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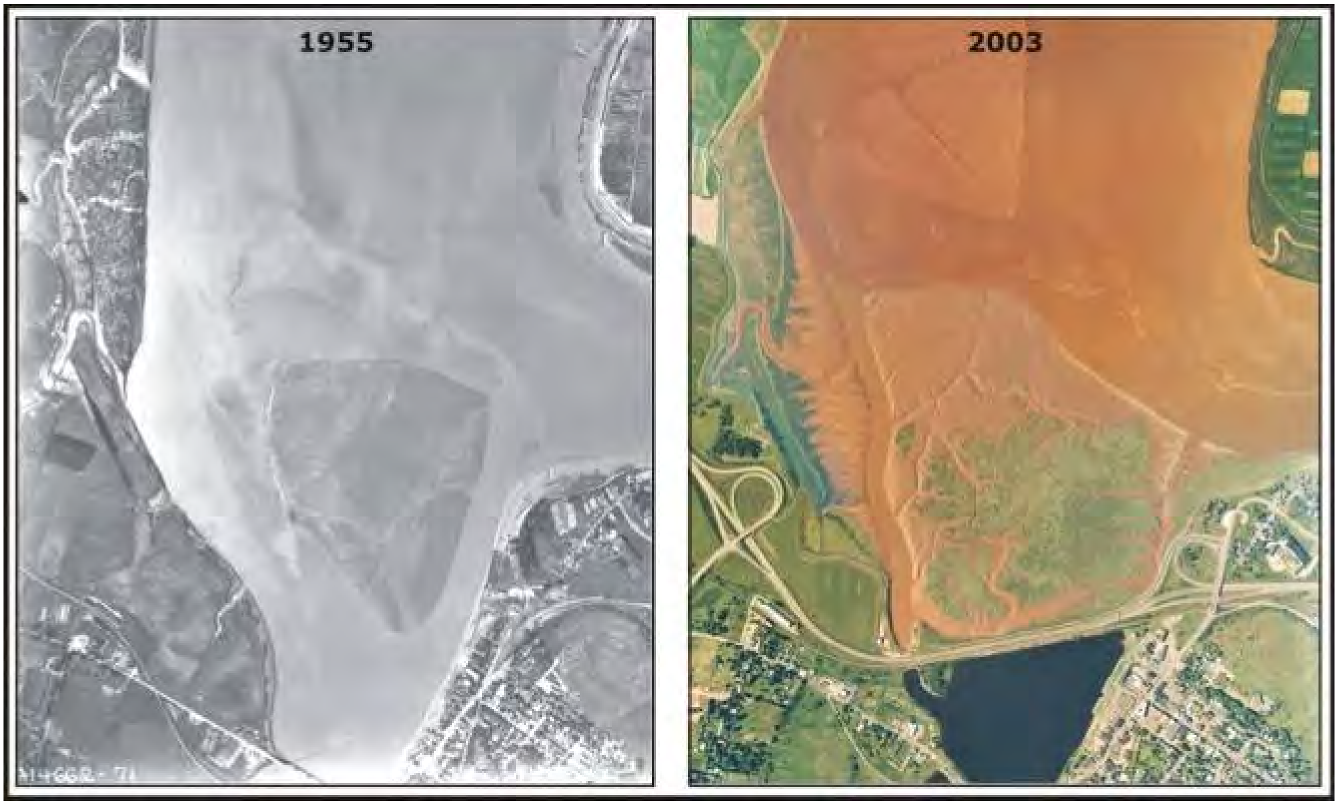
Spatial and Temporal Variations in the Intertidal Geomorphology of the Avon River Estuary



Final report submitted to the
Nova Scotia Department of Transportation and Public Works (NSTPW)

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In collaboration with the
Nova Scotia Department of Agriculture,
Resource Stewardship Division, Land Protection Section

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EXECUTIVE SUMMARY

The purpose of this research project was to examine the historical changes in intertidal geomorphology in a section of the Avon River estuary in the Minas Basin, extending from the town of Windsor to a lighthouse at Horton Bluff approximately 16 km downstream. These results were then used to begin to assess the overall stability and evolution of intertidal environments with the study area. Contemporary cross sectional bathymetric surveys were conducted in December 2005 and compared with historical surveys conducted by the Maritime Marshland Rehabilitation Administration (MMRA) in the late 1960s and early 1970s. In addition, changes in salt marsh habitat were quantified using aerial photo mosaics in ArcGIS 9.1 from 1944 to 2003. As previous research has indicated, the intertidal geomorphology of the Avon River Estuary has been impacted by the construction of the Windsor causeway however the magnitude of this impact is much less than originally postulated in the 1970s. Many of the changes might also be associated with natural changes in the position of main tidal channel thalweg. Key findings of the research presented below:

- The St. Croix River has maintained relatively constant cross sectional area since July 1969 despite major shifts in the position of the main river thalweg.
- The most significant (although not statistically tested at this time) changes in cross sectional area and sedimentation were recorded along lines 1A_DS_1A1AA and 1_DS_11AA immediately downstream of the Windsor causeway. This decrease in cross sectional area (measured from HHWLT) ranged from 71% to 48% along the two lines and between 5.8 to 6.5 m of sediment has accumulated downstream of the causeway.
- The significant accumulation of sediment however has occurred at the site of an intertidal bar present before the construction of the Windsor causeway. This marsh and mudflat surface is now near the limit of the HHWMT level.
- An approximate 21% decrease in cross sectional area was recorded 1000 m downstream of the causeway at Line 5 however there is no change in wetted perimeter and w/d or D/d ratios.
- By Lines 7 and 9, a new intertidal bar (Newport Bar) has developed since 1969, with between 2.9 to 7.1 m of sediment accumulation. However 150 m ($1500m^2$) of marsh has eroded from the western shore (Line 7) since 1955. The resultant cross sectional area in 2005 is only 7% smaller than in November 1970 and this change is lower than those associated with seasonal variability.
- Lines 15 and 16 near Hantsport display very minor changes in bed elevation since 1969, associated with a shift in channel position, and changes in cross sectional area or intertidal channel cross sectional area have been negligible.
- In general, cross sectional area increases with distance from the causeway.
- The shape of the curve of channel width versus distance from causeway does not vary between 1969 and 2005.
- Measures of channel form (e.g. width to depth ratio (w/d) and max to mean depth ratio (D/d)) clearly demonstrate that there is a significant shift in channel form approximately 1 km from the causeway. This suggests that the direct influence of the causeway may be limited to the first 1000m. Beyond this point, the w/d and D/d pattern of change with distance vary only minorly

between 1969, 1970 and 2005. Accretional and erosional changes in the Avon River beyond the first 1000 m may be due to more natural processes such as shifts in the main river thalweg.

- After the first 1000 m, the Avon River is joined by the St. Croix and further downstream by the Kennetcook which both likely play a key role in maintaining a more natural channel form.

- Evidence is presented to support seasonal cycles of changes in bed elevation by as much as 2 m which exceed the difference recorded between 1969 and 2005 in some locations. However this phenomenon will need to be tested further due to potential impacts of the construction process during the historical surveys. This study suggests that seasonality and meteorological conditions can exert a strong influence on the interpretation and comparison of survey data.

- Cycles of erosion and accretion of mudflat and marsh habitat were shown to be strongly influenced by the position of the thalweg of the main tidal channel. The eroded material has the potential to subsequently ‘feed’ any new bar formation however this remains to be tested. This cyclicity in marsh habitat is similar in rate and pattern to studies elsewhere (e.g. UK and Cumberland Basin).

- There is a general increase in the percentage of total marsh area from 1944 (7.6%) to 1955 (8.9%) followed by a sharp decrease in 1964 (5.7%) associated with marsh erosion along the western bank and dyke construction. After this time there is a slight increase in habitat due primarily to progradation of marsh along the south shore of the St. Croix River and initial colonization of the Windsor mudflats. This level jumps to 8.3 % in 2003, likely associated with new marsh growth downstream of the Windsor Causeway. If one bases the analysis on marsh areas common to all of the air photos, the amount of salt marsh (as a % of study area) is higher in 2003 than in 1944 and potentially then may compensate for marsh lost prior to the 1950s due to land reclamation and dyke construction in the area.

There are a number of recommendations that can be made for future research that will directly compliment this study and provide additional valuable information to try and understand the ecomorphodynamics of this system. These are summarized in the points below:

- Conduct at least one or two additional bathymetric surveys over the next year to try and document and quantify the seasonal variability in bed elevation. Since the 2005 survey was conducted in December after considerable rainfall events, it is recommended that the next survey take place during the mid to late summer (July and August) prior to potential influences of the hurricane season in the Maritimes.

- Examine and compare the modern surveys with the 1863 bathymetric chart obtained from the British Admiralty Hydrographic Survey. In addition, it is recommended that the 1969 and 1976 surveys used by Amos (1977) be re-examined and incorporated into the present study to place his results in a more appropriate context.

- Examine tidal and meteorological records, specifically wind speed, direction, rainfall and freshwater discharge records around the dates of the historical and modern surveys to better understand any observed changes. In addition, these variables, particularly the tide and storm records as in conjunction with a detailed lidar survey would help assess the degree of risk to causeway infrastructure from storm surge and rising sea levels.

ACKNOWLEDGEMENTS & FUNDING SOURCES

This research project would not have been possible without the continued support of the Nova Scotia (NS) Dept of Agriculture, Resource Stewardship Division, Land Protection Section personnel, specifically Ken Carroll, Darrel Hingley and Hank Kolstee.

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Tim Milligan and Gary Bugden of the Department of Fisheries and Oceans, Maritimes Division at the Bedford Institute of Oceanography are thanked for providing moral support and a sounding board for issues and ideas that have arisen from this project.

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This research project has been funded by the NS Department of Transportation with in-kind support from the NS Dept of Agriculture, Resource Stewardship Division, Land Protection Section. Components of the research were also supported by a Natural Sciences and Engineering Research Grant (NSERC) to D. van Proosdij and a Student Employment Experience Grant from Saint Mary's University.

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INTRODUCTION

In a ‘natural’ world, salt marshes and mudflats represent systems delicately balanced between hydrodynamic forces and ecological, sedimentological and morphological responses. However, this balance may be changed as a result of anthropogenic activities such as construction of engineering structures (e.g. causeways, culverts, shore protection), dredging or altering landuse activities. Over the last century, the majority of rivers entering into the Bay of Fundy have been highly modified through the construction of tidal barriers such as causeways and culverts. The construction of these barriers has resulted in either partial or complete obstruction of tidal flow in many areas around the Bay. Tidal barriers decrease turbulent energy in the tidal system causing sediments and other particles to drop from suspension and accumulate as deposits of mud, sand and silt. The development of the highly productive marsh downstream of the existing causeway below Windsor, NS is a prime example and has been described in a number of publications (e.g. Amos 1977; Turk et al., 1980; van Proosdij and Townsend, 2004; Daborn et al., 2003a;b; van Proosdij et al., 2004). In other areas, localized erosion may be initiated either directly upstream or downstream of a partially restrictive barrier (Bowron and Fitzpatric, 2001). Ecosystems such as mudflats and salt marshes are some of the first environments to feel the effects of coastal modification.

The construction of barriers across tidal rivers and estuaries has a long history of altering the sediment dynamics and ecosystem processes in their surrounding area. The degree of alteration to the system depends in part on structure design, surrounding geology, sediment characteristics, tidal range and basin morphology. Tidal barriers can cause changes in sedimentation patterns within the estuary that may, over time, alter the cross sectional area of the channels and the overall capacity of the system to distribute tidal waters. Restriction of flow can increase the risk of flooding from both upstream (e.g. tide gate will not be able to ‘flush’ or discharge water due to high amounts of sedimentation) and downstream (e.g. storm surge and perigeen spring tides) sources. The potential for flooding will continue to increase with rising sea levels, placing infrastructure at risk. However, mudflats and salt marshes can also play a positive role in protecting infrastructure through the dissipation of storm waves. Therefore it is critical to know how intertidal systems evolve over time and how and at what rate the intertidal geomorphology is changing.

Research on the impacts of these structures generally is stimulated in the initial scoping phase of the project (e.g. Fundy tidal power or Storm surge barriers in the Netherlands) or after the effects on ecosystems become noticeable (e.g. Petitcodiac, Netherlands land reclamation project, Australian Ord River Estuary). In most cases excessive siltation is reported in the years following closure of the estuary with extensive changes to the intertidal geomorphology (eg. Wolanski et al., 2001 in Ord River Estuary, Australia; Bray et al., 1982 in the Petitcodiac River, Canada; Tonis et al., 2002 in Haringvliet estuary, Netherlands), in the composition of intertidal sediments (e.g. Turk et al., 1980 on the Windsor mudflats), in ecosystem processes and composition (e.g. Locke et al., 2003 in the Petitcodiac River; Smaal and Nienhuis, 1992 in the Eastern Scheldt, Netherlands) and altered hydrodynamics and decreased tidal prism (e.g. Amos, 1977 in the Avon River; Owen and Odd, 1972 on the Thames Estuary, UK).

The ecological impacts of tidal barriers have been extensively documented (e.g. Locke et al., 2003 in the Petitcodiac River; Smaal and Nienhuis, 1992 in the Eastern Scheldt, Netherlands; Wells, 1999;

Niles, 2001, Bay of Fundy) and range from changes in intertidal habitat and nutrient cycling to interference with the movement of fish or invertebrates. In some cases fish passage is completely obstructed. Impacts of tidal barriers are both negative (e.g. decrease fish passage) and positive (e.g. new growth of intertidal habitat) and it is often difficult to discern natural versus anthropogenic impacts. Many studies are limited by the lack of accurate and reliable historical data.

'Ecomorphodynamics' refers to the study of the interactions and feedbacks that occur between topography, biota (e.g. vegetation and invertebrates), hydrodynamic (e.g. waves and currents) and sedimentary (e.g. suspended sediment concentration, deposition, erosion) processes and the resultant adjustment of morphology. These feedbacks are clearly evident within the vast intertidal ecosystems located in the Bay of Fundy. For example, changes in marsh or mudflat surface elevation within the tidal frame or changes in edge morphology will in turn induce changes in tidal prism (volume of water that must pass through a particular cross section to raise the water level from low water to high water), hydrodynamic forces, vegetation community structure, rates of sedimentation and dissipation (marsh platform) or amplification (cliff) of wave energy. The rate of these changes can be significantly influenced by human development such as the construction of tidal barriers or installation of shore protection.

However, teasing out the impacts of these large scale structures from natural ecosystem changes (e.g. storm frequency, sea level, sediment sources) or non point impacts (e.g. historical dyking) can be a challenge. Cycles of progradation and retreat have been documented on a number of marsh and intertidal systems (e.g. Ollerhead et al. in press: Baker and van Proosdij, 2004; van der Wal and Pye, 2004; Cox et al., 2003; Pringle, 1995). These cycles have been linked to changes in sea level (van der Wal and Pye, 2004; French and Burningham, 2003; van der wal and Pye, 2003; Vos and van Kesteren, 2000; Allen, 2000; Allen, 1989) and in the tidal prism due to human activities such as tidal barrier construction (Allen, 2000), dyke construction (e.g. Hood, 2004) or dredging (French and Burningham, 2003; Cox et al., 2003), changes in wind/wave climate (van der Wal and Pye, 2004; Cox et al., 2003; Allen and Duffy, 1998; Pye, 1995; Allen, 1989), sediment supply (Allen, 2000; Gordon et al, 1985), cliff morphology (Moller and Spencer, 2002; Pringle, 1995; Pye, 1995), intertidal sedimentation (Schwimmaer and Pizzuto, 2000; Shi et al., 1995), river discharge (Allen et al., 1976) and changes in the location of the major tidal channel (Allen, 1996; Pringle, 1995; Pye, 1995; Shi et al., 1995). Many of these studies also indicate the difficulty of discerning changes based on limited field data either of a historical or contemporary nature.

One of the most effective ways of documenting these changes is through the analysis of rectified aerial photographs and bathymetric charts within a GIS system. This is the preliminary stage that is required before any true questions regarding the 'why' of these changes can be addressed and the future vulnerability of the area to flooding be assessed. This information can then serve as the basis for future hydrodynamic modeling exercises. The purpose of this research project was to examine historical changes in the intertidal geomorphology of the Avon River Estuary. This project forms one component of a larger collaborative research project between Saint Mary's University, the Nova Scotia Department of Agriculture Resource Stewardship Division, Land Protection Section, the Nova Scotia Department of Transportation and Public Works (NSTPW) and the Department of Fisheries and Oceans (DFO) Maritimes Region. The study area focuses on areas where historical data are most widely available, specifically on a section downstream of the existing causeway at Windsor, N.S., and includes sections of both the St. Croix and Kennetcook Rivers (Figure 1). Four specific objectives were addressed:

1. Detailed examination of the position of intertidal geomorphological features (e.g. salt marsh and mudflats) downstream of the Windsor Causeway, pre and post causeway construction.

2. Quantification of changes in salt marsh habitat from 1944 to 2003.

3. Preliminary integration of available bathymetric data into GIS environment including datum conversions and generation of preliminary cross sectional area calculations for selected transects.

4. Evaluation of the overall stability and evolution of intertidal environments within the study area and management implications.

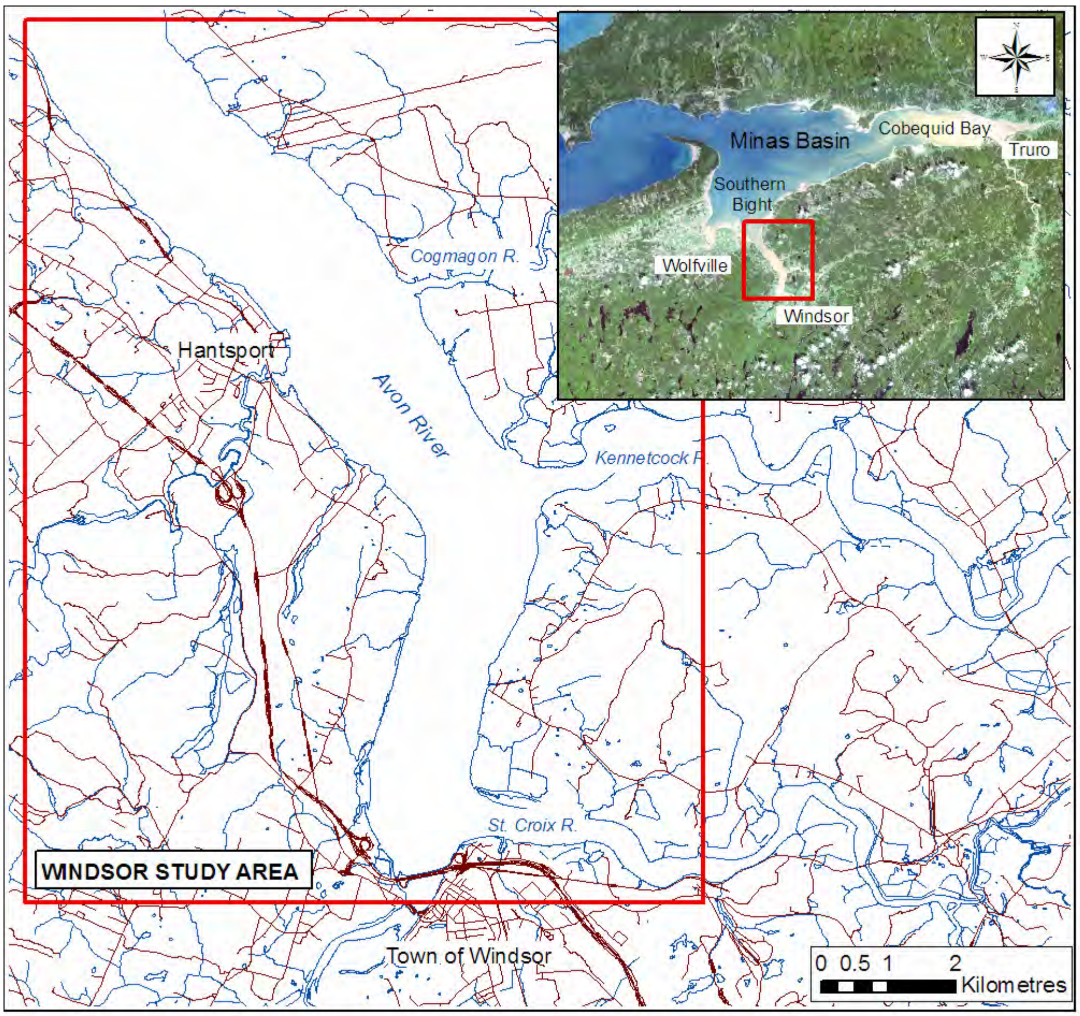

Figure 1: Location of study Windsor study area based on 1:10,000 digital planimetric data and Landsat 7 satellite imagery.

STUDY AREA

Geographical Setting and Characteristics

The upper Bay of Fundy is a macro tidal estuary characterized by a semi-diurnal tidal regime with a maximum tidal range of 16 m, high suspended sediment concentrations and the presence of ice and snow for at least 3 months of the year. This research project was conducted on a section of the Avon River estuary in the Minas Basin, extending from the town of Windsor to a lighthouse at Horton Bluff approximately 16 km downstream, incorporating sections of both Hants and Kings Counties. It incorporates both the St. Croix and Kennetcook Rivers which drain into the Avon River from the eastern section of the study area (Figure 1). The mean annual temperature (1913-2006) at the nearby Kentville meteorological station was 6.8 ^{0}C with a mean total annual precipitation of 92 mm (Figure 2).

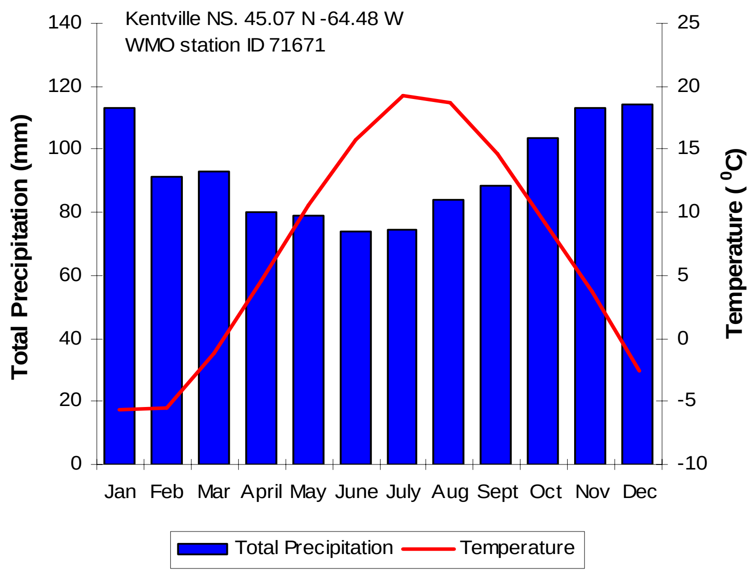

Figure 2: Climatograph for Kentville, NS, based on data from 1913-2006

Intertidal Ecosystems

Due to its macrotidal nature the upper Bay of Fundy has an extensive intertidal zone which contains primarily sand or mudflat and salt marsh ecosystems. These ecosystems form an important component of the estuarine food web contributing nutrients and organic matter (e.g. Daborn et al., 2003; Gordon and Cranford, 1994; Gordon et al., 1985; Van Zoost, 1969). Salt marshes may be categorized as either high (e.g. *Spartina patens*) or low marsh (e.g. *Spartina alterniflora*) species (Figure 3). In general, high marsh occurs above the mean high water level while the low marsh occupies the zone between mean high water and the high water level of neap tides (Daborn et al., 2003a).

Figure 3: Spartina alterniflora on Windsor salt marsh August, 2001.

During the winter months, intertidal areas are covered with snow and ice that is rafted in with the tides and stranded on the marsh surface and within the tidal creek channels (Figures 4 and 5). This ice is quite ephemeral in nature, and can appear and disappear within only a few tides (van Proosdij, 2005). These ice blocks contain high concentrations of both sediment and plant rhizome material which are important inputs to the salt marsh system (Ollerhead et al., 1999; van Proosdij et al., 2006). This sediment, including very coarse material, can be deposited on the marsh surface in the spring. Standing vegetation in the spring is quite sparse, having been sheared off in most years by ice and wave action. Significant amounts of marsh wrack material will then accumulate along the edge of the causeway and dykes. This material will be exported into the estuary in areas exposed to wave action (e.g. Windsor mudflats). Marshes in more sheltered areas will retain more of their dead material and it will decompose *in situ* (Gordon and

Cranford, 1994). This is also evident at the Windsor site with dead *spartina alterniflora* lying flat on the marsh surface in more sheltered areas.

Figure 4: Ice blocks stranded on the Windsor saltmarsh close to the Windsor Tourist Bureau on Feb 16, 2005. Photo by K. Carroll, 2005.

Spartina alterniflora will rapidly colonize exposed mudflats once these flats have risen to at least the high water level of neap tides if there is a seed or rhizome source nearby. One of the most effective means by which colonization occurs on isolated mudflat areas such as the Windsor mudflat is through rhizome fragments contained within ice blocks (Figure 5). The new growth displays an initial circular form with annular expansions. Once several of these colonies have coalesced, colonization follows more of a radial pattern. The patterns of this mechanism of colonization have been documented on the Windsor marsh/mudflat complex (van Proosdij and Townsend, 2004) (Figure 6). A comprehensive description of the estuary and surrounding region as well as a summary of previous research in the area may be found in Daborn et al., 2003. Detailed ecological studies on flora, invertebrate, avian and fish population dynamics near the causeway are provided in Daborn et al., 2003a; van Proosdij et al., 2004 and Daborn and Brylinsky, 2004.

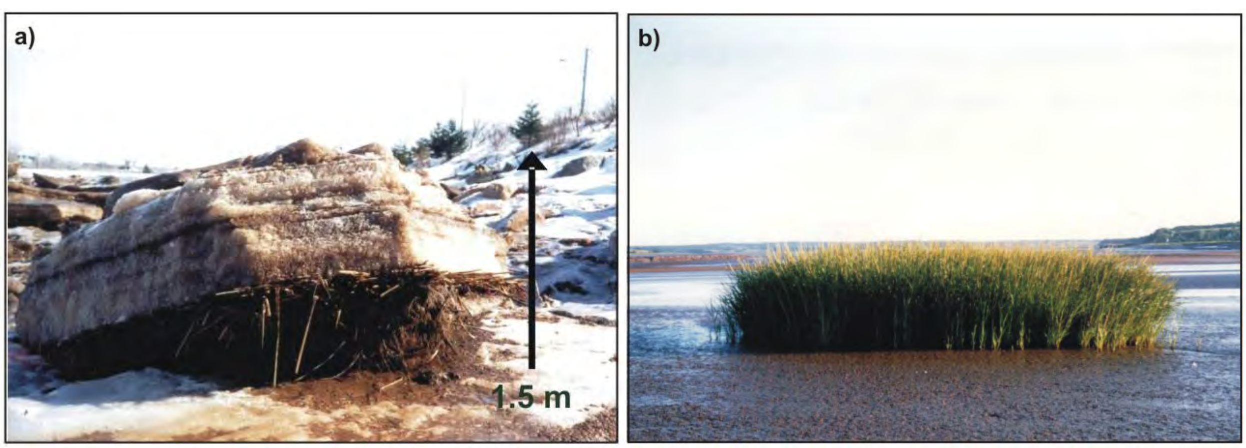

Figure 5: a) Rafted ice block (Feb, 2002) adjacent to the Windsor Causeway and b) Spartina alterniflora colony on the north-east edge of the Windsor marsh/mudflat ecosystem (Aug, 2003).

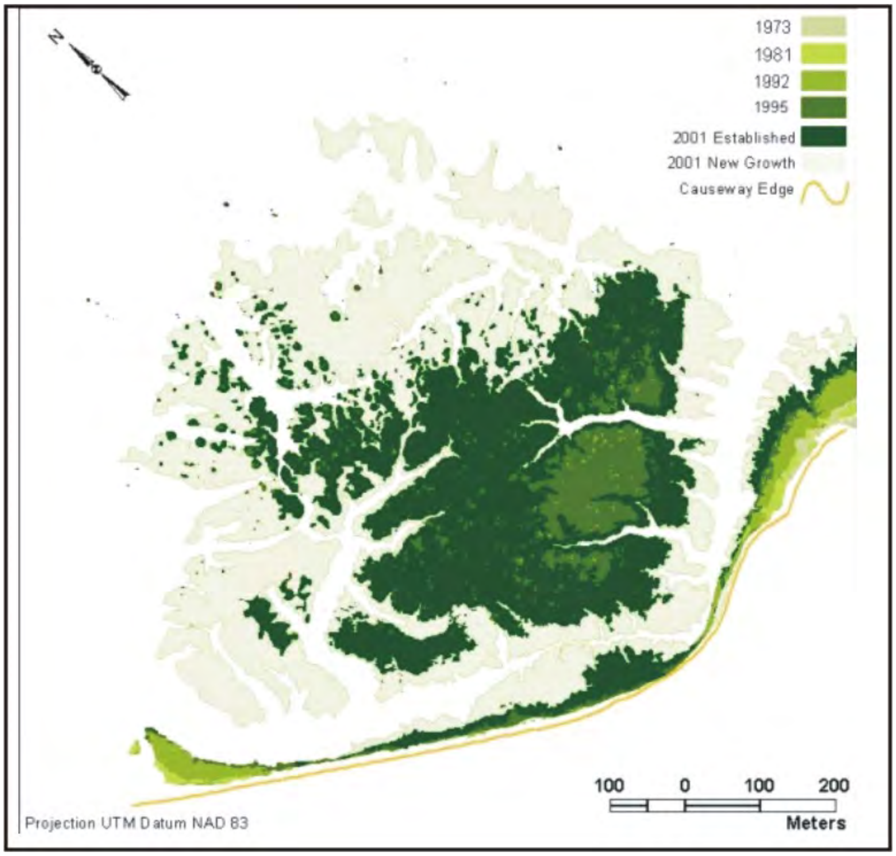

Figure 6: GIS analysis of growth of spartina alterniflora on the Windsor mudflat since causeway construction. Analysis based on aerial photo interpretation and ground field GPS surveys. Shades of green indicate marsh area visible for each year (van Proosdij and Townsend, 2004).

History of Dyking and Construction of the Windsor Causeway

Settlers around the Bay of Fundy, primarily of Acadian stock, have constructed dykes and aboiteaux for over 350 years in order to farm the fertile tidal marshes of the Bay of Fundy. Marshland in the province was privately dyked until 1948 when the federal government set up the Maritime Marshland Reclamation act to rebuild the dykes in the Maritimes. Under the act, the federal government was responsible to provide the main protective works (where economically sound), while the provinces assured proper use of the protected land (MMRA, 1966). From 1948, the Maritime Marshland Rehabilitation Administration (MMRA) has been applying modern engineering techniques to the traditional problems of dykeland construction and maintenance (MMRA, 1966).

The protection of marshlands from the tides is normally accomplished by the construction of dykes. Tidal gate structures, known as aboiteaux are incorporated at major stream crossings where fresh water runoff is discharged and salt water prevented from entering. River bank control and foreshore protection works are installed where required. The MMRA ensured the protection of 18,000 hectares of tidal farmland in Nova Scotia and 13,500 hectares in New Brunswick, building over 370 kilometers of dyke in the two provinces (NSDAM, 1987). In 1966, the Federal Government turned over the responsibility of maintenance for the dykes to the province. The construction trend at the time was directed by economic feasibility studies focusing towards protecting areas in groups, using a single large aboiteaux or dam instead of miles of dyke and large numbers of small aboiteaux (MMRA, 1966). In addition, multipurpose projects (e.g. creating or improving transportation corridors) were encouraged. This resulted in a number of major tidal dams (.e.g Annapolis, Petitcodiac, Windsor, Memramcook) being constructed in the 1960s and 1970s. Today the NS Department of Agriculture (NSDA), Resource Stewardship Division, Land Protection Section is responsible for tidal dyke maintenance along a total of 241 km of dyke with 260 aboiteaux structures (NSDAM, 1987).

Figure 7: Extensive intertidal flats evident at low tide on the Avon River near the Town of Windsor during the Winter of 1963. This aerial photo demonstrates evidence of natural bar formation in the location of the future causeway. Photo by C.A. Banks, 1963.

Interest in the construction of a causeway across the Avon River in the Town of Windor was formally initiated sometime around 1966 in collaboration with the Nova Scotia Department of Highways and the Dominion Atlantic Railway (MMRA, 1966, Figure 7). During that same year, construction was started on a major multipurpose dam on the Petitcodiac River in New Brunswick immediately adjacent to the City of Moncton with a similar goal of providing protection for upstream marshlands and a highway crossing (MMRA, 1966).

The construction of the Windsor Causeway was conducted in phases. In September 1968, rock fill was extended from the western edge for a distance of 300 feet from the new tide gate structure (K. Carroll, per com. and Fig 8 and 9). In November 1968, infilling began from the east side. By July 30, 1969 33% of the project had been completed, increasing to 54% by November 28th, 1969. By January 20th, 1970 (K. Carroll, pers com.) a gap of only 1000 ft remained for water exchange (Fig 9). During

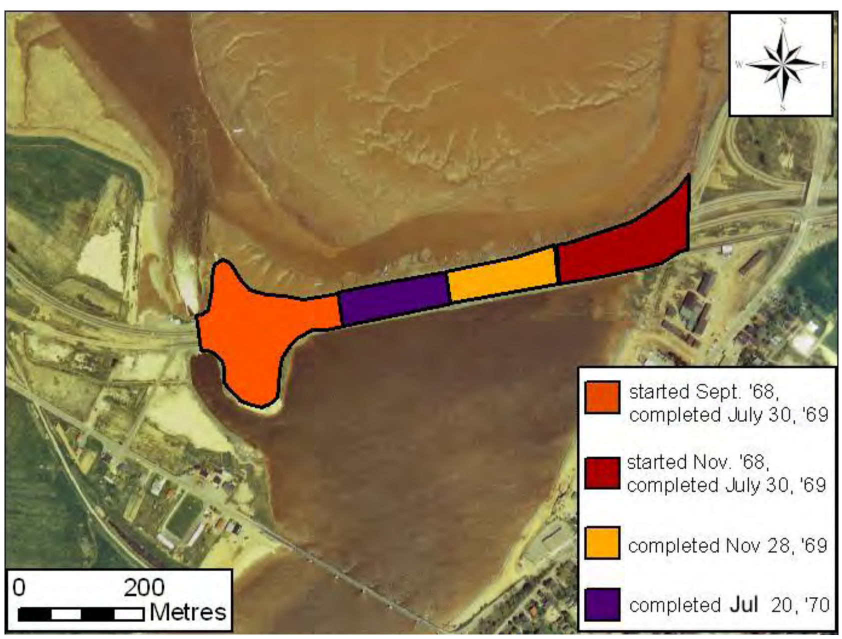

Figure 8: Sequence of closure during the construction of the Windsor Causeway superimposed on 1973 aerial photo mosaic. Data obtained from MMRA architectural drawing of proposal causeway, 1967.

this time the tide gates were being constructed on land. The causeway was closed completely in July 1970 and the gates opened.

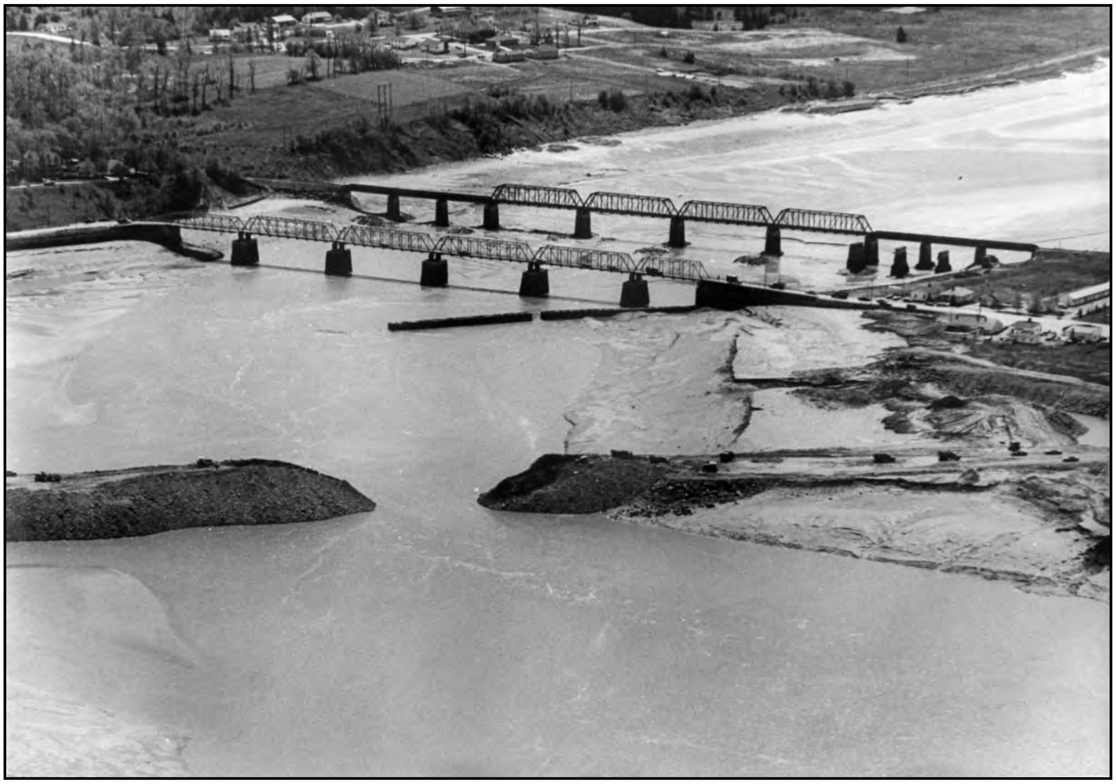

Figure 9: Final phase of the construction of the Windsor Causeway, around November, 1969. Photo from NSDA archives. Note presence of groyne installed during the construction process.

Sediment began accumulating rapidly in the vicinity of an existing mud/sand bar (Figure 7). Sedimentation rates measured in 1975 and 1976 ranged from 1 to > 14 cm·mth^{-1} with an average value of 5 cm·mth^{-1} (Amos, 1977). This early material was very unconsolidated and contained high water contents, smaller grain sizes and elevated organic carbon content (Amos, 1977; Turk et al., 1980). As part of these early studies, six bathymetric profiles were obtained in June 1976 at transects between the causeway and the mouth of the Avon River. Amos (1977) compared these profiles with a Canadian Hydrographic Survey conducted in October of 1969. Based on these results an average net siltation amount of 2.0 m was calculated for the approaches to the estuary more than 20 km from the Windsor Causeway. However, seasonal cyclicity in bed elevation has been observed (as much as 2 m in places) over many years by NSDA personnel and this phenomenon will be addressed in more detail later in the report.

The Windsor Tide Gate was run on demand from its inception until 1981. This involved manually opening the gates fully on the outgoing tide then the lake level and river were equal. Since 1981, the gates have operated as an automatic system (with manual override) and is designed to maintain Pesiquid Lake at a set elevation. It is designed to open when the lake level is above a particular set point on the outgoing tide to allow for freshwater discharge. It closes when the incoming tide is within 6/10th of the lake level therefore does not allow salt water to penetrate upstream (K. Carroll, pers. com.). The number of gates can be modified and gate openings will also vary depending on upstream flow conditions (e.g. to discharge flood waters). It is opened periodically in consultation with DFO for fish passage. Refer to Daborn and Brylinsky, 2004 for information regarding fish population studies of the Avon River estuary.

Salt marsh vegetation began to appear on the exposed mudflat surface around 1981, likely introduced by rafted ice (van Proosdij and Townsend, 2004). After 1992 the rate of colonization by *Spartina alterniflora* increased exponentially as the vegetation became firmly established on the mudflat surface, expanding in size from ~41,000 m^2 to >390,000 m^2 by 2001 (Figure 6). By the summer of 2005 almost the entire suitable mudflat surface had been colonized. Colonies of marsh vegetation are now appearing on the Newport Bar (Daborn and Brylinsky, 2004), downstream of the Windsor marsh/mudflat.

METHODS

General Research Approach

The research presented here represents a component of a larger study examining the ecomorphodynamics of intertidal ecosystems in the upper Bay of Fundy being conducted as a collaborative exercise between Saint Mary’s University, Nova Scotia Department of Agriculture, Resource Stewardship, Land Protection Section, Nova Scotia Department of Transportation and Department of Fisheries and Oceans, Maritimes Region. Of specific interest is the impact of the many tidal barriers within the region on the evolution of intertidal geomorphology and the resulting influence on contemporary sediment dynamics and ecosystem response to climate change. However, before any direct cause and effect relationships can be determined or the future response of the system can be predicted, it is important to understand quantitatively what has changed and to what degree these changes have occurred in the past. Therefore the general approach of this component of the research program was to utilize available cross sectional surveys conducted by the MMRA in the late 1960s and early 1970s, and contemporary bathymetric surveys (Dec 2005) conducted by this research team, combined with available aerial photography to quantify changes in the intertidal geomorphology of the Avon River Estuary downstream of the causeway.

Cross Sectional Profiles

Historical

The MMRA undertook a field survey campaign during the construction of the Causeway to monitor changes in the cross sectional profiles in the Avon and St. Croix Rivers. Surveys were conducted by MMRA survey technicians along 12 transects downstream of the causeway and approximately 12 upstream of the future causeway. Posts were put in at either end of each line and a detailed sketch and description were recorded in field logs. Bathymetry was recorded using an echosounder on a small open boat guided between the two posts at high tide. A detailed record of the tide water levels during the survey was maintained to assist in interpretation of water levels. A marker was placed at either end of the line when an echosounding survey was no longer feasible due to water level and standard rod and level surveying techniques were used to complete the profiles over the marsh itself. All of the downstream profiles were initiated in July 1969 and repeated in November 1969 however only those in the immediate vicinity of the causeway and along the St. Croix River were repeated in spring (May) and fall (Nov) until May 1971 (Table 1). These echo sounding profiles were then drafted to scale (point created for each topographic change in slope) on paper charts by the survey engineers and tied to geodetic datum (CGVD28). This study will focus on the profiles collected in the downstream section (Figures 10 and 11).

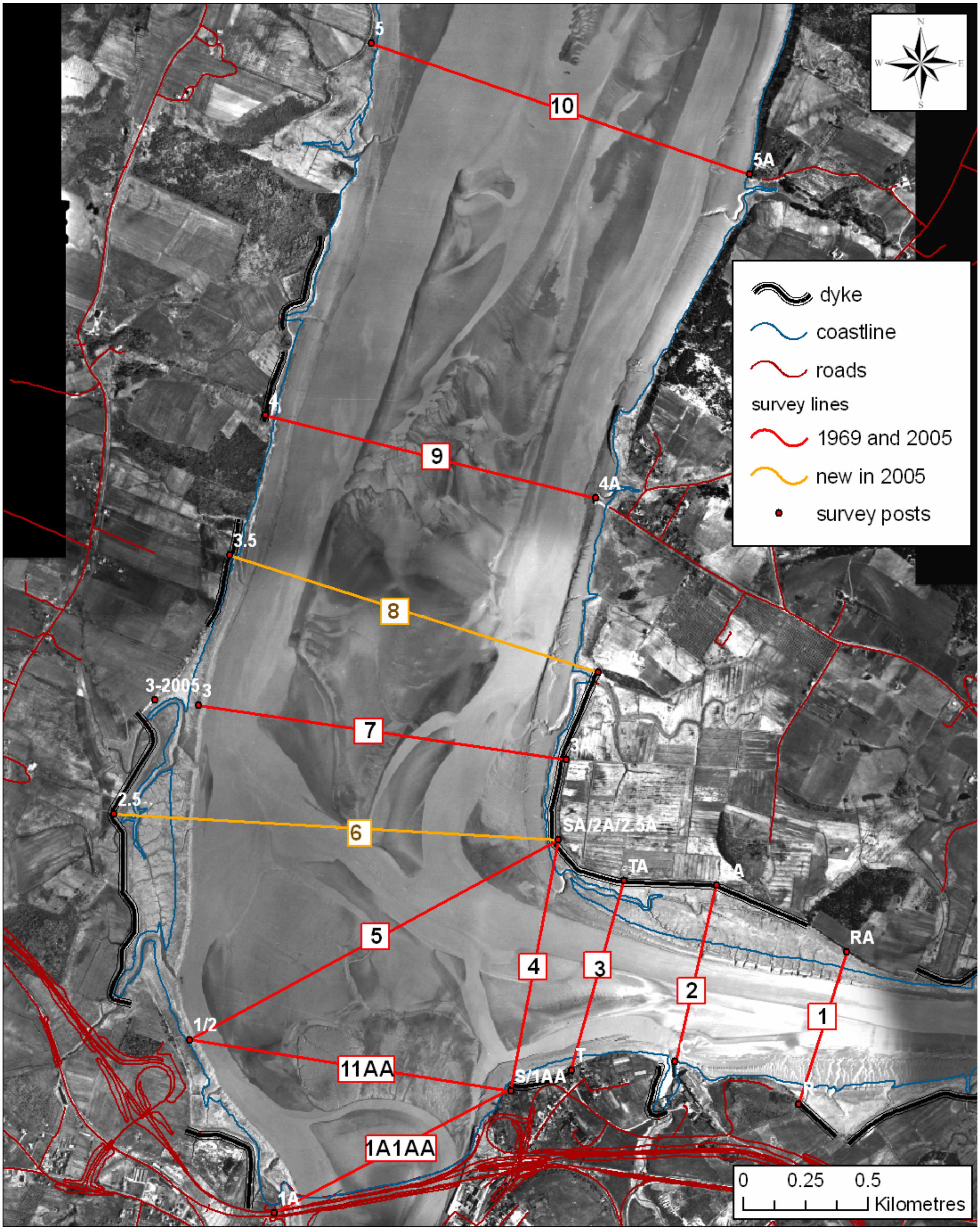

Figure 10a) Location of historical and contemporary survey lines closest to the Windsor causeway. Note that the road and coast vector layers are based on data from 1986 to 1996 (Service NS Municipal Relations) overlain onto a 1964 digital photo mosaic.

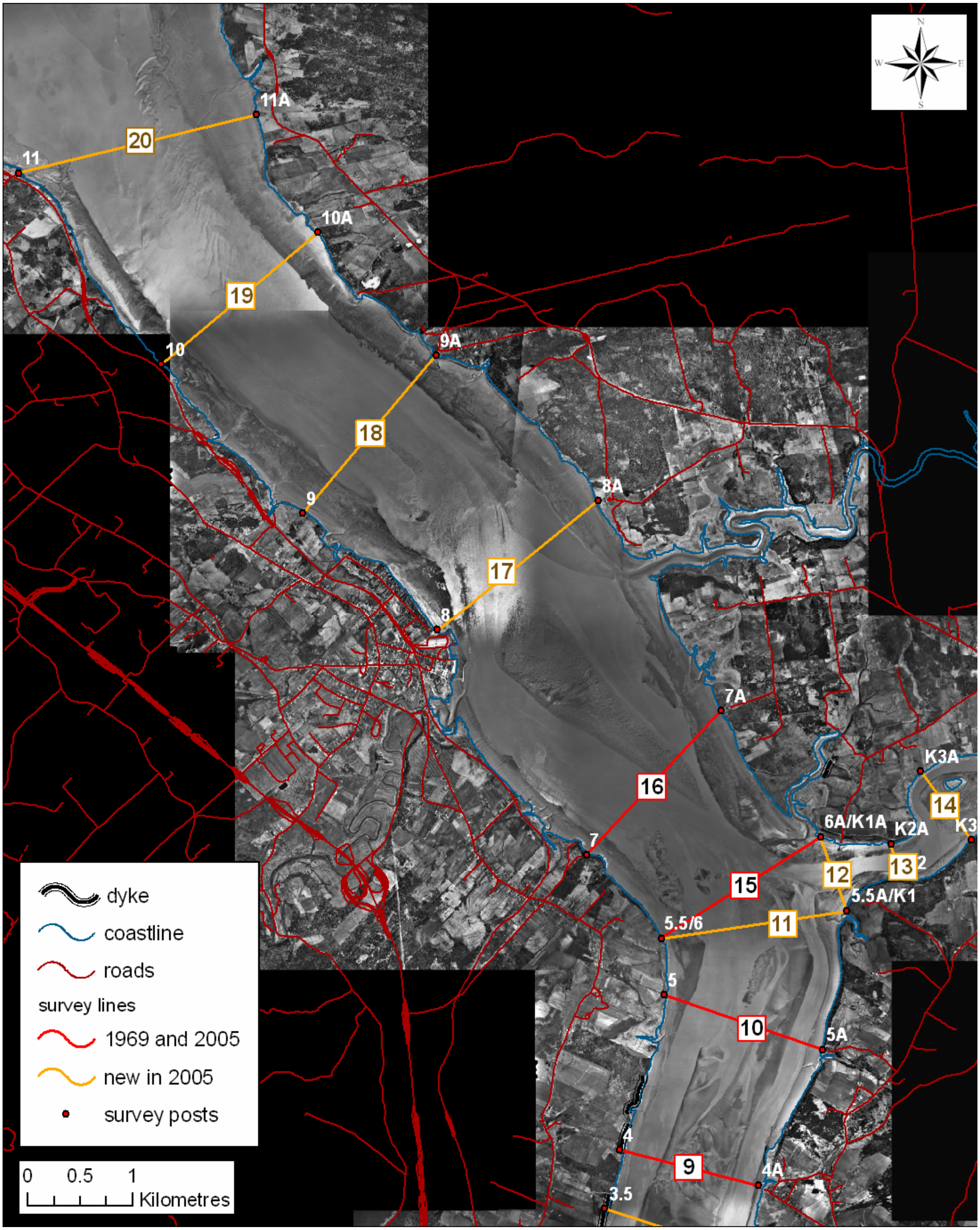

Figure 10b) Location of historical and contemporary survey lines near the mouth of the Avon River. Note that the road and coast vector layers are based on data from1986 to 1996 (Service NS Municipal Relations) overlain onto a 1964 digital photo mosaic.

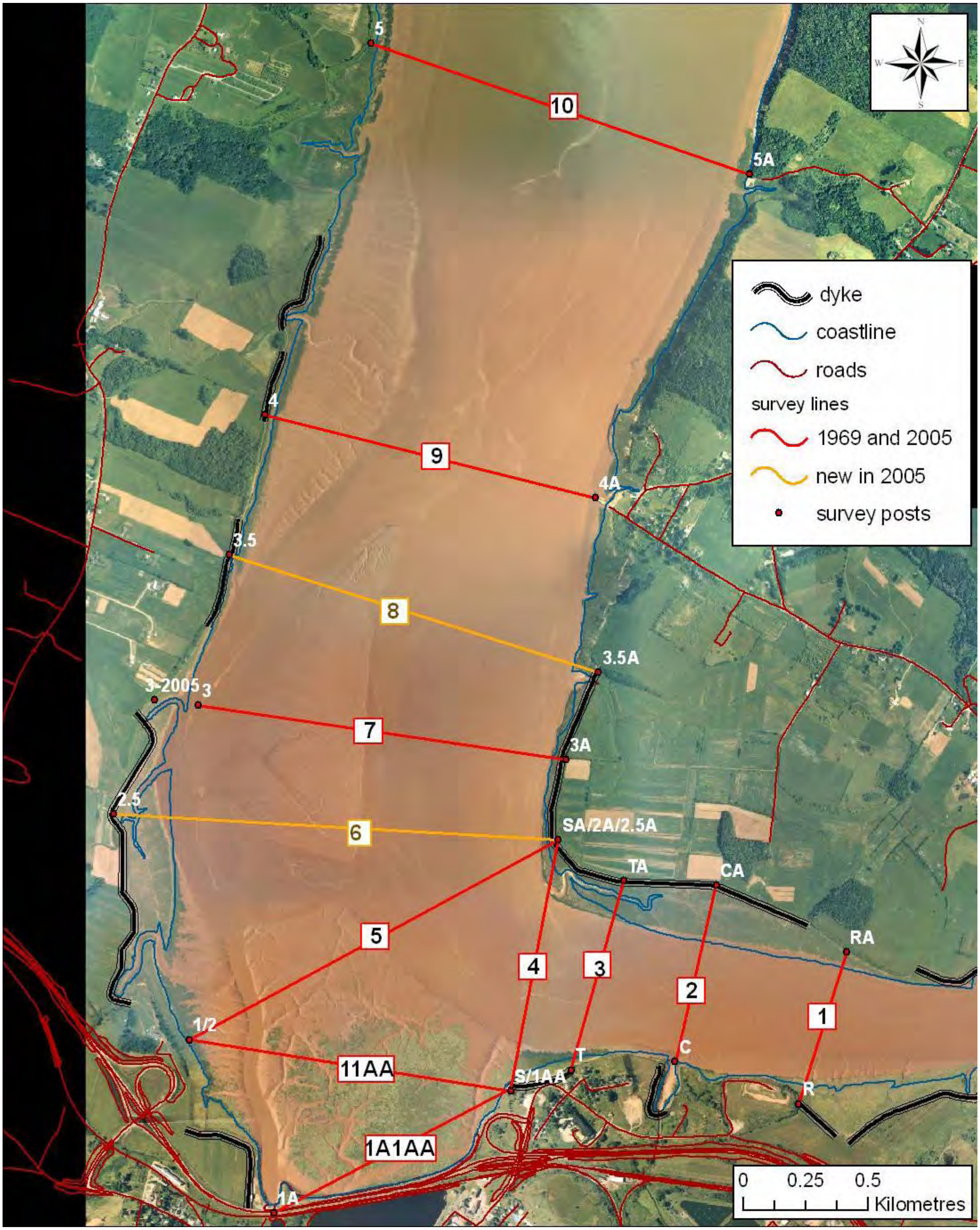

Figure 11a) Location of historical and contemporary survey lines near the Windsor Causeway overlain onto a 2003 digital air photo mosaic.

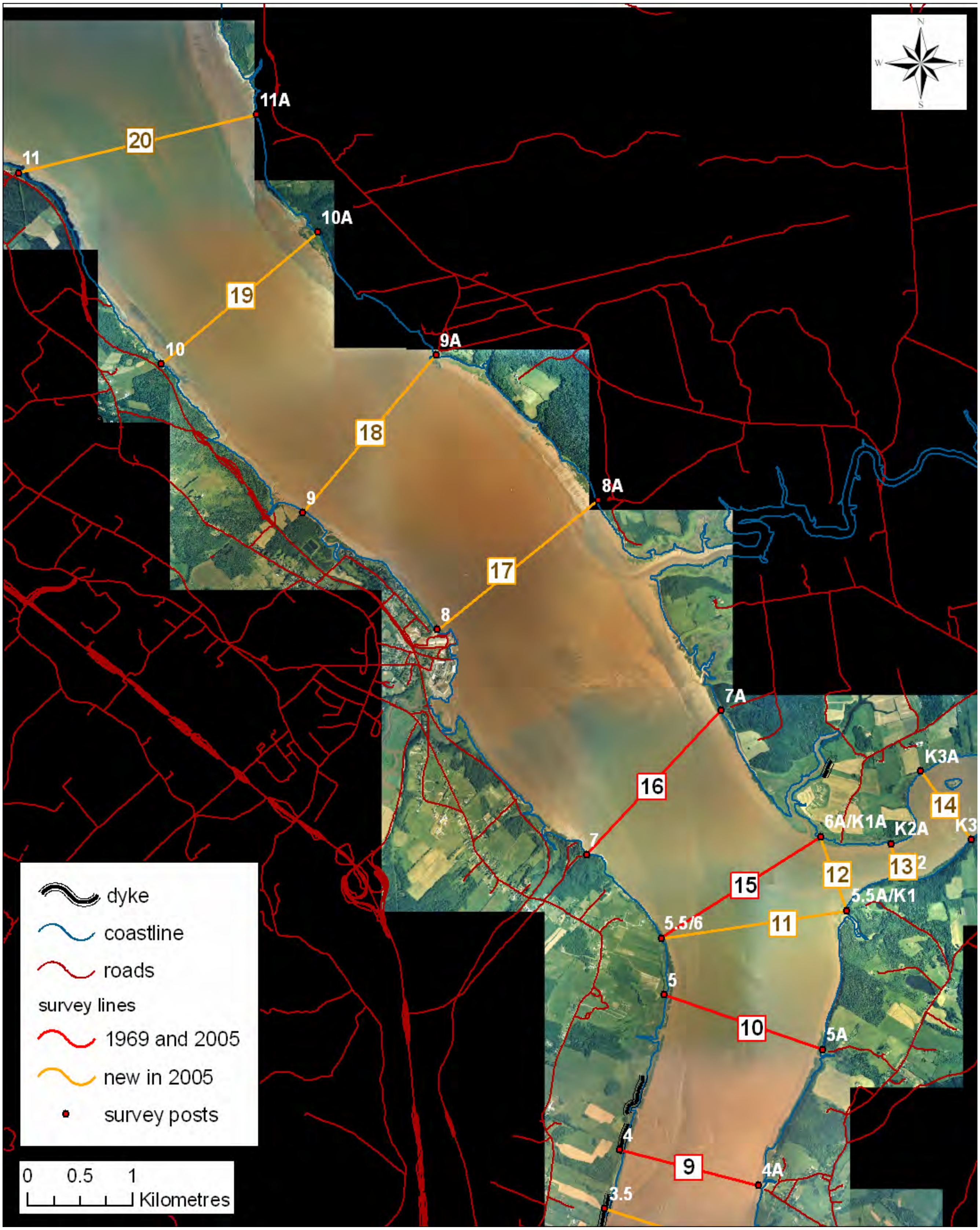

Figure 11b) Location of historical and contemporary survey lines near the mouth of Avon River overlain onto a 2003 digital air photo mosaic.

The paper charts were digitized at MP_SpARC at Saint Mary's University for comparison with the contemporary surveys. Each paper survey was registered using Cartesian coordinates on a 44" x 60" Super L III GTCO Calcomp digitizing tablet. Lines were digitized from post to post with the 'start post' indicated as zero on the paper chart in ArcMap[tm] 9.1 (ESRI®, Redlands, CA). Since the contemporary surveys were conducted with a maximum of 2 m spacing between survey points, the historical surveys needed to be densified. In this procedure, vertices are added to an arc (line) at a specified interval (2 m).

Profile Line	Survey Dates				
	July 9-11,1969	Oct. 28-30 & Nov 4-7, 1969	May 26, 1970	Nov 4, 1970	May 1971
L1_SC_ RRA	X	X	X	X	X
L2_SC_CCA	X	X	X	X	X
L3_SC_TTA	X	X	X	X	X
L4_SC_SSA	X	X	X	X	X
L1A_DS_1A1AA	X	X			
L1_DS_11AA	X	X			
L5_DS_22A	X	X	X	X	
L7_DS_33A	X	X	X	X	
L9_DS_44A	X	X	X	X	
L10_DS_55A	X	X	X		
L15_DS_66A	X	X			
L16_DS_77A	X	X			

Table 1: survey dates for historical profiles conducted by the MMRA. Location of survey lines are indicated on Figure 11.

This was achieved using the ETGeoTools (ET Spatial Techniques, 2005) extension for ArcMap 9.1. The resultant densified lines were then converted to an ASCII text file using a 'Shape_To_Text' executable file (Taylor, 2003) and opened in Microsoft Excel. A custom template spreadsheet was created to convert the X and Y values from the digitized lines, representing orthometric distance in feet (X) from a certain starting post, and height above geodetic datum (Y), also in feet. The 2_D X,Y coordinates were converted to 3-D x,y,z values in metric units, representing Easting (x) and Northing (y) in the UTM map projection and the height above geodetic datum (z). The second step required the UTM Easting/Northing locations of the start and end posts of the cross-sectional line. Theses post coordinates were determined in consultation with Ken Carroll and Daryl Hingley of NS Dept of Agriculture, old field logs, and georeferenced air photo mosaics from the 1960s. Post coordinates could then be extracted to create new point features. These coordinates were used in a range/bearing configuration to calculate the new x,y location for each distance value along the line. The z value was simply copied from the original metric 'Y' value.

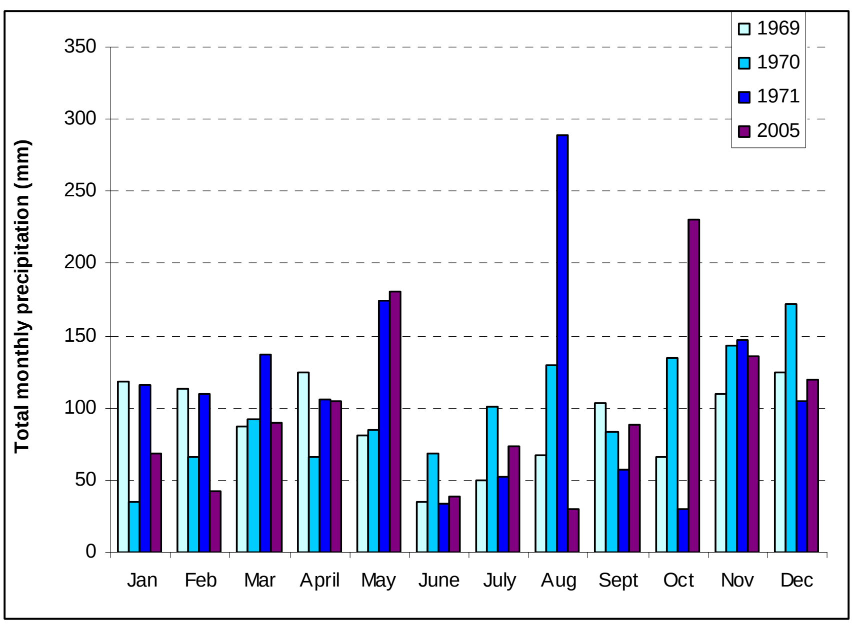

Figure 12: Total monthly precipitation at Kentville (45.07N, -64.43 W)

Total monthly precipitation values are presented from 1969-1971 from the Kentville meteorological station and compared to the 2005 contemporary survey period (Figure 12) to identify any potential large run-off events that might influence the surveys.

Contemporary Profiles

Hughes Surveys and Consultants Inc, consulting engineers with experience in macrotidal surveys (e.g. Petitcodiac) were contracted to perform a contemporary survey of the Avon, St. Croix and Kennetcook River Estuaries. Originally scheduled for October 2005, surveys were postponed until December 4 & 5, 2005 due to a combination of weather restrictions and non-optimal tidal heights (e.g. not high spring tides). Heavy rainfall in October and November created a freshet conditions so the resultant surveys likely represent lower bed elevations than are typically found in the Fall (Figures 12 & 13).

Surveys were conducted from a 20-foot welded aluminium Sounding Launch using a Knudsen 320 B/P Dual Frequency Digital Echo Sounder. Data were recorded at both 28 and 200 KHz in order to try and record the presence of fluid mud (US Army Corps of Engineers, 2002). Navigation and positioning as well as tide height monitoring was conducted using DGPS and Real Time Kinematic GPS techniques. Real time corrections for navigation to points (posts) supplied by MP_SpARC were performed using the Canadian Coast Guard Realtime Beacon (RTB). GPS data were post-processed for higher precision against a Hughes operated base station set up over a geodetic benchmark at the Hantsport wharf. Data were also post processed against a survey monument installed at the Windsor Tide Gate (by Darrell Hingley, NSDA) and monument 69N142 at the Hantsport Wharf. Three dimentional x,y,z coordinates of river bed elevation were computed using xyz post-processed DGPS values and subtracting the depth of echo sounding to produce a new z value. Appropriate offsets for the difference in location of the GPS antenna and the echo sounding equipment were applied. All data were referenced to CGVD28 vertical datum.

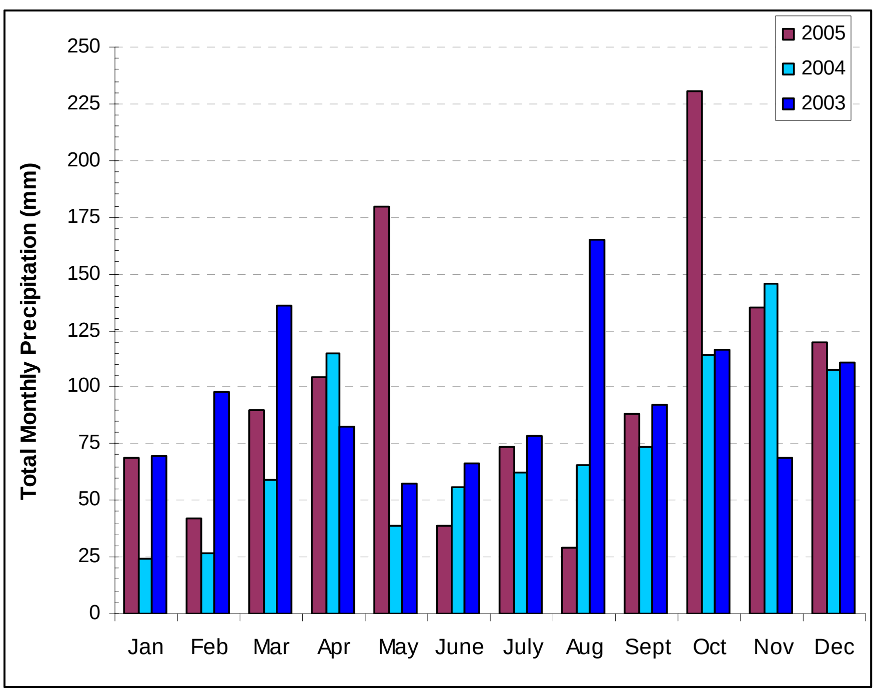

Figure 13: Monthly precipitation record recorded at the Kentville, NS Environment Canada Weather Station from 2003-2005. Note the very high values for Oct and May 2005.

Topographic surveys of the marsh surface were conducted using differential GPS survey techniques using a Leica GS50 single frequency GPS receiver in late November and early December, 2005. Prior to the start of the survey on each line, the instrument was initialized at a known base point (e.g. post) and then the marsh and start of the adjacent mudflat zone were surveyed with data being collected as a kinematic phase chain. These data were then post processed using Leica® software against a base station collecting phase chain data at the Windsor tide gate. The surveys are accurate to within 0.10 m in the vertical plane. Not all posts were surveyed during this field season due to weather and tide constraints. In most cases, those 6 lines did not contain appreciable marsh (as shown by 2003 aerial photographs, eg. Lines 7-10). Some however which did contain marsh (e.g. K3A and 5A) were not accessible due to private property restrictions at the time of the survey. Others (e.g. 11 and C) were completely inaccessible due to cliffs or significant unconsolidated sediments.

Both bathymetric and marsh point survey data were displayed in ArcMap 9.1. Points were selected along the survey line of interest and the associated attribute table was exported and inserted into another Excel spreadsheet template. This permitted non relevant data to be excluded (e.g. boat turning). The exported data were expressed as Easting (x), Northing (y) coordinates with elevation (z) values and were converted to a distance and elevation value suitable for comparison with the historical surveys. A custom spreadsheet was designed which effectively 'snapped' the data to a straight line using the post coordinates and trigonometry. An additional distance filter was applied to the data which excluded any point which was more than 20 m off line. A resultant straight line distance and associated elevation value was generated for each vertex. These data were filtered using a 3 sample running mean to smooth the data.

Lines 1A_DS_1A1AA and 1_DS_11AA (Figure 11a) were extrapolated from a digital elevation model (DEM) generated from a detailed survey of the Windsor marsh surface in July 2004 with the assistance of Darrel Hingley (NSDA). The DEM was created using the TopoGrid function in ArcINFO which creates a hydrologically correct surface. TypeConvert v 2.3.5, ETgeoTools and ShapetoText were used to extract and convert the line data to point data suitable for inclusion in the analysis.

Profiles for each survey for each line were plotted in excel and examined for consistency, accuracy and depiction of realistic changes using the original paper charts, digital air photo mosaics, old marsh plans and expert opinions of NSDA personnel familiar with the Avon system since the 1960s. A total of 4 lines needed to be corrected due to slight errors on the original field sheets, data interpretation or incorrect post locations. Much of this was due to the disappearance of a key feature (e.g. bank erosion or wharf decay) where an old post was situated. If it was determined that a post needed to be re-located, all of the data for that line were re-calculated using the new parameters. If the survey ended below either the HHWLT (Higher High Water Large Tides) or HHWMT (Higher High Water Mean Tides) level, it was extended up to either the 10 m contour from the NS 1;10,000 digital topographic series or nearest dyke to allow for proper cross section calculations. The coordinates of the intersection of the line and the 10 m contour were determined within ArcMap. These new coordinates were added to the lines and calculations redone using the extended parameters.

Data Analysis

In order to examine the morphological changes in the Avon River channel over time, a series of hydraulic geometry parameters were calculated. Channel depth, width and x-sectional area will control tidal discharge and current speed (Knigthon, 1984). Since most of these parameters will vary depending on the tidal height used, all variables were calculated for both HHWLT and HHWMT from Hantsport. These values were obtained from the Canadian Hydrographic Service (CHS) Chart 4140, 1982 (Table 2). Values were then converted from chart to geodetic datum (pers comm. Charles O'Reiley, 2005) to be used with the survey data referenced to CGVD28 vertical datum. HHWLT refers to the 19 year average of the highest annual predicted high waters whereas HHWMT represents the average of all of the higher high water from 19 years of prediction. Mean Water level (MWL) refers to the average of all hourly water levels over the available period of record (Forrester, 1983).

Datum	Large tides		Average tides		Mean water level
	HHWLT	LLWLT	HHWMT	LLWMT	MWL
CGVD28 (m)	7.57	-7.33	5.77	-6.03	-0.03

Table 2: Geodetic elevations converted from chart datum values obtained from the CHS chart 4140 at Hantsport. Non-published conversion value obtained from Charles O'Reiley, CHS, 2005.

A	Cross sectional area (m^2)
A_i	Intertidal cross sectional area (m^2)
pw	Wetted perimeter (m)
w	Width (m)
H	Mean elevation (m CGVD28)
H_{min}	Minimum bed elevation (m CGVD28)
D	Maximum water depth (m)
d	Mean water depth (m)

Table 3: Definitions and abbreviations used for analysis of hydraulic geometry

All of the data were analyzed in Microsoft Excel and calculations were performed relative to the intersection of the segment cross sectional line with the tidal limit horizontal plane. Parameters calculated and abbreviations used are summarized in Table 3. Cross sectional areas (A) were calculated as the area of water contained in the channel below either the HHWLT and HHWMT tidal limits. These values were obtained using a modified Trapezoid rule (A = sum of trapezoid areas between water level and bed elevation calculated from $(b_1+b_2)\cdot h/2$ between each sample point). Intertidal cross sectional area (A_i) is defined as the amount of water moving within the channel. It is calculated as the difference between the HHW and LLW cross sectional area values (Figure 14b). In most cases, the LLW values were below the measured bed elevations. In those cases, the lower limit for the A_i calculations was taken as the bed elevation and is equal to the cross sectional area (Figure 14a).

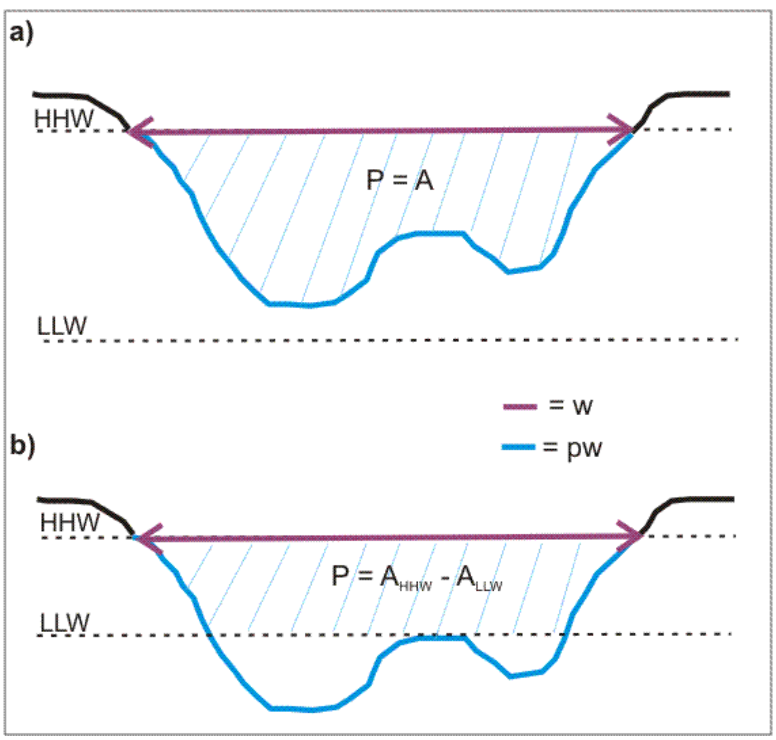

Figure 14: a) Intertidal cross sectional area (A_i) when LLW level falls below the lowest surveyed bed elevation; b) Intertidal cross sectional area measured as the difference between cross sectional areas calculated for HHW and LLW. The geodetic elevation of these tidal limits will vary depending on whether the calculations are being performed for large tides or average tides. Channel width (w) and wetted perimeter (pw) are also indicated.

Wetted perimeter (pw) is the distance along cross sectional profile that is below the water level. Channel width was calculated as the horizontal distance between the channel banks where the tide intersects the cross sectional profile. Both mean and minimum elevations were derived directly from the survey data and are presented relative to the CGVD28 datum. These values will not vary between tide levels. Maximum water depth (D) was calculated as the tide level minus the minimum surveyed elevation. Mean depth was calculated as the tide level minus the mean elevation.

Salt Marsh Habitat

Aerial Photo Mosaics

Digital aerial photo mosaics were created in a concurrent study (van Proosdij and Horne, 2006) at the Maritime Provinces Spatial Analysis Research Centre (MP_SpARC) at Saint Mary's University. Relevant flight lines were identified and individual aerial photographs were examined and assessed for suitability for intertidal analysis (i.e. salt marsh and marsh / mudflat boundary were visible). Air photos were scanned to provide a 1-m ground resolution. The images were then georeferenced and rectified in ArcMap 9.1 using 1:10,000 digital topographic map sheets and referenced to UTM Zone 20N NAD 83 CSRS 98. Mosaics were generated using a custom Arc Macro Language tool created by Greg Baker (MP_SpARC). However, the macrotidal conditions of the upper Bay of Fundy present considerable challenges to the seamless creation of images. Flight lines are generally flown along a west-east transect within each county, essentially bisecting the Southern Bight. As a result tidal conditions were not comparable over the entire mosaic. Furthermore, since flights are flown on a county basis, this can result in the western shore of the Avon River being flown as much as 4 years before or after the eastern shore. For example, Hants County was flown in 1973, 1981, 1992 and 2003/04 while the adjacent Kings County was flown in 1977, 1987, 1992 and 2002 (van Proosdij and Horne, 2006). At times, a county may also be divided even further (e.g. Hants 2003/04). Table 4 summarizes the dates of photographs used and resultant mosaics. Detailed lists of photos are included in van Proosdij and Horne, 2006.

	Decade						
Study Area	**1940s**	**1950s**	**1960s**	**1970s**	**1980s**	**1990s**	**2000s**
Avon	1944, 45	1954,55	1964	1973	Not available	1992	2002, 03, 04

Table 4: Aerial photographs used for mosaic creation. All aerial photographs from the 1980s were at high tide.

Salt Marsh Habitat Quantification

The amount of salt marsh habitat was determined for each air photo mosaic based on the area of digitized polygons within ArcGIS 9.1. Since the boundaries between high and low marsh vegetation types were very difficult to determine from the aerial photographs without any field ground truthing, salt marsh habitat polygons incorporated both high and low marsh zones as defined by the mudflat or upland boundary. For some areas, particularly in the early mosaics, marsh area was very difficult to distinguish from adjacent mudflat. Surveyed dyke lines were used to help define the upland boundaries, as were GIS polygons of 'incorporated' marshes supplied by the NSDA. Old marsh surveys from the MMRA and NSDA were used in other areas as well as consultation with Ken Carroll (NSDA). This study is restricted to marsh areas located downstream of the main bridge in Windsor. Since the spatial area covered by each air photo mosaic is different due to limitations with flight lines and low tide conditions, normalization procedures were required to facilitate comparison between years (refer to van Proosdij and Horne, 2006 for detailed extents of air photographs). Marsh area was normalized by the area of the mosaic occupying the zone below the 10 m topographic land contour. Upland boundaries were not as critical for this study. The main objective of incorporating marsh areas in the analysis of changes in intertidal geomorphology was to identify zones of accretion and erosion. Salt marsh habitats common to all of the mosaics were also extracted for direct comparison.

RESULTS

Cross Sectional Profiles

Figures 15, 16 and 17 present the cross sectional profiles and associated hydraulic geometry graphs for lines on the St. Croix, Avon and Kennetcook Rivers respectively. Due to the wide range of channel widths and depths from the causeway to the mouth of the Avon River, vertical and horizontal scales on the graphs vary. Data are presented for both large and mean tides in order to compare changes which occur primarily within the tidal river channel (e.g. below HHWMT) with changes of the whole intertidal profile including the marsh surface (e.g. between HHWMT and HHWLT). Refer to Figures 11 and 12 for location of the survey lines. Two standard measures of channel form are also presented: the width to mean depth ratio (w/d) and max to mean depth ratio (D/d). In general, as the w/d ratio increases, the form of the river is becoming wider and shallower. If the opposite occurs, it is generally becoming deeper and narrower. A large D/d ratio generally indicates the presence of a deep channel relative to the surrounding bathymetry. As the D/d ratio becomes closer to 1, the channel exhibits a relatively flat form in the mud and sand flat areas. Descriptions are provided only for those lines which have historical data.

Description of Changes in the St. Croix River

The most noticeable changes in the cross sectional profiles within the St. Croix river occur on Lines 1 (Fig 15a) and 2 (Fig 15b) as erosion of the north river bank and associated salt marsh habitat by as much as 62 m between May 1971 and December 2005. This represents approximately 411 m^2 in marsh loss (vertical plane). In Line 1, there is also evidence of extensive growth of a mudflat deposit along the southern shore (Fig 15a) which becomes vegetated by most likely *spartina alterniflora* between 1973 and 1992 (Fig 15e). This extends the southern shore by approximately 20 m since 1971 and represents an accumulation of sediment 8.7 m deep since November 1969. Closer to the Avon River, there is a general narrowing of the river channel by 108 m (Table 5b) as mud and marsh accumulates at either end of the Line 4.

Seasonal cyclicity is evident within most lines on the St. Croix River. On Line 1, the southern bank had retreated approximately 20 m between July and November 1969 but in May 1970 had expanded back to the July 1969 level (Fig 15a). This phenomenon is also observed along the south shore on Line 4: bank erosion of 14 m from July 69 to Nov 69, expansion by 24.2 m and by May 71 the extent of the bank was at the same distance from the post as it was in July 69. A marked period of erosion (29m) was recorded between November 1970 and May 1971 (Fig.15d) however by 1992 mudflat and marsh deposits are visible on the aerial photographs (Fig 15e) and by 2005 the south bank along Line 4 had extended by 74 m (Fig 15d). On Line 2 the same phenomena was observed in the bed elevation, with a decrease in elevation (at point 200 m Fig 15b) of 2.45 m July 69 to Nov 69 followed by an increase of 1.02 m by May 1970. The sequence of changes in bed elevations along Line 4 in the central portion of the channel (point 500 m Fig 15d) show the disappearance and potential shift of an intertidal bar present in May 70 and a return to 1969 bed elevation levels in Dec 2005. Triggers between an erosion or accretion phase on either channel bank appears to coincide with a shift in the thalweg of the main channel.

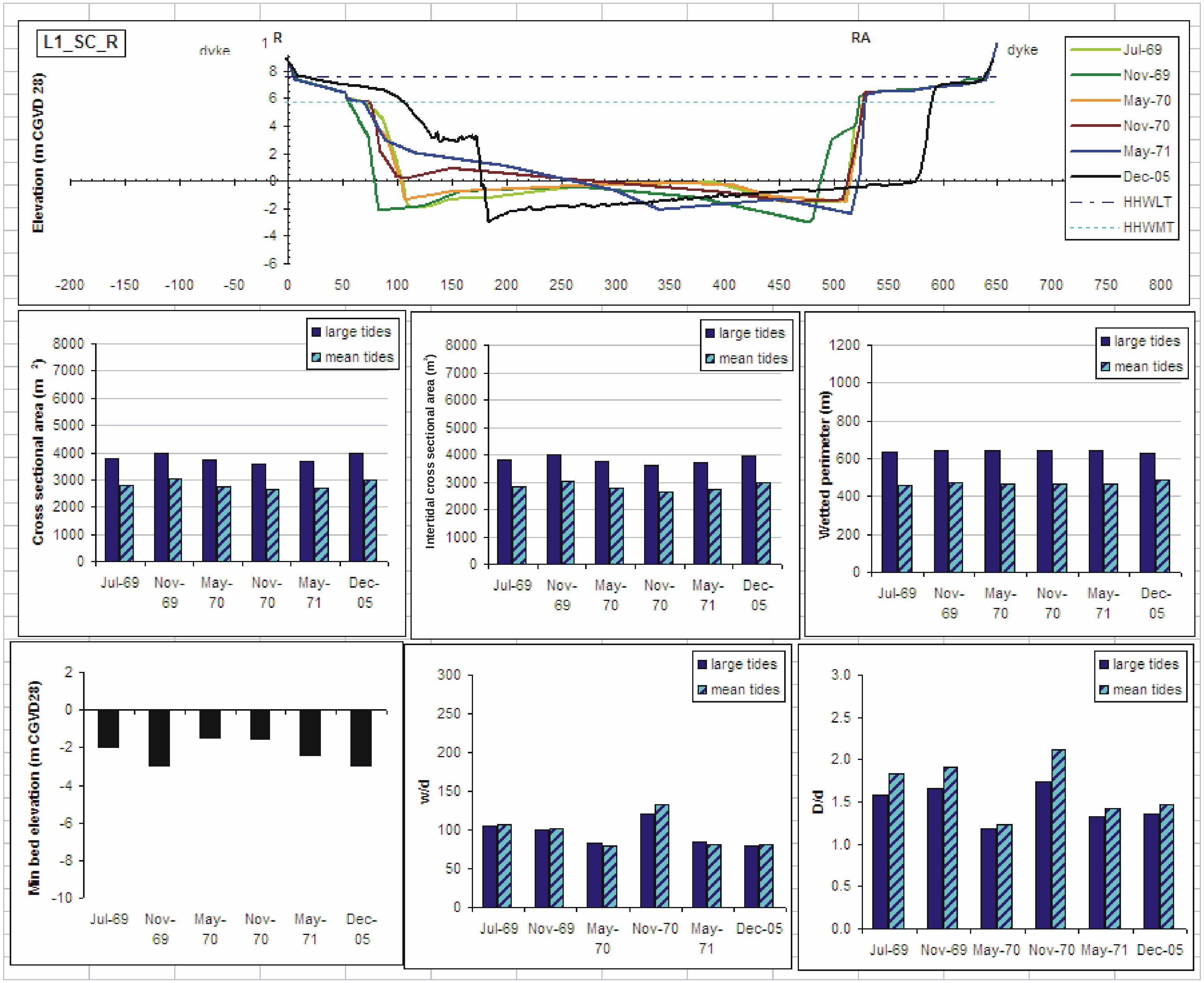

Figure 15a: Cross sectional profiles for Line 1_SC_RRA and associated hydraulic geometry parameters on the St. Croix River. Vertical exaggeration on cross sectional profile = 62.5 X. Distance on cross sectional profile in metres.

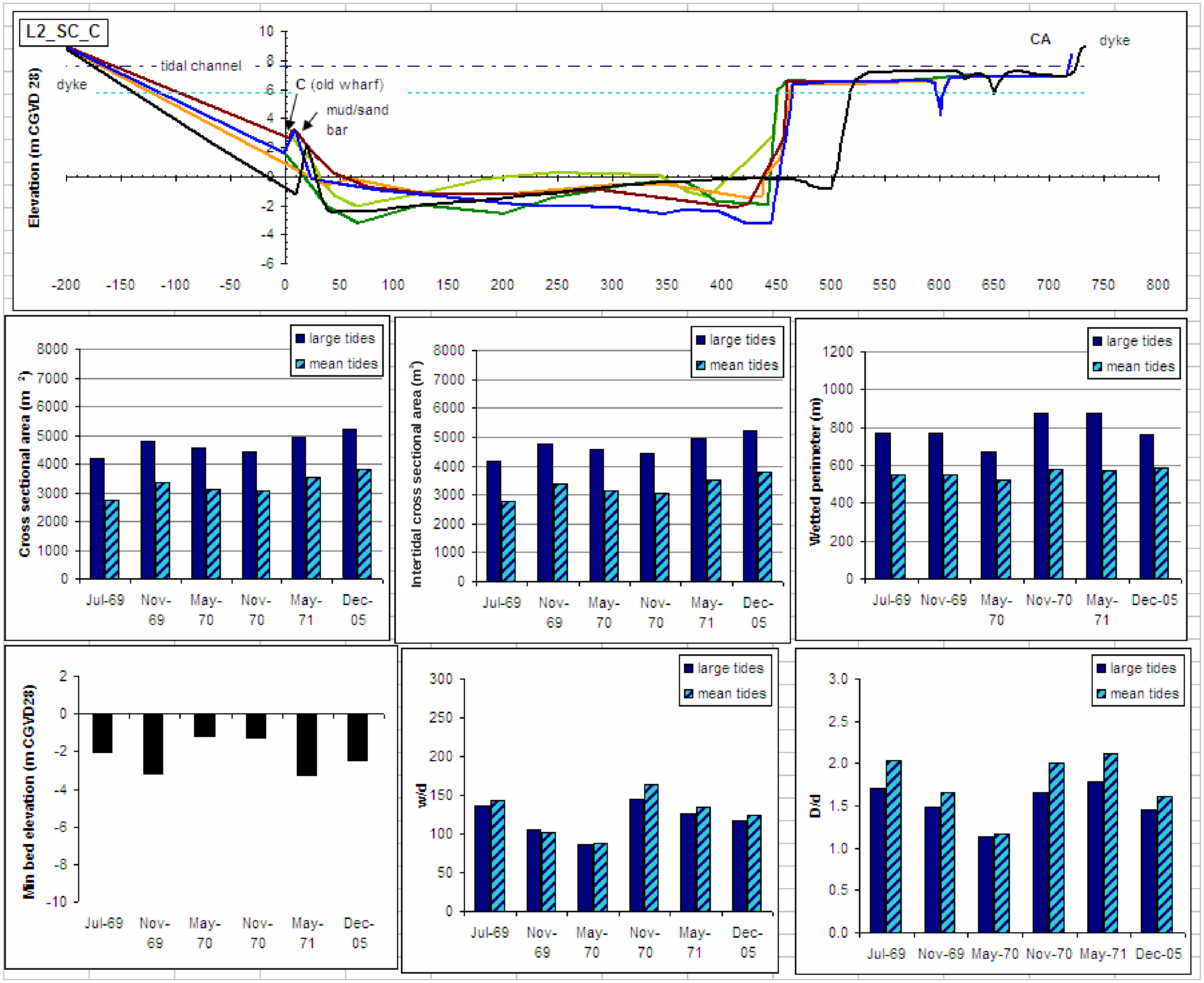

Figure 15b: Cross sectional profiles for Line 2_SC_CCA and associated hydraulic geometry parameters on the St. Croix River. Vertical exaggeration on cross sectional profile = 62.5 X. Distance on cross sectional profile in metres. Prism and cross sectional area calculations are to be interpreted with some caution due to significant extrapolation on southern bank due to low elevation at the start of the survey and position of line within a tidal creek. . Refer to figure 16e for position of line.

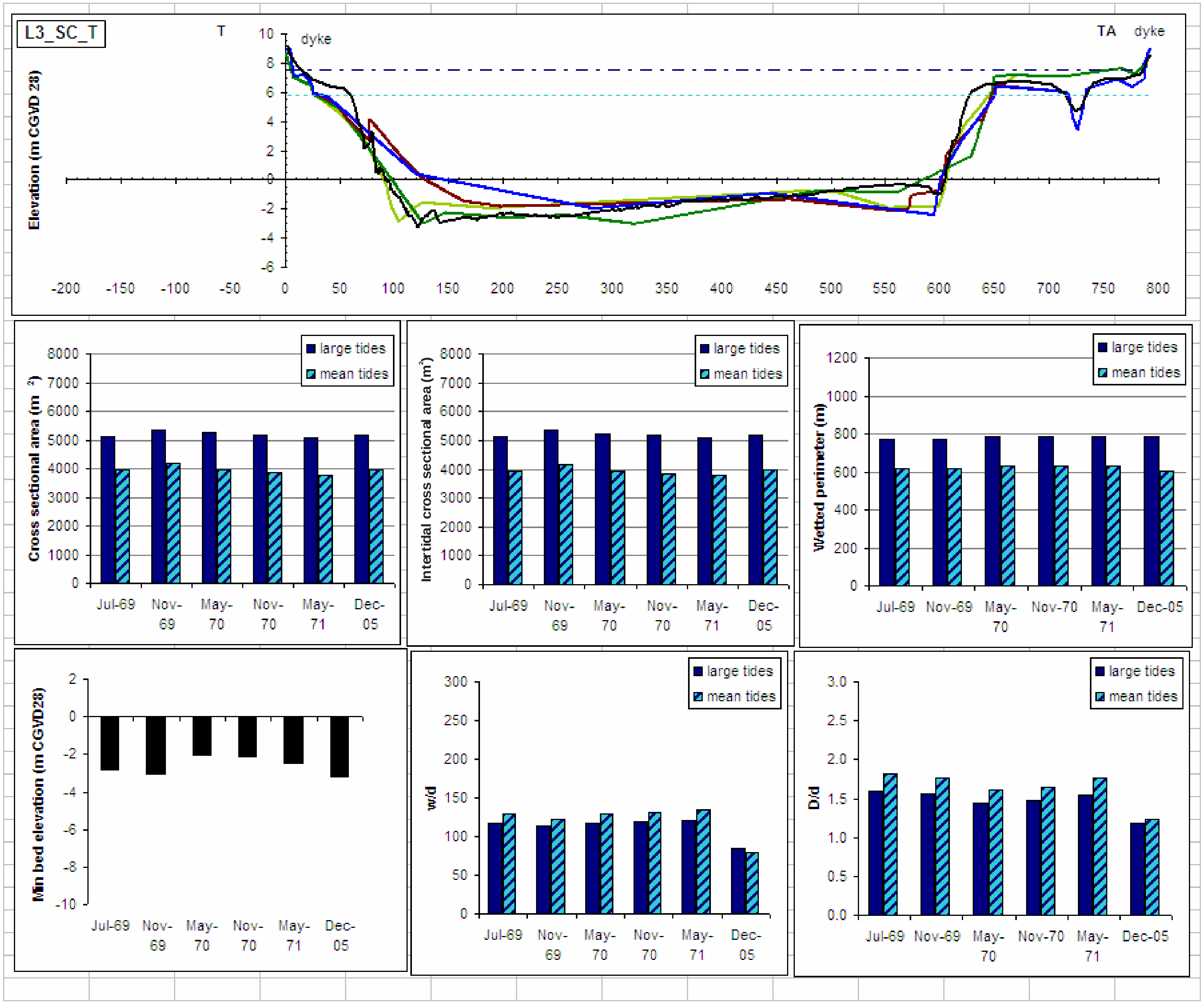

Figure 15c: Cross sectional profiles for Line 3_SC_TTA and associated hydraulic geometry parameters on the St. Croix River. Vertical exaggeration on cross sectional profile = 62.5 X. Distance on cross sectional profile in metres. Potential error on 1969 marsh survey near post TA, needs additional verification with raw echo sounding data.

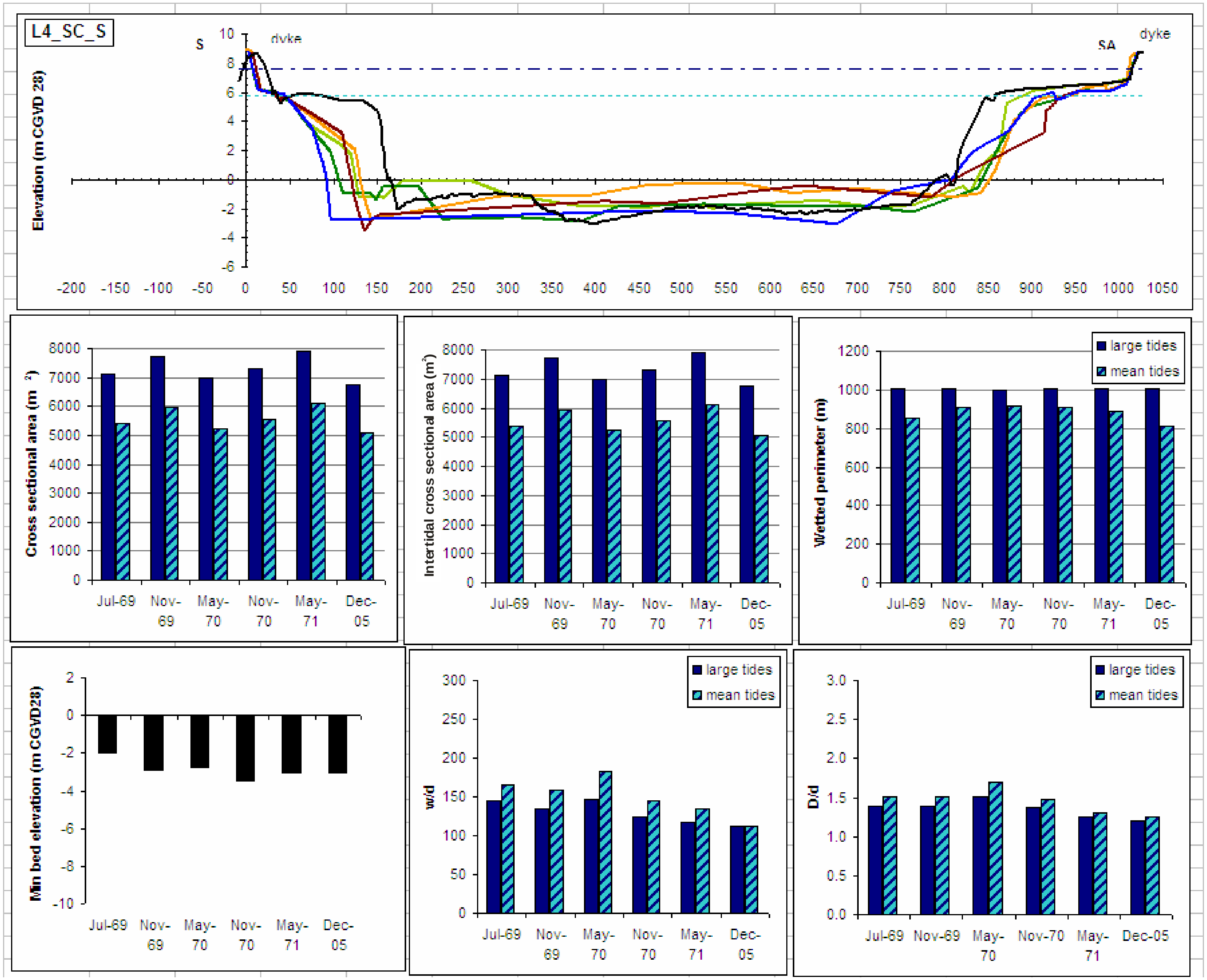

Figure 15d: Cross sectional profiles for Line 4_SC_SSA and associated hydraulic geometry parameters on the St. Croix River. Note change in vertical exaggeration on cross sectional profile to 78 X. Distance on cross sectional profile in metres.

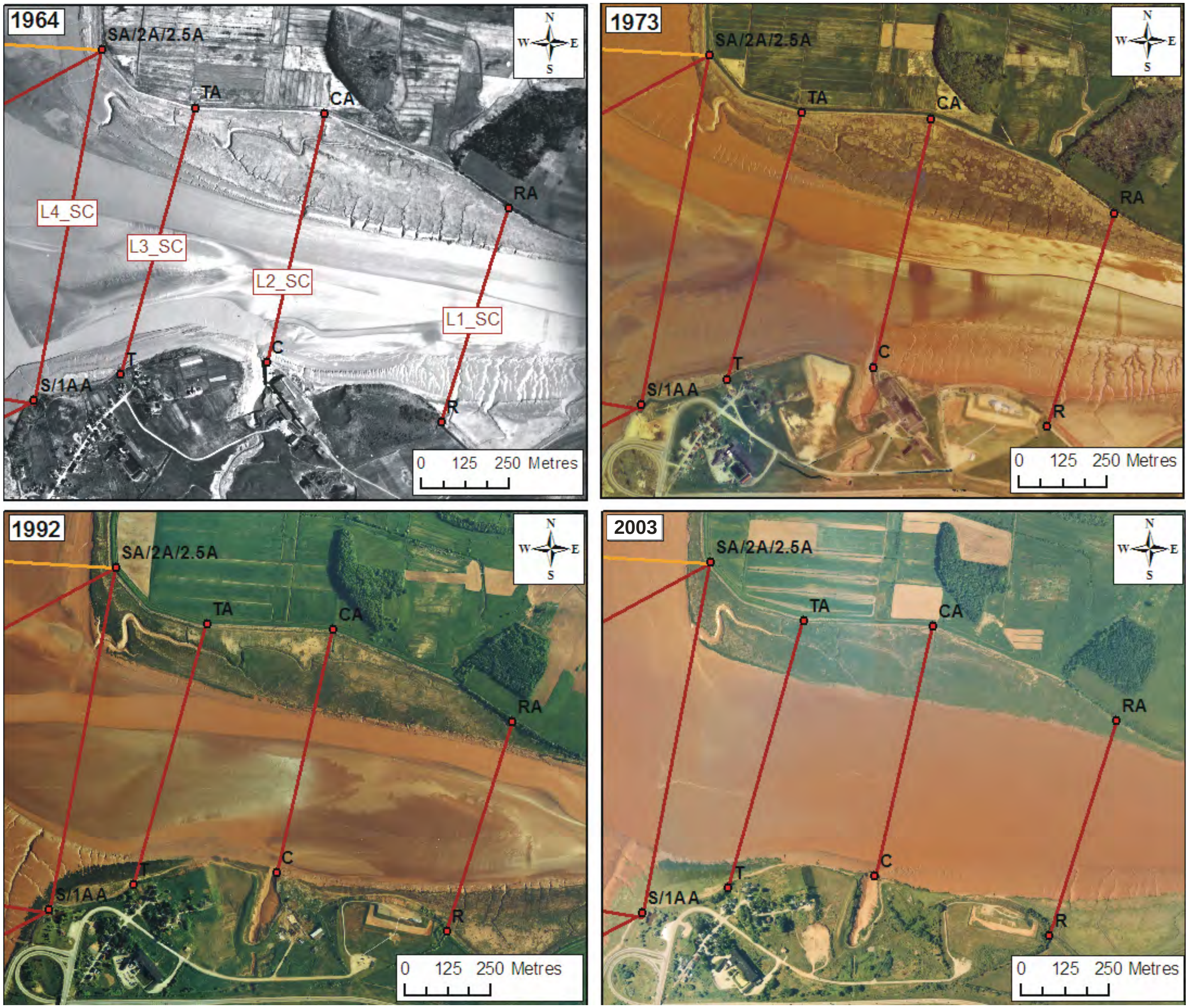

Figure 15e: Location of St. Croix cross sections lines 1-4. Note shift of main channel thalweg from south to north shore and associated marsh erosion from 1964 to 2003.

a)

Date	Line	Distance	total distance	A	pw	H	Hmin	d	D	w	A_i	w/d	w/D	D/d
				Hydraulic geometry Large Tides										
Jul-69	L1_SC_R	0	1190	3781	639	1.5	-2.0	6.0	9.5	635	3781	105.3	66.6	1.6
	L2_SC_C	548	642	4178	767	1.9	-2.1	5.6	9.6	764.7	4178	135.6	79.4	1.7
	L3_SC_T	386	256	5138	771	1.0	-2.8	6.6	10.4	768.9	5138	117.3	73.8	1.6
	L4_SC_S	256	0	7110	1005	0.6	-2.0	6.9	9.6	1003	7110	144.6	104.7	1.4
Nov-69	L1_SC_R	0	1190	3996	639	1.2	-3.0	6.4	10.6	635.3	3996	99.6	60.2	1.7
	L2_SC_C	548	642	4772	768	0.3	-3.2	7.2	10.8	765	4772	105.9	71.0	1.5
	L3_SC_T	386	256	5349	773	0.8	-3.0	6.8	10.6	770.8	5349	113.1	72.6	1.6
	L4_SC_S	256	0	7719	1007	0.0	-2.9	7.5	10.5	1006	7719	133.7	96.2	1.4
May-70	L1_SC_R	0	1190	3734	642	-0.1	-1.5	7.7	9.1	638.7	3734	83.3	70.4	1.2
	L2_SC_C	548	642	4560	673	-0.2	-1.2	7.7	8.8	670.2	4560	86.5	76.4	1.1
	L3_SC_T	386	256	5239	783	0.9	-2.1	6.7	9.6	780.4	5239	116.9	81.0	1.4
	L4_SC_S	256	0	6977	1000	0.8	-2.7	6.8	10.3	998.9	6977	146.9	97.0	1.5
Nov-70	L1_SC_R	0	1190	3606	641	2.3	-1.5	5.3	9.1	638.7	3606	121.5	70.2	1.7
	L2_SC_C	548	642	4428	876	2.3	-1.3	5.3	8.8	768.2	4428	144.7	87.0	1.7
	L3_SC_T	386	256	5163	784	1.0	-2.1	6.6	9.7	780.4	5163	118.4	80.3	1.5
	L4_SC_S	256	0	7317	1003	-0.5	-3.5	8.1	11.0	1001	7317	123.7	90.6	1.4
May-71	L1_SC_R	0	1190	3691	642	0.0	-2.4	7.5	10.0	638.7	3691	84.9	64.1	1.3
	L2_SC_C	548	642	4938	873	1.5	-3.3	6.1	10.8	768.2	4938	126.6	71.0	1.8
	L3_SC_T	386	256	5084	783	1.1	-2.4	6.5	10.0	780.4	5084	120.7	78.0	1.5
	L4_SC_S	256	0	7887	1008	-1.0	-3.1	8.5	10.6	1001	7887	117.2	94.1	1.2
Dec-05	L1_SC_R	0	1190	3955	627	-0.2	-3.0	7.7	10.5	620.2	3955	80.0	58.9	1.4
	L2_SC_C	548	642	5216	759	0.7	-2.5	6.9	10.0	814.2	5216	118.1	81.1	1.5
	L3_SC_T	386	256	5183	787	-1.5	-3.2	9.1	10.8	761.9	5183	84.1	70.7	1.2
	L4_SC_S	256	0	6737	1005	-1.3	-3.1	8.9	10.6	994.8	6737	112.0	93.5	1.2

b)

Date	Line	Distance between	total distance	A	pw	H	Hmin	d	D	w	P	w/d	w/D	D/d
				Hydraulic geometry Mean Tides										
Jul-69	L1_SC_R	0	1190	2811	459	1.5	-2.0	4.2	7.7	455.7	2811	107.7	58.9	1.8
	L2_SC_C	548	642	2760	549	1.9	-2.1	3.8	7.8	547.1	2760	142.5	69.9	2.0
	L3_SC_T	386	256	3953	617	1.0	-2.8	4.8	8.6	615.2	3953	129.3	71.4	1.8
	L4_SC_S	256	0	5394	856	0.6	-2.0	5.1	7.8	854.1	5394	166.2	109.8	1.5
Nov-69	L1_SC_R	0	1190	3025	471	1.2	-3.0	4.6	8.8	467.9	3025	102.2	53.5	1.9
	L2_SC_C	548	642	3354	551	0.3	-3.2	5.4	9.0	547.8	3354	100.9	61.0	1.7
	L3_SC_T	386	256	4166	619	0.8	-3.0	5.0	8.8	617.9	4166	123.2	70.1	1.8
	L4_SC_S	256	0	5950	906	0.0	-2.9	5.7	8.7	905.5	5950	158.1	104.6	1.5
May-70	L1_SC_R	0	1190	2759	464	-0.1	-1.5	5.9	7.3	461.4	2759	78.6	63.4	1.2
	L2_SC_C	548	642	3134	522	-0.2	-1.2	5.9	7.0	519.2	3134	87.3	74.4	1.2
	L3_SC_T	386	256	3932	633	0.9	-2.1	4.9	7.8	631.2	3932	129.5	80.5	1.6
	L4_SC_S	256	0	5225	918	0.8	-2.7	5.0	8.5	916.4	5225	183.3	107.8	1.7
Nov-70	L1_SC_R	0	1190	2631	464	2.3	-1.5	3.5	7.3	461.4	2631	133.4	63.3	2.1
	L2_SC_C	548	642	3057	577	2.3	-1.3	3.5	7.0	573.9	3057	163.5	81.6	2.0
	L3_SC_T	386	256	3856	634	1.0	-2.1	4.8	7.9	631.2	3856	131.8	79.7	1.7
	L4_SC_S	256	0	5558	908	-0.5	-3.5	6.3	9.2	906.4	5558	144.0	98.0	1.5
May-71	L1_SC_R	0	1190	2714	469	0.0	-2.4	5.7	8.2	461.4	2714	80.7	56.5	1.4
	L2_SC_C	548	642	3519	571	1.5	-3.3	4.3	9.0	573.9	3519	134.4	63.6	2.1
	L3_SC_T	386	256	3782	633	1.1	-2.4	4.7	8.2	631.2	3782	135.3	76.9	1.8
	L4_SC_S	256	0	6125	885	-1.0	-3.1	6.7	8.8	906.4	6125	134.4	102.5	1.3
Dec-05	L1_SC_R	0	1190	2995	486	-0.2	-3.0	5.9	8.7	478.5	2995	80.4	54.9	1.5
	L2_SC_C	548	642	3799	589	0.7	-2.5	5.1	8.2	633.1	3799	124.3	76.9	1.6
	L3_SC_T	386	256	3956	602	-1.5	-3.2	7.3	9.0	580.2	3956	80.0	64.6	1.2
	L4_SC_S	256	0	5068	810	-1.3	-3.1	7.1	8.8	797.7	5068	112.6	90.3	1.2

Table 5: Summary of hydraulic geometry parameters and measures of channel form for lines on the St. Croix River from July 1969 to December 2005 where available for a) large tides and b) mean tides. Distance = distance between lines, Total Distance = distance from confluence of Avon and St. Croix Rivers. Refer to Table 3 for additional abbreviations.

Despite the relatively large shifts in channel bank position, the cross sectional area and wetted perimeter, Lines 1 & 3 remain quite constant between the time periods (Figs 15a & d; Table 5). This indicates that although the form of the river channel is changing, primarily due to a shift in the main channel thalweg from south to north shore of the river (Fig 15e), the hydraulic capacity of the system has not changed. Seasonal fluctuations in cross sectional area by as much as 600 m^2 are clearly evident on Line 4, the closest line to the confluence of the Avon and St. Croix rivers (Fig 15d; Table 5). It should be noted that the changes recorded for Line 2 should be interpreted with caution due to the position of the line (Fig 15e) and extrapolation for the area calculations on the south shore. In addition, this is also the outlet for a large aboiteaux which could significantly deepen the channel temporarily after a heavy rainfall and subsequent freshwater discharge.

In general, the highest rates of change in cross sectional area are recorded during the 1969 year, with the largest and fastest being recorded along L4_SC_S (Table 6). This trend continues through the remaining years however the rate of change decreases markedly from 1969 to 2005. The data suggest that there is considerable seasonal and inter annual variability however when one examines the net changes in cross sectional area from July 1969 to 2005, Lines 1 and 3 show between 4.6 and 0.9% increase in cross sectional area and Line 4 exhibits a 5.2% decrease in area.

a)	Change in Cross Sectional Area Large Tides														
	July 69 to Nov 69			Nov 69 to May 70			May 70 to Nov 70			Nov 70 to May 71			July 69 to Dec 05		
	net	%	rate	net	%	rate	net	%	rate	net	%	rate	net	%	rate
L1_SC_R	-215	-5.7	-43.0	262	6.6	37.4	128	3.4	18.2	-85	-2.4	-12.1	-174	-4.6	-0.4
L3_SC_T	-210	-4.1	-42.1	110	2.0	15.7	76	1.5	10.9	79	1.5	11.2	-45	-0.9	-0.1
L4_SC_S	-609	-8.6	-121.8	742	9.6	105.9	-340	-4.9	-48.6	-570	-7.8	-81.5	373	5.2	0.9
b)	Change in Cross Sectional Area Mean Tides														
	July 69 to Nov 69			Nov 69 to May 70			May 70 to Nov 70			Nov 70 to May 71			July 69 to Dec 05		
	net	%	rate	net	%	rate	net	%	rate	net	%	rate	net	%	rate
L1_SC_R	-215	-7.6	-42.9	266	8.8	38.1	128	4.6	18.2	-83	-3.1	-11.8	-185	-6.6	-0.4
L3_SC_T	-213	-5.4	-42.6	234	5.6	33.4	76	1.9	10.9	74	1.9	10.6	-3	-0.1	0.0
L4_SC_S	-555	-10.3	-111.1	725	12.2	103.6	-333	-6.4	-47.6	-567	-10.2	-81.0	326	6.1	0.7

Table 6: Summary of changes in cross sectional area for lines on the St. Croix River from July 1969 to December 2005 for a) large tides and b) mean tides. Rate of change is expressed in m^2 per month (net change divided by number of months between sampling dates). The changes recorded for Line 2 are not included in this analysis due to the position of the line (see Fig 16e) and extrapolation needed for the prism and area calculations on the south shore. In general (with the exception of % values), a negative net value indicates accretion whereas a positive value indicates erosion for net and rate values.

Description of Changes in the Avon and Kennetcook Rivers

Although statistical analyses have not yet been performed on the data, the most significant changes in cross sectional form since 1969 have occurred in lines closest to the causeway (Fig. 16d, Table 7). Both lines 1A (Fig 16a) and 1 (Fig16b) saw a general decrease in bed elevation of around 1m between July 69 and November 1969. However, between 1969 and Dec 2005, a sediment layer approximately 6.5 m (Fig 16a) deep has accumulated in the central section (point 600 m on profile) in the vicinity of an existing intertidal bar (Fig 16c). In addition, the thalweg of the tidal creek which runs parallel to the causeway (Fig 16c) has filled in by around 3.8 m of sediment. This surface is now at the limit of the HHWMT level. These changes resulted in a 71% and 89% decrease in cross sectional area for large and mean tides respectively (Table 8) along Line 1A. The wetted perimeter for large tides remained fairly constant along that line however its value decreased by half when calculated for mean tides due to the limited amount of channel area below the HHWMT line. This also resulted in a marked difference between w/d and also D/d ratios between the 1960s and the present day.

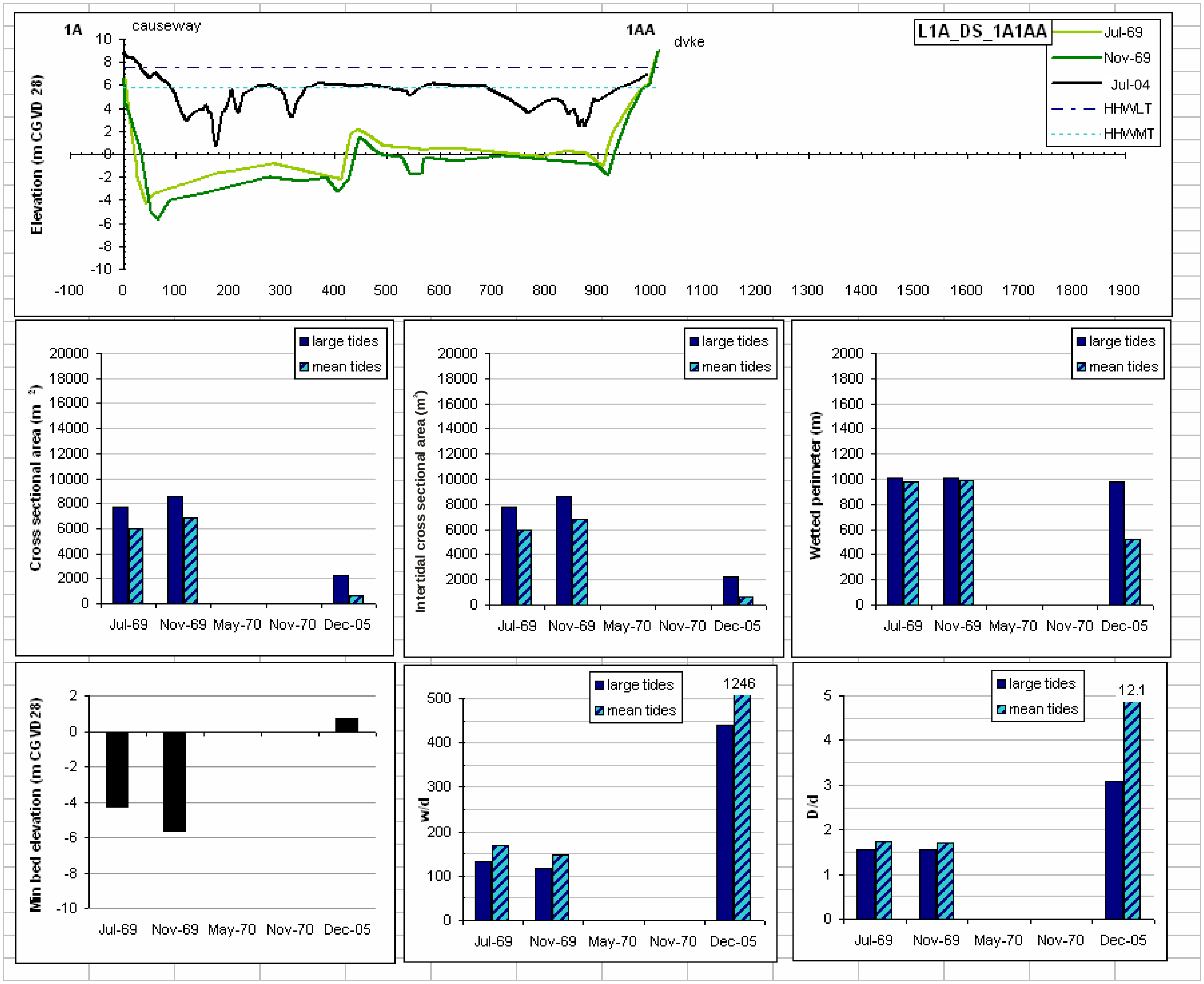

Figure 16a: Cross sectional profiles for Line 1_DS_1A1AA and associated hydraulic geometry parameters on the Avon River. Note changes in vertical exaggeration on cross sectional profile to 95 x and on scale of y axes. Distance on cross sectional profile in metres.

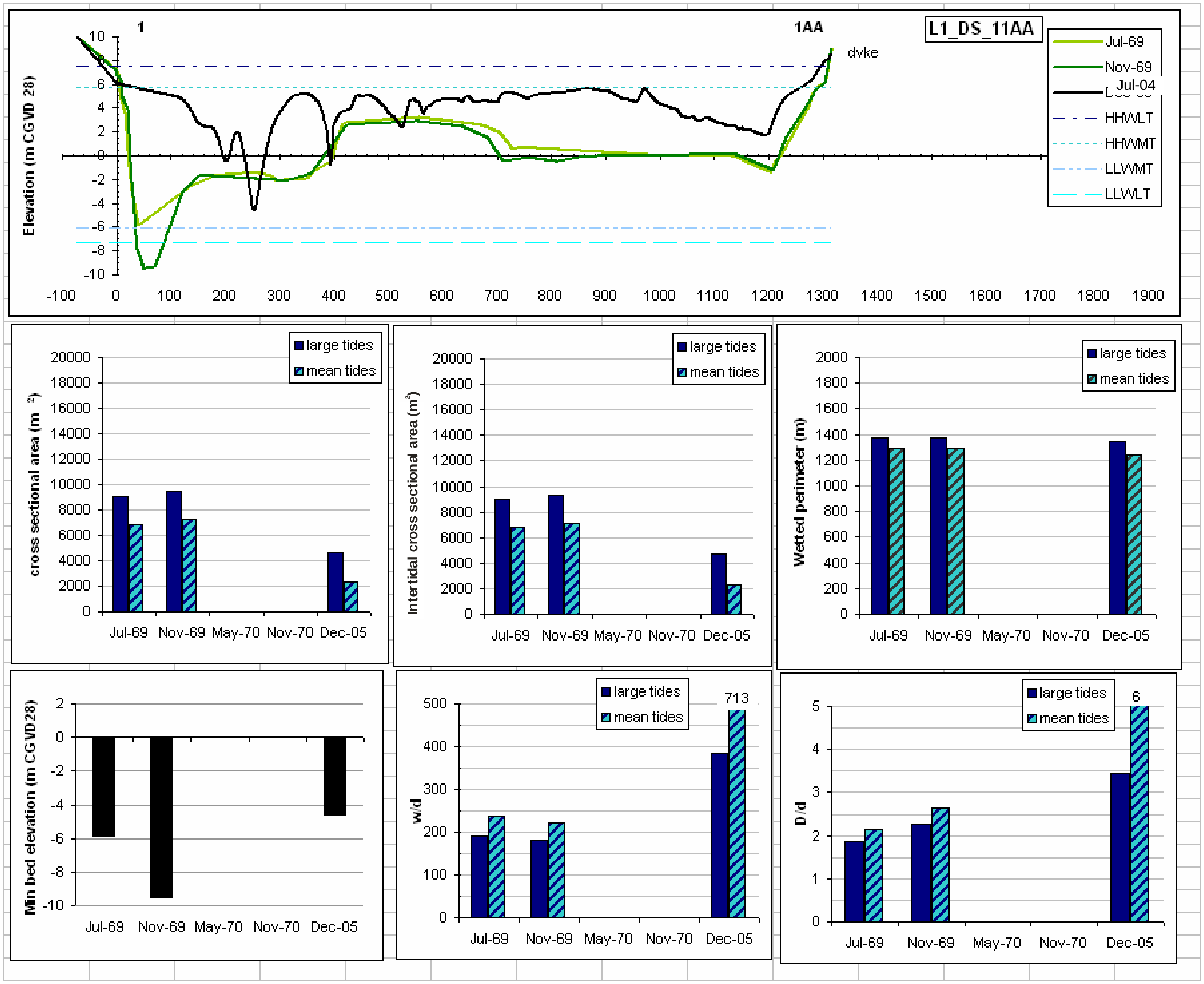

Figure 16b: Cross sectional profiles for Line 1_DS_11AA and associated hydraulic geometry parameters on the Avon River. Vertical exaggeration on cross sectional profile = 95X . Distance on cross sectional profile in metres.

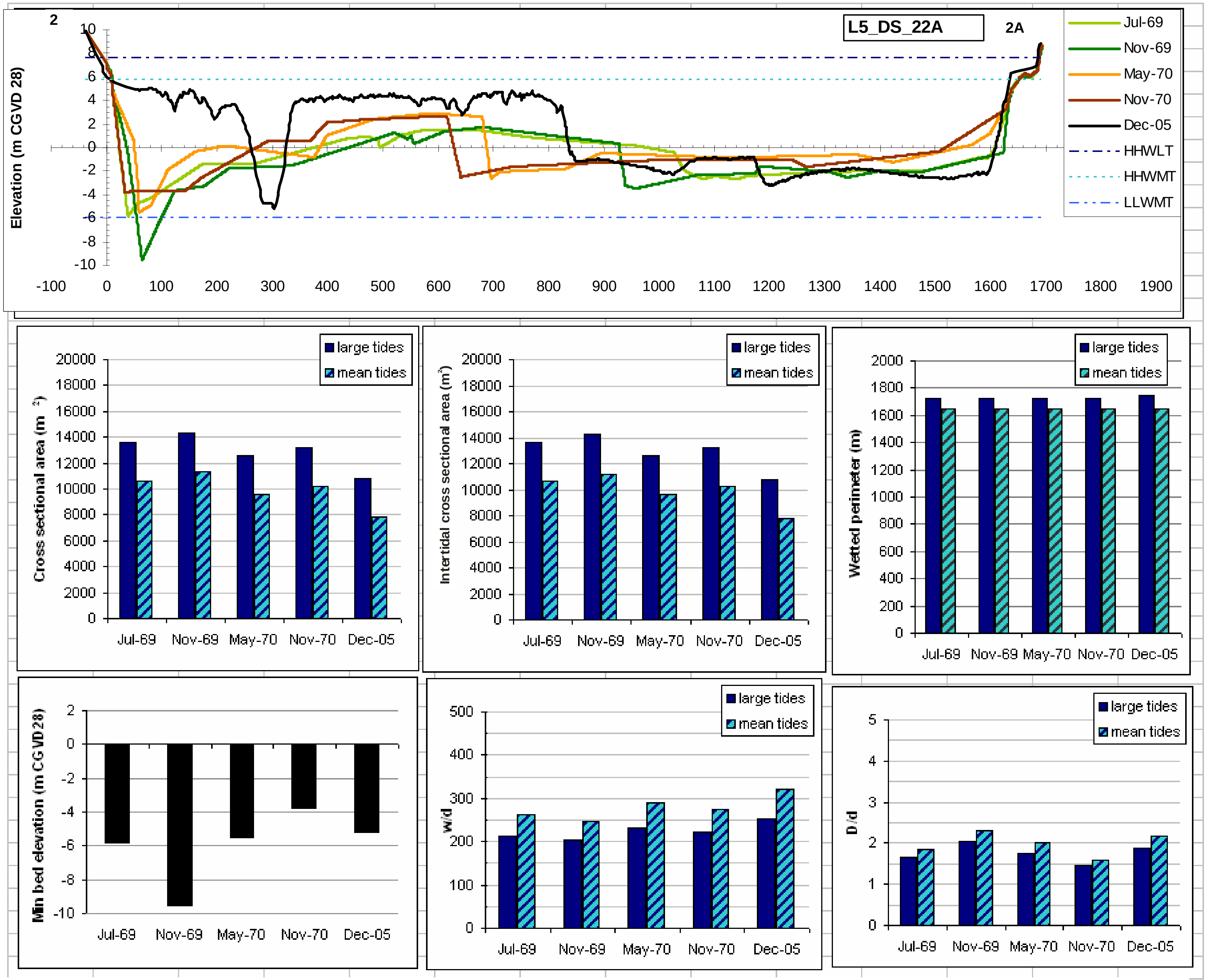

Figure 16c: Cross sectional profiles for Line 5_DS_22A and associated hydraulic geometry parameters on the Avon River. Vertical exaggeration on cross sectional profile = 95X. Distance on cross sectional profile in metres.

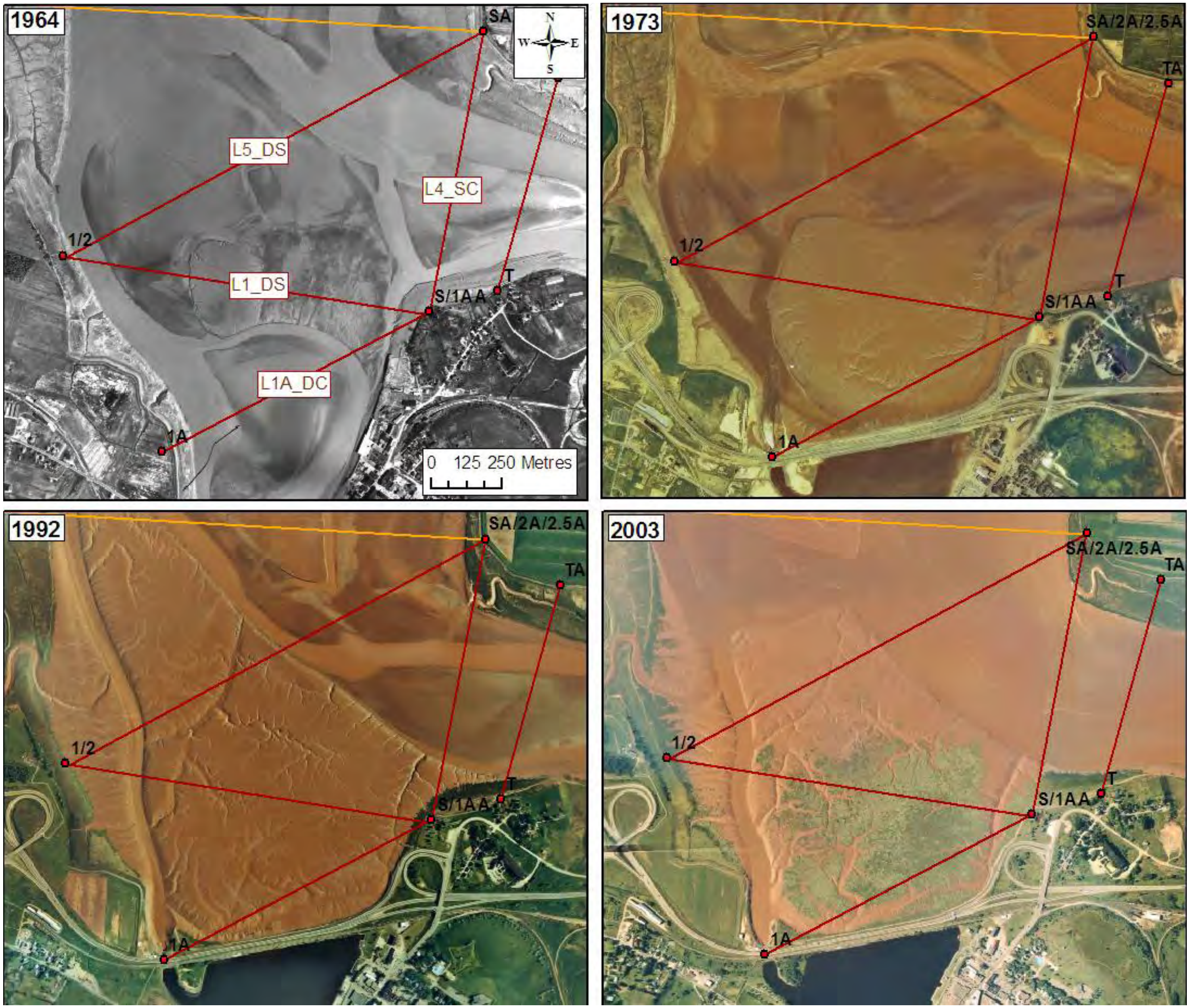

Figure 16d: Location of downstream survey lines 1A, 1 and 5. Note changes in channel thalwegs, bar location and marsh growth from 1964 to 2003.

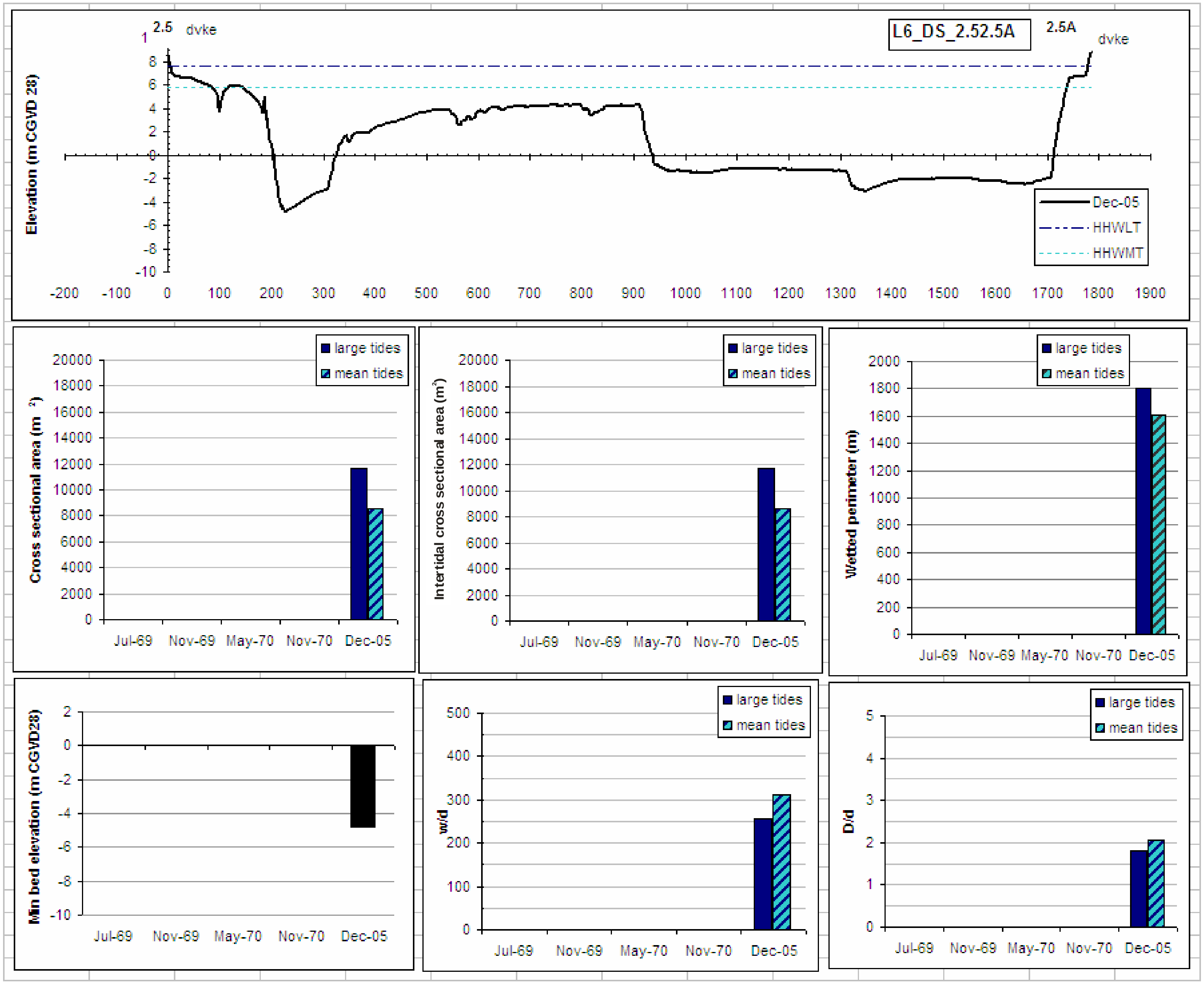

Figure 16e: Cross sectional profiles for Line 6_DS_2.52.5A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 95X. Distance on cross sectional profile in metres.

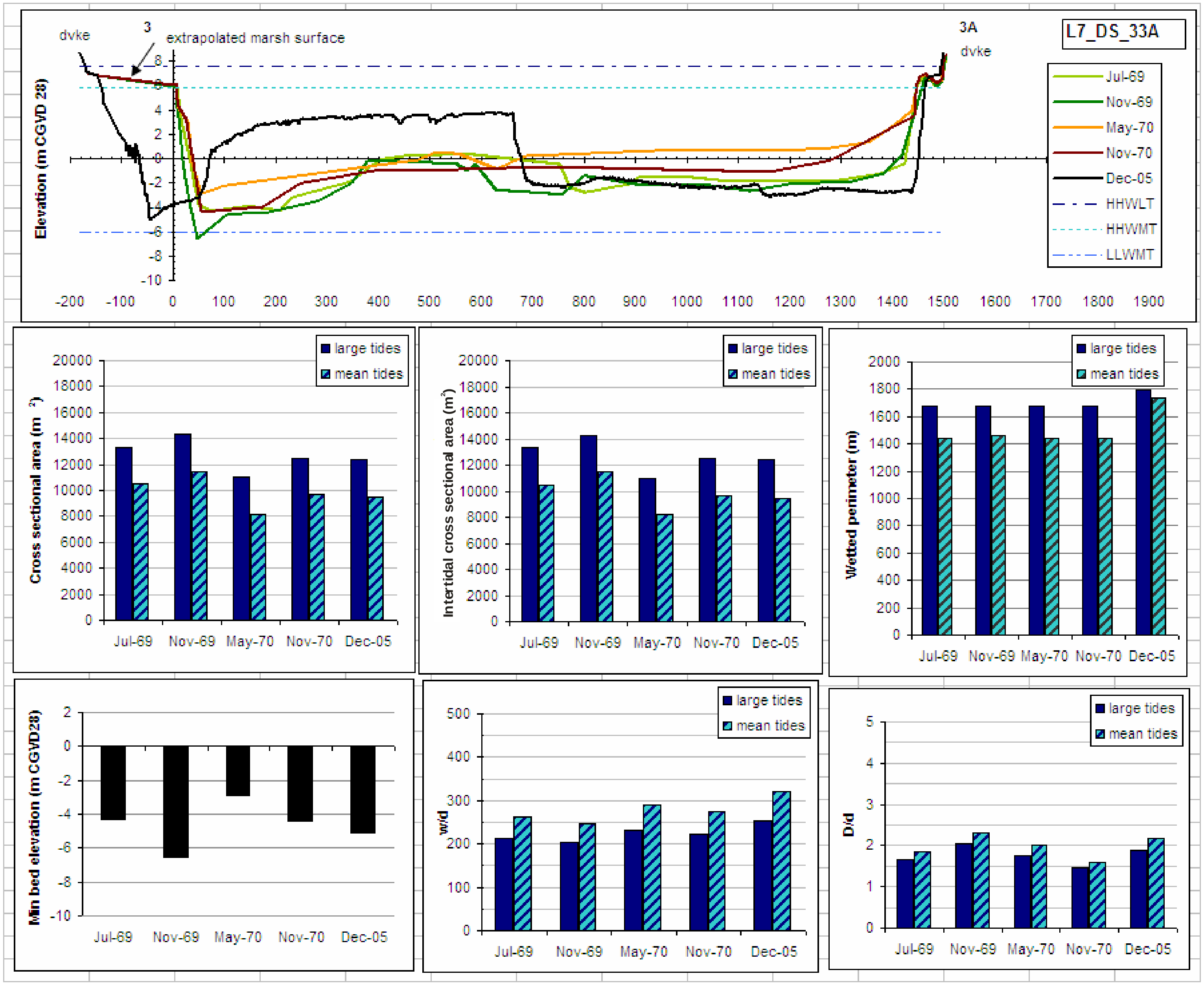

Figure 16f: Cross sectional profiles for Line 7_DS_33A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 95X. Distance on cross sectional profile in metres.

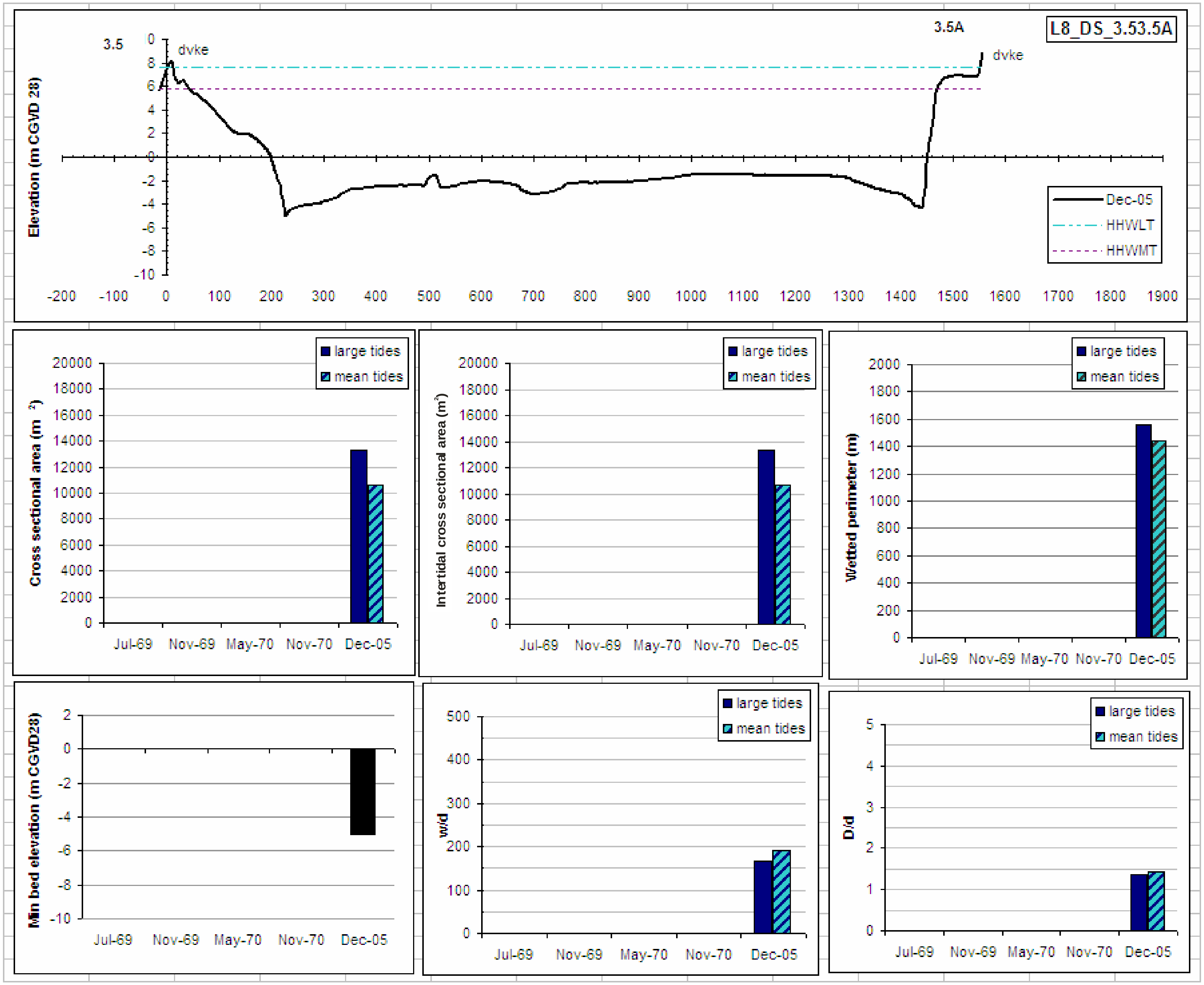

Figure 16g: Cross sectional profiles for Line 8_DS_3.53.5A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 95X. Distance on cross sectional profile in metres.

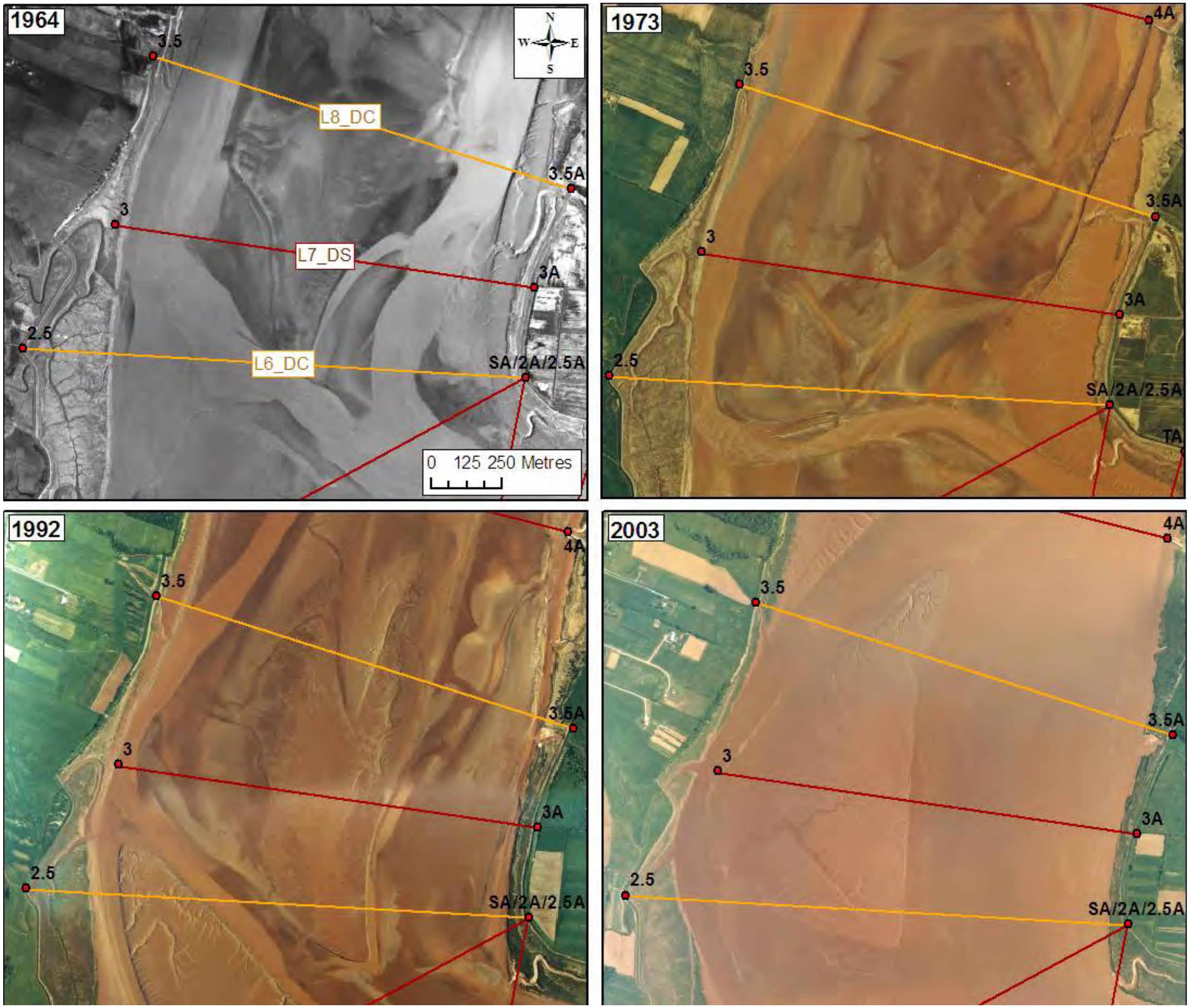

Figure 16h: Location of downstream survey lines 6,7 and 8. Note changes in channel thalwegs, bar location and marsh loss on west bank from 1964 to 2003. A new post '3' was added in 2005 for navigational purposes due to erosion of the west bank however all calculations were performed relative to the original stake 3.

Figure 16i: Cross sectional profiles for Line 9_DS_44A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 95X. Distance on cross sectional profile in metres

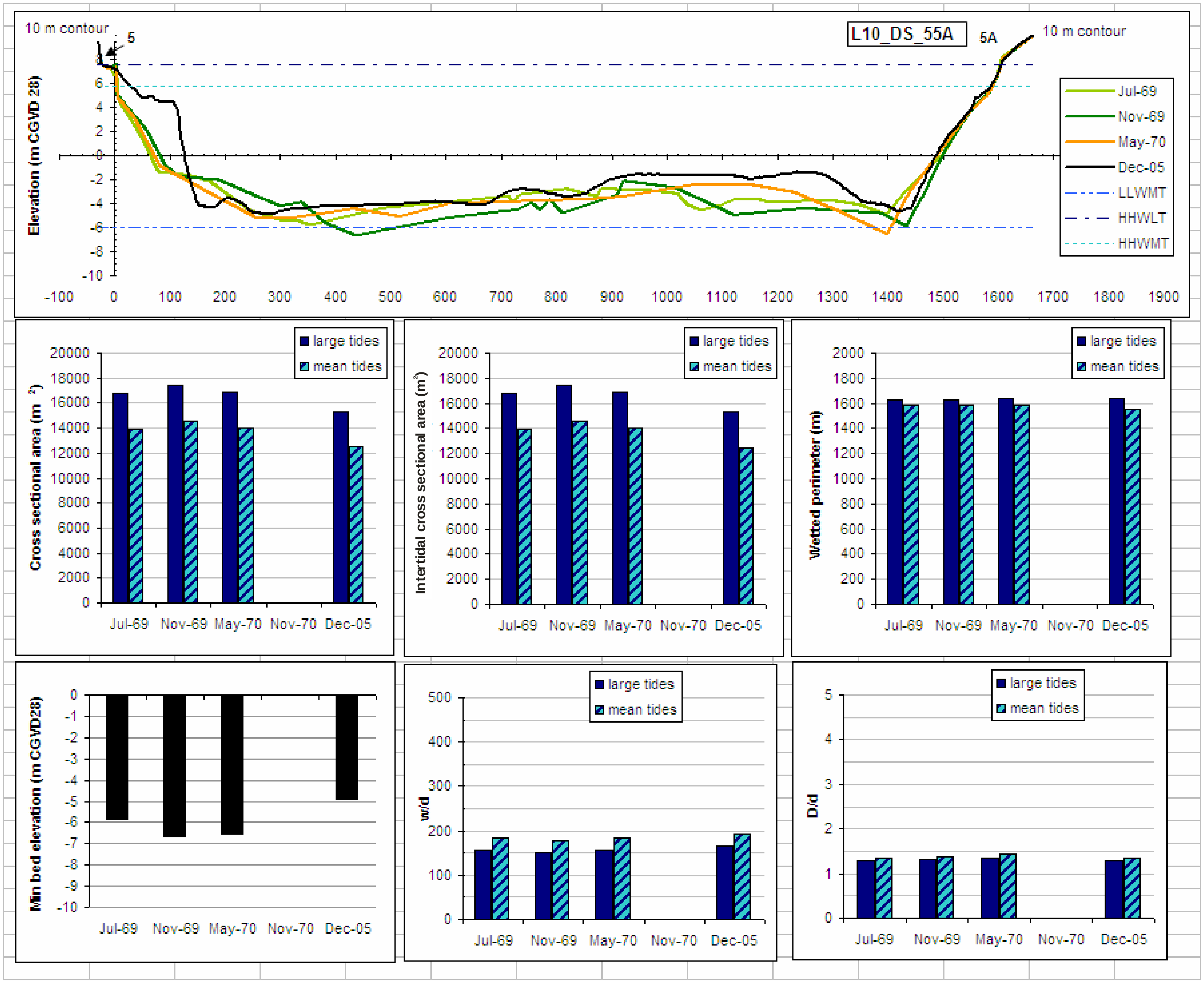

Figure 16j: Cross sectional profiles for Line 10_DS_55A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 95X. Distance on cross sectional profile in metres

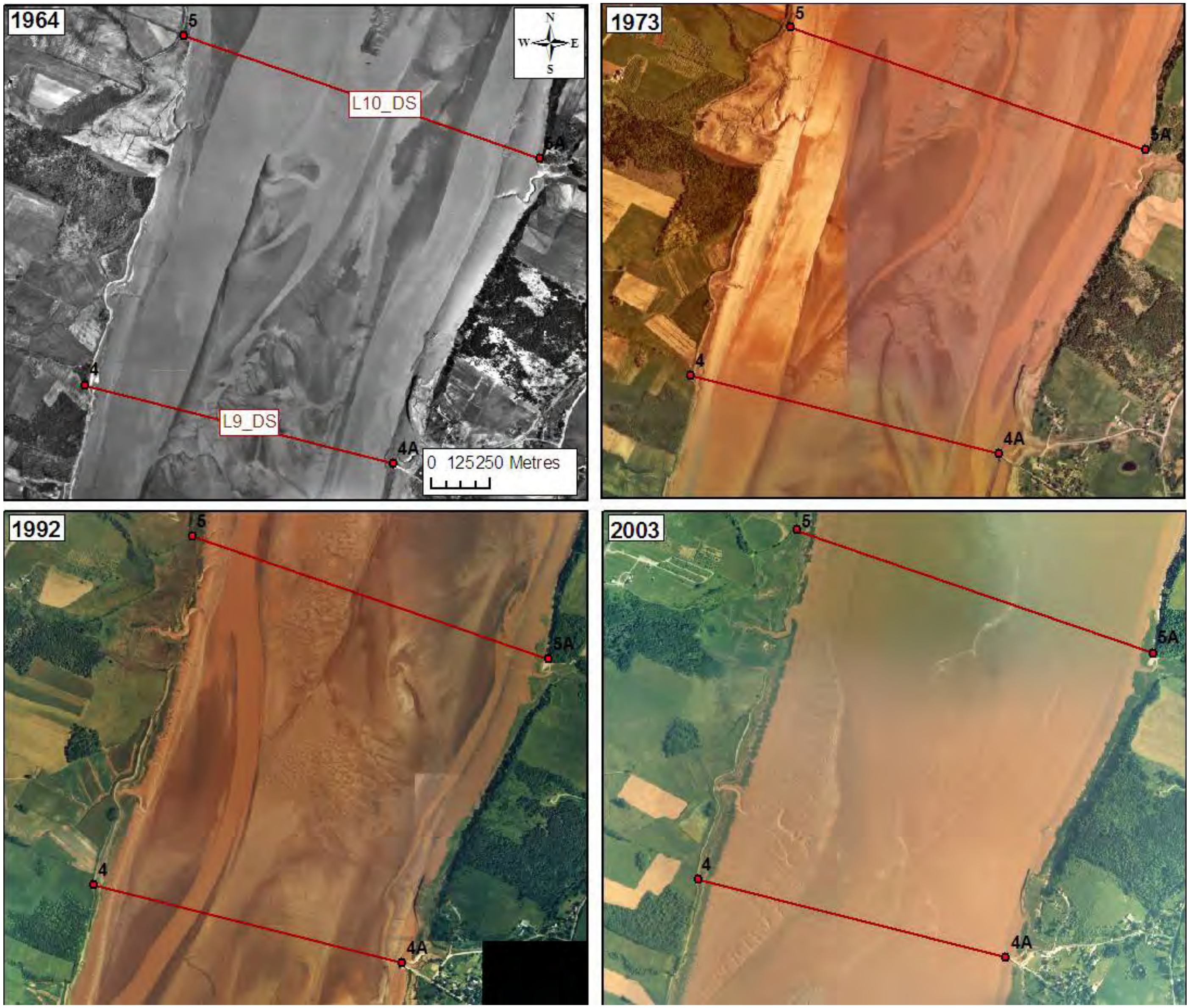

Figure 16k: Location of downstream survey lines 9 and 10. Note changes in channel thalwegs, bar location and marsh and mudflat expansion on west bank from 1964 to 2003. Distance on cross sectional profile in metres.

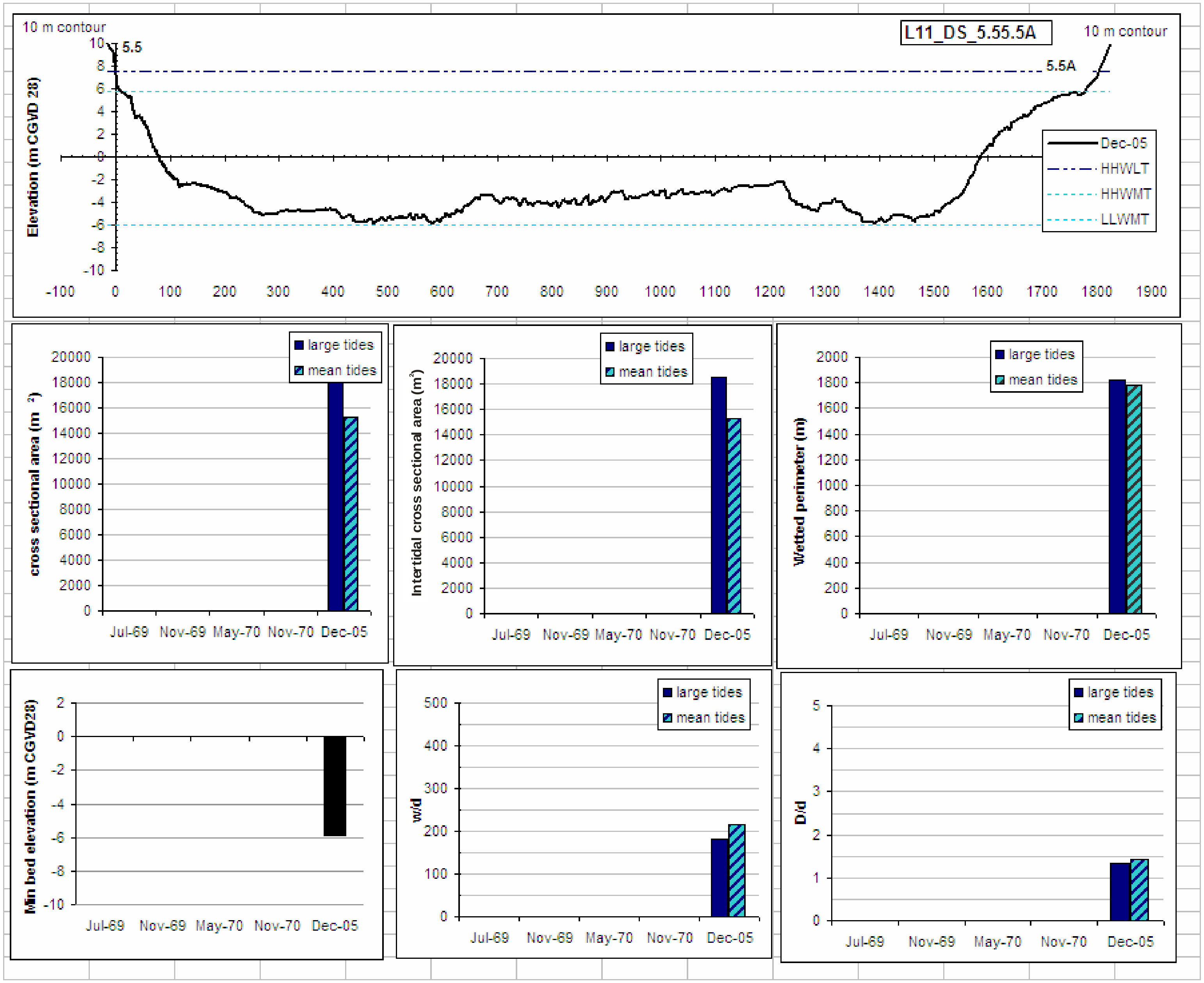

Figure 16l: Cross sectional profiles for Line 11_DS_5.55.5A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 95X. Distance on cross sectional profile in metres

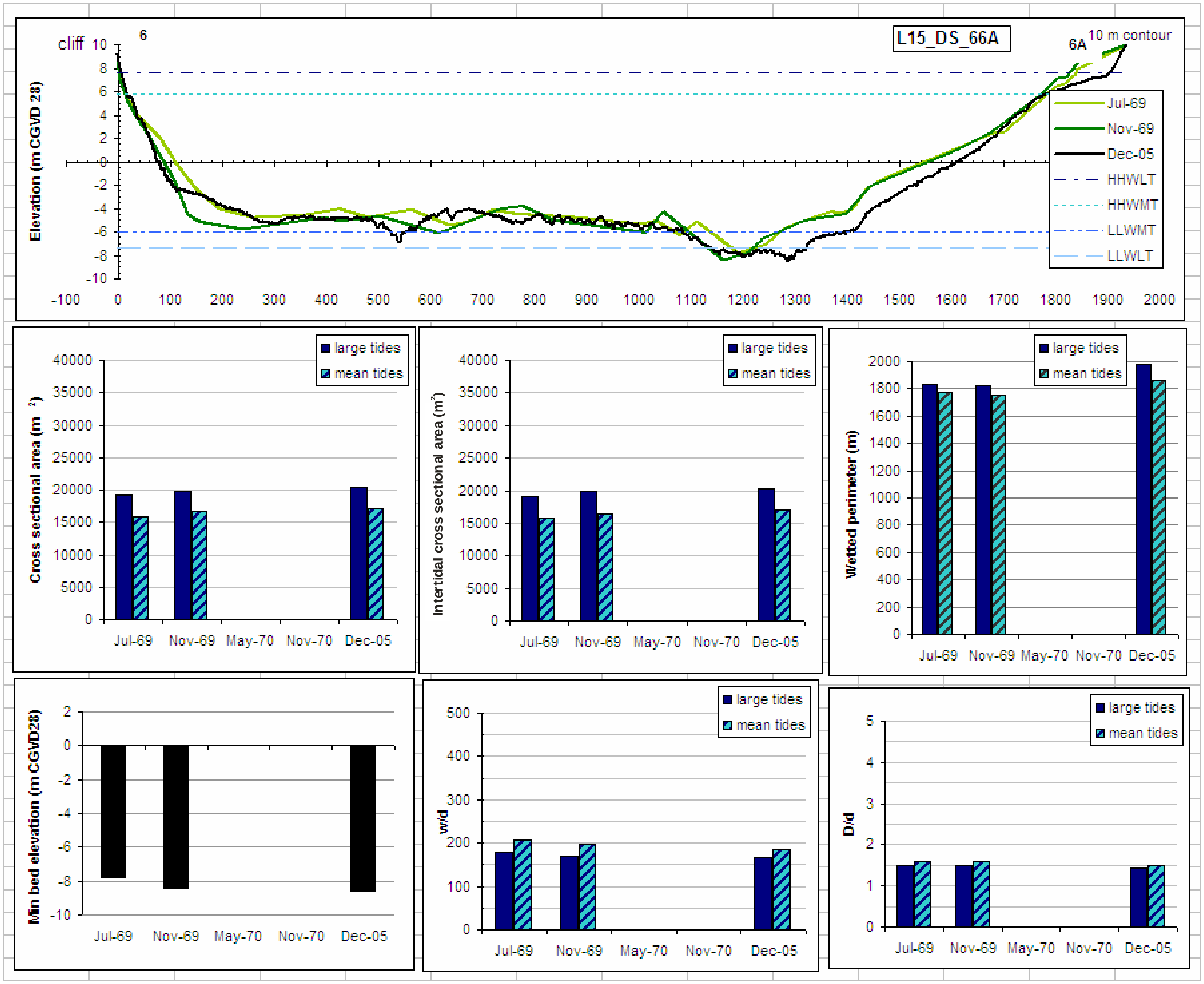

Figure 16m: Cross sectional profiles for Line 15_DS_66A and associated hydraulic geometry parameters. Note change in vertical exaggeration on cross sectional profile to 100X and change in scale on y axis for cross sectional area and intertidal cross sectional area. Distance on cross sectional profile in metres

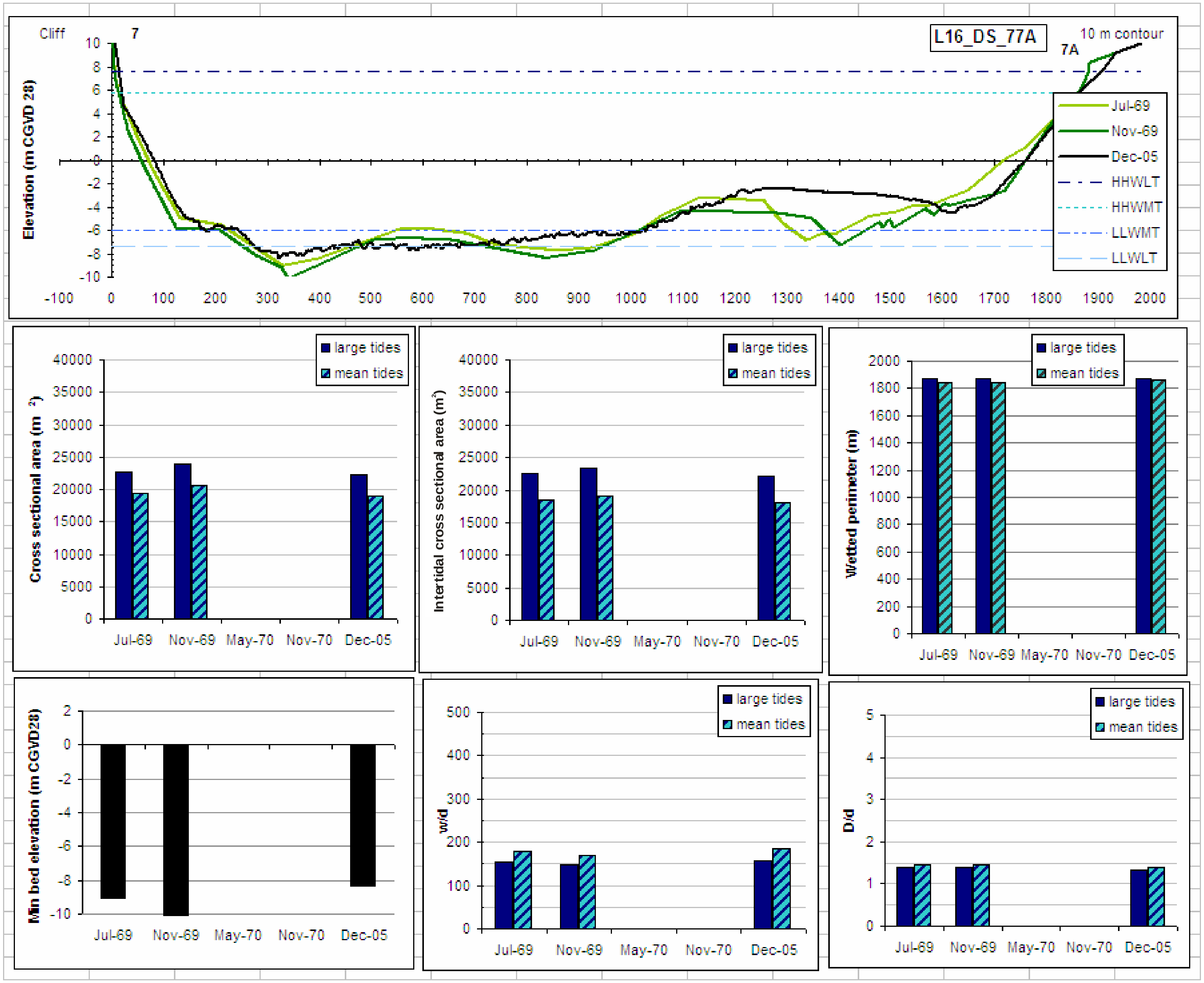

Figure 16n: Cross sectional profiles for Line 16_DS_77A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 100X . Distance on cross sectional profile in metres

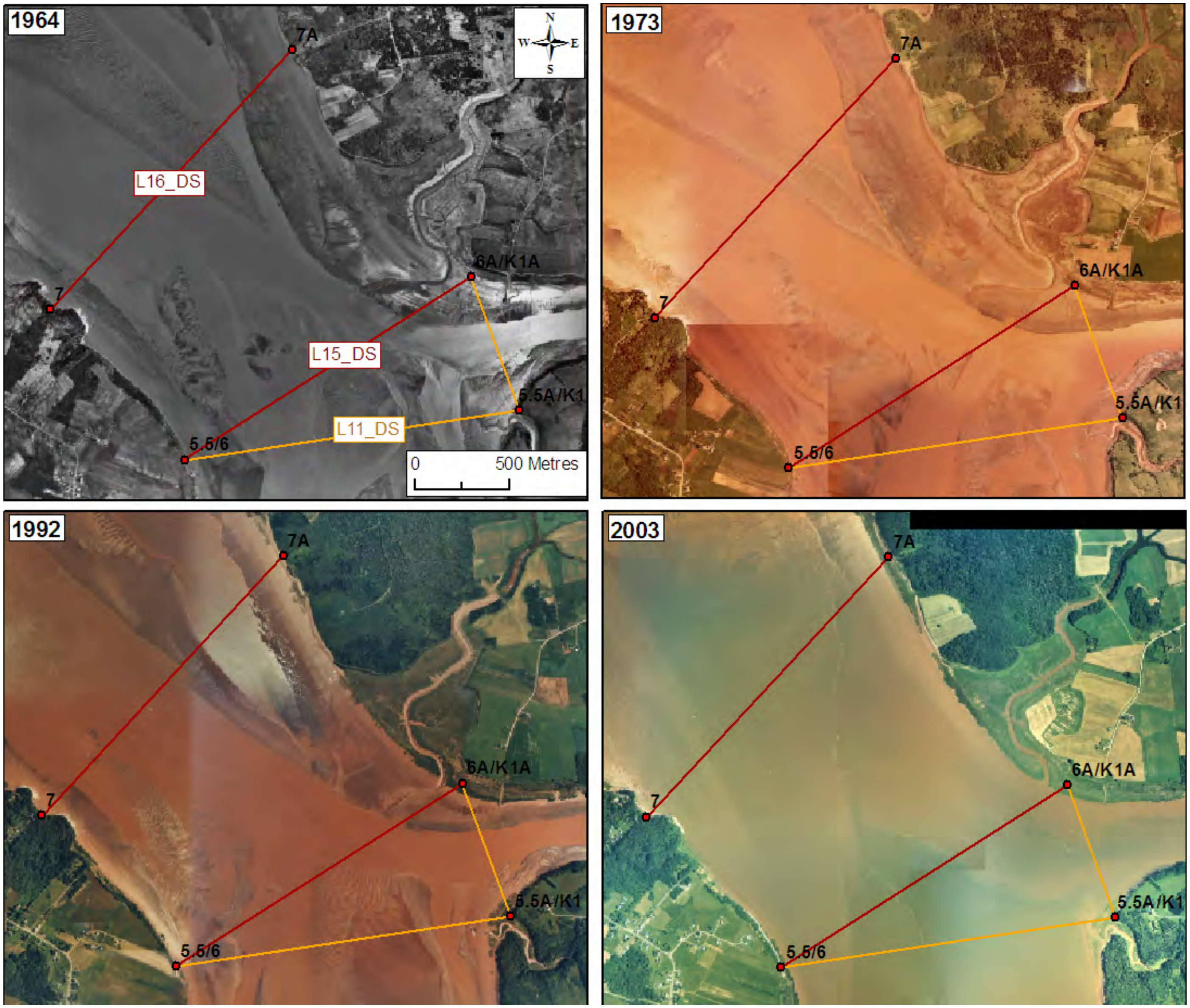

Figure 16o: Location of downstream survey lines 11,15 and 16. Minor changes in channel thalwegs and bar location from 1964 to 2003.

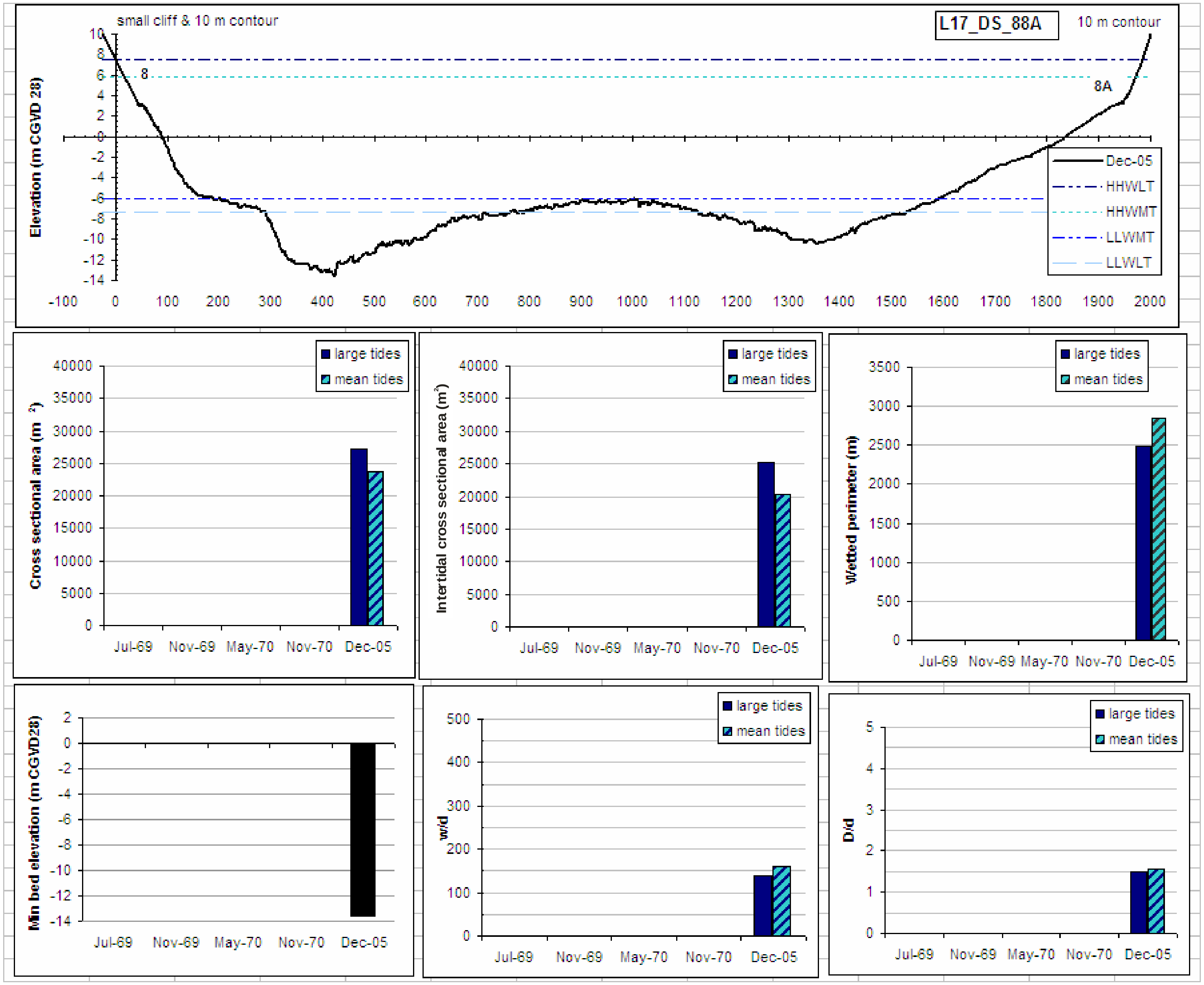

Figure 16p: Cross sectional profiles for Line 17_DS_88A and associated hydraulic geometry parameters. Note change in vertical exaggeration on cross sectional profile to 83X and change in scale for wetted perimeter and minimum bed elevation. Distance on cross sectional profile in metres.

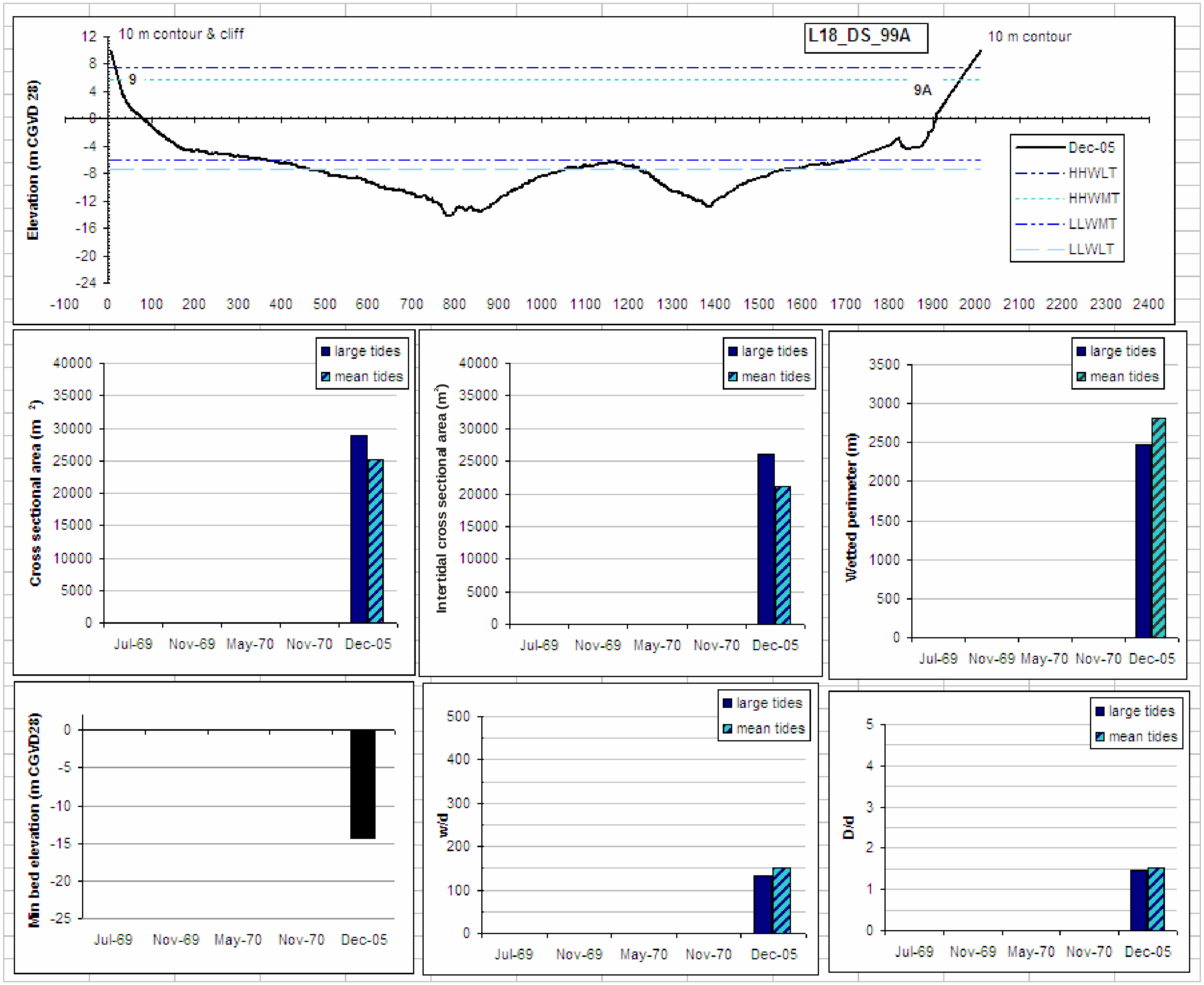

Figure 16q: Cross sectional profiles for Line 18_DS_99A and associated hydraulic geometry parameters. Note change in vertical exaggeration on cross sectional profile to 67X and change in scale for minimum bed elevation. Distance on cross sectional profile in metres.

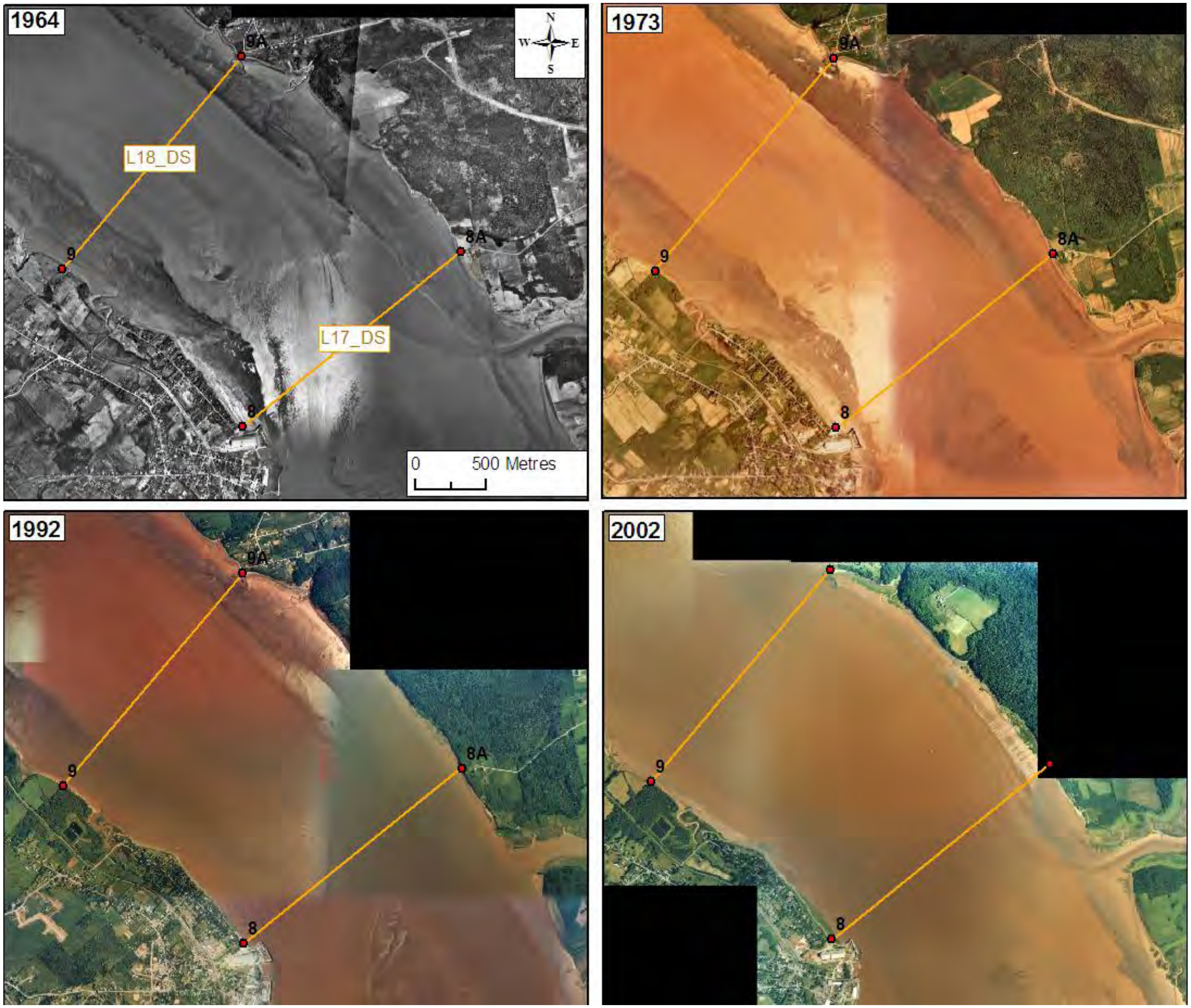

Figure 16p: Location of downstream survey lines 17 and 18. Note relative stability of position of the main channel thalwegs and bar locations from 1964 to 2003.

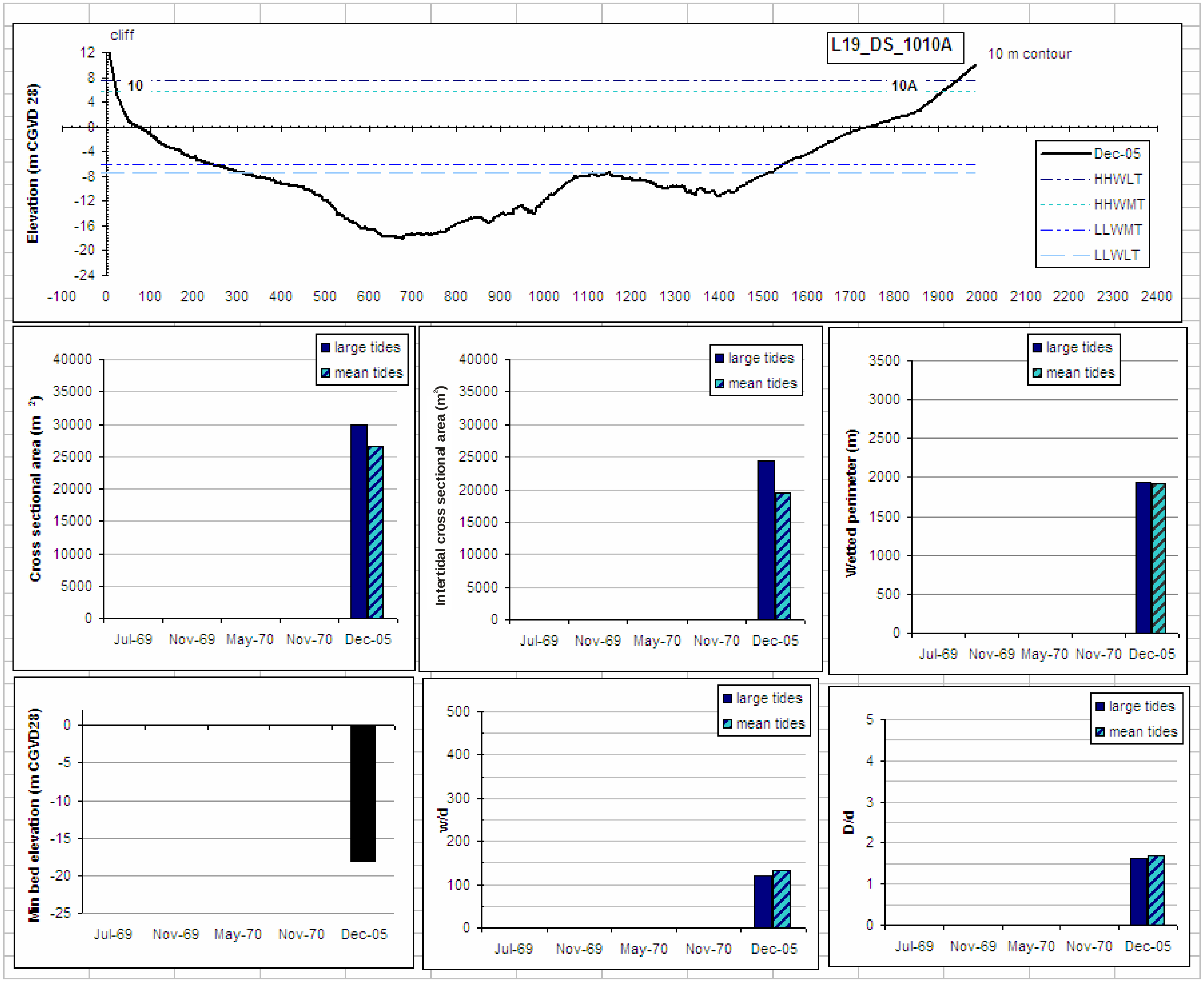

Figure 16r: Cross sectional profiles for Line 19_DS_1010A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 67X. Distance on cross sectional profile in metres.

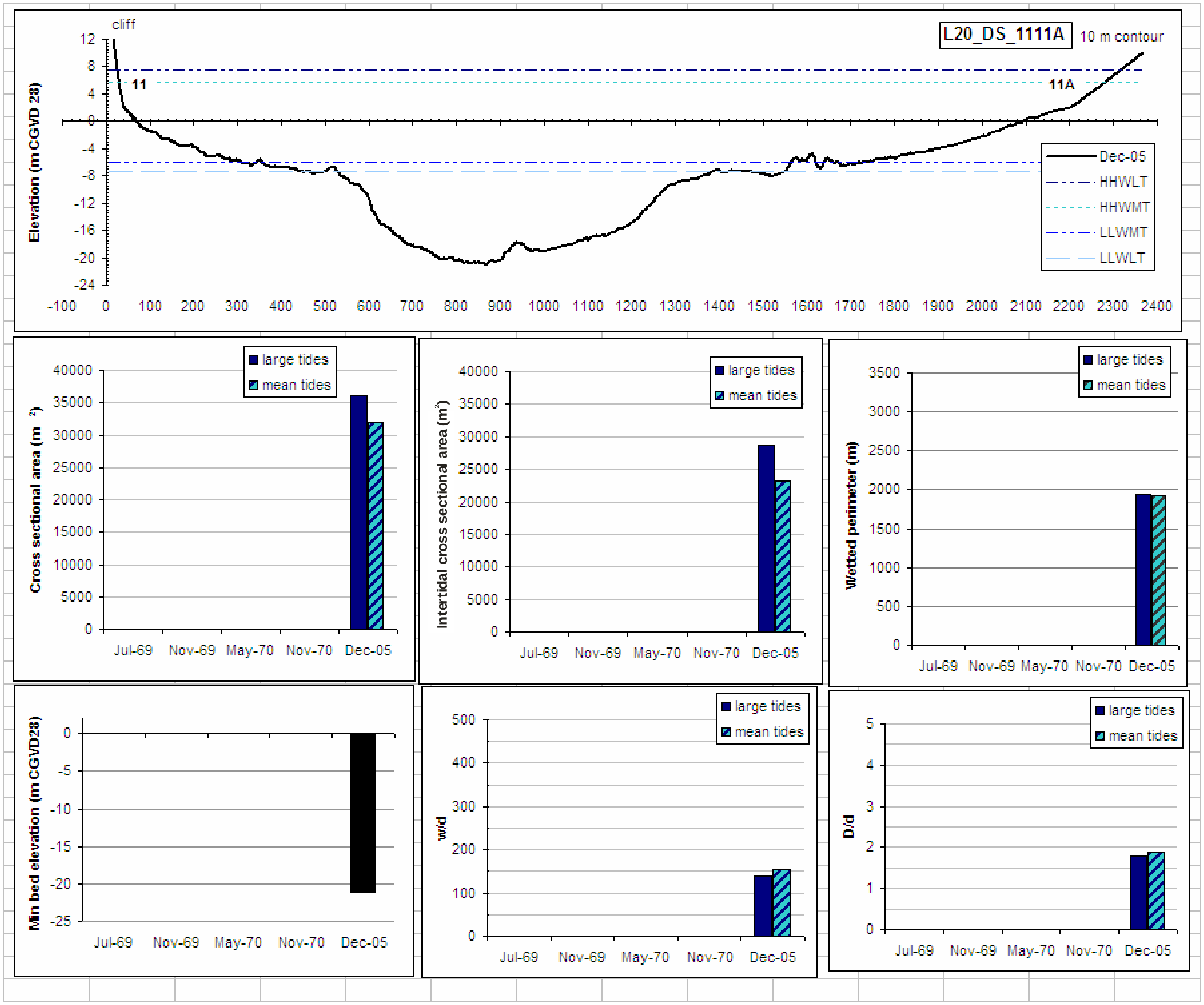

Figure 16s: Cross sectional profiles for Line 20_DS_1111A and associated hydraulic geometry parameters. Vertical exaggeration on cross sectional profile = 67X. Distance on cross sectional profile in metres.

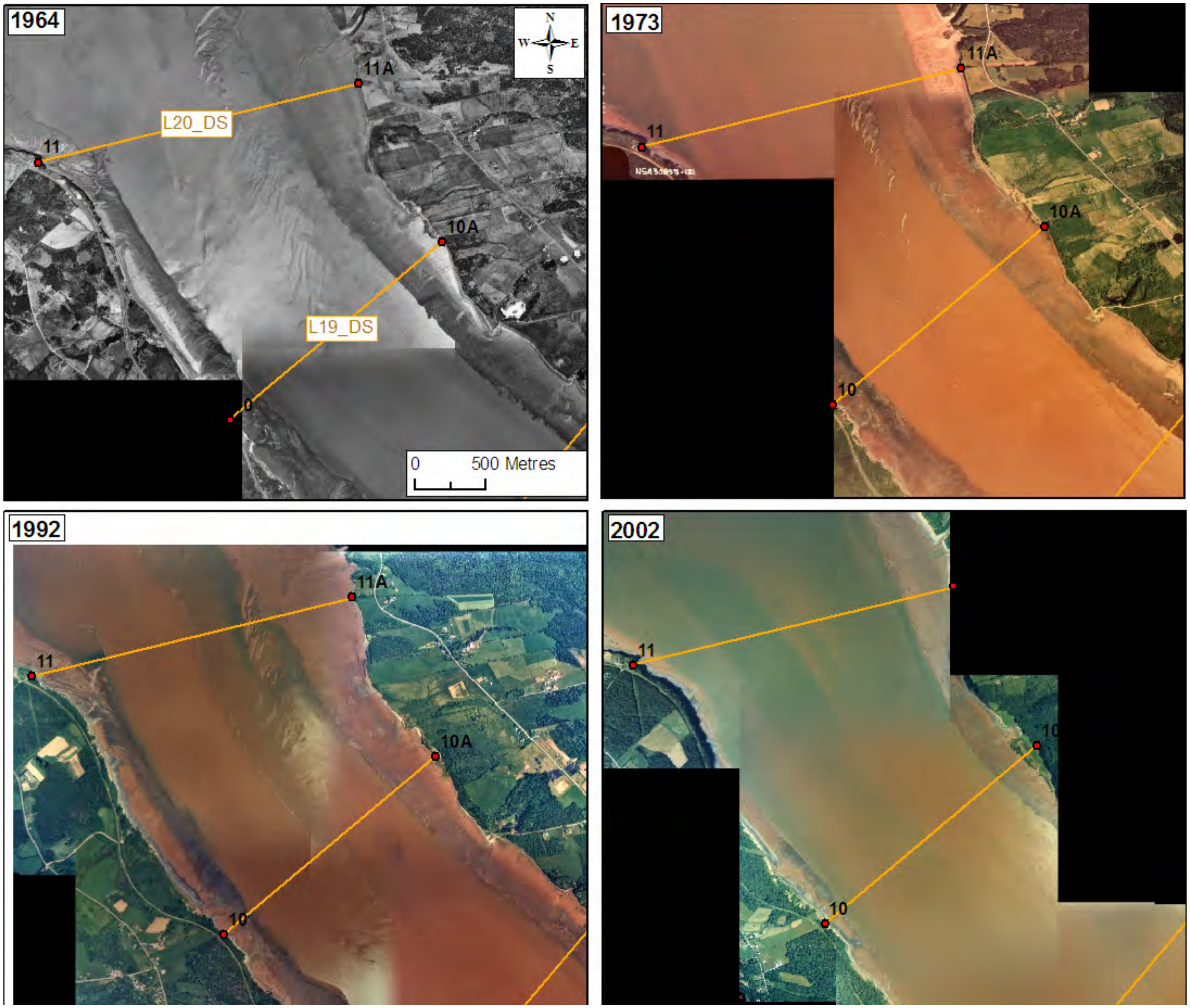

Figure 16t: Location of downstream survey lines 19 and 20. Note relative stability of position of the main channel thalwegs and bar locations from 1964 to 2003.

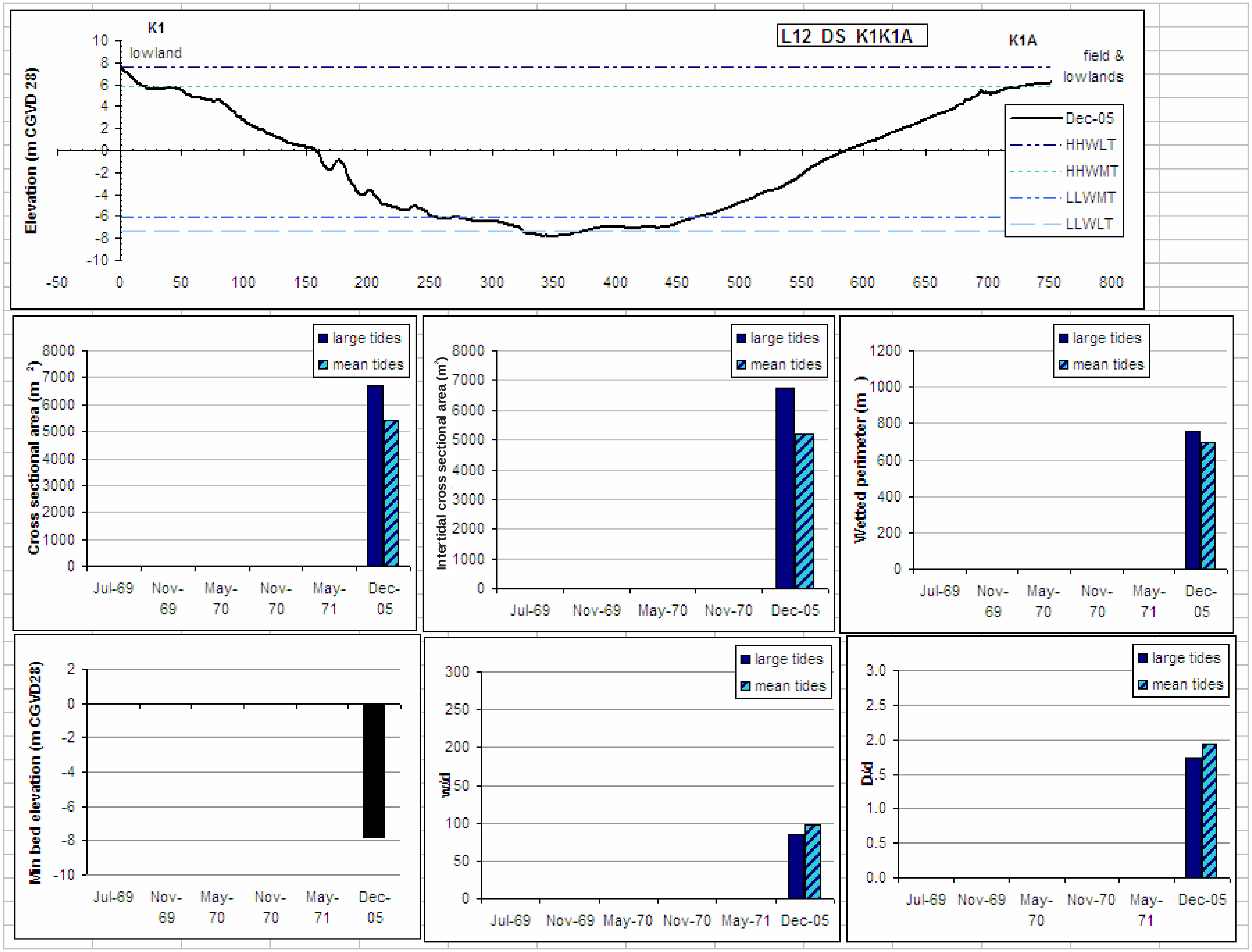

Figure 17a: Cross sectional profiles for Line 12_DS_K1K1A and associated hydraulic geometry parameters along the Kennetcook River. Vertical exaggeration on cross sectional profile = 42.5 X. Distance on cross sectional profile in metres. The section of the profile near K1A could not be extended further due to the extensive lowland area adjacent to it.

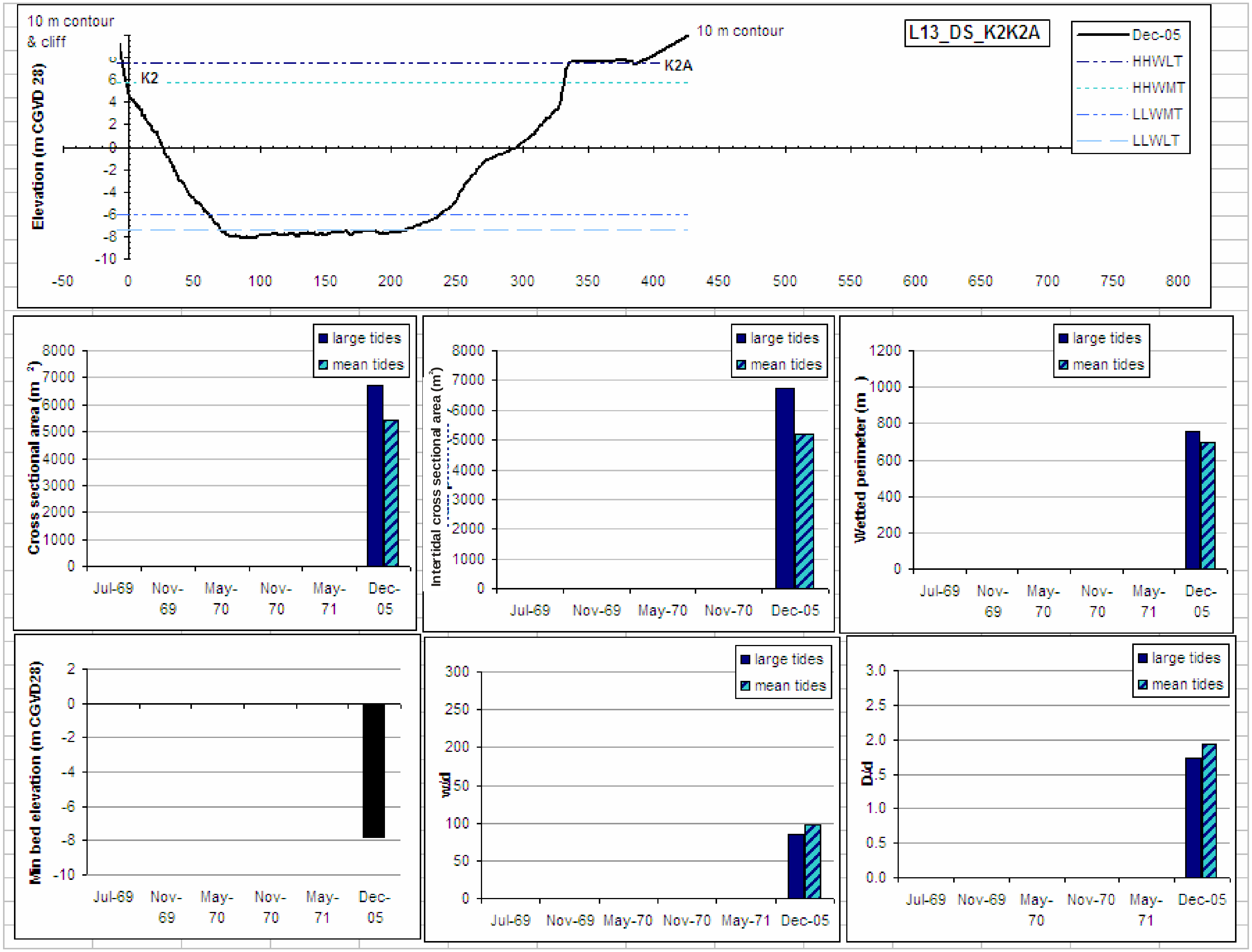

Figure 17b: Cross sectional profiles for Line 13_DS_K2K2A and associated hydraulic geometry parameters along the Kennetcook River. Vertical exaggeration on cross sectional profile = 42.5 X. Distance on cross sectional profile in metres.

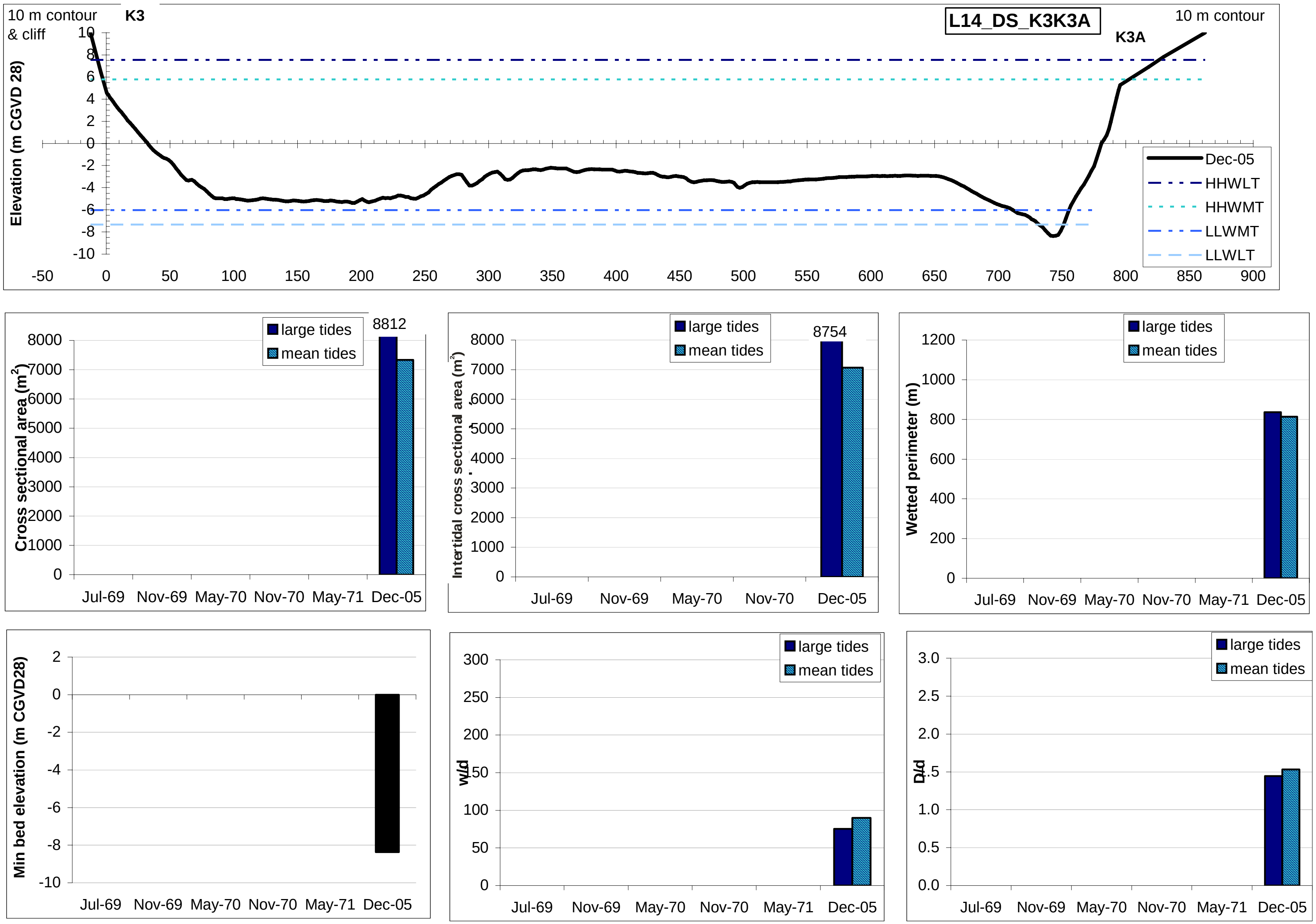

Figure 17c: Cross sectional profiles for Line 14_DS_K3K3A and associated hydraulic geometry parameters along the Kennetcook River. Vertical exaggeration on cross sectional profile = 47.5 X. Distance on cross sectional profile in metres.

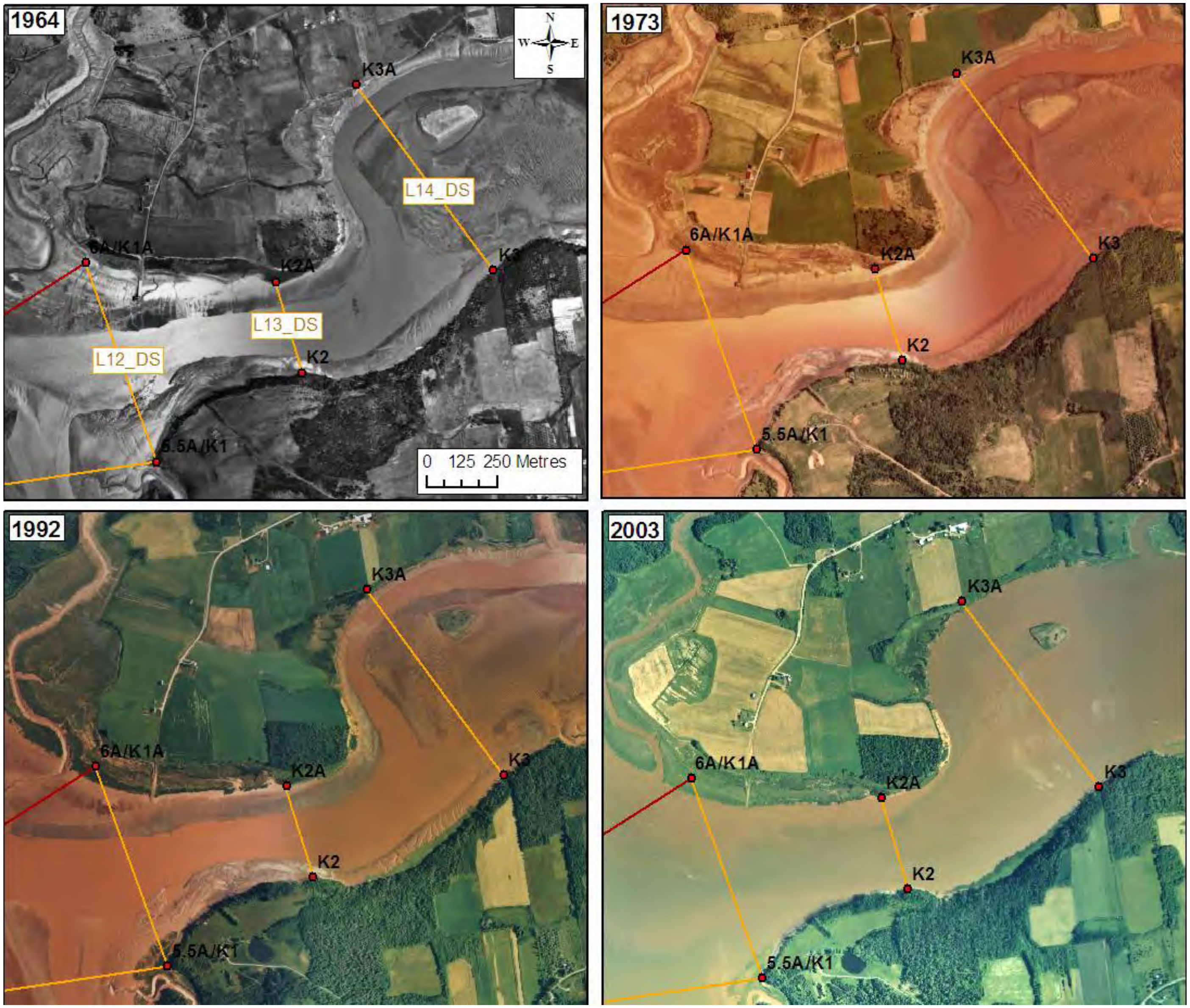

Figure 17d: Location of downstream survey lines 12,13 and 14 on the Kennetcook River. Note relative stability of position of the main channel thalwegs and bar locations from 1964 to 2003.

a) Avon River

			total		Hydraulic geometry Large Tides									
Date	**Line**	**Distance**	**dist**	***A***	***pw***	***H***	***Hmin***	***d***	***D***	***w***	***A*** $_i$	***w/d***	***w/D***	***D/d***
Jul-69	L1A_DS_1A1AA	143	143	7732	1010	0.0	-4.3	7.6	11.9	1005	7732	132	85	1.6
	L1_DS_11AA	328	471	9002	1378	0.4	-5.9	7.2	13.4	1374	9002	190	102	1.9
	L5_DS_22A	548	1019	13641	1726	-0.5	-5.8	8.0	13.4	1722	13641	214	129	1.7
	L7_DS_33A	385	1873	13345	1674	-1.1	-4.3	8.7	11.9	1672	13345	193	140	1.4
	L9_DS_44A	624	3008	12930	1405	-1.8	-5.7	9.4	13.2	1403	12930	149	106	1.4
	L10_DS_55A	1483	4491	16807	1629	-2.8	-5.8	10.4	13.4	1627	16807	157	121	1.3
	L15_DS_66A	428	5862	19173	1837	-2.8	-7.8	10.3	15.4	1836	19161	178	119	1.5
	L16_DS_77A	1333	7195	22744	1875	-4.5	-9.0	12.0	16.6	1873	22517	156	113	1.4
Nov-69	L1A_DS_1A1AA	143	143	8609	1012	-0.9	-5.7	8.5	13.2	1007	8609	119	76	1.6
	L1_DS_11AA	328	471	9428	1378	0.0	-9.5	7.6	17.1	1372	9352	181	80	2.3
	L5_DS_22A	548	1019	14306	1726	-0.9	-9.6	8.4	17.1	1721	14275	204	100	2.0
	L7_DS_33A	385	1873	14299	1677	-1.8	-6.6	9.3	14.1	1671	14299	179	118	1.5
	L9_DS_44A	624	3008	14778	1412	-2.0	-6.6	9.6	14.1	1403	14778	146	99	1.5
	L10_DS_55A	1483	4491	17451	1632	-3.2	-6.7	10.8	14.3	1629	17451	151	114	1.3
	L15_DS_66A	428	5862	19888	1826	-3.1	-8.4	10.7	16.0	1825	19831	170	114	1.5
	L16_DS_77A	1333	7195	23882	1876	-5.0	-10.1	12.6	17.7	1874	23440	149	106	1.4
May-70	L5_DS_22A	548	1019	12614	1726	0.1	-5.5	7.4	13.1	1721	12614	232	132	1.8
	L7_DS_33A	385	1873	11001	1672	0.4	-2.9	7.1	10.5	1669	11001	234	159	1.5
	L9_DS_44A	624	3008	14246	1424	-2.7	-4.9	10.2	12.5	1402	14246	137	112	1.2
	L10_DS_55A	1483	4491	16871	1634	-2.9	-6.6	10.4	14.1	1630	16871	156	115	1.4
Nov-70	L5_DS_22A	548	1019	13219	1725	-0.2	-3.7	7.8	11.3	1721	13219	221	152	1.5
	L7_DS_33A	385	1873	12520	1673	-0.6	-4.4	8.1	12.0	1670	12520	205	139	1.5
	L9_DS_44A	624	3008	13883	1419	-2.4	-5.2	10.0	12.8	1402	13883	141	109	1.3
Dec-05	L1A_DS_1A1AA	143	143	2261	976	5.4	0.7	2.2	6.9	973.2	2261	439	142	3.1
	L1_DS_11AA	328	471	4662	1348	4.0	-4.6	3.5	12.2	1352	4662	383	111	3.5
	L5_DS_22A	548	1019	10811	1743	0.7	-5.2	6.8	12.7	1719	10811	252	135	1.9
	L6_DS_5.55.5A	469	1488	11679	1801	0.6	-4.8	6.9	12.4	1777	11679	257	143	1.8
	L7_DS_33A	385	1873	12400	1798	-0.2	-5.1	7.7	12.7	1666	12400	216	131	1.6
	L8_DS_3.53.5A	511	2384	13347	1559	-1.8	-5.0	9.3	12.6	1550	13347	166	123	1.3
	L9_DS_44A	624	3008	11953	1846	-0.8	-4.2	8.4	11.8	1441	11953	173	123	1.4
	L10_DS_55A	1483	4491	15331	1634	-2.2	-4.9	9.8	12.5	1625	15331	166	130	1.3
	L11_DS_5.55.5A	943	5434	18512	1825	-2.4	-5.9	10.0	13.5	1804	18512	180	134	1.3
	L15_DS_66A	428	5862	20395	1976	-3.8	-8.6	11.4	16.1	1898	20395	166	118	1.4
	L16_DS_77A	1333	7195	22224	1876	-4.4	-8.4	12.0	15.9	1891	22132	158	119	1.3
	L17_DS_88A	2453	9648	27292	2481	-6.7	-13.6	14.2	21.2	1978	25332	139	93	1.5
	L18_DS_99A	1892	11540	28764	2467	-7.3	-14.3	14.9	21.9	1962	26102	132	90	1.5
	L19_DS_1010A	1802	13342	29916	1939	-8.4	-18.1	16.0	25.7	1901	24476	119	74	1.6
	L20_DS_1111A	1791	15133	35986	2301	-8.6	-21.2	16.2	28.7	2248	28762	139	78	1.8

Kennetcook River

			total		Hydraulic geometry Large Tides									
Date	**Line**	**Distance**	**distance**	***A***	***pw***	***H***	***Hmin***	***d***	***D***	***w***	***A*** $_i$	***w/d***	***w/D***	***D/d***
05-Dec	L12_K1	874	874	6723	753	-1.3	-7.9	8.9	15.4	744	6723	84.0	48.3	1.7
	L13_K2	614	1488	3974	480	-3.5	-8.2	11.0	15.8	362	3916	32.8	22.9	1.4
	L14_K3	707	2195	8812	837	-3.5	-8.4	11.0	15.9	831	8754	75.3	52.1	1.4

Table 7a: Summary of hydraulic geometry parameters and measures of channel form for lines on the Avon and Kennetcook Rivers from July 1969 to December 2005 where available for large tides. Distance = distance between lines, Total Distance = distance from confluence of Avon and St. Croix Rivers. Refer to Table 3 for additional abbreviations.

b) Avon

Date	Line	Distance	total dist	*A*	*pw*	*H*	*Hmin*	*d*	*D*	*w*	A_i	*w/d*	*w/D*	*D/d*
				Hydraulic geometry Mean Tides										
Jul-69	L1A_DS_1A1AA	143	143	5939	981	-0.05	-4.29	5.8	10.1	978.3	5939	168	97	1.7
	L1_DS_11AA	328	471	6840	1288	0.36	-5.86	5.4	11.6	1285	6840	237	110	2.1
	L5_DS_22A	548	1019	10627	1643	-0.5	-5.81	6.2	11.6	1639	10627	263	142	1.9
	L7_DS_33A	385	1873	10488	1440	-1.1	-4.35	6.9	10.1	1438	10488	209	142	1.5
	L9_DS_44A	624	3008	10465	1351	-1.8	-5.66	7.6	11.4	1350	10465	177	118	1.5
	L10_DS_55A	1483	4491	13929	1583	-2.8	-5.83	8.6	11.6	1582	13929	184	136	1.4
	L15_DS_66A	428	5862	15925	1770	-2.8	-7.81	8.5	13.6	1769	15785	207	130	1.6
	L16_DS_77A	1333	7195	19393	1846	-4.5	-9.04	10	14.8	1845	18435	180	125	1.4
Nov-69	L1A_DS_1A1AA	143	143	6808	989	-0.9	-5.65	6.7	11.4	985.6	6808	148	86	1.7
	L1_DS_11AA	328	471	7279	1288	0	-9.5	5.8	15.3	1283	7130	222	84	2.6
	L5_DS_22A	548	1019	11292	1646	-0.9	-9.56	6.6	15.3	1642	11215	248	107	2.3
	L7_DS_33A	385	1873	11439	1456	-1.8	-6.56	7.5	12.3	1451	11439	193	118	1.6
	L9_DS_44A	624	3008	13345	1332	-2	-6.55	7.8	12.3	1325	13345	170	108	1.6
	L10_DS_55A	1483	4491	14577	1587	-3.2	-6.69	9	12.5	1586	14541	176	127	1.4
	L15_DS_66A	428	5862	16666	1759	-3.1	-8.42	8.9	14.2	1758	16445	197	124	1.6
	L16_DS_77A	1333	7195	20531	1847	-5	-10.1	11	15.9	1845	19168	171	116	1.5
May-70	L5_DS_22A	548	1019	9602	1644	0.14	-5.5	5.6	11.3	1640	9602	291	146	2.0
	L7_DS_33A	385	1873	8163	1442	0.44	-2.9	5.3	8.67	1440	8163	270	166	1.6
	L9_DS_44A	624	3008	11815	1342	-2.7	-4.9	8.4	10.7	1324	11815	157	124	1.3
	L10_DS_55A	1483	4491	13995	1588	-2.9	-6.57	8.6	12.3	1586	13995	184	128	1.4
Nov-70	L5_DS_55A	548	1019	10206	1644	-0.2	-3.74	6	9.51	1641	10206	275	173	1.6
	L7_DS_33A	385	1873	9684	1442	-0.6	-4.43	6.3	10.2	1440	9684	227	141	1.6
	L9_DS_44A	624	3008	11451	1338	-2.4	-5.23	8.2	11	1324	11451	162	120	1.3
Dec-05	L1A_DS_1A1AA	143	143	679	523	5.35	0.701	0.4	5.07	519.9	679	1246	103	12.1
	L1_DS_11AA	328	471	2338	1238	4.04	-4.63	1.7	10.4	1233	2338	713	119	6.0
	L5_DS_22A	548	1019	7810	1650	0.75	-5.17	5	10.9	1619	7810	322	148	2.2
	L6_DS_5.55.5A	469	1488	8581	1607	0.65	-4.82	5.1	10.6	1591	8581	310	150	2.1
	L7_DS_33A	385	1873	9466	1737	-0.2	-5.11	5.9	10.9	1604	9466	271	147	1.8
	L8_DS_3.53.5A	511	2384	10667	1436	-1.8	-5	7.5	10.8	1430	10667	190	133	1.4
	L9_DS_44A	624	3008	9422	2037	-0.8	-4.18	6.6	9.95	1403	9422	214	141	1.5
	L10_DS_55A	1483	4491	12471	1556	-2.2	-4.91	8	10.7	1547	12471	194	145	1.3
	L11_DS_5.55.5A	943	5434	15292	1783	-2.4	-5.88	8.2	11.7	1765	15292	215	151	1.4
	L15_DS_66A	428	5862	17104	1863	-3.8	-8.56	9.6	14.3	1780	17073	185	124	1.5
	L16_DS_77A	1333	7195	18866	1867	-4.4	-8.37	10	14.1	1872	18044	184	132	1.4
	L17_DS_88A	2453	9648	23771	2846	-6.7	-13.6	12	19.4	1991	20341	160	103	1.6
	L18_DS_99A	1892	11540	25256	2816	-7.3	-14.3	13	20.1	1971	21077	150	98	1.5
	L19_DS_1010A	1802	13342	26499	1917	-8.4	-18.1	14	23.9	1900	19421	134	80	1.7
	L20_DS_1111A	1791	15133	31931	2271	-8.6	-21.2	14	26.9	2245	23179	156	83	1.9

Kennetcook

Date	Line	Distance	total distance	*A*	*pw*	*H*	*Hmin*	*d*	*D*	*w*	A_i	*w/d*	*w/D*	*D/d*
				Hydraulic geometry mean Tides										
05-Dec	L12_K1	874	874	5394	699	-1.3	-7.9	7.1	13.6	695	5210	98.4	51.0	1.9
	L13_K2	614	1488	3368	370	-3.5	-8.2	9.2	14.0	339	3101	36.8	24.3	1.5
	L14_K3	707	2195	7337	814	-3.5	-8.4	9.2	14.1	829	7070	89.8	58.6	1.5

Table 7b: Summary of hydraulic geometry parameters and measures of channel form for lines on the Avon and Kennetcook Rivers from July 1969 to December 2005 where available for mean tides. Distance = distance between lines, Total Distance = distance from confluence of Avon and St. Croix Rivers. Refer to Table 3 for additional abbreviations.

a)	Change in Cross Sectional Area Large Tides														
	July 69 to Nov 69			Nov 69 to May 70			May 70 to Nov 70			Nov 70 to May 71			July 69 to Dec 05		
Line	net	%	rate	net	%	rate	net	%	rate	net	%	rate	net	%	rate
L1A_DS_1A1AA	-877	-11	-175.4										5470	71	12.8
L1_DS_11AA	-426	-5	-85.3										4340	48	10.2
L5_DS_22A	-665	-5	-132.9	1692	12	241.66	-605	-5	-86.4				2830	21	6.5
L6_DS_2.52.5A							no historical surveys								
L7_DS_33A	-954	-7	-190.9	3298	23	471.20	-1519	-14	-217.0				945	7	2.2
L8_DS_3.53.5A							no historical surveys								
L9_DS_44A	-1848	-14	-369.5	532	4	75.99							977	8	2.2
L10_DS_55A	-644	-4	-128.8	580	3	82.87							1475	9	3.4
L11_DS_5.55.5A							no historical surveys								
L15_DS_66A	-715	-4	-142.9										-1222	-6	-2.8
L16_DS_77A	-1138	-5	-227.6										519	2	1.2
L17_DS_88A							no historical surveys								
L18_DS_99A							no historical surveys								
L19_DS_1010A							no historical surveys								
L20_DS_1111A							no historical surveys								

b)	Change in Cross Sectional Area Mean Tides														
	July 69 to Nov 69			Nov 69 to May 70			May 70 to Nov 70			Nov 70 to May 71			July 69 to Dec 05		
Line	net	%	rate	net	%	rate	net	%	rate	net	%	rate	net	%	rate
L1A_DS_1A1AA	-869	-15	-173.8										5260	89	12.3
L1_DS_11AA	-439	-6	-87.7										4502	66	10.6
L5_DS_22A	-665	-6	-133.1	1691	15	241.51	-604	-6	-86.3				2817	27	6.4
L6_DS_2.52.5A							no historical surveys								
L7_DS_33A	-951	-9	-190.2	3276	29	467.95	-1521	-19	-217.3				1022	10	2.3
L8_DS_3.53.5A							no historical surveys								
L9_DS_44A	-2880	-28	-576.0	1530	11	218.63							1043	10	2.4
L10_DS_55A	-648	-5	-129.5	581	4	83.05							1458	10	3.3
L11_DS_5.55.5A							no historical surveys								
L15_DS_66A	-741	-5	-148.2										-1180	-7	-2.7
L16_DS_77A	-1138	-6	-227.5										527	3	1.2
L17_DS_88A							no historical surveys								
L18_DS_99A							no historical surveys								
L19_DS_1010A							no historical surveys								
L20_DS_1111A							no historical surveys								

Table 8: Summary of changes in cross sectional area (m^2) for lines on the Avon River from July 1969 to December 2005 for a) large tides and b) mean tides. Rate of change is expressed in m^2 per month (net change divided by number of months between sampling dates). In general (with the exception of % values), a negative net value indicates accretion whereas a positive value indicates erosion for net and rate values.

Similar to profiles along Line 1A, those along Line 1_DS_11AA (Fig 16b,d) show approximately 5.8 m of sediment accumulation in the general area of an existing intertidal bar (Fig 16d) and accumulation both in the tide gate channel (15 m of accumulation and shift in channel thalweg by 187 m) and in the tidal creek adjacent to the Windsor Tourist bureau (Fig 16b,d) (3 m increase in bed elevation). However, there was an initial deepening of the tide gate channel by about 4 m between July 69 and November 69 (Fig 16b) whereas minimal changes were observed in the tidal creek near the Tourist bureau. Once again there was a 48% and 66% decrease in cross sectional area between July 1969 and December 2005 (Table 8). The wetted perimeter however remains relatively constant between the survey periods.

Line 5_DS_22A picks up the major shift (219 m) in the location of the tide gate channel and the infilling of the new channel by around 2 m of sediment (Fig 16c). However a total of 10 m of sediment has accumulated in the location of the old tide gate channel. Approximately 2 m of sediment has accumulated over time at what is now an extension of the Windsor mudflat/salt marsh system (Fig 16d). There is also evidence of significant bank erosion along the eastern edge of an intertidal bar which developed in the 1970s and was later expanded to form the modern feature. The present day bed elevation of the main Avon River channel along the eastern portion of the line (Fig 16c,d) has decreased down to the 1969 base level. Some seasonality in changes in cross sectional area are evident (Fig 16c) with an overall 21% and 27% decrease in cross sectional area (Table 8) for large and mean tides respectively. As in the previous line, the wetted perimeter remains relatively constant between the study periods. The w/d and D/d ratios in the present day are quite similar to those recorded for May 1970 and July 1969.

Further downstream Line 7 (L7_DS_33A) crosses the edge of a bar feature now referred to as the Newport Bar (Daborn and Brylinsky, 2004). This bar has accumulated between 7.1 (in old channel) and 2.9 m of sediment since July 1969 (Fig 16f). However the western bank of the river saw approximately 150 m of erosion resulting in approximately 1500 m^2 loss of sediment. Inter annual fluctuations in cross sectional area are observed (Fig 16f) however there has been only a negligible change in cross sectional area from Nov 1970 to Dec 2005 despite large apparent changes in the profiles and air photographs (Fig 16h). There was only a 7% decrease in cross sectional area between July 1969 and Dec 2005 (Table 8a). The formation of the large intertidal bar did have an affect on increasing the wetted perimeter.

Line 9 (Fig 16i) clearly depicts the extensive mudflat and expanding salt marsh which has developed on the western shore once the channel thalweg shifted after 1973. This bank has prograded by about 335 m and infilled approximately 6.1 m (Fig 16i). Conversely, the bed of the new channel has lowered by 3 m (measured at 600 m from post 4). The thalweg closest to the old wharf at 4A has maintained a relatively constant bed elevation (Fig16i) and position (Fig16k). Changes in cross sectional area were recorded ranging between a 14% increase in area to a 4% decrease in cross sectional area. The modern intertidal channel cross sectional area is very similar to the original one in July 69 (Fig 16i) and has infilled by only about 7% (Table 8a).

Line 10 (Fig 16j) shows very little change in the overall form of the cross sectional profile, with new marsh developing along the western shore and gradual accumulation of an intertidal bar along the eastern edge. This bar however remains quite low and represents about 2.3 m of accumulation. There has been about a 9% decrease in intertidal cross sectional channel area (Table 8) since July 1969. However the wetted perimeter, w/d and D/d ratio show very little change.

Line 15 (Fig 16m), located downstream of the confluence of Avon and Kennetcook Rivers depicts very little change in cross sectional area or form. Aerial photographs (Fig 16o) illustrate the relative stability of the location of the main channel thalwegs and which is reflected in the intertidal cross sectional area comparisons. This is the only line which has recorded an increase (6%) in cross sectional area and intertidal cross sectional area (Table 8) and is essentially deepening. Line 16 (Fig 16n) depicts a very similar trend and only 2% decrease in cross sectional area and associated intertidal cross sectional area (Table 8). The decrease is associated with an intertidal bar starting to develop along the eastern section of the profile (Fig 16n,o).

Downstream changes in cross sectional form along the Avon River

All of the hydraulic geometry parameters for each line were plotted against distance from the causeway and are presented in Figures 18 to 20. In general, there is an increase in both cross sectional area and intertidal channel cross sectional area with increasing distance from the Windsor Causeway (Fig 18a,b). The shape of both curves is quite similar for the first 6000 m since the river channel within this area drains completely during low tides however the rate of change decreases after this point as water remains at the base of the channel.

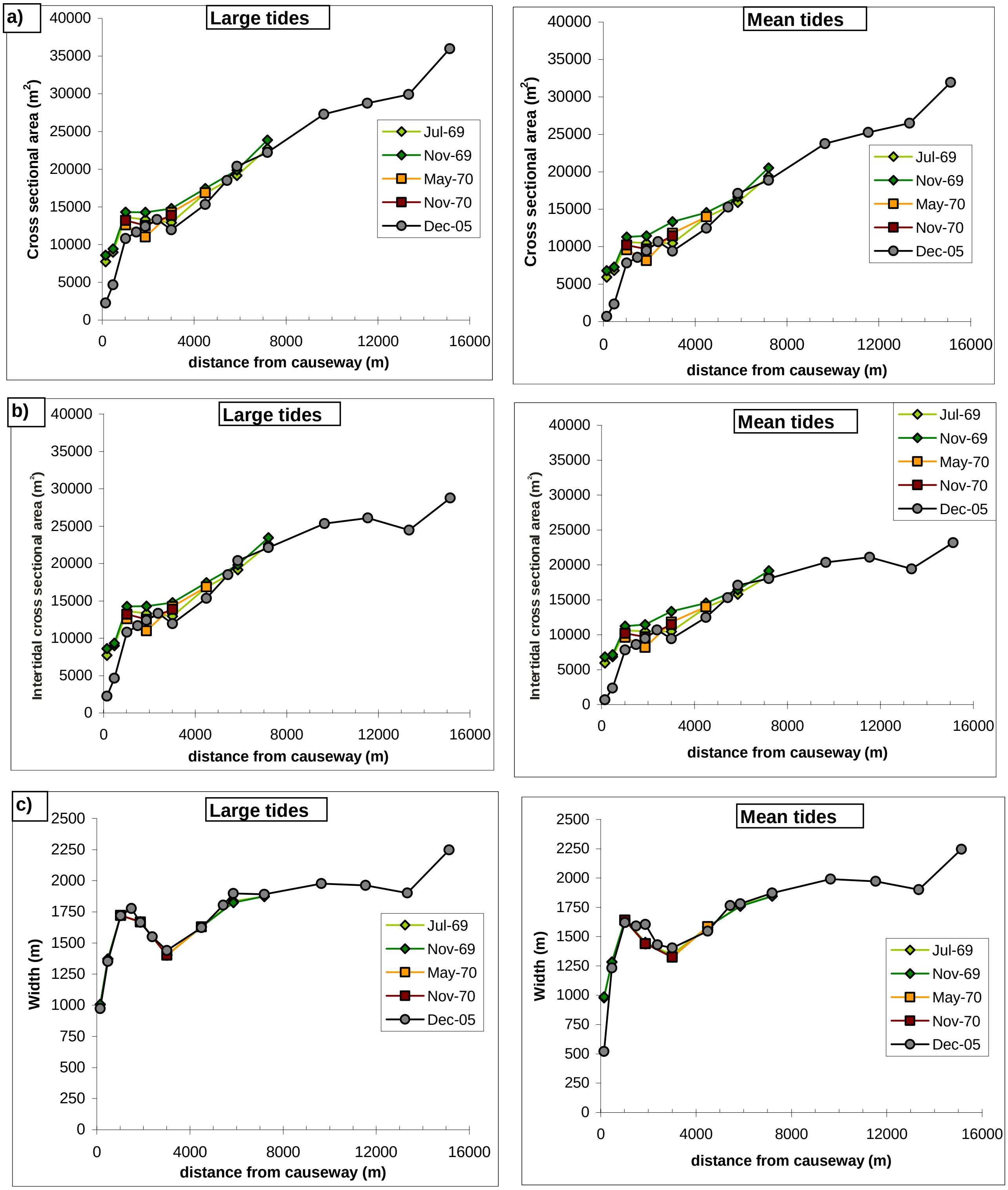

Figure 18: Downstream changes in channel form parameters for large and mean tides for a) cross sectional area, b) intertidal channel cross sectional area and c) channel width

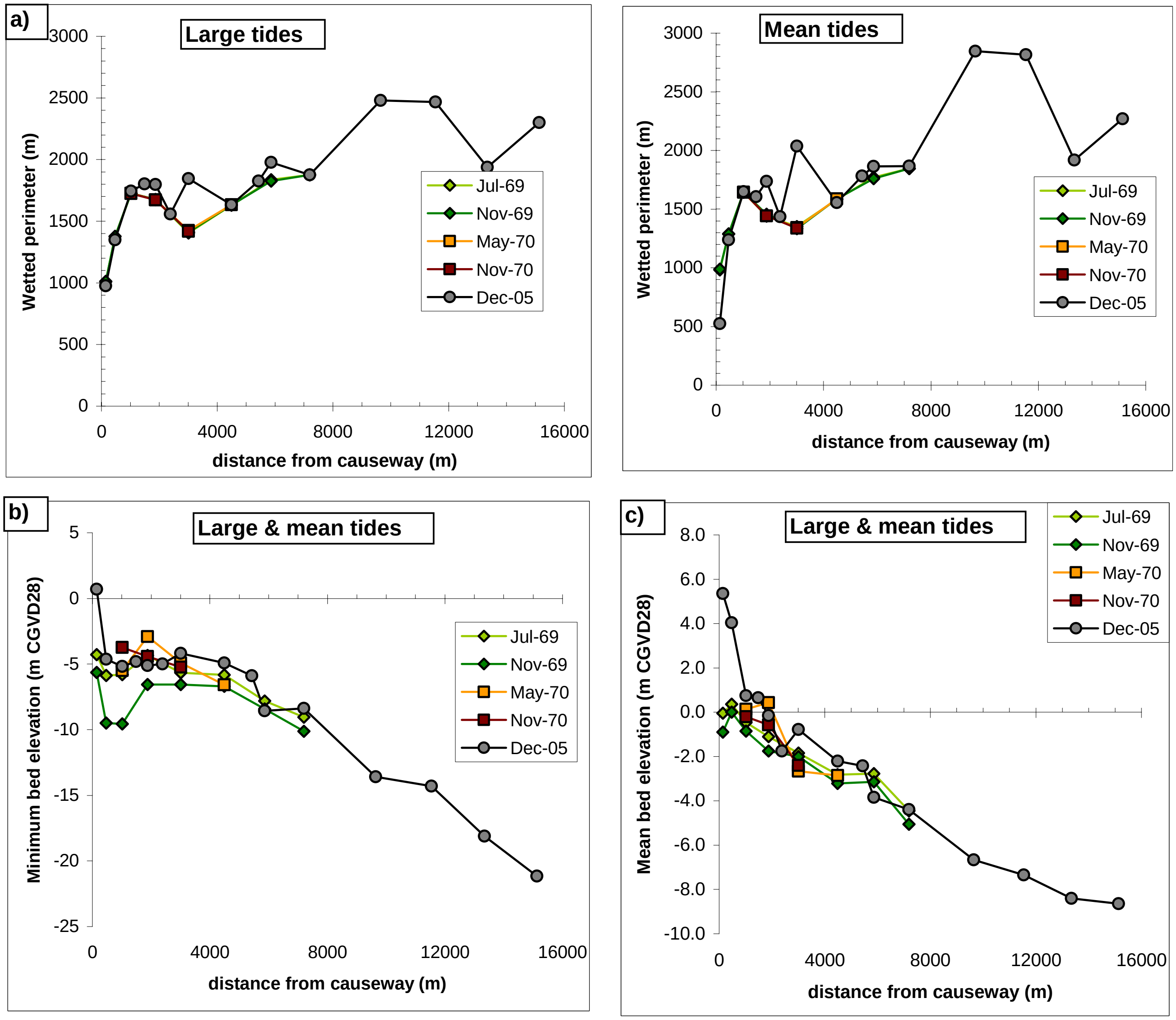

Figure 19: Downstream changes in channel form parameters for large and mean tides for a) wetted perimeter, b) minimum bed elevation and c) mean bed elevation.

The width of the Avon River increases very rapidly in the first 1500 m until just downstream of where it is joined by flows from the St. Croix River (Fig 10 and 11a) after which time there is a sharp decrease in width until Line 9, 3000 m downstream (Table 7; Fig 18c). This corresponds to the area in which numerous intertidal bars (e.g. Newport Bar) essentially split the flow into two smaller channels and new marsh growth has been recorded along the western bank (Fig 11a, 16e-h). This splitting also causes an increase in the wetted perimeter (Fig 19a). A more gradual increase in channel width continues beyond the Kennetcook and remains relatively constant until line 10 at the mouth of the Avon River. There are no major differences in the shape of the curves from 1969 to 2005.

Both minimum bed elevation relative to CGVD28 datum and mean bed elevation exhibit a general decreasing trend with increasing distance from the causeway (Fig 19 b,c). Most of the variability in bed elevation levels after the first 2000 m from the causeway. Lowest elevations were recorded in Nov

69 and those recorded in Dec 2005 were actually lower than those recorded in the 1970s (Fig 19b) with the exception of the first 500 or so metres downstream of the causeway. Directly adjacent to the causeway, there is more than a 5 m difference in the minimum bed elevation. However, after this point the min bed elevation has remained at almost the same level since 1969 (with the exception of the decrease in Nov 69) (Fig 19b). The mean bed elevation however has increased noticeably within the first 1000m of the causeway which is seen as the large mudflat and marsh system which has developed (Fig 16d) downstream of the structure. An additional area of accumulation occurs around 3000 m downstream reflecting the growth of an extensive mudflat and new marsh along the western shore (Fig 16i,k).

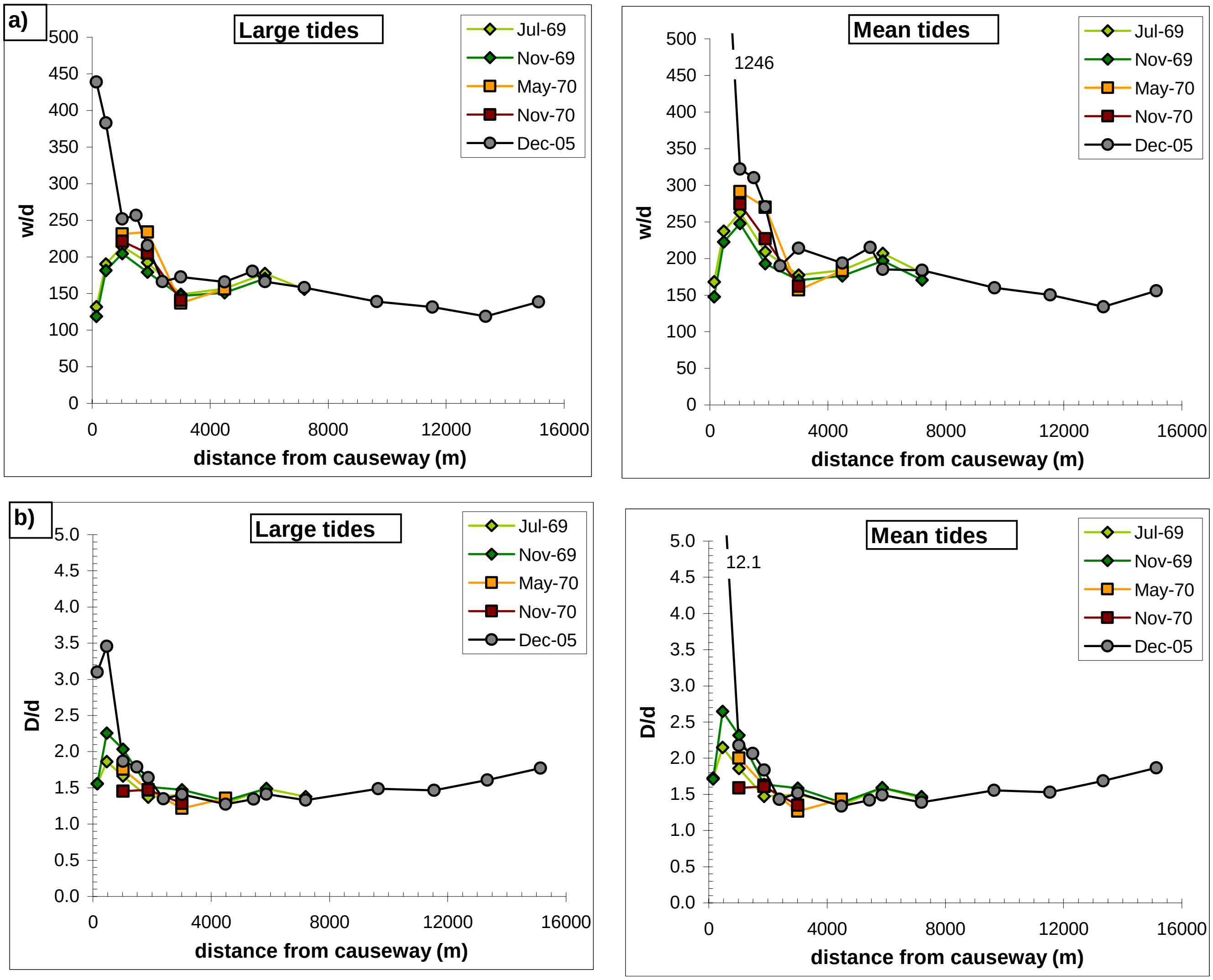

Figure 20: Downstream changes in channel form ratios for large and mean tides for a) w/d and b) D/d.

Figure 20 illustrates quite effectively the pivot point around which there is a marked change in channel cross sectional form. Based on the w/d and D/d ratios, this pivot point occurs around the 1000 m mark at line 5 where the St. Croix River joins the Avon (Fig 16d, 20). Although not tested statistically at this time, it is anticipated that this difference in form is significant. Beyond this point, all of the survey dates display a very similar gradually decreasing trend with increasing distance. This maintenance of channel form is particularly evident in examining the D/d ratios (Fig 20b).

Salt Marsh Habitat and Intertidal Features

The air photo mosaics and digitized salt marsh polygons were examined within the ArcGIS environment. In general, there is an overall decrease in marsh area from 1944 to 1964 with the exception of 1955 (Table 9). Over the following decade however the percentage of marsh area remains constant at around 6 % and begins to increase slightly in 1992. By 2003, the proportion of the Avon River study area covered by salt marsh vegetation had increased, and exceeded 1944 levels, however did not exceed the 1955 levels (Table 9).

a) Entire Study Area	**1944**	**1955**	**1964**	**1973**	**1992**	**2003**
10m polygon area (km^2)	23.31	15.39	40.35	43.59	42.74	39.36
Marsh area (km^2)	1.76	1.37	2.30	2.65	2.67	3.25
Marsh area (%)	7.55	8.89	5.70	6.08	6.24	8.27
b) Common Areas Only	**1944**	**1955**	**1964**	**1973**	**1992**	**2003**
10m polygon area (km^2)	11.5	11.5	11.5	11.5	11.5	11.5
Marsh area (km^2)	0.9	1.22	0.84	0.94	1.00	1.42
Marsh area (%)	8.62	10.64	7.29	8.17	8.69	12.37

Table 9: Marsh area calculated within each aerial photo mosaic. Values do NOT include marsh located upstream of the Windsor causeway. The 10 m polygon area represents the actual area of visible air photo that occurs below the 10 m elevation contour and is indicated on Figures 22 to 25. Marsh area data are expressed as a percentage of the 10 m polygon area to allow for comparison between years. Values are presented for **a)** entire study area (all 20 lines) and **b)** only the common area for all years (Figures 22-25).

Figures 21 to 24 depict the change in intertidal geomorphology (as viewed on aerial photographs) and marsh habitat since 1944. The 1944 and 1964 extents of marsh habitat are included on all figures for reference as are the location of the survey posts and modern roads and dykes. From 1944 to 1955, there was a large expansion of marsh habitat along both the Avon (west bank) and St. Croix (north bank) Rivers (Fig. 21). If measured as a straight line distance from 1944 along line 6 (post 2.5), there was approximately 295 m of marsh growth on the Avon River and 80 m of growth along line 3 (post TA) on the St. Croix. Very little change was observed elsewhere, except some loss of salt marsh due to dyking. Marsh area decreased from 1955 to 1964 along the river edge with erosion (~35 m) initiated along the western shore near post 2.5, likely associated with increased bank erosion from the developing channel evident in Figure 21. However, during this period a number of dykes were constructed along the western shore which cut off areas of marsh from tidal flow (Fig 21).

From 1964 to 1973, the erosion trends along the western bank of the Avon River continued and new erosion was initiated on the north shore of the St. Croix River between lines 1 and 2 (Fig 22). However, the southern bank of the St. Croix along the same lines saw about 16 m of new marsh growth. The main river thalweg is quite visible on the air photograph along the north shore of the St. Croix, swinging over to the western shore of the Avon River, joining with flows coming down the Avon through the Windsor tide gate. A mudbank becomes evident along the eastern edge near post SA/2A. The mudflat adjacent to the causeway continues to grow in size although there is still a defined channel running along the causeway itself.

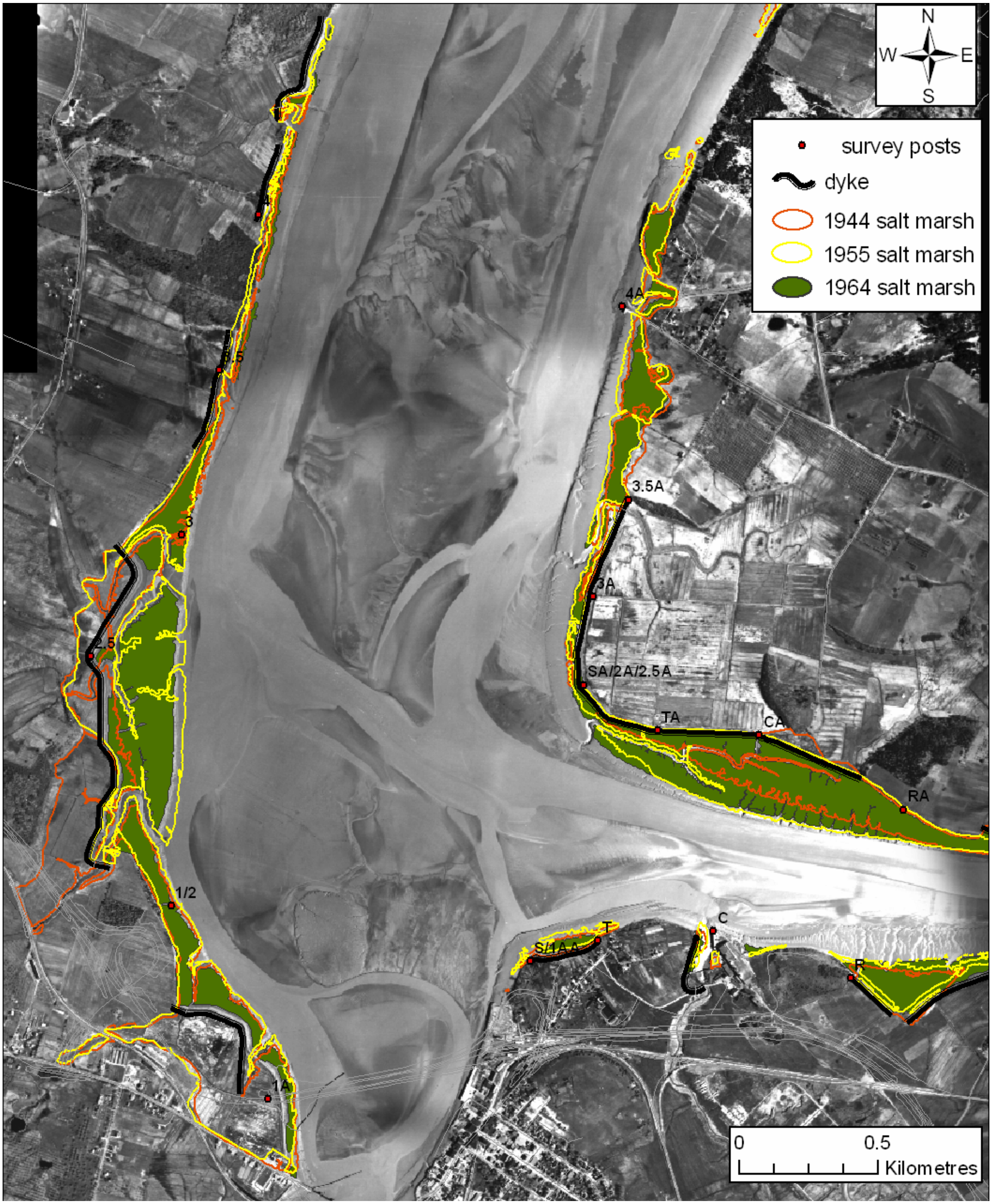

Figure 21: Digitized salt marsh polygons from 1944, 1955 and 1964 overlain on a 1964 aerial photograph. Note expansion of marsh particularly on the west bank of the Avon River near post 2.5. Dyke lines and roads represent modern day.

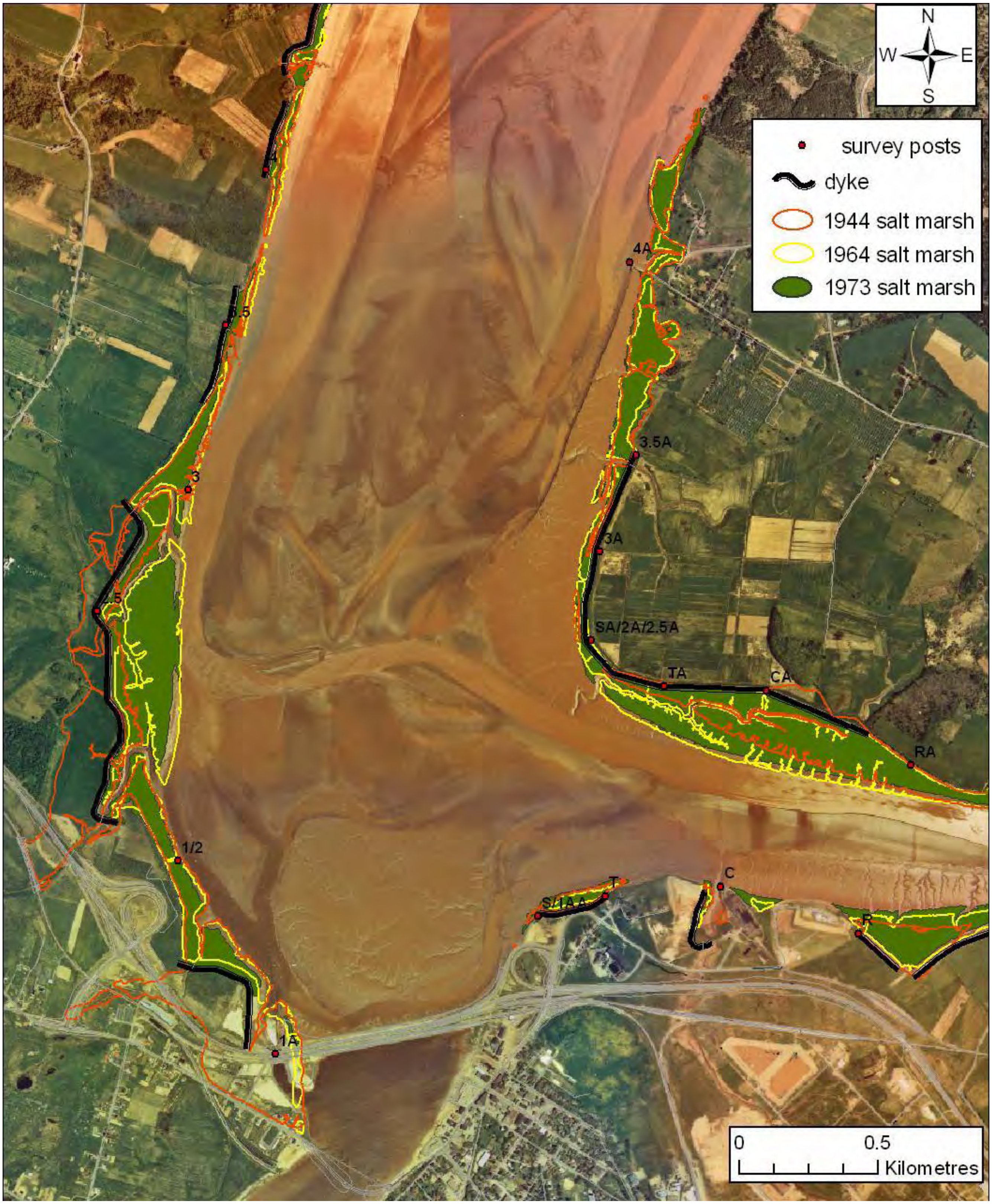

Figure 22: Digitized salt marsh polygons from 1944, 1964 and 1973 overlain on a 1973 aerial photograph. Note relative stability of marsh vegetation with some erosion initiated near post 3. Dyke lines and roads represent modern day.

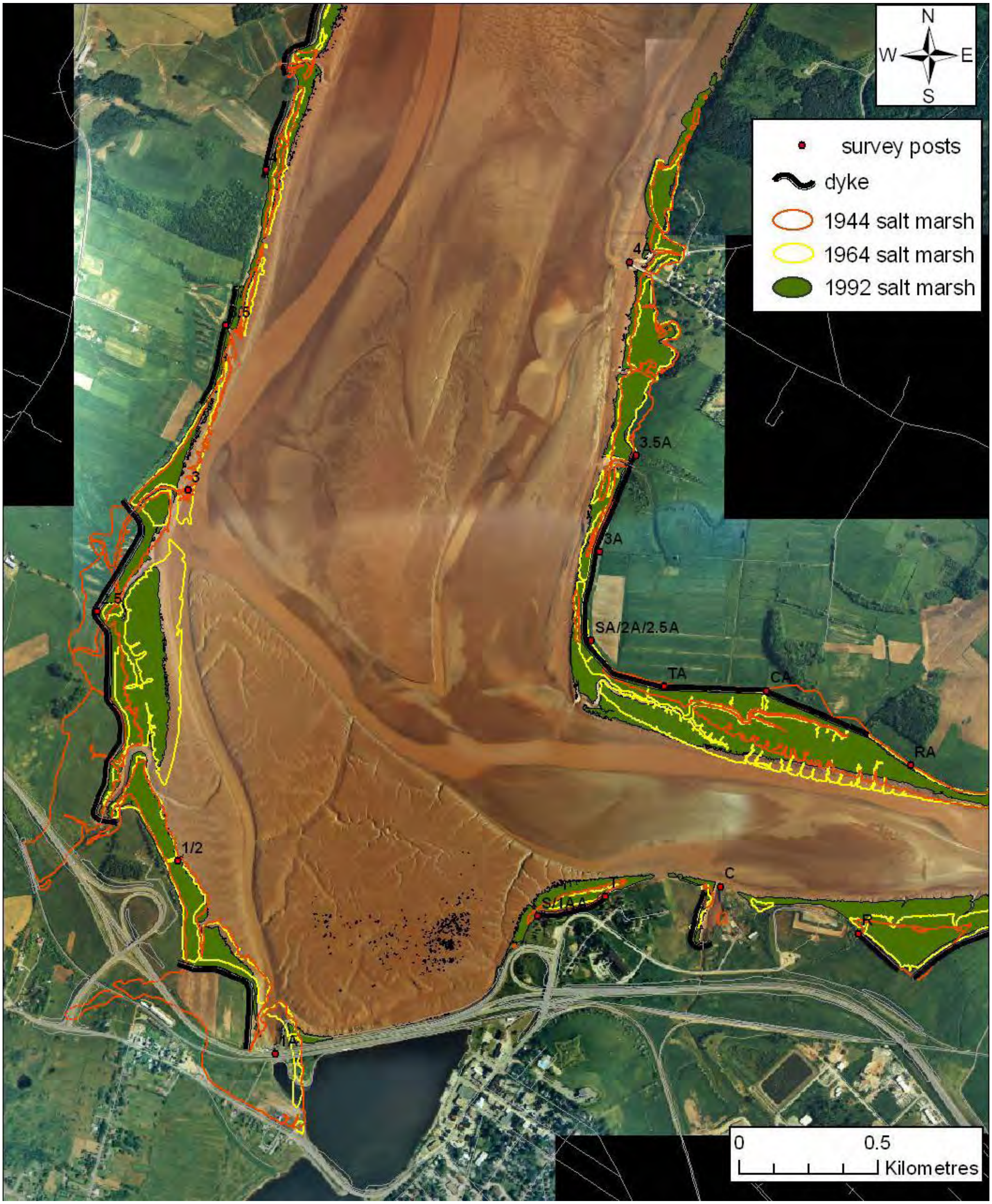

Figure 23: Digitized salt marsh polygons from 1944, 1964 and 1992 overlain on a 1992 aerial photograph. Note accelerated erosion along west bank near post 3 and 2.5 and new channel thalweg position. Also note expansion of marsh on St. Croix south shore and extensive mudflat development near causeway. Dyke lines and roads represent modern day.

Figure 24: Digitized salt marsh polygons from 1944, 1964 and 2003 overlain on a 2003 aerial photograph. Note extensive erosion near line 3 and colonization of mudflat adjacent to the causeway. Dyke lines and roads represent modern day.

The mudbank observed in the 1973 air photo has facilitated the expansion of approximately 60 m of marsh vegetation by 1992 (Fig 23) when compared to the 1964 levels. The St. Croix River thalweg continues to meander towards the northern bank of the river, causing 30 m marsh loss since 1964. Approximately 65 m of new marsh has established on the south shore since 1964. Extensive erosion is still ongoing along the western bank and the limit of influence of the shifting channel has shifted further downstream (Fig 23). The mudflat deposit adjacent to the causeway has now increased in size considerably and elongated into almost a triangular form oriented downstream. A very defined and narrow channel from the tide gate is visible with accumulation along the western edge near post 1 / 2 (Fig 23). The causeway channel and tidal creek closest to the Windsor Tourist Bureau has infilled considerably. New marsh grass is visible on the mudflat surface.

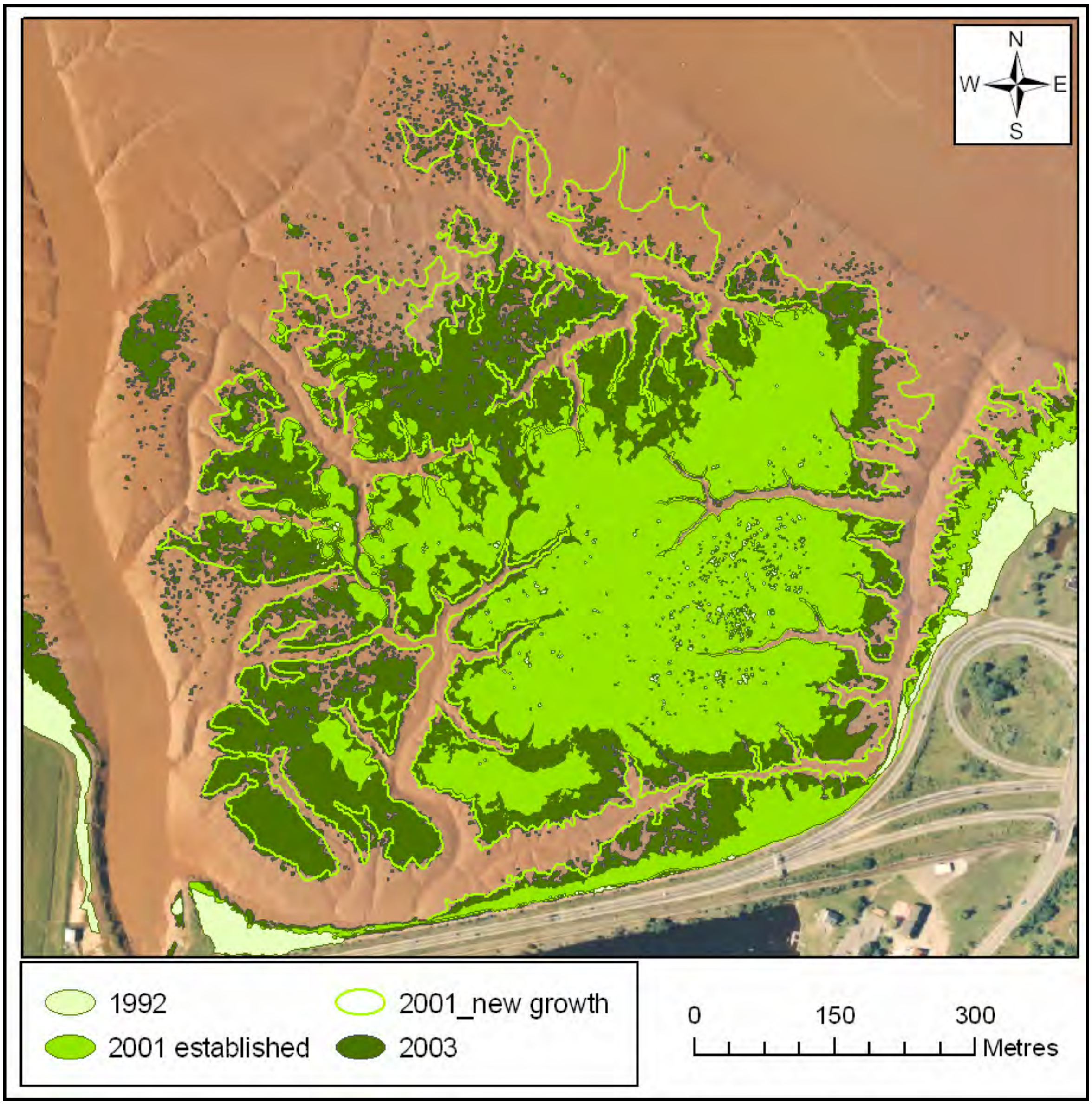

Figure 25: Comparison of Townsend, 2002 marsh GPS survey conducted in the fall of 2001 distinguishing between established spartina alterniflora (e.g. mature) and juvenile s. alt. Note expansion and coalescence within juvenile boundaries from 2001. In addition note relative stability of position of the tidal creek channels.

The most noticeable change between 1992 and 2003, particularly when compared with the earlier years (Fig 24) is the extensive growth of marsh vegetation of the Windsor Causway (refer to Townsend and van Proosdij, 2004 for a detailed account and mechanisms of colonization by *Spartina alterniflora*) (Fig 25). Additional marsh growth is visible along the south shore of the St. Croix and erosion continues along the western edge, threatening the dyke along that section (pers comm. K. Carroll, 2005) as the thalweg continues to shift towards the west. The mudflat area near post 1/ 2 now shows evidence of marsh colonization (Fig 24).

DISCUSSION

The influence of the construction of barriers across tidal rivers and estuaries on altering the sediment dynamics and ecosystem processes in their surrounding area has been well documented in many tidal systems (e.g. Owen and Odd, 1972; Bray et al., 1982; Wolanski et al., 2001 and Tonis et al., 2002). However, teasing out the impacts of these large scale structures from natural ecosystem changes such as changes in metereological conditions, sea level and thalweg position can be a challenge. The primary findings of this research project suggest that the direct impacts of the causeway can only be attributed to changes within the first 1000 m of the Windsor causeway and not the 20 km originally proposed by Amos, 1977. Change in the bathymetry and overall morphology further downstream is more likely be associated with changes in the position of the main river thalweg as has been suggested by other researchers in other estuaries around the world (e.g. Allen, 1996; Pringle, 1995; Pye, 1995 and Shi et al., 1995). The St. Croix and Kennetcook Rivers likely have played a key role in moderating the impacts of the causeway construction and preventing the massive build up of sediment and decreased hydraulic capacity recorded in the Petitcodiac River (Bray et al., 1982; Locke et al., 2002).

Within the first 1000 m of the Windsor causeway however there has been a very marked decrease in cross sectional area due to excess sedimentation. This supports previous research in the Avon system (e.g. Amos, 1977; Turk et al., 1980) and elsewhere (e.g. Allen, 2000; Schwimmaer and Pizzuto, 2000; Shi et al., 1995). This area has provided an ideal environment for the colonization of an extensive and productive salt marsh habitat (Daborn et al., 2003a,b; van Proosdij and Townsend, 2004). This vegetation is expanding at an exponential rate (37%) (Townsend, 2002) and is rapidly colonizing all available space. Comparison of the 2001 GPS field survey of juvenile S*partina alterniflora* (sparse, representing new shoots in 2001) conducted by Townsend (2002) with the 2003 marsh polygons digitized from aerial photographs (Fig 26) supports the mechanism of colonization by rhizome expansion as mature marsh vegetation is now contained with the 2001 survey boundary. Growth however appears to be limited in certain areas such as along the edge of the deeper tidal creek channels and on the northern mudflat/marsh edge which is heavily scoured by ice during the winter months (van Proosdij, 2005).

Further downstream from this area to the mouth of the Avon River, the changes in cross sectional area over time are low (-6 to 9% change) despite very visible changes in the intertidal geomorphology. The formation of intertidal bars (e.g., Newport bar – Daborn et al., 2003a,b and Daborn and Brylinski, 2004) is balanced by lateral erosion of the marsh bank, mostly along the western edge between 1.1 and 2.2 km from the causeway. This bank erosion however is less perceptible to casual observers and can lead to overestimates of sedimentation. In addition, the magnitude of change in elevation of channel bed will vary depending on the timing of the survey. Seasonal differences in cross sectional area between surveys may be just as large as differences over many years. This seasonal cyclicity in bed elevation has been observed (as much as 2 m in places) over many years by NSDA personnel and is supported by a recent study in the Salmon River (Crewe, 2004). However this phenomena has not often been officially documented in the Avon River. It will be critical to conduct some additional cross sectional surveys at different times of the year to examine this phenomenon in more detail. It is not possible at this time to distinguish if the seasonal changes observed in the 1969 and 1970 surveys are due to seasonality or to differences in the stages of construction of the causeway. The surveys in 1969 and May 70 were conducted while construction was taking place and some of the tidal and river flow was being restricted. Differences in findings of this study with Amos 1977 may potentially be explained by the timing of the surveys used for Amos' analysis. The CHS 1969 survey was conducted in October of 1969 and the 1976 survey was conducted in June 1976, typically a period of channel infilling. The November 1969 survey by the MMRA recorded an overall lowering of bed elevation which may have also been present in October 1969. It will be important to try and incorporate the CHS surveys into future analysis.

Cycles of progradation and retreat in marsh habitat were recorded along the Avon and St. Croix Rivers as have been documented on a number of marsh and intertidal systems (e.g. Cumberland Basin - Ollerhead et al. in press; Cobequid Bay - Baker and van Proosdij, 2004; United Kingdom - van der Wal and Pye, 2004; Cox et al., 2003; Pringle, 1995). These changes appear to be a response primarily to shifts in the main channel thalweg however additional forcing functions such as wind and wave climate (Fan et al., 2006; van der Wal and Pye, 2004; Cox et al., 2003; Allen and Duffy, 1998; Pye, 1995; Allen, 1989), sediment supply ((Allen, 2000; Gordon et al, 1985), sea level (van der Wal and Pye, 2004; French and Burningham, 2003; van der wal and Pye, 2003; Vos and van Kesteren, 2000; Allen, 2000; Allen, 1989) and other human activities such as dredging (French and Burningham, 2003; Cox et al., 2003) or dyke construction and practices (Hood, 2004) remain to be examined.

Salt marshes and mudflats represent systems delicately systems between hydrodynamic forces and ecological, sedimentological and morphological responses. Changes in the elevation of the intertidal habitat within the tidal frame or changes in edge morphology will in turn induce changes in tidal prism, hydrodynamic forces, vegetation community structure, rates of sedimentation and dissipation (marsh platform) or amplification (cliff) of wave energy. These will in turn influence the morphology of the intertidal feature. However, in many areas along the Avon River this natural response is limited in areas by the presence of dykes.

Figure 26: Storm impacts on Feb 1, 2006 at the Avonport Dyke. a) storm waves battering marsh; b) storm surge reached upper limits of dyke and c) dyke overtopped. Photo by T. Hamilton, 2006.

These dykes are valuable features, protecting hundreds of acres of agricultural land and associated infrastructure however will also impede natural retreat of these habitats. In some areas this then places this infrastructure at direct risk of erosion or overtopping by storm waves (Fig 26). On February 1st of this year, a strong storm caused the dykes to be overtopped in a number of areas (e.g. Avonport & Grand Pré) and caused approximately $68,000 in damages (H. Kolstee, pers. com.) (Fig 26). These impacts and risk to infrastructure and lives protected by these dykes are likely to continue to increase over time with strong lunar forcing (18 year cycle), rising sea levels and climate change. It will be crucial to try and preserve natural buffers against erosion while still allowing for tidal exchange. The Windsor causeway, although now protected from direct impacts of storm waves will still be at risk from storm surge. This risk will be compounded if the tide gate channel continues to infill. It appears at this time however that the current maintenance practice at the gate does allow for sufficient freshwater discharge to maintain a channel (Fig 27).

Figure 27: Freshwater discharge downstream of the Windsor tide gate following heavy rainfall in November, 2002 (photo by K. Carroll, 2002).

Recommendations

There are a number of recommendations that can be made for future research that will directly compliment this study and provide additional valuable information to try and understand the ecomorphodynamics of this system. These are summarized in the points below:

- Conduct at least one or two additional bathymetric surveys over the next year to try and document and quantify the seasonal variability in bed elevation. Since the 2005 survey was conducted in December after considerable rainfall events, it is recommended that the next survey take place during the mid to late summer (July and August) prior to potential influences of the hurricane season in the Maritimes. Examination of meteorological records from the last 3 years indicate that July and August recorded some of the lowest amounts of rainfall. All 20 lines should be re-surveyed at this time.

- Follow through with an examination and comparison of the modern surveys with the 1863 bathymetric chart obtained from the British Admiralty Hydrographic Survey. This could not be achieved during this study due to difficulties in tying in the historical survey with modern chart datum and delays in acquisition of these materials. In addition, it is recommended that the 1969 and 1976 surveys used by Amos (1977) be re-examined and incorporated into the present study to place his results in a more appropriate context.

- Examine tidal and meteorological records, specifically wind speed, direction, rainfall and freshwater discharge records around the dates of the historical and modern surveys to better understand any observed changes. In addition, these variables, particularly the tidal record can help also assess the degree of risk to causeway infrastructure from storm surge and rising sea levels.

CONCLUSIONS

The purpose of this research project was to examine the changes in intertidal geomorphology in the Avon River and assess the overall stability and evolution of intertidal environments within the study area. As previous research has indicated, the intertidal geomorphology of the Avon River Estuary has been impacted by the construction of the Windsor causeway however the magnitude of this impact is much less than originally postulated in the 1970s. Many of the changes might also be associated with natural changes in the position of main tidal channel thalweg. Key findings of the research presented below:

- The St. Croix River has maintained relatively constant cross sectional area since July 1969 despite major shifts in the position of the main river thalweg.

- The most significant (although not statistically tested at this time) changes in cross sectional area and sedimentation were recorded along lines 1A_DS_1A1AA and 1_DS_11AA immediately downstream of the Windsor causeway. This decrease in cross sectional area (measured from HHWLT) ranged from 71% to 48% along the two lines and between 5.8 to 6.5 m of sediment has accumulated downstream of the causeway.

- The significant accumulation of sediment however has occurred at the site of an intertidal bar present before the construction of the Windsor causeway. This marsh and mudflat surface is now near the limit of the HHWMT level.

- An approximate 21% decrease in cross sectional area was recorded 1000 m downstream of the causeway at Line 5 however there is no change in wetted perimeter and w/d or D/d ratios.

- By Lines 7 and 9, a new intertidal bar (Newport Bar) has developed since 1969, with between 2.9 to 7.1 m of sediment accumulation. However 150 m (1500m^2) of marsh has eroded from the western shore (Line 7) since 1955. The resultant cross sectional area in 2005 is only 7% smaller than in November 1970 and this change is lower than those associated with seasonal variability.

- Lines 15 and 16 near Hantsport display very minor changes in bed elevation since 1969, associated with a shift in channel position, and changes in cross sectional area or intertidal channel cross sectional area have been negligible.

- In general, cross sectional area increases with distance from the causeway.

- The shape of the curve of channel width versus distance from causeway does not vary between 1969 and 2005.

- Measures of channel form (e.g. width to depth ratio (w/d) and max to mean depth ratio (D/d)) clearly demonstrate that there is a significant shift in channel form approximately 1 km from the causeway. This suggests that the direct influence of the causeway may be limited to the first 1000m. Beyond this point, the w/d and D/d pattern of change with distance vary only minorly between 1969, 1970 and 2005. Accretional and erosional changes in the Avon River beyond the first 1000 m may be due to more natural processes such as shifts in the main river thalweg.

- After the first 1000 m, the Avon River is joined by the St. Croix and further downstream by the Kennetcook which both likely play a key role in maintaining a more natural channel form as compared to the Petitcodiac River for example.

- Evidence is presented to support seasonal cycles of changes in bed elevation by as much as 2 m which exceed the difference recorded between 1969 and 2005 in some locations. However this phenomenon will need to be tested further due to potential impacts of the construction process during the historical surveys. This study suggests that seasonality and meteorological conditions (e.g. rainfall and runoff) can exert a strong influence on the interpretation and comparison of survey data.

- Cycles of erosion and accretion of mudflat and marsh habitat were shown to be strongly influenced by the position of the thalweg of the main tidal channel. The eroded material has the potential to subsequently 'feed' any new bar formation however this remains to be tested. This cyclicity in marsh habitat is similar in rate and pattern to studies elsewhere (e.g. UK and Cumberland Basin, NB).

- There is a general increase in the percentage of total marsh area from 1944 (7.6%) to 1955 (8.9%) followed by a sharp decrease in 1964 (5.7%) associated with marsh erosion along the western bank and dyke construction. After this time there is a slight increase in habitat due primarily to progradation of marsh along the south shore of the St. Croix River and initial colonization of the Windsor mudflats. This level jumps to 8.3 % in 2003, likely associated with new marsh growth downstream of the Windsor Causeway. If one bases the analysis on marsh areas common to all of the air photos, the amount of salt marsh (as a % of study area) is higher in 2003 than in 1944 and potentially then may compensate for marsh lost prior to the 1950s due to land reclamation and dyke construction in the area.

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