 40 ft dune leads to a natural beach.
1988-There was a high berm present at the fall survey.
1989-The 35 ft wide beach has no cusps. A large accumulation of wind blown sand appears at the bluff base. No evidence of slumping exists.

UM13 is a beach access at the end of Buchanan St. south of Grand Haven. This area is almost completely residentially developed. The bluff is well vegetated, but slumping. There are old wooden seawalls to the north and south.
1988-At the spring survey there was a steep beach with loose sand and three offshore bars. At the fall survey snow fences had been placed from the bluff half way to water's edge and cuspate beach forms were present.
1989-A gently sloping berm exists at the water line in the spring. Very pointy cusps exist about 300 ft north of the site, between the site and a low profile wooden groin field, however, no cusps appear directly at the site.

UM14 is a beach access at P.J. Hoffmaster State Park. There is a wooden walkway over the well vegetated dune with a broad natural beach.
1988-The wooden walkway had been replaced and a garbage bin and anchoring pole set on top of the TBM at the fall survey.
1989-The broad beach has a low berm and no cusps. The first of three sand bars is very broad. This bar narrows and moves offshore south of the site and eventually splits into two bars north of the site. In the fall, a large amount of tree growth has occurred. The wide, inshore sand bar falls steeply on the landward edge.

UM15 is a public road easement on the south side of the Duck Lake outlet near Whitehall. There are rubble mound structures to the north protecting the road bed and a steep sand bluff lies above the site.
1988-There was a steep scarp near the waterline and three bars present at the spring survey. The TBM had been buried under 2 ft of sand at the fall survey.
1989-A high berm exists above the swash while another small berm appears at the swash zone. The larger berm runs to the northern rubble mound and pinches out to the

south. The broad flat beach has inflated. In the fall, the TBM is mostly covered by the path and sand has accumulated to create a larger beach.

UM16 is located at the south end of Claybanks Township Campground. Bluffs of glacial till dominate this area. There is evidence of recent bluff erosion over a narrow natural beach.
1988-At the fall survey, the TBM was not relocated and a new TBM was placed. It is possible that the bluff slumped and buried the TBM.
1989-Continued evidence of slumping exists at the base of the bluff. The broad flat beach includes a minor berm. Sand runs half way up the bluff, then clay evolves. In the fall, the beach appears in a summer inflated condition with no cusps. The dune is highly vegetated except for the path.

UM17 is located at the Little Sable Point Lighthouse. The concrete at the base of the light is broken and the beach is natural.
1988-There were cuspate beach forms at the fall survey.
1989-In the spring, the old TBM has been buried by rubble at the base of the light. The nearshore bar, which has already welded to the north and south, is welding to the shore at the line. In the fall, the broad beach has low profile cusps with the site lying at the peak of a cusp.

UM18 is located within Summit Township Park. This region is characterized by 40 ft bluffs to the north and south. However, the site is located at a sand terrace. Previous severe erosion of the bluff is evident above a natural beach. A sheet pile structure lies to the north.
1988-The bluff slumped on the north side of the TBM to slightly bury the pipe prior to the fall survey.
1989-Cobbles appear on the beach which has a gently sloping berm. A stream outflows to the south. In the fall, a large sandy beach with high berms exists. There are many pebbles on the berm and larger stones in the water.

LUDINGTON:

UM19 is located in Buttersville Park south of the Ludington harbor jetties. The site is characterized by a very steep bluff. There are three offshore breakwaters just north of this otherwise natural beach site.
1988-At the spring survey there was a tombolo forming behind the southernmost breakwater. Prior to the post-storm survey, the tombolo was completely formed out to the southernmost structure and there had been no movement of the bluff.
1989-Tombolos to the north are well developed. A small berm exists above the swash which heightens to the north, towards the tombolo, and then recedes again. No evidence of bluff slumping exists and three bars occur. In the fall, the TBM was buried under 6 in of clay. Runoff from the bluff has created a beach with a hard clay shell. Sand is only present on the berm and at the shoreline.

UM20 is a broad natural beach adjacent to undeveloped shorefront property south of the Ludington harbor jetties.
1988-At the fall survey the TBM was slightly covered with sand.
1989-The broad beach contains cobbles and a lot of driftwood. The beach cusps to the north with a wavelength of about 100 ft eventually die out north of the site. At the fall survey the TBM lies flush with the sand. The large sandy beach contains high berms and the cusps have decreased to about a 50 ft wavelength.

UM21 is located at the north end of Stearns Park. There is a rubble mound to the north and the Ludington harbor jetties to the south. The broad beach is snow fenced every winter and bulldozed in the spring prior to the opening of the park concessions.
1988-During the fall survey the beach showed small cuspate forms.
1989-In the spring the pipe was possibly hit by a bulldozer and found 2 ft above the sand, at a 60 degree angle leaning towards the water. A depression occurs in the sand behind the TBM due to the presence of sand/snow fence. In the fall, the TBM was found pulled out so a backup TBM was utilized. The cuspate beach has accumulated sand since last year and is building in front of the rubble mound.

UM22 is located at the end of Juanita St. in Ludington. There is a wood groin and rubble revetment to the north near the water line and a wood seawall to the south shoreward of a broad beach.
1988-The site has not incurred any noticeable variations this year.
1989-A major slumping of the bluff has occurred in the spring. A new snow/sand fence runs about 10 ft south of the TBM. At the fall survey a new wood structure exists west of the TBM. The large, flat beach has accumulated sand compared to last year. A berm has developed near the water's edge.

UM23 is located adjacent to the check-in station at Ludington State Park.
1988-There is a broad natural beach and vegetated dune.
1989-In the spring, the beach appears to be twice as large as last year. A very small steep berm of 1-2 in has developed near the shore. The beach landward of the berm is damp indicating a recent overtopping. In the fall the large beach encompasses two berms. The first sandbar lies 150 ft offshore and two mild troughs exist. The shoreline appears fairly straight.

UM24 is located at the beach house at Ludington State Park. There is a concrete seawall at the swash zone with coarse sand fill behind.
1988-At the post-storm survey there was approximately 10-15 ft of beach exposed in front of the seawall, and at the fall survey there was approximately 4-6 ft.
1989-In the spring 10-15 ft of beach exist. The coarse fill which lies landward of the seawall appears the same. Rubble has been placed on the northern side of the river entrance to the south about 200 ft away. A small cutback emerges on the northern side of the site yet does not affect the beach at the site. The cusps on the beach to the north have a 200 ft wavelength.

UM25 is located north of the outpost camp in Ludington State Park.
1988-At both the post-storm and fall surveys the beach was highly cuspate with the forms approximately 60 to 70 ft in length.
1989-The wavelength of the cuspate shore has grown to about 100 ft in the spring. Two of the bars are very visible. Some sand has built up around the amafala grass. During the fall survey, the cuspate beach has a 300 ft wavelength and a height of 20 ft with the site situated at a shoreward peak. Between lines UM25 and UM26, there are some shore normal bars welding to the beach.

UM26 is just south of the Big Sable Point Lighthouse. There is a failing sheet pile structure to the north protecting the lighthouse which may influence the survey site. The dunes of approximately 30 ft height are vegetated.
1988-Prior to the post-storm survey a rubble mound had been placed tying the sheet pile to shore on the south side of the structure. The TBM was buried and the beach cusped at both the post-storm and the fall surveys.
1989-In the spring, a cusped shoreline lies to the south and sand has built out in front of the rubble. During the fall survey, the cuspate shoreline maintains a 300 ft

wavelength with the site lying at the midpoint between the crest and trough. A high berm appears about 1 ft in height.

UM27 is located in the wilderness area of Ludington State Park north of the lighthouse. The area is characterized by low dunes near the beach and numerous blowouts.
1988-At the post-storm survey, the beach was cuspate, however, at the fall survey these forms were absent and two prominent bars were present.
1989-At the spring survey, no cusps appear on the shoreline. The first trough cuts very deep and a small berm has appeared. Pebbles exist throughout the beach. In the fall, the shoreline has become mildly cuspate again. The large sandy beach has a high berm with a terrace on the shoreward side.

UM28 is located at the north boundary of the Ludington State Park. This site is similar to UM27 with low dunes and blowouts.
1988-At the post-storm and fall surveys there was coarse material on the beach.
1989-The site appears stable and the shoreline contains no cusps. Three bars are evidenced from the shore. The first trough cuts deep and consists of cobbles. The cobbles also appear at the swash zone and the nearshore water is very murky. Roots of a tree lie across the survey line about 10-15 ft in front of the TBM. In the fall, a large berm appears and a wide sandbar occurs 30 ft offshore. Cobble stones appear at the base of the bluff.

DAVIS SITES:

UM29 is located north of Manistee at a public road easement near the Bar Lake outlet. There is rubble revetment at the side of road with seawalls to the north and south of the site. This forms a small pocket beach.
1988-At the fall survey gravel covered the swash zone.
1989-The pocket beach material has concentrated on the north margin. North of the Bar Lake outflow a cut back occurs. The beach contains rubble at the midbeach and a small berm. In the fall the sandy, pebbly beach includes a larger berm. The first sandbar has migrated to within 1 ft of shore and starts to connect at the northern end of the beach with a little water occurring between the berm and connected sandbar. Sand is exposed in front of both the northern and southern seawalls.

UM30 is located at the Sunset Valley Resort near the Benzie/Manistee county line. There is a 250 ft bluff to the north exceeding the angle of repose. The site is characterized by an eroding bank with a wood seawall to north and old dock pilings to the south. The beach material is gravelly.
1988-At the fall survey, it appeared that beach material had accumulated at the base of the bluff.
1989-The beach has widened in the spring. Rocks appear on the shoreline and throughout the wading survey. The shoreline cusps to the north. A large tree is falling down on the bluff immediately behind the TBM. In the fall, one band of 3 in rocks lies 10 ft from the TBM parallel to the shoreline with another lying at the shoreline. Sand inhabits the area between the bands. The TBM was buried under 1 in of sand.

UM31 is located just south of the Point Betsie Lighthouse. There are steel groins to the north and south. Low-lying vegetated dunes containing numerous blowouts are adjacent to the beach.
1988-At the spring survey the beach face was very steep and nearshore accretion between the structures showed littoral drift to the south. At the fall survey, the beach was wider.

1989-The beach remains large in the spring. The southern groin is totally exposed containing about 10 ft of gravel and sand seaward. The swash appears at the end of the northern groin.

PETOSKEY:

UM32 is located at Magnus Municipal Park in Petoskey west of the harbor jetties. There is a stone groin to the west and the nearshore bottom is rock slabs. The site has a vegetation line instead of a bluff.
1988-The beach material is sand with coarse cobble material.
1989-Two berms of large cobble material appear. A build up has occurred on the western side of the groin. At the post-storm survey, more dune grass appears in the TBM area.

UM33 is located at the Petoskey Bayfront Park east of the harbor jetties. The nearshore bottom is very rocky.
1988-At the fall survey, evidence of water level drop was prominent.
1989-The park has planted grass on the bluff for stabilization. Small rocks (1-3 in) appear from the base of stairs to the rubble (1-16 in) on the shore. In the post-storm survey a moveable webbed plastic piece has been placed over the TBM.

UM34 is located in the Bayview Association in Petoskey. The site hosts a rubble revetment to the East.
1988-The beach consists of sand and rock.
1989-To the east, there is a rubble mound groin in place at the end of the rubble revetment. At the post-storm survey, new large rocks (8-18 in) appear on line at the waterline, surrounded by little rocks. In the fall, sand appears about 10 ft behind the waterline.

UM35 is located at the beach access of Petoskey State Park.
1988-There is a broad natural sandy beach at this location.
1989-The broad beach remains. In the fall, large pebbles appear on the beach and a sloping berm occurs at the water's edge.

UM36 is at the end of a city street in Harbor Springs. There is a rubble mound at the site with a sheet pile structure to the West.
1988-Prior to the fall survey, a new rubble mound had been placed to the East.
1989-The profile of the nearshore area is as follows: rubble revetment, 10 ft of sand, 30 ft of smaller rubble (.5-2 ft diameter), sand. At the post-storm survey the eastern house has put up a wooden embankment near the westward corner of lot. In the fall more rubble has been placed at the eastern house next to the site and more large boulders appear on line.

TAWAS:

UM37 is located at the end of Aster St. in Tawas. There is a storm sewer drainage pipe on a natural beach.
1988-During the fall survey there was a large drainage canal from the storm sewer, most likely due to the rain storm earlier that day.
1989-The drain pipe has created more water. Sand has accumulated in front of the drain, trapping the water. The DNR has placed a permanent monument 15 ft shoreward of the TBM around which sand is beginning to erode. At the post-storm survey the large

beach has become very swampy with a small pond lying south of the TBM. Grass has grown at the swampy part near the drain in the fall.

UM38 is located at the end of E. Birch Dr. in Tawas. This site is characterized as a pocket beach with rubble mounds to the north and south.
1988-There is a very low berm at the vegetation line.
1989-The first bar has welded to the shore creating a small pond extending south to north, parallel to the shore. At the post-storm survey the beach is large with a straight shoreline. Water still lies south of the TBM, however, no flow occurs into the lake. Southward the water stream has dried and hollowed out. A large berm occurs 10 ft from the swash.

UM39 is located east of the Tawas Point Light near the beach house at Tawas Point State Park.
1988-This area is very shallow showing welding of bar forms to the shoreline. During the spring survey, there was a cuspate shore. The fall survey caught a sand wave migrating to the south in the survey record.
1989-The beach has accumulated and the sandbar has welded to the shore and begins to weld north of the line. The southerly migrating bar from last year has been exposed. In the post-storm survey, the shoreline has large cusps with sandbars perpendicular to the beach. A large beach appears north of the TBM, mostly covered with water. Small pebbles lie throughout the beach. At the fall survey, a swim area has been created to the north. Compared to the previous survey, the water covers more of the beach. The cusps of the shoreline have a wavelength of nearly 40 ft.

UM40 is located south of the Tawas harbor pier in the city park. There is a narrow beach seaward of a small concrete seawall.
1988-At the fall survey there was a small berm on the beach resulting from the storm activity earlier in the day.
1989-In the spring a slight berm appears. A large mound of sand occurs in front of the TBM. Black dirt covers the swash area. In the post-storm survey, drainage occurs to the south from the pipe and black dirt remains in the swash area.

PORT SANILAC:

UM41 is at the base of Murphy Drive in Port Sanilac north of the harbor jetties. This site has a broad sandy beach.
1988-There was gravelly material at the swash zone during the fall survey.
1989-The beach contains gravel at the swash zone. The fence behind the TBM is nearly covered with sand. Vegetation has grown on the hill behind the TBM. At the post-storm survey, the TBM lies flush with the sand level.

UM42 is located at a private residence south of the harbor jetties. This entire stretch of coast is structured with an undercut concrete slab at the site and seawalls and groins to the north and south.
1988-At the fall survey, dredge spoils were being deposited south of the harbor and this loose clay/mud material was 2-3 in deep in the nearshore region.
1989-The seawall remains unchanged. Slippery boulders (3-4 ft wide) augment the sand at the seawall's bottom. In the fall sand bags and rebars have been added at the base of the seawall. Since the post storm survey, the cement at the base of the wall has cracked into 3 pieces.

UM43 is located at the end of Goldman Avenue in Port Sanilac.

1988-This site was a rocky shoreline with no beach at the spring survey. However, at the fall survey, the dredge spoils were actively being deposited approximately 150 ft south of the survey range. Approximately 150 ft of material was exposed to air seaward of the TBM. The dredge disposal pipe passed across the survey range, and crews were busy bulldozing the mud and sand.
1989-No evidence of dredge spoils exist from previous survey in the spring. Large pebbles lie on the beach between the revetment and water line. The nearshore bottom is very rocky. The owner next to the line reports hazards exposed during the summer and that the dredge muck was in suspension all last summer. At the post-storm survey, a small beach has been created in front of the northwest and southwest sides of the TBM with a larger beach lying farther south. Many pebbles lie on the beach with larger rocks further out. Beyond the rocks, the bottom is very mucky with few rocks. In the fall, the beach has narrowed considerably. Only large rocks (2-4 in) remain at the swash. Smaller pebbles exist from the shore to the sewer pipe. The beaches mentioned in the post storm survey have almost disappeared.

UM44 is located at the south end of a roadside park near Port Sanilac. This site showed gravel in the sand above the swash and a steep bluff to the north with a stream bed to the south.
1988-At the fall survey the stream bed was dry and there was a rocky berm present.
1989-In the spring a rocky berm with 3-4 in rocks exists and large rocks lie in the water. Mucky sand lies at the shoreline and the sand, when present, is very fine. At the post-storm survey large rocks and boulders lie offshore. In the fall the rocky berm is not noticeable

UM45 is located at the base of Walker Road south of Port Sanilac. This site is a natural beach with a small vegetated bluff.
1988-At the fall survey, there was a wide swash zone and no evidence of dredge spoils in the nearshore survey.
1989-The sandy beach contains cobble (1-1.5 in) at the water line. One sand bar exists past the rocks at a 2 ft depth.

Data Reduction

During year one of this research effort, the Interactive Survey Reduction Program (ISRP) was utilized (Birkemeier, 1984). This software was selected in order to remain consistent with the archive data format of other government agencies engaged in survey activity. The program is an IBM based application.

In 1989, the OEL, in a move toward consistency of computing facilities within the Naval Architecture and Marine Engineering Department of the College of Engineering, purchased a Macintosh IIx personal computer and peripheral digitizing board. This provided not only departmental consistency, but streamlined the majority of the laboratory's work efforts to the use of one type of computer. The Corps of Engineers, as yet, had not adapted ISRP for use on such a mainframe, therefore the OEL designed a similar interactive data reduction system with a translator for interchange of data files between the UM format and the ISRP format. In this way, consistency of database storage was preserved.

The reduction and analysis of the raw field data then proceeded in a similar manner to that described in the Year One Report. Bathymetric records for each survey period and individual site for the two year study were then overplotted for a detailed comparison of long and short term topographic changes. These plots are supplied as Appendix A.

All bathymetric data collected for each survey site was analyzed for unit volume change. In addition, detailed analysis of the natural or "equilibrium" profiles for the regions of the survey was performed, as well as an investigation of the offshore bar characteristics and movement in response to storm induced waves as well as water level changes. Methods and results of this analysis are presented in the Discussion section of this report.

Background

A brief summary of past investigations of coastal erosion on the Michigan coastline is provided in the Year One Report. It is the purpose of this report to evaluate the response of the nearshore profile to storm activity, evaluate short and long term changes in water level, and provide a database for the design of a numerical model of shoreline evolution. Therefore, a discussion of previous work on modelling of this type, equilibrium profile theory and shoreline response to changing water levels follows.

Modelling of Shoreline Evolution

Three primary approaches exist to the prediction of shoreline evolution and beach response for both natural and structurally impacted beaches. These approaches are: i) physical models; ii) analytical solutions; and, iii) numerical solutions to the mathematical equations which describe the physics of nearshore sediment transport. Physical models are generally very costly to accurately construct and tend to be site specific. Complete analytical solutions to the governing equations only exist for the most simple cases and are generally not applicable to most real shorelines. A numerical approximation to the solutions of the governing equations is, therefore, the most reasonable approach to the accurate prediction of beach response.

Numerous studies of sediment transport and shoreline evolution models have been conducted: Bowen (1980) provides an initial formulation of bed and suspended load sediment transport; Bailard (1981, 1982, 1983, and 1985) has developed an energetics sediment transport model for a plane sloping beach; Dally and Dean (1984) have also developed a suspended sediment transport and beach profile evolution model; Hanson (1987) discussed the use of a one-line model of general shoreline change (GENESIS); Yang (1981) has investigated on-offshore sediment transport; and, Moore (1982) has discussed beach profile evolution in response to changes in water level and wave height. Vellinga (1983, 1986) and Kreibel (1982, 1984a, 1984b, 1986, and Dean 1985b) have both recently developed relatively reliable beach erosion models. Dragos (1981) and Perlin and Dean (1983) developed an N-Line model to predict shoreline evolution in response to groin field emplacement. This model was further enhanced for application to other coastal structures by Sheffner and Rosati (1987). Meadows (1982) adapted this model for use along the Pennsylvania shoreline of Lake Erie, a region of relatively simple bathymetry.

The one-line model approach, as discussed by Hanson (1987), is limited by the fundamental assumption that the natural beach profile does not change with time. One important implication of this assumption is that cross-shore sediment transport must be considered negligible and that the response time for the return of the bottom profile to equilibrium after storms is on the order of days or weeks. However, due to the hydrodynamic forces in operation within the Great Lakes, such as drastic changes in sea level and fetch limited wave growth and as evidenced from this data set, the response time is believed to be orders of magnitude longer. In addition, a true two-dimensional representation of coastal evolution is what is clearly needed, especially in the vicinity of coastal structures, both natural and man-made.

Birkemeier, et al (1987) recently evaluated Bailard's, Vellinga's, and Kriebel's qualitative shoreline evolution models. Bailard's theoretical models have not had their applicability demonstrated, and when they were compared to actual shoreline evolution data, the results were "disappointing". The Vellinga model provides good results, but is not valid for situations in which there is a mildly sloping beach. The Kriebel model was found to work well, but in a limited region; it is only applicable from the swash zone to the breaker zone, which is not sufficient coverage for proper prediction of shoreline evolution. Therefore, a need exists to develop a well-formulated model which can be generally applied to the broad spectrum of real shoreline environments.

A numerical model which has been successfully demonstrated for use in the Great Lakes region (Meadows, 1982), based upon the previous work and models of LeMehaute and Soldate (1977, 1980), and Dragos (1981), and a precursor to the work of Perlin and Dean (1983), utilizes a sediment budget technique to numerically balance flows of beach material in the alongshore and on-offshore directions. The sediment motions are driven by the changes experienced by the incident wave field as it approaches the beach. If more sediment enters than leaves the volume of beach under consideration, the beach profile swells with sediment. Conversely, if a net deficit of material exists during a particular time interval, the beach profile will exhibit erosion.

To adapt this capability to the Great Lakes, the models' ability to account for a large variation in sediment characteristics and coastal environments must be evaluated.

Equilibrium Profiles in the Great Lakes

The theory that a beach profile will tend toward an equilibrium shape when exposed to constant wave and water level conditions provides a valuable tool for numerical modelling of beach profile evolution. The two-thirds power law equilibrium beach profile was empirically derived by Bruun (1954). Dean (1977) provided a theoretical derivation of this model based on uniform wave energy dissipation per unit water volume. This relationship is expressed as:

$$d = A_s x^{2/3}$$

where d is the water depth, x is the distance offshore, and A_s is a constant which is dependent upon sediment and fluid properties. Moore (1982) presented a relationship between A_s and sediment diameter. This relationship was based on extensive experimental data for a wide range of sediment sizes. Balsillie (1987) proposed a model for A_s based on a parameter which includes sediment fall velocity (w) and wave period (T) and wave height at the break point (H_b):

$$\frac{H_b}{wT}.$$

The usefulness of the two thirds power law equilibrium beach profile has been demonstrated by many investigators. Hughes and Chiu (1978) studied the applicability of the two-thirds power law model to the Florida coast. It was found that the equation modelled the profile well to 1200 ft offshore. The two thirds power law equilibrium profile is used in most current numerical models for coastal evolution, including the Genesis model (Larson and Kraus, 1989) and Perlin and Dean (1984). Larson and Kraus (1989) showed that Deans equilibrium profile could be useful in zones of wave reformation. In the development of the SBEACH model of beach profile evolution they applied the relationship to the formation and movement of nearshore bars.

Shoreline Response to Changes in Water Level

As outlined by the Impact of Great Lakes Water Levels on Shore Processes workshop (Davidson-Arnott and Law, 1989), the key processes affecting the nearshore environment are waves and wave generated currents which control sediment erosion, transport and deposition. At any individual site, the wave climate is determined by the shoreline orientation, fetch lengths, wind climate, and presence of shorefast ice. Storms results in an increase of wave energy reaching the shoreline, thus the storm climate is an important parameter. In addition, there is a wide range of coastal environments in the Great Lakes, ranging from bedrock shorelines through cohesive bluffs to protected bays. Each shoreline type may be characterized by a different subset of controlling coastal processes. Variations in water levels change the location of still water elevation and thus, the area over which these coastal processes operate.

In the sand beach and dune environment, increased water levels produce beach erosion and act to cut the dune face, while low water levels result in build up of the foredune by wind action. Along the Lake Michigan shoreline, there is evidence that the foredune construction during lower water levels is inactive, thus indicating that water level cycles may shift the range over which the dominant wave-induced sediment processes occur, but may not alter the long term sediment budget.

Much of the southern Lake Michigan shoreline is characterized by steep bluff faces. In this environment, high water levels may accelerate the bluff recession in the short term, thus steepening the bluff slope and decreasing the offshore slope. The nearshore would then adjust quickly. Lower water levels would result in a simple adjustment (lowering) of the nearshore profile. In some cases, the bluff material exposed near the water surface contains boulders or more erosionally resistant material. Its presence may serve to reduce erosion by decreasing the exposure of erodible bluff to wave forces.

Structurally impacted shorelines suffer greatly from our inability to accurately predict water level fluctuations. High water levels will overtop structures rendering them ineffective, while low water levels may expose the bases of structures causing structural degradation.

The impact of changing water levels on shoreline morphology and bathymetry has long been a topic of interest in both oceanic and Great Lakes coastal research. Bruun (1962) suggested that an increase in the mean water level tends to shift the nearshore profile landward. Therefore, as water levels rise, erosion prevails on the upper beach causing the shoreline to recede. This eroded material supplies the offshore region causing an upward building of the outer profile (see Figure 2).

Investigations of beach changes on tideless coasts have been limited. Evans (1940) and King and Williams (1949) investigated the variability of longshore bars and troughs in the Great Lakes and Mediterranean Sea respectively. The studies of Bajorunas and Duane (1967), Davis and Fox (1971, 1974), and Fox and Davis (1971, 1973) were of limited duration, and therefore were inadequate to evaluate long term variability in nearshore bathymetry. Hawley and Judge (1969) evaluated two sets of profiles obtained in 1966 and 1967 along the southern Lake Michigan shoreline, defining a possible closure depth for the region. Hands (1976, 1979, 1980, and 1983) analyzed beach and offshore profile data taken during a period of rising water levels. He found Bruun's sediment balance approach to work well for sandy Great Lakes coastlines under rising water levels and recommends further investigation under falling water levels.

Weishar and Wood (1983) propose a conceptual model for barred bathymetry response to changes in mean water level based upon a four year set of nearshore profiles taken at one month intervals along the Indiana shoreline of Lake Michigan. The model is shown in Figure 3. Under the condition of rising lake levels, the inner bar and outer bar

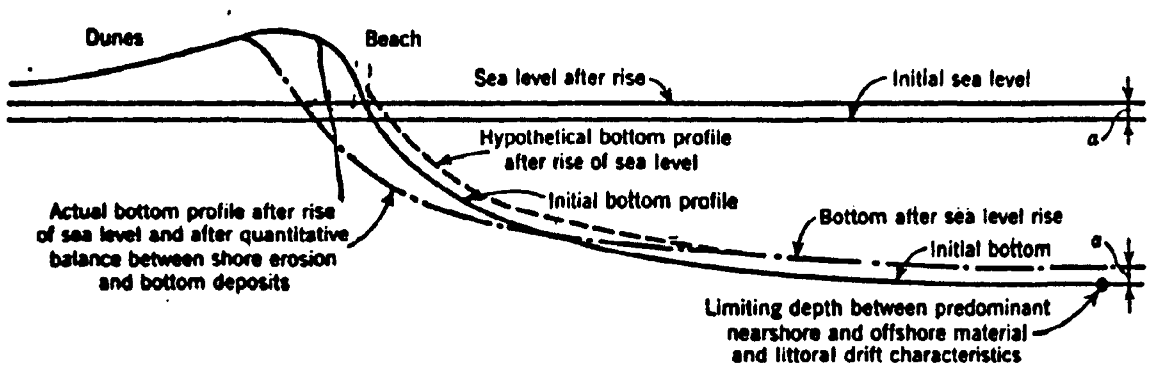


Figure 2. Illustration of Bruun's conceptual model of shoreline change (from Bruun, 1962).

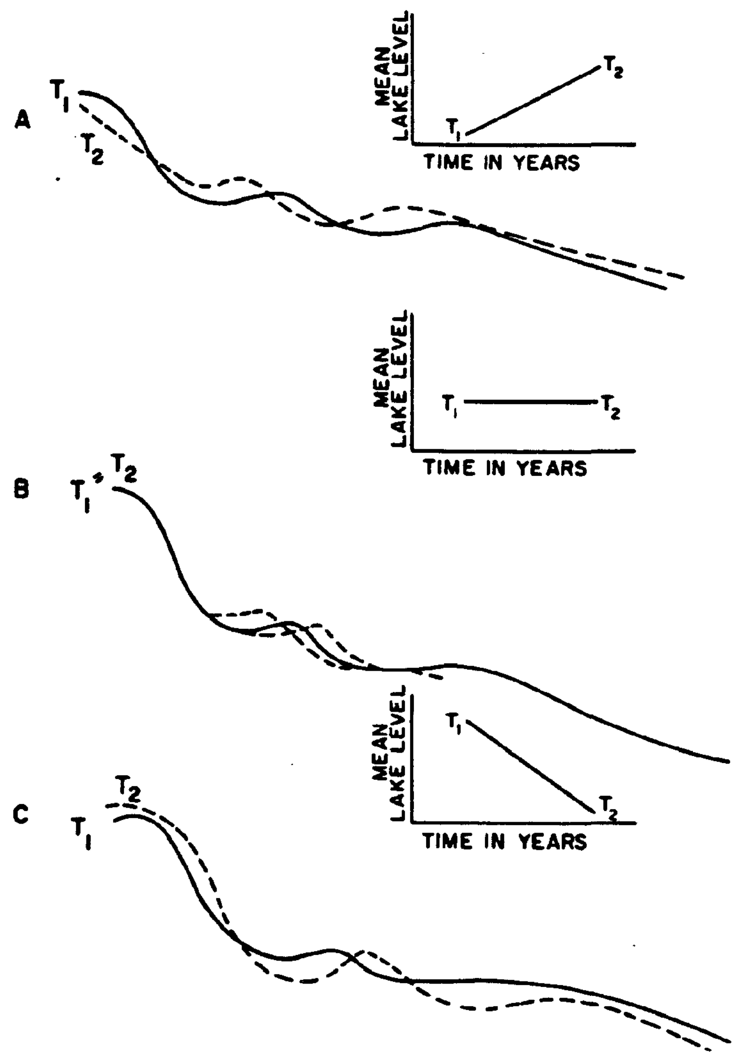


Figure 3. Illustration of Weishar and Wood's conceptual model of tideless coastal response (from Wieshar and Wood, 1983).

migrate shoreward. The beach and nearbeach region show a corresponding erosion as lake level and wind wave activity advance up the shore face. If no change in water level is experienced, there will be movement only of the inner bar in response to storm activity. Should water levels decrease, as seen through the duration of the MDNR Coastal Monitoring Program, the inner bar and outer bar may migrate offshore and/or show erosion. The beach and berm area will increase in subaerial extent and experience deposition. As the wave base is lowered, the amount of wave energy impinging the bottom at any point will increase, thus increasing sediment transport in deeper regions of the profile.

Discussion

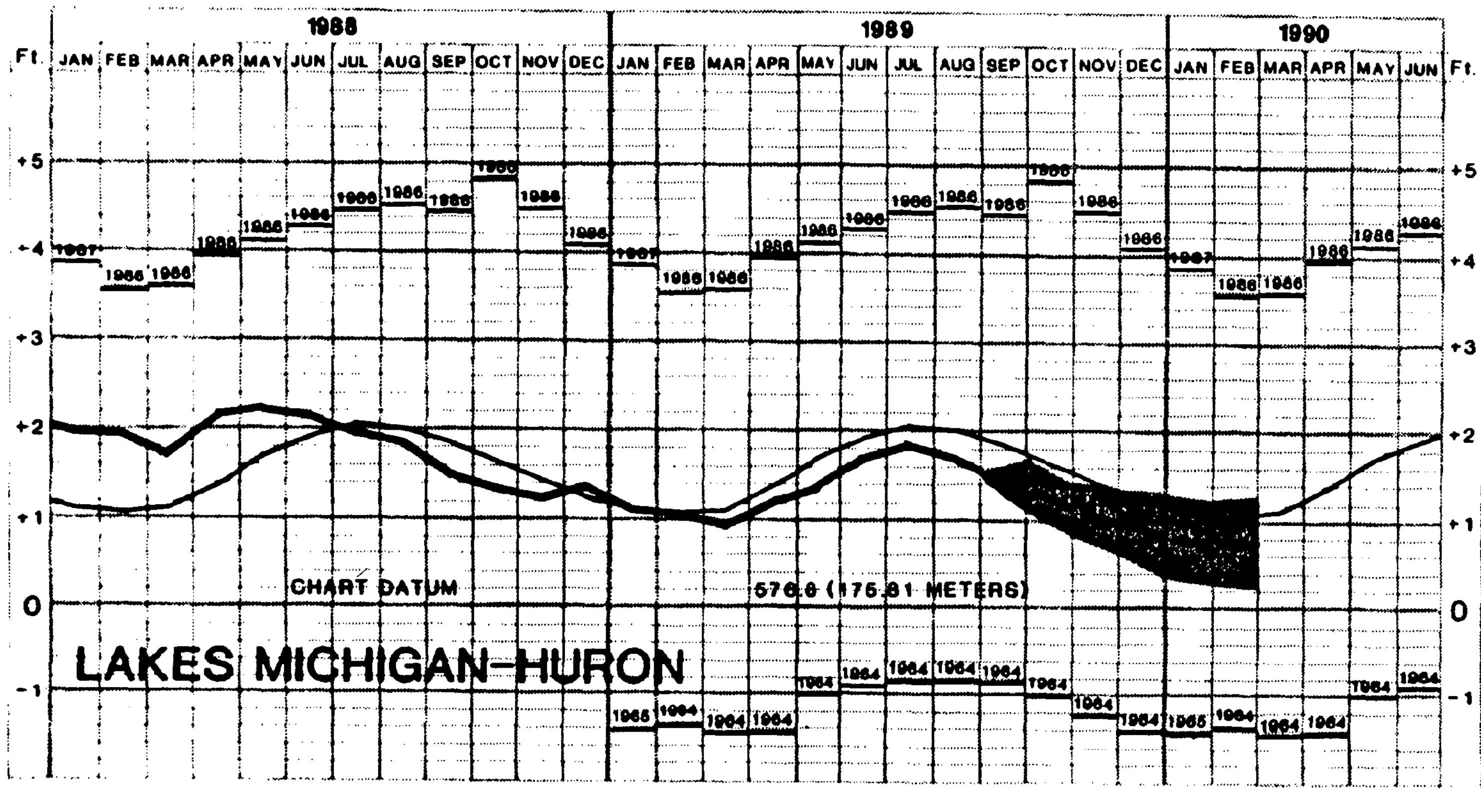
To gain basic insight into the dominant coastal processes through the duration of this study, a detailed analysis was performed. In order to examine the forces acting to shape the coastal environment, an evaluation of the wind climate and water level history was completed. Bathymetric response of the nearshore region was estimated through a volume change analysis and longshore bar migration assay. In an effort to establish a characteristic profile shape for various nearshore environments, an examination of the application of the equilibrium profile concept to the data set was undertaken. This section presents a summary of the data analysis and a discussion of the results.

Climatology

In any study of environmental response, it is of utmost importance to characterize the forcing functions responsible for the observed changes. In this study, and as indicated by previous studies, the two most important factors responsible for coastal evolution, in order of importance, are storm wave activity and water level variations. Engineering structures play a secondary role in modifying the flow structure of the nearshore zone and will be treated in the bathymetric response discussion.

Figure 4 illustrates the water level changes experienced through the two year data collection period. The duration of the study saw an overall change in mean water level from 0.6 ft above to 0.2 ft below the long-term mean; 0.8 ft overall.A seasonal cycle is superimposed upon this overall change in mean level. Water level rises during spring and declines during late summer and fall. Between successive spring surveys, the water level fell 0.8 ft, while successive fall surveys experienced a drop of only 0.1 ft. In summary, there was a drastic decline in water levels from May to November of 1988, followed by a slight rise through the winter of 1988/89. The field season of 1989 experienced a sustained lower mean water level, with a slight fall from July to August.

The wind climate of the northern and southern portions of Lakes Michigan and Huron through the 1989 field season is provided in Figure 5. Similar data for 1988 is included in the Year One Report. Large waves resulting from sustained winds of 10 miles per hour or greater are the primary force responsible for the movement of sediment in the coastal zone. Storm frequency was tabulated for the northern and southern reaches of the study for both 1988 and 1989. This data in Figure 6 shows that 1988 was characterized by a large number of storms from the south and southwest



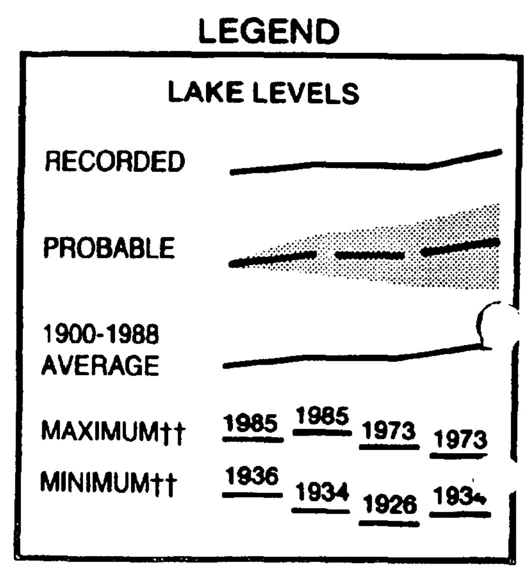


Figure 4. Water level history for Lakes Michigan and Huron, 1988 and 1989 (from USAE, 1988).

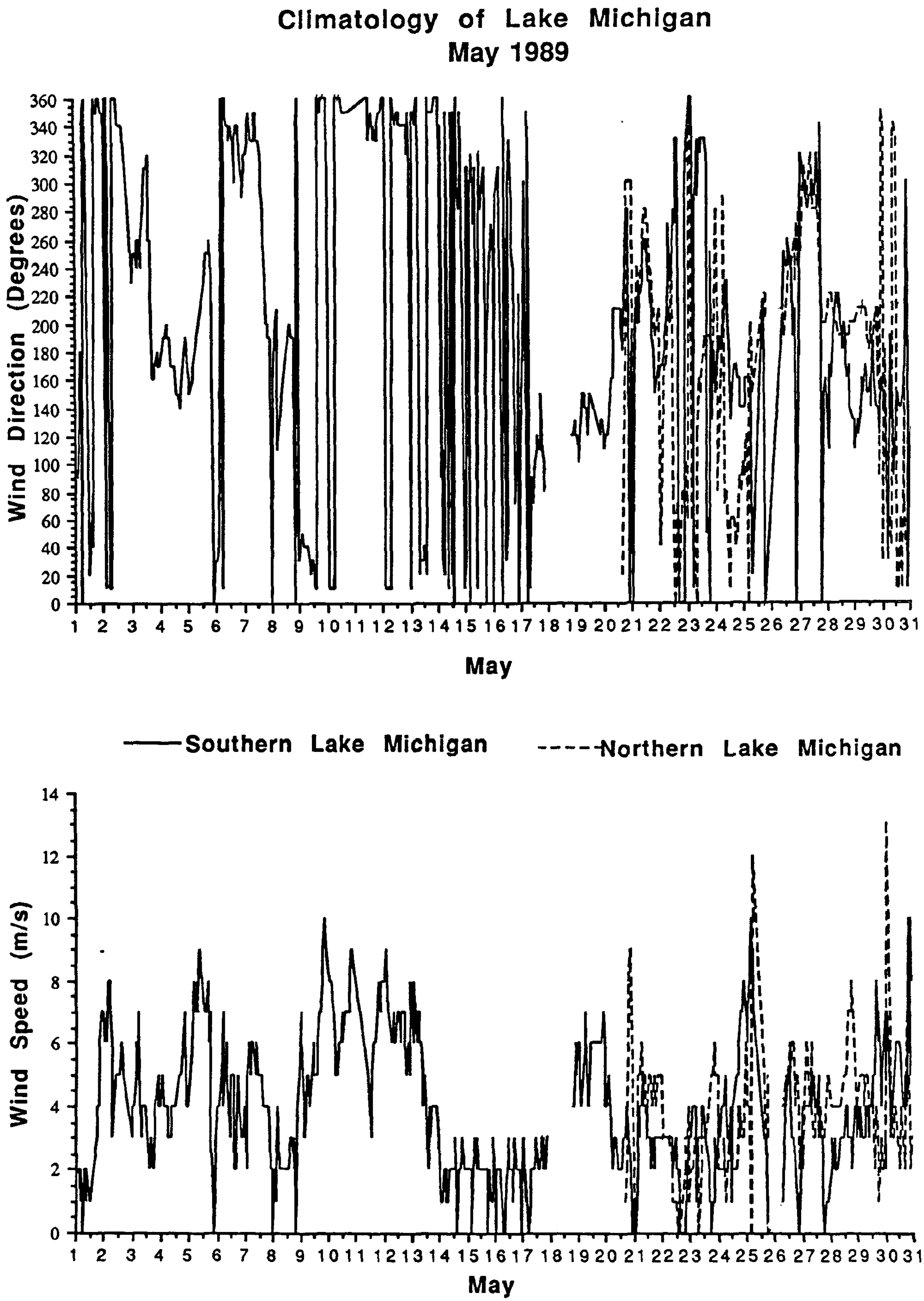
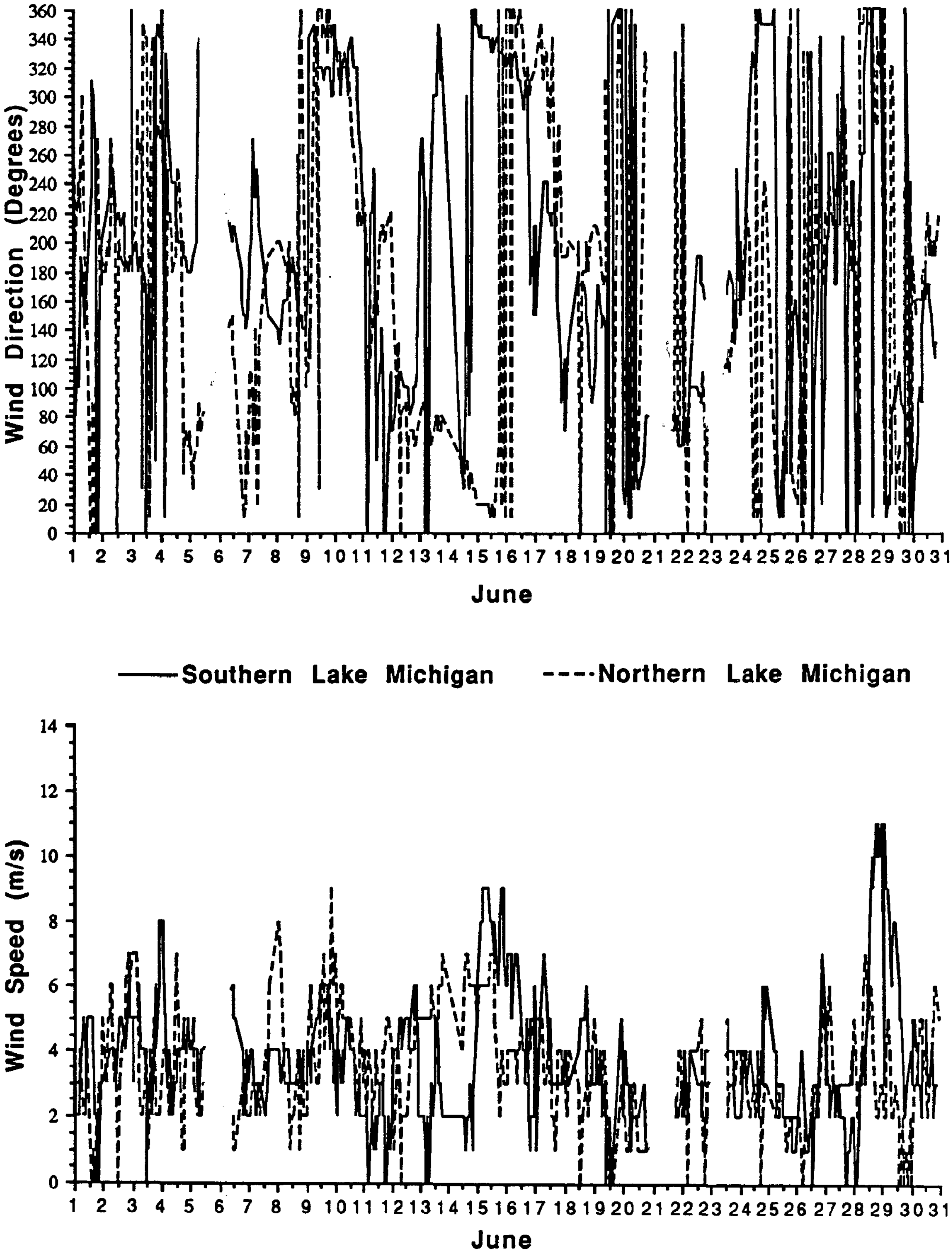


Figure 5. Timeseries of 1989 field season wind speed and direction data from National Data Buoy Center.

Climatology of Lake Michigan
June 1989



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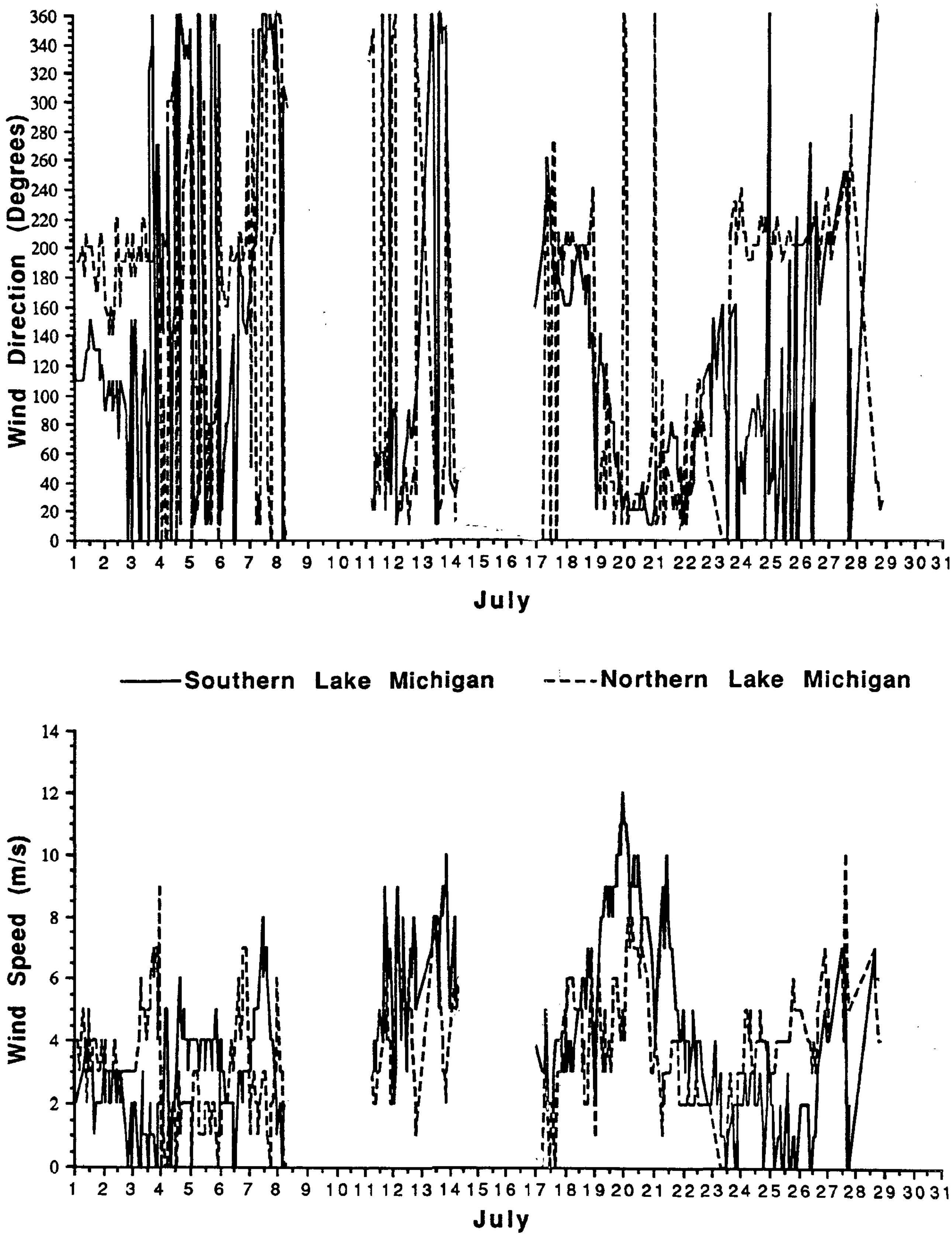

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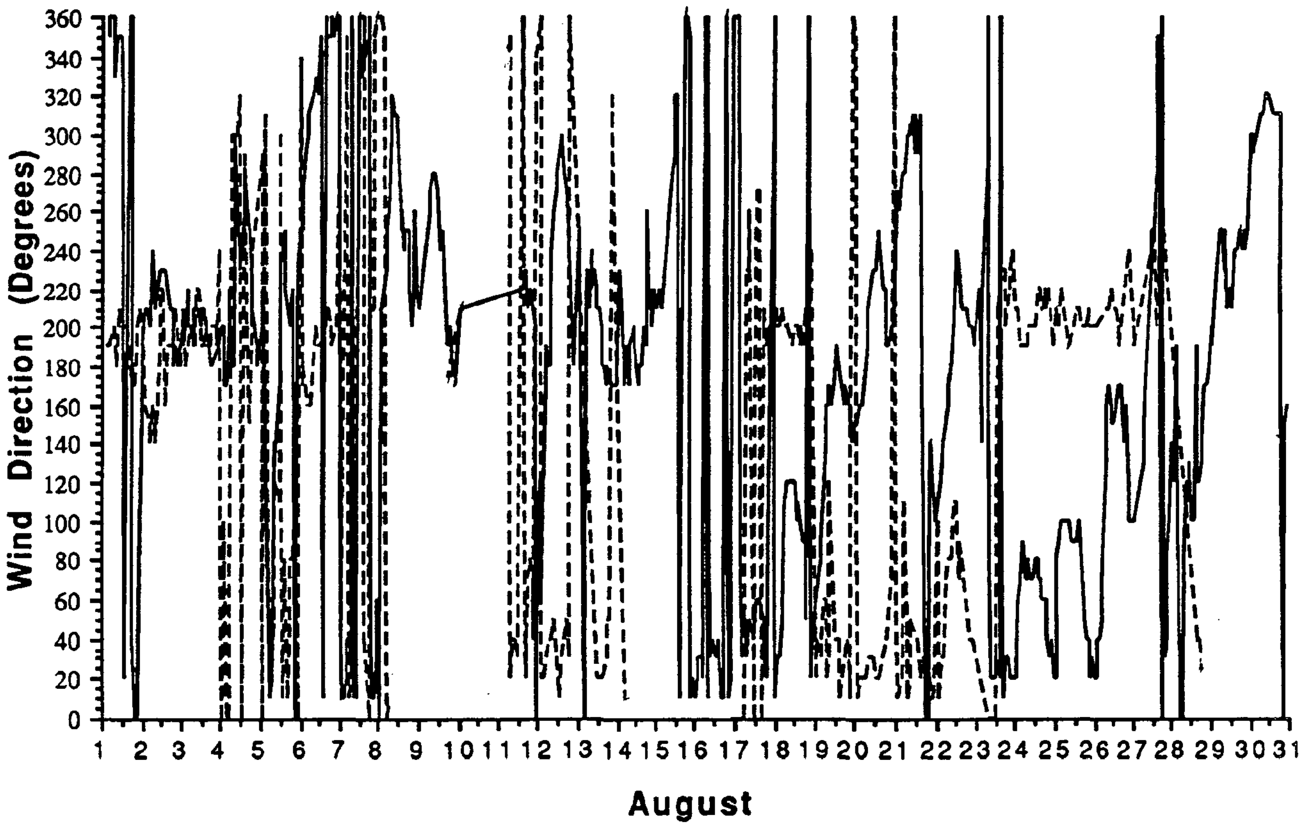
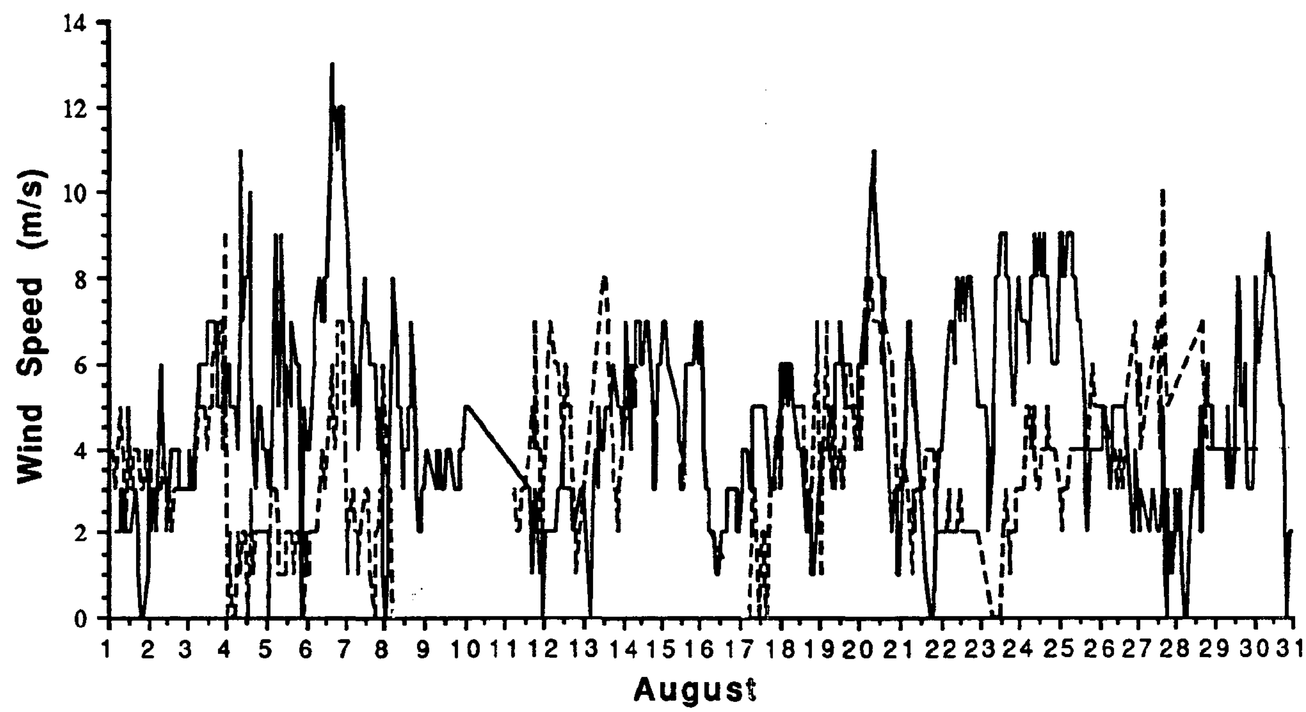
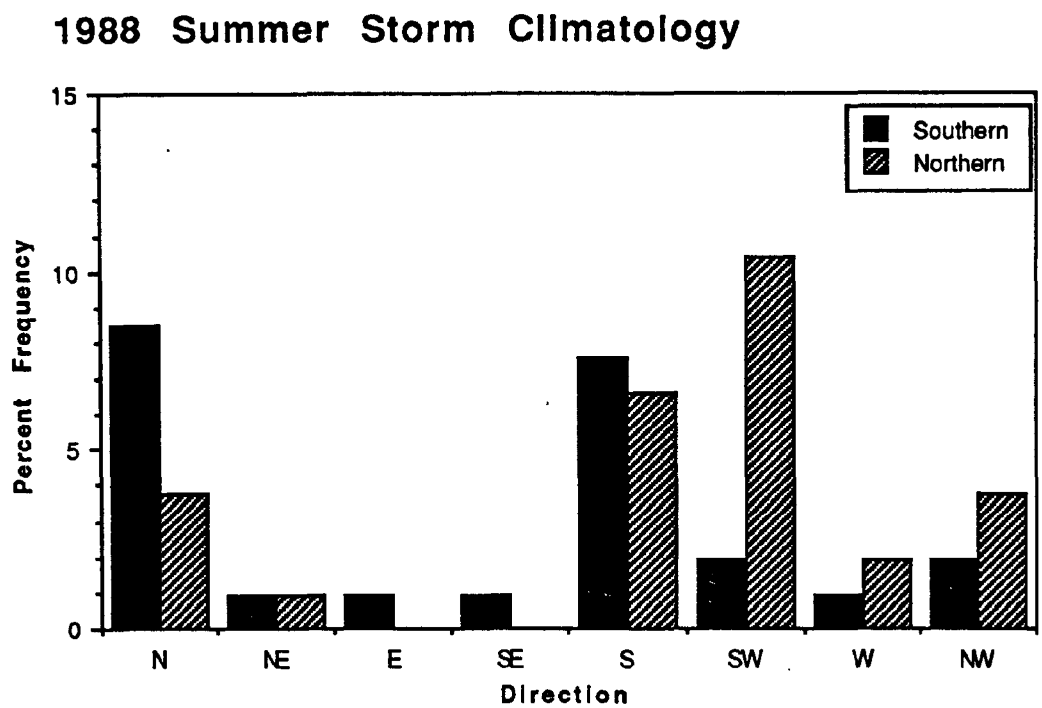


——Southern Lake Michigan ----Northern Lake Michigan





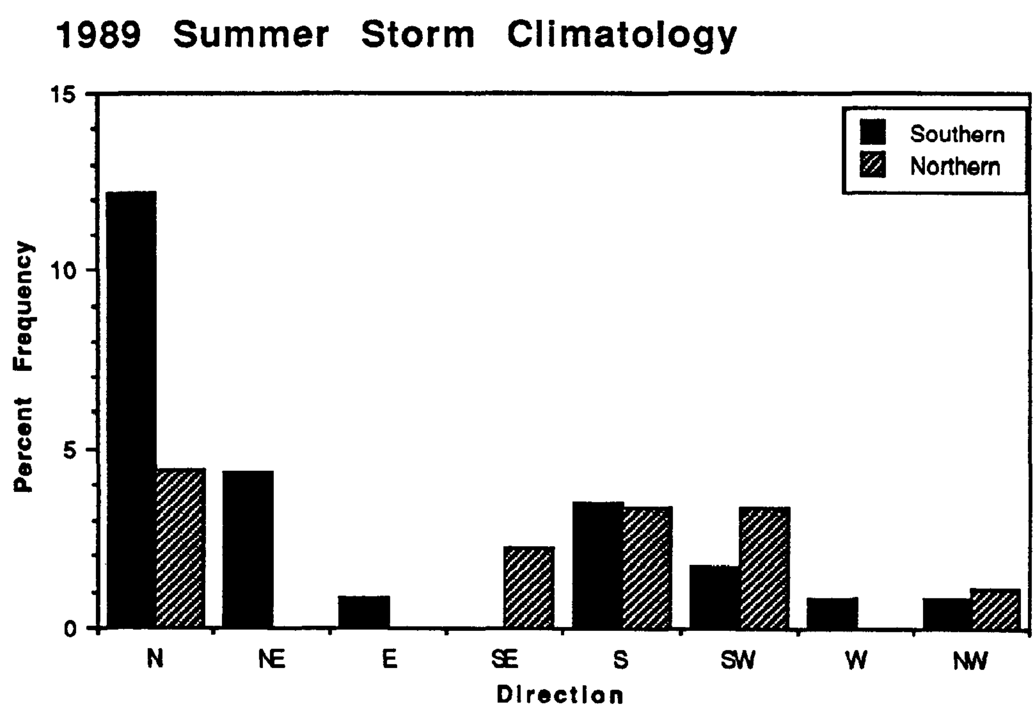


Figure 6. 1988 and 1989 Field season storm climatology by wind direction.

impacting northern beaches, and an equal distribution of storms from north and south dominating the southern reach of the study. As is evident from Figure 6, the 1989 field season storm climate was significantly different from 1988. The southern survey sites experienced a large number of storms from the north, while the northern sites enjoyed a fairly mild storm season.

Volumetric Change and Bathymetric Response

All bathymetric data collected for each survey site was analyzed for unit volume change. The volume analysis program computes changes in elevation and cross-sectional area for successive surveys of each profile line. To accomplish this, the program linearly interpolates the actual survey data into a series of uniformly spaced elevations. Calculations are then made of the elevation change at each digitized distance between each survey. The incremental change in cross-sectional area is computed by averaging adjacent elevation changes and then multiplying the average by the digitizing interval. Incremental volumes are summed to obtain a net profile change. The gross profile change is computed as the sum of the absolute values of the incremental volume changes. The net can be interpreted as the total material added to or removed from the surveyed area, while the gross is the amount of material in motion. "Cut" and "fill" quantities are also determined. These are areas where a series of adjacent incremental volumes are either all negative (cut) indicating erosion, or all positive (fill) indicating deposition (see Figure 7).

Calculations of annual volume change were derived from both the successive spring surveys, as well as the successive fall surveys. A bar chart of the gross and net volume change is presented in Figure 8. The difference between gross volume change and the absolute value of the net volume change is an indication of the amount of profile adjustment such as bar migration. In general, many sites experienced a large amount of profile readjustment due to storm activity and the drop in water levels, and very little net gain or loss of sediment. However, many high risk erosion areas as identified by the MDNR (1974), continued to show overall loss during this period of falling water levels.

The New Buffalo sites (UM 1 through 5) show evidence of structural impact with growth of the profile at UM 4 and 5, north of the harbor structure, and loss of sediment at UM 2 and 3 in the spring comparison. The fall survey comparison for this region shows the impact of the beach nourishment at UM 3 which helped to alleviate a large portion of the potential erosion, even though some nearshore loss occurred. UM 5 and nearby UM 6, two sites with very steep bluffs and nearshore zones, are enjoying a much needed period of accretion following the initial adjustment to lower water levels.

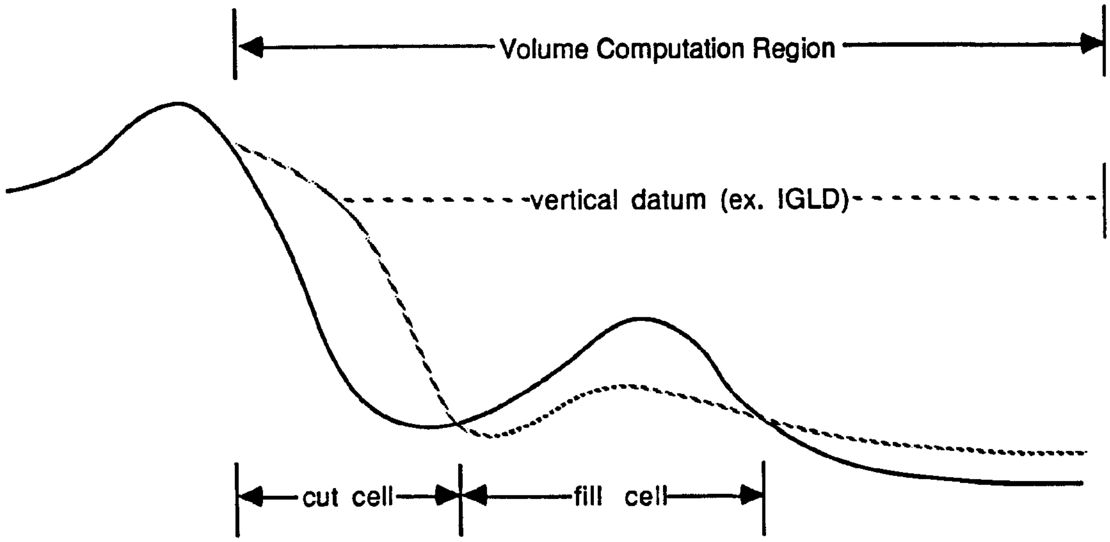
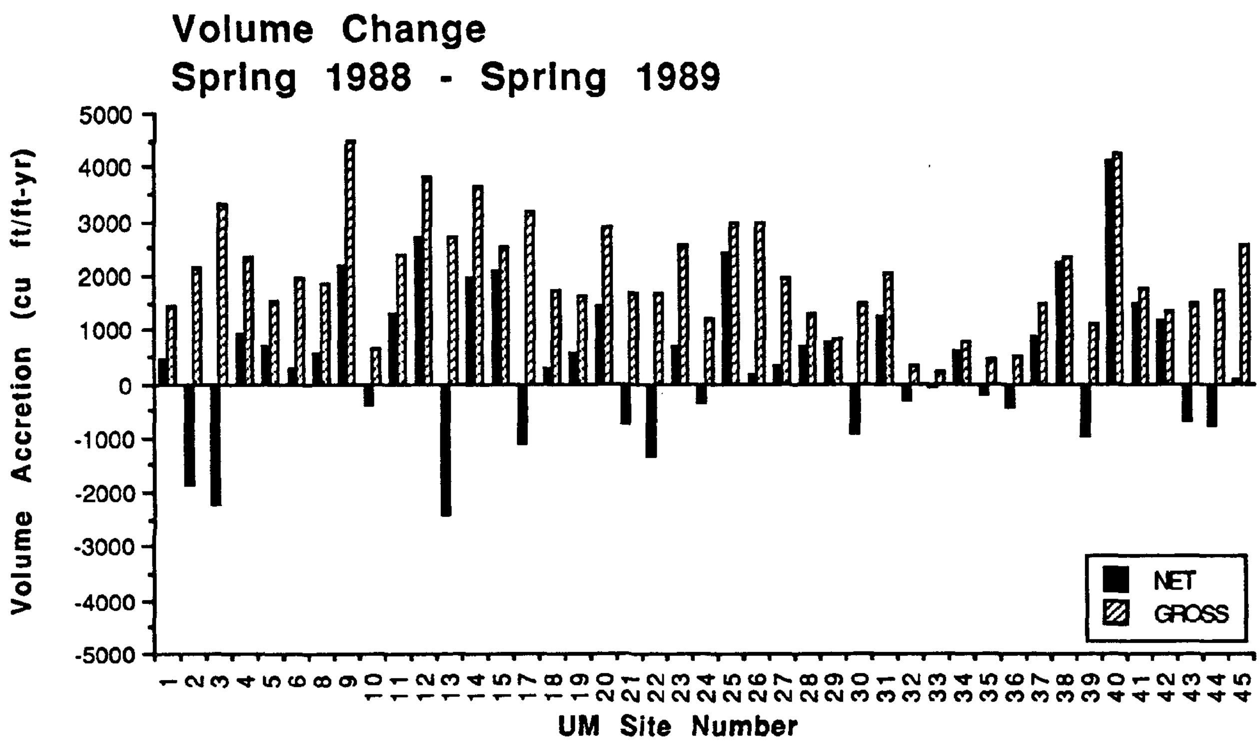


Figure 7. Volume change computation diagram (after Birkemeier, 1984).



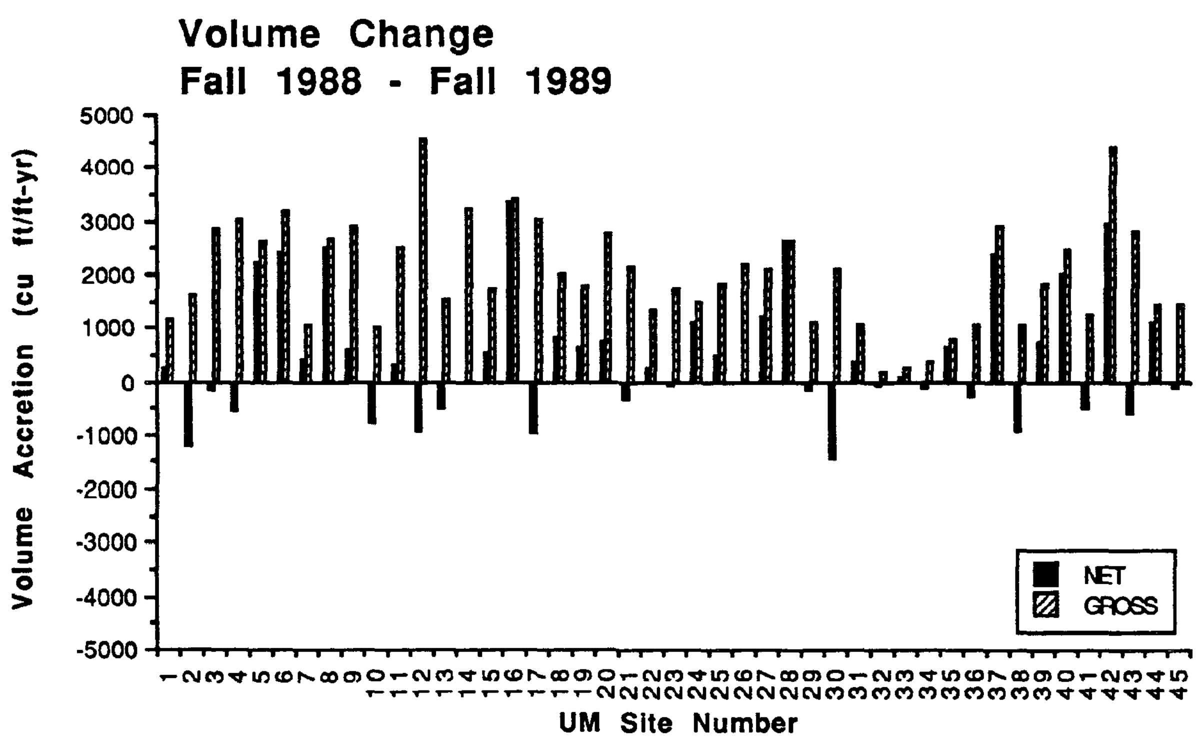


Figure 8. Volume change calculations for UM survey sites.

Throughout the reoccupied Davis (1976) sites (UM 6 through 18, and 29 through 31), high risk erosion areas continued to exhibit either dominant shoreline adjustment or continued nearshore loss. Bluffs and dune faces remained fairly stable, reducing the supply of littoral material to the coastal zone and causing nearshore loss to maintain the sediment budget balance.

Volume change analysis at the Ludington sites (UM 19 through 28), as in New Buffalo, exhibits the effect of the harbor structure at the City of Ludington. Recall from the climatology that the major portion of the storms during the field season of 1988 were from the south. This is physically expressed by the gain of sediment on the south side of the harbor jetties (UM 19 and 20) and a loss on the north side (UM 21 and 22). During 1989, this region experienced very few storms with slightly higher occurrence of a southerly component. The volume change data for the fall surveys reflects this as a decrease in net movement for the sites near the structure and a reversal in the gain/loss pattern. The sites comprising the Ludington State Park and Big Sable Point experienced some combination of coastal readjustment and nearshore gain.

The five survey lines in Little Traverse Bay (UM 32 through 36) show the smallest volumetric change of the study. UM 32, 33, 34 and 36 are shaped by large boulders, and in some cases bedrock, thus very little nearshore change should be expected. It is impossible to distinguish survey error from real volume change if the value lies below approximately 500 cu ft/ft-yr, therefore, it is necessary to conclude that any changes in the nearshore bathymetry for this region were too small during the past two field seasons to be detected by this hydrographic survey technique, with the exception of a small gain at the Bayview site for the spring comparison and a small gain at the Petoskey State Park for the fall.

The Tawas region (UM 37 through 40) appears, on average, to have benefited from the falling water levels. The profiles have inflated in all but two annual comparisons. The spring volume change shows a loss of material at the Tawas Point site. This site is an extremely active region of the point characterized by multiple nearshore bars and cross-shore sand waves. This loss may be attributed to the longshore migration of a sand wave through the survey range.

Five sites were monitored in the Port Sanilac area (UM 41 through 45). The volume analysis for this site is complicated by dredge activity at the harbor during the late summer 1988. In August, the harbor mouth was dredged and the very fine spoil material was deposited at site UM 43. In addition, the activity of the dredge caused a large amount of material to accumulate at UM 42. The north side of the harbor structure (UM 41) exhibited normal structurally impacted behavior, similar to that of another southern site, UM 4. The southernmost survey site (UM 45) shows simple coastal readjustment with very little net change.

To examine the process of coastal readjustment in more detail, measurements of inner and outer nearshore bar position were made for all of the survey sites. These values were then compared over a one year time lapse (spring to spring, fall to fall) to provide estimates of bar migration. These data are presented in Figure 9. As proposed by Weishar and Wood (1983), on a tideless coast, the inner bar will move in response to the wind wave climate, while the outer bar depth will exhibit a strong correlation to variations in water level. The model suggests that as water level falls, one should expect the outer bar to migrate offshore. These two trends are exhibited in Figure 9. Here it can be seen that the inner bar migration is approximately equally distributed between onshore and offshore movement, while the outer bar exhibits a strong tendency for offshore migration. In the New Buffalo region, however, the migration of the outer bar is adverse to the Weishar and Wood model. The site exhibiting this adverse bar movement in the New Buffalo region are exposed to large structural impact which may affect onshore transport to the depth of the outer bar and produce onshore migration of that bar, which will far outweigh the effects of falling water levels.

Equilibrium Profile Evaluation

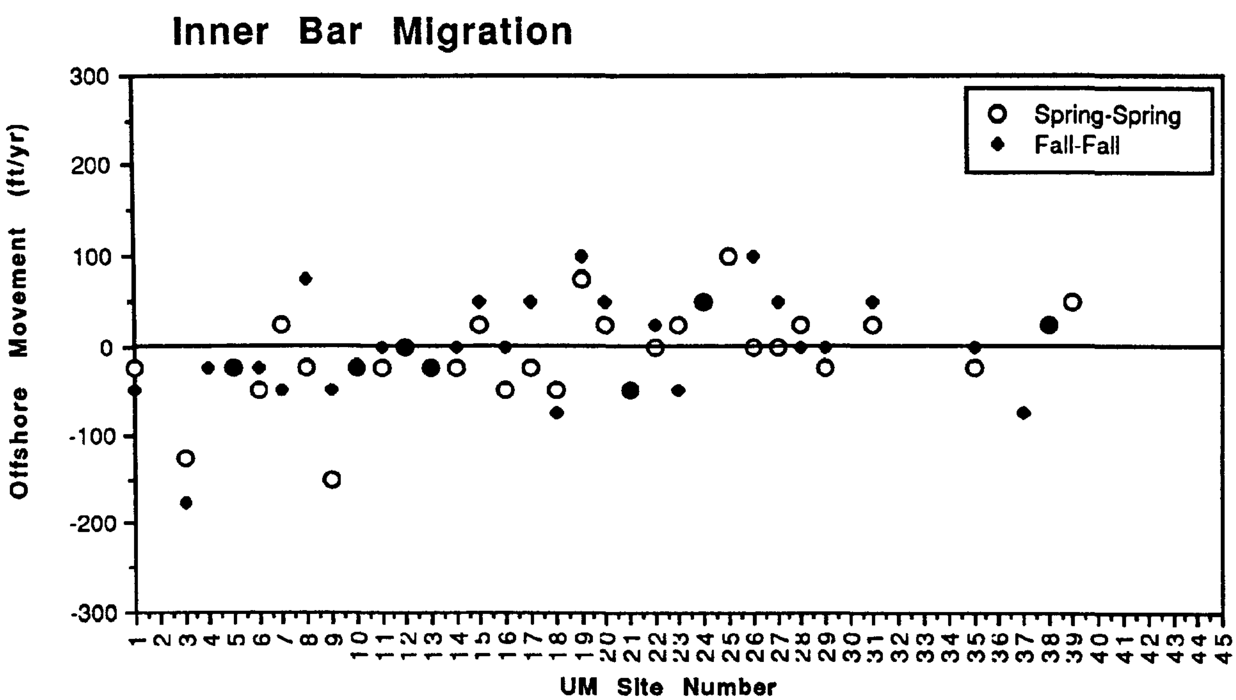
The procedure used to analyze the data is from Balsillie (1987). A_s values were calculated using the numerical curve fitting procedure described in the above paper. The exponent is fixed at 2/3 and A_s is calculated by the following direct method:

$$A_s = \frac{\sum d_m x^{2/3}}{\sum x^{4/3}}$$

where d_m is the actual water depth and x is the distance offshore. The power curve fit is assessed using the root-mean-square-error, E_{rms}. The lower the value of E_{rms} the better the fit.

$$E_{rms} = \sqrt{\frac{\sum (d - d_m)^2}{n - 1}}$$

where $d = A_s x^{2/3}$ is the calculated depth.



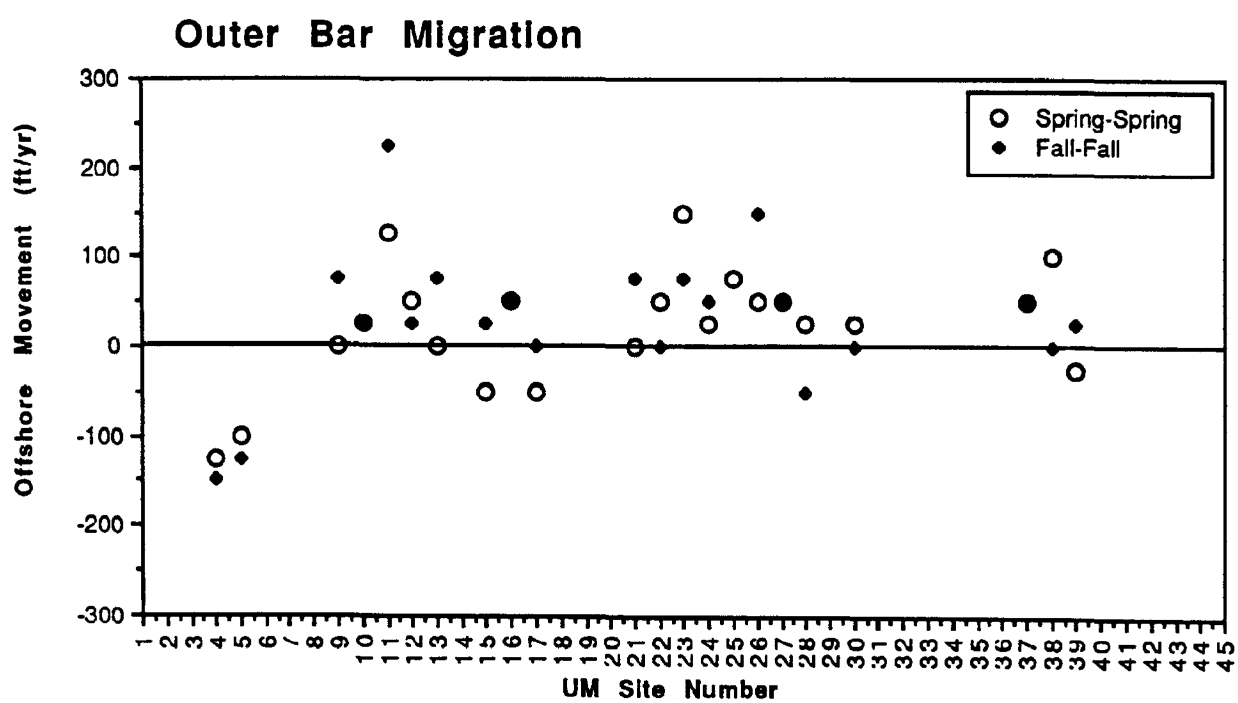


Figure 9. Inner and outer bar movement values for UM survey sites.

Balsillie used the following scale for determining the nature of the profile from the E_{rms} value:

E_{rms}	Description
0.0 - 1.0	Smooth
1.0 - 2.0	Slightly Barred
2.0 - 3.0	Moderately Barred
3.0 - 4.0	Strongly Barred
> 4.0	Suspect

The use of this scale required that the linear correlation coefficient exceeded 0.95 and that the E_{rms} value was less than 4.0. The linear correlation coefficient was calculated by the following equation:

$$r_{xd_m} = \frac{\sum_{i=1}^{n} x_i\, d_{mi} - N\,\bar{x}\,\overline{d_m}}{\sqrt{\left(\sum_{i=1}^{n} x_i^2 - N\bar{x}^2\right)\left(\sum_{i=1}^{n} d_{mi}^2 - N\overline{d_m}^2\right)}}$$

where N is the number of depth measurements, $\bar{x}$ is the average distance and $\bar{d}_m$ is the average depth.

The analysis was performed for the full surveyed profile for two reasons. The first was to facilitate comparison with Balsillie's results. The second reason was because the surveys were designed to extend to the depth of closure for the Great Lakes, hence any shoreward limit such as that suggested by Hughes and Chiu (1978) could yield unreliable results. The correlation coefficients for the entire surveyed profile were generally above the 0.95 limit set by Balsillie (see Figure 10). Most of the UM profiles were slightly to moderately barred as exhibited in Figure 10. The temporal constancy of the E_{rms} values shows that the barred profile is a stable feature of the Great Lakes coastline. The barred nature of most of the profiles renders the power law unsuitable for modelling processes which are strongly dependent upon the smaller scale features of the profile. The general shapes of the entire surveyed profiles are modelled accurately by the two-thirds power law.

The model gives very consistent results for UM1-UM25, the best fit shape coefficients in Figure 11 show that the profiles maintain the same general shape over

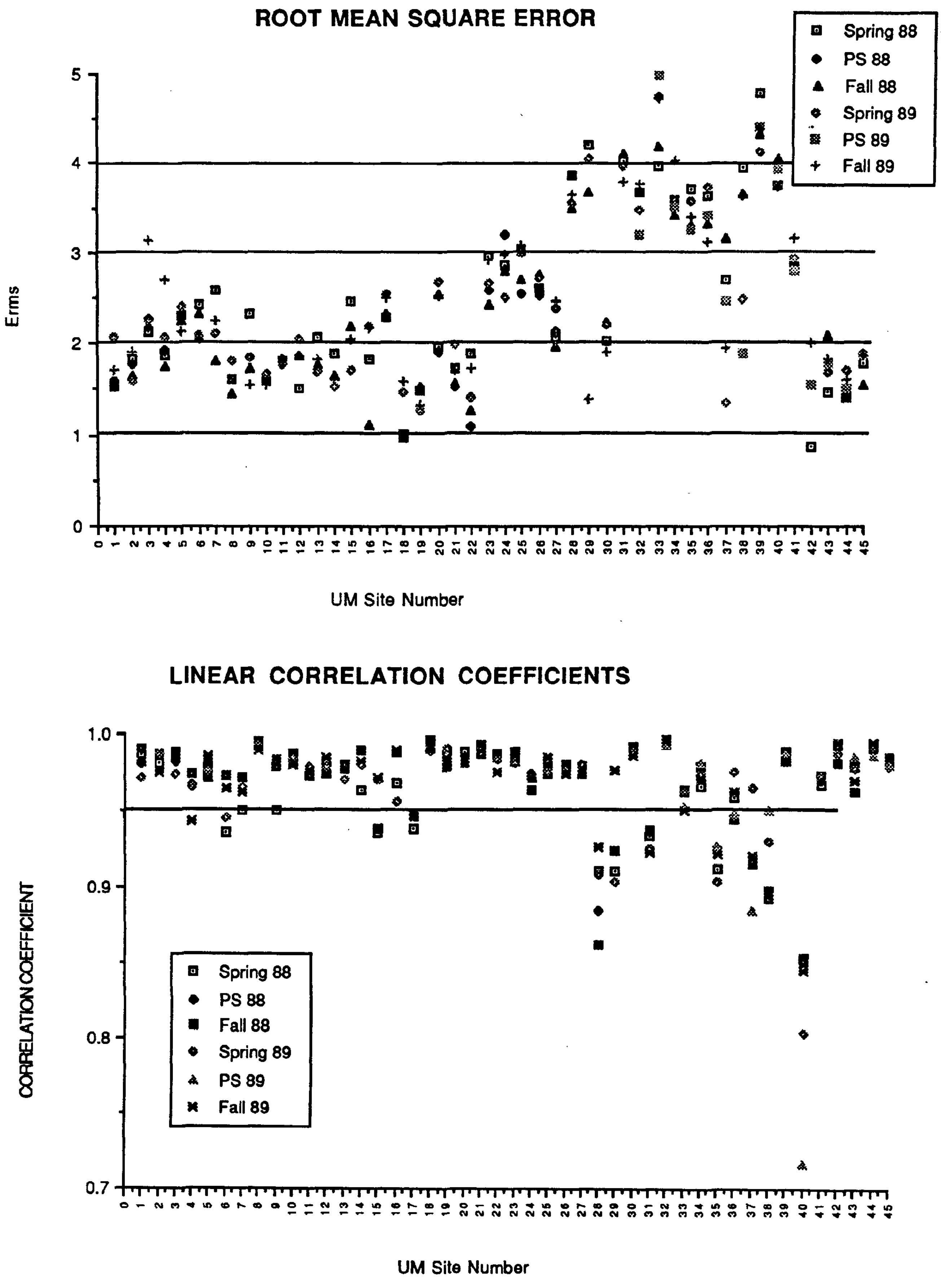


Figure 10. Root mean square error and linear correlation coefficients for two thirds power law equilibrium profile model.

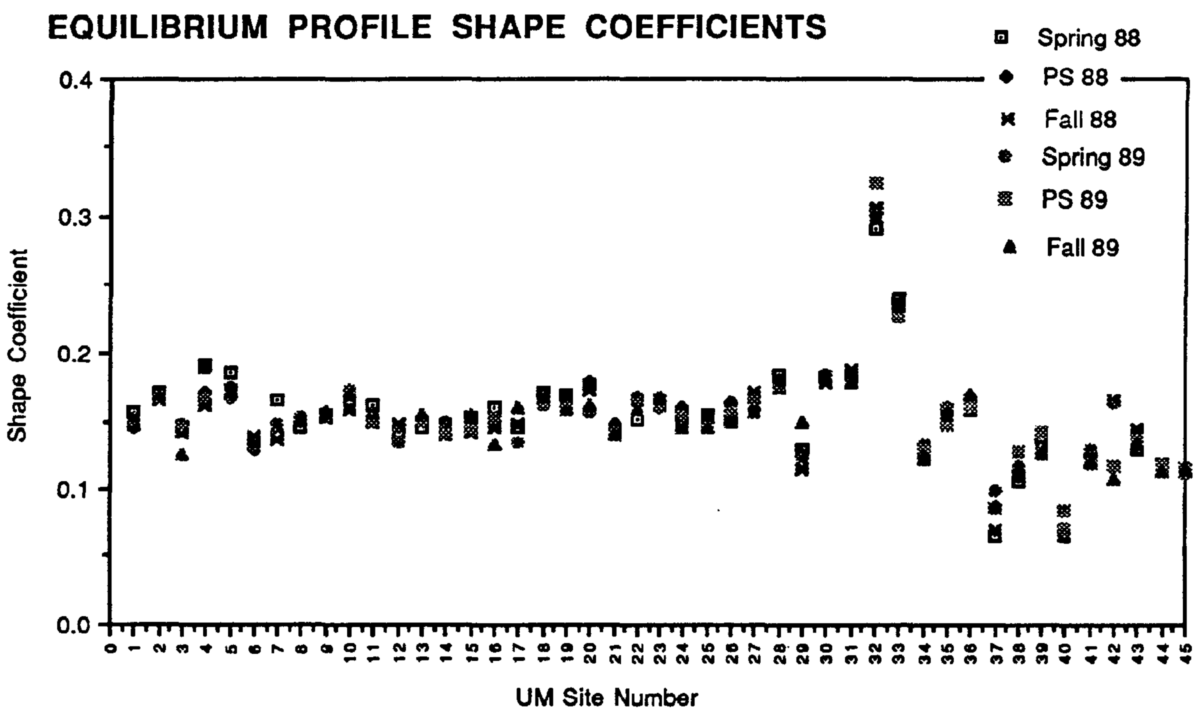
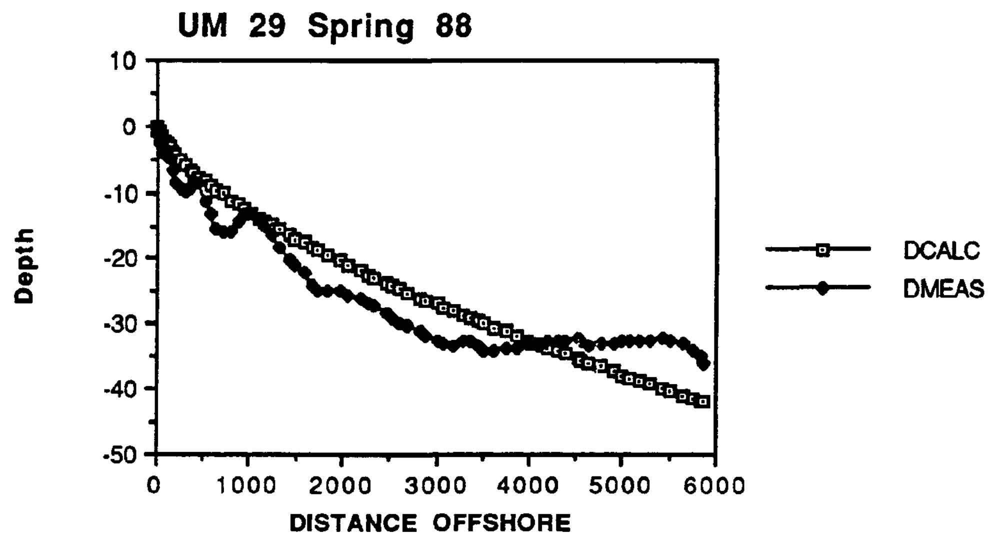


Figure 11. Equilibrium profile shape coefficients for UM survey sites.

time. The profiles exhibiting considerable variation are those for which the E_{rms} values indicate that the two thirds power law does not adequately describe the profile shape.

The fall, spring, and post-storm values of A_s (Figure 12) were compared using paired sample T-tests. These tests show that despite the fluctuations in water level between the surveys the mean A_s values do not change. This indicates that the general profile shape is not changed by water level fluctuations; it is shifted landward or seaward while maintaining the same general form. Therefore models that utilize this assumption to predict recession due to water level changes should be useful on the Great Lakes (Bruun, 1962)

The sediment size distributions were obtained as described in the Year One Report. The mean Phi values acquired at 3 ft depth intervals were averaged for each profile. Comparison of mean sediment diameter with best fit A_s values (Figure 13) shows that there is no direct relationship. Moores' relationship between sediment diameter and shape coefficient was based on a wide range of sediment sizes, however, all of the profiles had mean sediment size of medium to fine sands. The variations in mean sediment diameter occurred on too small a scale to allow the use of Moores' empirical relationship. It is therefore recommended that A_s values be computed directly from profile data if available.



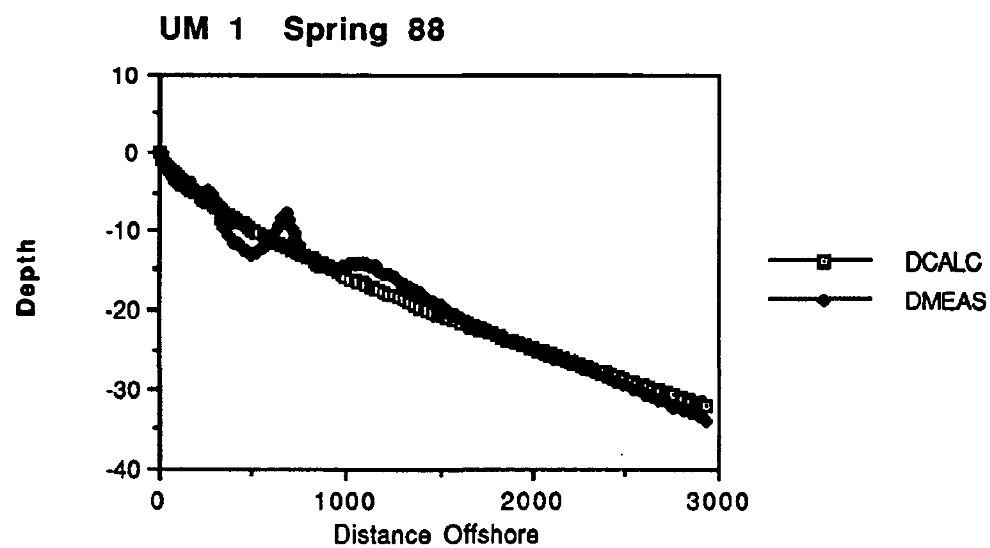


Figure 12. Examples of two thirds power law equilibrium profile fit to data. UM29 is a poor fit. UM1 is a good fit.

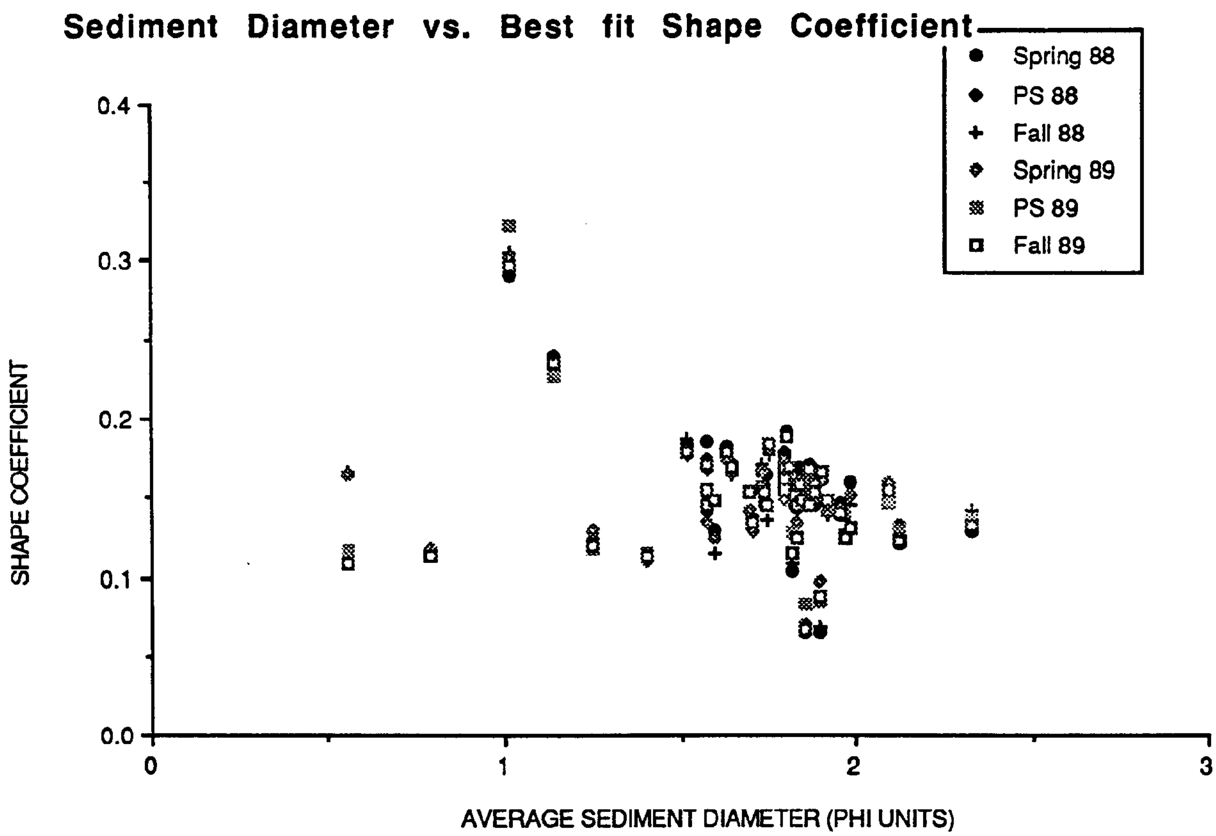


Figure 13. Mean sediment diameter vs. best fit shape coefficients.

Conclusions

Through the support of the Michigan Department of Natural Resources and the people of the State of Michigan, The University of Michigan Ocean Engineering Laboratory has completed two years of a study of the long term response of the lower peninsula coastline to changes in wave climate and mean water level. In addition to providing insight into the physical processes shaping the coastal zone, this research effort has provided a large portion of the data necessary for evaluation of shoreline evolution models for use in the Great Lakes.

The study encompassed a period of falling mean water levels throughout the Great Lakes. It was found that the conceptual model proposed by Weishar and Wood (1983) is an accurate characterization of the changes of the nearshore region in response to falling mean water level. In general, the model suggests that as water level falls, the outer bar will migrate offshore and the inner bar will remain sensitive to storm influence. However, it was found that in regions exposed to large structural impact, onshore transport may be affected to the depth of the outer bar. This may produce onshore migration of that bar, which greatly outweighs the effects of falling water levels.

In addition to coastal readjustment, the nearshore zone, in some cases, exhibited net volume loss with falling lake levels, contrary to the belief that lower water levels will halt erosion. This is due to the fact that the coastal zone always strives for a balanced sediment budget. If bluff erosion is discontinued due to falling lake levels, this sediment source must be shifted to another area of the profile, specifically, the nearshore zone. The erosion rate may decrease, but will probably not stop altogether.

In an effort to gain insight into shoreline evolution modelling, it was found useful to examine the conformation of the coastal bathymetry to an equilibrium profile. The popular two-thirds power law of Dean (1977) was tested for the profiles in this database. In general, it was found that the two-thirds power law equilibrium profile worked well for the open coast profiles, indicating that profile shape does not change in response to water level changes, rather the profile is shifted landward or seaward. In the past the shape parameter was determined by an empirical relation with the mean sediment grain size. This study indicates that the range of sediment sizes in the study region is too narrow for Moores' relationship to adequately characterize the shape parameter. It is suggested that this value be determined from a best fit to the profile data when available, as recommended by Balsillie (1987).

The water level history of the past two years has provided the OEL with a unique opportunity to study the response of the shoreline to falling mean lake levels. Historic studies in the Great Lakes region have typically characterized periods of rising lake levels, or have concentrated on the short term effects of storm induced waves. As sited by Hails (1974), the long term commitment of funds to monitor changes throughout a lake level cycle are not readily available, and many historic studies reflect this lack of commitment.

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UM05	-	Ms. Dorothy Kriz, New Buffalo Mr. and Mrs. Bethel, New Buffalo
UM06	-	Mr. Eric Berman
UM07	-	Ms. Phyllis Rieves, Resident Manager, Chalet-on-the-Lake, Stevensville
UM08	-	Mr. Frank Vitale, Hagar Township Board
UM11	-	Mr. Bill Campion, Village of Douglas
UM12	-	Mr. Stuart Visser, Park Township
UM13	-	Mr. Jerry Postema, Grand Haven Township
UM18	-	Summit Township
UM19	-	Ms. Connie Anderson, Treasurer, Pere Marquette Township Mr. Frank Schubert
UM20	-	Mr. and Mrs. Ptaszenski
UM21	-	Mr. Gerald J. Richards, City Manager, Ludington
UM24	-	Dr. Ronald Hutchinson, Foundation for Behavioral Research Mr. and Mrs. Ed Hallin, Big Sable Point Conference Center Mr. and Mrs. Dick Smith, Big Sable Point Lightkeepers Assn.
UM30	-	Mr. and Mrs. Howard Saidla, Sunset Valley Resort
UM32-33	-	Mr. Allen Hansen, Dir. of Parks and Recreation, City of Petoskey
UM34	-	The Bayview Association
UM37	-	Dr. Leslie A. Lambert, Tawas
UM38	-	Davison and Son Builders, Inc., Tawas
UM42	-	Mr. Paul Weeman, Port Sanilac Mr. and Mrs. Wallaert, Port Sanilac
UM43	-	Mr. Don Dharte, Warren

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Appendix A:
Bathymetry

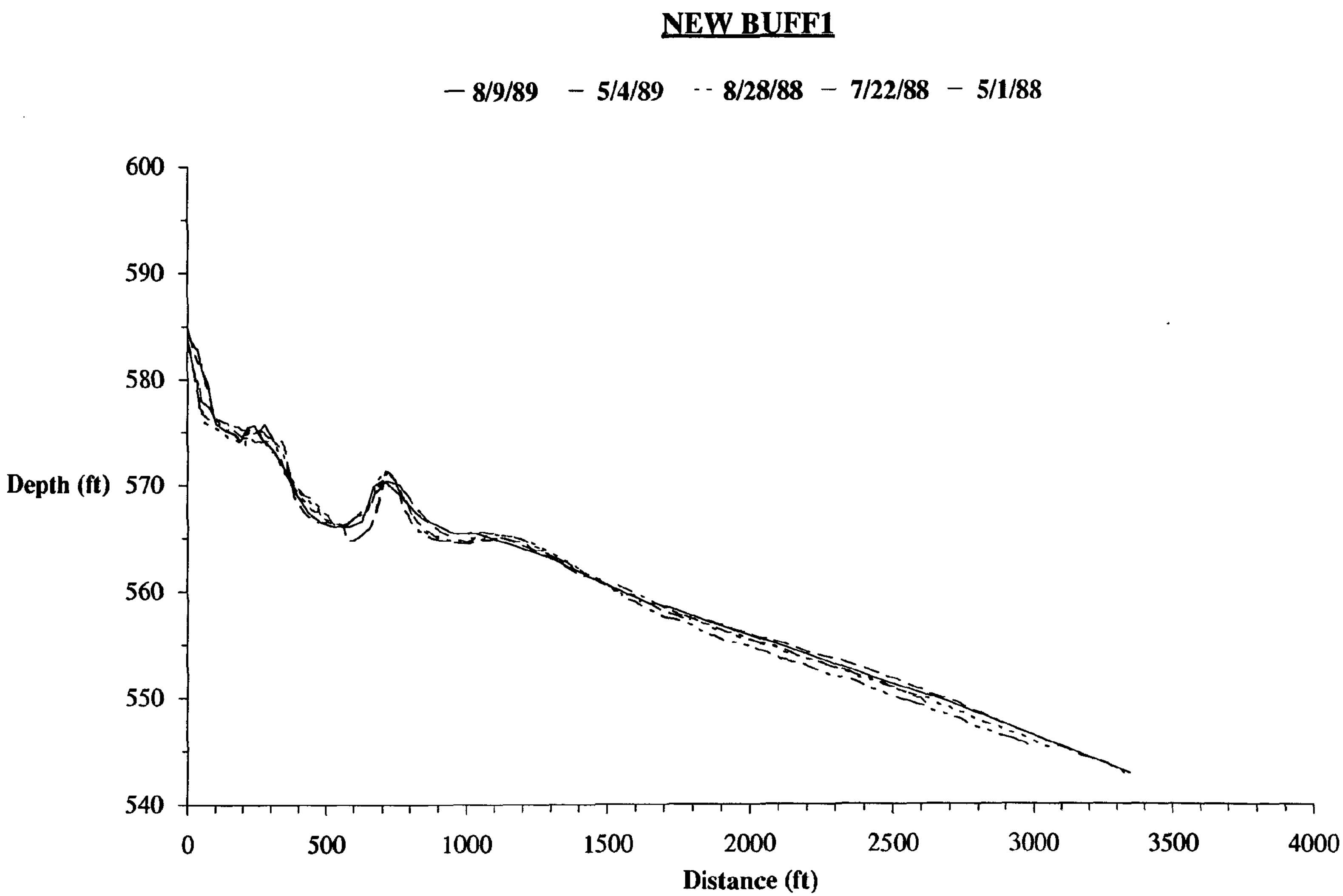
Appendix A consists of overplots of successive surveys at each site. The dates beneath the plot title are the actual survey dates. In general, the key proceeds from most recent survey through the original survey. Due to an error in the Excel software as provided by Excel, the key is illegible. Therefore, the following table will provide the key for the survey graphs.

Line Type	UM1-5,19-28	UM6-18,29-31	UM32-45
————————	Fall '89	Fall '89	Fall '89
— — —	Spring '89	Spring '89	Post-Storm '89
----------	Fall '88	Fall '88	Spring '89
— - — - — -	Post-Storm '88	Spring '88	Fall '88
—— -- —— --	Spring '88		Spring '89

The site names associated with each survey number are tabulated on the following page.

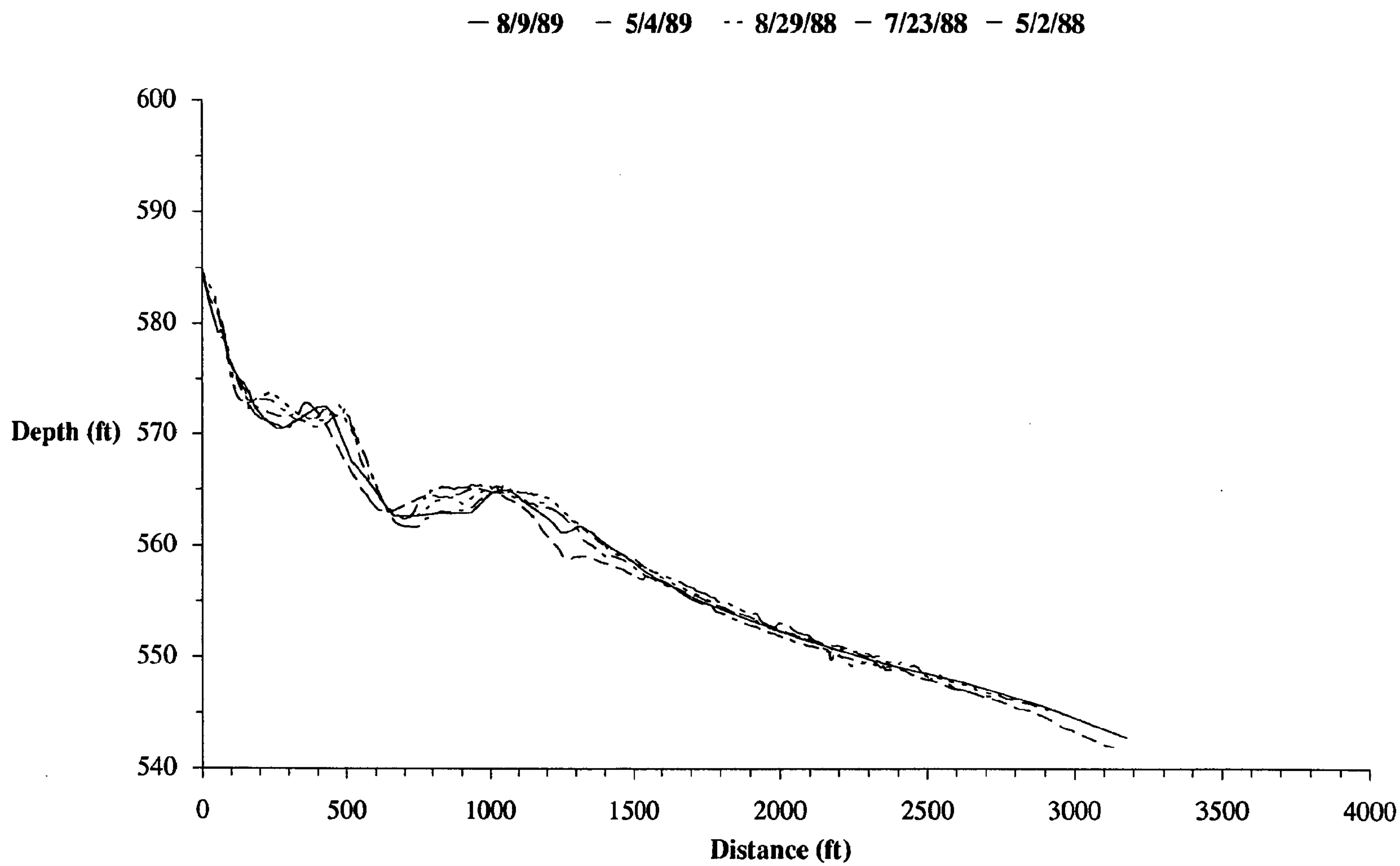
SURVEY LINES
ISRP CHARACTER LABEL

No.	Location	Char. Label
UM01	NEW BUFFALO	NEW BUFF1
UM02	NEW BUFFALO	NEW BUFF2
UM03	NEW BUFFALO	NEW BUFF3
UM04	NEW BUFFALO	NEW BUFF4
UM05	NEW BUFFALO	NEW BUFF5
UM06	CHIKAMING	CHIKAMING
UM07	STEPHENSVILLE	STEPHEN
UM08	HAGAR TOWNSHIP	HAGAR
UM09	VAN BUREN ST PARK	VAN BUREN
UM10	GLENN	GLENN
UM11	DOUGLAS VILLAGE	DOUGLAS
UM12	HOLLAND	HOLLAND
UM13	GRAND HAVEN	GRAND HAVEN
UM14	HOFFMASTER ST PK	HOFFMASTER
UM15	WHITEHALL	WHITEHALL
UM16	CLAYBANKS	CLAYBANKS
UM17	LITTLE POINT SABLE	LITTLESABLE
UM18	SUMMIT TOWNSHIP	SUMMIT
UM19	LUDINGTON	LUDINGTON1
UM20	LUDINGTON	LUDINGTON2
UM21	LUDINGTON	LUDINGTON3
UM22	LUDINGTON	LUDINGTON4
UM23	LUDINGTON ST PK	LUDINGTON5
UM24	LUDINGTON ST PK	LUDINGTON6
UM25	LUDINGTON ST PK	LUDINGTON7
UM26	BIG SABLE POINT	LUDINGTON8
UM27	LUDINGTON ST PK	LUDINGTON9
UM28	LUDINGTON ST PK	LUDINGTON10
UM29	MANISTEE	MANISTEE
UM30	BEN/MAN CNTY LINE	BENZIE
UM31	POINT BETSIE	PT BETSIE
UM32	PETOSKEY	PETOSKEY1
UM33	PETOSKEY	PETOSKEY2
UM34	PETOSKEY	PETOSKEY3
UM35	PETOSKEY ST PK	PETOSKEY4
UM36	PETOSKEY	PETOSKEY5
UM37	TAWAS	TAWAS1
UM38	TAWAS	TAWAS2
UM39	TAWAS ST PK	TAWAS3
UM40	TAWAS	TAWAS4
UM41	PORT SANILAC	PT SANILAC1
UM42	PORT SANILAC	PT SANILAC2
UM43	PORT SANILAC	PT SANILAC3
UM44	PORT SANILAC	PT SANILAC4
UM45	PORT SANILAC	PT SANILAC5

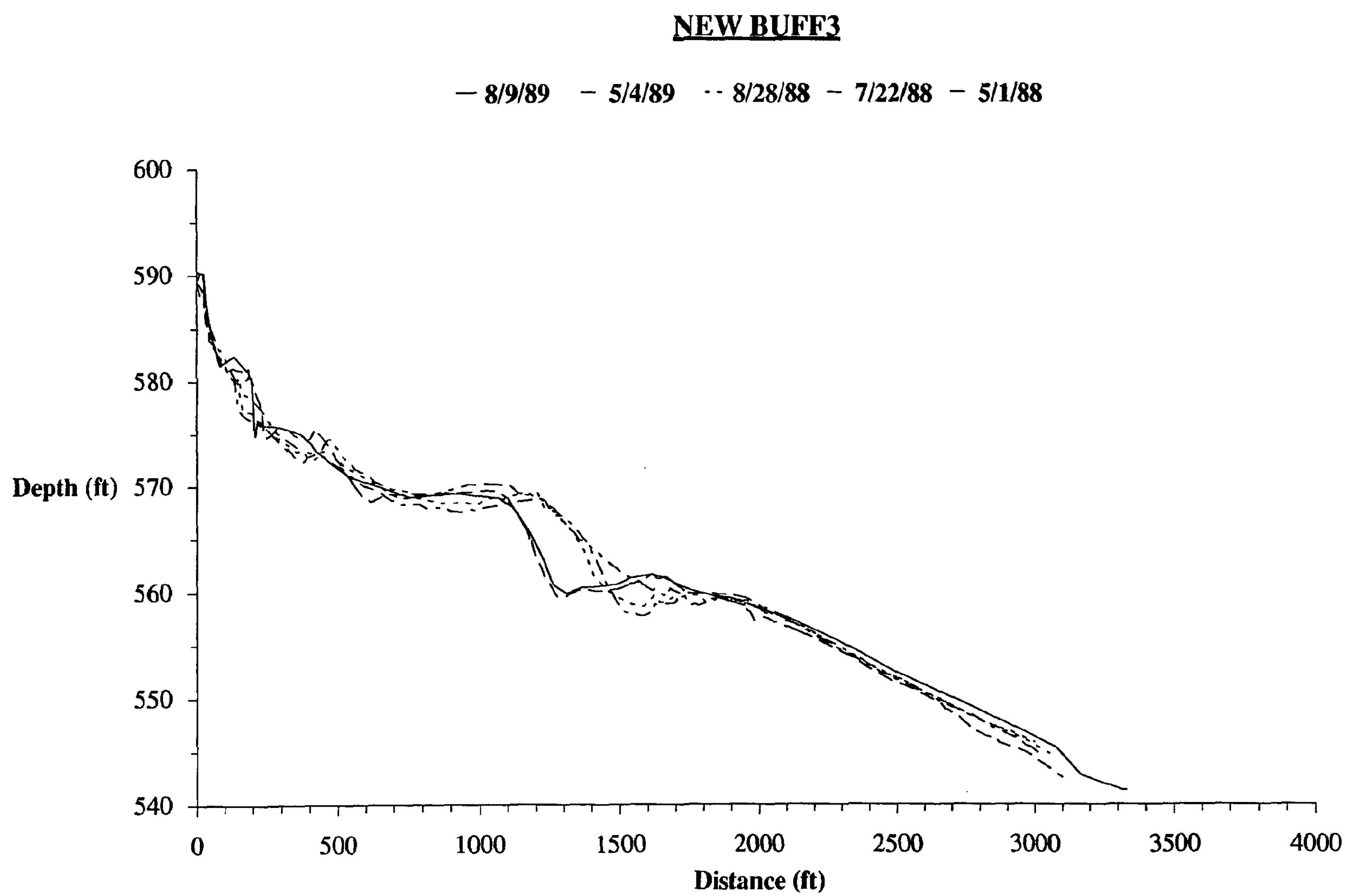


NEW BUFF1
— 8/9/89 — 5/4/89 -- 8/28/88 — 7/22/88 — 5/1/88
600
590
580
Depth (ft) 570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

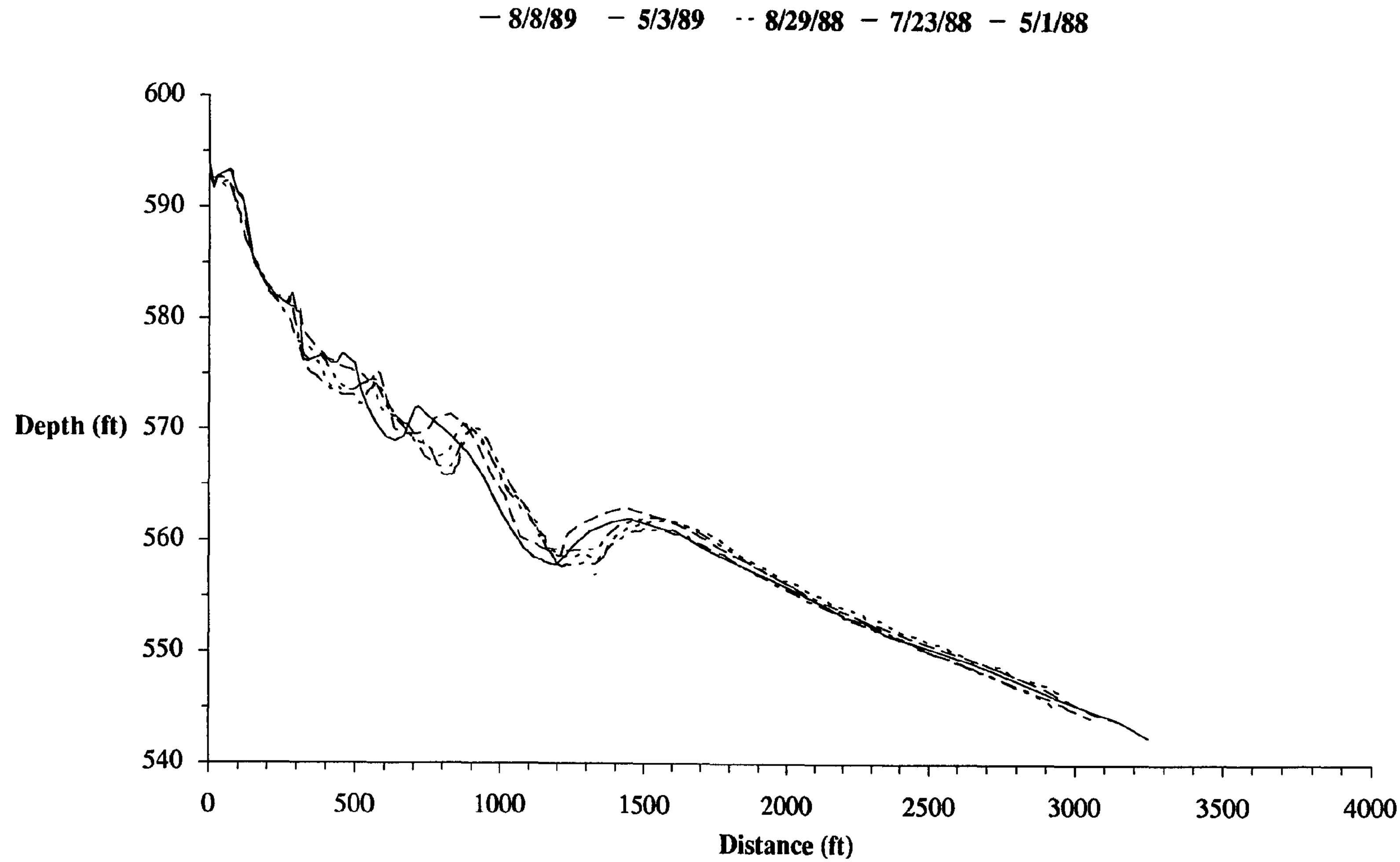
NEW BUFF2



— 8/9/89 — 5/4/89 ·· 8/29/88 — 7/23/88 — 5/2/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

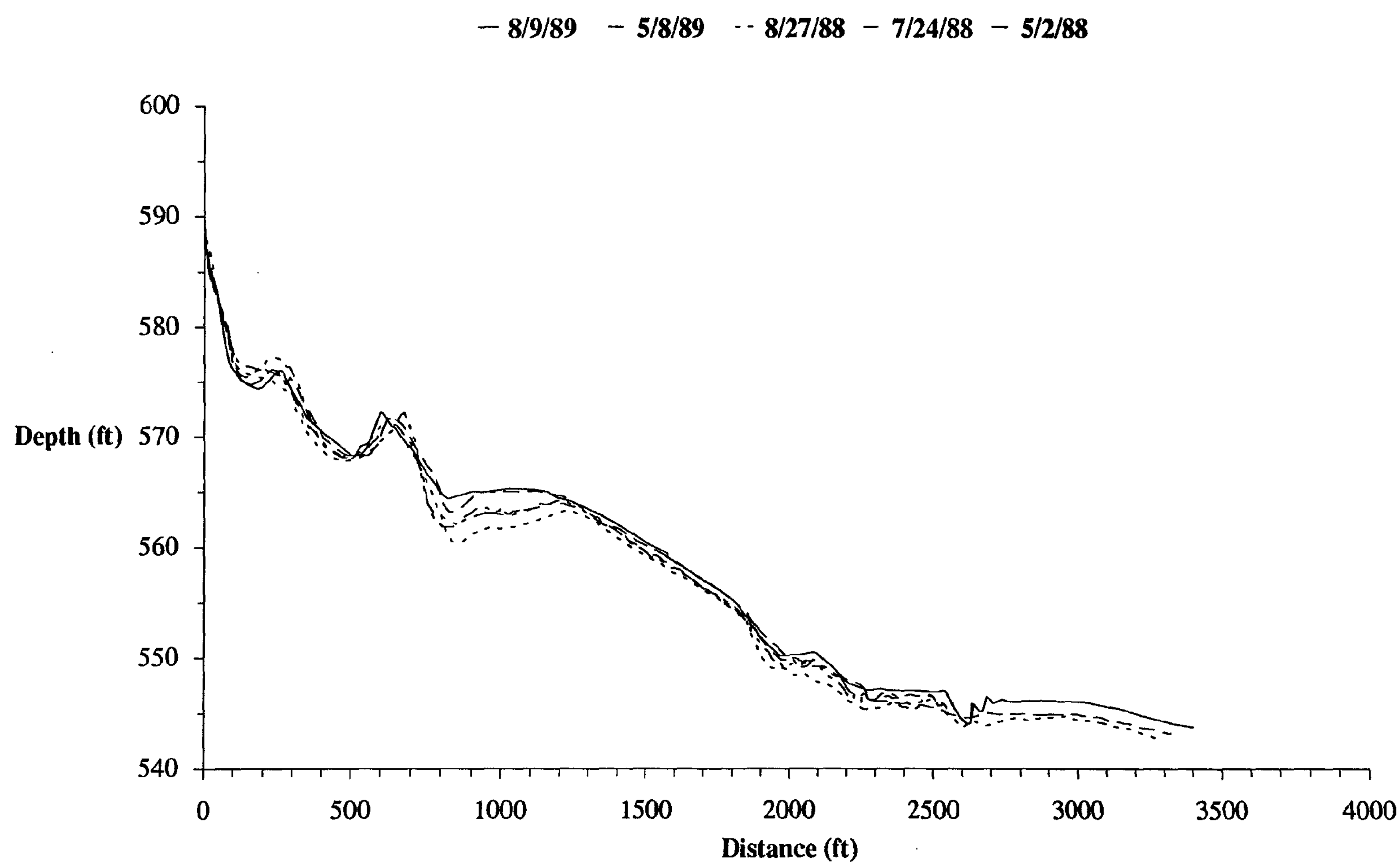

NEW BUFF3
— 8/9/89 – 5/4/89 ·· 8/28/88 – 7/22/88 – 5/1/88
600
590
580
570
560
550
540
Depth (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

NEW BUFF4



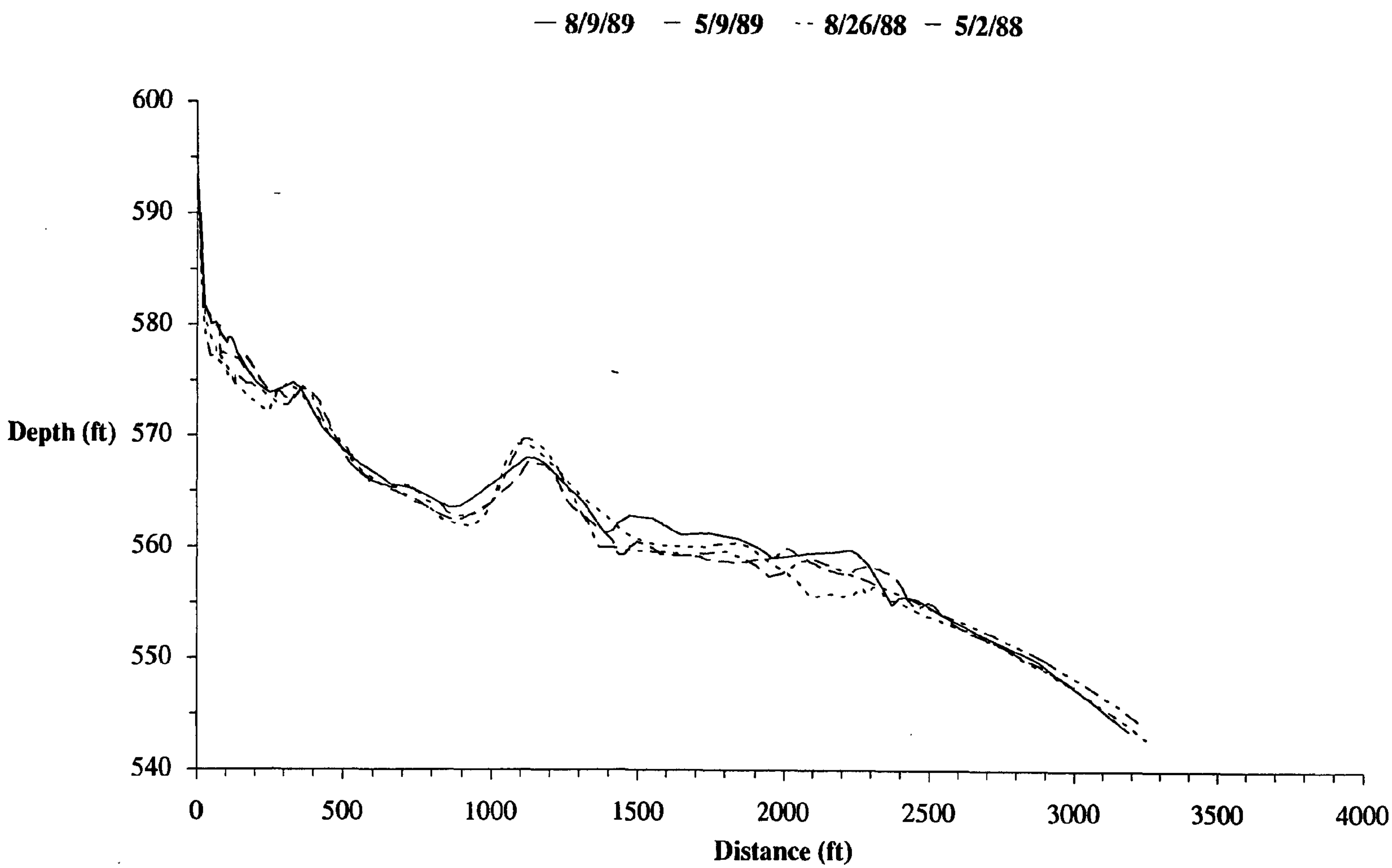
— 8/8/89 — 5/3/89 -- 8/29/88 — 7/23/88 — 5/1/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

NEW BUFF5



— 8/9/89 — 5/8/89 - - 8/27/88 — 7/24/88 — 5/2/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

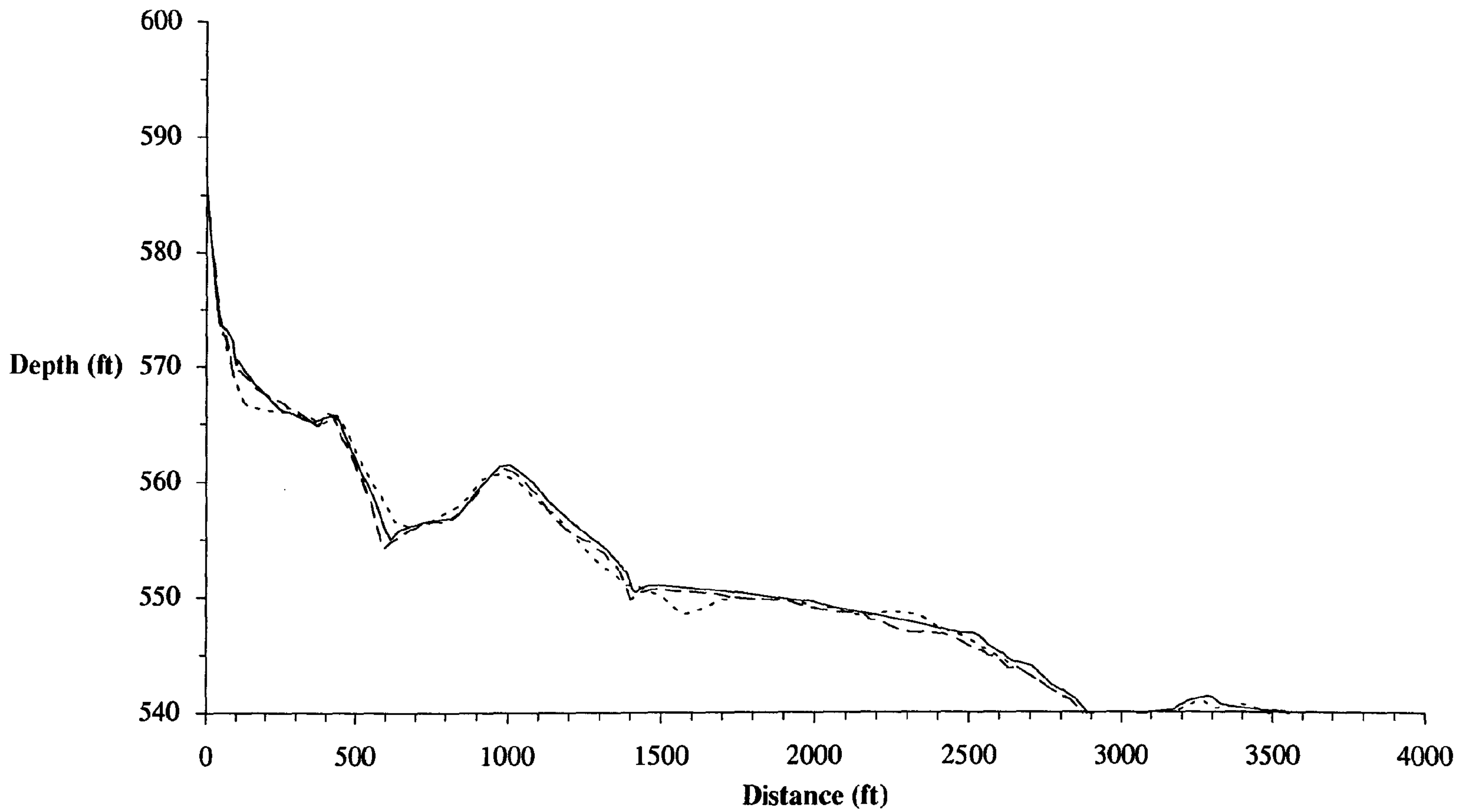
CHIKAMING

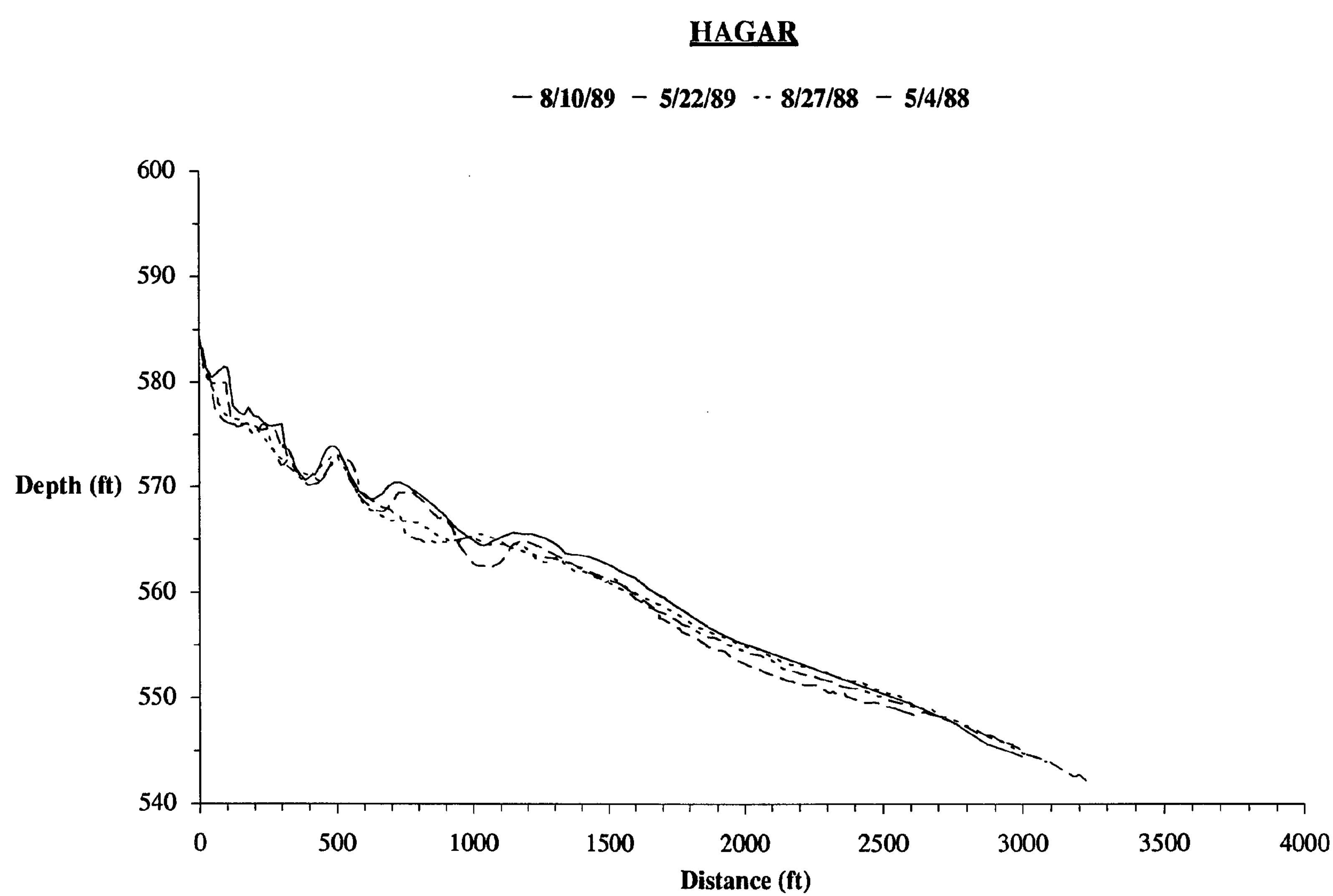


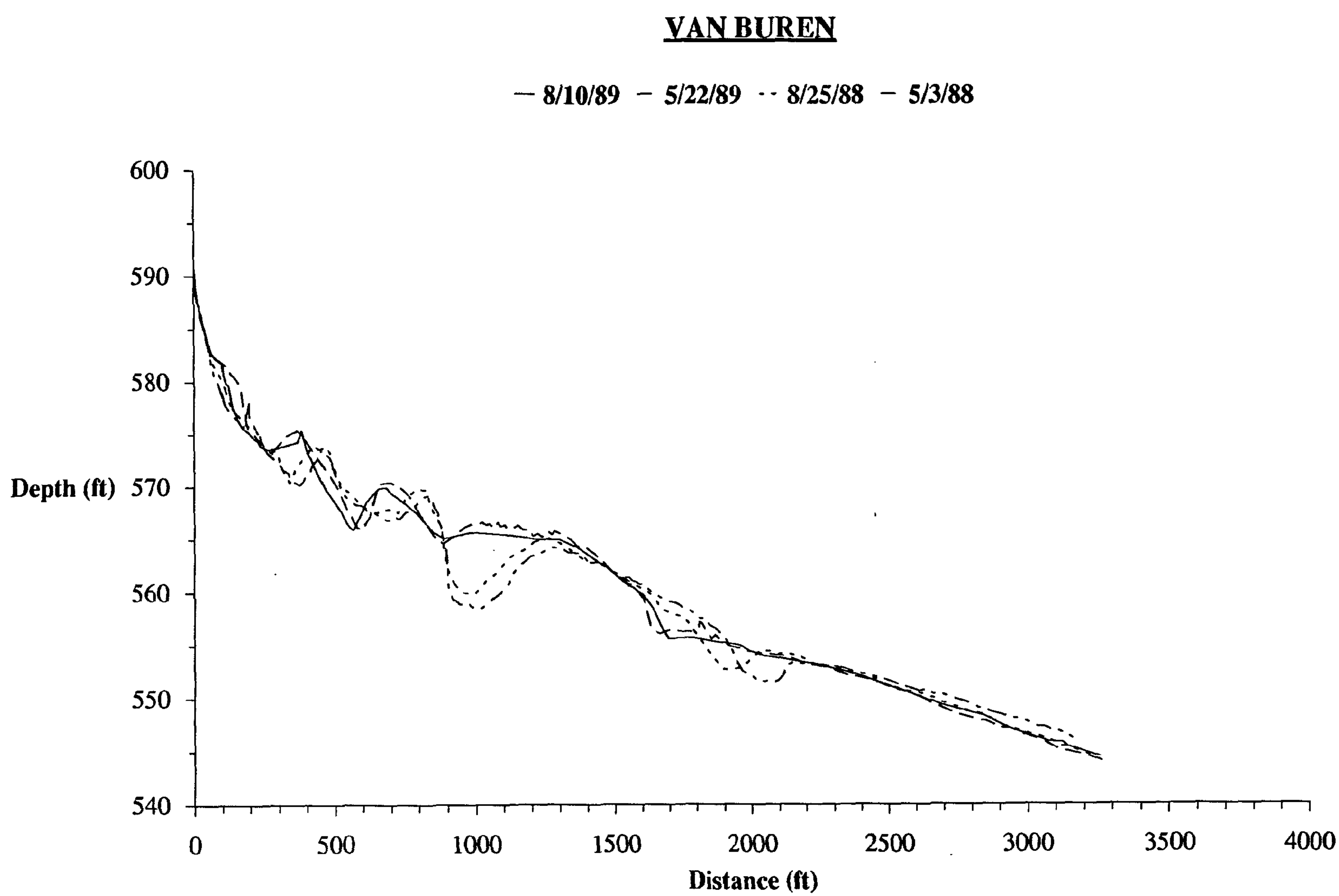
— 8/9/89 — 5/9/89 - - 8/26/88 — 5/2/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

STEPHEN

— 8/9/89 — 5/22/89 - - 8/30/88

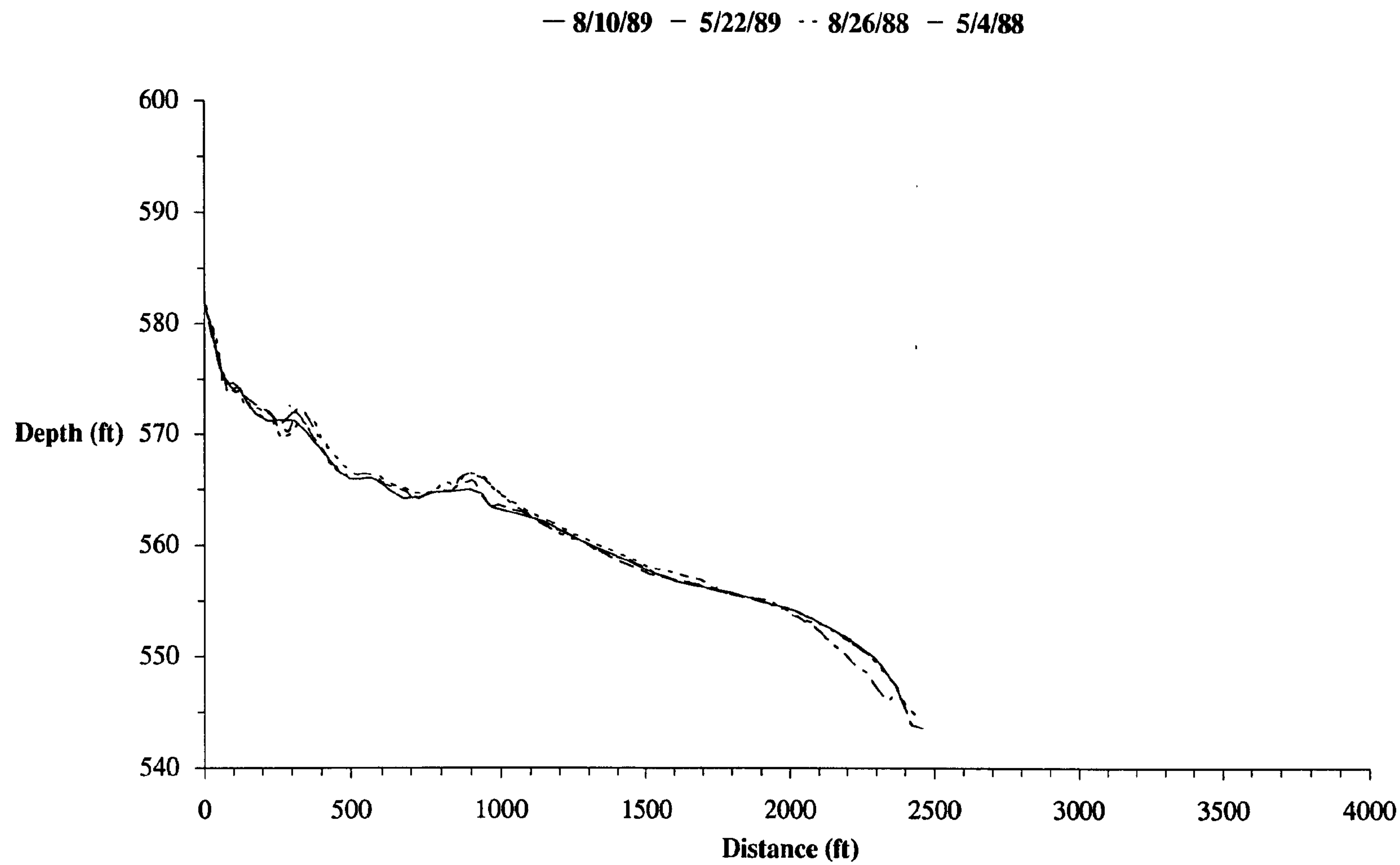



HAGAR
— 8/10/89 – 5/22/89 - - 8/27/88 – 5/4/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)



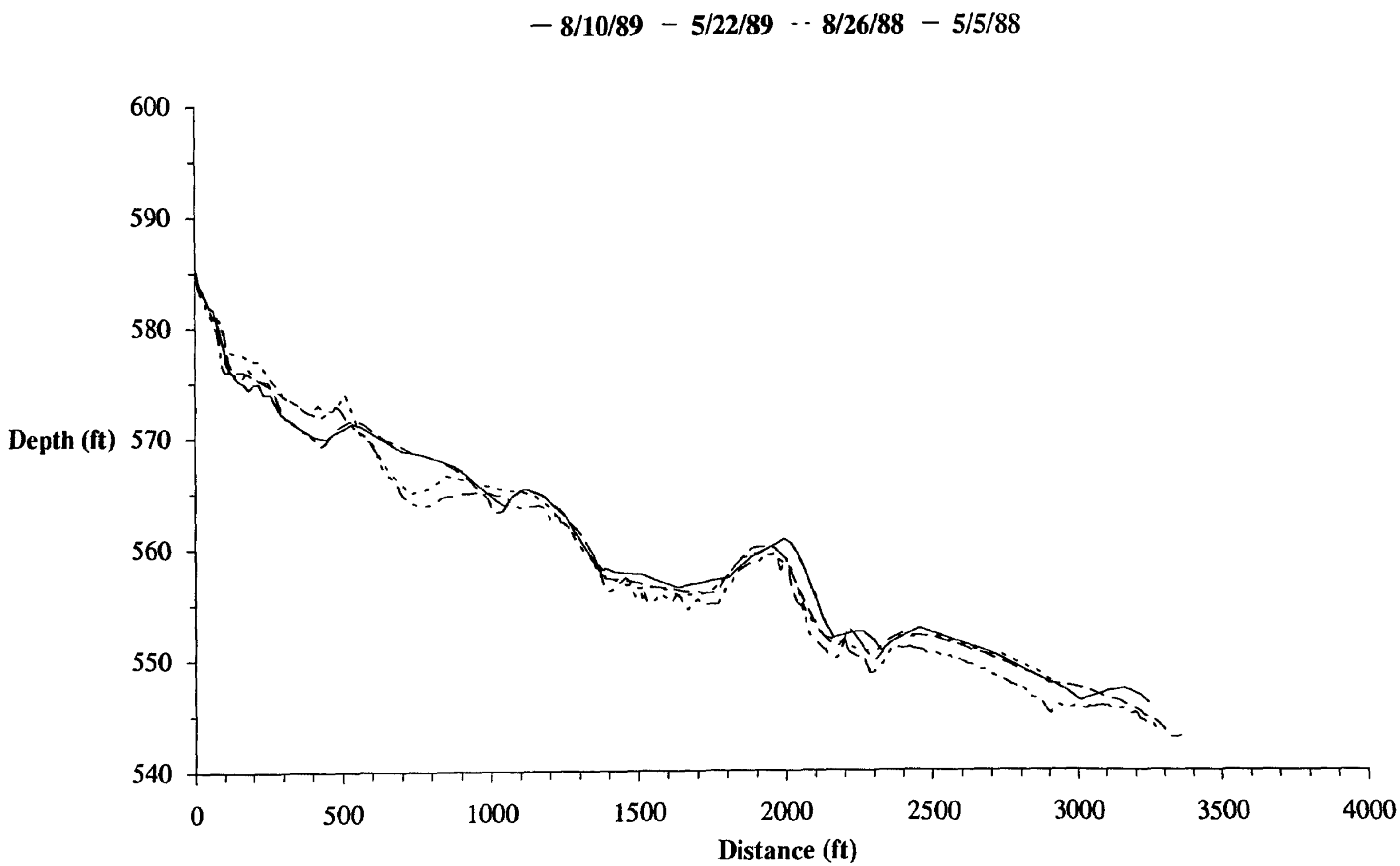
VAN BUREN
— 8/10/89 – 5/22/89 -- 8/25/88 – 5/3/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

GLENN

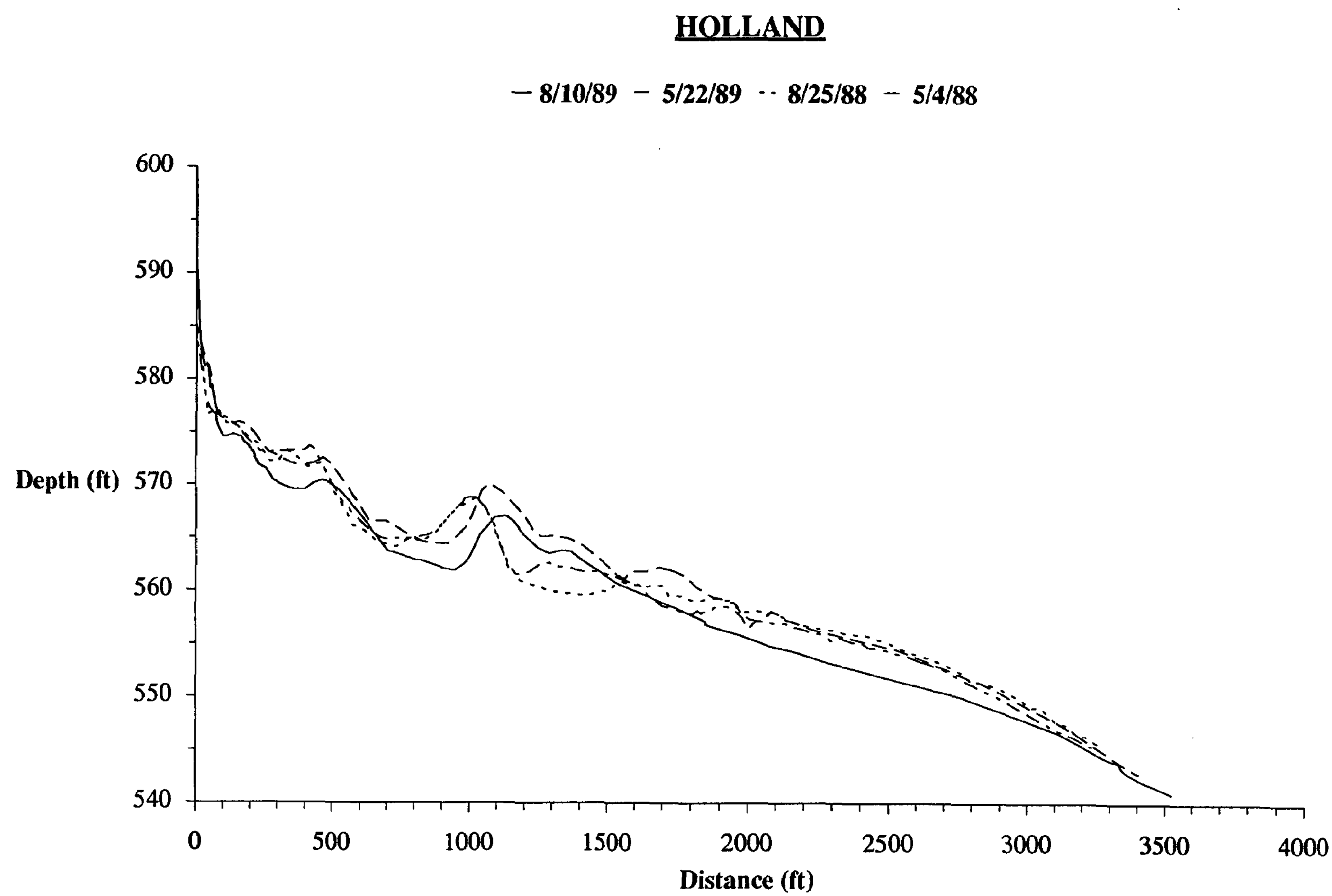


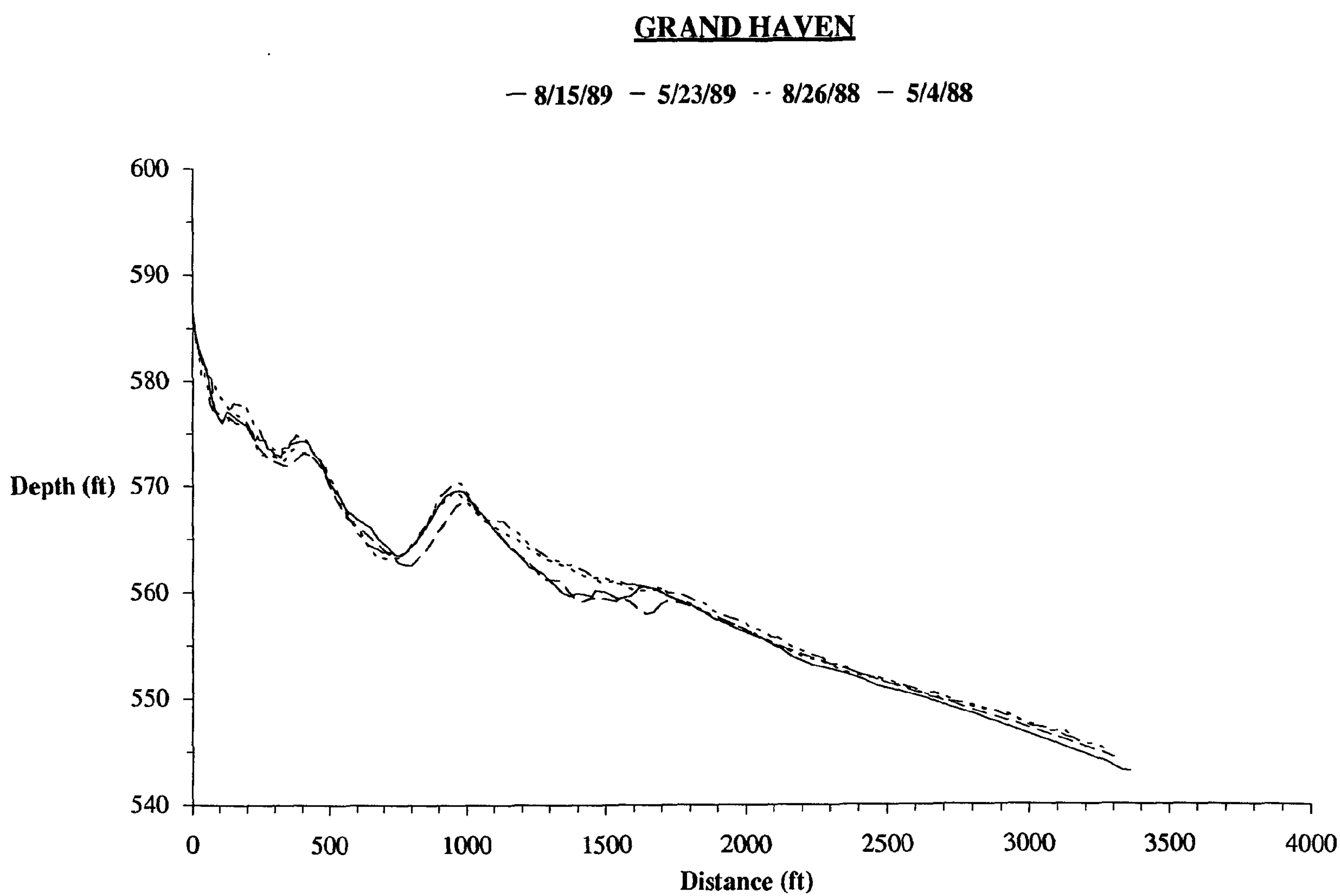
— 8/10/89 — 5/22/89 - - 8/26/88 — 5/4/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

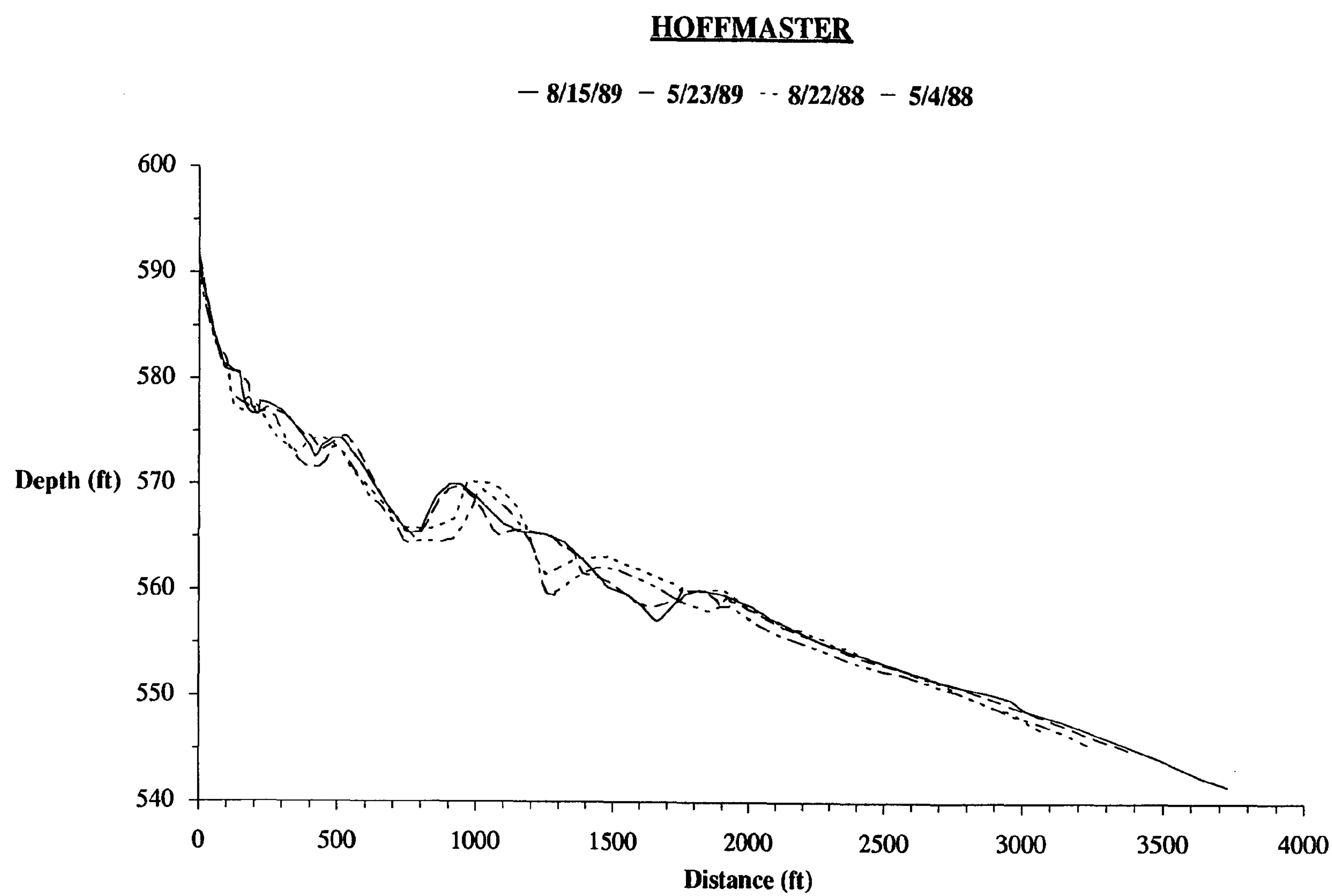
DOUGLAS

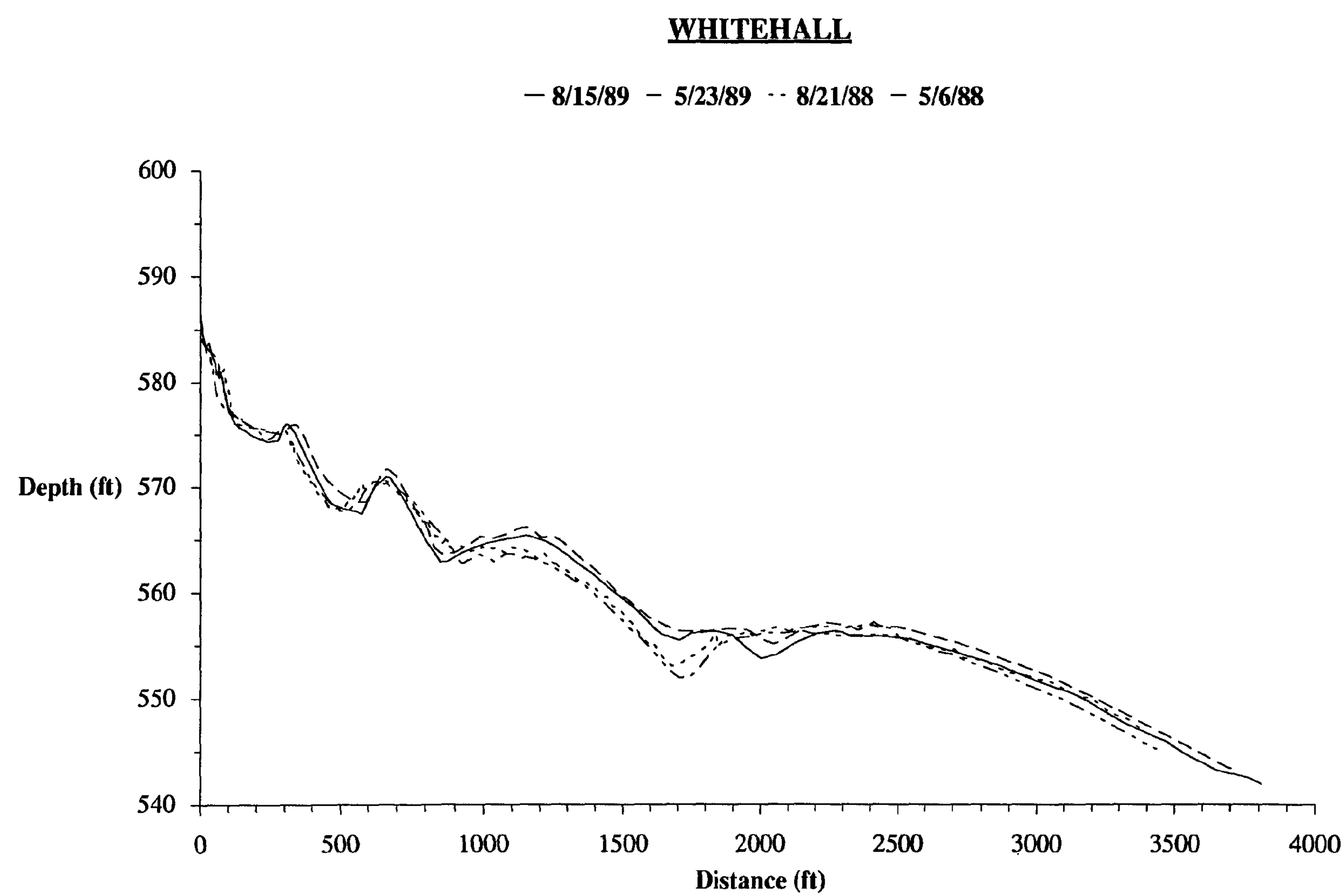


— 8/10/89 – 5/22/89 -- 8/26/88 – 5/5/88
600
590
580
570
560
550
540
Depth (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)


HOLLAND
— 8/10/89 — 5/22/89 ·· 8/25/88 — 5/4/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

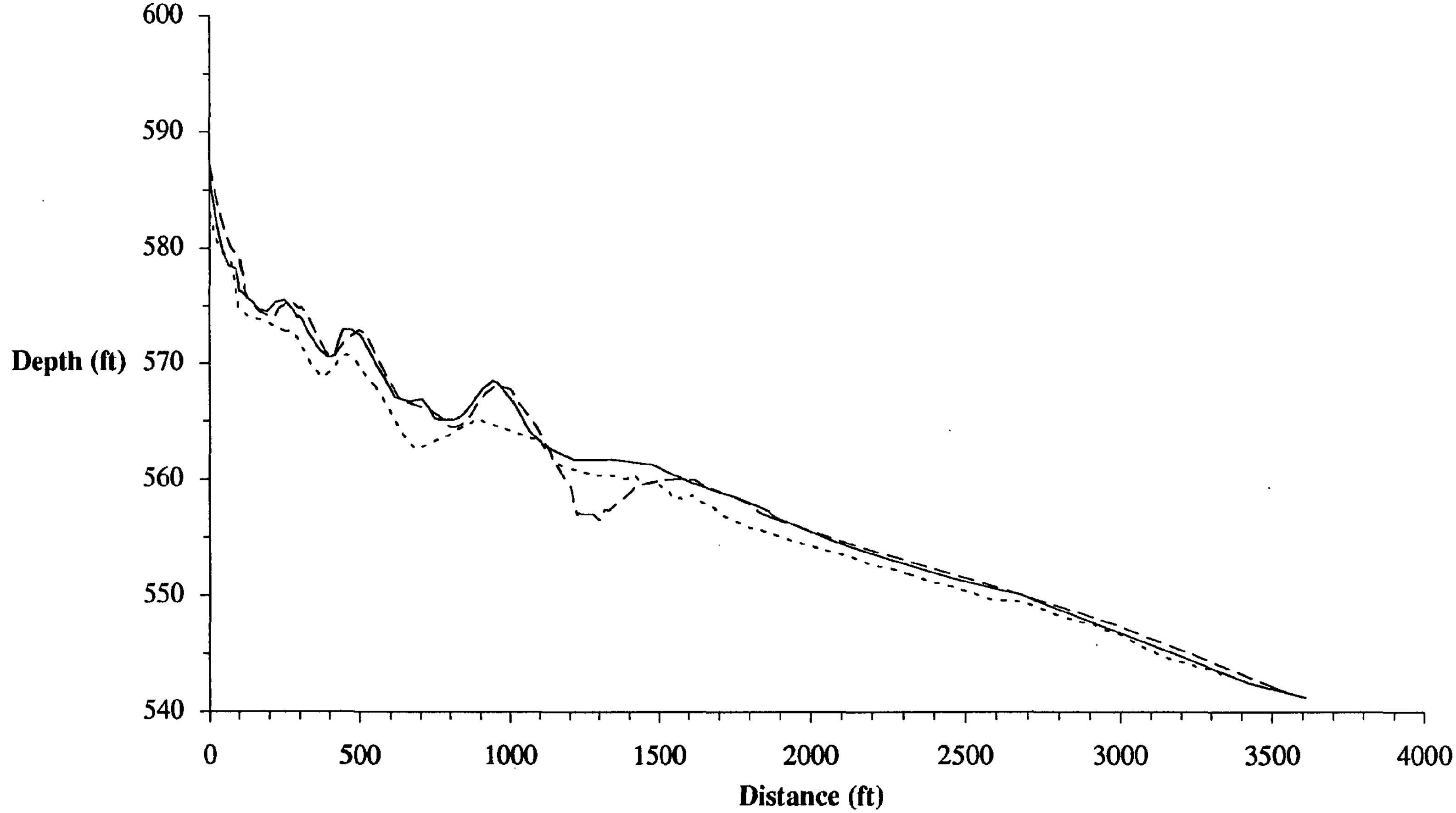

GRAND HAVEN
— 8/15/89 – 5/23/89 ·· 8/26/88 – 5/4/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)


HOFFMASTER
— 8/15/89 — 5/23/89 - - 8/22/88 — 5/4/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

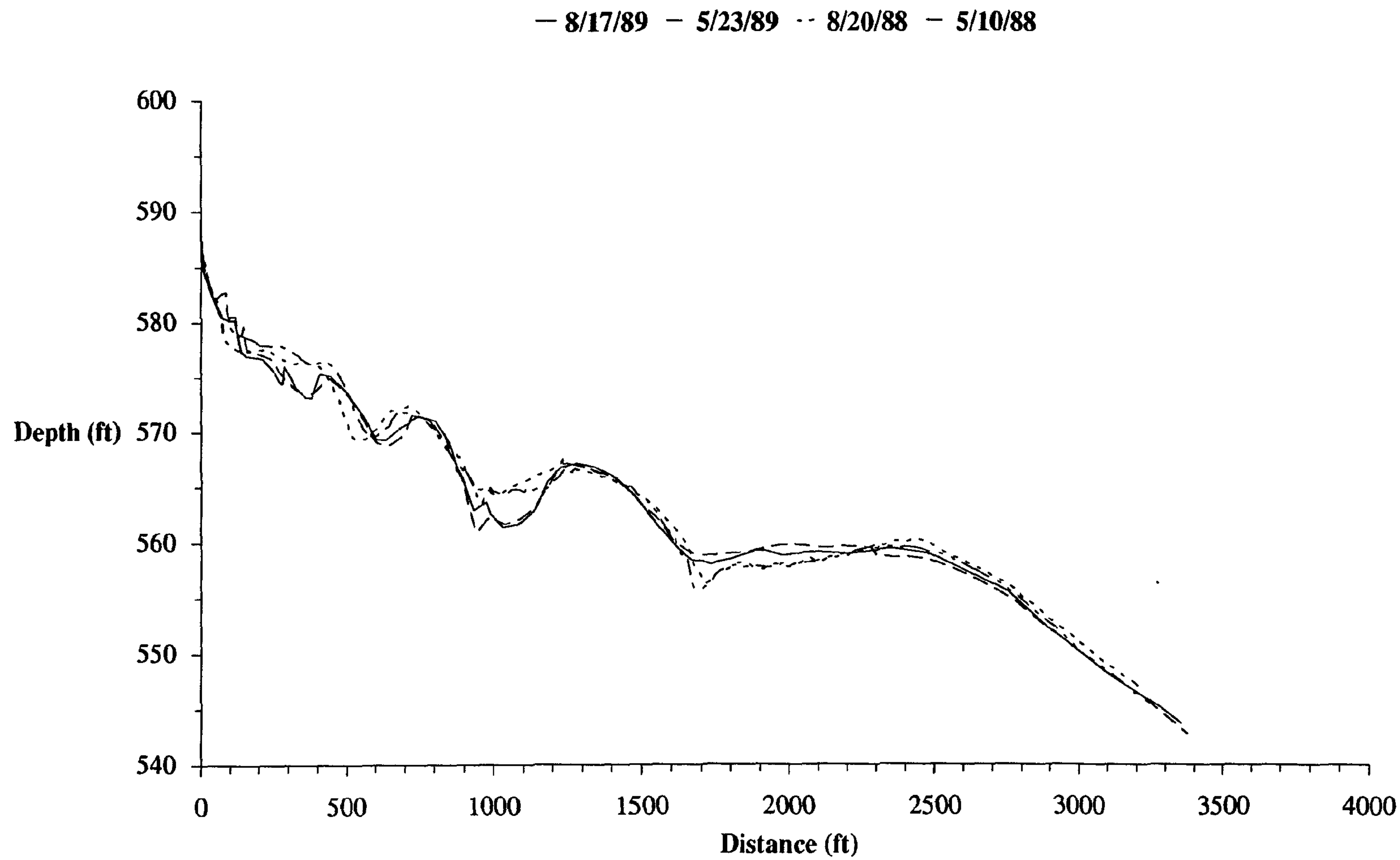

WHITEHALL
— 8/15/89 — 5/23/89 - - 8/21/88 — 5/6/88
600
590
580
Depth (ft) 570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

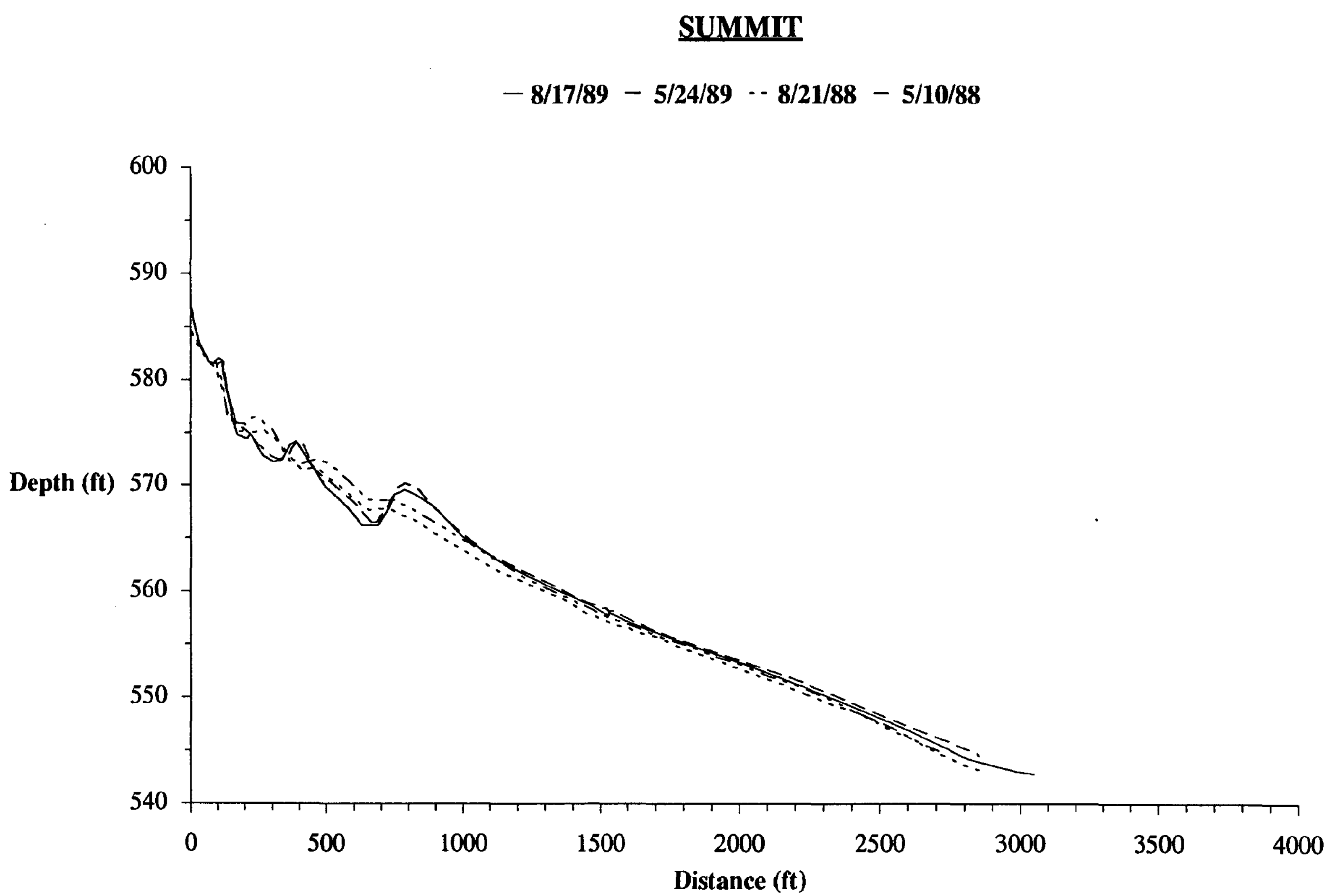
CLAYBANKS

— 8/15/89 — 5/23/89 - - 8/20/88

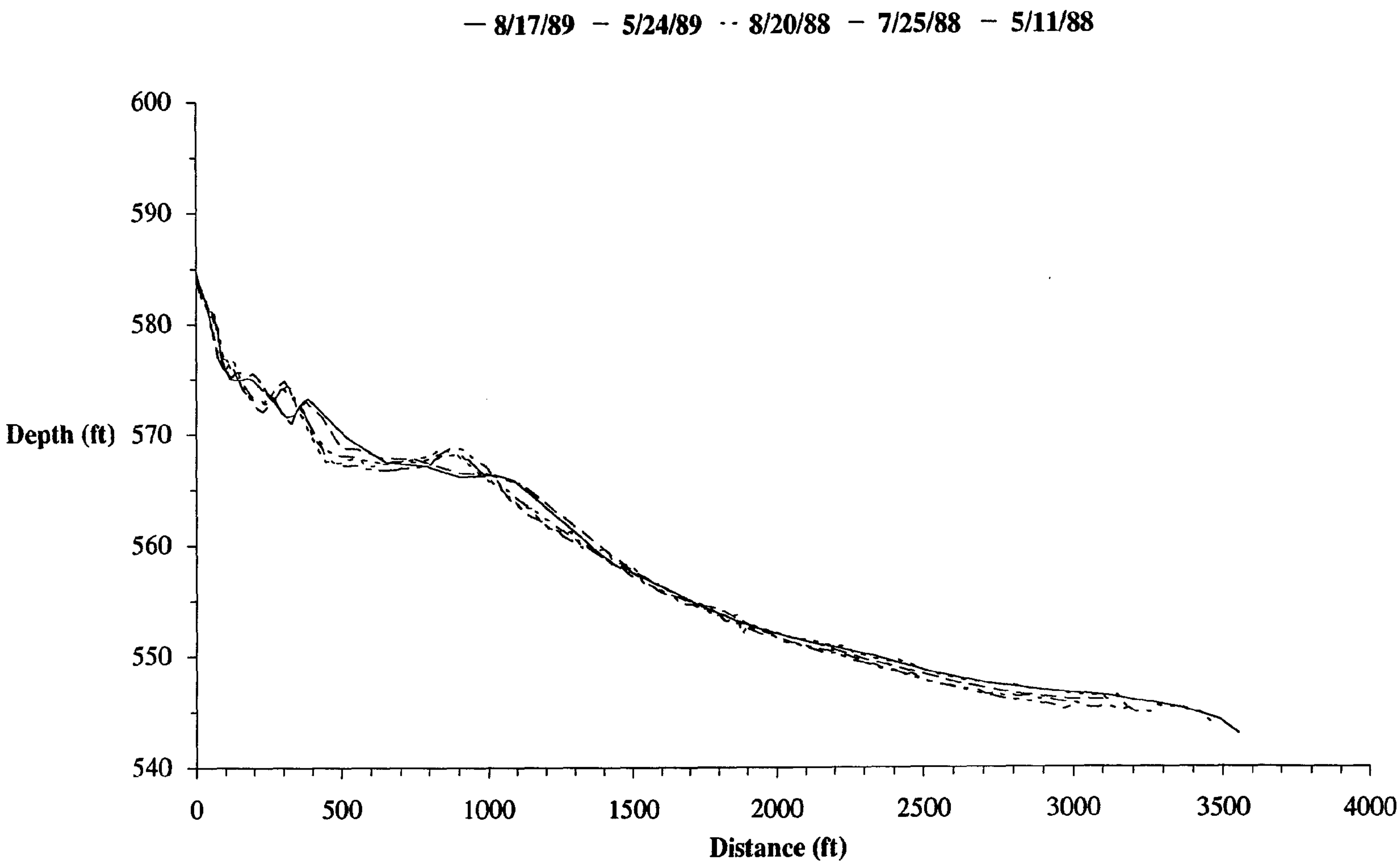


LITTLESABLE

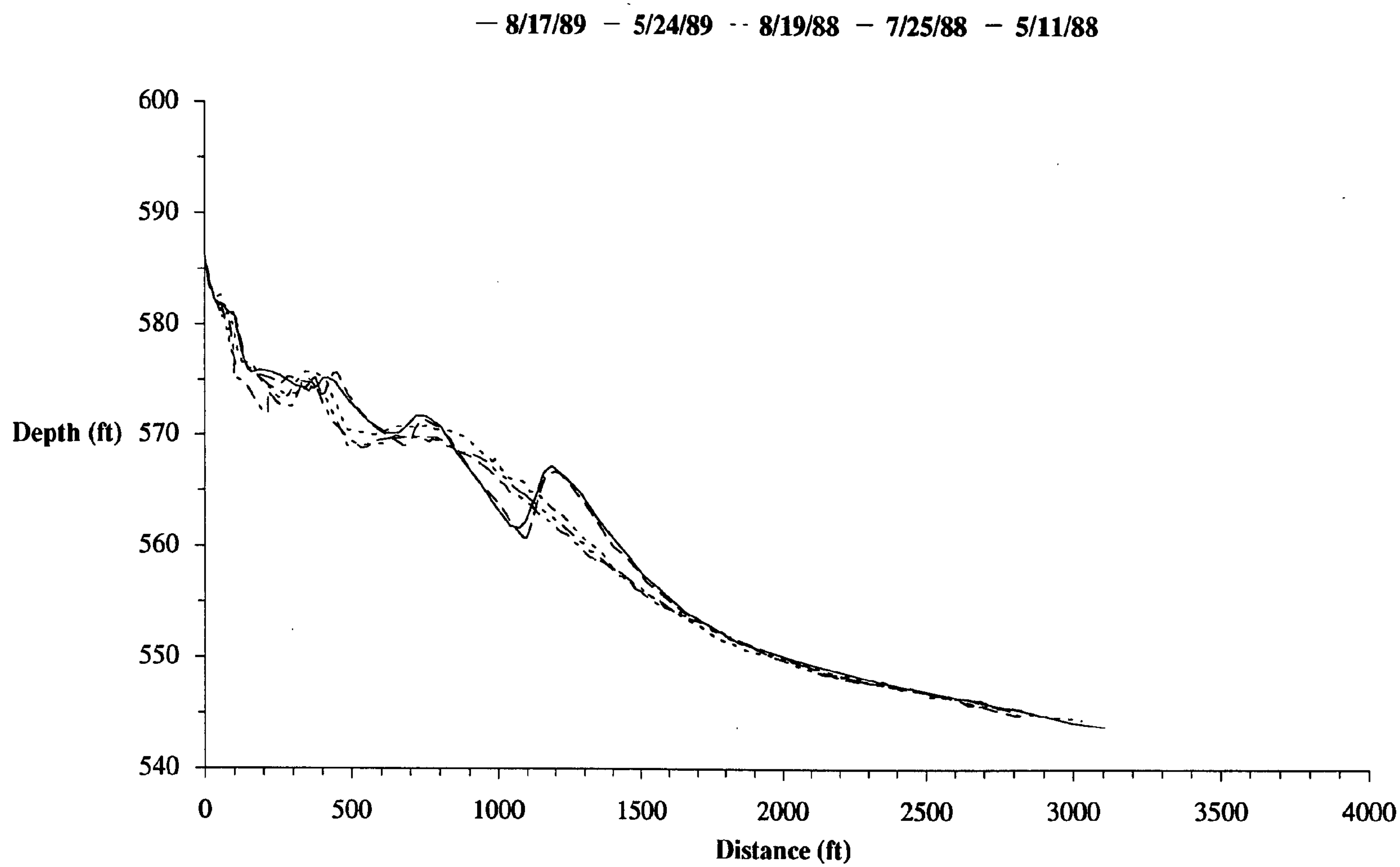


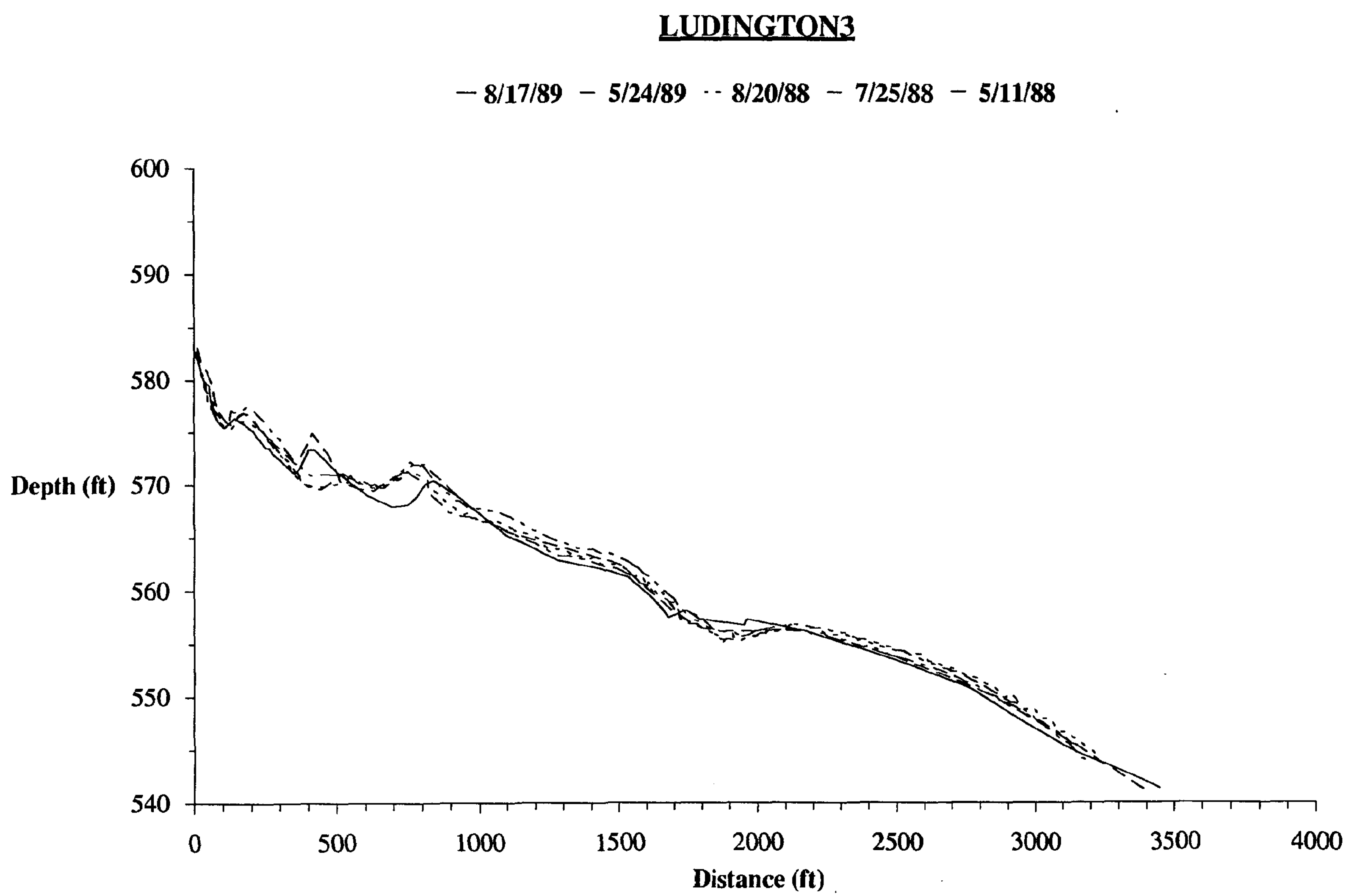

SUMMIT
— 8/17/89 — 5/24/89 -- 8/21/88 — 5/10/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

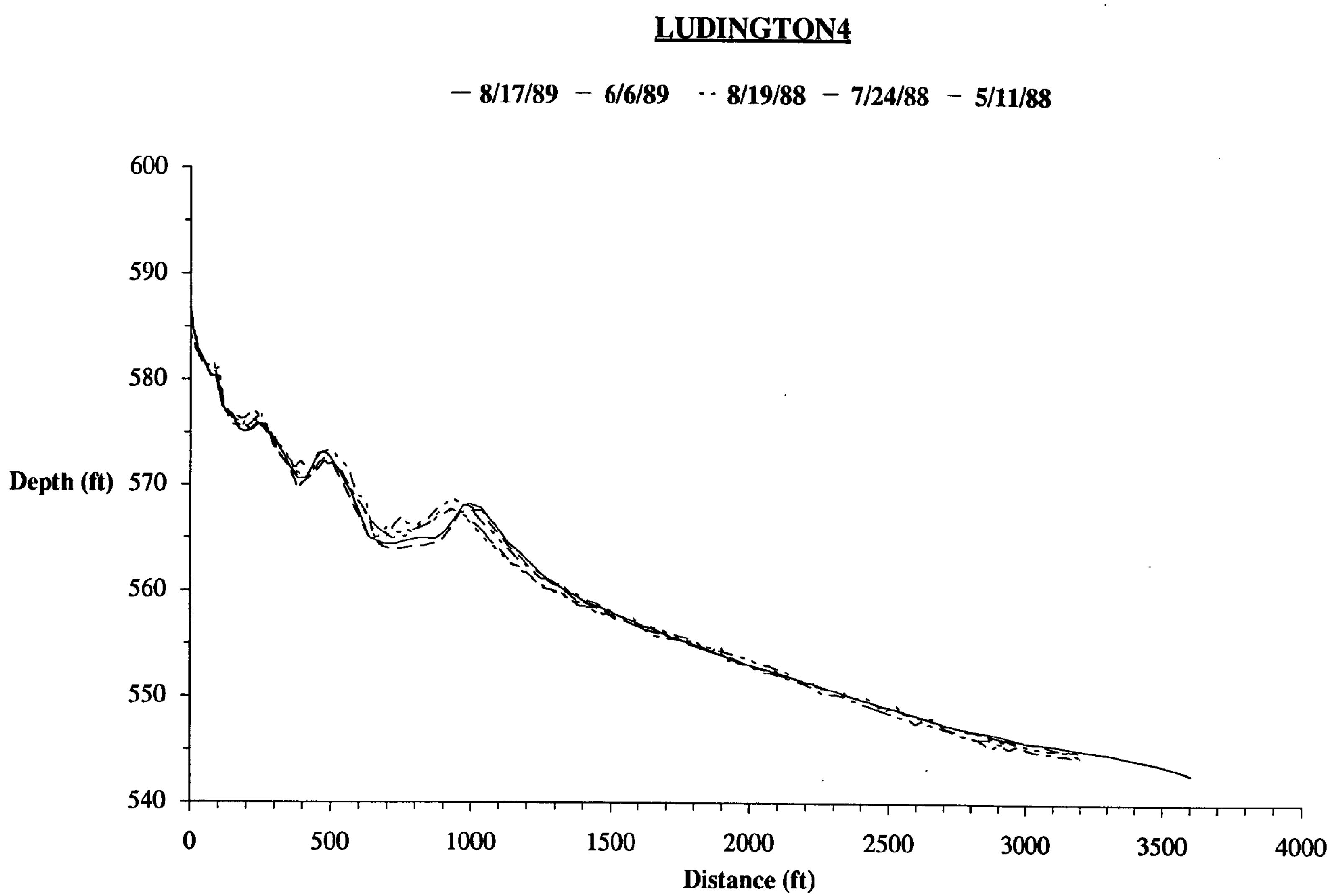
LUDINGTON1


— 8/17/89 – 5/24/89 ·· 8/20/88 – 7/25/88 – 5/11/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

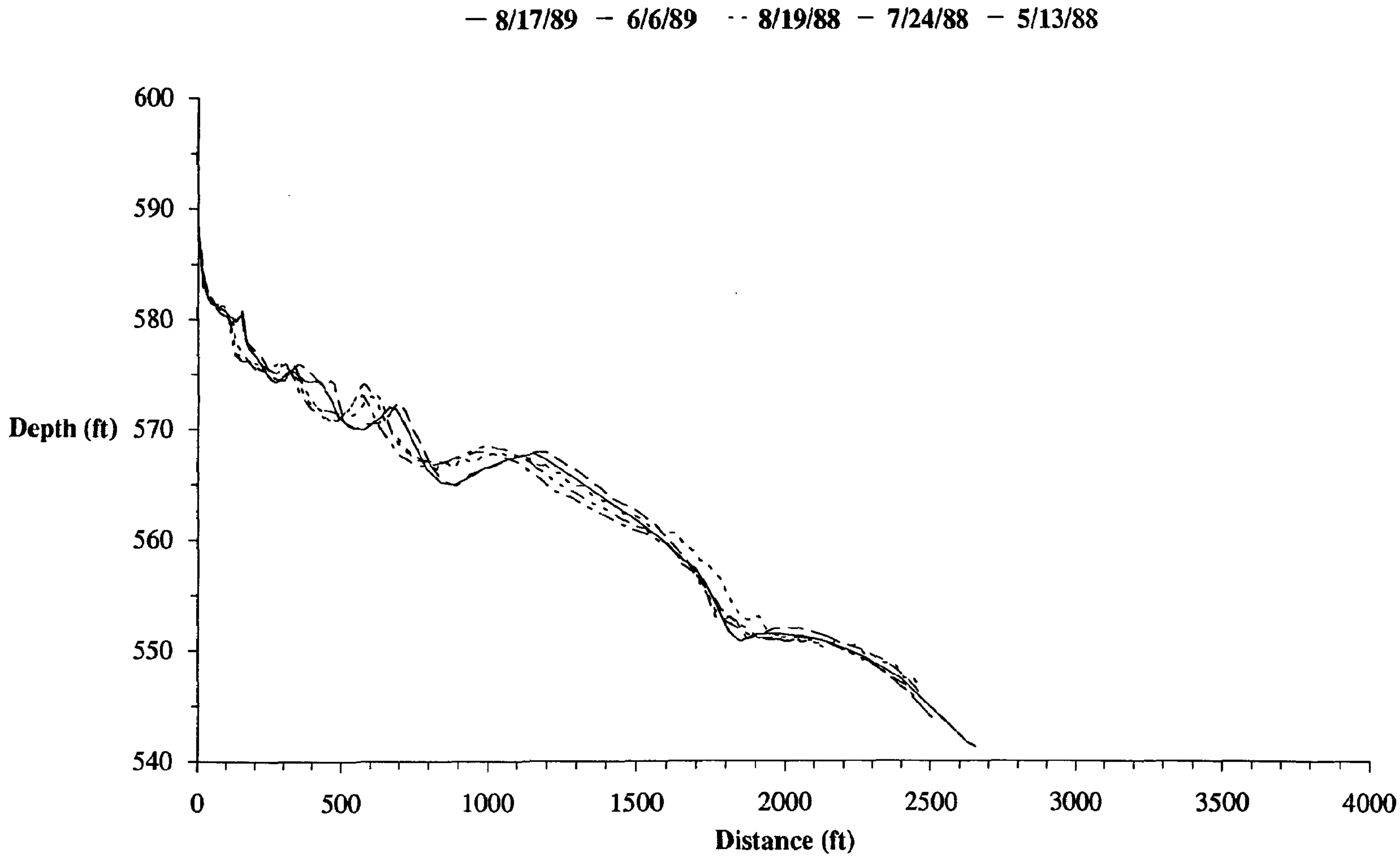
LUDINGTON2

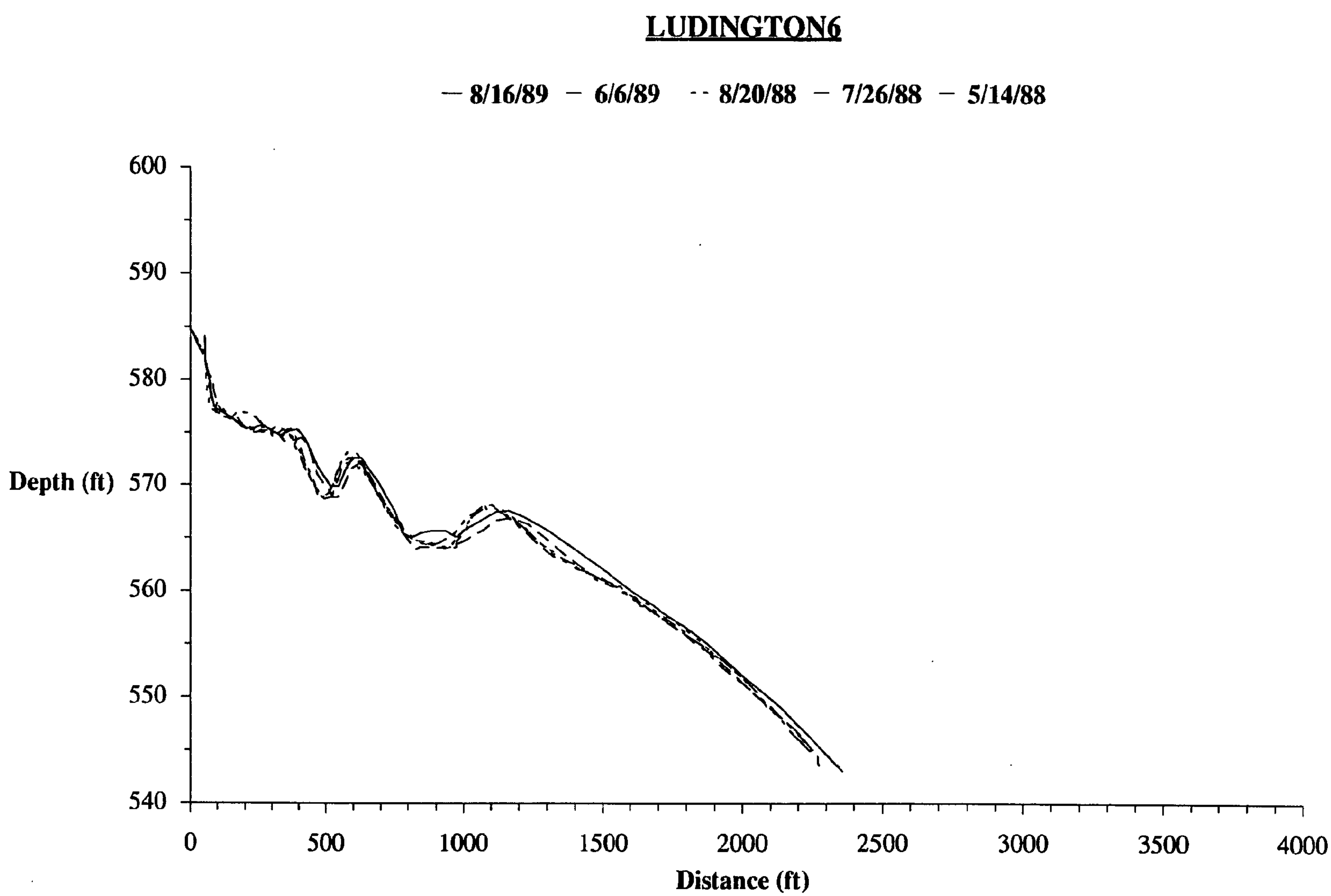

— 8/17/89 — 5/24/89 - - 8/19/88 — 7/25/88 — 5/11/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)


LUDINGTON3
— 8/17/89 — 5/24/89 -- 8/20/88 — 7/25/88 — 5/11/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

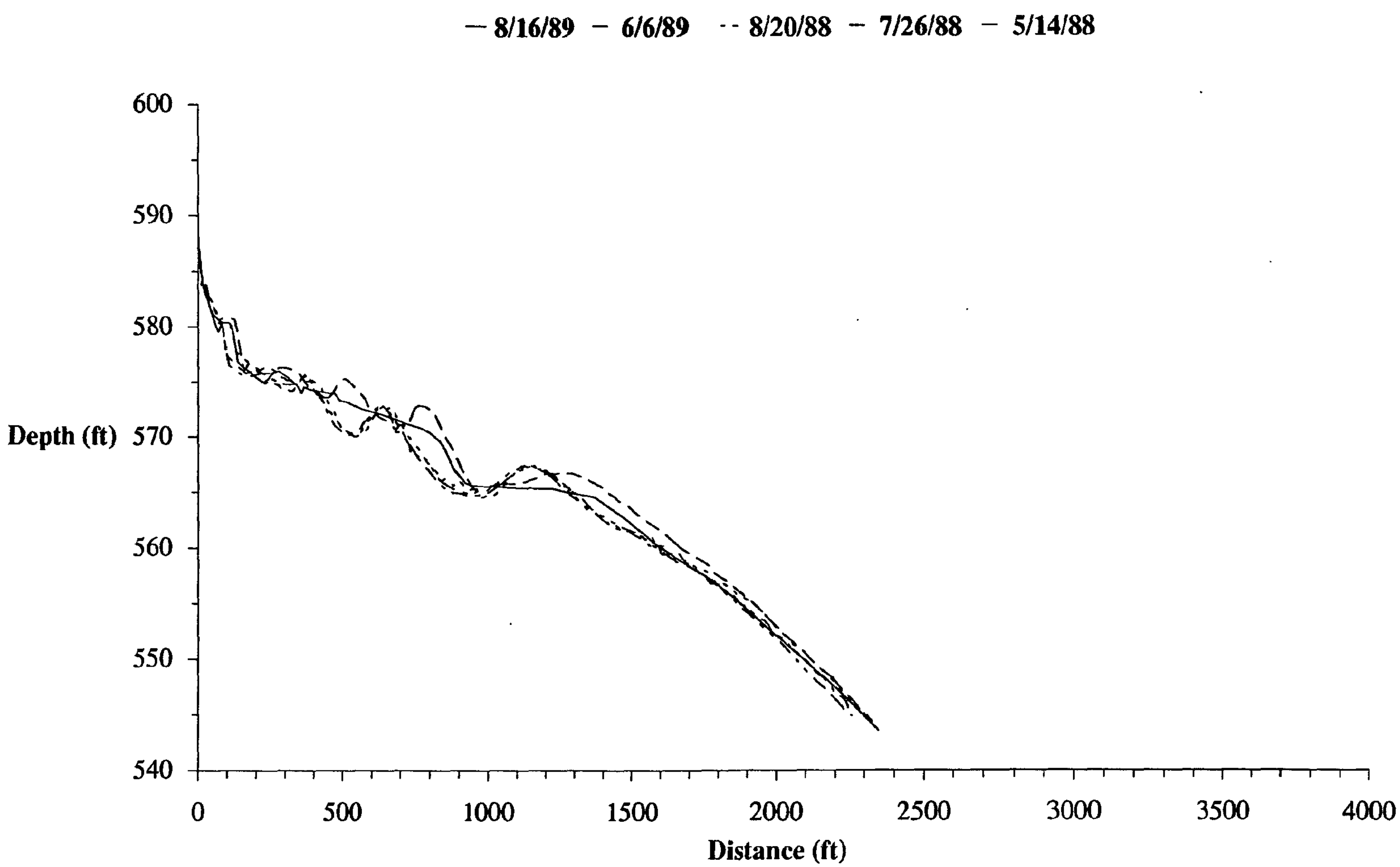

LUDINGTON4
— 8/17/89 — 6/6/89 -- 8/19/88 — 7/24/88 — 5/11/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

LUDINGTON5


— 8/17/89 – 6/6/89 ·· 8/19/88 – 7/24/88 – 5/13/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

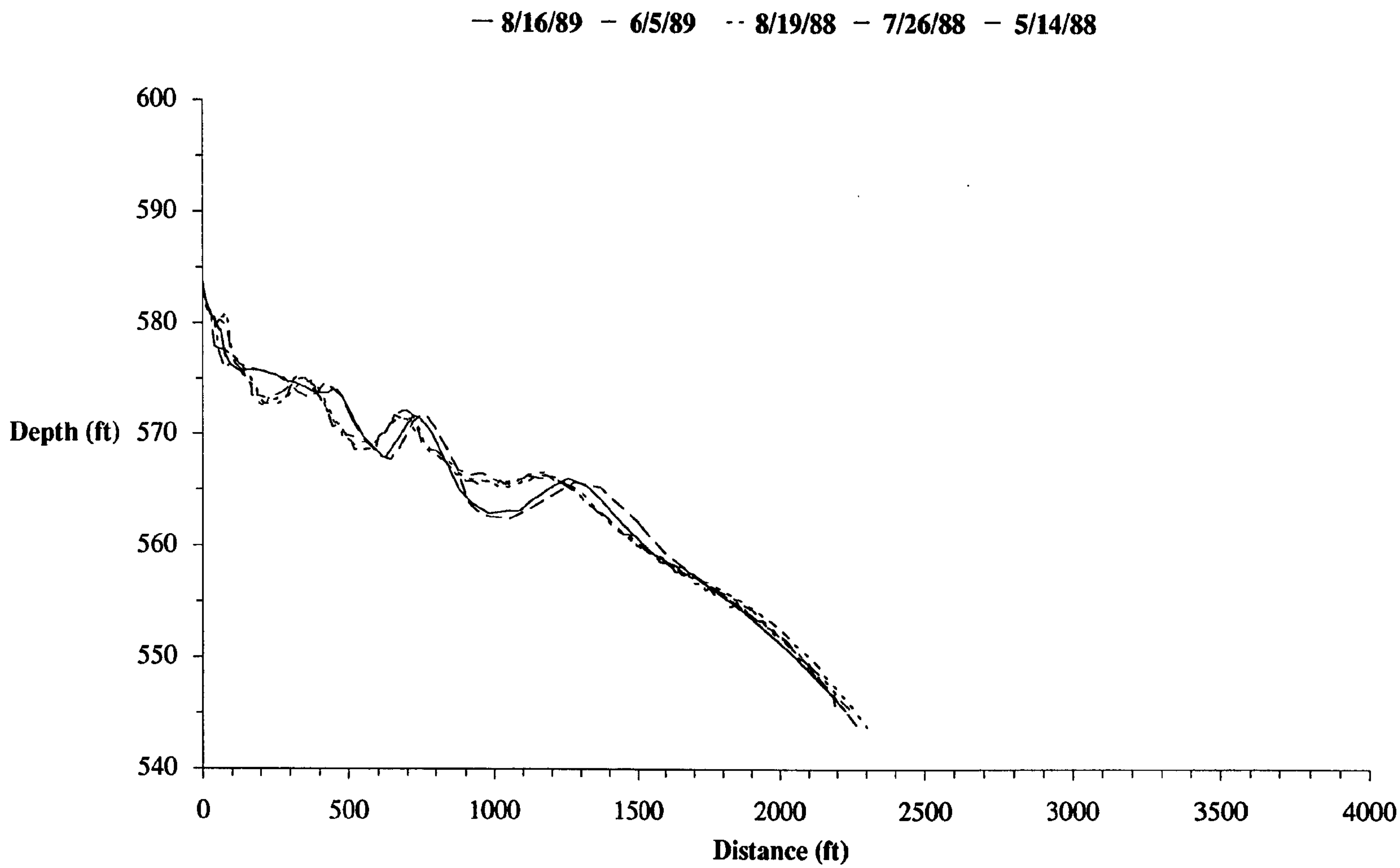

LUDINGTON6
— 8/16/89 — 6/6/89 -- 8/20/88 — 7/26/88 — 5/14/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

LUDINGTON7



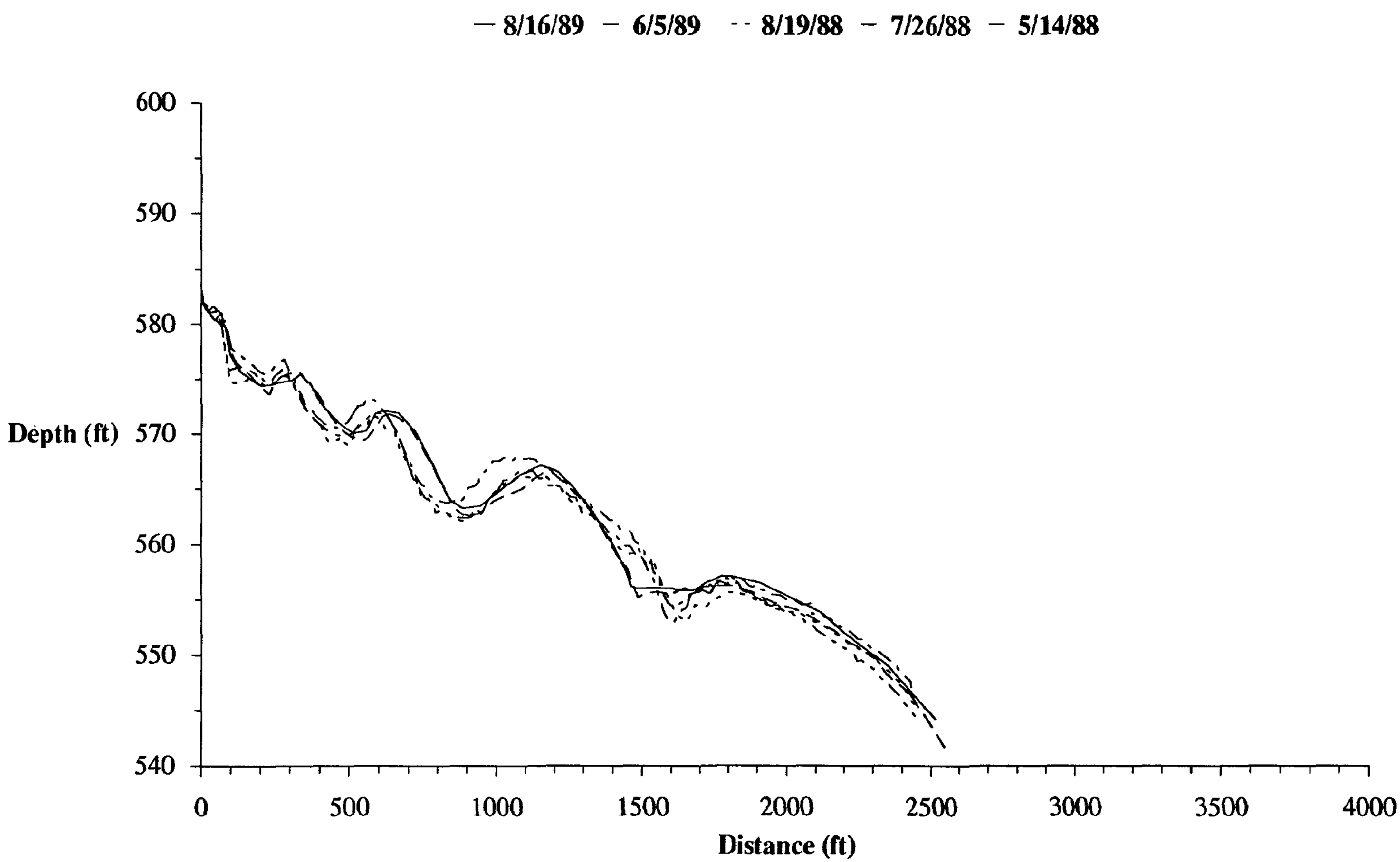
— 8/16/89 — 6/6/89 - - 8/20/88 — 7/26/88 — 5/14/88
600
590
580
Depth (ft) 570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

LUDINGTON8

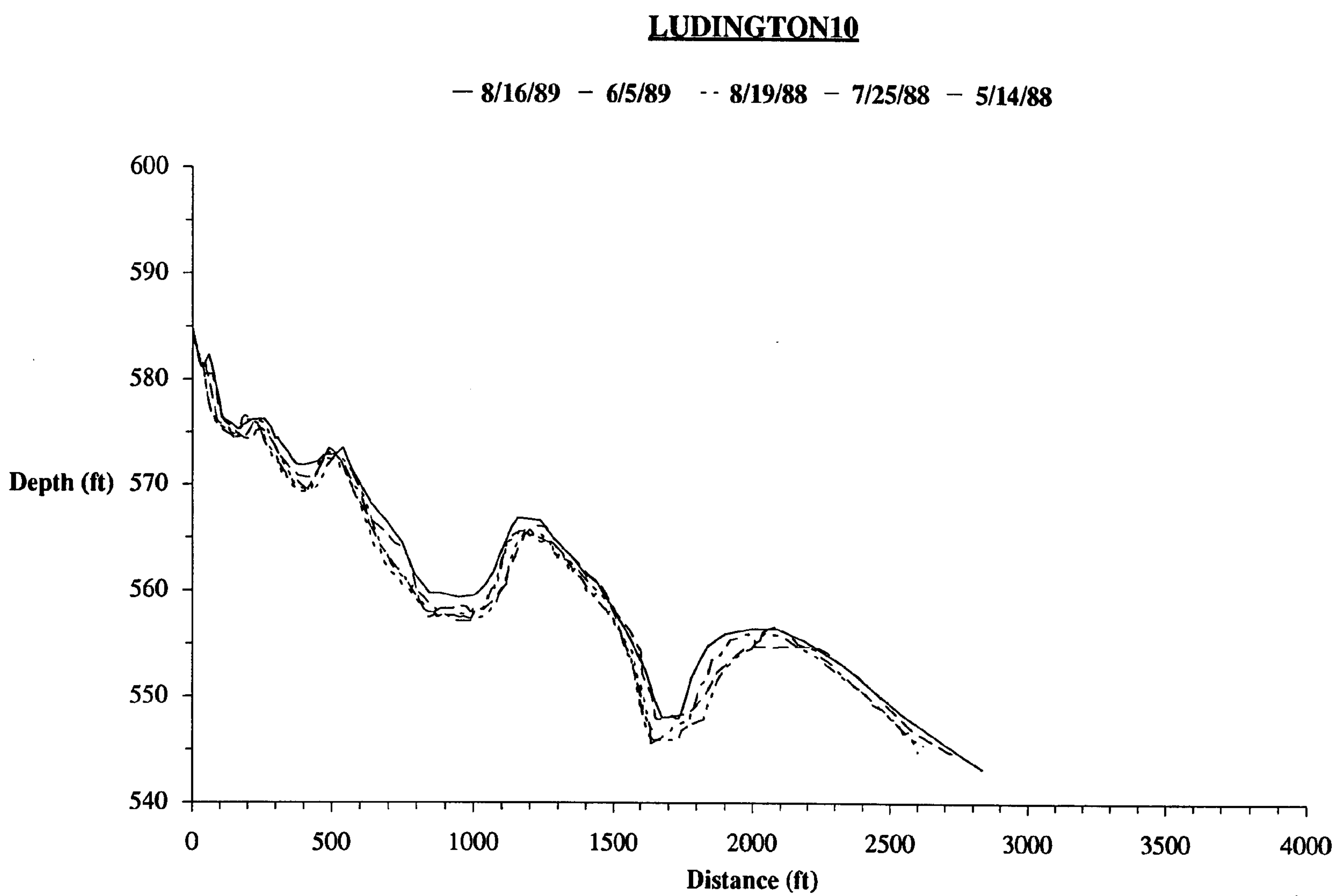


— 8/16/89 – 6/5/89 -- 8/19/88 – 7/26/88 – 5/14/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

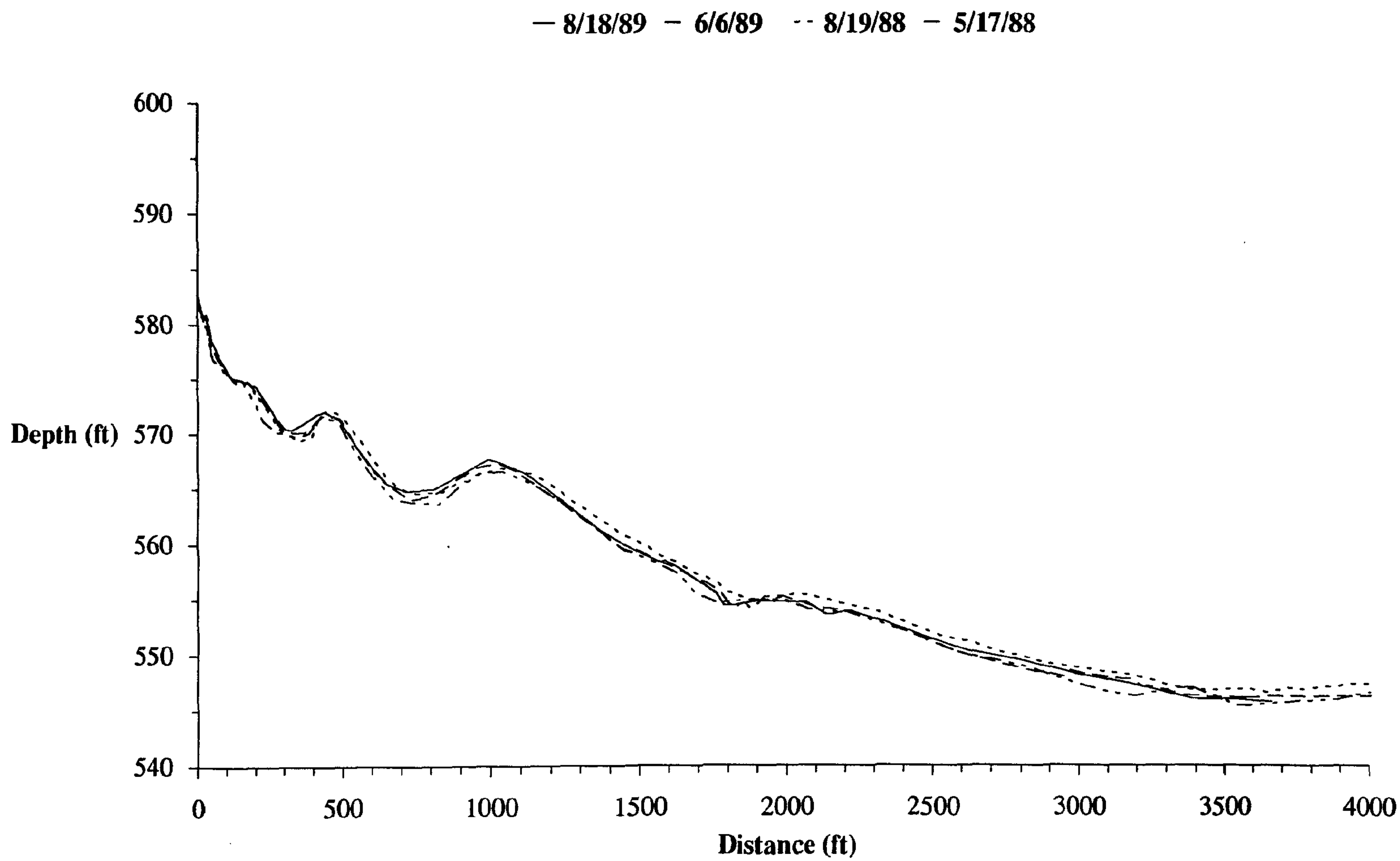
LUDINGTON9



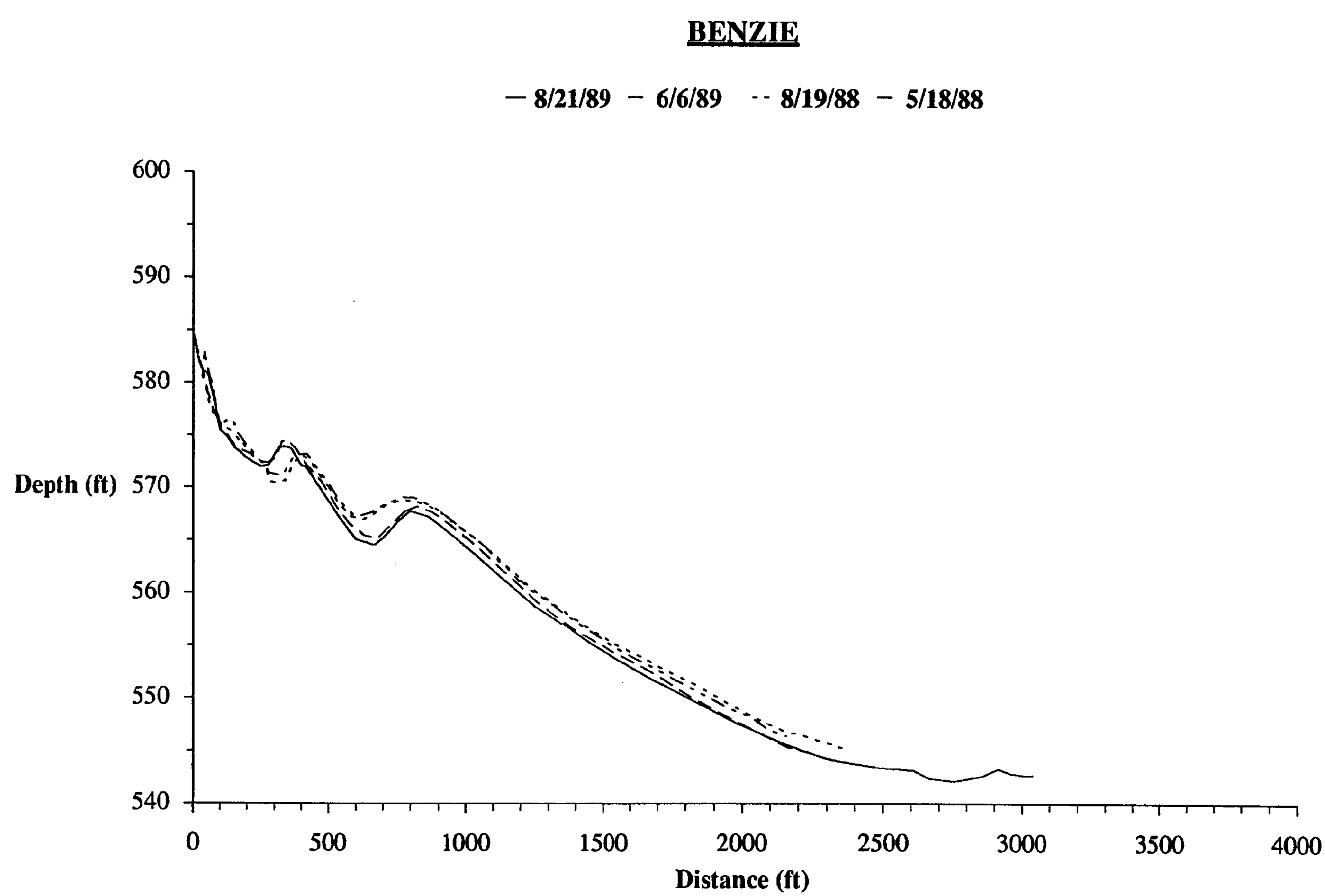
— 8/16/89 — 6/5/89 - - 8/19/88 — 7/26/88 — 5/14/88
600
590
580
570
560
550
540
Depth (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

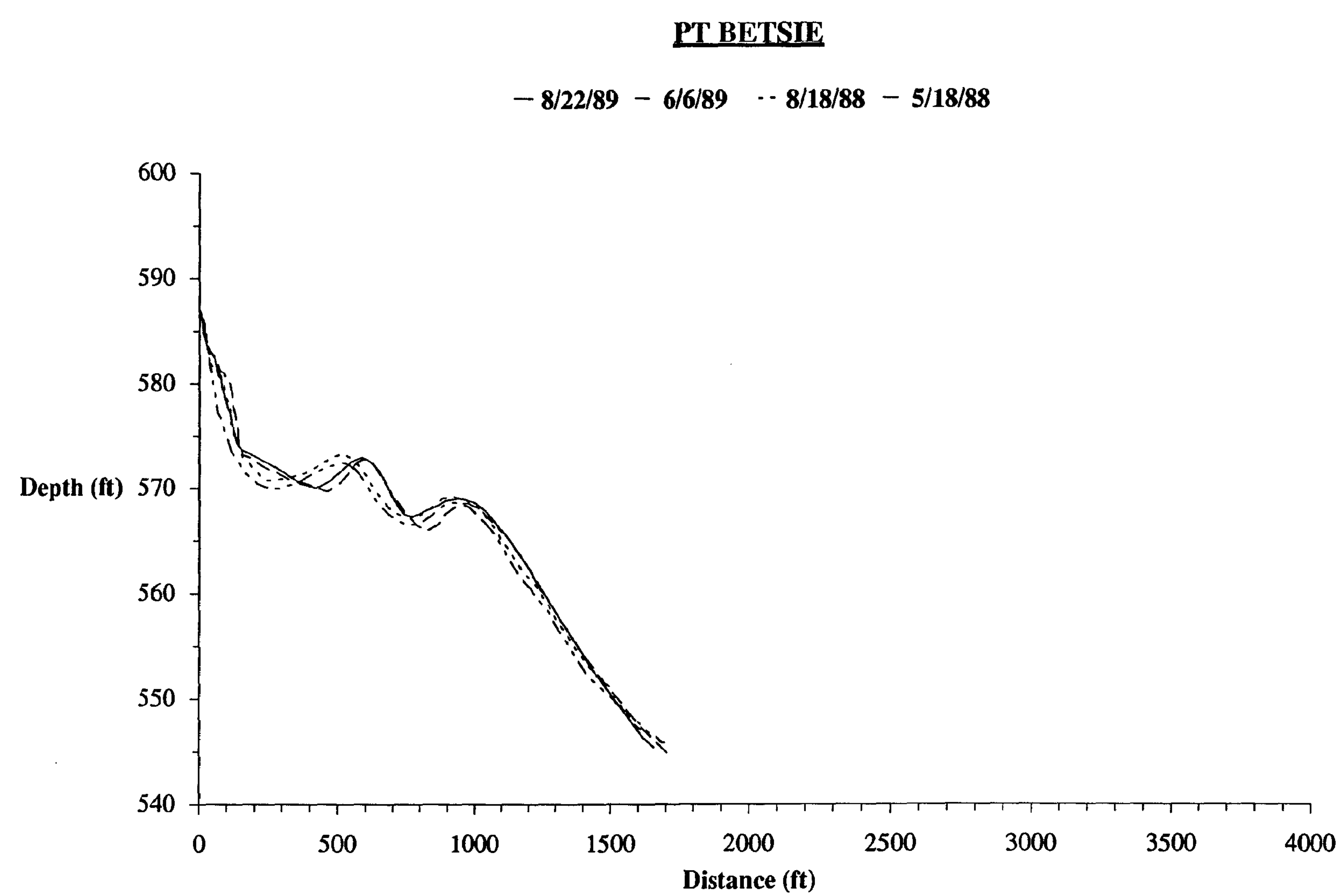

LUDINGTON10
— 8/16/89 — 6/5/89 - - 8/19/88 — 7/25/88 — 5/14/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

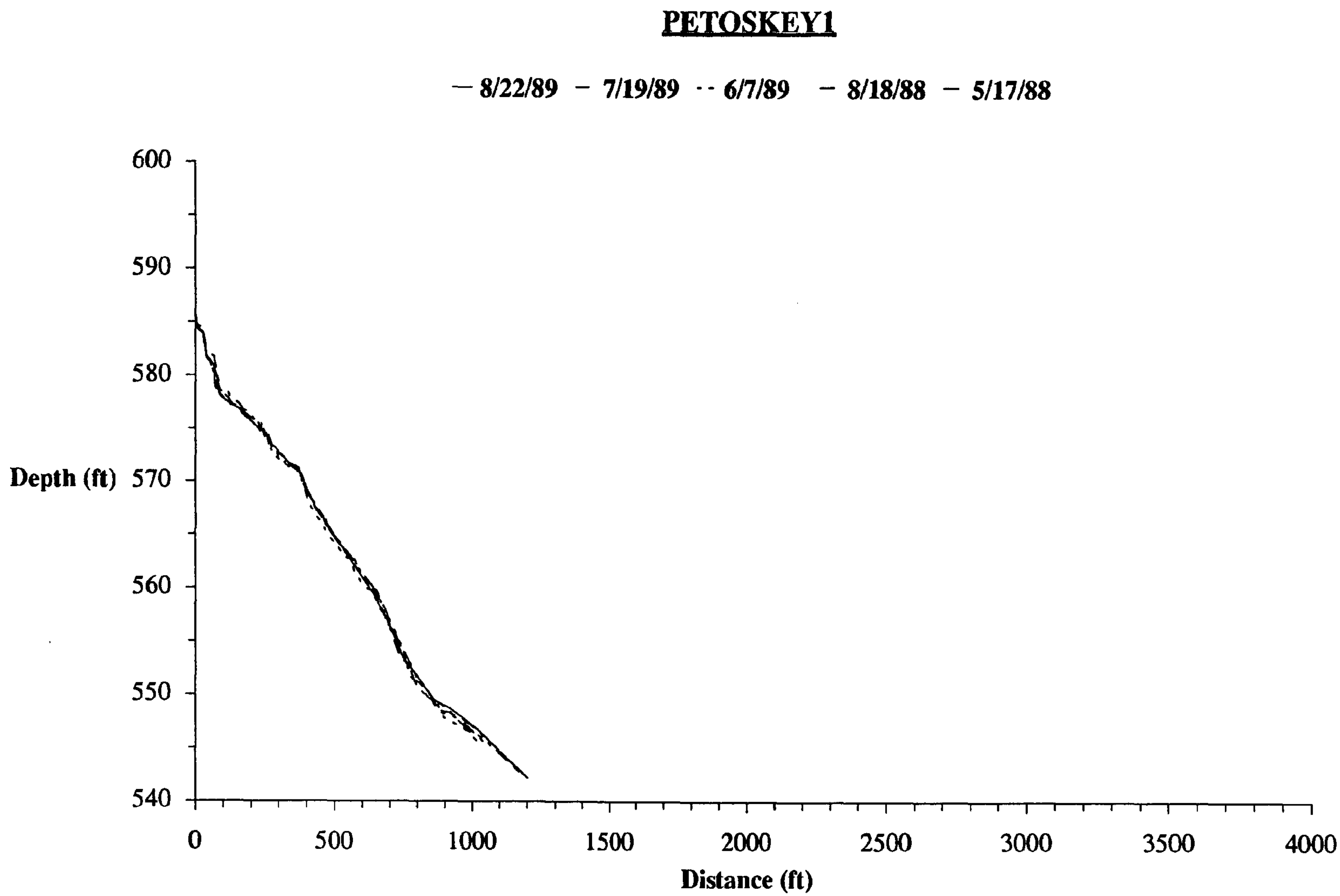
MANISTEE



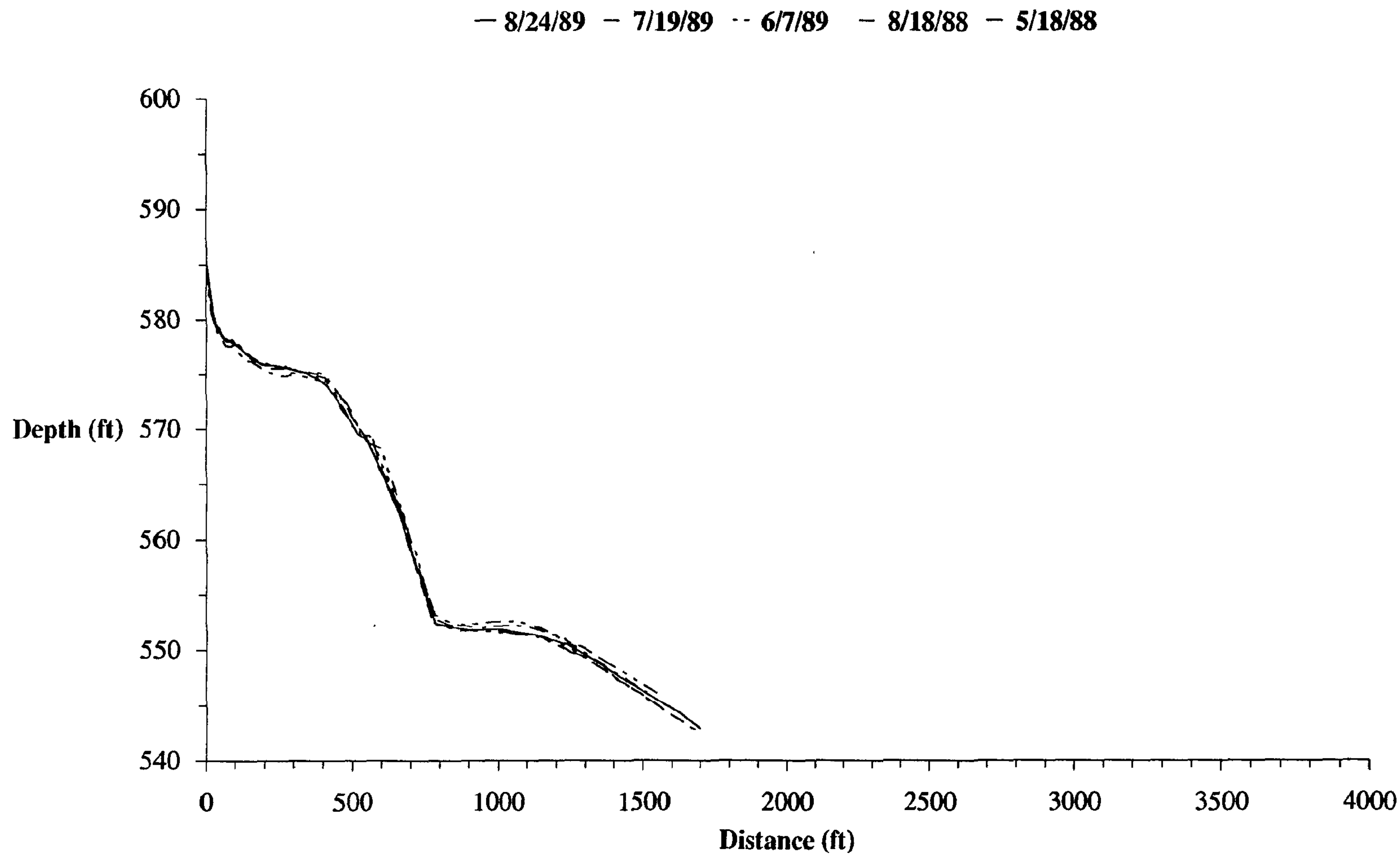
— 8/18/89 – 6/6/89 - - 8/19/88 — 5/17/88
600
590
580
570
560
550
540
Depth (ft)
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)


BENZIE
— 8/21/89 — 6/6/89 -- 8/19/88 — 5/18/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

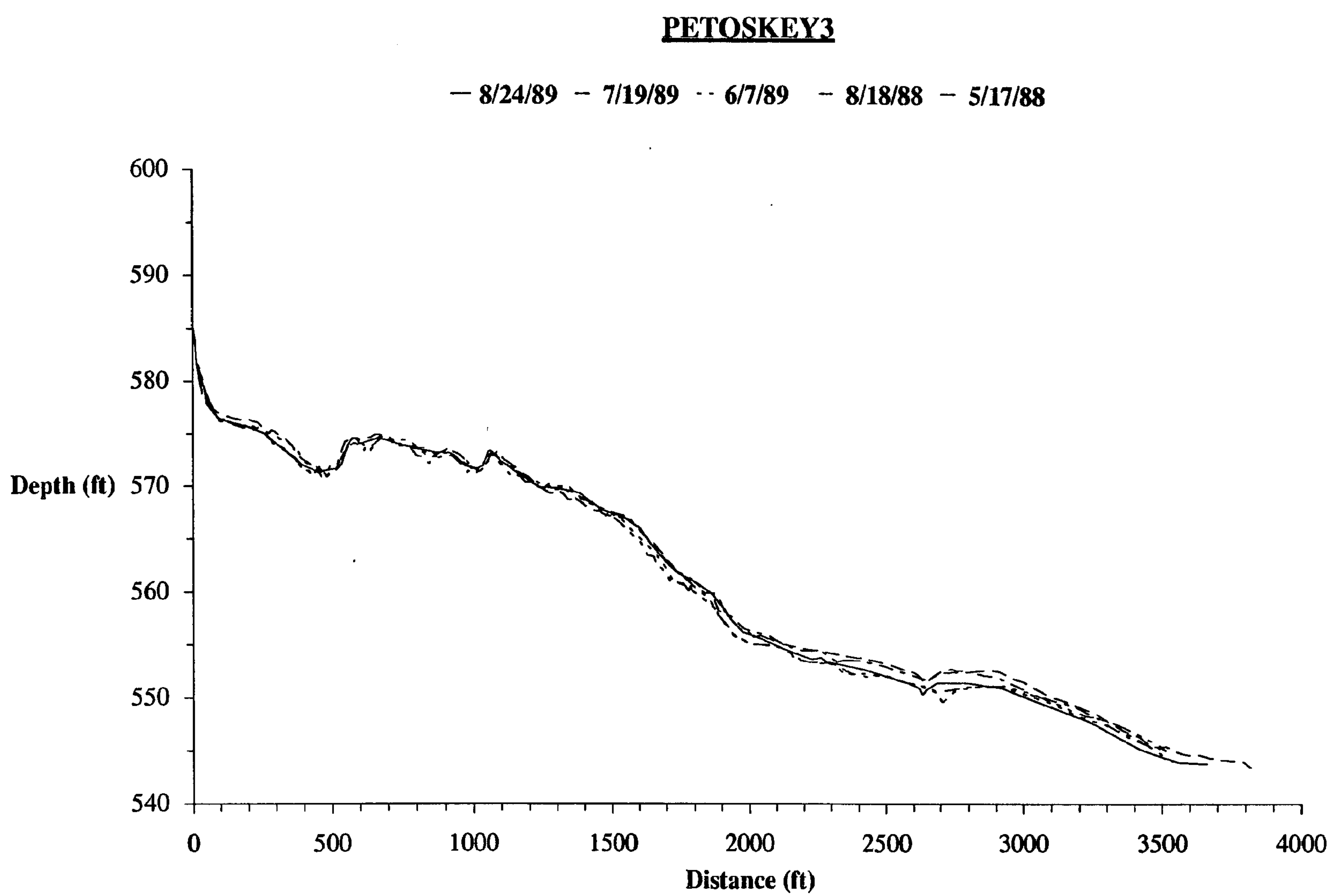

PT BETSIE
— 8/22/89 — 6/6/89 -- 8/18/88 — 5/18/88
600
590
580
Depth (ft) 570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)


PETOSKEY1
— 8/22/89 – 7/19/89 ·· 6/7/89 – 8/18/88 – 5/17/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

PETOSKEY2

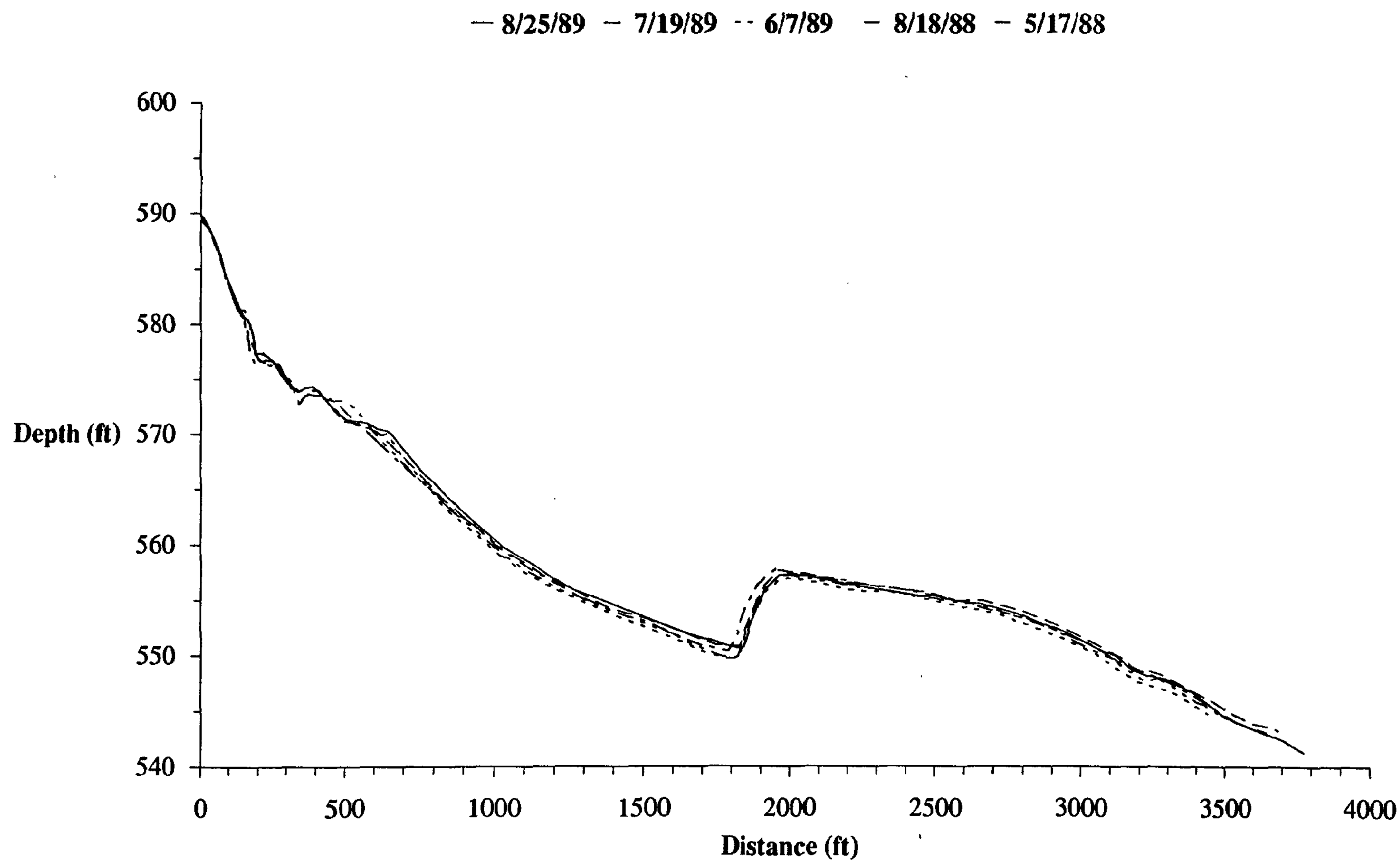


— 8/24/89 – 7/19/89 ·· 6/7/89 – 8/18/88 – 5/18/88
600
590
580
Depth (ft) 570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

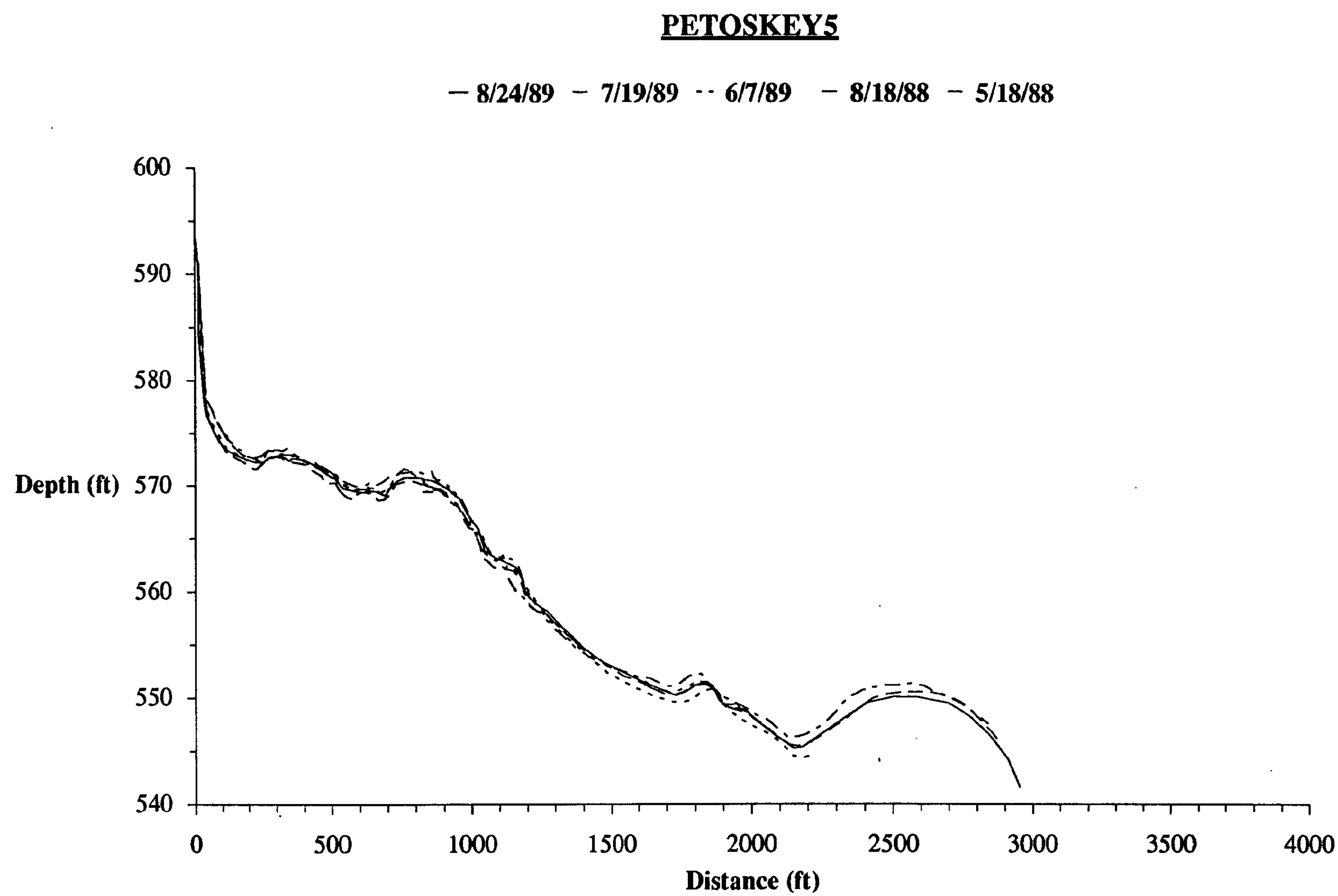


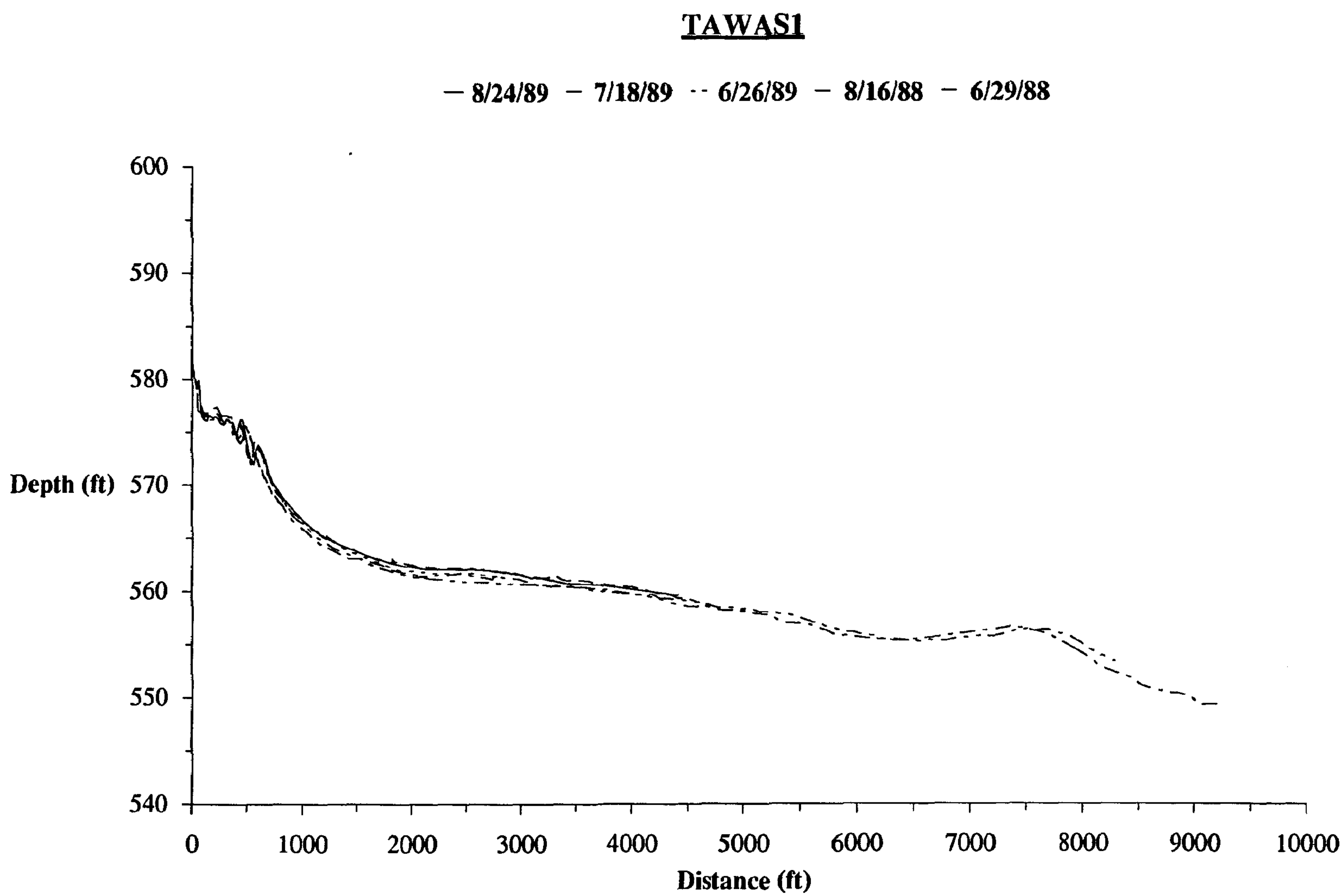
PETOSKEY3
— 8/24/89 – 7/19/89 ·· 6/7/89 – 8/18/88 – 5/17/88
600
590
580
Depth (ft) 570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

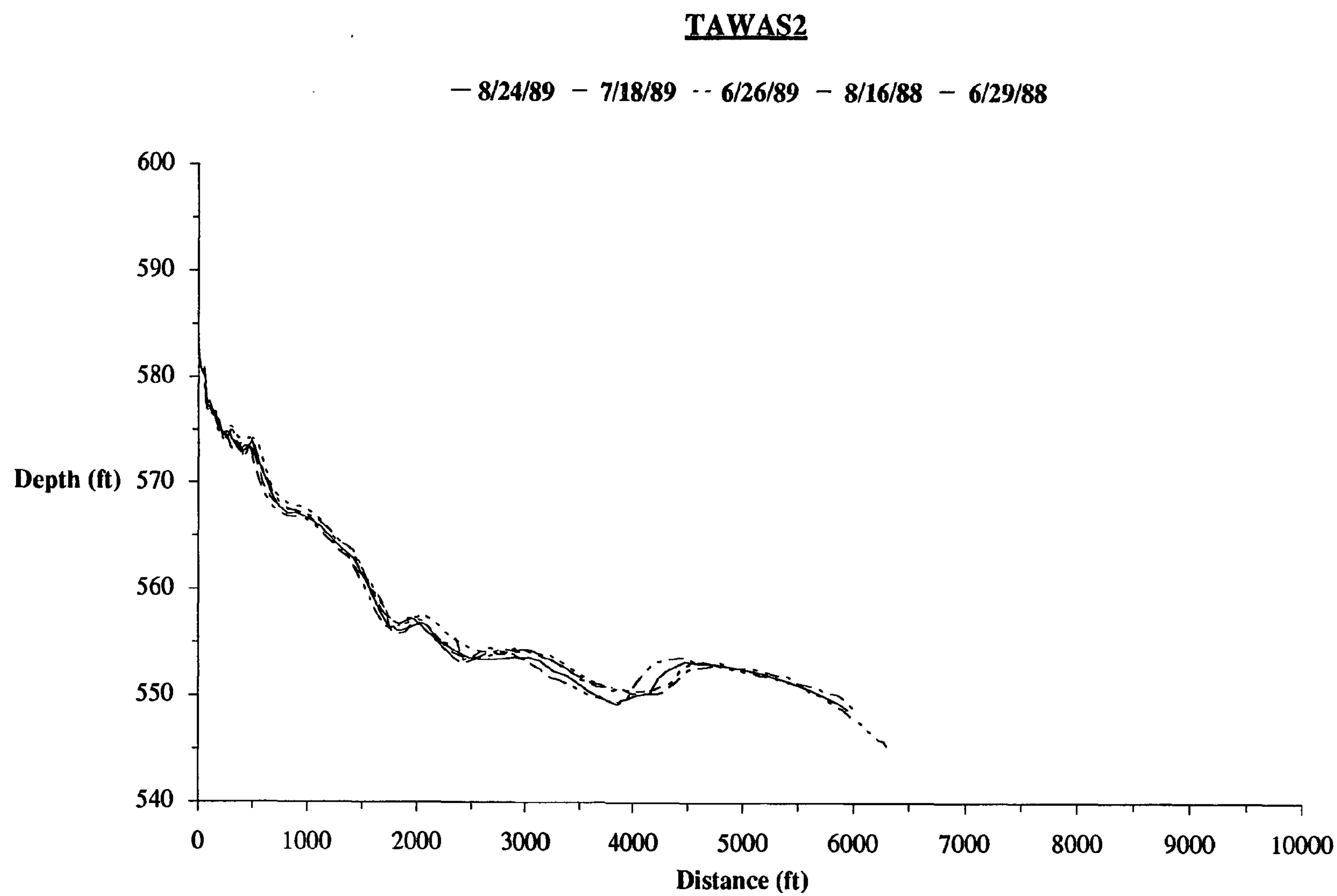
PETOSKEY4



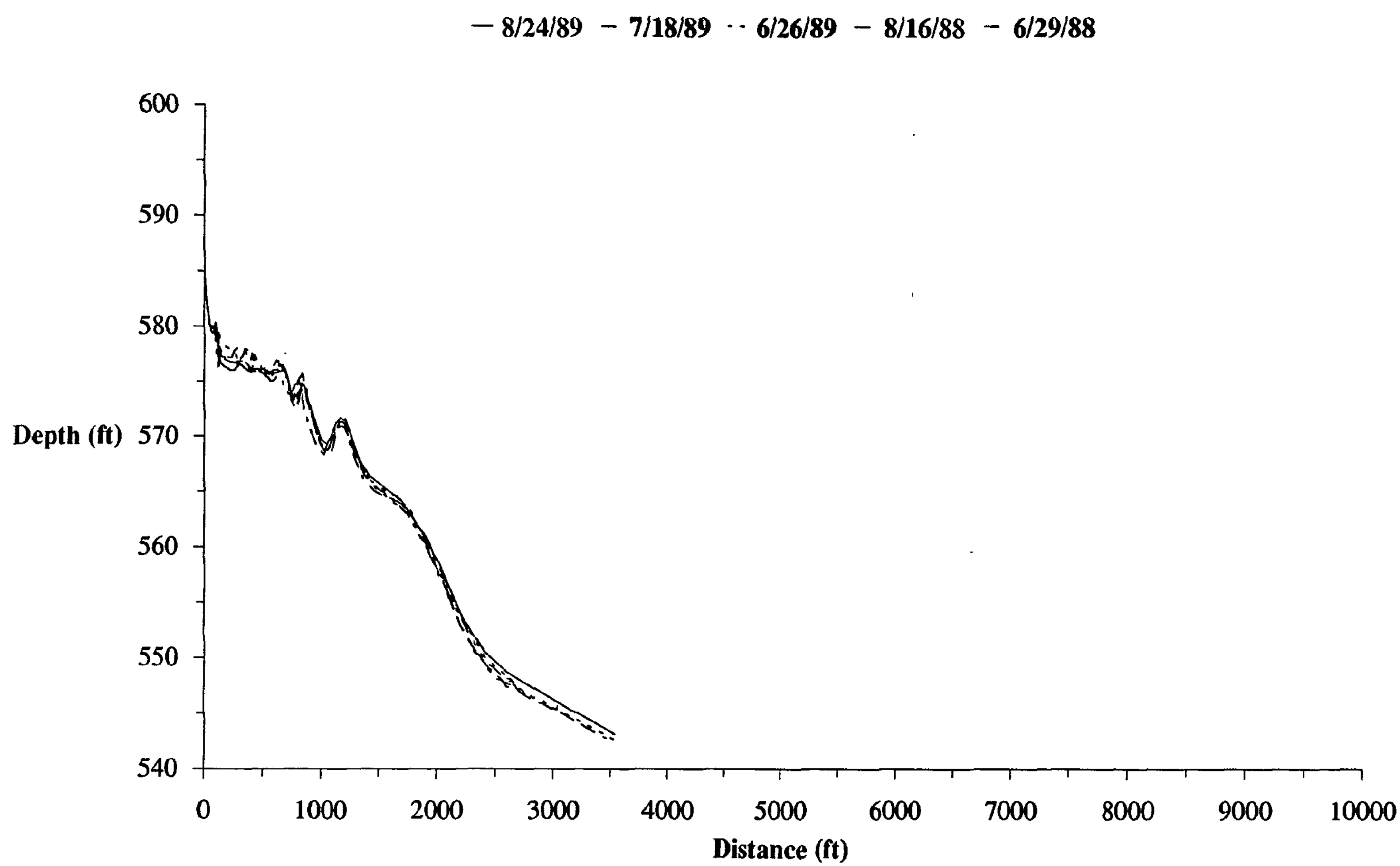
— 8/25/89 — 7/19/89 -- 6/7/89 — 8/18/88 — 5/17/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

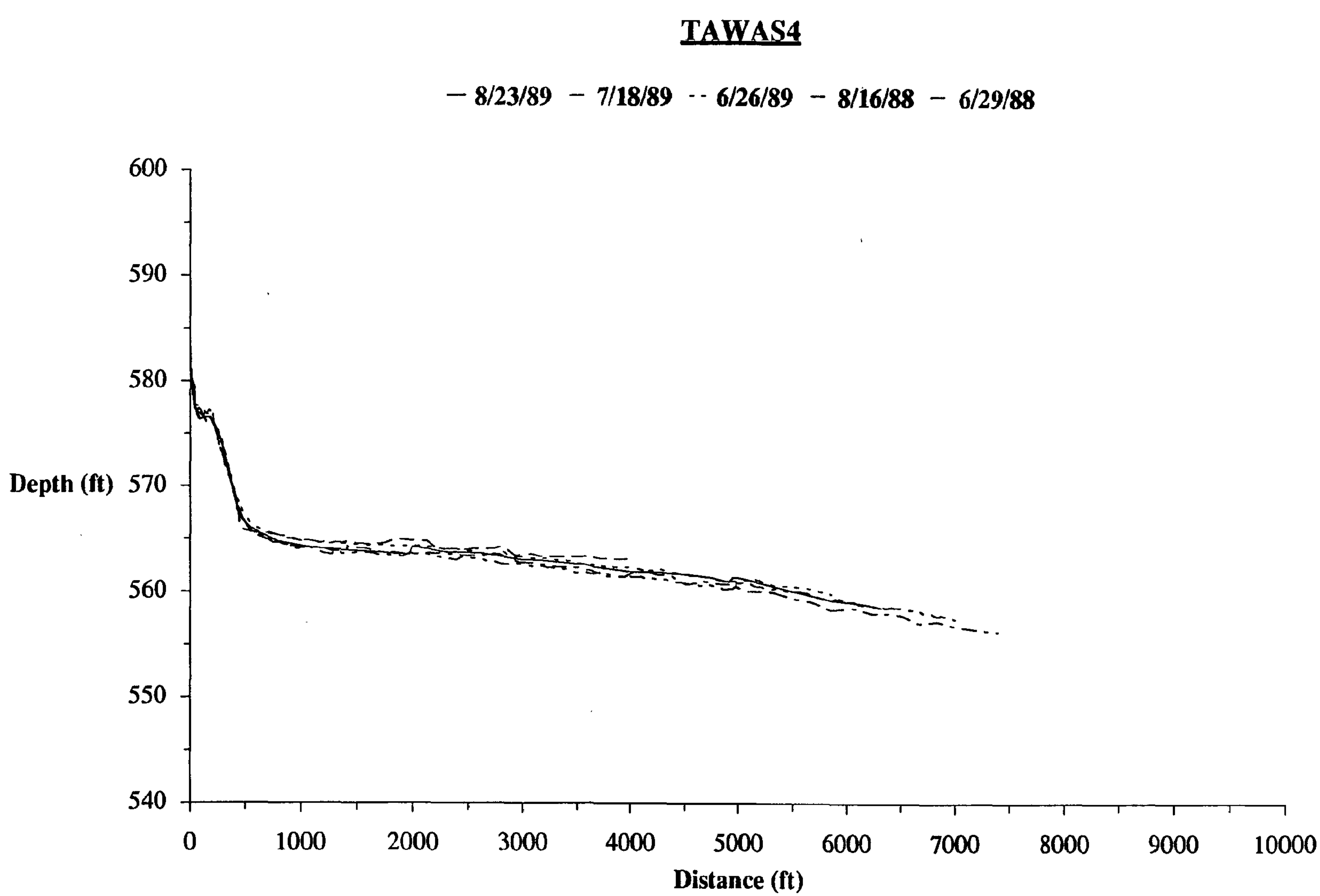

PETOSKEY5
— 8/24/89 — 7/19/89 -- 6/7/89 — 8/18/88 — 5/18/88
Depth (ft)
600
590
580
570
560
550
540
0
500
1000
1500
2000
2500
3000
3500
4000
Distance (ft)

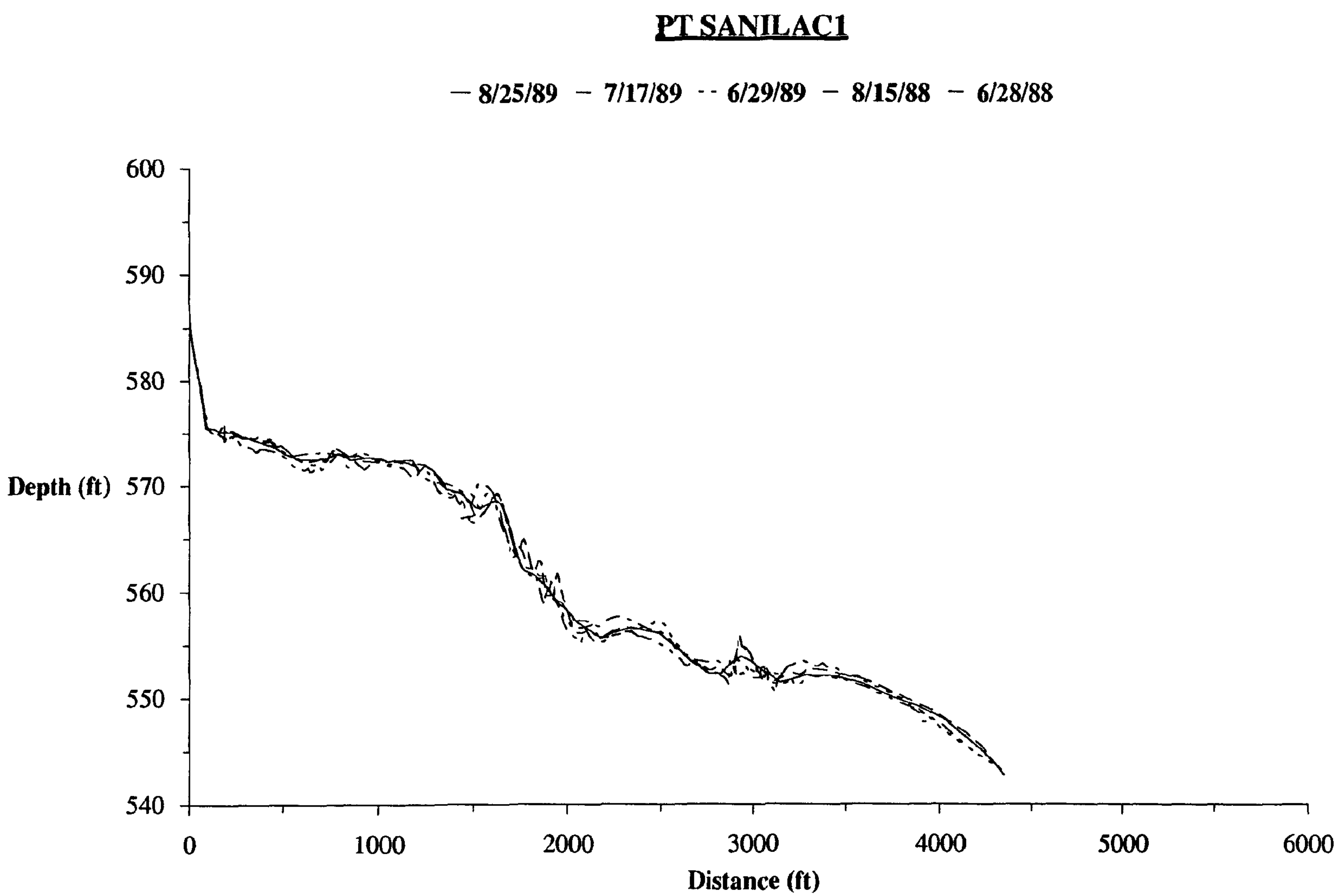

TAWAS1
— 8/24/89 — 7/18/89 -- 6/26/89 — 8/16/88 — 6/29/88
Depth (ft)
600
590
580
570
560
550
540
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Distance (ft)

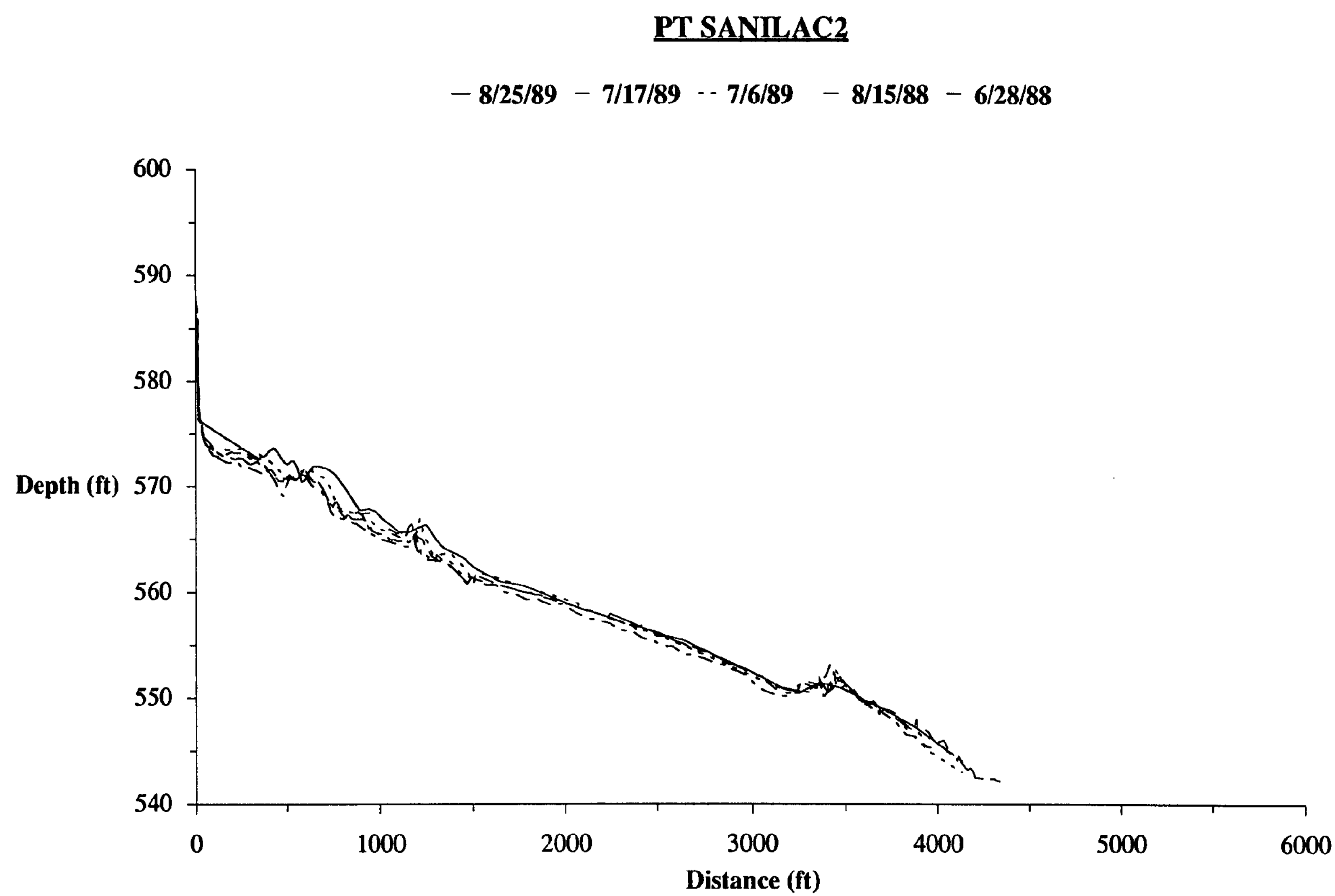

TAWAS2
— 8/24/89 — 7/18/89 - - 6/26/89 — 8/16/88 — 6/29/88
Depth (ft)
600
590
580
570
560
550
540
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Distance (ft)

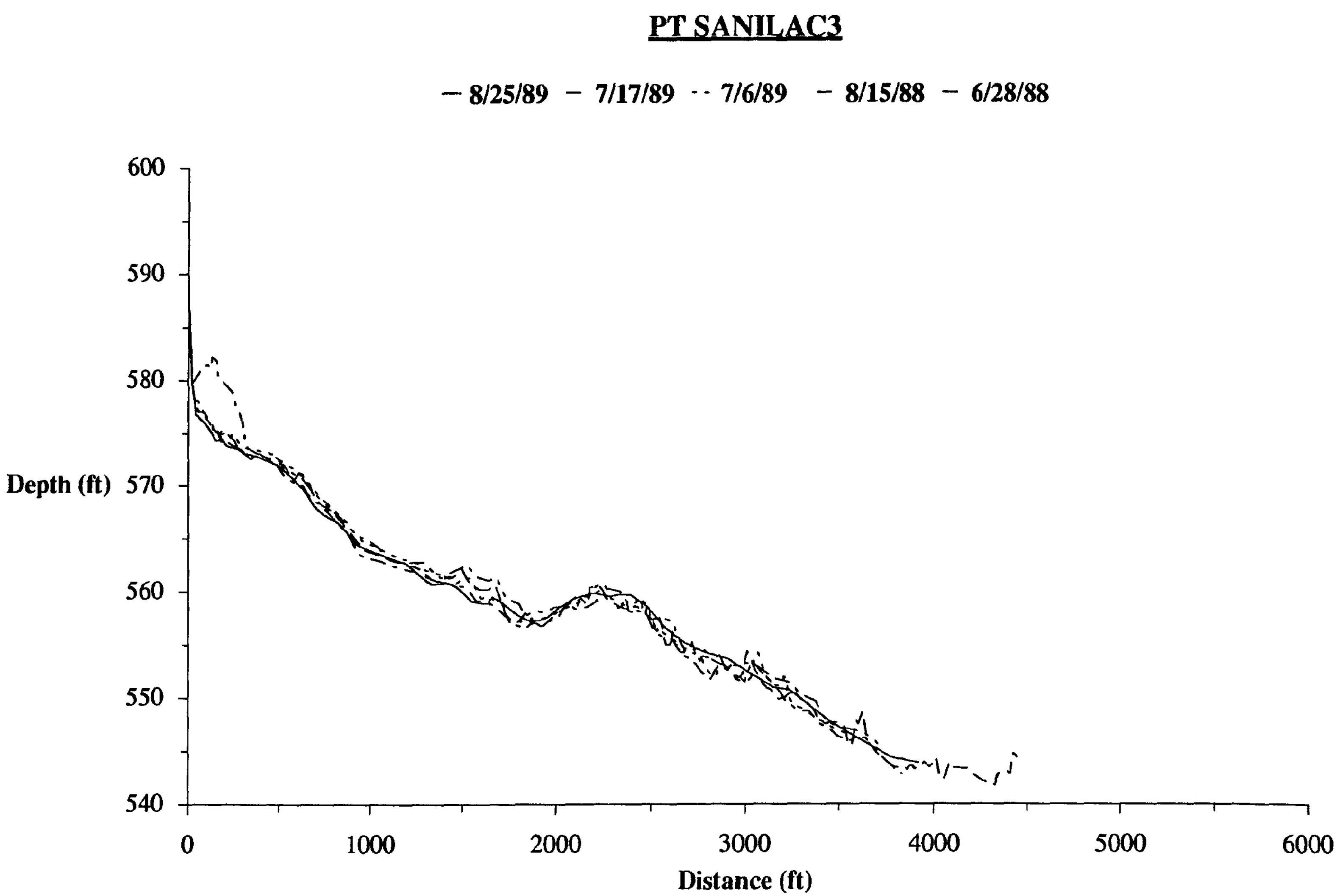
TAWAS3


— 8/24/89 – 7/18/89 ·· 6/26/89 – 8/16/88 – 6/29/88
600
590
580
Depth (ft) 570
560
550
540
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Distance (ft)

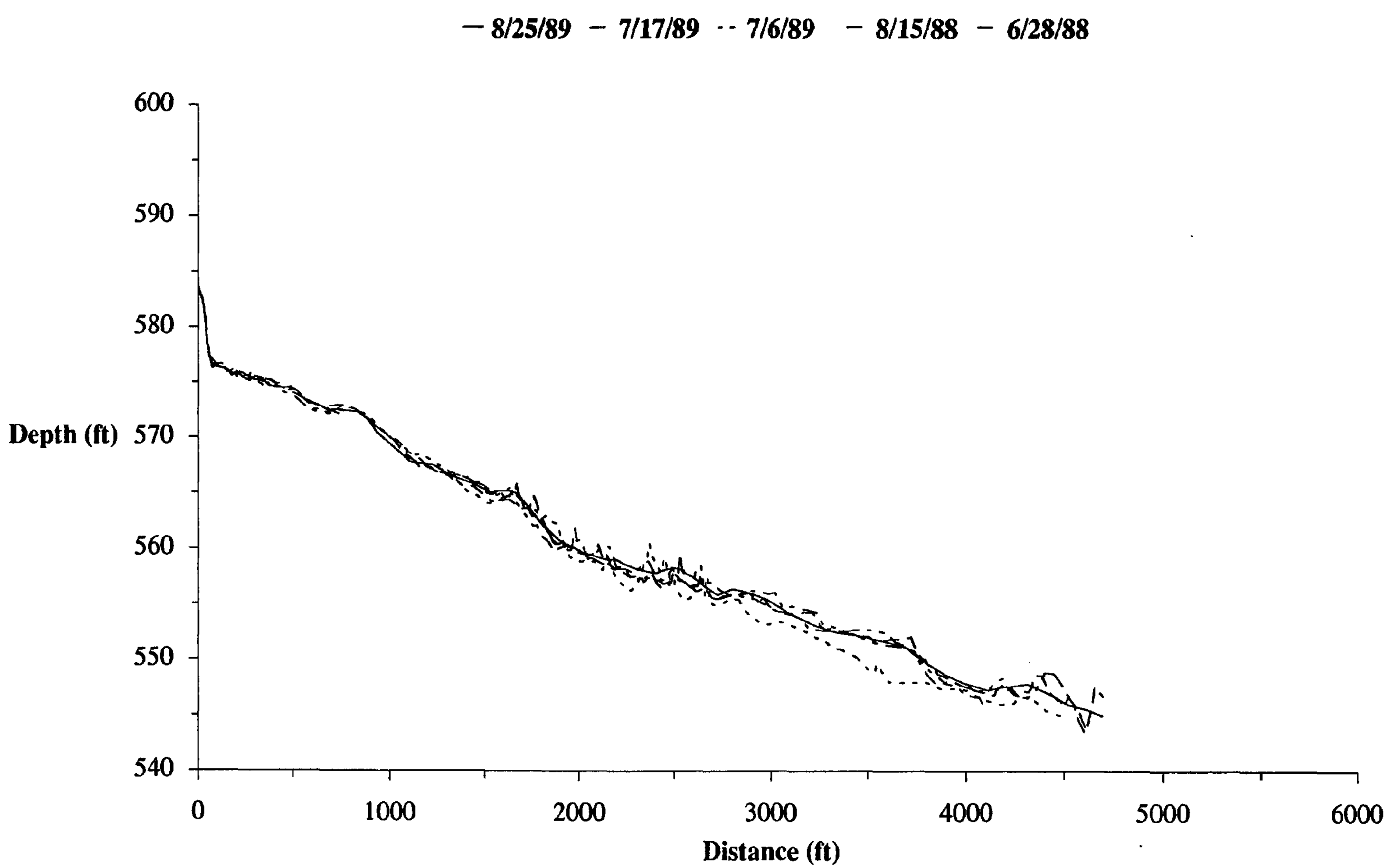

TAWAS4
— 8/23/89 — 7/18/89 -- 6/26/89 — 8/16/88 — 6/29/88
600
590
580
Depth (ft) 570
560
550
540
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Distance (ft)


PT SANILAC1
— 8/25/89 — 7/17/89 - - 6/29/89 — 8/15/88 — 6/28/88
Depth (ft)
600
590
580
570
560
550
540
0
1000
2000
3000
4000
5000
6000
Distance (ft)


PT SANILAC2
— 8/25/89 — 7/17/89 -- 7/6/89 — 8/15/88 — 6/28/88
600
590
580
Depth (ft) 570
560
550
540
0
1000
2000
3000
4000
5000
6000
Distance (ft)

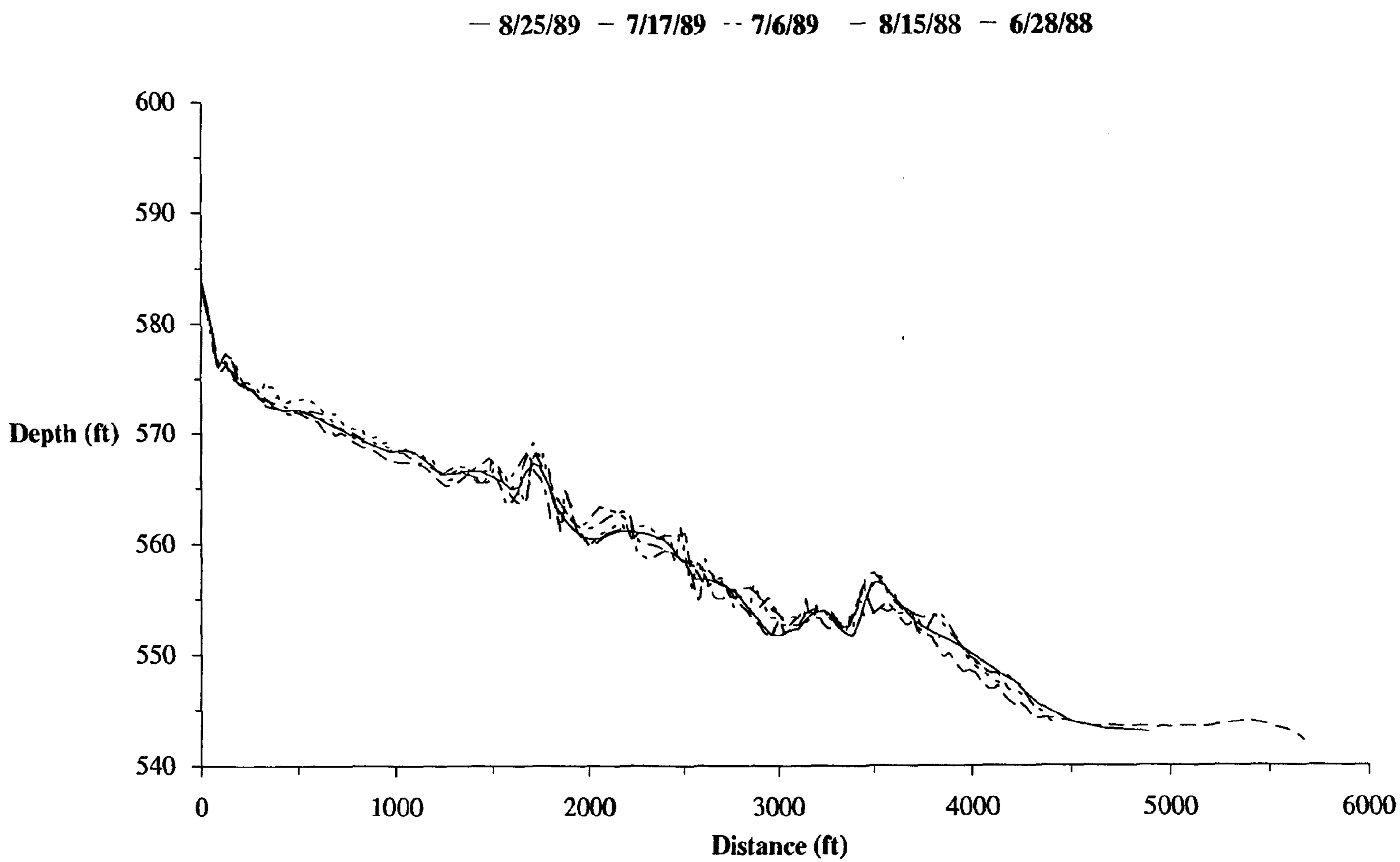

PT SANILAC3
— 8/25/89 — 7/17/89 -- 7/6/89 — 8/15/88 — 6/28/88
Depth (ft)
600
590
580
570
560
550
540
0
1000
2000
3000
4000
5000
6000
Distance (ft)

PT SANILAC4



— 8/25/89 — 7/17/89 -- 7/6/89 — 8/15/88 — 6/28/88
Depth (ft)
600
590
580
570
560
550
540
0
1000
2000
3000
4000
5000
6000
Distance (ft)

PT SANILAC5



8/25/89
7/17/89
7/6/89
8/15/88
6/28/88
600
590
580
570
560
550
540
Depth (ft)
0
1000
2000
3000
4000
5000
6000
Distance (ft)