Bathymetric Change Analysis of the Lower Passaic River

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The cessation of dredging in the Lower Passaic offers a unique opportunity to observe changes in the hydrodynamics of an estuarine strait when anthropogenic alteration is halted. A great deal of research has focused on the effects of dredging and the hydrodynamic changes resulting from the creation of an artificial equilibrium. Little research has looked at the hydrodynamics of an area as the environment changes from an artificially maintained dredged channel to a natural estuarine flow, primarily because this rarely occurs. Historical data gathered in this Lower Passaic on hydrodynamic parameters such as flow, sediment load and deposition is largely based on the dynamic of an altered regime. Dredging began in 1890 so anthropogenic change preceded the development and deployment of instruments to measure the effect of these changes. The Lower Passaic Study Area and Navigation Channels are shown in Figure 1.

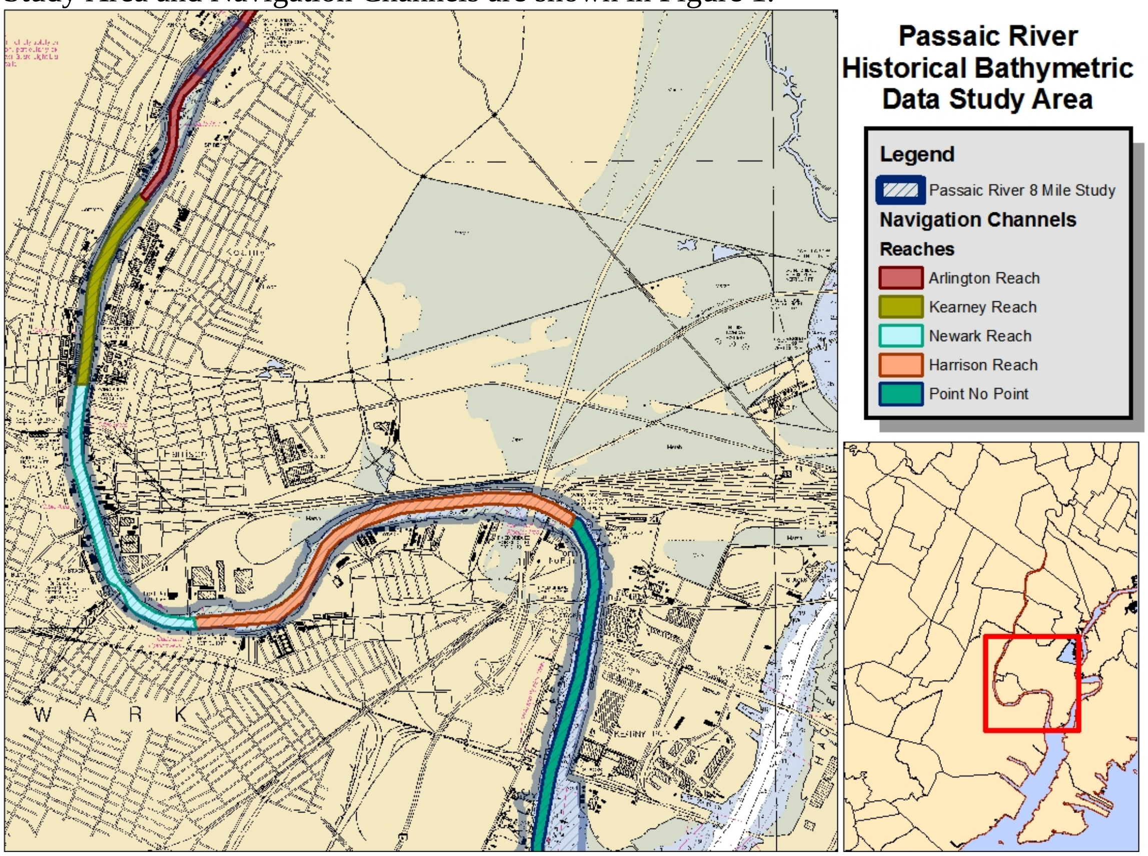

Figure 1 Lower Passaic River Study Area with Navigation Reaches

The current situation gives researchers the change to examine the transformation of a depositional regime. These changes are an important consideration in both regulatory considerations and the potential for revitalizing the economic and recreational use of the Passaic River.

The sediments of the Lower Passaic River are highly contaminated with a variety of organic chemicals and heavy metals including some of the highest concentrations of 2,3,7,8-tetrachlorinated dibenzo-dioxin ever measured in the ambient environment. These sediments are being transported from the Passaic River and redistributed throughout the Harbor Estuary including the Hudson River (Chaky, et al. 2004).

The Passaic River exchanges significant volumes of sediment with the adjacent Newark Bay. Port Elizabeth and Port Newark, located on the Bay, together form one of the largest container cargo facilities in the world. These facilities are vital to the metropolitan area, fifty million tons of cargo per year is delivered here with an impact on the regional economy estimated to be around 20 billion dollars per year. Suszkowski (1978) calculated a sediment exchange between Newark Bay and the Passaic River. Annually 41,500 metric tons (MT) moves from the Passaic into Newark Bay and 23,400 MT are transported into the Passaic, a net gain to Newark Bay of 18,100 MT/y. Fine-grained silts and clays make up the bulk of the bottom sediments. The Lower Passaic sediments contain significant organic material; concentrations are higher than anywhere else in the Hudson Estuary. Contaminated sediments from the Passaic significantly impact the economics of the port facilities due to the high cost of disposing of these materials.

Description of Approach

Recent hydrographic surveys of the heavily polluted estuarine reaches of the Lower Passaic River have resulted in a wealth data on current depositional characteristics. Data is now captured digitally and is available to researchers, regulators and the public. Hydrographic surveys for 1989 and annually from 1999 through 2004 have revealed large variations in sedimentation rates in the lower stretch of the river. The Lower Passaic River Restoration Project's contractor, Malcolm Pirnie Inc., examined eight hydrographic surveys covering a period of 15 years from 1989 to 2004 (MPI, 2006). Annual sedimentation rates were calculated by dividing the change in depth by the number of years between surveys (units of inch/year). The results showed high variability both spatially and temporally. However, no extremely large floods occurred during this time period; the largest flow (1999) had a return period of approximately 9 years based on flow measured at the gage in Little Falls. There have been 11 larger events in the last 120 years at this gage and the peak discharge of record is 2.7 times larger than the 1999 peak.

Depositional activity during the 1949 – 1989 intervals represents a key gap in knowledge about the hydrological and sedimentation behavior of the Lower Passaic. During this time period dredging of the Lower Passaic River above River Mile 3 ceased and the channel began to fill in. The early part of this time period was characterized by largely unregulated discharge of effluent from the facilities along the river. Core samples taken by Maxus (1993), the Environmental Protection Agency (1995, 2003) show high levels of contamination in subsurface samples including Polychlorinated Biphenyls, DDT, Dioxins, Heavy Metals and a host of other contaminants.

Digital scanned hydrographic survey sheets were obtained from the US Army Corps of Engineers, New York District, through a Freedom of Information Act (FOIA) request. The original survey sheets were compiled on mylar at a scale of 1:1200, (one inch equals 100 feet). These survey sheets were scanned to microfiche by the Corps of Engineers. The request was for Hydrographic surveys carried out in the Passaic River between the time period of 1949 to 1989. Data were provided by the Corps on 2 CDs containing 256 scanned hydrographic sheets in Joint Photographic Experts Group (JPEG) format. The original microfiche were at a scanned at a nominal resolution of 300 dots per inch (dpi). The first date provided was 1949 and the last survey date was 1986.

The data compilation and analysis was carried out at the Worcester State Colleges Geographic Information System (GIS) lab. The lab consists of 12 Dell PCs, a Dell SAN with 800 Gigabytes of storage, a large format plotter and a number of other output devices. The lab runs a full suite of Environmental Systems Research Institute (ESRI) GIS software, including the Spatial Analyst Extension and ERDAS remote sensing software.

Hydrographic Data – Historical hydrographic surveys for the time period 1949 – 1986 are maintained by the US Army Corps of Engineers New York District office in microfiche. These data sheets were originally large format (1 inch = 100 feet or 1:1200 scale) Mylar maps with survey points locations determined by Loran and manual surveying methods depending on the year of the survey. Water depths were determined by echo sounders for the time period of the study, depths were taken as mean low water based on 1900 tidal datum at the Battery tidal station. This station is located on the southern tip of Manhattan Island and has been recording tidal data since 1850. The surveys corrected depths to mean low water using shoreline datum poles and manual surveying methods using transit and levels.

The hydrographic survey sheets consist of a series of transects with points indicating the location at which soundings were taken. A section of one of the US Army Corps of Engineers bathymetric sheets is shown in Figure 2. Physical structures in the river such as bridges and piers are indicated on the survey sheets and were during the rectification process

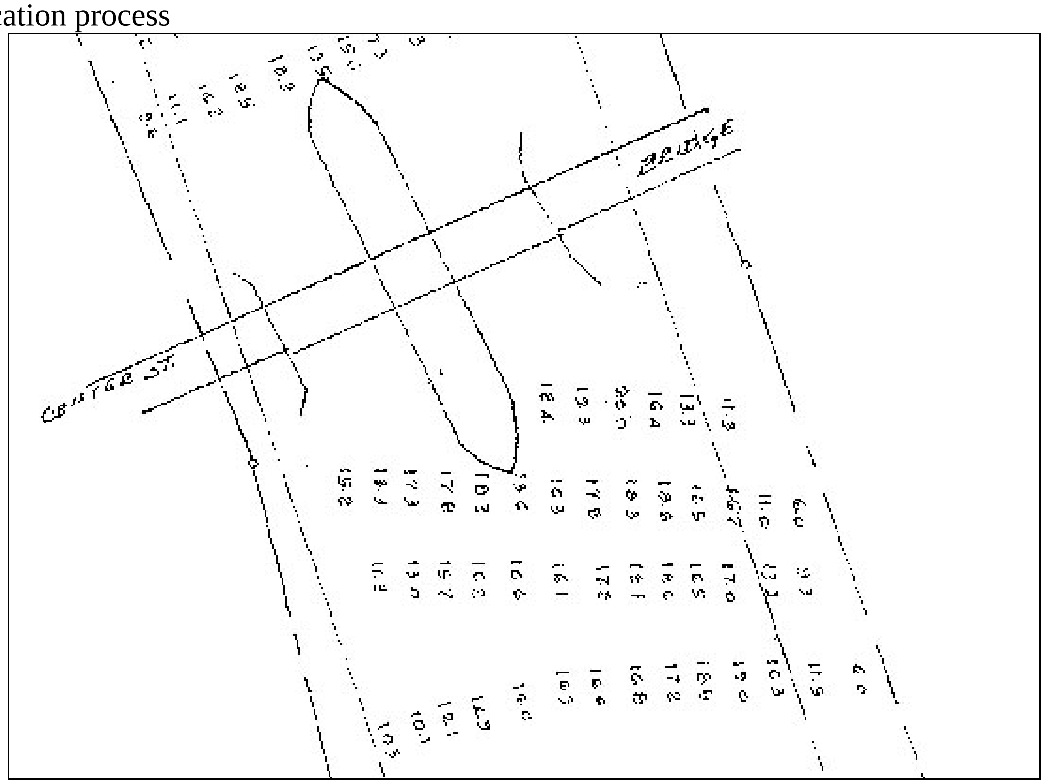

Figure 2: Section of Historical Bathymetric Survey Sheet.

Rectification of scanned images was done using ArcGIS 9.3 software from the Environmental Systems Research Institute (ESRI). Physical structures in the river such as bridges and piers are indicated on the survey sheets and were used during the rectification process in the creation of control points. In addition the channel lines, particularly the turns in the channel, were used. After carrying out a number of “test rectifications” it was determined that the channel markers offered the highest accuracy as they are common to all the Corps of Engineers survey sheets and have not changed during the time period of the study. These lines were present on the 2006 digital bathymetry data that was provided by the Corps digitally in Document eXchage Format (DXF). The channel lines were extracted from this dataset and projected into New Jersey State Plane projection. A minimum of 5 control points was identified on each scanned sheet. In the absence of useable channel turns points were identified on New Jersey Department of Environmental Protection (NJDEP) Digital Orthophotos. Careful selection was made of these control points as the shoreline and bridge features found on the survey sheets did not always match the locations on the Orthophotos. Bridge abutments are not accurately rendered on the survey sheets and the shoreline features such as piers and bulkheads have changed over time.

Control points were selected iteratively with the goal of minimizing the overall and individual root mean squared error for the adjusted pixels. The average RMS error during the rectification process was kept under 3 feet for all survey sheets and averaged 2.1 feet for all the images used. The rectified images were written out into a new JPEG image, clipped to the extent of the survey to allow images to be edge-matched to the next in sequence. Pixel size of the output image was 0.3 feet with image extents ranging from 12,000 to 21,000 rows and columns. Uncompressed image size was 200 – 350 Megabytes (Mb), saving as a compressed jpeg brought the size down to a more manageable 10Mb. The large fie sizes were necessary to decipher the depths which were hand written on the survey sheet.

The scanned hydrographic images were digitized by the student workers under supervision of the Project Director. Digitizing was carried out as a “heads-up” on-screen process using the scanned sheet with the digital shoreline file and Orthophotos as a background image. A vector point dataset of hydrographic soundings in New Jersey State Plane (NJSP) coordinates was created to store the survey depths resulting from digitizing. The structure of this file is basically an x,y,z vector point data file of coordinate locations and measured water depths. The format for the point file is ESRI shapefile format. The specifications for the format have been distributed by ESRI so a number of other software systems such as CAD and modeling programs can read shapefile format affording the greatest flexibility for distributing the data. The units of the soundings are feet with one decimal place (tenth of a foot) matching the format on the survey sheets.

When each year’s surveys were completed, the Project director performed a quality control check of the resulting dataset. This consisted of a visual examination of the datafile, calculating mean, maximum and minimum values to determine outliers or problems. Then the data were visually displayed using hypsometric tinting. Finally the points were labeled with the depths and randomly selected locations were visually checked.

Datum adjustment between subsequent years survey sheets were calculated based on National Ocean Service (NOS) Hydrographic Survey Specifications using tidal datum data from the NOS Battery Tidal Station. Tidal variations for the past 150 years are shown in the figure below.

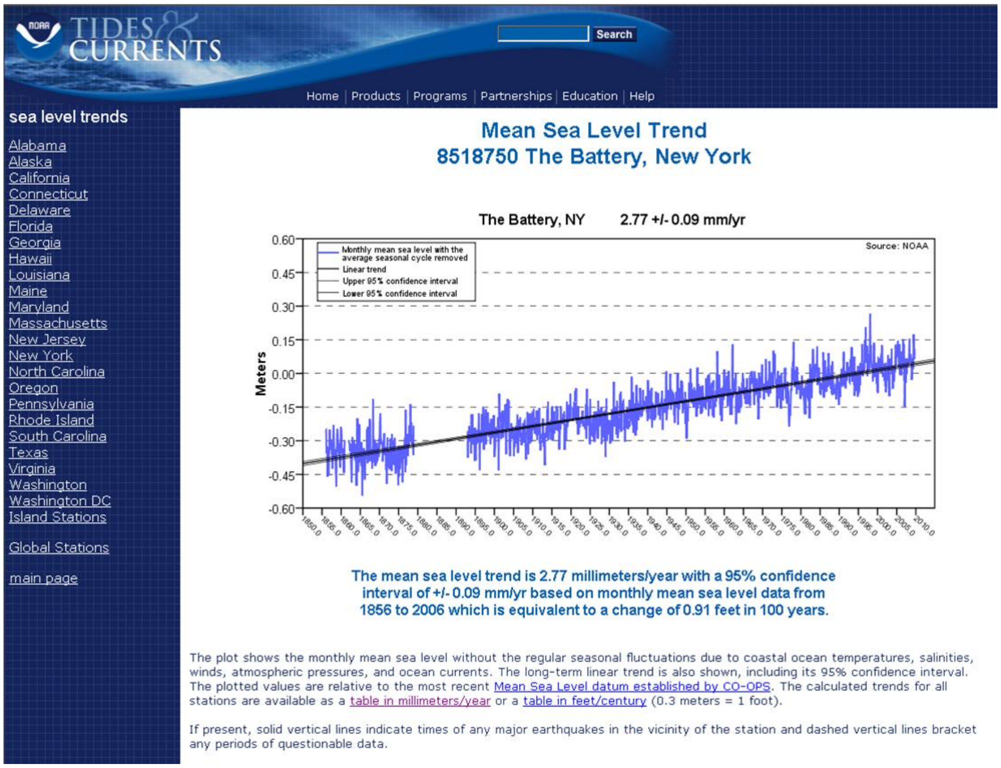

Figure 3: Sea Level Trend at The Battery Tidal Station

The Battery Station is NOAA Tidal Station 8518750 currently located on the pier behind the US Coast Guard Inspection Station in lower Manhattan. Tidal levels have been recorded at that general location since 1850, the current location was established in 1920. The baseline used by the Army Corps of Engineers was 1900, mean sea level (MSL) was 1.54 feet at the station. The 1949 survey took place April 19-22, 1949, MSL was 2.13 feet, a difference for 1900 – 1949 of 0.59 ft. For the April 21–26, 1966 survey, MSL was 2.29 feet. a difference of 0.75 feet. These datum differences and the remaining years are listed in Table 1, below.

Table 1: Datum change in Sea Level for Hydrographic Surveys.

Survey/Baseline Dates	**Mean Sea Level (in Feet)**	**Difference with Baseline**
April 1900	1.54	NA
April 19-22, 1949	2.13	+0.59
April 21–26, 1966	2.29	+0.75
April 18-24, 1976	2.25	+0.71
Nov-Dec 1986	2.43	+0.89

The depths were recalculated using the datum adjustments into a new field, ***depth_ft_dt*** (depth in feet, datum transformed).

Interpolation

The next step in the process was to create a continuous surface from the discrete points. This process is known as interpolation, it involved calculating the value for a physical condition at an unmeasured location, based on the value at nearby measured locations. There are a variety of methods for carrying out interpolation; inverse distance weighting, trend surfaces, regression, Thiessen polygons and splines. Kriging is considered the optimal interpolation method as it statistically calculates variation and auto-correlation and adjusts interpolation factors to account for the underlying nature of the data distribution. Kriging calculates a variaogram, a spatial measure of variance with distance. For this analysis, kriging was used to create the bathymetric surfaces. One potential problem with the transect data is that it is highly anisotropic. Depth varies greatly over a short distance across the channel, however it varies over a much greater distance along the channel. Kriging provides the means for measuring variagrams in different directions, known as directional kriging. However when the direction of the anisotropy changes, as with a meandering river, even directional kriging yields poor results. Figure 4 shows the results for using a spherical search pattern for sample points and the kriging interpolation method for the 1976 hydrographic survey of the Lower Passaic.

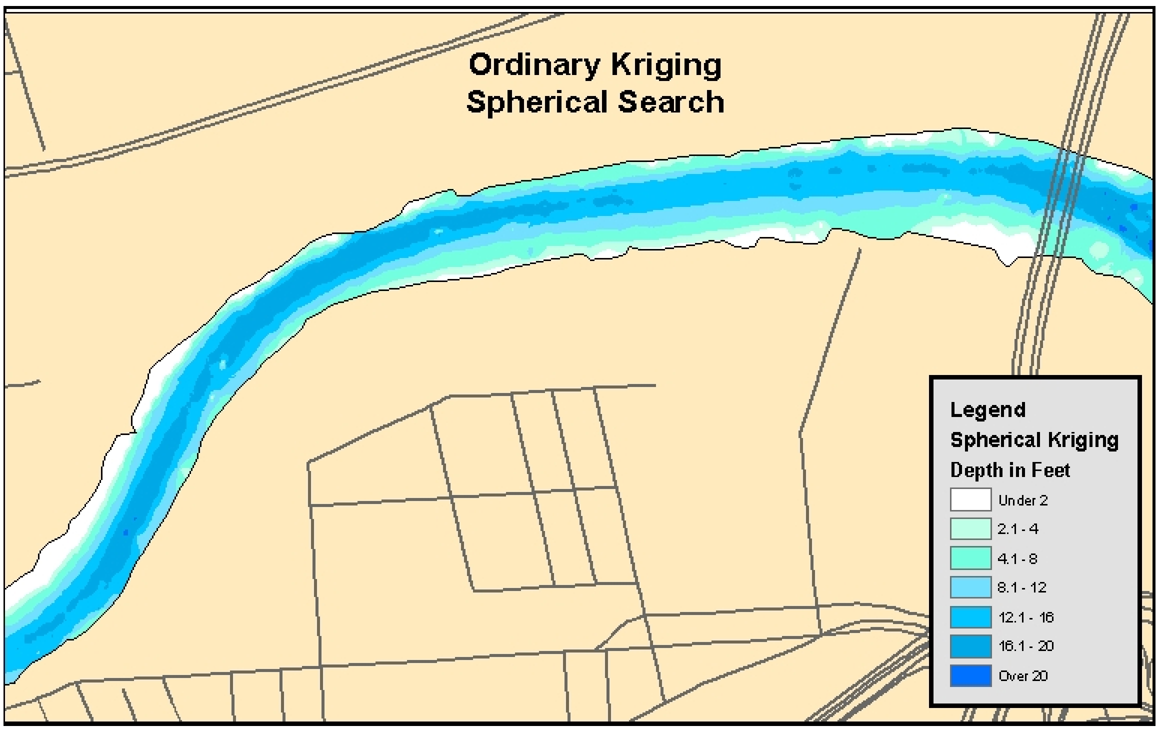

Figure 4 Spherical Kriging of Point Depths in the Lower Passaic River

To allow more accurate interpolation the hydrographic sample points transformed into upstream and across stream coordinates to allow the interpolation algorithm to compute a directional variogram. The x,y values were transformed to upstream and cross-stream coordinates.

Transformation Process

Using the hypsometrically tinted bathymetry points as a guide, a thalweg line shapefile was created. This line file was used to create a file of points at 10 foot intervals along the thalweg. The points were given the upriver distance from the lower limit of the furthest downstream survey. Then these points were spatially joined to the digitized depths. The spatial join process adds the upstream distance to the survey depth file, and adds a field and calculates a distance from the survey point to the thalweg. The thalweg line file was then used to split a polygon file of the river to create a polygon for the left side of the river (with respect to the thalweg) and the right side of the river. This polygon was used to select survey points on the left side of the river thalweg, the distance value was changed to a negative number.

ESRI's Geostatistical Analyst was then used to examine the across stream variagram and the along stream variogram. The variagram is the distance away from the calculated location at which the value of the measured physical parameter is statistically unimportant to the location. These values were then used to transform the across stream coordinates based on the ratio between along stream and across stream. This process essentially stretches the river to equalize the anisotropy of the river. Figure 5 below shows the transformation.

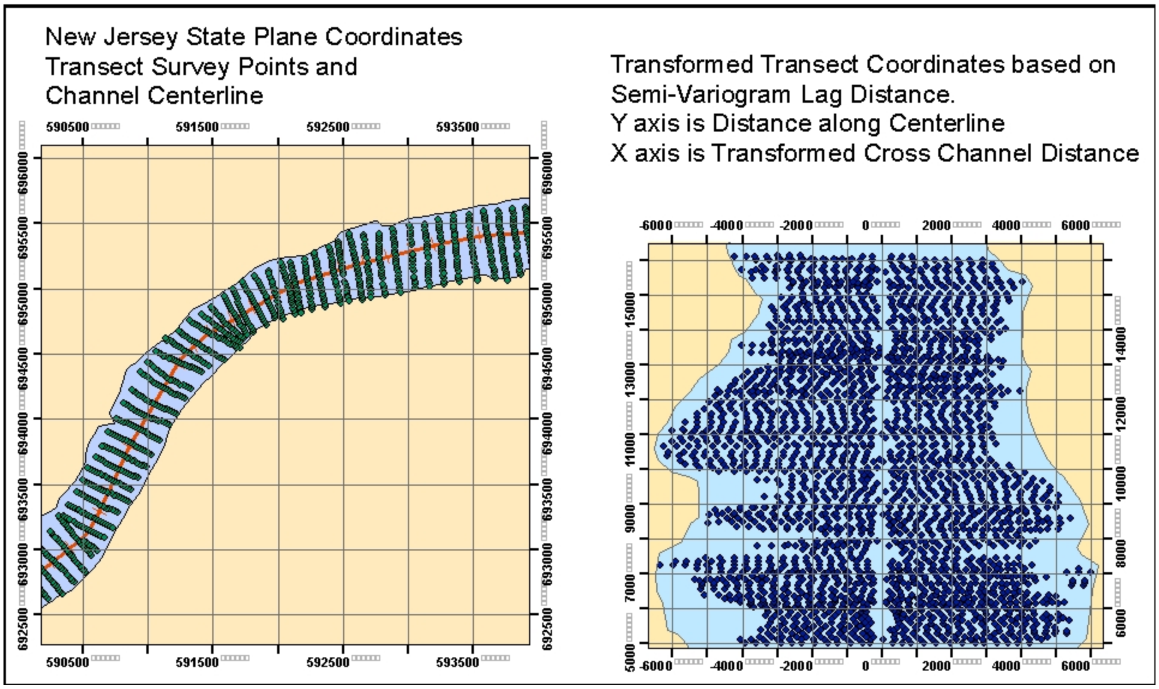

Figure 5: Transformation of New Jersey State Plane Coordinates to Upstream - Across Stream Coordinates.

The transformed points were then interpolated using Universal Kriging in ArcGIS GRID program. This method is considered the most accurate interpolation method for analysis of geophysical parameters that are spatially correlated; topography, soils and geologic formations for example.

The resulting output surfaces were transformed back to NJSP coordinates using a 5 foot cell size grid file of the Lower Passaic River from shoreline to shoreline. The grid was converted to a point file. Fields were added and calculated to the New Jersey State Plane eastings and northings (x and y) coordinates. Then fields were added to the grid point file and calculated to the transformed across stream and upstream coordinates in the same manner as the depth points by using the thalweg point file. This point file converted into an Event Theme using the transformed coordinates. A depth field was added and was then calculated to hold the values of the interpolated data using the Spatial Analyst zonal function. The point file was then transformed back into NJSP coordinates using the eastings and northings. Figure 6 shows the 1976 bathymetric surface processed using the transformation process which is described below.

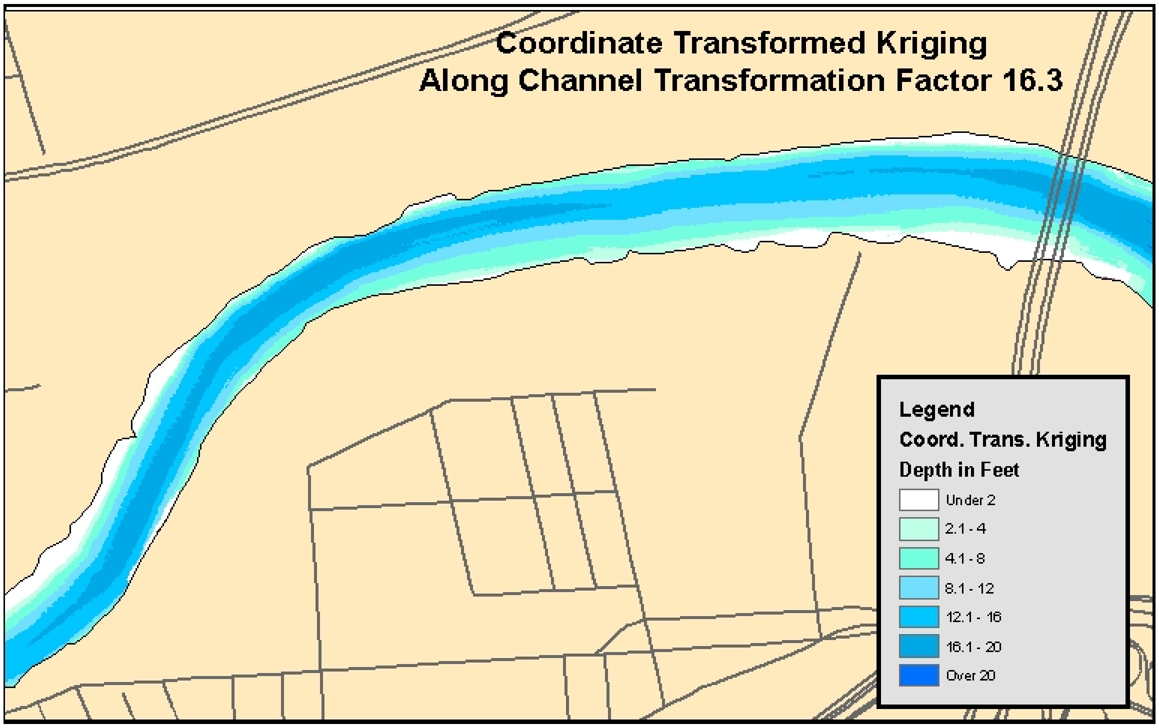

Figure 6 Coordinate Transformational Kriging of Lower Passaic River.

<u>Bathymetric Change Surface Development -</u> The interpolated hydrographic surface grids were then used to create hydrographic change surface files. The temporally earlier grid format files was subtracted from the later grid format file to create a surface with values indicating the hydrographic change which occurred between the time periods. Negative values indicate erosion occurred while positive values indicate deposition during the time period.

<u>Results</u>

The 1949 to 1966 time period is shown in Figure 7 below.

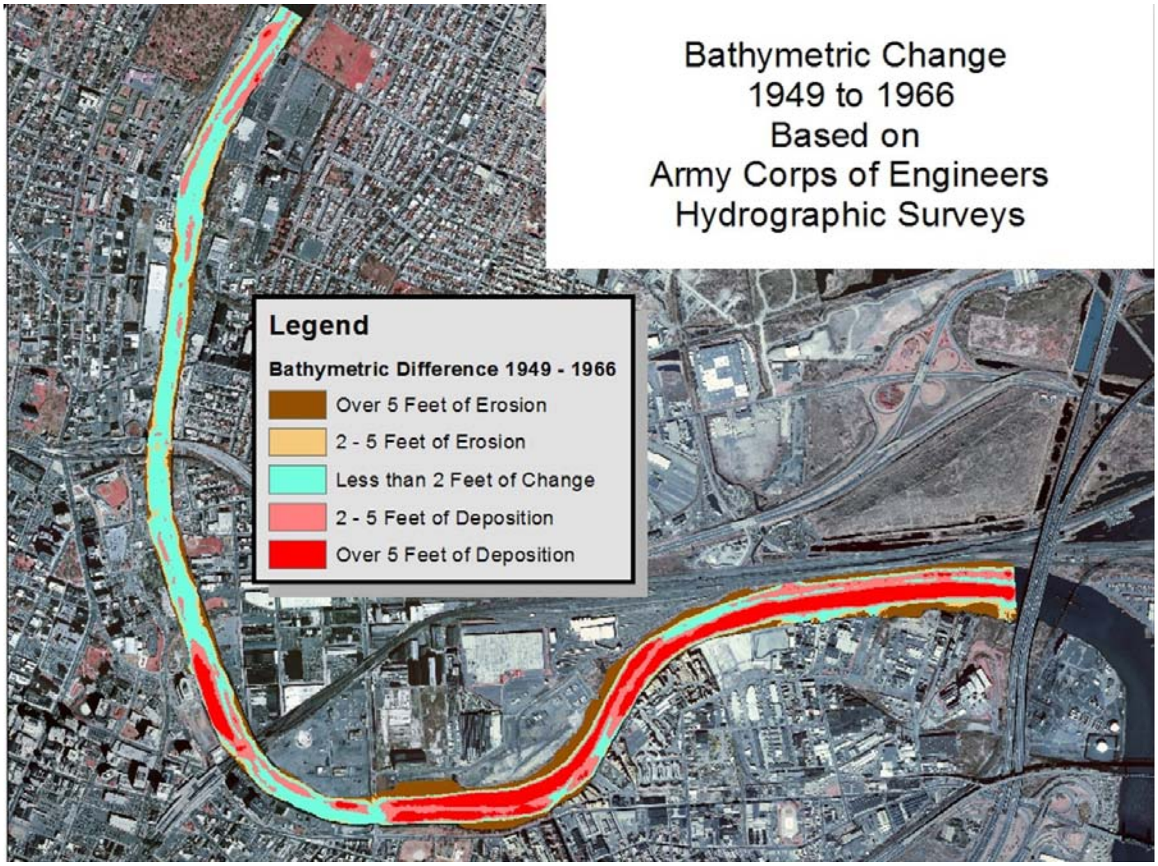

Figure 7 Bathymetric Change 1949 to 1966 time frame.

Infill was concentrated on the channel areas in the lower stretch of the study area, predominantly along the inner curve of the river. Some of this sediment was transported to the channel from the area between the channel edge and the bank. This is evidenced by the erosion which took place in this area.

Shown below in Figure 8 is bathymetric change during the time period 1966 to 1976. For 1976 surveys were available only for the Harrison Reach. During this time period deposition was greatest in the lower stretch of the river, from the Diamond Alkali site down to the New Jersey Turnpike Bridge. Additional heavy deposition occurred along the banks outside the channel. This area however is furthest from the actual measured depths and so is prone to the largest error in interpolation. Surveys were largely limited to the channel and the area immediately outside the channel and rarely extended to the bank. This was due to the fact that the focus was on the navigation channel. In addition the bank configuration changed over the time period of the study making comparisons of this area problematic.

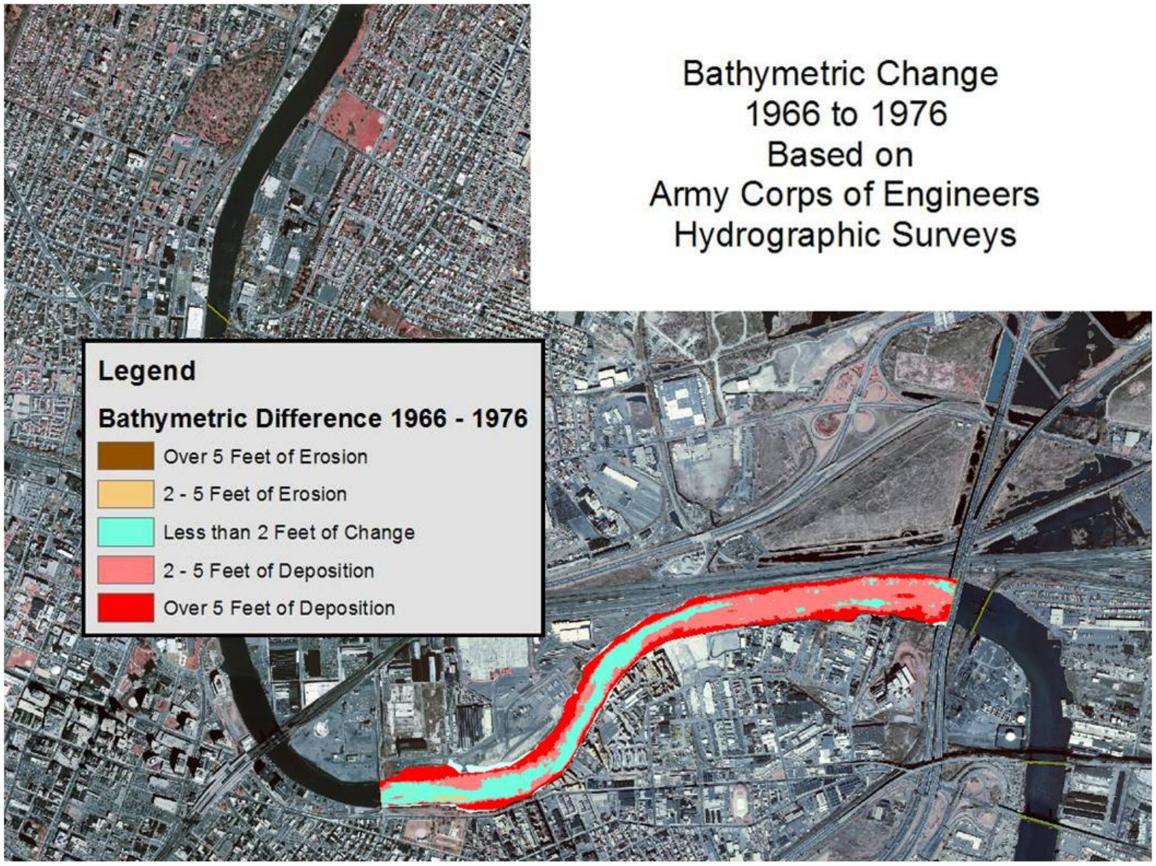

Figure 8: Bathymetric Change for 1966 - 1976 time frame.

Figure 9 below shows the bathymetric change from 1976 to 1986. The 1976 survey only covered the lower stretch of the river so the comparison is limited to this area. More channel infill occurred during this time period in addition to erosion along the outer banks of the river.

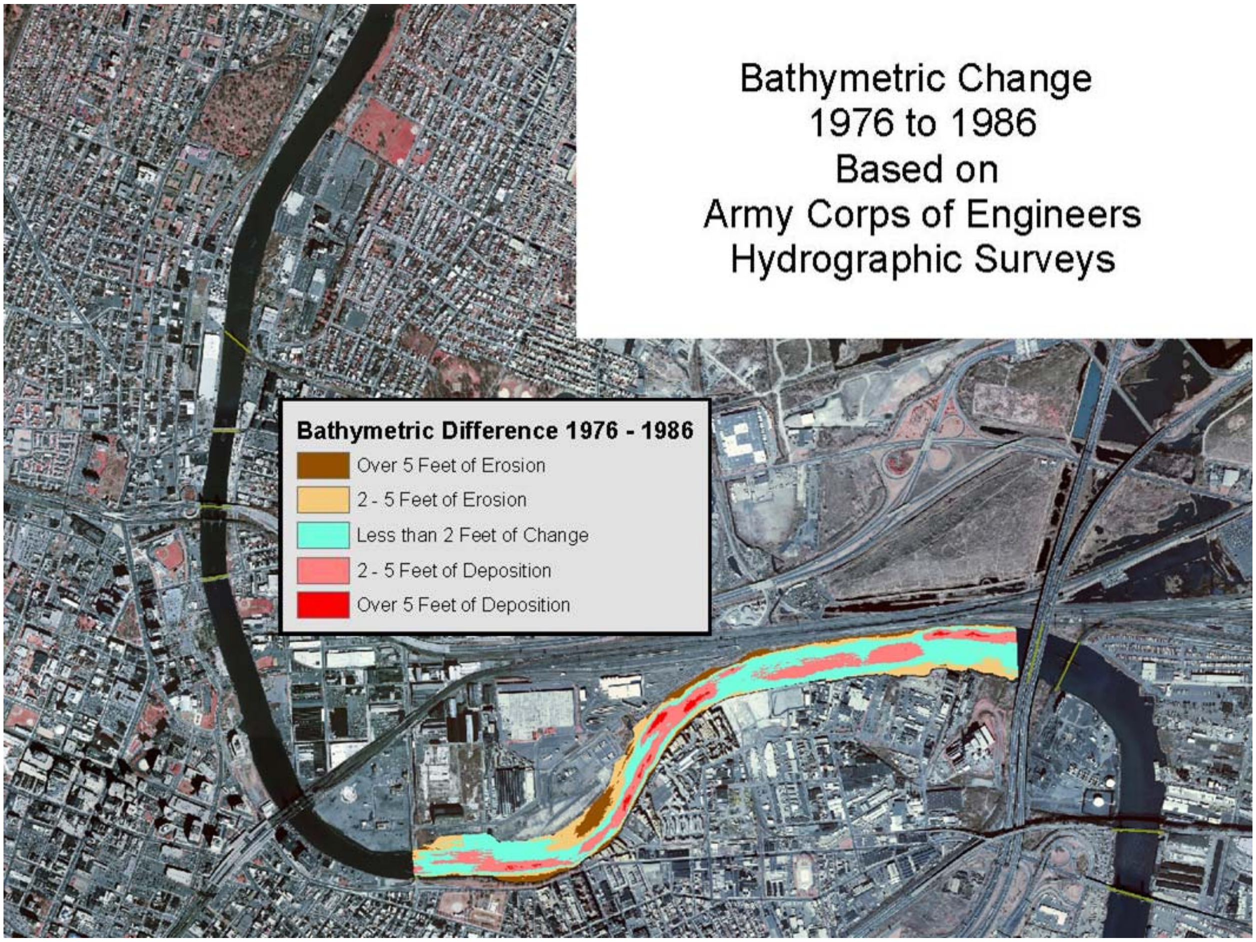

Figure 9 Bathymetric change for 1976 - 1986 time frame.

Figure 10 shows the across stream change by the 4 survey dates for the river section 0.5 kilometers upstream from the New Jersey Turnpike Bridge. The Federal Navigation Channel is superimposed on the cross section. The 1949 profile most closely mimics the Federal Channel, 1966 shows infill primarily along the inner edge, up to 7.2 feet (2.4 meters) on the inner channel edge but erosion along the outer (northern) bank. The 1976 profile shows even infilling in the channel and along the outer bank. 1986 shows additional fill on the outer channel and outside channel area and the establishment of a thalweg in the mid-river area.

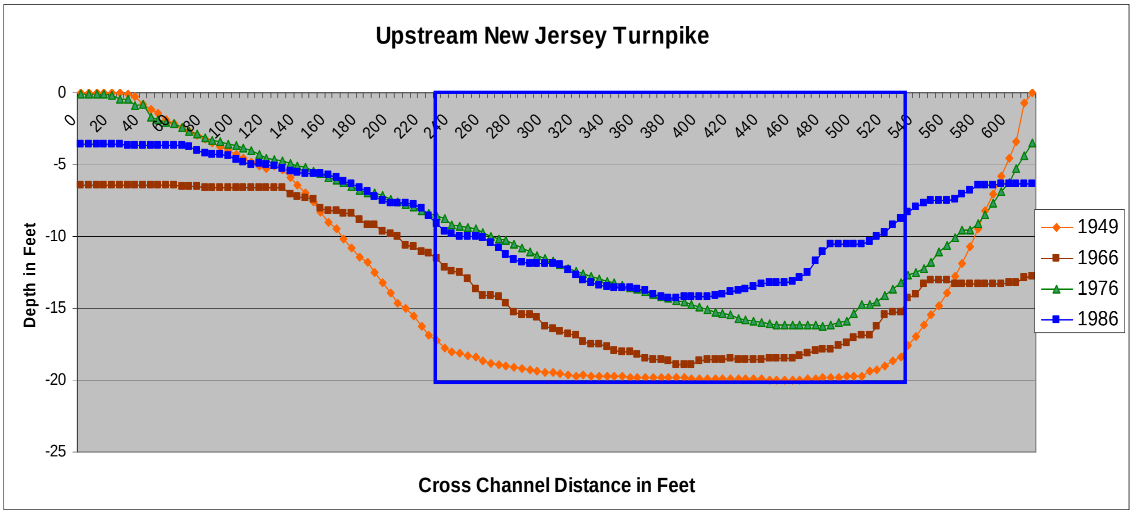

Figure 10 Channel Cross Section south of New Jersey Turnpike bridge, Harrison Reach.

Figure 11 shows the across stream change by the 4 survey dates for the river section adjacent to the Diamond Alkali Site. The 1949 survey show a deep channel with a relatively small shallow nearshore section. By 1966 significant infill has occurred within the channel, up to 6.7 feet (2.2 meters). Rapid channel fill on the inner (south) bank continued during the 1966-76 and 76-86 time periods

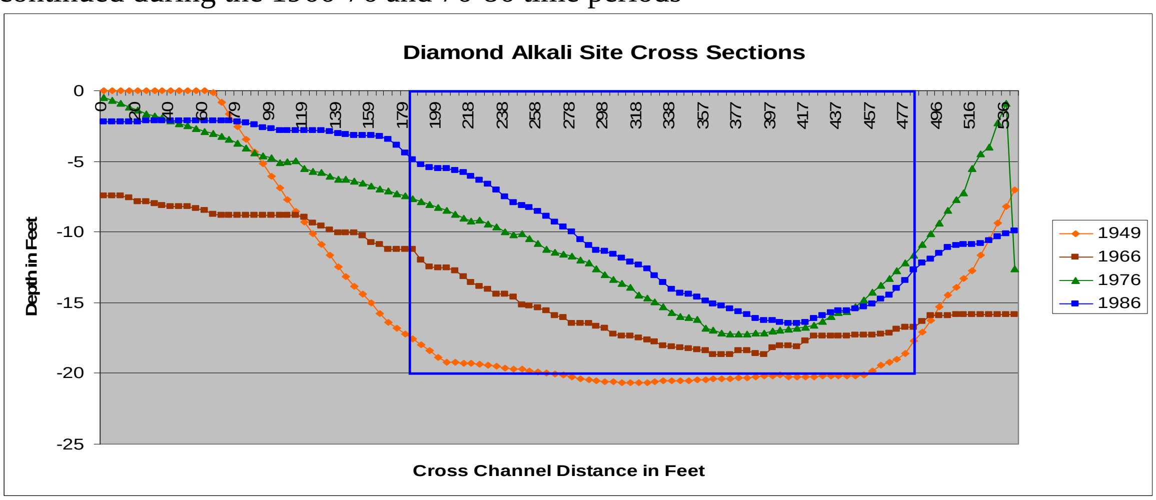

Figure 11 Cross Channel Section at Diamond Alkali Site.

Conclusion

Historical hydrographic surveys provide a valuable tool for examining changes in bathymetry. The US Army Corps of Engineers' repository of hydrographic surveys on microfiche allows changes, resulting from the cessation of dredging in the Lower Passaic River to be examined in detail. This is a unique situation, where a river is no longer be artificially maintained as a navigation channel and is returning to a natural estuarine circulation pattern.

Coordinate Transformation Interpolation provides a more accurate method for generating continuous surfaces for highly anisotropic hydrographic features such as rivers and narrow tidal straits. The transformational kriging method employed in this analysis facilitated the production of a bathymetric surface that reflected the morphology of the Lower Passaic River rather than the configuration of the sampling design with phantom features. The surface shown in Figure 4 demonstrates the effects of sampling method and the high variability in the cross channel direction. The method of data collection, cross channel transects with sample locations close together and transects at a large distance apart, is reflected as ridge-like artifacts in the resulting surface.

Coordinate transformation removes the effects of the sampling method in transforming the original data points into new coordinates based on variance in the data. The resulting surface, Figures 6, shows a smoother texture which would be associated with an unconsolidated bottom in a bi-directional flow regime. This is vital for comparing datasets taken with variable transect locations and distances as is the case with the Lower Passaic historical hydrographic surveys. In addition it is important to remove the effecto of sampling when calculating change over time as the sampling distribution changed both across channel as well as along channel between the time periods of the study. The variation in sampling locations did prove problematic in near shore areas as surveys from different years varied in how far beyond the Federal Channel data collection occurred.

An examination of the changes over time showed that the Lower Passaic River has been filling in rapidly. For the area adjacent to the Diamond Alkali Site, deposition averaged 0.16 feet per year for the 1949 – 1966 time period. From 1966 to 1976 deposition averaged 0.33 feet, from 1976 to 1986 deposition was 0.16 on a per year average. This rapid filling in is a concern as this was a time period of largely unregulated discharge from industrial plants along the river, especially from the Diamond Alkali Site. This infill occurred initially in the formerly dredged Federal Navigation channel, then spread to near bank areas. The latter time period consisted of some infill but also a re-configuration of the channel and the development of a natural thalweg rather than an artificial channel.