THE APPLICATION OF GIS TO THE ANALYSIS OF HISTORICAL SHORELINE CHANGES OF NEW YORK CITY

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ABSTRACT: A survey of historical maps of New York City was undertaken, 15 maps dating from the between 17 and 18 century were found. Most of the maps are small scales and lack detail needed for comparison. The map of Lieut. Ratzer, issued in 1776, based on a survey of 1766 was found to be most suitable for the historical map analysis due to the relatively large scale ~ 1 : 11258 and detail in depicting such objects as churches, fortifications and piers. The Trinity Church and corner of the Bowery and Grand Streets served as reference points for superimposing the modern map of 1987.

The accuracy of the comparison was estimated using three different approaches:

- probability of the shifting of the reference point location;
- accuracy estimation using Tanner's method;
- accuracy of the historical surveys;

These analyses indicated that the accuracy of the obtained data lies within the limits of 1% or 20 - 25 m.

A comparison of the historical changes of the Manhattan shorelines of 1766 and 1987 showed that the shoreline of Lower and Midtown Manhattan advanced seaward from 30 to 213 meters (or beyond the accuracy of the shoreline). The area of Lower Manhattan to 29th - 32nd Streets increased ~24% and the length of the shoreline increased ~ 40%, in comparison with the initial area. All these changes were caused by the intensive expansion of Manhattan Island.

Using GIS in the historical data analysis gives certain advantages in the accuracy and quality of the final results. Since practically all historical maps have different scales and projections, GIS helps to overcome these difficulties resulting in unified data.

INTRODUCTION

Historical changes of any geographical object are always interesting, but the shoreline of Manhattan is a special case, when there are combined economical tendencies of urbanization and natural peculiarities of the "island in the river". The purpose of this study is to define quantitative parameters of the Manhattan shoreline changes due to the urbanization process. One of the main problems connected with compiling base maps from historical records is the choice of the reference points which implies the choice of points in existance a long time ago and which are preserved now. These points have to be stable over time, otherwise it is impossible to make a comparison. This condition is imperative while choosing historical maps and thus was chosen the map, published in 1776 by Faden & Jeffery's. This map was prepared by Lieutenant Ratzer during surveys 1766 - 67 and it reflects the Lower and Midtown Manhattan with some environments of Long Island and New Jersey. This map indicates that

the sawtooth appearance already existed by 1767. At that time the city was much smaller an its borders didn't stretch farther than Grand Street.

On the map of Lieut. Ratzer are also shown a lot of details of the shoreline and othe landforms, though without any quantitative parameters of elevations and scale, except for som sounding data in the Hudson River and East River. There are indicated such remarkable place as Trinity Church and Grand Street, which existed at that time and exist now, which wer chosen as a reference points for the investigation. The detailed map of modern Manhattar (1987) was digitized. Also digitized was the 1776 map of Lieut. Ratzer, using the NE corner o Trinity Church and SE corner of Grand Street & Bowery Street as reference points.

One of the attempts in historical analysis was done in 1874 by engineer Egbert L. Viele. He drafted and published the Topographical Atlas of the City of New York that time. In his map he showed the coastal boundary of Manhattan from the 1874 survey together with the origina shoreline, which existed during the Dutch period. E.L.Viele showed on his map all available geomorphology, including water reservoirs and creeks. On this map are also shown characteristic pier chain of Manhattan and landfill areas in 1874. His map became invaluable for the modern planning and developing purposes in Manhattan and now is widely used in engineering and construction.

The second known attempt to bring together old and recent cartographic plans was done by McCoun Townsend, who published in 1909 the map "Early New York", in which he compiled data from Lieut. Ratzer's map (survey 1766-67), John Montressor's map (survey 1766) and some other surveys of 1867. His map displays only Manhattan Island and contains practically all old Indian names which were given to the numerous remarkable places in Manhattan. This map is more historical, while E.Viele map fits better for the practical purposes of the analysis.

Development of modern software and hardware opens a new page in cartographic historical studies, especially some very precise vector data programs, such as AutoCad, ArcInfo and others. They allow so-called "rubber sheeting", the process which makes it possible to use two or more reference points for the comparison of maps with different scales. Taking into account that some old maps don't have any coordinate system or their coordinate grid is just conditional, the great value of such software is quite obvious. Moreover, the creation of the historical GIS may considerably improve the management and application of the historical data.

THE HISTORICAL MAP SOURCE

The first step in the historical map comparison was to define the possible sources of the cartographical information. Just in time for this project the book of J.A.Kroessler's guide appeared in 1988. His book "A Guide to Historical Map Resources for Greater New York" contains a huge amount of information related to the maps, charts and plans sources. There are listed collections of 49 libraries and archives which held cartographic information about New York area. In the descriptions J.A.Kroessler gave also some brief information about the quality and content of some particular interesting maps.

An analysis was done of the available information in the Map Division of New York Public Library. A summary of some cartographic source data is given in Table I. These data are related to the 17 - 18 century, when first more or less precise Manhattan maps were produced. The earliest maps of Manhattan were done apparently in 1606. Then they were compiled with

the 1867 surveys and issued in 1909 by Townsend MacCoun. This is a famous map which has visual shapes of the different landforms in Manhattan and old Indian names for the different parts of Manhattan and surrounding terrains. One of the first mentioned surveys with the purpose of straightening out streets was done in 1655, when commission of four surveyed the entire town (Mackay A.D., 1987).

Other maps, related to the 17 - 18 century have many different malfunctions, including small sizes, scales and depicted areas. The map issued in 1766, with the survey of John Montressor is remarkable by the relatively big size, scale and accuracy, but depicts less of Manhattan than would be favorable.

TABLE I. Available cartographic source for the historical studies of the 17-18 century, from the Map Division of N.Y.P.L.

YEAR	NAME OF THE MAP	SCALE	SIZE	RELATED INFORMATION
1609	Manhattan Island, & survey of Ratzer, Montressor, Bradford, Duyckinck, etc. and survey 1867	Approximate $3^1/_2$ inch- 1 mile.	$45^3/_8 \times 12^1/_{16}$	5 maps, compiled by MacCoun Townsend and published as "Early N.Y." in 1909 with the Indian nomenclature.
1624-39	Manhattan,1624-1639			2 maps, published by Van Winkle Edward in 1878.
1630-34		not given	$5^1/_4 \times 7$	Buchelius chart, 1630-34, in Dutch Nat. Archives.
1655	New York Province	1:2,750,000	$14^3/_4 \times 17^1/_2$	Held by NJ Historical Society
1668	New York City			by Gooze, Pieter
1686-89	A sand drought of NY Harbor		$7 \times 5^1/_2$	by Phillip - Wells
1730	A plan of NY Harbor	1 inch - 2 miles	$1^1/_4 \times 20^1/_2$	Photostatic copy of original map in Henry E. Huntington Library
1730		1:300,000	$5^3/_4 \times 4$	Proof sheet of plate in: Stocke's Iconographs
1731	A Draught of NY			Bears Tiddeman's name
1733	NY & Perth Amboy	1 inch - 2 miles	$9^1/_2 \times 11$	
1757-59	NY Harbor (Narrows)	1 inch - 1000 feet	16 x 10	Plan of Narrows, Stocke's,N.Y.
1766	Plan of Governor's	1 inch - 400 feet	$28^1/_2 \times 28$	Kennedy's & Brown Island, Red Hook, together with the part of Bar and Sound. John Montressor, Engineer
1776	Province of NY for Henry Moore	1 inch - 9,500 feet	$30^1/_2 \times 40$	Lieut. Ratzer, survey 1766-67 Manhtn., Brooklyn, part of NJ
1783		Approximate 1:20500	$47^3/_4 \times 12$	5 maps, showing Revolution Fortifications
1784	Sandy Hook, NJ	1:38500	$25 \times 23^1/_4$	A chart of Sandy Hook with the entrance in Hudson River

One of the most valuable maps of this period is a map issued in 1776 for the Governor Henry Moore. The surveys for this map were done by Lieutenant Ratzer in 1766-67, and the major convenience of this map is its large scale - 1 : 11258, i.e. 1 cm ~ 113 m. This map is apparently the only one among other maps from 17 - 18 century having such a valuable and convenient scale. Though this map doesn't have any coordinate grid there are visible, very distinctly, such small objects as churches, fortifications and piers. These objects, if any would be found on the modern map, can serve as perfect reference points. Also this map shows a lot of various landforms, wetlands, swamps, waterways and forests, though without any appropriate elevation data. There are some soundings near the southern end of Manhattan shown on the map also.

The modern map of Manhattan Island was published in 1987 and it depicts the most recent shape of the Manhattan shoreline with the detailed view of maritime structures.

CARTOGRAPHIC ANALYSIS OF HISTORICAL MAPS

One of the main problems connected with compiling base maps from historical records is the choice of the reference points which implies the choice of points which existed long time ago and which preserved now. These points have to be stable with time, otherwise it is impossible to make a comparison. This condition is imperative while choosing historical maps and thus was chosen the map, published in 1776 by Faden & Jeffery's. This map was prepared by Lieutenant Ratzer during surveys 1766 - 67 and it reflects the Lower and Midtown Manhattan with some environments of Long Island and New Jersey.

The first chosen point was the Trinity Church. Its position was found on both modern and historical maps. Despite the fact that this church was burned soon after the 1776 map was published, it was then rebuilt. The fire, which burned nearly one-forth of the city happened in September 1776, when the army of G.Washington left the city (Mackay A.D., 1987). Then it was necessary to chose the second reference point, which would be located as far as possible Trinity Church and also appear on both maps. Finally the SE corner of Bowery Street and Grand Street was chosen suggesting that its location didn't change substantially. Grand Street and next to it Bullock Street, marked the end of the city in 1776.

Since the purpose of this research was to define linear changes of the shoreline the vector data software AutoCad was chosen. During digitizing it created polylines which were then linked together and closed. To measure the length and the area of that resultant polyline the program AREA was used. This routine in AutoCad is able to define the area of the closed polygons and their perimeters. There were two files - the digitized shoreline of the 1776 map and the shoreline of the 1987 map. Both of them end at the level of 29th - 32nd street polyline. The results of the measurements were summarized in the Table II, where the area means the area of the particular polyline and the length means the length of the polyline. In geographical sense they mean the area of the Lower Manhattan and the length of its shoreline respectively. Thus, the area of the Lower Manhattan increased from 1776 on ~24% and the length of its shoreline increased on ~40%. The resultant map is shown on a Fig.1.

On the modern maps of Manhattan (Coastal Zone Boundary of New York City, 1986) one can see also two lines, which mark artificial maritime boundaries of Manhattan. They are pierhead line and pierbase line. The first one bounds all tips of piers and the second one bounds their base. The pierbase line reflects the length of the Manhattan shoreline without

additional lenghts of the piers, so the difference between the pierbase line area and pierhead line area means the area which is occupied by piers, including water spaces between them.

TABLE II. The comparison between the square and linear parameters of the Lower Manhattan in 1776 and 1987.

Years	1776			1987		
Parameters	Shoreline	Pier-base	Pier-head	Shoreline	Pier-base	Pier-head
AREA (km2)	13.9	14.5	14.8	17.2	18.0	20.0
LENGTH (km)	16.1	15.4	16.2	23.9	15.0	15.4

The modern shoreline was digitized in Universal Transverse Mercator Coordinates, a planear coordinate system incremented in meters. Then the historical map was digitized in the same coordinates, using Trinity Church and the corner of Grand Street and Bowery Street as reference points. Then there was calculated the area of the Downtown Manhattan and the length of the shoreline.

In the future study will help the use of GPS devices, for example "Magellan". The method assumes coordinate measurements at the historical sites shown both on the modern map and historical one. Then these coordinates would be used during the map calibration on the digitizing tablet before digitizing.

THE ACCURACY

The accuracy of the map comparison is based on two main factors - accuracy of the reference points location and the scale of compared maps. The accuracy of the SE corner of the Grand Street and the Trinity Church would be defined basing on the probable dispositions of these places. The Trinity Church today is the third building, erected on the site after numerous fires in New York, but since there are no statements about its relocation we can assume that possible changes of the location of the chapel didn't exceed the width or length of the building itself. The same approach was applied to the Grand Street and Bowery Street corner. The expanding of Bowery and Grand Streets wouldn't cause considerable changes in their corner location. There are houses which were built more than century ago, and since that time these streets didn't undergo considerable reconstructions. Thus, if the length of the Trinity Church approximately equal 50 m and its width equal ~ 25 m we can assume on that base that the accuracy limits are between 25 and 50 meters. Second factor is the scale of the map. The modern one has the scale of 1:24 000 and the Ratzer's map scale is 1:11 258. Based on the application of Tanner's method of accuracy determination to the shoreline changes measurements (V.Goldsmith, 1978) we are able to define possible errors, connected with each shoreline. Tanner draft publication "Standards for Measuring Shoreline Changes" outlines errors to be considered when dealing with different scales and different types of maps (Goldsmith V. et.al.,1978). Using this method we defined the following parameters, represented in the Table III.

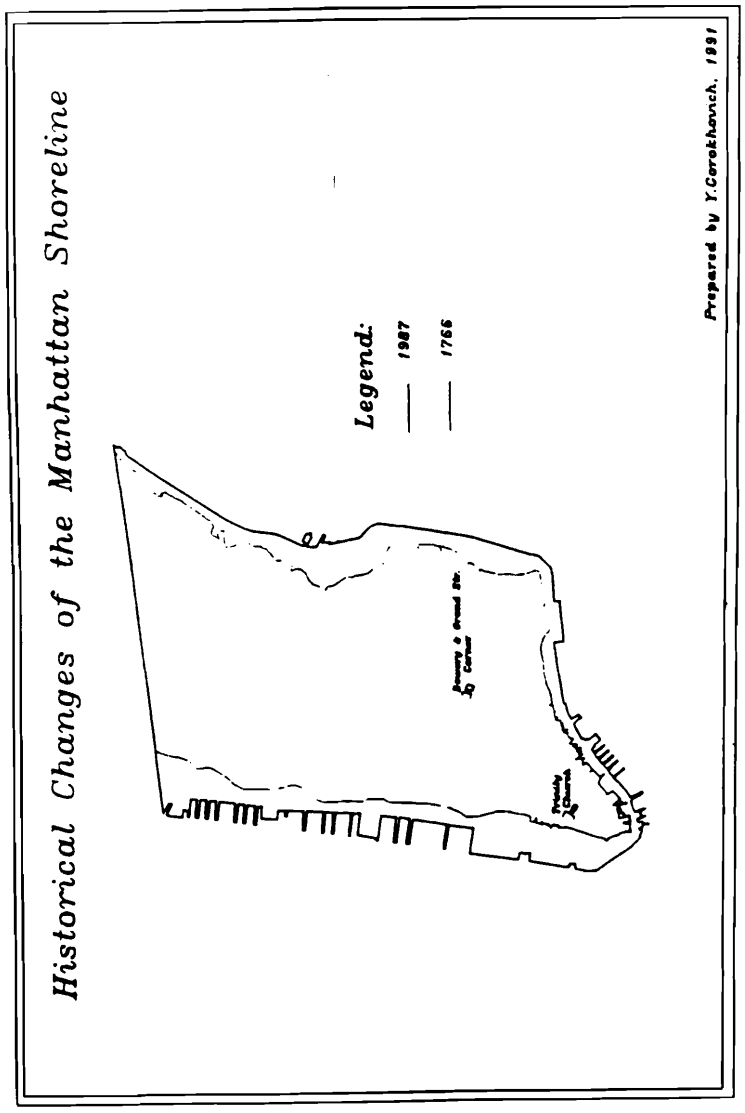

Fig.1. The map of the changes of the Lower Manhattan shoreline, as a result of city expanding.

Table III. Accuracy Parameters.

Map Scale	Year	Scale Limitations (Accuracy Limits for the Given Map Scale)	Mapping Standards (Accuracy Due to the Mapping Technique)	Total Accuracy
1:11258	1766	2.3 meters	5.63 meters	7.93 m
1:24000	1987	4.8 meters	12.0 meters	16.8 m
			Total:	24.73 m

There is also a way to define the accuracy of the historical maps comparison, using data about the accuracy of the measurements in past time. Surveyors in the 18 century used more or less the same techique as today.One of the main tools was theodolite invented in 1555 by Leonard Digges from London and modernized by Jonathan Sisson in about 1720, which added a telescope (Wilford J.N., 1981). So, Lieut. Ratzer in his surveys probably used already modernized instrument.

It is not easy to say what level of accuracy existed during his surveying, but according to Wilford J.N. at the turn of the eighteenth century French surveyors measured the altitude of Mont Canigou in the Eastern Pyrenees with an overestimate of less than 1% of the present figure, using triangulation method. Thus we can assume that Ratzer's survey was pretty accurate and the possible error may not exceed 1%. To check this assumption we measured the distance between the center of the fort in Governor's Island and St.Paul depicted on both modern and historic maps and got the difference of 20 meters, which is actually close to 1% error.

URBANIZATION TRENDS & SHORELINE CHANGES IN THE DOWNTOWN

One of the peculiar things about the Manhattan growth is that it was under the huge urban development pressure. From the book of Ann Buttenweiser "Manhattan Water-Bound" it is evident that the rapid growth of the business activity in New York stimulated most of the changes on the shoreline. Moreover Manhattan is an island and any attempt to build or throw away something will result in its expanding toward the river, due to the creation of landfills and dump sites, connected with these activities.

Before 19th century the main things which affected the shoreline changes were bulkheads, sunken ships, the excavated material from the building sites and roads, wastes, dumped right in the water. The first excavated sediments were dumped off shore during the digging of a Dutch-dug canal in 1664, which is Broad Street in Downtown Manhattan (Mackay A.D.,1987). This canal stretched until Wall Street and later was filled in. Because of the population growth during the 18th century people started buying even the parts of the river and filled these lots with a dirt. Thus, for example, the Water Street appeared. Also in 1789 the parts of the old fortress in the southern tip of Manhattan were torn down and this way the Battery and Broadway extended further to the water.

On the Lieut. Ratzer map there are depicted many swamps and wetlands around Manhattan which during the 18th century served as a landfill sites. These places for a century provided

people with a sufficient space for waste. On the shoreline at that time were built mostly piers and bulkheads (Buttenweiser A., 1987). Later old maritime constructions were filled with an excavated material and new piers were built instead. The remnants of this activity were discovered during the World Trade Center construction (Legget F.R., 1973).

At the beginning of the 19 century were so-called dumping boards were built on the shore. They represented ordinary piers or berths where the refuse and garbage from the city was loaded on barges and taken away to sea or to swampy areas. That time also the city's first landfill project was realized on Blackwell Island (now it is called Roosevelt Island). Not only swamps and wetlands were filled that time with dirt and refuge, but even water reservoirs, which existed in Manhattan in 18 and even 19 century. One of them - Collect Pond or "Der Kolek" (Rippling Water) was filled with the fresh water and even had fish. It was polluted, drained and finally filled in with the dirt and construction garbage in 1815.

The most dynamic advance of the Manhattan shoreline took place recently in 1966 - 71 with the construction of the World Trade Center, which cost 600 billion dollars. During this construction approximately 9.5 hectares of the shore was filled with the excavated rocks (Legget F.R., 1973). According to Mackay A.D. (1987), the area covered with the excavated deposits equaled 23.5 acres. This landfill (or waterfill) was designated to get rid of the huge volumes of sediments during construction. It was necessary to reach hard rocks - manhattan schist, in order to erect tall skyscrapers of the World Trade Center. Now manhatan schist bears the load of more than million tons of constructions and people, using the building. Since these hard rocks were on the depth of 21.3 m below the surface, the volumes of excavated sediments were considerable and apparently the most economical solution was to dump them off the shore of Lower Manhattan. This landfill is now occupied by Battery Park City. The average propagation of the city toward the river is approximate 200 meters.

The waterfront of Lower Manhattan is bound by a chain of piers, parks and has completely lost its ancient shape. Cliffs, small estuaries, rivers, fresh ponds and hills shown on Ratzer's map have disappeared. They have been replaced by modern buildings of Battery Park City. Above the ancient bottom of the East River, the FDR Drive, South Street Seaport and Jeannette Park were built. The recent coastal zone boundary of New York City is now an extremely complex combination of different natural and man-made features. According to the Waterfront Revitalization Program (1986) it includes the following geographical objects:

- Flood Plains;
- Steep Slopes;
- High Water Table/Shallow Soils;
- Significant Flora and Fauna;
- Scenic Vistas;
- Historic and Archeological Sites;
- Parks and Beaches;
- Tidal Wetlands;
- Freshwater Wetlands;
- Unique Flora and Fauna;
- Special Revitalization Areas:
  - Areas of Particular Waterfront Significance;
  - Erosion/Flood Hazard Areas;
  - Special Zoning Districts.

CONCLUSIONS

A comparison between old and new maps of Downtown Manhattan was done and established that the shoreline was advanced considerably toward the Hudson and East River. The minimum and maximum values are 30 and 200 meters respectively. As a result the area of Lower Manhattan increased 20% and the length of its shoreline increased 29%.

There were several driving forces which caused such unusual expanding of the city - maritime activity, construction and land trading. Maritime activity influenced constant renovation and rebuilding of the old piers and docks, which were eventually filled with the dirt and refuse. Construction activity created huge amount of excavated deposits, the cheapest way to get rid of them was to put them offshore, creating additional territory.

The main natural geographic feature which caused people to develop Manhattan in this way is that the territory of the city is confined on an island. If people on the land dump all excavated material and refuge from the city somewhere nearby, they can create only additional elevations, which spoil surrounding views and make transportation difficult. Islanders however have invaluable opportunities to get rid of their refuse by using the river bed or the shore. Engineering developments have allowed these artificial territories to be built upon. Another natural factor, which allowed the growth of the city in this way is a hard metamorphic basement of the island (manhattan schist) which is capable to bear huge loads and construction.

Since the first attempt of E.Viele to follow historical changes of the city environments there were many geological, engineering and geodetic surveys done together with the further development and growth of the city. Using the automated cartography tools, including creation of historical GIS database will help considerably in future city planning activities.

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