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Model Evaluation Workgroup

Technical Memorandum 2g

Quantification of Lower Fox River Sediment Bed Elevation Dynamics through Direct Observations

Prepared by:

Wisconsin Department of Natural Resources

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1.0 SUMMARY

This technical memorandum is provided in partial fulfillment of the Memorandum of Agreement ("Agreement") between the State of Wisconsin and seven paper companies ("Companies"), dated January 31, 1997.

Model evaluation procedures will be undertaken according to the procedures discussed in the "Workplan to Evaluate the Fate and Transport Models for the Fox River and Green Bay" ("workplan"). This workplan was developed by Limno-Tech, Inc. ("LTI") on behalf of the Companies and the Wisconsin Department of Natural Resources ("WDNR") and was conditionally approved by WDNR on September 26, 1997. This technical memorandum is an extension of the Task 2 series of model evaluation work products, entitled "Quantification of Lower Fox River Sediment Bed Elevation Dynamics Through Direct Observations."

The objective of this technical memorandum is to quantify the spatial and temporal dynamics of elevation changes in the sediment bed of the Lower Fox River through direct observations. The results presented in this document are based on the application of engineering cross-sectioning methods to data from three sources; the U.S. Army Corps of Engineers (COE), the U.S. Environmental Protection Agency (USEPA), and the U.S. Geological Survey (USGS). Data from these sources describe Lower Fox River sediment bed elevations for the period 1977 to 1998; most of these data were collected downstream of the DePere dam in the last 15 kilometers (seven miles) of the river. The COE is responsible for operations and maintenance of the Lower Fox River navigation channel and has a long history of conducting bathymetric mapping surveys of the channel. The COE uses this information to determine if areas of the navigation channel require maintenance dredging as a result of sediment accumulation. In addition to regular inspections by the COE, the USEPA and the USGS have conducted studies to determine elevation changes of the Lower Fox River sediment bed.

Results of this study document that sediment bed elevations changes occur in the Lower Fox River over short-term and long-term time frames. Sediment bed elevation changes are observed in cross-channel and downstream profiles. These changes show little spatial or temporal continuity. The complexity of these sediment bed changes reflects the prevailing hydrologic and sedimentologic conditions that occurred over a 22 year period (1977 through 1998): the Lower Fox River sediment bed is continuously reshaped by the wide range of discharges and sediment loads the river experiences. Short-term (annual and sub-annual) average net sediment bed elevation changes range from a decrease of 28 centimeters to an increase of 36 centimeters. Long-term (several years) average net elevation changes range from a decrease of more than 100 centimeters to an increase of nearly 45 centimeters. The changes documented by short-term and long-term cross-section transects are well-supported by COE sediment volume calculations from pre- and post-dredge sediment bed elevation surveys, as well as results of the USGS analysis of bed surveys performed at intermediate time scales (8 months to 45 months).

2.0 INTRODUCTION

2.1 Purpose

To complete the model evaluation process as described in the Agreement, the spatial and temporal changes in sediment bed elevations of the Lower Fox River must be examined. This sediment bed elevation information provides data to quantify sediment transport dynamics of the Lower Fox River for spatial (point-in-space) and temporal (point-in-time) analysis of model performance. The purpose of this document is to present:

1. documentation of a methodology to estimate changes in sediment bed elevation from direct field observations; and

2. application of this methodology to the Lower Fox River to quantify sediment bed elevation dynamics through the analysis of short-term and long-term sediment bed elevation data.

Sediment bed elevation data for Green Bay (e.g. the Green Bay navigation channel) are not presented or quantified in this document. Indirect data sources, such as radio-dated sediment cores, from which sediment bed elevation may sometimes be inferred are not presented in this document.

2.2 Overview

Located in northeastern Wisconsin, the Lower Fox River is 63 kilometers (39 miles) long and descends 51 meters (185 feet) between Lake Winnebago and Green Bay. The study area location and elevation profile are presented in Figures 1-2. To make navigation possible, the U.S. Army Corps of Engineers (COE) constructed nine dams and seventeen locks on the river, between 1850 and 1870. Since that time, the COE has been responsible for maintaining the navigation channel by regulating water levels (pool elevations) and removing accumulated sediments. Since the late 1870s, the COE has regularly performed extensive sounding of the Lower Fox River sediment bed. This information has been routinely used by the COE to plan shipping routes and keep these routes navigable by maintaining necessary channel depths through dredging.

There is a long history of surveying the Lower Fox River downstream of DePere to determine elevation changes due to deposition and erosion of sediment. The hydrographic mapping techniques used by the COE and other groups have evolved over the years from basic vector-based mechanical soundings with lined weights to multi-beam raster sonar and satellite global positioning systems (GPS). Other organizations, particularly the U.S. Environmental Protection Agency (USEPA) and U.S. Geological Survey (USGS), have also conducted hydrographic surveys for the purpose of determining sediment bed elevation changes over time.

Numerous investigations of Lower Fox River sediment bed elevations have been completed by the COE, USEPA, and USGS between 1954 and 1997 (and more recently 1998) using similar methods and equipment. Technological advancements over the last 20 years have lead to accuracy improvements in acoustic (sonar) sounding devices and has made this equipment both portable and more affordable. Land-based positioning methods have also been improved in this time; infrared and laser ranging devices no longer limit conventional surveying to short, taped distances. Similarly, developments in military and civilian satellite communication and navigation have lead to the development of the Global Positioning System (GPS). Since 1977, these technologies were used to repeatedly survey chosen range lines across the Lower Fox River. This study examines long-term data collected by the COE during 1977, 1982, 1990, 1993, 1997, and 1998, short-term data collected by the USEPA during 1994 and 1995, and confirmatory information collected and analyzed by the USGS during 1989, 1990, 1991, 1992, and 1996.

Data from these sources describe the elevations of the Lower Fox River sediment bed, and comparison of these data reveals changes in the bed elevations at both short-term (months) and long-term (years and decades) time intervals. Although the analytical methods and time scales considered by the individual studies are different, the data collection strategies were similar enough to produce data sets consisting of elevation data comparable in detail and accuracy.

3.0 DATA SOURCES, PRE-PROCESSING, AND ANALYSIS

3.1 COE Dredge Data

In order to compare Lower Fox River sediment bed elevation data to determine what changes were due to natural river dynamics (i.e. not due to dredging), it was first necessary to consider the locations and collection times of the survey profiles with respect to dredging locations and dates. To determine river reaches where elevation data could be compared without the influence of dredge events, the 1956 - 1998 dredge history of the Lower Fox River was reconstructed by consulting data provided by the COE.

Although the COE has been actively dredging the Lower Fox River for the last 149 years, accurate record keeping was not commonplace until the latter half of this century. Dredging locations, amounts of material removed, and spoil deposit sites are on record only after 1956. Prior to 1968, material dredged downstream of the DePere dam was side-cast outside the navigation channel, or dumped in the deeper waters of Green Bay. With the onset of provisions set forth in section 404 of the Federal Clean Water Act (FWPCA, 1972), and the subsequent Wisconsin state administrative code NR347 (WDNR, 1995) establishing disposal criteria for dredge spoils, open water disposal in Wisconsin waterways was restricted. By 1967, the Bayport Confined Disposal Facility (CDF) was complete, as the COE constructed diked disposal cells in the Atkinson Marsh west of the river mouth. A second CDF located just east of the river mouth, Renard Island, was in operation by 1978. These two CDFs have been the primary disposal sites for Fox River and Green Bay Harbor dredge spoils for the last 30 years.

Dredge efforts on the Lower Fox River have continued to change in response to the navigational requirements by commercial shipping. By 1967, commercial ship traffic upstream of Fort Howard Paper Co. (now Fort James Paper Co.) had ceased thereby making channel maintenance unnecessary. In 1967 and 1968, the Fort Howard turning basin was deepened to 6.1 meters (20 feet), and the river and bay navigation channel was deepened to its present project depth of 7.3 meters (24 feet). Nearly 1.5 million cubic meters (2 million cubic yards) of sediment were dredged in order to accommodate the larger supply ships needed to meet the demands of growing industry.

Upstream of the DePere dam, complete records exist only after 1964. In this portion of the river, dredging was performed predominantly in the lock slips and the Menasha navigation channel in Little Lake Buttes Des Morts. Resulting dredge spoils were commonly used to build-up the above-water channel edges, or side-cast along the banks or into deeper waters. The COE ceased maintenance dredging of the river upstream of DePere between 1983 and 1984 in response to decreased recreational boat traffic through the locks and the fiscal streamlining of the Detroit District COE Operation and Maintenance program.

In 1984, the COE began to conduct navigational dredging in the Great Lakes region on a contract basis. Although the Kewaunee (Wisconsin) COE Area Office no longer performs the dredging, this office is still responsible for determining dredge locations and the amount of material to be removed. To meet this responsibility, the COE conducts pre- and post-dredge surveys are using the methods described below (Section 3.2: Long-term Transect Data). Sediment volume estimates derived from these surveys are used to calculate pay-outs and unit costs for dredging. In 1996, the Kewaunee Area Office COE began recording sediment volumes in the navigation channel on a (channel condition) chart by chart basis. Volumes are calculated by determining the differences between the mapped channel condition elevations and the elevations of the channel at the required project depths.

3.1.1 Pre-Processing of COE Dredge Data

Dredge data for the Lower Fox River downstream of the DePere dam was obtained in digital form from the COE Detroit District Office and hardcopy form from the COE Kewaunee Area Office. Dredge information for the river upstream of the DePere dam was obtained in hardcopy form from the Kaukauna Area Office. Hardcopy data were converted to digital form and all data assimilated into one table.

3.1.2 Analysis of COE Dredge Data

Table 1 lists the known dredge history of the Lower Fox River in downstream order: Lake Winnebago to DePere, DePere to Green Bay, and Green Bay to the outer harbor. In addition to reconstructing the 1956 through 1998 dredge history of the Lower Fox River, COE dredge information was used to summarize the total volume of sediment dredged during this 42 year period by dredge location and disposal site. Note that labels associated with COE survey stations have changed over time. The information presented in Table 1 includes an old as well as a new labeling system. Under the old system, Grassy Island in Green Bay was the origin (i.e. ‘0’) and areas north or south of this point were labeled N or S, respectively. Under the new system, the Lower Fox River mouth is the origin and areas upstream (in the river) or downstream (in the bay) of this point are labeled R (river) and B (bay), respectively.

Data collected for recent COE dredging projects were used to investigate large area (rather than specific transects) changes in the sediment bed. Channel survey volume differences for 1996 through 1998 were computed and used to determine natural losses and gains to the sediment bed from 1996 to 1998 for each channel condition chart.

3.2 Long-Term Transect Data

Annual bathymetric mapping of the Lower Fox River and Green Bay navigation channel is carried out by the COE office in Kewaunee, Wisconsin. This information is used to identify areas in the harbor and bay navigation channels that require maintenance dredging and to compute costs of contracted dredge work. Mapping techniques consist of using a sonar-equipped survey vessel to transect the navigation channel at set intervals, with sonar returns recorded continuously. The Lower Fox River is surveyed from the channel entry at 19 kilometers (12 miles) out in Green Bay, to the turning basin immediately downstream of the DePere dam. Range line data (information from which channel transects are computed) are collected every 30 meters (100 feet) from the river mouth upstream to the DePere turning basin, or downstream (bayward) to the outer harbor entry. The river mouth is the zero point (0 + 00). All distances are recorded as feet (in hundreds) upstream (in the river) or downstream (in the bay) from the river mouth (e.g. Range 324 +00 is 32,400 feet from the river mouth). This approach allows the COE to ensure that the same cross-river range lines are mapped year to year. Although dredging no longer occurs in the channel between the DePere and Fort James turning basins, this reach of the river is still mapped on a regular basis.

To insure accuracy and consistency in their engineering work, the COE developed guidelines and methodologies for hydrographic mapping (COE, 1994). The COE methods are considered standard methods for hydrographic surveying. These methods include instruction, guidance, and data density and accuracy requirements for boat navigation, mechanical and electronic positioning (surveying), and mechanical and electronic sounding. The COE uses some of the most sophisticated equipment available today, including a hydrographic survey vessel outfitted with acoustic transducers and kinematic GPS for real-time differential positioning and waypoint navigation. Both the sounder and GPS are linked to an on-board computer, and processed to reference the International Great Lakes Datum (IGLD 1955) for real-time graphical readout and digital storage. The centimeter-level accuracy of the sounding equipment and the sub-meter accuracy of the GPS are used for pre-dredge and post-dredge calculations of sediment volumes and associated dredge contract pay-outs.

It is important to note that equipment accuracy and survey methods have changed between 1977 and 1998. The COE hydrographic surveying manual specifies that site conditions be considered before surveys are performed. Expected sea-state conditions, channel bottom composition, water temperature and thermal stratification (density), channel gradients, etc. must all be considered before selecting/calibrating survey equipment and methods. The intended level of accuracy in the horizontal and vertical directions is also a consideration. COE guidance identifies three classifications of surveys.[1] Class I surveys are the most accurate (designed for contract payment) with a maximum measurement error not to exceed +/- 3 meters in the horizontal and +/- 15 cm in the vertical. Class II surveys are of intermediate accuracy (designed for determining project conditions) with a maximum measurement error not to exceed +/- 6 meters in the horizontal and +/- 30 cm in the vertical. Class III surveys are intended for site reconnaissance. All long-term Lower Fox River surveys presented are either Class I or Class II. The 1977 and 1982 surveys were Class II surveys. The 1990, 1993, 1997, and 1998 surveys were Class I surveys.

3.2.1 Pre-Processing of Long-Term Data

Because the COE uses their sounding data to determine areas of the navigation channel requiring dredging, the data collected are processed to provide specific information for dredge operations. The high-density sounding data yields over 100 points per range line. For example, 150 sounding points were collected during the COE 1997 profiling of Lower Fox River range 324+00. This averages to one sounding for every 0.7 meters (2.2 feet) of the cross-channel distance. These high-density data must be reduced to plot the soundings at the 1:1200 scale of the channel

[1] Recent COE guidance presents accuracy performance standards for each survey classification as a function of water depth (Table A-1, EC 1130-2-210, 1 October 1998).

condition charts. Data reduction is performed using automated mapping software by selecting the individual data values on or nearest to every 3.05 meters (10 feet) of range line distance. This 3.05 meter distance was selected by the Kewaunee COE Area Office because it adequately defines the navigation channel condition while still being readable at the 1:1200 chart scale. The end products of this data reduction process are hardcopy, 1:1200-scale charts of the Lower Fox River navigation channel from the DePere turning basin to the outer bay harbor that show water depths along sounded range lines.

Both digital and hard copy formats of the channel soundings were provided by the COE. Digital data were available for three years (1996 through 1998). Hardcopy channel condition charts used were available for the years 1977 through 1998. Although channel condition charts exist back to the late 1800s, only those charts from 1977 and later were used because the procedural accuracies of the data collection methods are known and the dredge history of the navigation channel during this time frame is well-documented. Table 2 lists the dates, methods, equipment, and associated accuracies for procedures that the COE used to create the channel condition charts in this study.

A total of 15 COE range lines downstream of DePere dam was chosen for cross-sectional plotting and temporal comparison. Selection of these range line locations was based on three key considerations: dredge history, location within water quality model water column segments (to facilitate model evaluation), and proximity to short-term (USEPA) transect locations. To document changes of the sediment bed elevation over a period of years and decades, it was essential to focus on areas where no dredging occurred within the study time period of 1977 through 1998. In addition to the river reach between the DePere dam and the Fort James turning basin, additional downstream reaches without dredging activity were identified by consulting Table 1. The locations of the selected long-term COE range lines and the short-term USEPA transects are shown in Figure 3. Because a 61 meter (200 feet) interval between range line data collection stations was used for the 1977, 1982, and 1990 soundings, nine of the 15 long-term transect comparisons contain profiles interpolated by averaging the neighboring range soundings (Table 3).

Transformation of 1:1200 scale, hard-copy COE channel condition charts to digital form was performed by first dividing the scaled range line length by the number of plotted depth sounding points so as to determine the average distance between points. For 1990, 1993, 1997, and 1998, the average scaled distance between plotted points is three meters (10 feet). For 1977 and 1982 sounding sheets, a point to point plot distance of six meters (20 feet) was used because map sheets prior to 1984 were drafted at 1:2400 scale. This distance was likewise confirmed by scaled map measurements. All COE map data were converted to digital form and then transformed from standard to metric (feet to meters) units of measure in the horizontal (across-river) and vertical (depth). Water depth measures were transformed to sediment bed elevations by referencing them to the International Great Lakes Datum (IGLD) of 1955.

3.2.2 Analysis of Long-Term Data

While the shapes (and therefore locations) of the banks of the Lower Fox River have changed over time as a result of shoreline development and other engineered modifications, the location of the navigation channel has not changed. To determine the absolute starting point of each range line transect, scaled distances were measured from the first plotted point on the range line to the charted navigation channel boundary. These distances were subtracted from the distance between the present left river bank to the left navigation channel boundary, thereby marking the "distance from left bank" beginning of each plotted range line. Once relative chart lengths were converted to absolute scaled distances, the selected range lines were plotted using spreadsheet graphics. Plotting the same range lines over the six study dates (1977, 1982, 1990, 1993, 1997, and 1998) resulted in time-dependent cross sectional profiles of the navigation channel.

In addition to the graphical plots of the navigation channel, a channel width-weighted average area (cumulative trapezoid) method was used to determine the average elevation changes between sediment bed profiles, such that:

$$E = \frac{\sum_{i=1}^{n-1}\left[\left(L_i - L_{i+1}\right)\left(\frac{D_i + D_{i+1}}{2}\right)\right]}{L_n - L_1}$$

where: E = Average elevation of sediment bed (m)
L = Distance along transect (m)
D = Elevation of sediment bed at distance L in channel transect (m)
n = Number of points in range line that define the transect

Maximum bed elevation changes were also quantified by comparing year-to-year sounding measures at specific locations within the navigation channel.

3.3 Short-Term Transect Data

In 1994, the USEPA Large Lakes Research Station (LLRS) initiated a hydrographic study of the Lower Fox River to very precisely measure sediment bed elevation changes over short time frames (months) as well as to map the general topography of the sediment bed. This work included four site visits over a 16 month time period.

A 21-foot Boston Whaler boat, outfitted with a mid-ship catamaran containing an Odom Echotrac DF3200 dual frequency acoustic transducer (6° beam) operated at 200 kHz, was used to conduct bathymetric surveys at 12 locations throughout the lower 19 kilometers (12 miles) of the Lower Fox River. A Trimble 4000 DS real-time differential GPS receiver with Trimble Hydro navigation and mapping software was used for navigation and logging real-time positions and depths during the sonar scans. Transects were run perpendicular to the river banks at five locations upstream of the DePere dam and seven locations downstream of the dam. Surveys were conducted during May 1994, November 1994, and August 1995. Three transects sites downstream of the DePere dam (Transects 3, 5, and 6) were also surveyed in July 1994. Following a pre-established target line, each transect was surveyed with multiple runs using the waypoint navigation features of the GPS software. Water levels were referenced from nearby accessible surveyed benchmarks such as docking bollards or bridge abutments prior to, and at the completion of, each set of transect runs. These measurements were used to adjust the recorded soundings to a common reference datum (i.e. International Great Lakes Datum 1955).

In addition to the 12 transect runs, the LLRS survey crew mapped the general topography of the sediment bed by dividing the river study area into 24 sectors and running continuous sounding lines across the river throughout each sector. Tie lines were then run perpendicular to these sounding lines (cross lines). This information was used to examine the spatial heterogeneity in sediment bed elevations by comparing bed elevations located within a one meter radius of the intersection of the tie lines and cross lines. Results of the topography survey point comparison are presented in Section 5.

All data were recorded digitally as time (UTC), location (Wisconsin State Plane Coordinates), and bathymetry (referenced to IGLD 1955), and verified for accuracy by conducting regular checks of the remote sensing equipment. Transducer calibration bar-checks were conducted daily, unless sea-state (water surface fluctuations) conditions were severe. Bar-checks were conducted by means of an expanded metal plate lowered on incremented chains to a two meter depth and then to the maximum depth encountered at any single cross-section of the river (up to 5 meters maximum depth). The incremented depths were checked against the depth as computed from the sonar signal return. These checks showed sonar operations to be within the manufacturer's stated precision of 0.01 meters (0.03 feet). Quality checks of the GPS real-time differential corrections were also conducted each day by comparing the coordinates received by the shipboard GPS receiver to COE survey controls on shore. These checks were consistent with the manufacturer's stated limits of real-time kinematic survey accuracy. These accuracies were +/- 1 to 3 meters for 1994 surveys and sub-meter for 1995 surveys. The accuracy change represents a change in operations to a stronger base station transmitter used during the 1995 survey. The data were approved for Quality Assurance and Quality Control by USEPA.

3.3.1 Pre-Processing of Short-Term Transect Data

USEPA coordinate data were inversed (converted to range/azimuth information) and used to verify horizontal distances listed for each sounding point. The coordinates were also used to compare sounding locations with reference to the target range lines. Sediment bed elevations collected by the USEPA were referenced to the IGLD, 1955. The reference to the IGLD 1955 datum was verified by comparing elevations to those established on navigational charts for the Lower Fox River (NOAA, 1992).

Each transect was comprised of high-density data from multiple profiling runs for data redundancy. To reduce these data, same-date profile runs were treated as a single data set. A method was then established to filter the individual data points to those collected closest to the target line. All recorded sounding points falling within five meters (16 feet), three meters (10 feet), and one meter (3.3 feet) of the target line were selected. All three perpendicular-offset data sets were then plotted to determine which set resulted in the most complete cross-sectional profile (Table 4). Vertical "noise" in the cross-sectional plots is caused, in part, by the spatial heterogeneity of soundings not precisely located on the target transect line but that fall within the 1, 3, 5 meter offset distances used in data reduction. This "noise" was minimized by averaging inter-point distances and associated elevations. The filtered data were used to construct the representative survey profile transect for each study date. By treating the same-day profile runs as a single data set, this data pre-processing procedure eliminates the potential for introducing error that might occur if the data for each individual profile run were directly averaged without regard to horizontal position.

3.3.2 Analysis of Short-Term Transect Data

The filtered, short-term elevation data were used to generate plots of cross-sectional profiles at six of the seven surveyed locations downstream of DePere dam (T3, T5, T6, T7, T8, and T9). Transect T4 was not analyzed because the navigational channel at that location was dredged during the study period. The filtered survey profiles for the six remaining transects were plotted to determine if differences in sediment bed elevation occurred during the 15 month study period. Like the long-term transect data, average bed elevations were estimated by channel width-weighted area calculations for each profile. Bed elevation differences were computed for three divisions of the cross-section width as well as for the entire cross-section width. The divisions were: 1) left bank to left channel margin; 2) left channel margin to right channel margin; and 3) right channel margin to right bank. Maximum elevation differences within each division were also recorded. The significance of short-term differences in observed sediment bed elevation was assessed by comparing those differences to the spatial heterogeneity of the observations and the accuracy of the sounding equipment. Further description of this assessment is presented in Section 5.

3.4 Confirmatory Transect Data

Beginning in 1989, the USGS Water Resources Division conducted a sediment bed elevation study of the Lower Fox River from the DePere dam to the river mouth. This study had two objectives. The first objective was to determine if slumping occurred along the steep edges of the navigation channel. The second objective was to determine if scouring and filling of the sediment bed could be measured.

Like the COE and USEPA efforts, the USGS used acoustic methods to survey the river at designated ranges. The USGS range line locations are presented in Figure 4. Ranges were surveyed five different times over an eight year period: October 1989, September 1990, May 1991, January 1992, and September 1996. A 14 foot John Boat equipped with a Lorance depthfinder was used for each survey. Navigation along the ranges was performed by choosing shore-based waypoints (e.g., light poles, smoke stacks, water towers, etc.) and piloting between them. Relative vertical control was maintained by measuring water levels from shore-based references (steel piling corners, dock edges, etc.) at the beginning of each transect group.

Special care was taken to keep boat speeds constant during transect runs so as to make the plotted scales of horizontal (cross-river) distances comparable between site visits. Sounder accuracy was maximized by adjusting the depth settings according to the maximum water depth at each profile run, and daily calibrations and checks confirmed the manufacturer's stated accuracy of 2% to 3% of the depth setting. Result summaries and hardcopies of sounder graph printouts were compiled by the USGS.

All pre-processing of confirmatory transect data was performed by the USGS Water Resources Division in Madison, Wisconsin. Information provided with the study results does not detail the specific procedures used to pre-process these data. All analyses of confirmatory transect data were also performed by the USGS. Information provided with the study results does not detail the specific procedures used to pre-process or analyze these data. Comparison of sounder plots, adjusted for measured water level differences, was performed to confirm the transect elevation changes cited in the USGS study results. Transects GS-13 and GS-14 were surveyed only once over the study period. As a result, soundings at these transects could not be compared to any earlier soundings.

4.0 RESULTS AND DISCUSSION

4.1 COE Dredge Data

A summary of dredge locations, the volume of material dredged, and disposal sites for the Lower Fox River downstream of the DePere dam and Green Bay harbor for the period 1957 though 1998 is presented in Table 5. It is significant to note that although the Bayport CDF was the disposal site for the majority (60%) of dredged material during this period, nearly one quarter (24%) of the total spoils were disposed in open water locations. This is significant because open water disposal of dredge spoils occurred during a period believed to coincide with the peak use (and discharge) of polychlorinated biphenyls (PCBs) in the Lower Fox River. More than 3.1 million cubic meters (4.1 million cubic yards) of potentially PCB contaminated material was disposed in open water locations.[2] Open water disposal may represent a potentially significant PCB transport pathway.

Sediment volume differences for each COE channel condition chart downstream of the DePere dam are presented in Table 6. It is important to note that even over large areas (each chart cover 1000 to 4000 feet of the navigation channel length), overall scour and fill are observed. Presentation of sediment volume differences averaged over large areas does not indicate the full magnitude of the spatial and temporal dynamics of sediment bed elevation changes. Data for each analyzed transect shows the spatial and temporal complexity of these sediment bed elevation changes. While sediment volume differences for a given chart may indicate a net loss or gain of sediments (over the entire area) of a few centimeters, sediment bed elevation changes at individual sites (transects) can differ in magnitude and direction by more than an order of magnitude or more. For example, between 1993 and 1997 there was a net sediment bed elevation loss of approximately 0.5 cm for the area covered by Chart 19. In this chart area at Transect 324 + 00 there was an average sediment bed elevation loss of 17 cm. However, during this same time period, over the area covered by Chart 17 there was a average elevation loss of 5 cm with a average elevation gain of 3 cm at Transect 237+ 00.

4.2 Long-Term Transect Data

Long-term, cross sectional profiles of the Lower Fox River navigation channel from the DePere turning basin to the river mouth are presented in Appendix A. The spatial and temporal differences between these plots indicate magnitude and variation in sediment bed elevation dynamics. A summary of these changes, listing average and maximum elevation differences in the navigation channel, is presented in Table 7.

The long-term transect data show both gains and losses (fill and scour) (Figures 1A through 15A) as well as some lateral migration of the navigation channel over time (Figures 1A, 6A, 8A, and 13A). Although both sediment bed elevation gains and losses occur, these conditions are not

[2] Note that 73% of the total amount of sediment disposed in open waters originated from navigational channel deepening in Green Bay. According to COE staff, the majority of this sediment should be considered “virgin” material uncontaminated by PCBs (D. Zande, 1999, personal communication).

uniform in space or time. Across time, channel edges may show fill while during the same time period the thalweg may show scour (Figure 2A, for example). As a result, average channel elevation differences over time can be relatively minor, while point elevation differences in the same cross-section can be extreme.

Long-term sediment bed elevation patterns do not exhibit spatial continuity across all transects for any single time interval. Although some individual transects (e.g. Transect 324 + 00) show temporal continuity (i.e. consistent scour or fill), scour and fill patterns alternate from transect to transect and time to time. Alternating scour and fill patterns are most likely the response of the sediment bed to differences in local water velocities (caused by differences in channel morphology) and sediment loads. Overall, sediment bed elevation losses occur immediately downstream of DePere dam. As water flows past Voyager Park, water velocities decrease and sediment bed elevations increase. Although the width of the navigation channel remains constant, overall river width decreases significantly in the area of the DePere wastewater treatment plant, and sediment bed elevations decrease throughout this reach. Downstream of this point, the river widens (water velocities decrease) and there is sediment input from Ashwaubenon Creek. However, despite these factors, there is a varied pattern of scour and fill at this site (Transect 294 + 00); overall more scour occurs and an average 40 cm decrease in sediment bed elevation was observed at this location between 1977 and 1998. Near the Wisconsin State Highway 172 bridge crossing (Transect 272 + 00), significant scour occurs. Sediment bed elevation losses here may be in response to the hydraulic influence of the bridge piling which are located on each side of the navigation channel (constricting the channel area and increasing water velocities). Further downstream near Cooke Park (Transect 237 + 00), the river widens to its maximum extent and sediment bed elevations increase. Further downstream near the Fort James Company plant, the river narrows and sediment bed elevations decrease. Just downstream of this area (1200 feet downstream), sediments bed elevations typically increase in the Fort James turning basin.

Downstream of the Fort James turning basin, there are differences in both the river and navigation channel. The river width decreases to less than half of its upstream dimensions, resulting in a higher ratio of navigation channel to river width (6:11 downstream of the turning basin, compared to 4:35 upstream). Channel depths increase from 6 meters (19 feet) to 8 meters (26 feet). There are no tributary inputs until the East River confluence 2.1 kilometers (1.3 miles) upstream of the river mouth. Unlike the reach upstream of the turning basin, the river banks in this reach have been straightened and consist of concrete bulkheads or steel sheet-piling. Between the Fort James turning basin and the East River, sediment bed elevation changes in the navigation channel are influenced by these factors.

From the Fort James turning basin to the river mouth (and into Green Bay), the COE maintains the navigation channel by dredging in areas where sediments accumulate and interfere with commercial ship traffic. Although the navigation channel between the Mason Street and Walnut Street bridges is part of the maintained channel, dredging has not occurred here since 1985. In this reach, long-term net accumulation of sediment has not been observed. Transects 117+00 and 104+00 (Figures 10A and 11A) show scour and fill across the entire channel width while over the

22 year period of observations, Transect 117 + 00 has 1 cm of net sediment loss and Transect 104 + 00 has 9 cm of net gain. However, Transect 91+00 (Figure 12A) shows spatially and temporally variable channel profiles. Transect 91 + 00 is located between the Walnut Street and Dousman Street bridges. Ships traveling the river navigate between these bridge crossings without the aid of tugboats. As a result, the force of propeller and thruster wash has the potential to cause extreme disturbances in the sediment bed (Darrel Pederson COE, personal communication).

Downstream (1700 feet downstream) of the Dousman Street bridge, the East River joins the Lower Fox River. The river is wider here relative to the reaches immediately upstream or downstream. The East River turning basin is located at this wider area. Delta-like sediment deposition occurs here as a result sediments entering the Lower Fox River from the East River. Occasional dredging is required to maintain the turning basin and channel to navigable depths. Transect 61+00 (Figure 13A) is located within the turning basin and shows a pattern of net sediment bed elevation increase.

Longitudinal (downstream) profiles of the average sediment bed elevations in the navigation channel were constructed for the six years highlighted in the 22 year study period (1977, 1982, 1990, 1993, 1997, and 1998). These profiles are presented in Figure 5. The profiles presented do not include areas where the river has been dredged during the 22 years examined. In the absence of dredging, the profiles demonstrate the spatial and temporal complexity of sediment bed elevations dynamics attributable to natural fluvial processes. The profiles clearly show that average sediment bed elevation changes vary in both space and time. The magnitude of these variations range from a net gain of approximately 30 cm to a net loss of more than 60 cm. Maximum sediment bed elevation changes are more variable and extreme and range from a gain of nearly 80 cm and a loss of almost 200 cm. Sediment bed elevation changes in the navigation channel are presented in Table 7.

4.3 Short-Term Transect Data

Short-term, cross sectional profiles of the Lower Fox River from DePere to the river mouth are compiled in Appendix B. These profiles include transect areas outside the navigation channel. As computed for the long-term data, the spatial and temporal differences indicate elevation changes in the sediment bed. A summary of these changes, listing average and representative point elevation differences for the three cross-section divisions and the entire transect are presented in Table 8.

The short-term transect data show both gains and losses (fill and scour) (Figures 1B through 11B). Because the time period covered by these data is relatively short (16 months), lateral migration of the navigation channel is not as pronounced as was observed in the long-term data. Scour and fill of the sediment bed occurs over the entire river width. The magnitude and direction of sediment bed elevation changes outside the navigation channel are similar in scale to those observed inside the channel (Figures 7B and 9B, for example).

Short-term deposition and erosion patterns do not exhibit spatial continuity across all transects for any single time interval. However, over the full 16 month period studied, the transects show a consistent pattern of net sediment accumulation. That is, all transects show an average and maximum net increase in the sediment bed elevation. However, the apparent magnitude and direction of these observations may be influenced by uncertainties in horizontal location between same-transect profiles (i.e. spatial rather than temporal variation). Discussion of uncertainty issues is presented in Section 5.

At locations where short-term and long-term transects were located within close proximity, sediment bed elevation profiles were compared. Differences in both magnitude and direction are evident at some locations (Figures 3B and 4A, Figures 10B and 8A). It is not known whether these differences are due to the spatial heterogeneity of bed elevations between the transect locations or due to the variable frequency and magnitude of sediment bed elevation gains and losses occurring at these locations over the studies time intervals.

Longitudinal (downstream) profiles of the average sediment bed elevations in the navigation channel were constructed for the 4 months highlighted in the 16 month study period (May 1994, July 1994, November 1994, and August 1995). These profiles are presented in Figure 6. The profiles presented do not include areas where the river has been dredged during the 16 months examined. The profiles demonstrate that even at relatively small time scales, spatial and temporal variations in sediment bed elevations occur. The magnitude of these short-term variations range from a net gain of nearly 40 cm to a net loss of approximately 20 cm. Maximum short-term sediment bed point elevation changes are also more variable and extreme. These point changes range from a gain of nearly 75 cm and a loss of over 100 cm. Short-term sediment bed elevation changes in the navigation channel are presented in Table 8.

4.4 Confirmatory Transect Data

Results of confirmatory transect data collected by the USGS are presented in Table 9. In general, these data support the spatial and temporal trends and patterns observed in the long-term and short-term bed elevation data. The confirmatory data indicate that deposition and erosion patterns vary in both time and space. Some of the confirmatory transects (e.g. GS-5 and GS-7) suggest that between surveys sediment bed elevations increased in portions of the profile and decreased in other potions of the same transect. However, the summary information from this study suggests that a consistent pattern of net sediment bed elevation loss occurred during the eight month period May 1991 to January 1992. The study summary cites elevation changes that occurred outside as well as within the navigation channel. Changes within the channel were noted to be greater on average than changes outside the channel. This pattern was noted for Transects GS-1, GS-4, and GS-7. An observation made during the November 1990 survey of location GS-12 is of particular note. A grounded ship gouged a large (21 meters wide by 1.8 meters deep) trench into the east side of the navigation channel. This extreme cut was noted to have been entirely filled by the January 1992 survey, even though net erosion in the navigation channel was observed at this time.

At locations where short-term, long-term, and confirmatory transects were located within close proximity, sediment bed elevation profiles were compared. Sediment bed elevation changes indicated by the confirmatory transect information are nearly twice as large as those observed in the short-term transect data for similar time intervals and approach the magnitudes changes observed in the long-term data. However, it could not be determined whether these differences are due to the spatial variability of bed elevations between the confirmatory, short-term, and long-term transect locations or uncertainty in horizontal and verticals measurements caused by the lower accuracy and resolution of the equipment used to collect these data. Discussion of uncertainty issues is presented in Section 5.

5.0 UNCERTAINTY

Sediment bed elevation interpretations are affected by uncertainty attributable to data collection methods (horizontal and vertical measurement error) as well as uncertainty introduced by data handling (aggregation and filtering) procedures. Uncertainty attributable to data collection methods affects the interpretation of spatial and temporal trends in field observations of sediment bed elevations and cannot be minimized through optimization of interpretive procedures. In this study, uncertainties in horizontal and vertical location are attributable to the accuracy limits and resolution of the equipment and procedures used during data gathering. The greater the level of spatial heterogeneity and temporal variability in the sampled river bed elevations, the more influence uncertainties attributable to data collection and analysis have on the assessment of sediment bed elevation dynamics. The COE Hydrographic Surveying Manual (1994) provides a comprehensive overview and analysis of potential horizontal and vertical measurement errors and associated uncertainties.

5.1 Uncertainty in Horizontal Positioning

Uncertainty in horizontal positioning measurements of the sediment bed is also attributable to the accuracy of the navigation equipment used in the individual studies and the nature of navigation procedures. Factors that affect the accuracy of horizontal position measurements are described in the COE Hydrographic Surveying Manual. These factors include: instrument calibration, survey vessel motions (e.g. pitch and roll affecting the position of the GPS transceiver antenna), offsets between the GPS transceiver and the depth sounding transponder, and radio signal interference.

For the long-term and short term data collection efforts, the reported accuracy of the GPS equipment were checked and verified by the data collectors on multiple occasions throughout period of data acquisition. These checks involved comparison of survey-based and GPS-based locational coordinates to established geodetic survey controls. In this manner, the performance and accuracy of navigation equipment was quantified and data quality assured. The navigation methods used to collect the confirmatory data was the least accurate as it did not include a means to track or record absolute coordinate positions. To confirm horizontal positions during confirmatory data acquisition, transect runs were repeated and the precision with which transect profiles were reproduced was used to infer positional accuracy. The horizontal positioning accuracy of the long-term and short-term data sets was far more carefully quantified as absolute coordinate measurements are associated for each point where soundings were collected. The horizontal accuracy of the 1977 and 1982 long-term data was +/- 3 meters. The horizontal accuracy the 1990, 1993, 1997, and 1998 long-term and the short-term data was +/- 1 meter.

Long-term and short-term data were collected in a manner to minimize potential horizontal measurement errors attributable to causes other than the sensitivity (detection limits) of the GPS equipment. Although difficult to quantify, these other sources of potential error can contribute to the overall uncertainty of horizontal measurements. For this reason, the overall uncertainty in horizontal measurements may exceed the measurement uncertainty associated with the GPS equipment. This issue is explored in Section 5.4. In contrast, the confirmatory data collection effort was not subject to the same rigorous control/minimization of potential horizontal measurement errors. As noted in Section 3.4, horizontal positioning for the confirmatory data was based on visual navigation between shore-based waypoints. Although unquantified, this approach has the potential for more significant error. As a result, the confirmatory data are more qualitative (describing general trends) than quantitative. Further discussion of the overall uncertainty of measurements is presented in Section 5.4.

5.2 Uncertainty in Vertical Positioning

Uncertainty in vertical positioning measurements (i.e. elevations) of the sediment bed is attributable to the accuracy limits of the sounding equipment used in the individual studies and the nature of data collection procedures. Factors that affect the accuracy of vertical position measurements are described in the COE Hydrographic Surveying Manual. These factors include: instrument calibration, water levels, water temperature, sediment bed composition, and elevation gradients (slope) of the sediment bed.

In all studies, the accuracy of all equipment used was confirmed by the data collectors to be within acceptable limits for the instrument. The standard method to confirm the accuracy of sounding equipment is the bar check. These checks compare manually sounded water depths to water depths as measured by the automated equipment. In this way, the accuracy of equipment performance and operations is quantifiable and data quality assured. The limit of accuracy of the confirmatory data was +/- 15 cm for the Lorance sounder used by the USGS for cross-section soundings. Of all the data used in this study, these data have the greatest uncertainty in vertical positioning measurement. Sediment bed elevation changes presented in the confirmatory data summary information ranged a 61 cm loss to a 70 cm gain. Even in consideration of this limit of accuracy, the confirmatory data is still useful for documenting the direction and relative magnitude of sediment bed elevation changes. Thirty-five of forty-nine (71%) summary observations presented exceed the 15 cm threshold for successful measurement. The accuracy of long-term and short-term vertical positioning measurements at least equals (1977 and 1982 COE surveys) and most often greatly exceeds the accuracy of the confirmatory data.

Long-term and short-term data were collected in a manner to minimize potential vertical measurement errors attributable to causes other than the sensitivity (detection limits) of the sounding equipment. Although difficult to quantify, these other sources of potential error can contribute to the overall uncertainty of vertical measurements. For this reason, the overall uncertainty in vertical measurements may exceed the measurement uncertainty associated with the sounding equipment. In contrast, the confirmatory data collection effort was more simple in design and execution. Unlike the other data sets, the confirmatory data were not subject to the same rigorous control/minimization of potential vertical measurement errors. Although unquantified, these potential errors contribute to the overall uncertainty of vertical measurements. As a result, the confirmatory data are more qualitative (describing general trends) than quantitative. Further discussion of the overall uncertainty of measurements is presented in Section 5.4.

5.3 Uncertainty Introduced During Data Handling Operations

Additional uncertainty in the analysis of sediment bed elevation data may be introduced during data handling operations. To minimize the extent to which accuracy limitations in positioning confound efforts to identify spatial and temporal differences in sediment bed elevations, data must be gathered for the exact transect location each time a range is surveyed. Absolute sediment bed elevations can vary considerably from point to point. Deviations from the exact transect line is a component of uncertainty because of the spatial heterogeneity of sediment bed elevations that may occur at a site.

The short-term transect data has the potential for sediment bed elevation measurement uncertainty due to horizontal offsets from target range lines. To minimize this potential, the short-term data were filtered so that only those observations falling within a set distance from the target line were used to construct bed elevation profiles. A comparison of the filtered, short-term bed elevation data shows that for transect runs with elevation soundings located at +/- one, three, and five meters from the target line, average elevations vary between 1 and 10 centimeters. To refine comparisons of short-term bed elevation changes, average elevation differences attributed to target-line offset is as follows: T9: +/- 10 centimeters; T8: +/-5 centimeters; T6: +/- 4 centimeters; T5: +/- 3 centimeters; and T3: +/- 3 centimeters. Transect T7 was considered less reliable as the majority of observations were offset more than five meters from target line. Even in consideration of this potential uncertainty, the short-term transect data are still considered accurate since the sediment bed elevation changes measured typically exceeded the variability potentially introduced by observations that did not fall precisely along the target range line for the transect.

The long-term transect data has minimal potential for sediment bed elevation measurement uncertainty due to horizontal offsets from target range lines because of the navigation systems, equipment, and experience of COE survey crews. To minimize this potential uncertainty, the COE collects data with such high-density that a sufficient number of observations that fall precisely on the target range line is assured. Transect lines presented on COE channel condition charts are derived from these high-density data and provide the most accurate representation possible. However, during some surveys of the navigation channel between the DePere dam and the Fort James turning basin, the COE sometimes collected data at 200 foot intervals rather than the 100 foot interval used for the channel downstream of the Fort James turning basin. While each individual transect line may be considered essentially free from horizontal positioning uncertainty (i.e. limited only by the accuracy of the positioning equipment), in some years data were only available for transects located 100 feet upstream and 100 feet downstream from the transects lines presented for year-to-year comparisons of sediment bed elevations upstream of the Fort James turning basin. In these situations, the sediment bed elevations 100 feet upstream and 100 feet downstream of the target transect line were averaged to allow comparisons. Data averaging may introduce uncertainty into computed sediment bed elevation changes.

The magnitude of this potential uncertainty was assessed by computing differences due to the averaging of neighboring COE range lines was determined by comparing predicted (averaged) range elevations to measured sounding at random range locations on each channel condition chart used in the study. On average, predicted elevations varied from actual elevations by 12 centimeters. The maximum potential uncertainty introduced by averaged long-term data is smaller than the typical magnitude of observed sediment bed elevation changes. The average observed sediment bed elevation change (i.e. the average of the average change for each transect examined) was more than 15 centimeters; the average maximum change was nearly 31 centimeters. It is important to note that this potential uncertainty only applies to those few transects where data averaging was performed (identified in Table 3).

5.4 Overall Uncertainty in Hydrographic Survey Project Data

The overall uncertainty associated with hydrographic survey project data may potentially exceed the uncertainty in horizontal and vertical positioning instrument readings. Potential sources of uncertainty are described in the COE Hydrographic Surveying Manual and include: instrument calibration, survey vessel motions, offsets between the GPS transceiver and the depth sounding transponder, radio signal interference, water levels, water temperature, sediment bed composition, and elevation gradients (slope) of the sediment bed.

COE guidance provides a detailed assessment of potential horizontal and vertical measurement error sources. The guidance also describes equipment selection, instrument calibration, navigation, and verification procedures designed to minimize potential errors. In addition, the guidance establishes the maximum overall error permitted for any class of hydrographic survey. COE guidance identifies three classifications of surveys. Class I surveys are the most accurate with a maximum measurement error not to exceed +/- 3 meters in the horizontal and +/- 15 cm in the vertical. Class II surveys are of intermediate accuracy with a maximum measurement error not to exceed +/- 6 meters in the horizontal and +/- 30 cm in the vertical. Class III surveys are intended for site reconnaissance. All long-term data are either Class I or Class II surveys. The 1977 and 1982 surveys were Class II surveys. The 1990, 1993, 1997, and 1998 surveys were Class I surveys. All short-term data were conducted with equipment and procedures similar to those used for Class I surveys. Based on consideration of operating conditions and procedures, the short-term data are considered to be equivalent to Class I surveys for the purposes of this uncertainty assessment. As previously noted, all confirmatory data are more qualitative in nature. Based on consideration of operating conditions and procedures, the confirmatory data are considered to be equivalent to Class III surveys for the purposes of this uncertainty assessment.[3] Appropriate Class III survey maximum measurement errors are not to exceed +/- 100 meters in the horizontal and +/- 45 cm in the vertical (one sigma error).

Vertical measurement accuracy is arguably the most important aspect of efforts to determine changes in sediment bed elevations. While small horizontal positioning errors may not appreciably

[3] Performance standards for each survey classification have changed over time. For surveys conducted using the equipment and procedures described in the 1998 Engineering Circular for Hydrographic Surveying, there is little distinction in accuracy between Class II and Class III surveys (EC 1130-2-210, 1 October 1998). However, the confirmatory data were collected under conditions more representative of Class III surveys as described in the 1991 Engineering Manual for Hydrographic Surveying (EM 1110-2-1003, 28 February 1991).

affect the interpretation of hydrographic surveying data, small vertical measurement errors may have a proportionately greater effect. The analysis that follows therefore focuses on sources of potential vertical measurement error. Discussion of the largest potential error sources associated with vertical measurements is presented below.

The long-term, short-term, and confirmatory data sets were collected using acoustic sounding (depth measuring) equipment. Acoustic sounding techniques function by transmission of sound waves through the water column. When transmitted sound waves strike a submerged surface such as the sediment bed (or metal plates used for bar checks), the sound waves reflect (bounce) off that surface. The depth to the reflecting surface is determined from the elapsed time between signal transmission and return of the first reflected signal and the speed of sound in water.

The speed sound waves travel in water is affected by water temperature (which affects density). Water temperatures (densities) may vary with water depth, especially in deeper waters or other areas where strong thermal gradients exist (such as the thermocline). This potential error is addressed and minimized through sounding instrument calibration procedures (the bar check). Bar checks for the long-term and short-term survey data were performed at a series of water depths and included the full range of waters depths encountered during the survey.

Sediment bed composition also affects sounder return time and signal strength. Areas where bed composition is predominated by “soft” materials, may appear as “fuzzy” bands in the sounding record. Potential error caused by this condition is addressed and minimized through calibrating the sounding instrument sensitivity such that the first returned signal, which may be weak due to scattering at the sediment-water interface, is recognized as the sediment surface instead of signals which may return with greater strength but more time delay after reflecting off materials beneath the true sediment-water interface. Sounding sensitivity calibrations for the long-term and short-term data were performed to account for the occurrence of soft sediment materials in the project area. For the long-term data, additional calibration and verification was sometimes performed by comparison to mechanical depth measurements.

As noted in the COE guidance, vertical measurement errors are possible in areas where elevation gradients (slopes) of the sediment bed exist. The navigation channel sides often have significant elevation gradients (grades of more a few percent). Channel side slope areas therefore represent regions where the potential for vertical measurement error is greatest. In these situations, the maximum vertical measurement error possible is equal to one half of the elevation difference between the start and end points of the projected footprint of the sounding transducer beam on the slope face. The transducer beam footprint (and therefore potential error) increases with beam angle, slope, and water depth. For the locations analyzed, Transect 37 + 00 has the greatest slope encountered. The slope at this site is a 30% grade (computed as rise over run). This corresponds to a 17° angle of the navigation channel side slope. The worst case condition is for water depths of 7 meters (23 feet) (approximately the greatest water depth encountered). For the Class I long-term surveys, a 3° beam was used. The maximum possible vertical measurement error due to the slope under this condition is 6 cm (0.2 feet). The maximum error for a Class I survey for waters

15 to 40 feet deep is 30 cm (1 foot). This maximum potential error attributable to slope is much less than the standard for Class I surveys. For Class II long-term surveys, an 8° beam was used. The maximum possible vertical measurement error under this condition is 15 cm (0.5 feet). The maximum error for a Class II survey for waters 15 to 40 feet deep is 60 cm (2 feet). Again, this maximum potential error attributable to slope is less than the standard for Class II surveys. For the short-term surveys, a 6° beam was used which results in a maximum possible error due to channel slope of 12 cm (0.4 feet). The maximum slope error for the short-term surveys is well within the standard for Class I surveys.

The maximum potential errors described represent the worst case condition for the maximum slope encountered. The scale of potential errors decreases as transducer beam angle, slope, and water depth decrease. Since channel slopes (and water depths) are typically much less than the situation examined above, the maximum potential vertical measurement error at most sites will be considerably less than the worst case value. In no situation does the potential vertical measurement error attributable to elevation gradients approach even 50% of the maximum allowed error for the applicable survey classification.

Note that COE hydrographic survey guidance describes the maximum allowed error for any given survey class. While site-specific or survey-specific conditions have the potential to cause deviations from these error standards, accuracy levels exceeding these standards may be achieved with careful planning and quality management. In consideration of the full range and magnitude of potential horizontal and vertical measurement errors, the long-term and short-term data are appropriate for quantitative use to the limits of the accuracy standards identified in COE hydrographic surveying guidance for Class I and Class II surveys. The confirmatory data are best suited for describing the general trend and magnitude of sediment bed elevation changes and may be used qualitatively or semi-quantitatively. The accuracy of the confirmatory data is representative of Class III surveys defined in the 1991 COE guidance. For convenience, a summary of the applicable accuracy standards for these data is presented in Table 10.

6.0 REFERENCES

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Table 1: Lower Fox River COE Dredge History 1957-1998, Lake Winnebago to DePere.

Year	*Start*	*Finish*	*yd^3*	*Cost ($)*	*$/yd^3$*	*Dredge Area*	*Placement (Disposal)*	*Performed By*	*Comments*
1966	9/18/65	10/21/65	11,069			Menasha Channel	side cast	COE-Bucket Dredge Winneconne	
1966	10/22/65	10/25/65	284			Appleton Lock 2	side cast	COE-Bucket Dredge Winneconne	
1966	6/30/66		806			above Little Kaukauna Lock (Little Rapids)	side cast	COE-Bucket Dredge Winneconne	
1967	7/1/66	7/2/66	1,509			above Little Kaukauna Lock (Little Rapids)	side cast	COE-Bucket Dredge Winneconne	
1967	7/11/66	7/12/66	300			above Little Kaukauna Lock (Little Rapids)	side cast	COE-Bucket Dredge Winneconne	
1967	7/29/66	7/31/66	325			below Appleton Lock 4	side cast	COE-Bucket Dredge Winneconne	
1967	8/1/66	8/5/66	1,163			above Appleton Lock 2	side cast	COE-Bucket Dredge Winneconne	
1969	10/14/68	10/30/68	5,400				side cast	COE-Bucket Dredge Winneconne	
1974			400			above Little Kaukauna Lock (Little Rapids)	filled along lock		
1977			300			Kaukauna Lock 5	filled along lock		
1983			120			above Appleton Lock 3	filled along lock		

Table 1 (continued): Lower Fox River COE Dredge History 1957-1998, DePere to Green Bay.

Year	*Start*	*Finish*	*yd^3*	*Cost ($)*	*$/$yd^3$*	*Dredge Area*	*Placement (Disposal)*	*Performed By*	*Comments*
1958	5/1/58	5/27/58	15,050			River	Open Water	COE-Bucket Dredge Winneconne	
1959	7/27/59	11/17/59	59,391			River	Open Water	COE-Bucket Dredge Winneconne	
1960			19,554			River	Open Water	COE-Bucket Dredge Winneconne	
1960			16,285			River	Open Water	COE-Bucket Dredge Winneconne	
1961	10/28/61	11/21/61	37,061			River	Open Water	COE-Dipper Dredge Kewaunee	
1961	9/16/61	10/29/61	19,400			River	Open Water	COE-Bucket Dredge Winneconne	
1962	8/15/62	9/15/62	18,185			River	Open Water	COE-Bucket Dredge Winneconne	
1963	6/4/63	7/14/63	118,093			River	Open Water	COE-Dipper Dredge Kewaunee	
1964	5/28/64	6/30/65	50,960	43,512	0.85	River	Open Water	COE-Bucket Dredge Winneconne	
1966	5/5/66	6/29/66	34,330	21,580	0.63	River	Bayport CDF	COE-Bucket Dredge Winneconne	
1966	8/10/66	9/6/66	11,480	14,916	1.3	River	Bayport CDF	COE-Bucket Dredge Winneconne	
1966	11/8/66	12/1/66	376,891	1,239,667	3.29	River	Bayport CDF	Contract- Price Bros. (67-0015)	
1967			50,000	115,687	2.31	River	Bayport CDF	Contract- Price Bros. (67-0015)	
1968	8/16/68	9/15/68	75,600			River	Bayport CDF	COE-Dipper Dredge Kewaunee	
1974			83,618	735,787	8.8	River	Bayport CDF	Contract-Capital (73-0073)	
1978			25,750	188,309	7.31	River	Renard Island CDF	COE-Cranebarge Manitowoc	
1979			145,500	187,200	1.29	River	Bayport CDF	COE-Cranebarge Manitowoc	

Table 1 (continued): Lower Fox River COE Dredge History 1957-1998, DePere to Green Bay.

Year	*Start*	*Finish*	*yd^3*	*Cost ($)*	*$/yd^3$*	*Dredge Area*	*Placement (Disposal)*	*Performed By*	*Comments*
1983	3/30/83	6/24/83	177,831	889,278	5	River	Renard Island CDF	Contract-Roen (DACW35-82-C-0052)	
1985	10/23/85	5/1/86	120,143	1,101,792	9.17	River: 226+00 - 180+00	Bayport CDF	Contract-Luedtke (DACW35-85-C-0068)	
1988	8/15/88	6/2/89	36,521			River: 196+00S - 202+00S, 172+00S - 175+00S,100+00S - 93+00S, 78+00S - 69 + 00S, 20+00S - 80+00N	Bayport CDF	Contract-Roen (DACW35-88-C-0029)	
1989	10/16/89	11/14/89	9,445			River: offloading slip restoration	Bayport CDF	Contract-King (DACW35-89-C-0051)	
1990	10/17/90	11/1/90	46,413	374,828	8.08	River:TB (emergency)	Bayport CDF cell 4 then cell 2	Contract-Roen (DACW35-90-C-0040)	
1992	9/17/92	11/29/92	145,987	1,078,873	7.39	River: 141+00 - 175+30	Bayport CDF areas 4 -> 2 -> 1->3	Contract-Luedtke (DACW35-92-C-0029)	
1993	7/31/93	12/14/93	5,318			River: offloading slip restoration	Renard Island CDF	Contract-Luedtke (DACW35-93-C-0032)	
1994	6/6/94	8/15/94	136,350	1,091,435	7.5	River: 140+00 - 187+84, 0+00 - 10+00B, 60+00B - 70+00B	Bayport CDF cells 4 -> 3 -> 1	Contract-Roen (DACW35-94-C-0021)	
1994	6/6/94	8/15/94	9,214			River: 123+00 - 136+00	Bayport CDF cells 4 -> 3 -> 1	Contract-Roen (DACW35-94-C-0021)	
1994	6/6/94	8/15/94	5,294			River: offloading slip restoration	Bayport CDF cells 4 -> 3 -> 1->2	Contract-Roen (DACW35-94-C-0021)	
1996	8/20/96	11/22/96	29,529			River: 0+00 - 10+00, 19+00 - 33+00	Bayport CDF	Contract-Roen (DACW35-96-C-0020)	
1996	8/20/96	11/22/96	31,662			River: TB	Bayport CDF	Contract-Roen (DACW35-96-C-0020)	
1997	9/15/97	12/9/97	53,174			River: 142+00 - 172+00	Bayport CDF	Contract-Roen (DACW35-97-C-0026)	
1998	Sep-98	Dec-98	10,000			River: TB	Bayport CDF	Contract-Roen (DACW35-98-C-0025)	

Table 1 (continued): Lower Fox River COE Dredge History 1957-1998, Green Bay to outer channel.

Year	*Start*	*Finish*	*yd^3*	*Cost ($)*	*$\$/yd^3$*	*Dredge Area*	*Placement (Disposal)*	*Performed By*	*Comments*
1957	6/14/57	7/7/57	49,800			Bay	Open Water	COE-Dipper Dredge Kewaunee	
1958	6/16/58	8/12/58	143,195			Bay	Open Water	COE-Dipper Dredge Kewaunee	
1961	5/18/61	7/4/61	110,642			Bay	Open Water	COE-Dipper Dredge Kewaunee	
1963	7/15/63	10/13/63	428,543	127,673	0.71	Bay	Open Water	COE-Hopper Dredge Hoffman	
1964			176,029			Bay	Open Water	COE-Hopper Dredge Markham	
1964	7/1/64	8/16/64	426,343	129,898	0.3	Bay	Open Water	COE-Dipper Dredge Kewaunee	
1964	10/29/64	11/13/64	180,664	92,720	0.51	Bay	Open Water	COE-Bucket Dredge Winneconne	
1965	7/8/65	8/15/65	116,681	90,046	0.77	Bay	Bayport CDF	COE-Dipper Dredge Kewaunee	
1966			865,741			Bay	Bayport CDF	Contract- Price Bros. (67-0015)	
1969	9/10/69	10/28/69	664,225			Bay	Open Water	COE-Hopper Dredge Markham	
1970			1,416,690			Bay	Open Water	COE-Hopper Dredge Markham	
1971			940,000	1,338,685	1.42	Bay	Bayport CDF/Open Water	COE-Hopper Dredge Markham	
1972			960,000	1,264,670	1.32	Bay	Bayport CDF	COE-Hopper Dredge Markham	
1972			240,000	117,631	0.49	Bay	Bayport CDF	COE-Hopper Dredge Markham	
1973			100,000	185,800	1.86	Bay	Open Water	COE-Dipper Dredge Kewaunee	
1973			540,000	333,651	0.62	Bay	Bayport CDF	COE-Hopper Dredge Markham	
1973			940,000	1,248,393	1.33	Bay	Bayport CDF	COE-Hopper Dredge Markham	

Table 1 (continued): Lower Fox River COE Dredge History 1957-1998, Green Bay to outer channel.

Year	*Start*	*Finish*	*yd^3*	*Cost ($)*	*$/$yd^3$*	*Dredge Area*	*Placement (Disposal)*	*Performed By*	*Comments*
1973			57,000	147,152	2.58	Bay	Open Water	COE-Dipper Dredge Kewaunee	
1974	7/1/74	9/25/74	1,335,963			Bay	Bayport CDF	COE-Hopper Dredge Markham	
1975	4/28/75	5/28/75	821,214	910,517	1.11	Bay	Bayport CDF	COE-Hopper Dredge Markham	
1977	6/1/77	7/11/77	300,000	467,999	1.56	Bay	Bayport CDF	COE-Hopper Dredge Markham	
1977			315,794	48,572	0.15	Bay	Bayport CDF	COE-Hopper Dredge Markham	
1977			24,650	203,728	8.26	Bay	Bayport CDF	COE- No. 6027	
1979	5/3/79	6/20/79	665,708	557,000	0.84	Bay	Bayport CDF	COE-Hopper Dredge Markham	
1980			34,175	103,464	3.03	Bay	Renard Island CDF	COE-Cranebarge Manitowoc	
1981	6/24/81	8/14/81	559,587	895,107	1.6	Bay	Renard Island CDF	COE-Hopper Dredge Markham	
1982	9/7/82	10/12/82	209,602	420,451	2.01	Bay	Renard Island CDF	COE-Hopper Dredge Markham	
1982	10/1/82	9/30/83	273,606	463,587	1.69	Bay	Renard Island CDF	COE-Hopper Dredge Markham	
1983			53,273	213,726	4.01	Bay	Renard Island CDF	COE-Hopper Dredge Markham	
1984	7/30/84	11/14/84	131,344	594,433	4.53	Bay: 71+50N - 82+50N, 163+00N - 182+00N, 75+00S - 42+50S	Renard Island CDF	Contract-Luedtke (DACW35-84-C-0023)	
1985	7/3/85	9/2/85	102,143	568,376	5.56	Bay: 10+00N - 71+50N	Renard Island CDF	Contract-Gillen (DACW35-85-C-0012)	
1986	9/2/86	5/1/87	66,740	735,065	11.01	Bay: 372+00N - 438+00N	Renard Island CDF	Contract-J.F. Brennan (DACW35-86-C-0037)	
1987	9/14/87	11/17/87	114,127	1,035,946	9.08	Bay: 70+00S - 20+00S	Bayport CDF	Contract-Roen (DACW35-87-C-0038)	
1987	10/17/87	10/26/88	156,980	1,726,226	11	Bay: 270+00N - 116+00N	Renard Island CDF	Contract-Durocher (DACW35-87-C-0053)	

Table 1 (continued): Lower Fox River COE Dredge History 1957-1998, Green Bay to outer channel.

Year	*Start*	*Finish*	*yd^3*	*Cost ($)*	*$/yd^3$*	*Dredge Area*	*Placement (Disposal)*	*Performed By*	*Comments*
1988	8/15/88	6/2/89	128,693	1,529,289	9.16	Bay: 186+00D - 200+00D	Bayport CDF	Contract-Roen (DACW35-88-C-0029)	
1989	10/16/89	11/14/89	49,421	507,024	10.26	Bay: 20+00N - 48+00N (NW side of channel)	Bayport CDF	Contract-King (DACW35-89-C-0051)	
1990	9/17/90	12/18/90	161,150	742,213	4.61	Bay: 55+00S - 15+00S (SE side of channel)	Renard Island CDF (west half)	Contract-Roen (DACW35-90-C-0027)	Note: No Work at Renard Island 5/15 - 8/15 (terns)
1991	9/16/91	12/13/91	168,202	676,007	4.02	Bay: 70+00S - 0+00S (west side of channel)	Renard Island CDF	Contract-Roen (DACW35-91-C-0024)	Note: No Work at Renard Island 4/15 - 8/15
1992	9/17/92	11/29/92	164,080	736,751	4.49	Bay: 80+00B - 145+00B	Renard Island CDF	Contract-Luedtke (DACW35-92-C-0029)	
1993	7/31/93	12/14/93	127,802	975,972	7.64	Bay: 10+00B - 28+00B	Bayport CDF area 4 then area 2	Contract-Luedtke (DACW35-93-C-0032)	
1993	7/31/93	12/14/93	190,062	1,015,596	5.34	Bay: 28+00B - 60+00B	Renard Island CDF	Contract-Luedtke (DACW35-93-C-0032)	Note: No Work at Renard Island 5/15 - 8/15 (terns)
1995	8/22/95	11/13/95	103,000	904,606	4.9	Bay: 10+00B - 35+00B	Renard Island CDF	Contract-Roen (DACW35-95-C-0035)	Note: No Disposal into CDF Allowed Prior to 8/15
1995	8/22/95	11/13/95	81,697			Bay: 190+00B - 235+00B (north side to limit line)	Renard Island CDF	Contract-Roen (DACW35-95-C-0035)	
1996	8/20/96	11/22/96	48,701	1,082,114	7.67	Bay: 235+00B - 315+00B	Renard Island CDF	Contract-Roen (DACW35-96-C-0020)	
1996	8/20/96	11/22/96	31,142			Bay: 0+00 - 10+00B	Bayport CDF	Contract-Roen (DACW35-96-C-0020)	
1997	9/15/97	12/9/97	114,438	1,368,370	8.16	Bay: 70+00B - 145+00B	Bayport CDF	Contract-Roen (DACW35-97-C-0026)	
1998	Sep-98	Dec-98	218,000	1,850,000	7.75/10	Bay: 0+00 - 70+00	Bayport CDF	Contract-Roen (DACW35-98-C-0025)	

Table 2: COE channel condition charts and data collection methods and accuracies.

Year	*Positioning Method/Accuracy*	*Sounding Method/Accuracy*	*Survey Class/Overall Project Accuracy*	*Sounding Plot Distance*
1977 Areas 5-9	Range/Azimuth with right angle prism and cable tag-line (+/- 3 meters)	Sonic: Bludworth sounder at 208 KHZ, 8^0 beam (+/- 15 cm)	Class II Horizontal: +/- 6 m Vertical: +/- 30 cm	sounded and plotted every 6.1 meters
1982 *Areas 5-9*	Range/Azimuth with right angle prism and cable tag-line (+/- 3 meters)	Sonic: Bludworth sounder at 208 KHZ, 8^0 beam (+/- 15 cm)	Class II Horizontal: +/- 6 m Vertical: +/- 30 cm	sounded and plotted every 6.1 meters
1990 *Charts 11-21*	Krupp-Atlas Polar Fix range/azimuth laser (+/- 1-3 meters)	Sonic: Innerspace 448 sounder with Auto Comstar, 208 KHZ, 3^0 beam (+/- 3 cm)	Class I Horizontal: +/- 3 m Vertical: +/- 15 cm	sounded and recorded continuously; plotted every 3 meters
1993 *Charts 11-21*	Krupp-Atlas Polar Fix range/azimuth laser (+/- 1-3 meters)	Sonic: Innerspace 448 sounder with Auto Comstar, 208 KHZ, 3^0 beam (+/- 3 cm)	Class I Horizontal: +/- 3 m Vertical: +/- 15 cm	sounded and recorded continuously; plotted every 3 meters
1997 *Charts 11-21*	Starlink RTK GPS (+/- 1 meter)	Sonic: Innerspace 448 sounder with Coastal Oceanographic Hypack , 208 KHZ, 3^0 beam (+/- 3 cm)	Class I Horizontal: +/- 3 m Vertical: +/- 15 cm	sounded and recorded continuously; plotted every 3 meters
1998 *Charts 11-21*	Starlink RTK GPS (+/- 1 meter)	Sonic: Innerspace 448 sounder with Coastal Oceanographic Hypack, 208 KHZ, 3^0 beam (+/- 3 cm)	Class I Horizontal: +/- 3 m Vertical: +/- 15 cm	sounded and recorded continuously; plotted every 3 meters

Table 3: COE range lines used for long-term transect comparisons.

Location	*1977*	*1982*	*1990*	*1993*	*1997*	*1998*
370+00	√		•	√	√	√
360+00	√	•	√	√	√	√
341+00	•	√	•	√	√	√
324+00	√	•	√	√	√	√
294+00	√	•	√	√	√	√
272+00	√	•	•	√	√	√
237+00	•	√	√	√	√	√
205+00	•	√	√	√	√	√
193+00	•	√	√	√	√	√
117+00			√	√	√	√
104+00			√	√	√	√
91+00		√	√	√	√	√
61+00			√	√	√	√
37+00		√	√	√	√	√
13+00			√	√	√	√

√ = range lines used for sediment bed elevation comparisons
• = transects established by averaging of neighboring range lines

Table 4: Short-term transect data perpendicular offset distances (meters).

Date	*T9*	*T8*	*T7*	*T6*	*T5*	*T3*
May 1994	+/- 3	+/- 3	*	+/- 3	+/- 5	+/- 3
July 1994	NA	NA	NA	+/- 3	+/- 1	+/- 3
November 1994	+/- 5	+/- 1	+/- 5	+/- 3	+/- 3	+/- 3
August 1995	+/- 3	+/- 1	+/- 3	+/- 1	+/- 1	+/- 3

NA = no sounding data collected at this site.
* = majority of data offset greater than 5 meters from target line

Table 5: Lower Fox River between DePere and Green Bay Harbor Dredge Summary, 1957-1998.

Location	*Disposal Site: Open Water Disposal*	*Disposal Site: Bayport CDF*	*Disposal Site: Renard Island CDF*	*Totals*
Bay: m^3	2,869,644[1]	6,766,231[2]	1,914,820	11,550,695
yd^3	*3,753,131*	*8,849,374*	*2,504,342*	*15,106,847*
River: m^3	270,652	1,078,966[3]	159,724	1,509,343
yd^3	*353,979*	*1,411,151*	*208,899*	*1,974,029*
Total: m^3	3,140,296	7,845,197	2,074,544	13,060,038
yd^3	*4,107,110*	*10,260,525*	*2,713,241*	*17,080,876*

[1] 80% (2,309,739 m^3; 3,020,915 yd^3) of this sediment originated from deepening of the bay navigation channel during 1969-1971.

[2] 10% (661,930 m^3; 865,740 yd^3) of this sediment originated from deepening of the bay navigation channel during 1966.

[3] 30% (326,394 m^3; 426,891 yd^3) of this sediment originated from deepening of the river navigation channel during 1966-1967.

Table 6: Per-chart sediment volume changes in navigation channel.

Chart #	*August 1993 to July 1997*	*August 1996 to July 1997*	*July 1997 to July 1998*
11: m^3		- 443	3,134
yd^3		*- 580*	*4,099*
12: m^3		1,495	5,361
yd^3		*1,955*	*7,012*
13: m^3		- 2,581	1,004
yd^3		*- 3,375*	*1,313*
14: m^3		3,409	- 2,803
yd^3		*4,458*	*- 3,666*
15: m^3		9,192	
yd^3		*12,022*	(dredged)
16: m^3	- 15,105		2,224
yd^3	*- 19,755*		*2,909*
17: m^3	- 6,588		2,811
yd^3	*- 8,616*		*3,676*
18: m^3	- 4,297		4,068
yd^3	*- 5,620*		*5,321*
19: m^3	- 1,814		5,101
yd^3	*- 2,372*		*6,672*
20: m^3	- 4,123		4,728
yd^3	*- 5,393*		*6,184*
21: m^3	- 9,960		- 588
yd^3	*- 13,026*		*- 769*

Table 7: Lower Fox River navigation channel elevation summary (long-term data).

Location	*Average Elevation Change (cm)*	*Maximum Elevation Change (cm)*
370+00 (DePere Turning Basin)		
1977 to 1990	- 63	- 199
1990 to 1993	- 29	- 191
1993 to 1997	- 8	+ 25
1997 to 1998	- 16	+ 6
360+00 (Voyager Park)		
1977 to 1982	+ 6	+ 38
1982 to 1990	+ 4	+ 32
1990 to 1993	+ 22	+ 30
1993 to 1997	- 22	- 30
1997 to 1998	+ 6	+ 21
341+00 (Brown County Fairgrounds)		
1977 to 1982	- 8	- 6
1982 to 1990	- 3	- 4
1990 to 1993	+ 12	- 14
1993 to 1997	- 25	- 30
1997 to 1998	+ 5	+ 12
324+00 (DePere Wastewater Treatment Plant)		
1977 to 1982	- 49	- 64
1982 to 1990	- 5	- 40
1990 to 1993	- 11	- 12
1993 to 1997	- 17	- 18
1997 to 1998	- 1	- 3
294+00 (Ashwaubenon Creek)		
1977 to 1982	0	+ 23
1982 to 1990	- 18	- 62
1990 to 1993	- 24	- 28
1993 to 1997	- 13	+ 9
1997 to 1998	+ 15	+ 28
272+00 (Hwy. 172 bridge)		
1977 to 1982	+ 28	- 31
1982 to 1990	- 9	- 24
1990 to 1993	- 15	- 12
1993 to 1997	- 27	- 25
1997 to 1998	- 3	+ 3

Table 7 (continued): Lower Fox River navigation channel elevation summary (long-term data).

Location	*Average Elevation Change (cm)*	*Maximum Elevation Change(cm)*
237+00 (Cooke Park)		
1977 to 1982	+ 7	+ 8
1982 to 1990	+ 19	+ 24
1990 to 1993	- 1	+ 3
1993 to 1997	+ 3	+ 6
1997 to 1998	+ 6	0
205+00 (Fort James West Mill bulkhead)		
1977 to 1982	- 9	- 24
1982 to 1990	+ 24	+ 79
1990 to 1993	- 7	- 3
1993 to 1997	- 26	- 39
1997 to 1998	- 3	- 6
193+00 (Fort James West Mill intake)		
1977 to 1982	- 45	- 55
1982 to 1990	+ 2	+ 3
1990 to 1993	+ 4	- 6
1993 to 1997	- 13	- 18
1997 to 1998	+ 3	+ 12
117+00 (Green Bay Warehouses)		
1990 to 1993	+ 18	- 34
1993 to 1997	- 31	- 67
1997 to 1998	+ 12	+ 27
104+00 (Northwest Engineering Co.)		
1990 to 1993	+ 19	- 24
1993 to 1997	- 17	- 22
1997 to 1998	+ 7	+ 9
91+00 (Pine Street)		
1982 to 1990	- 58	+ 27
1990 to 1993	+ 5	+ 28
1993 to 1997	+ 2	- 110
1997 to 1998	-14	+ 21
61+00 (Fort James East Mill)		
1990 to 1993	+ 31	+ 43
1993 to 1997	+ 5	+ 54
1997 to 1998	+ 7	+ 6

Table 7 (continued): Lower Fox River navigation channel elevation summary (long-term data).

Location	*Average Elevation Change (cm)*	*Maximum Elevation Change(cm)*
37+00 (Amoco Oil Co.)		
1982 to 1990	- 7	- 19
1990 to 1993	- 20	- 15
1993 to 1997	+ 23	+ 9
1997 to 1998	- 6	+ 6
17+00 (F. Hurlbut Co.)		
1990 to 1993	- 36	- 40
1993 to 1997	+ 11	+ 22
1997 to 1998	+ 5	+ 85

Table 8: Lower Fox River Sediment Bed Elevation Summary (Navigation Channel and Nearshore Areas) (short-term data)

Transect	*Landmark*	*Distance from left bank, m*	*Sediment Bed Elevation Change (cm)*			
			Survey Period			
T9	Voyager Park		*May 1994 to November 1994*		*November 1994 to August 1995*	*May 1994 to August 1995*
		300 - 580	+ 9		- 6	+ 3
		400	+ 8		+ 11	+ 17
		580 - 680	+ 7		- 2	+ 5
		670	- 17		+ 3	- 14
		680 - 750	+ 13		- 2	+ 11
		725	+ 14		- 6	+ 8
		300 - 750	+ 10		- 6	+ 4
T8	DePere Wastewater Treatment Plant		*May 1994 to November 1994*		*November 1994 to August 1995*	*May 1994 to August 1995*
		60 - 125	+ 19		- 2	+ 17
		110	+ 15		+ 5	+ 20
		125 - 225	+ 16		+ 12	+ 28
		175	+ 13		+ 10	+ 23
		225 - 290	+ 10		+ 8	+ 18
		270	- 11		+ 26	+ 15
		60 - 290	+ 12		+ 9	+ 21
T7	Hwy. 172 Bridge				*November 1994 to August 1995*	
		88 - 125			- 3	
		100			- 8	
		125 - 245			+ 2	
		150			+ 17	
		245 - 380			- 12	
		340			- 9	
		88 - 380			- 3	

Table 8 (continued): Lower Fox River Sediment Bed Elevation Summary (Navigation Channel and Nearshore Areas) (short-term data)

Transect	*Landmark*	*Distance from left bank (m)*	*Sediment Bed Elevation Change (cm)*			
			Survey Period			
T6	Cooke Park		*May 1994 to July 1994*	*July 1994 to November 1994*	*November 1994 to August 1995*	*May 1994 to August 1995*
		90 - 300	+ 2	+ 11	- 3	+ 10
		125	- 6	+ 25	- 7	+ 12
		300 - 550	+ 2	+ 10	- 3	+ 9
		440	0	+ 7	- 2	+ 5
		550 - 870	0	+ 9	0	+ 9
		600	+ 3	+ 5	+ 1	+ 9
		90 - 870	+ 1	+ 10	- 1	+ 10
T5	Fort James West Mill bulkhead		*May 1994 to July 1994*	*July 1994 to November 1994*	*November 1994 to August 1995*	*May 1994 to August 1995*
		50 - 150	+ 5	- 9	+ 24	+ 20
		75	+ 4	- 11	+ 25	+ 18
		150 - 250	- 3	- 2	+ 29	+ 24
		200	- 10	+ 4	+ 25	+ 19
		250 - 310	- 5	- 11	- 2	- 18
		275	+ 6	- 23	+ 6	- 11
		50 - 310	+ 1	- 7	+ 19	+ 13
T3	Fort James East Mill		*May 1994 to September 1994*	*September 1994 to November 1994*	*November 1994 to August 1995*	*May 1994 to August 1995*
		35 - 150	+ 73	- 98	+ 20	- 5
		50	+ 73	- 111	+ 38	0
		150 - 250	+ 84	- 96	+ 23	+ 11
		215	+ 107	- 100	+ 28	+ 35
		250 - 330	+ 57	- 90	- 3	- 36
		275	+ 61	- 107	+ 15	- 31
		35 - 330	+ 72	- 94	+ 14	- 8

Table 9: Summary of confirmatory transect net sediment bed elevation changes.

Transect (Green Bay to DePere dam)	*Oct. 89 to Nov. 90 (11 months)*	*Nov. 90 to May 91 (8 months)*	*May 91 to Jan. 92 (8 months)*	*Oct. 89 to Jan. 92 (27 months)*	*Jan. 92 to Sept. 96 (45 months)*
GS-5	- 30 cm from nav. channel	+ 43 cm in nav. channel	- 46 cm in nav. channel	- 30 cm in nav. channel	- 15 cm in nav. channel; + 30 cm west of channel
GS-6	- 46 cm from nav. channel	- 61 cm in nav. channel; -40 at right of channel	- 46 cm in nav. channel; minor erosion at right of channel	- 30 cm in nav. channel; minor erosion at right of channel	(dredged in 1996)
GS-7	- 18 cm from nav. channel	+ 37 cm in nav. channel	- 30 cm in nav. channel; -15 cm ave. outside of channel	- 15 cm in nav. channel	+ 24 cm in nav. channel; - 27 cm near left bank
GS-8	- 15 cm over entire transect	+ 15 cm over entire transect	- 24 cm over entire transect	- 15 cm over entire transect	+ 30 cm in nav. channel and east of nav. channel
GS-9	+ 15 cm in nav. channel; erosion at right of channel	+ 3 cm in nav. channel; deposition at right of channel	- 37 cm in nav. channel	- 15 cm in nav. channel; erosion at right of channel	unknown; water reference mark removed
GS-10	- 46 cm in nav. channel	+ 70 cm in nav. channel	- 61 cm in nav. channel; - 24 cm to - 61 cm over entire transect	- 46 cm in nav. channel	unknown; water reference mark removed
GS-11	unknown; water reference mark removed	Unknown; water reference mark removed	- 23 cm ave. over entire transect	Unknown; water reference mark removed	unknown; water reference mark removed
GS-12	- 9 cm over entire transect; - 183 cm in nav. channel from ship grounding	+ 30 cm over entire transect; + 152 cm in ship cut	- 46 cm in nav. channel; ship cut filled in completely	0 (no net change)	(dredged in 1995)
GS-2	+ 15 cm right of nav. Channel	+ 30 cm ave. over entire transect	- 46 cm in nav. channel	0 (no net change)	+ 30 cm over entire transect
GS-3	- 27 cm in nav. Channel	+ 15 cm over entire transect	- 18 cm over entire transect	0 (no net change)	+ 15 cm in nav. channel; with depositon at both sides of the nav. channel
GS-4	- 55 cm in nav. Channel	+ 15 to + 30 cm in nav. channel; + 3 cm left and right of channel	- 30 cm in nav. channel	- 55 cm in nav. channel	0 (no net change)
GS-1	0 (no change)	+ 5 cm over entire transect	- 30 cm in nav. channel; - 9 cm left of nav. channel	- 3 cm over entire transect	+ 37 cm in nav. channel; + 15 cm left side of nav. channel

Table 10: Accuracy performance standards for sediment bed elevation data (95% confidence levels).

Data Group	*Source*	*Year*	*Survey Classification*	*Water Depth*	*Maximum Horizontal Error*[1]	*Maximum Vertical Error*
Long-Term	COE	1977 1982	Class II	> 4.5 m (15 ft) 4.5 m - 12.1 m (40ft)	+/- 5 m (16 ft)	+/- 30 cm (1.0 ft) +/- 60 cm (2.0 ft)
	COE	1990 1993 1997 1998	Class I	> 4.5 m (15 ft) 4.5 m - 12.1 m (40ft)	+/- 5 m (16 ft)	+/- 15 cm (0.5 ft) +/- 30 cm (1.0 ft)
Short-Term	USEPA	1994-1995	Class I[2]	> 4.5 m (15 ft) 4.5 m - 12.1 m (40ft)	+/- 5 m (16 ft)	+/- 15 cm (0.5 ft) +/- 30 cm (1.0 ft)
Confirmatory	USGS	1989-1996	Class III[2]	NA[3]	+/- 100 m (330 ft)	+/- 45 cm (1.5 ft)

[1] Class I survey accuracy performance standards are reported for "soft material" sediment bed composition.
[2] Estimated survey classification based on instruments used, calibration, and navigation methods.
[3] Not Applicable: water depth limits were not specified for Class III surveys in the 1991 COE Hydrographic Surveying Manual other than depth not to exceed 40 ft (12.1 m) (Table 3-1).

Figure 1: Study Area, Lower Fox River
Lake Winnebago to Green Bay

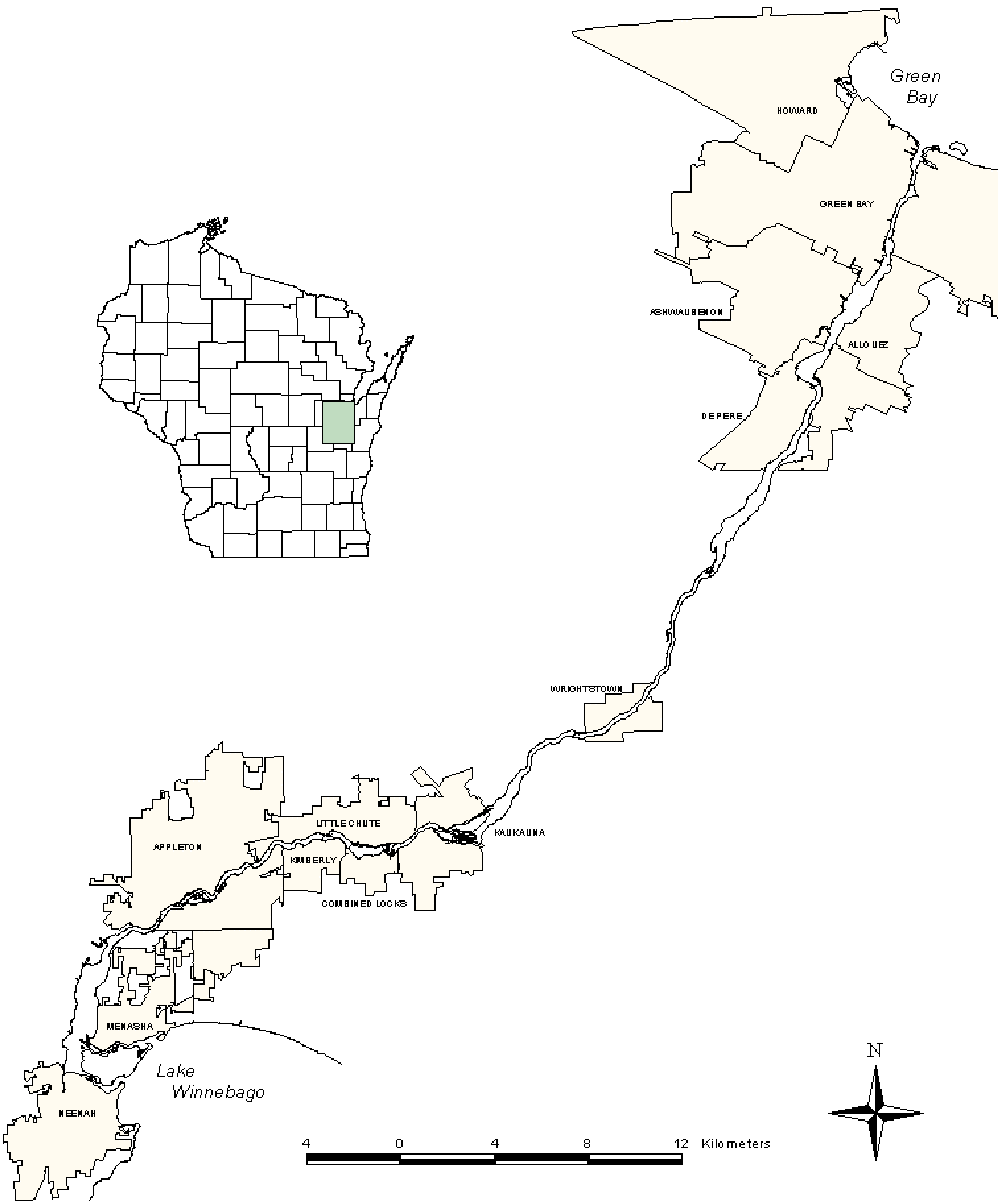
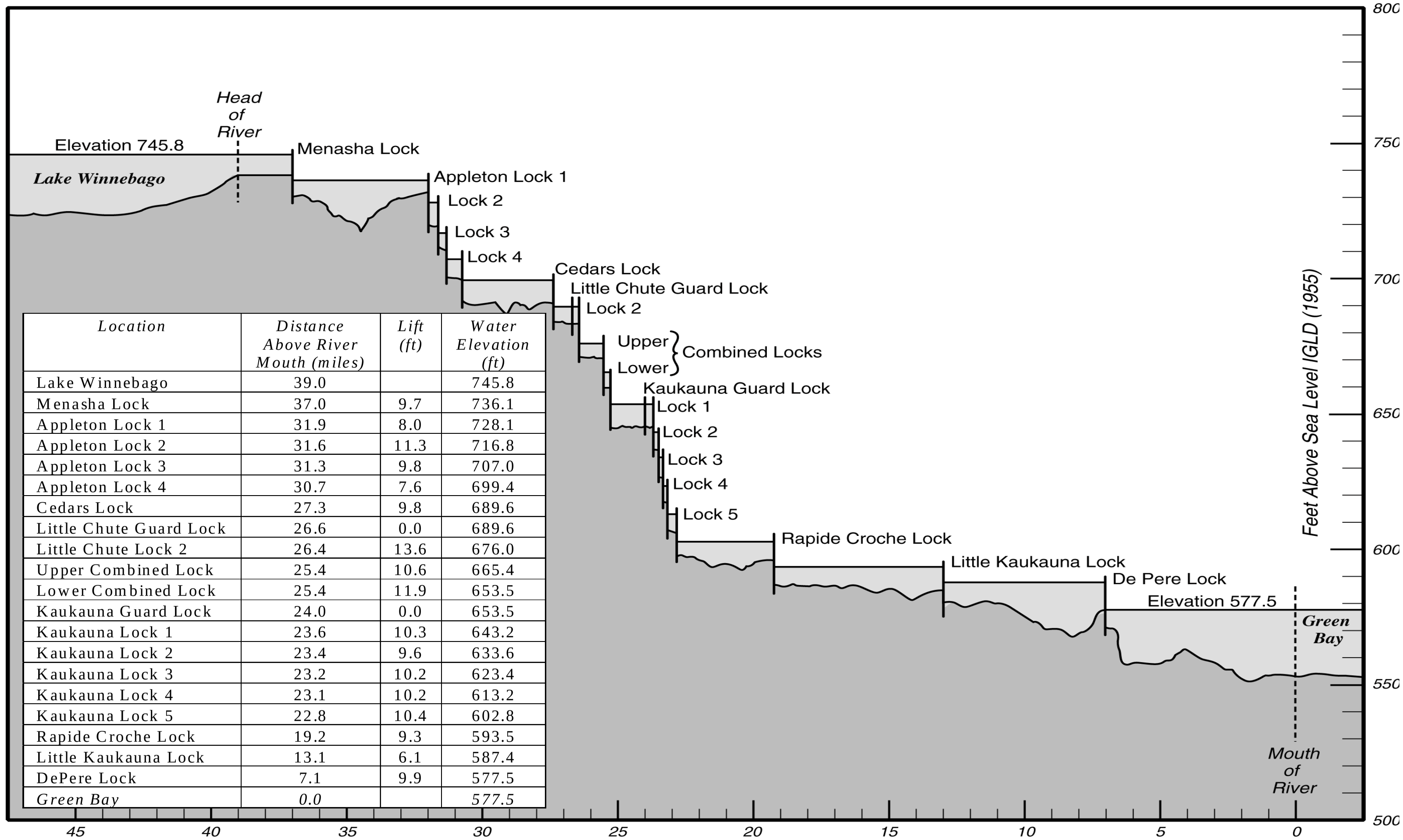


Figure 2: Profile of Lower Fox River



Location	*Distance Above River Mouth (miles)*	*Lift (ft)*	*Water Elevation (ft)*
Lake Winnebago	39.0		745.8
Menasha Lock	37.0	9.7	736.1
Appleton Lock 1	31.9	8.0	728.1
Appleton Lock 2	31.6	11.3	716.8
Appleton Lock 3	31.3	9.8	707.0
Appleton Lock 4	30.7	7.6	699.4
Cedars Lock	27.3	9.8	689.6
Little Chute Guard Lock	26.6	0.0	689.6
Little Chute Lock 2	26.4	13.6	676.0
Upper Combined Lock	25.4	10.6	665.4
Lower Combined Lock	25.4	11.9	653.5
Kaukauna Guard Lock	24.0	0.0	653.5
Kaukauna Lock 1	23.6	10.3	643.2
Kaukauna Lock 2	23.4	9.6	633.6
Kaukauna Lock 3	23.2	10.2	623.4
Kaukauna Lock 4	23.1	10.2	613.2
Kaukauna Lock 5	22.8	10.4	602.8
Rapide Croche Lock	19.2	9.3	593.5
Little Kaukauna Lock	13.1	6.1	587.4
DePere Lock	7.1	9.9	577.5
Green Bay	*0.0*		*577.5*

Source: NOAA Coast and Geodetic Survey Recreational chart 14916.

Figure 3: Long-Term and Short-Term Transect Locations

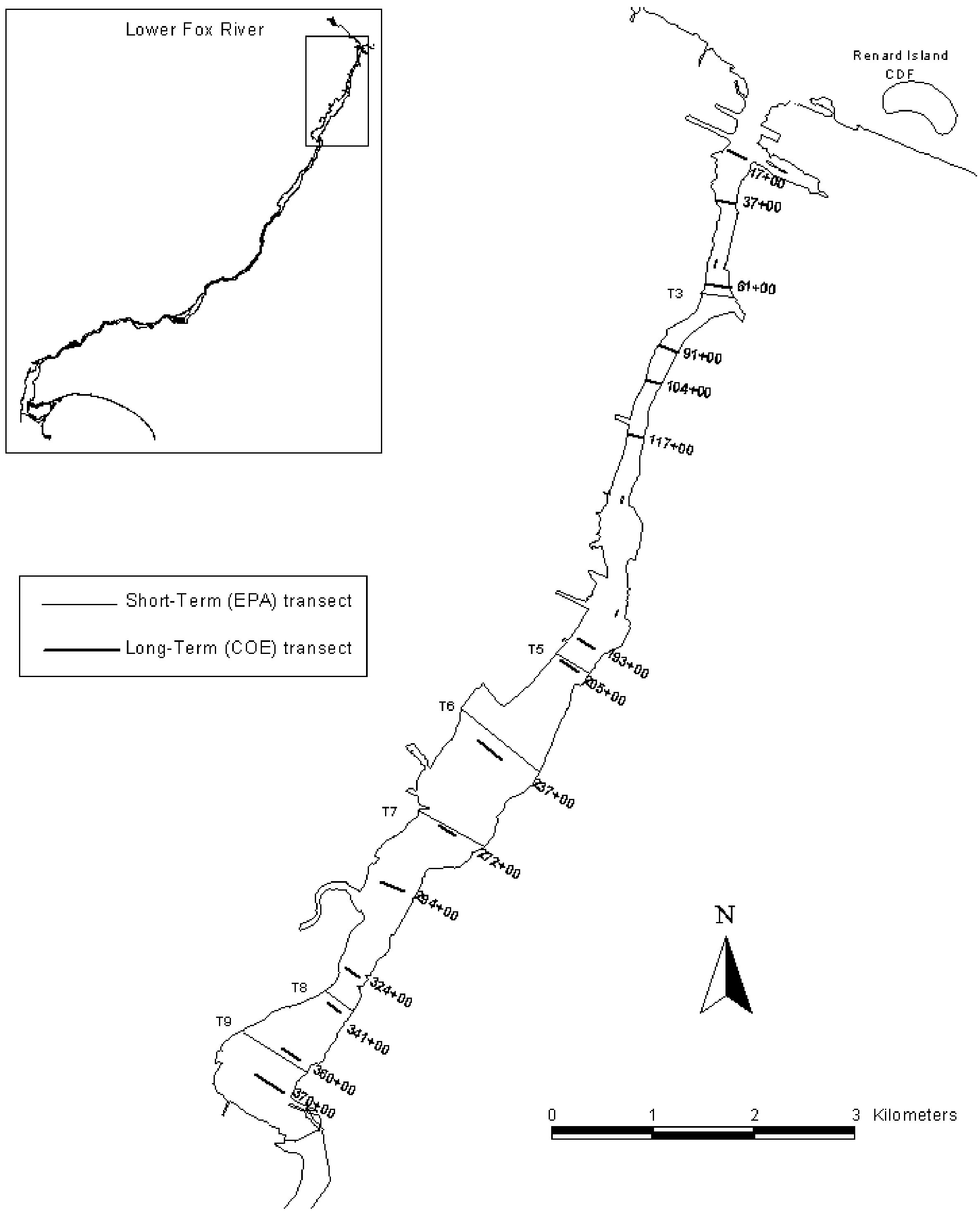


Figure 4: Confirmatory Transect Locations

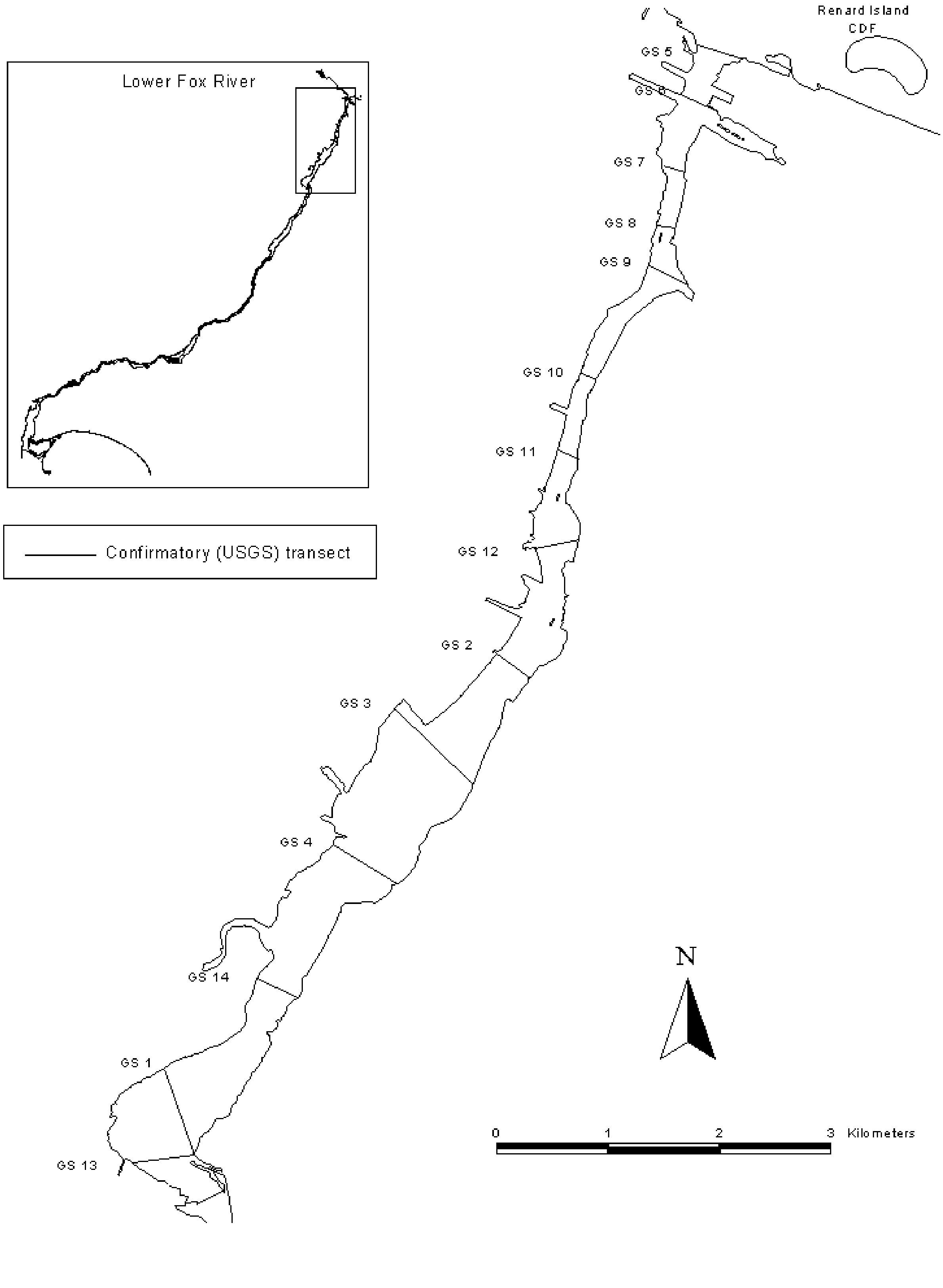


Figure 5: Lower Fox River Sediment Bed: Longitudnal Profile (long-term average bed elevation in navigation channel)

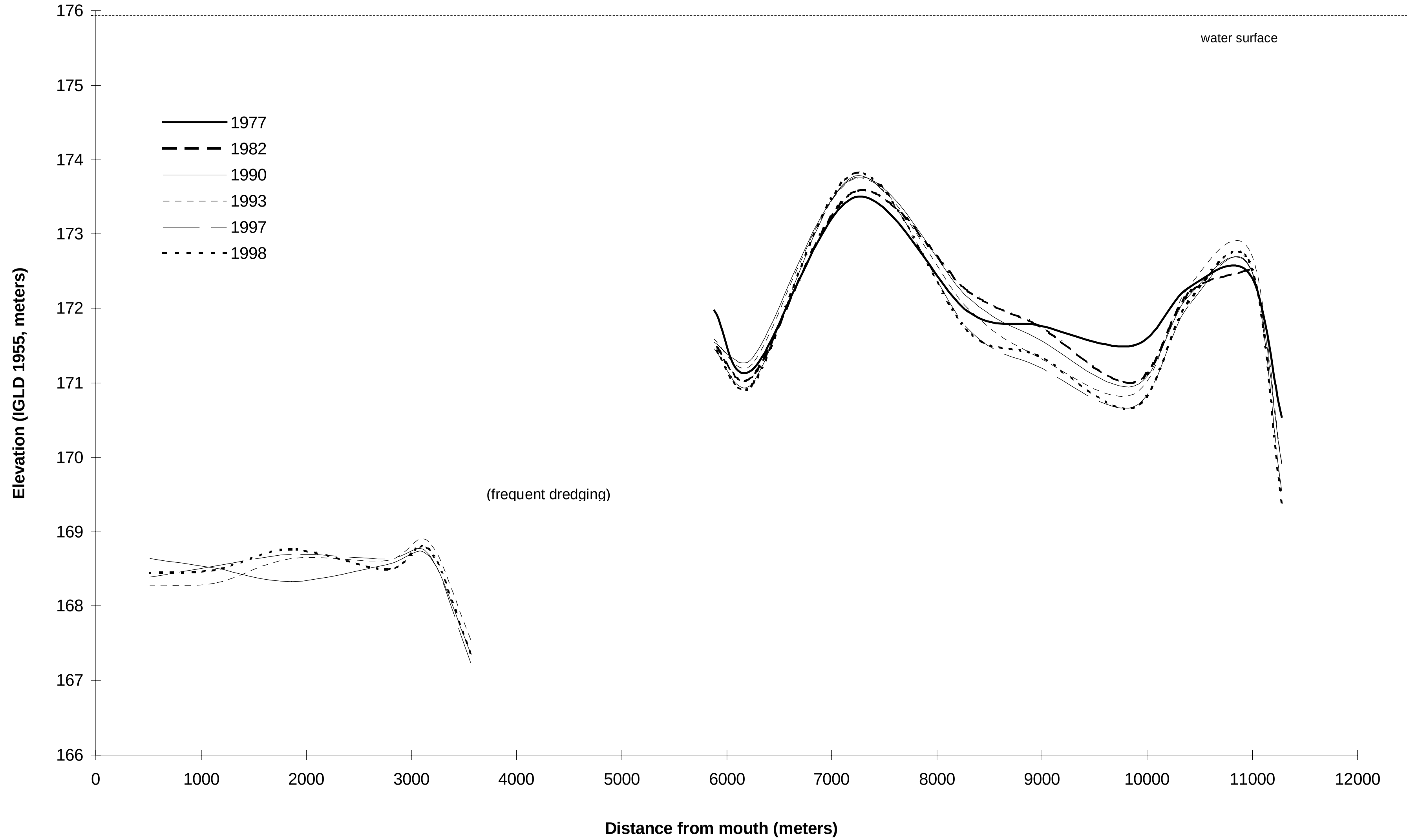
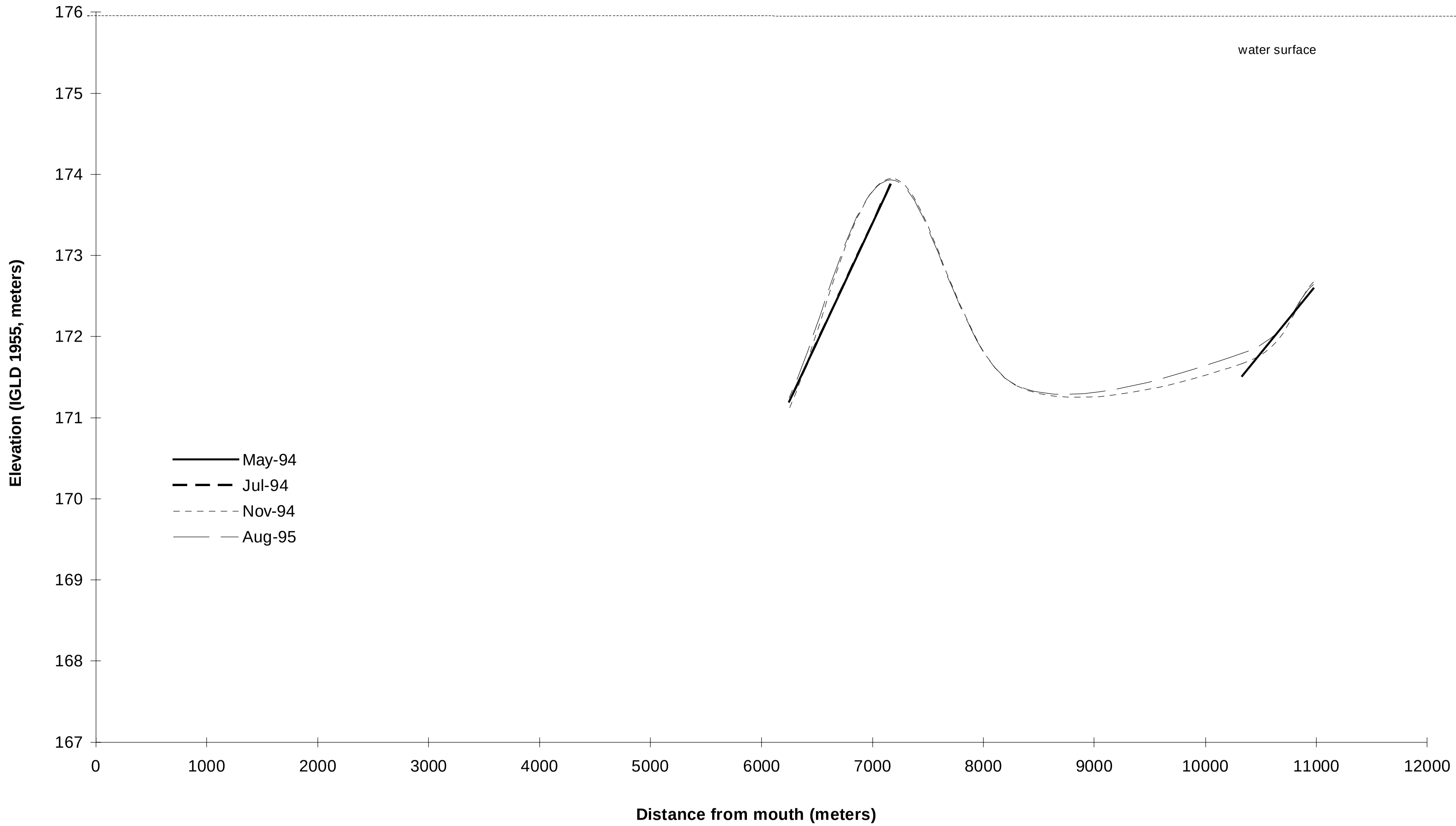


Figure 6: Lower Fox River Sediment Bed: Longitudnal Profile (short-term average bed elevation in navigation channel)



Appendix A

Figure 1A: COE transect 370+00, Lower Fox River at Depere turning basin

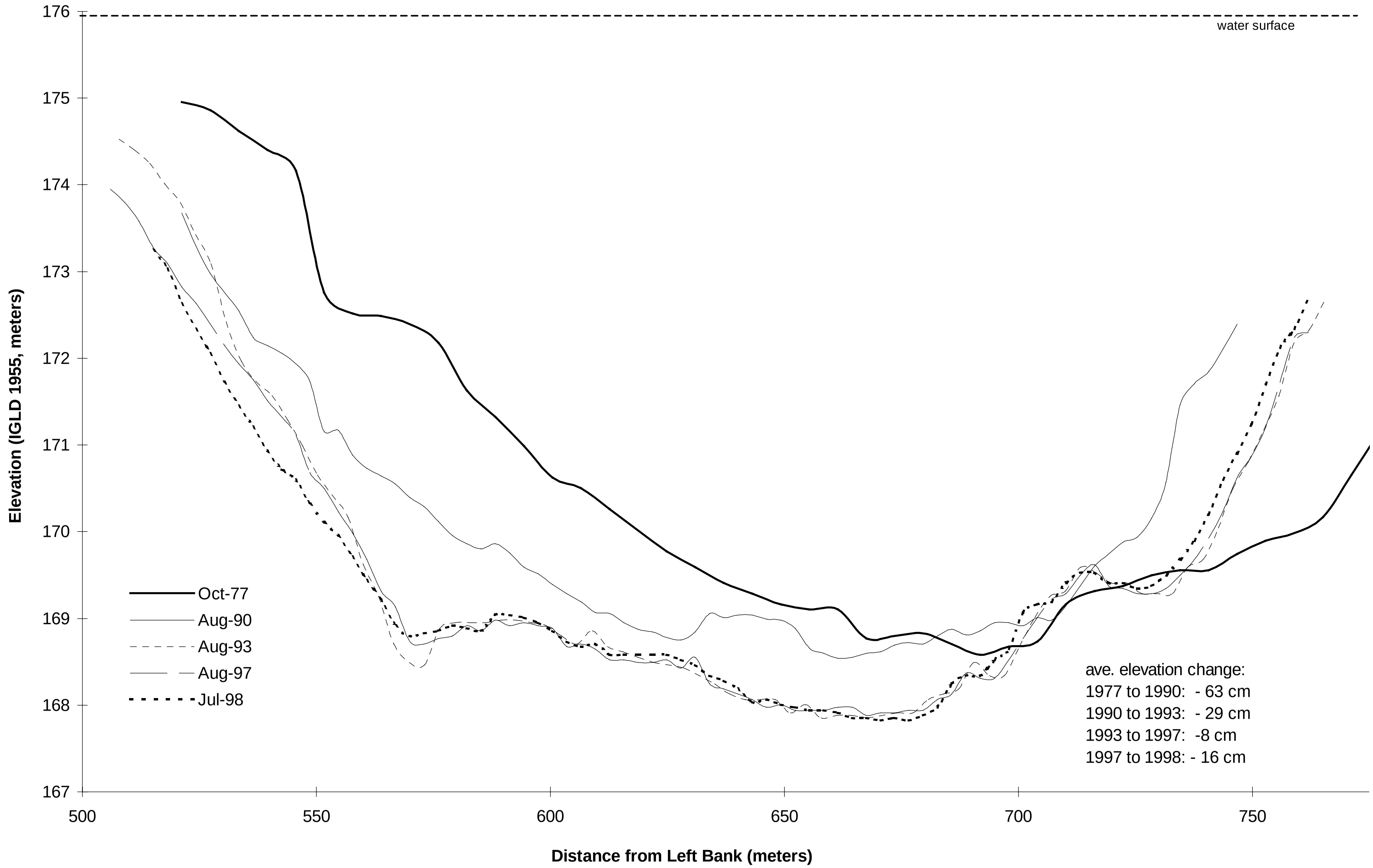


Figure 2A: COE transect 360+00, Lower Fox River at Voyager Park

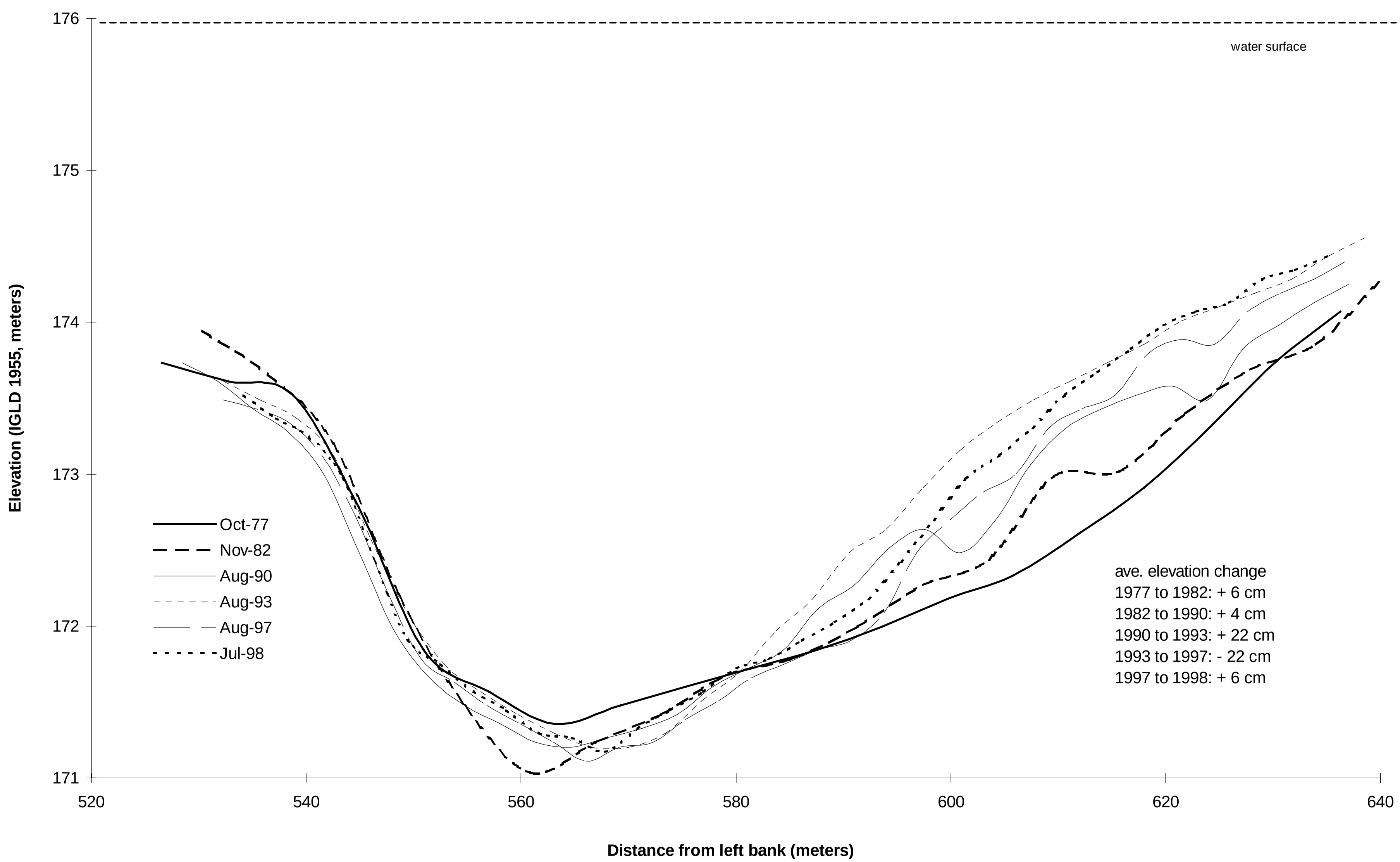


Figure 3A: COE transect 341+00, Lower Fox River at Brown Cnty. Fairgrounds

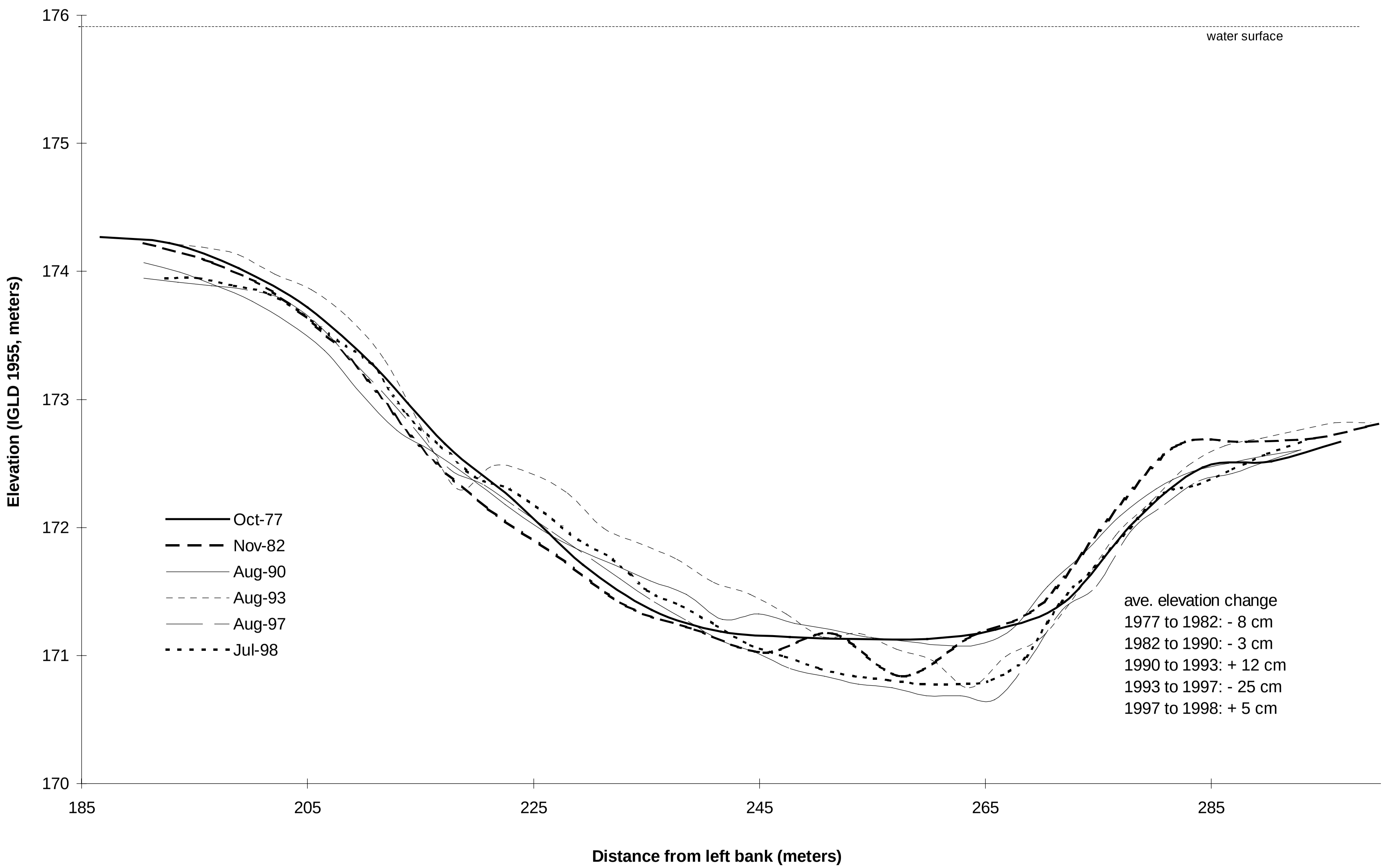


Figure 4A: COE transect 324+00, Lower Fox River at Depere wastewater plant

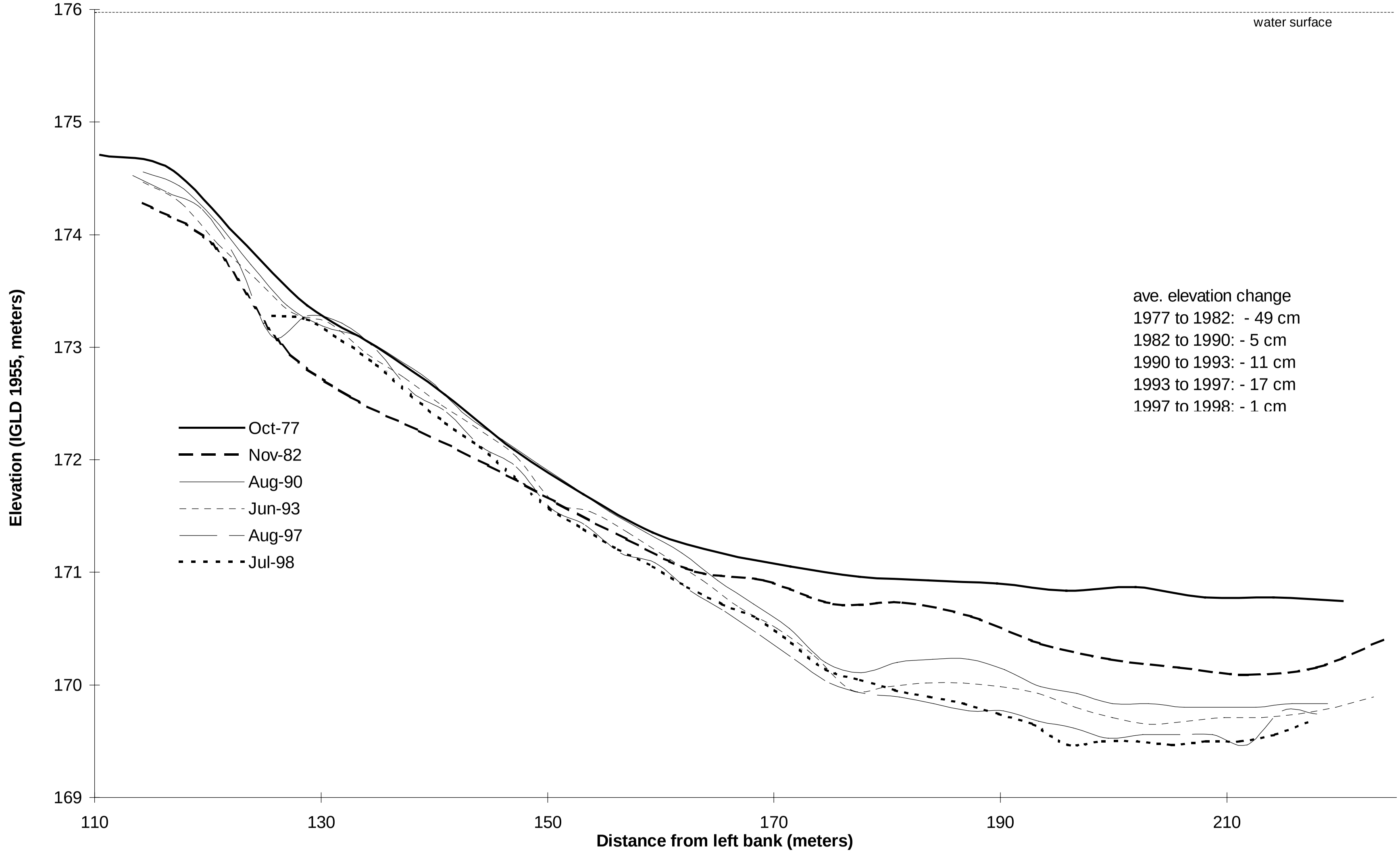


Figure 5A: COE transect 294+00, Lower Fox River at Ashwaubenon Creek

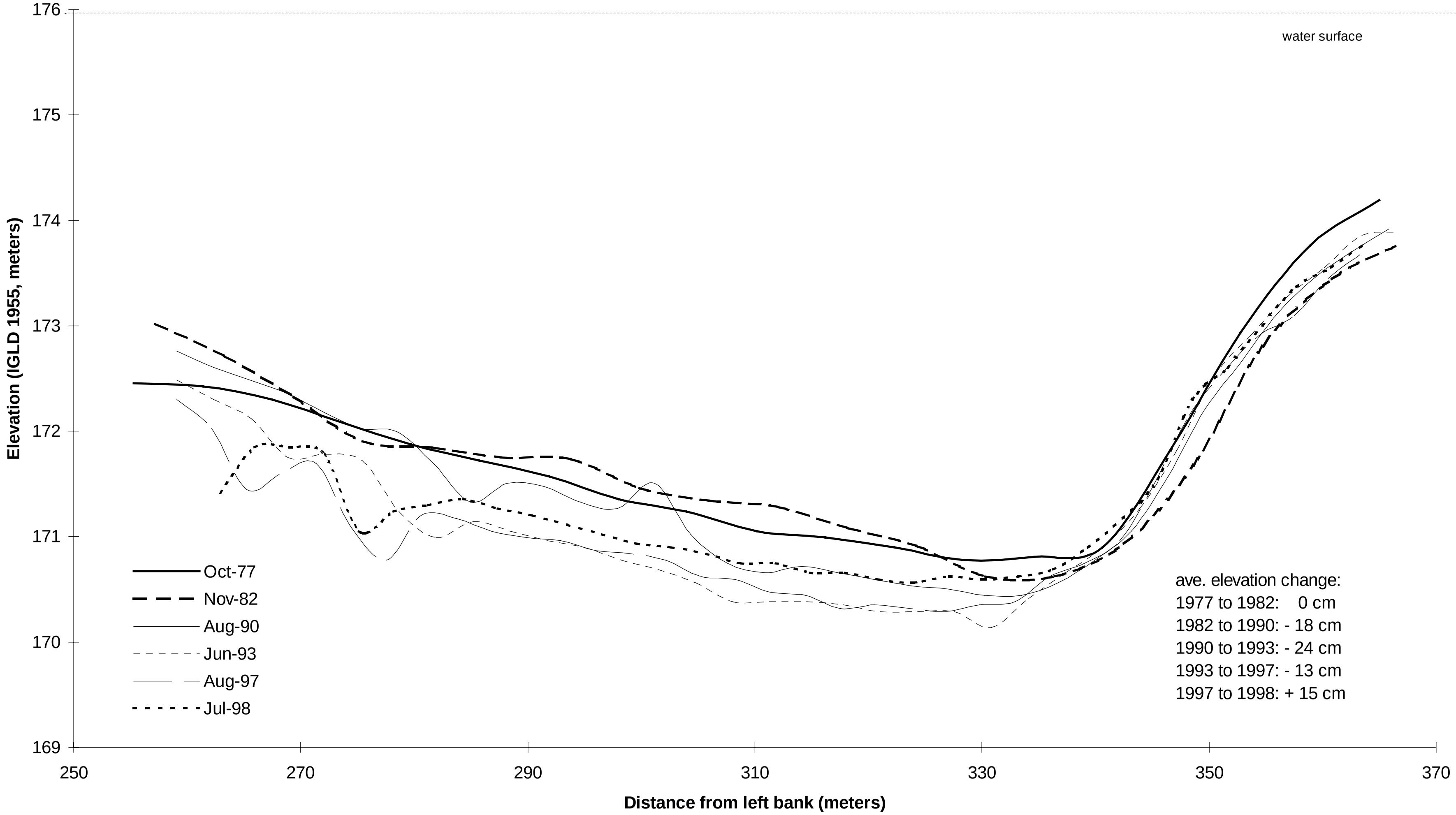


Figure 6A: COE transect 272+00, Lower Fox River at Hwy. 172 bridge

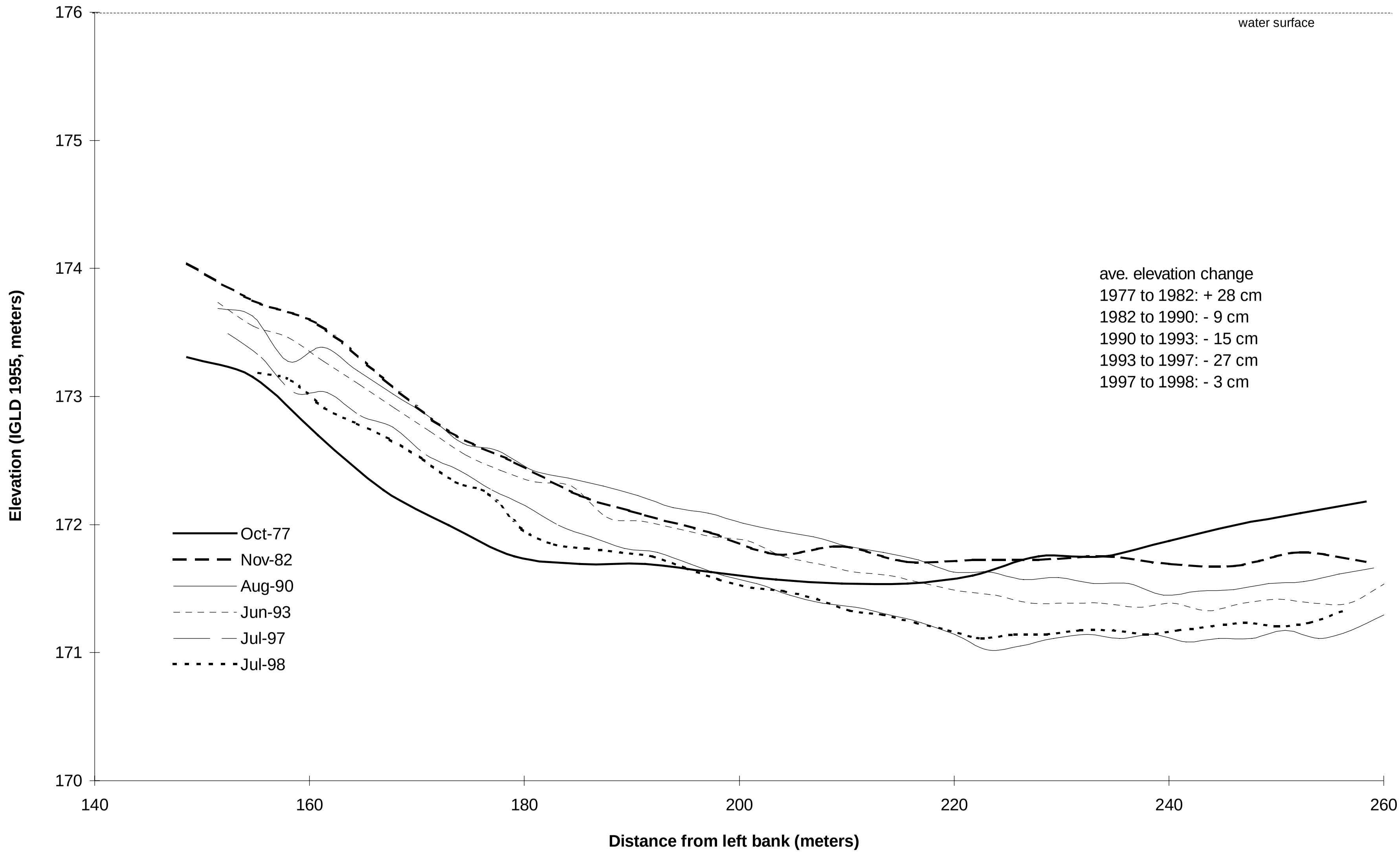


Figure 7A: COE transect 237+00, Lower Fox River at Cooke Park

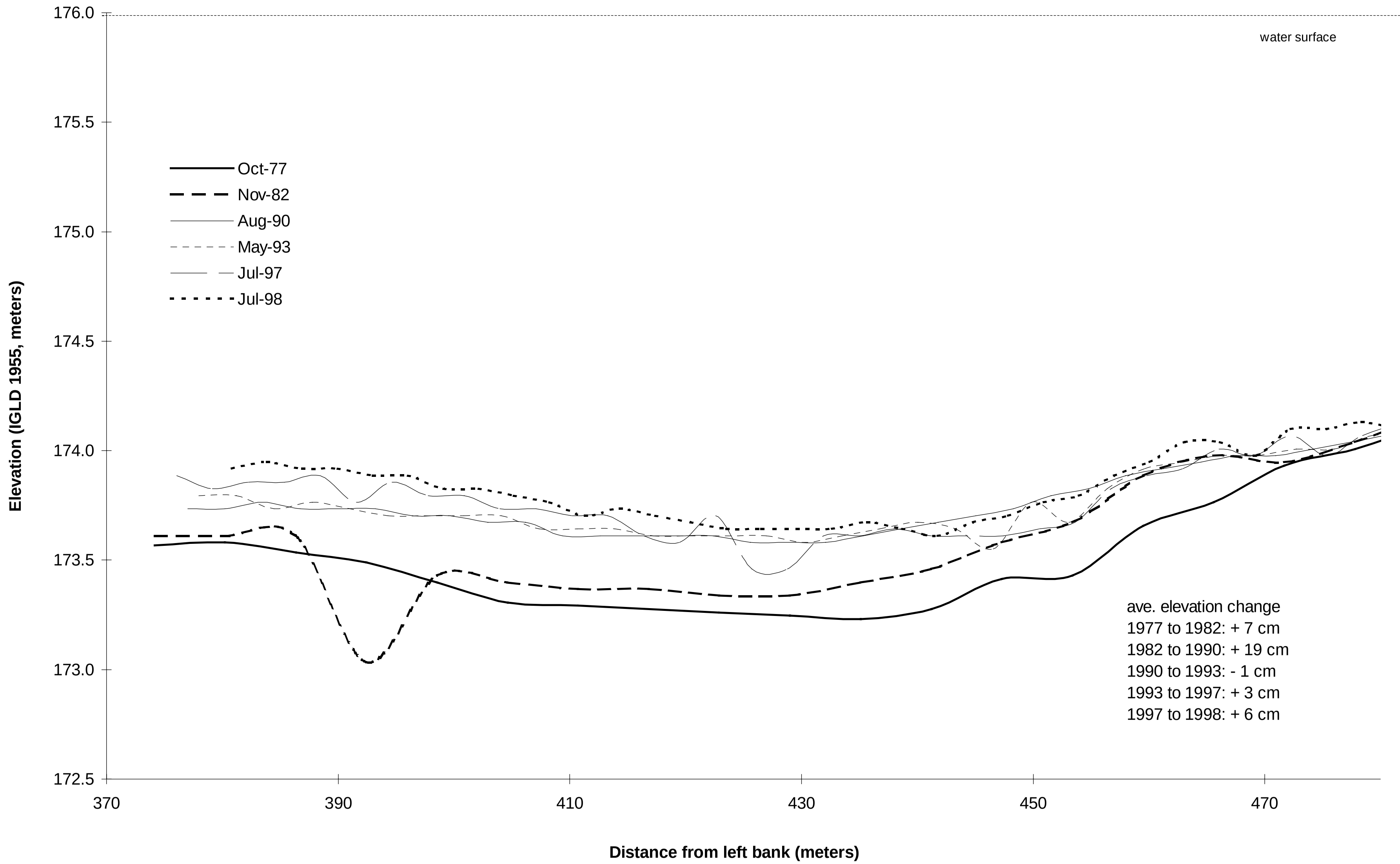


Figure 8A: COE transect 205+00, Lower Fox River at Fort James Co. (West) bulkhead

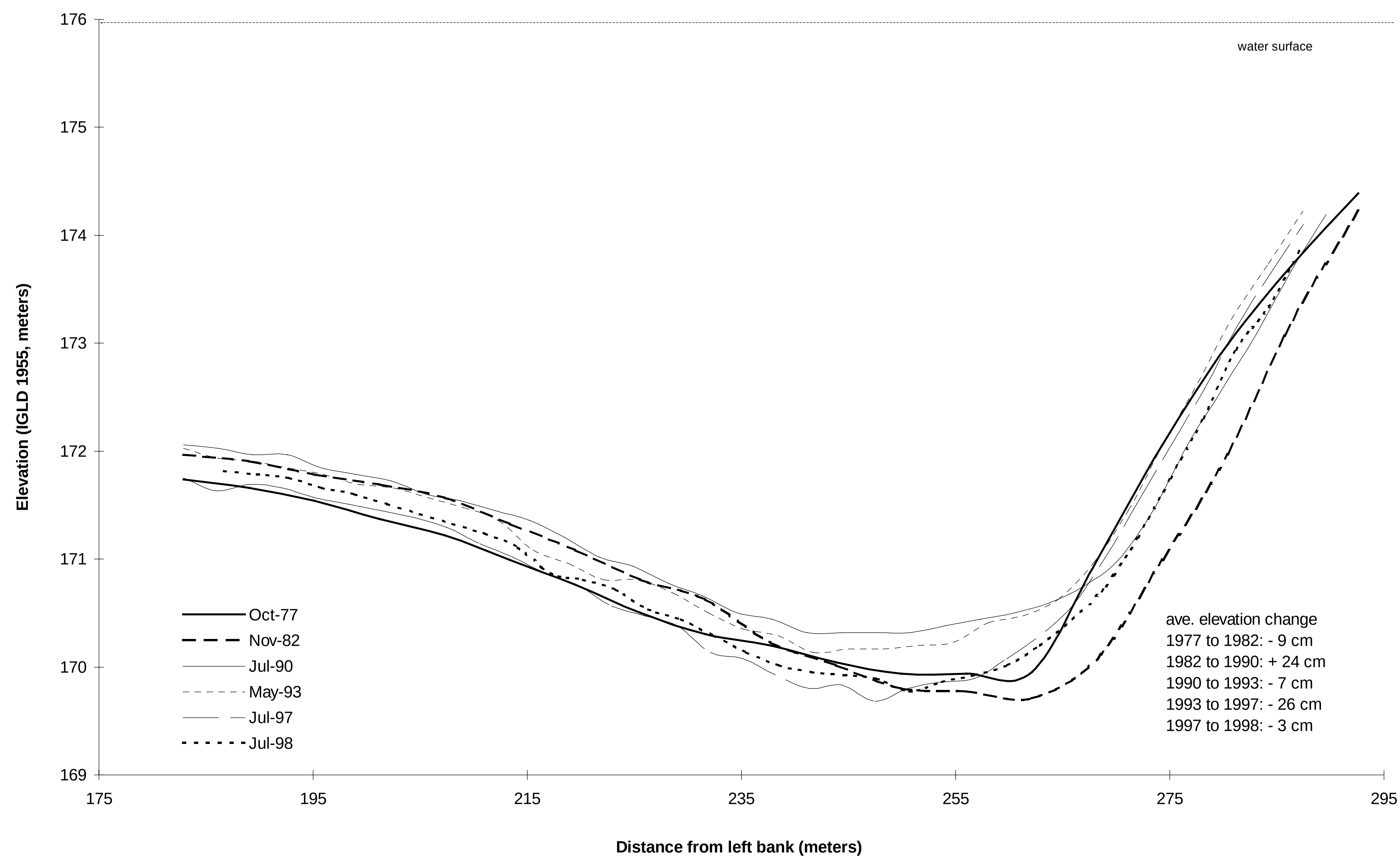


Figure 9A: COE transect 193+00, Lower Fox River at Ft. James Co. (West) intake

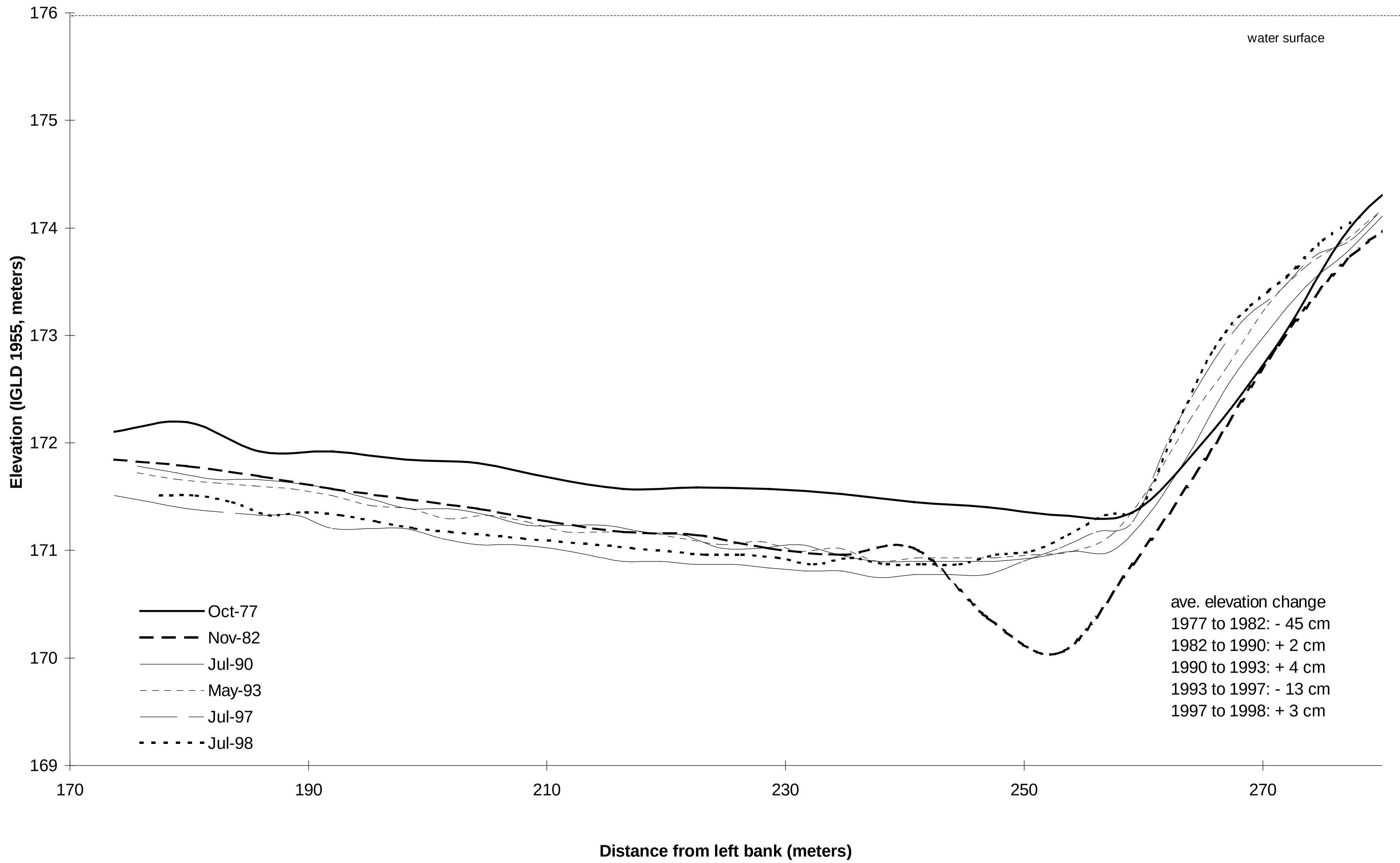


Figure 10A: COE transect 117+00, Lower Fox River at Green Bay Warehouses

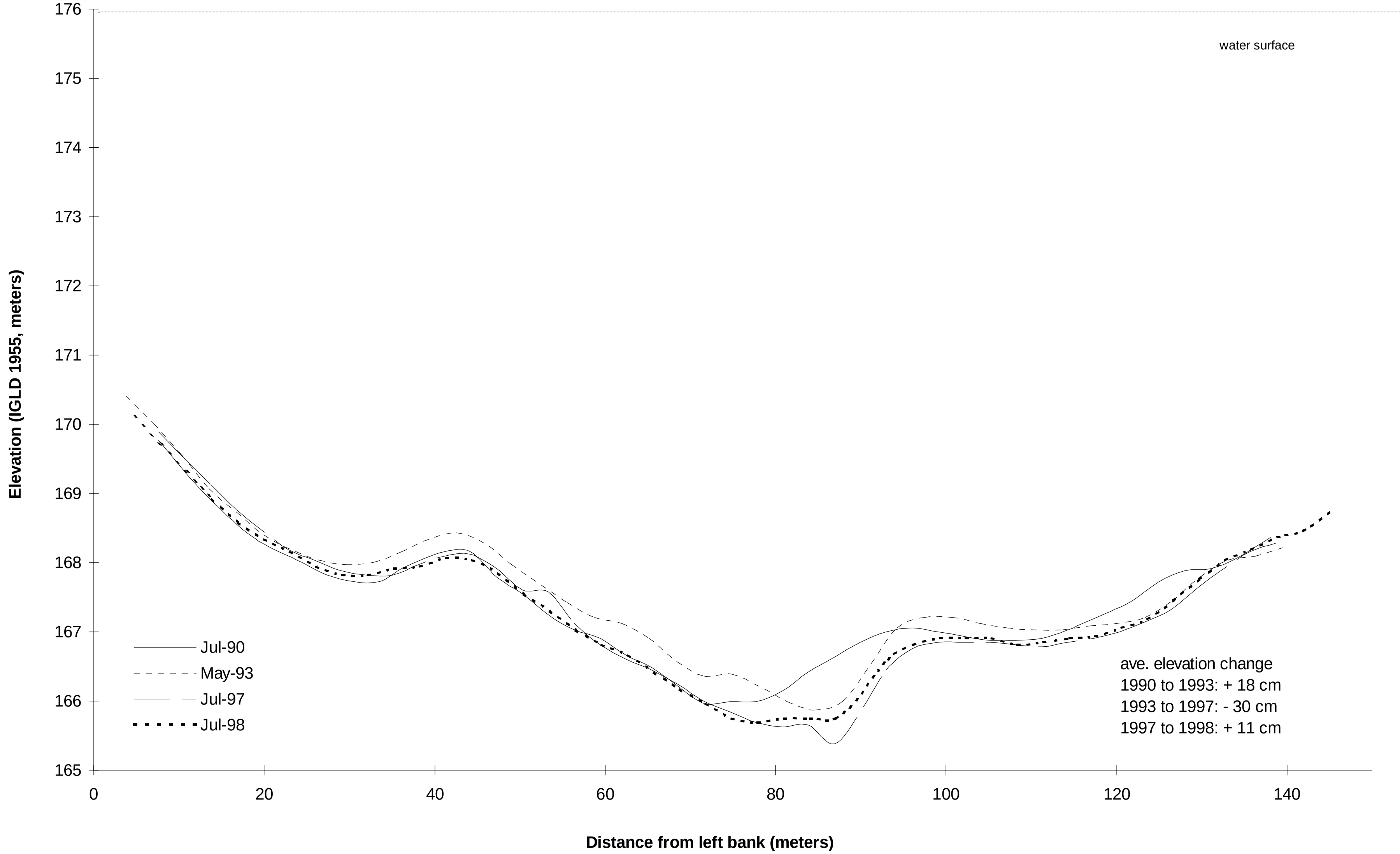


Figure 11A: COE transect 104+00, Lower Fox River at Northwest Engineering

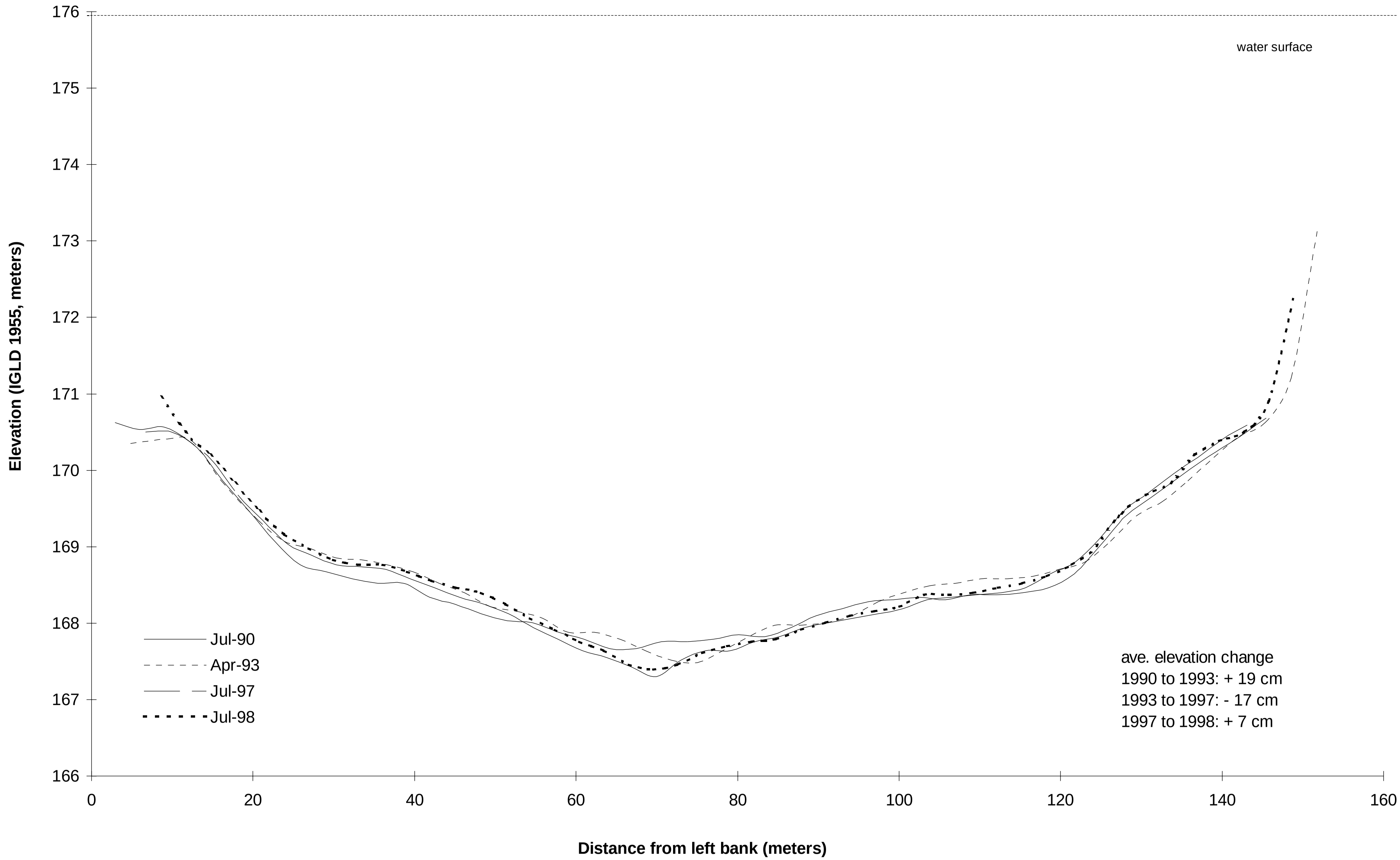


Figure 12A: COE transect 91+00, Lower Fox River at Pine Street

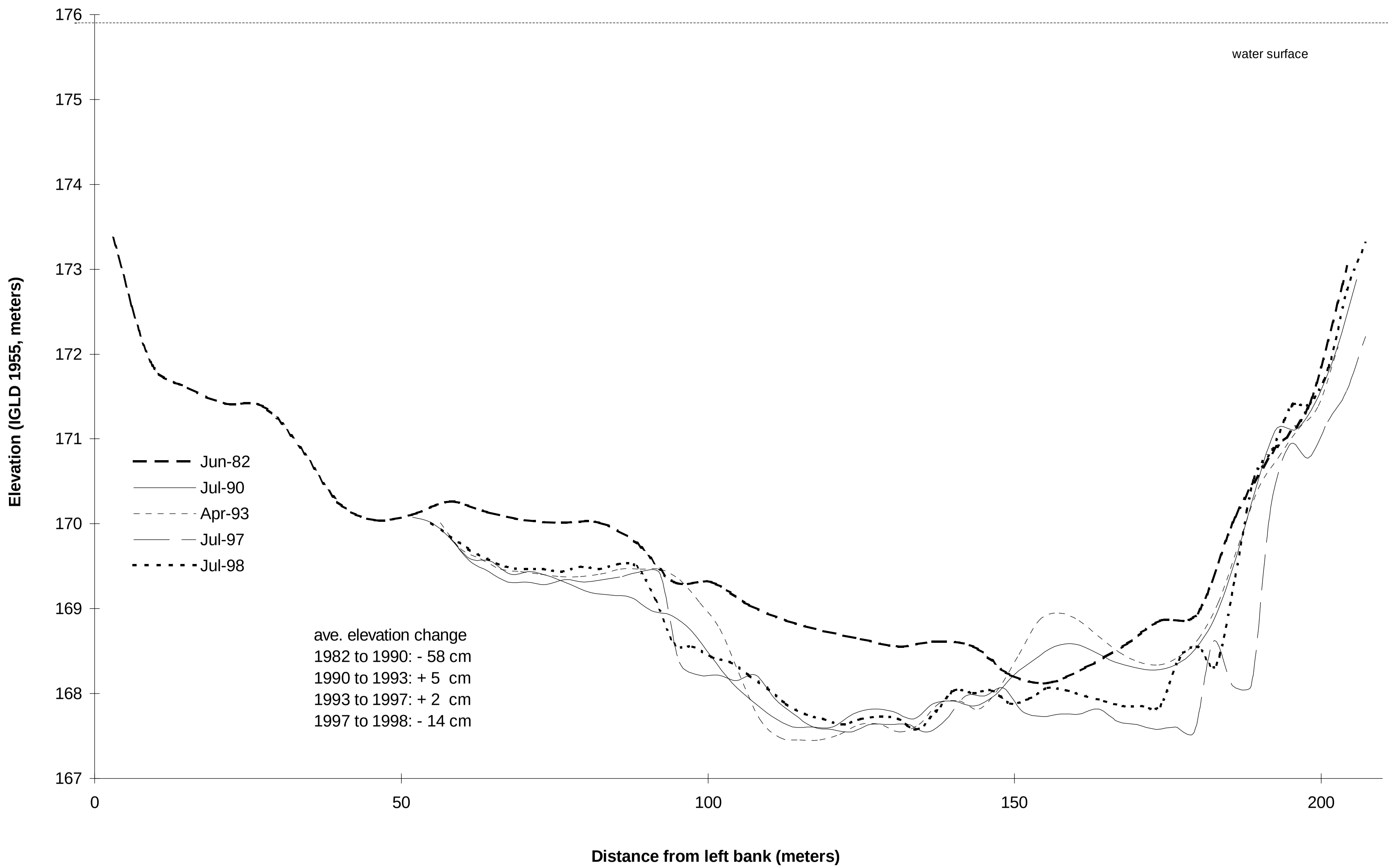


Figure 13A: COE transect 61+00, Lower Fox River at Ft. James Co. (East)

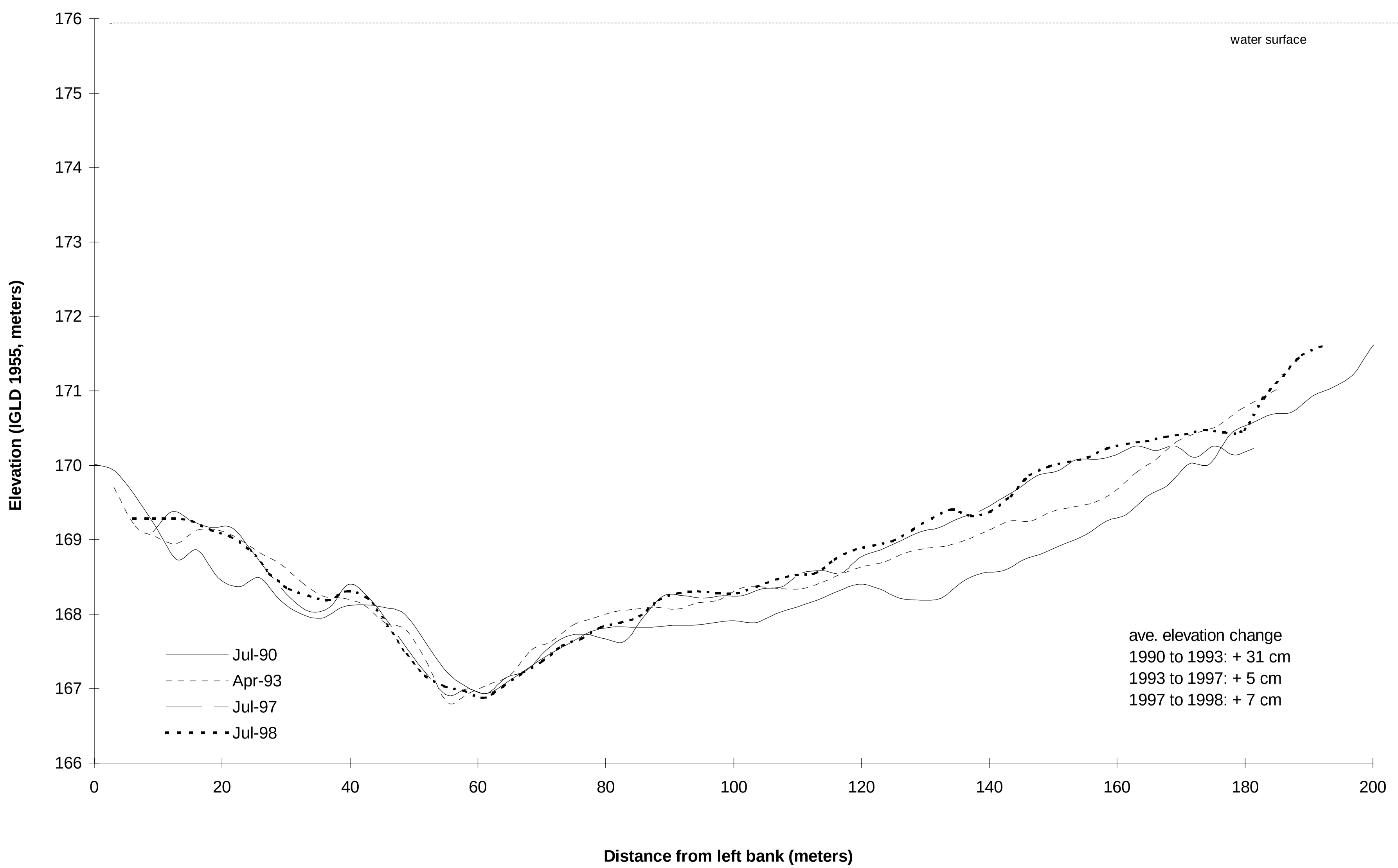


Figure 14A: COE transect 37+00, Lower Fox River at Amoco Oil Co.

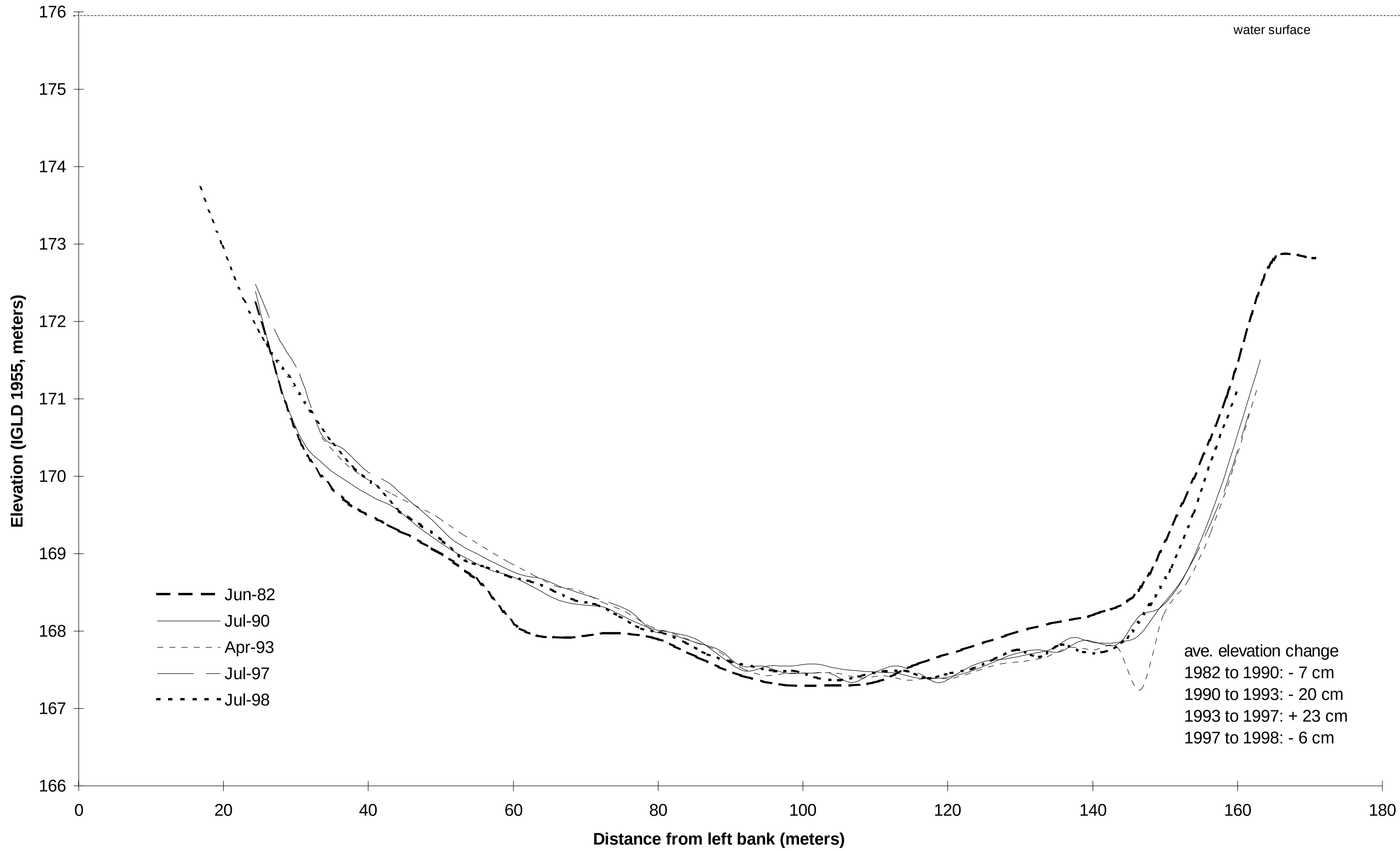
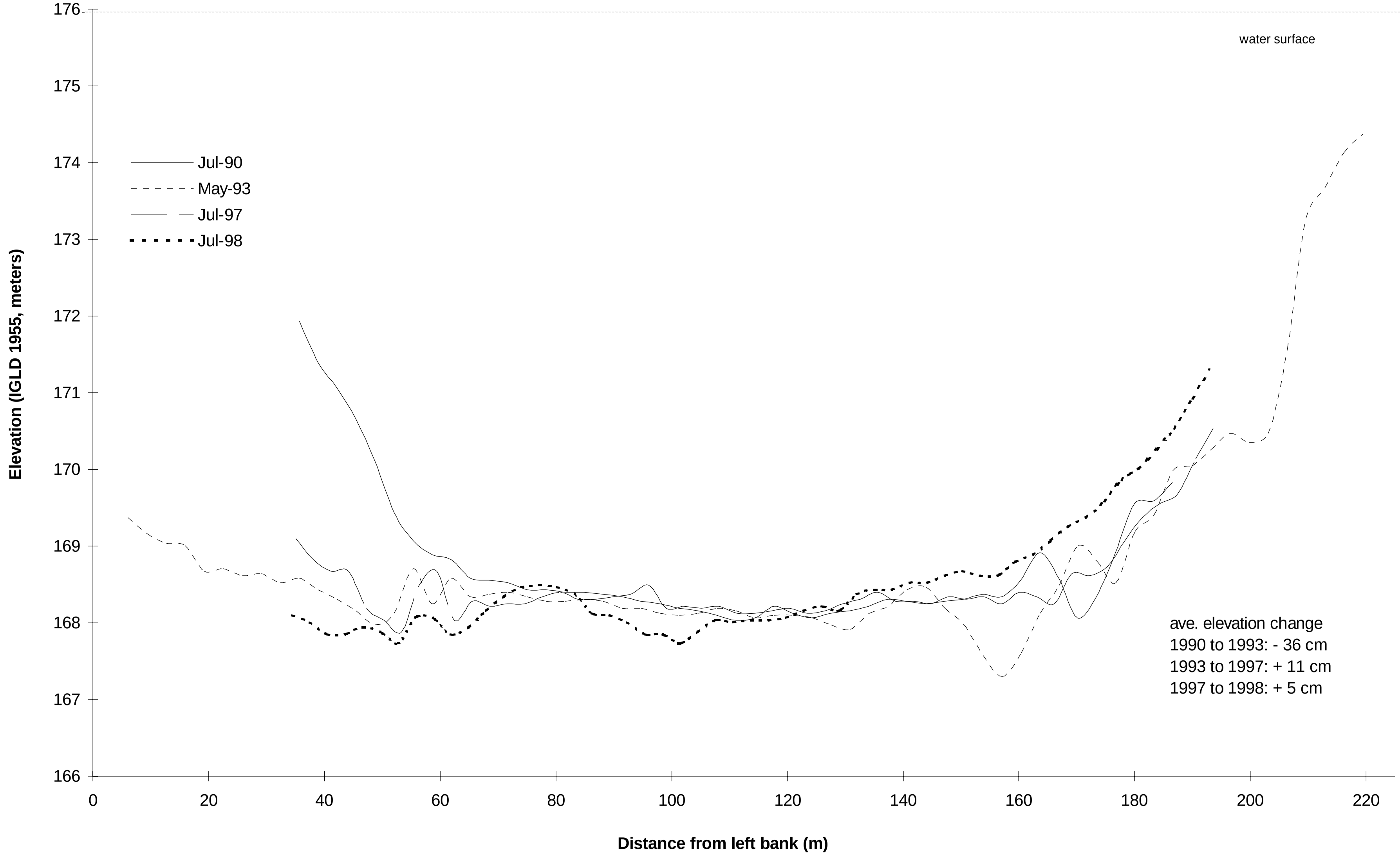


Figure 15A: COE transect 17+00, Lower Fox River at F. Hurlbut Co.



Appendix B

Figure 1B: USEPA Transect 9, Lower Fox River at Voyager Park

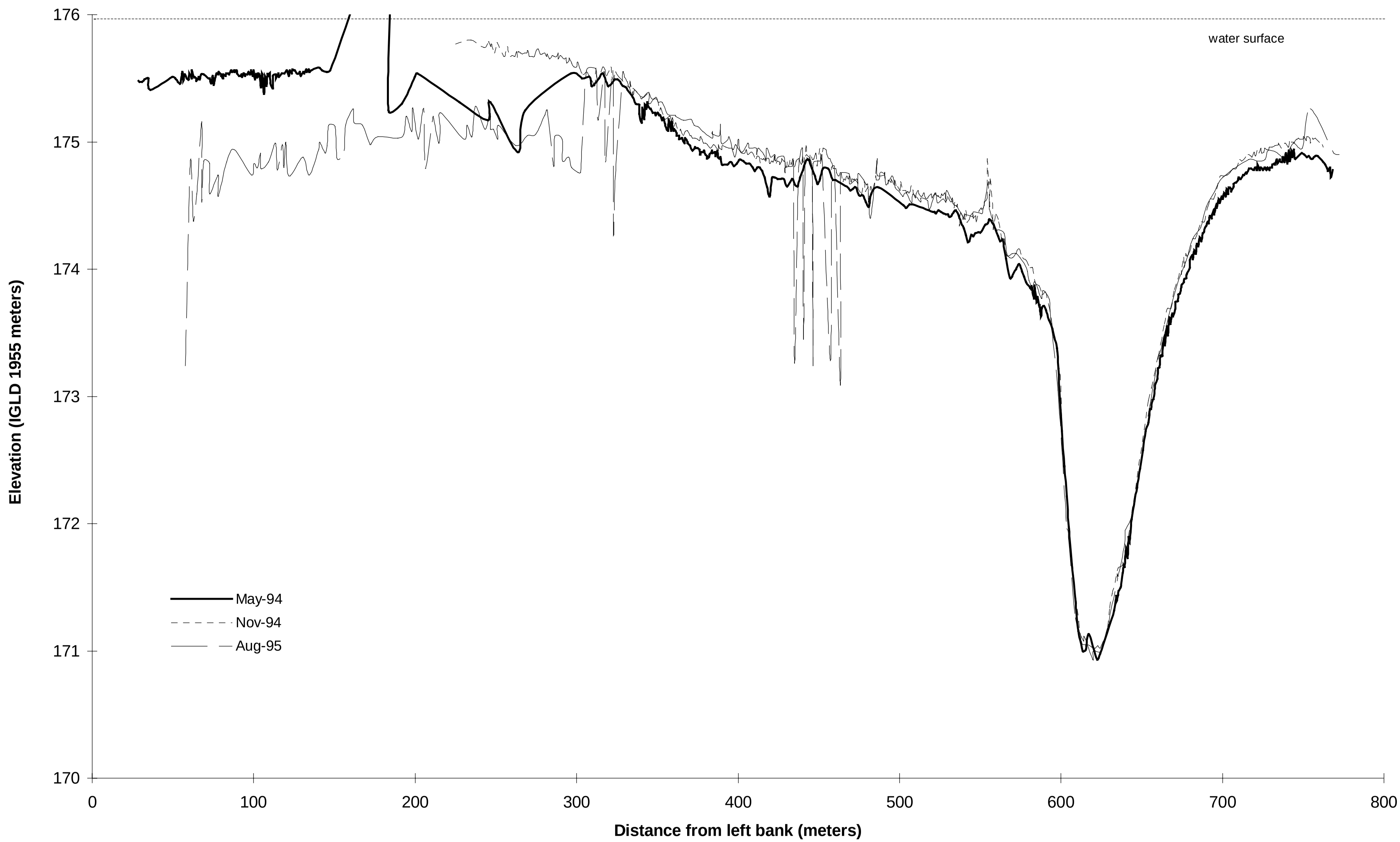


Figure 2B: USEPA Transect 9, Lower Fox River at Voyager Park, Navigation Channel Zoom

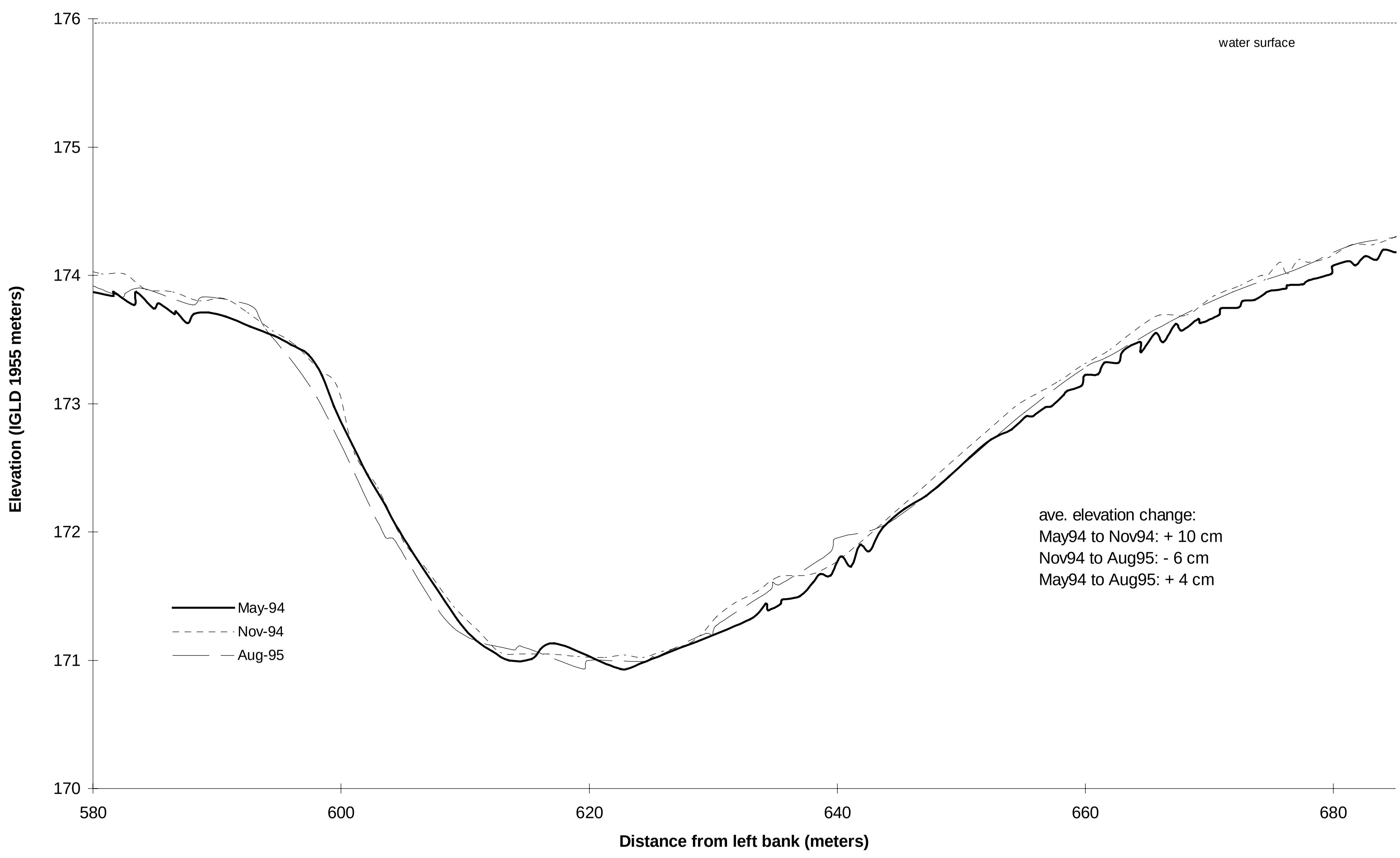


Figure 3B: USEPA Transect 8, Lower Fox River at Depere WWTP

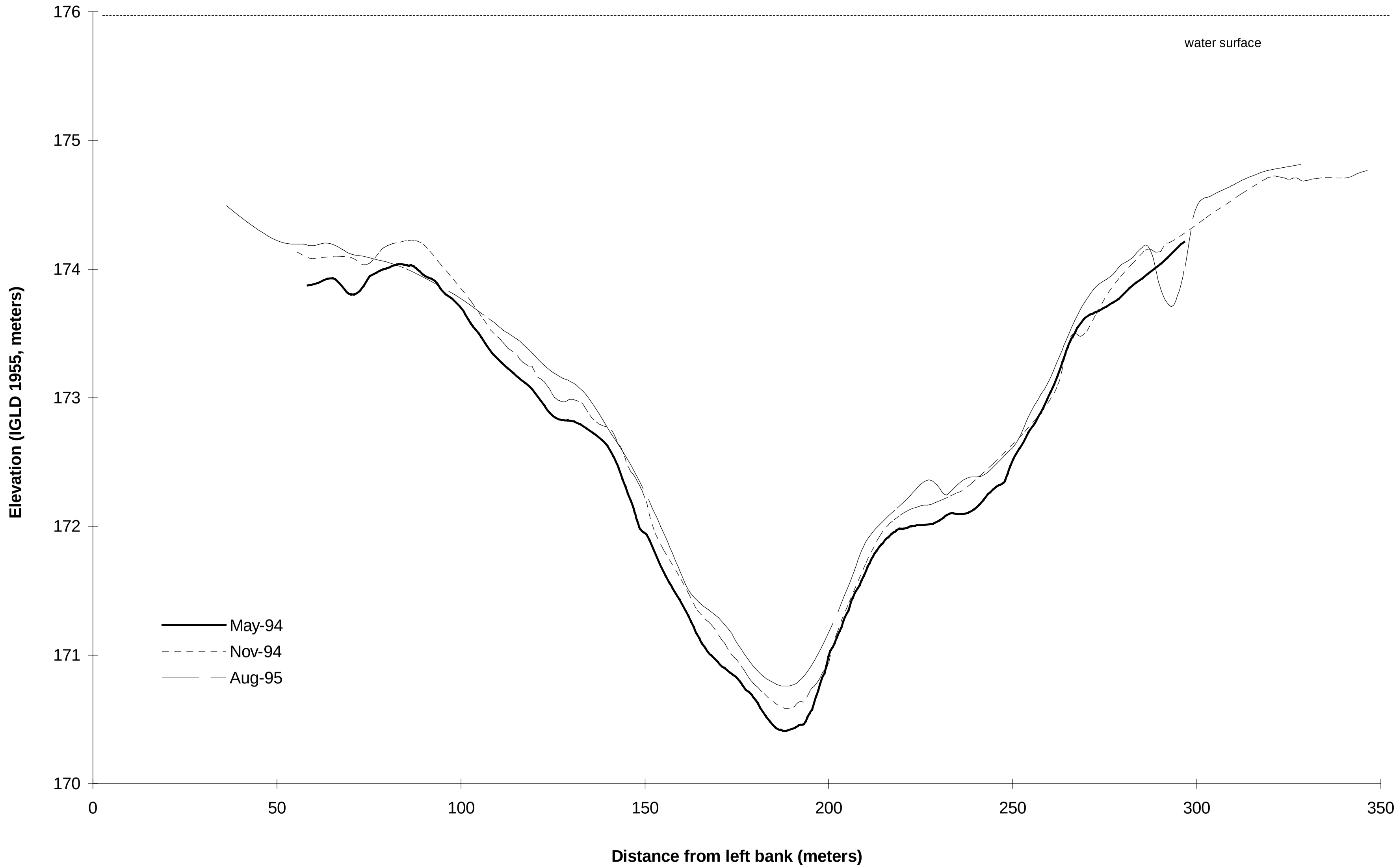


Figure 4B: USEPA Transect 8, Lower Fox River at Depere WWTP, Navigation Channel Zoom

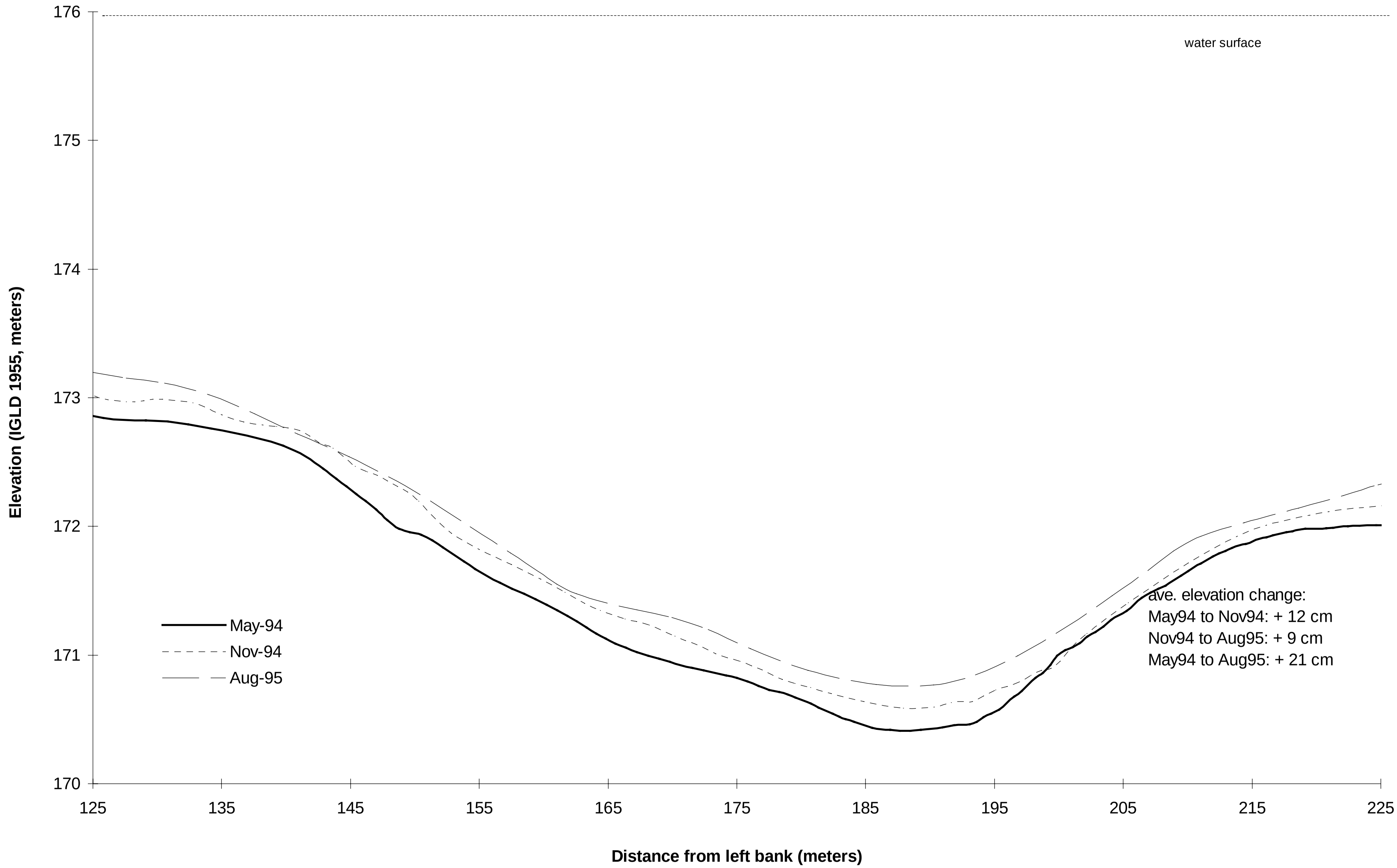


Figure 5B: USEPA Transect 7, Lower Fox River at Hwy. 172 bridge

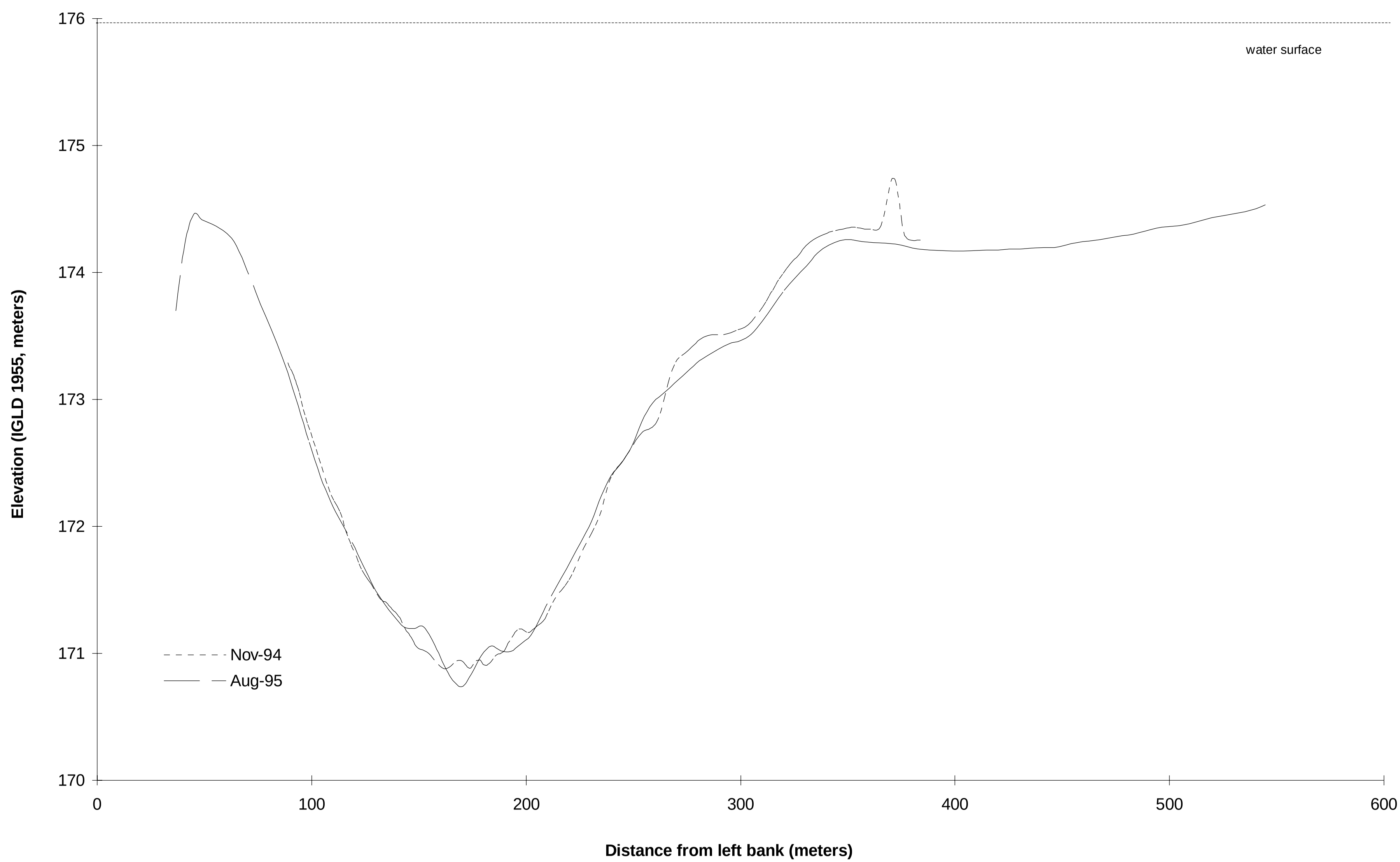


Figure 6B: USEPA Transect 7, Lower Fox River at Hwy. 172 bridge, Navigation Channel Zoom

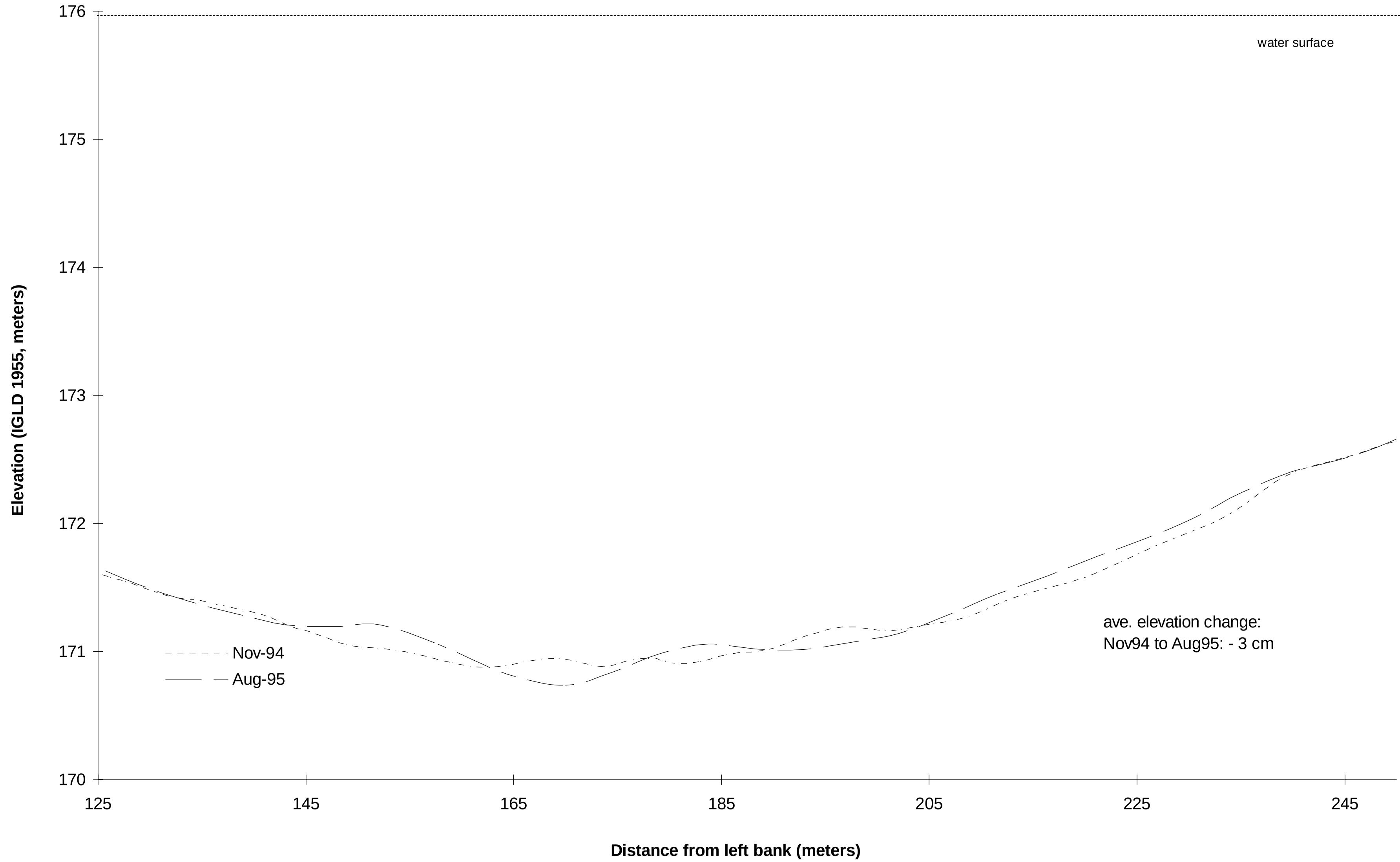


Figure 7B: USEPA Transect 6, Lower Fox River at Cooke Park

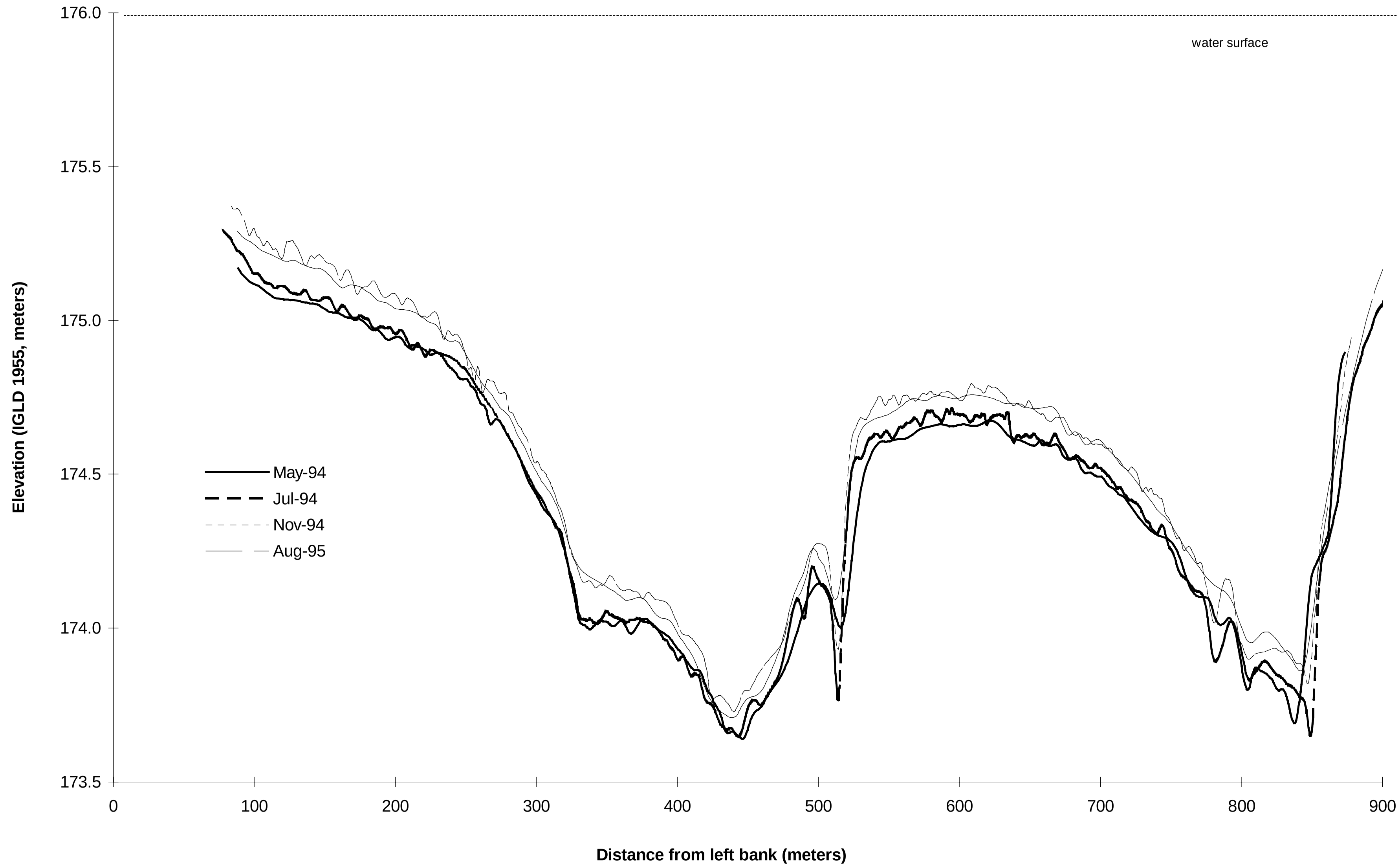


Figure 8B: USEPA Transect 6, Lower Fox River at Cooke Park, Navigation Channel Zoom

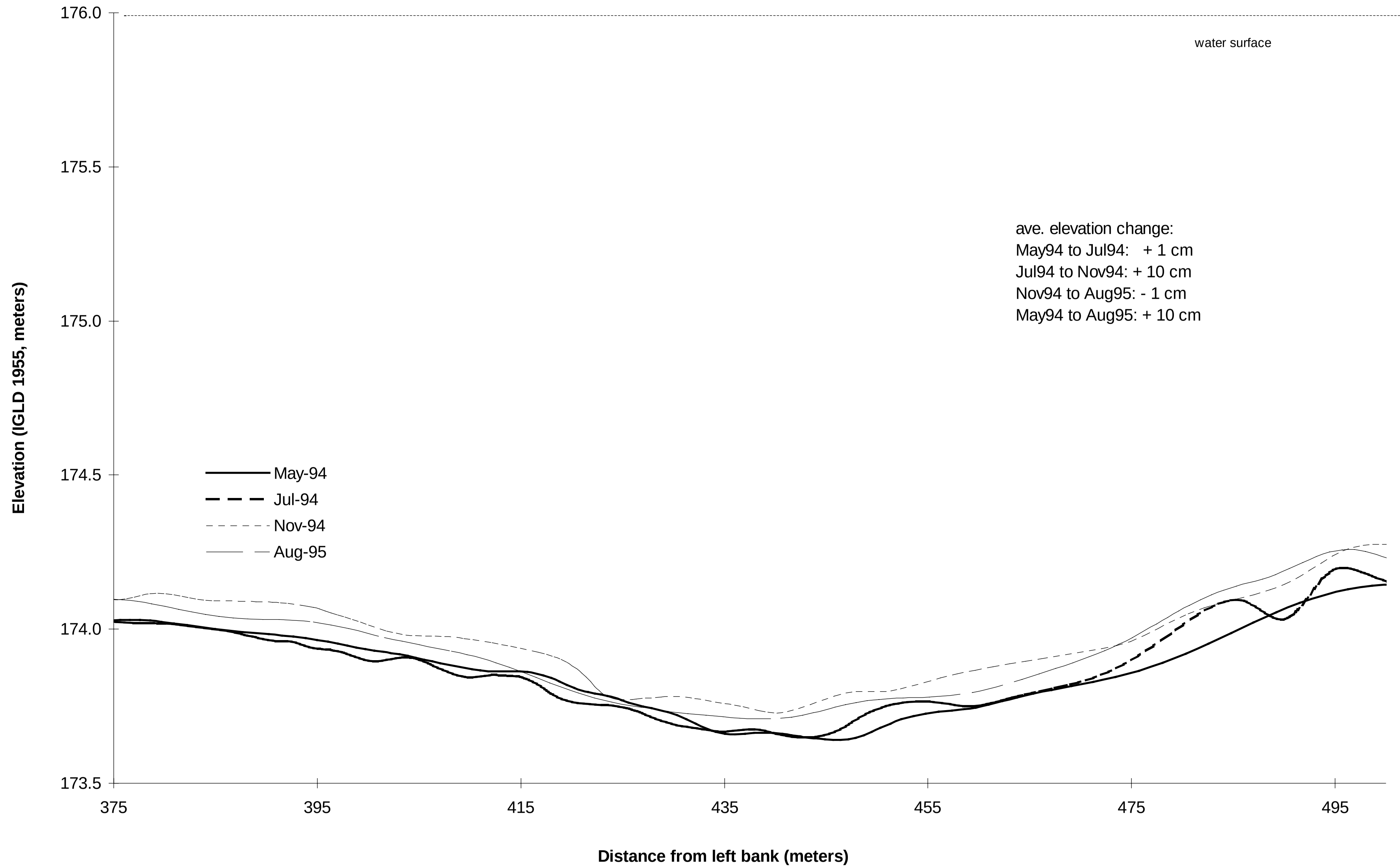


Figure 9B: EPA transect 5, Lower Fox River at Fort James West

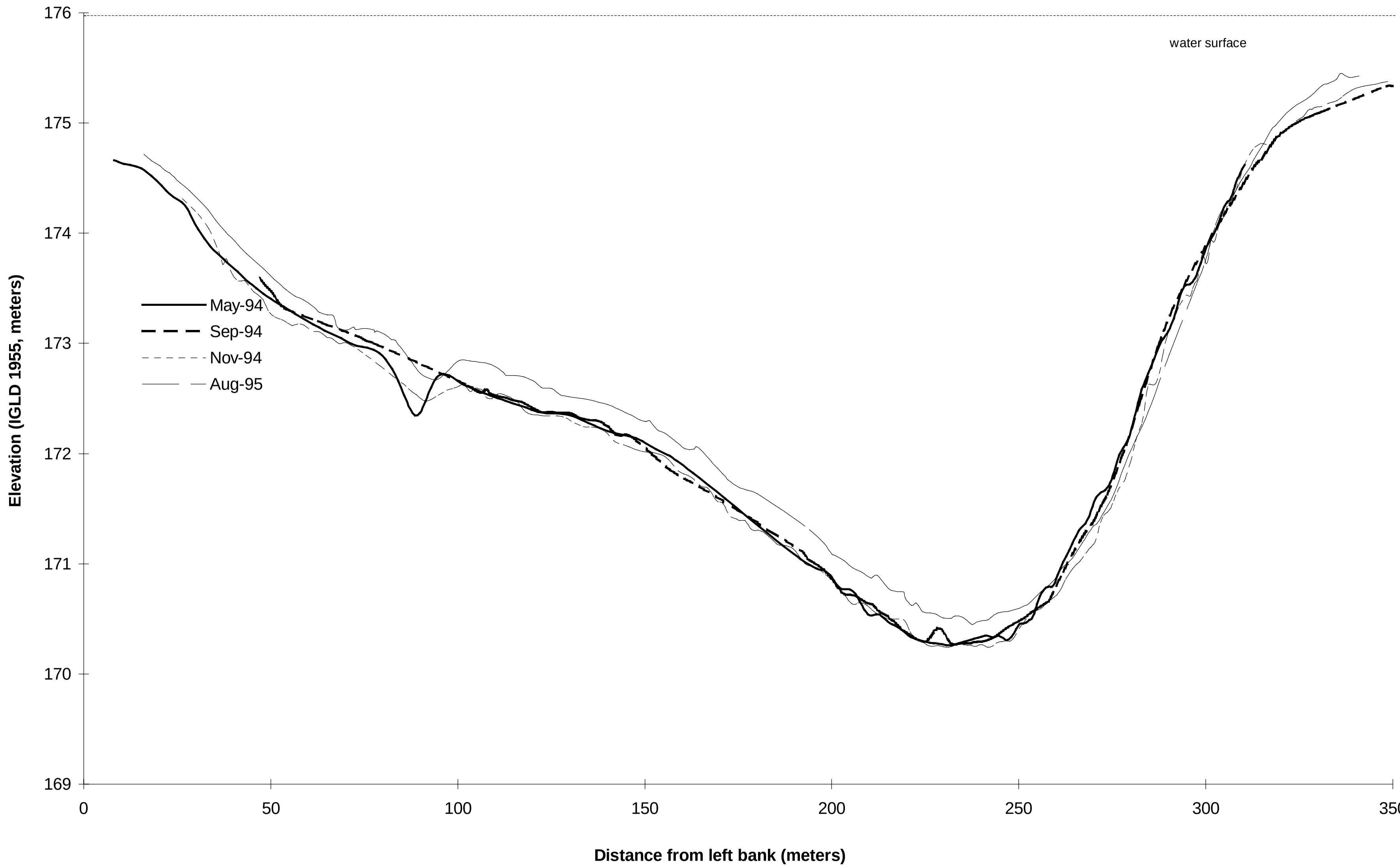


Figure 10B: EPA transect 5, Lower Fox River at Fort James West, Navigation Channel Zoom

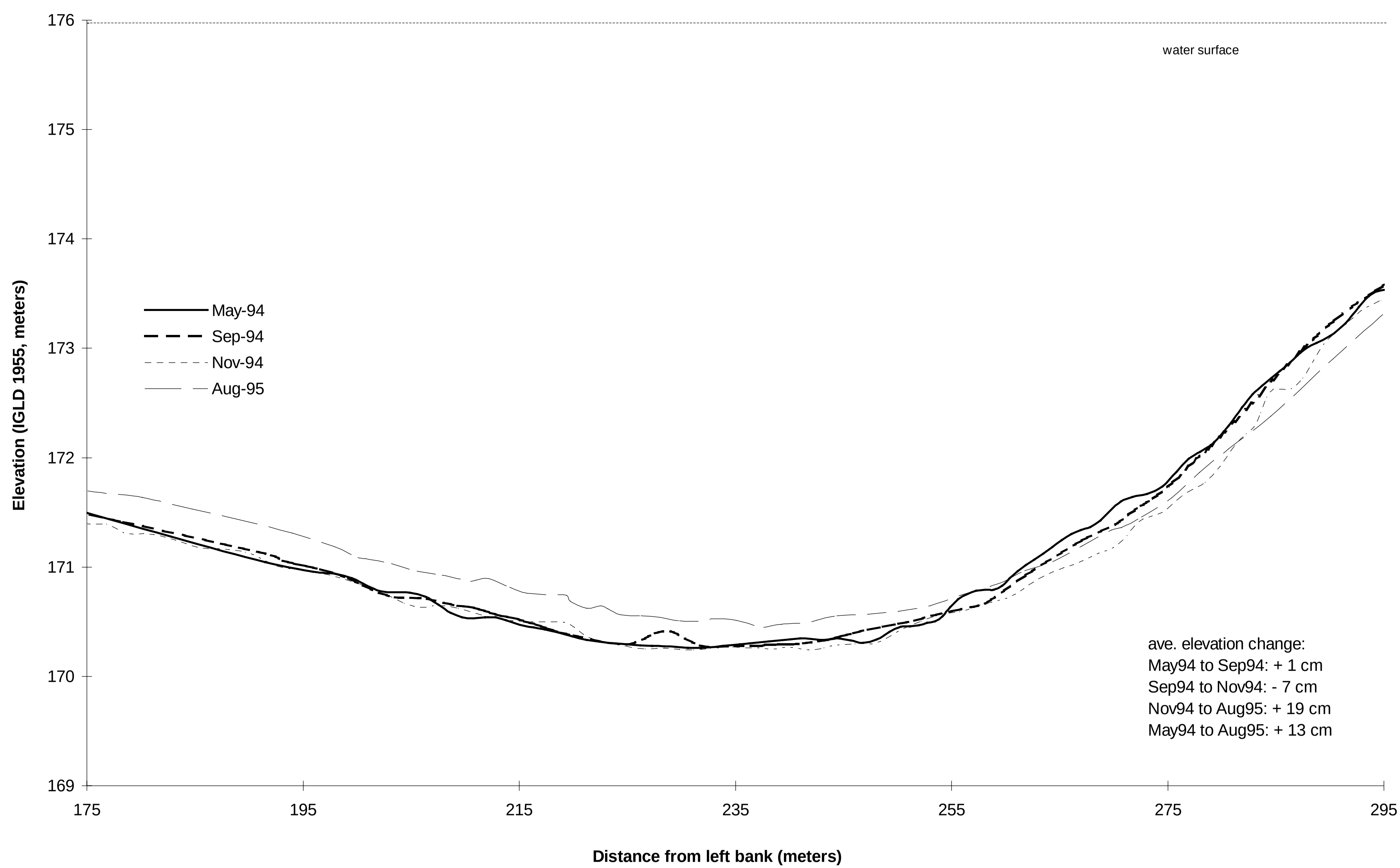


Figure 11B: USEPA Transect 3, Lower Fox River at Fort James East