Using GIS to Examine Shoreline Change & Potential Sea Level Rise in Connecticut

1. Introduction:

Coastal managers and planners rely on the shoreline as a basis for many legal, policy, and management decisions. Staff from the Connecticut Department of Environmental Protection's Office of Long Island Sound Programs, (OLISP) with assistance from the University of Connecticut and the Long Island Sound Resource Center are using Geographic Information Systems (GIS) and a variety of data (historic maps, aerial photography, ground surveys, elevation data, etc.) to examine Connecticut's shoreline to better understand where it was, where it is, and where it might go. Some of the preliminary results of this effort are presented here.

2. T-Sheet Data Processing - Finding the Shoreline & Wetlands from the 19th century:

During 2004-2005 OLISP and the University of Connecticut Center for Geographic Information and Analysis processed and analyzed historic shoreline maps called Topographic Survey Sheets (T-Sheets.) This project created new GIS data layers that show shoreline and tidal wetland features as they existed in areas of coastal Connecticut during the 1880s. These data layers depict the following types of shoreline and wetland features:

- Shoreline
- Approximate shoreline
- Wetland shoreline
- Wetland upland boundaries
- Wetland interior boundaries
- Low Marsh Boundaries
- Jetties/breakwaters/groins
- Piers/ramps/docks
- Man-made shoreline

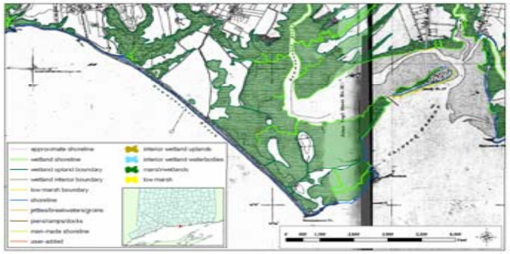
"Shoreline" on T-Sheets such as these reference Mean High Water (MHW). Although MHW is technically determined by averaging the height of the high water line over a 19 year lunar cycle, 19th century topographers approximated MHW by familiarizing themselves with the tidal conditions in a given area and noting the assorted physical characteristics of the beach.*

The figure to the right illustrates T-Sheets t1551a & t1551b and the resulting shoreline and wetland data for the area of Hammonasset in Madison and Clinton Connecticut circa 1884.

The tables below summarize shoreline lengths and wetland areas for all of Connecticut in the late 19th century.

Shoreline Proper (CT Only)	
Shoreline Type	*Length in Miles*
approximate shoreline	4.4
man-made shoreline	16.3
shoreline	362.7
wetland shoreline	484.7
Totals	***868.1***

Wetlands Features (CT Only)		
Wetland Polygons: All Types (CT Only)		
Wetland Type	*Acreage*	*Square Miles*
interior wetland uplands	166.5	0.3
interior wetland waterbodies	54.5	0.1
marsh/wetlands	14,168.4	22.1
low marsh	2,107.7	3.3
Totals	***16,497.1***	***25.8***

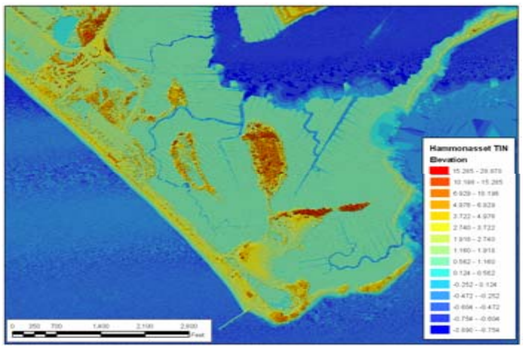


** For a more complete description of this and other shoreline indicators, the reader is directed to the following article: "Historical Shoreline Change: Error Analysis and Mapping Accuracy," Crowell, M., Leatherman, S., and Buckley, M. Journal of Coastal Research, Vol 7, No. 3, 1991, pp 839 852.*

3. LIDAR Data Processing - Finding the Shoreline from 2004:

LIDAR (**LI**ght **D**etection **A**nd **R**anging) data is remotely sensed data that can make detailed visualizations of the earth with great accuracy. LIDAR is collected by shooting a laser at the ground and using Global Positioning System (GPS) and inertial measurement technologies to record the data. The results are coordinates that define the spatial position and elevation of the earth where the laser hit. The data used here were provided by the University of Connecticut and the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center (CSC). The flight took place October 8, 2004 and covered about 116 mi^2 of the central Connecticut coast, illustrated in the graphic to the right.

These LIDAR data have an overall vertical accuracy of 11.2 cm, although it may be as good as 9.7 cm (~3.8 inches) in some areas, Hammonasset in particular.



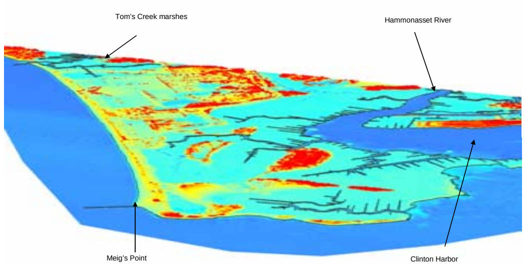
The graphic to the left represents a Triangulated Irregular Network (TIN) for the southern part of Hammonasset. A TIN is one of several ways to model elevation data, and is a surface derived from a set of points that are processed by a mathematical algorithm that creates tiny, irregularly shaped triangles to fill in the gaps between the points. The result is a 3-D representation of the terrain.

This TIN was created by first taking the raw LIDAR data and using Environmental Systems Research Institute (ESRI) GIS software to convert them to points. These point files were then further processed by ESRI 3-D Analyst software to create the TIN.

The color scheme depicts the elevation values in meters. Reds represent the higher areas and blues represent the lower areas. This shows that most of the land area is quite low, and may be especially susceptible to changes in sea level over time.

In addition to providing a different way of viewing the area, the TIN was also used to create an approximation of MHW for 2004 that will allow for comparison with other shorelines.

By using data from nearby NOAA tidal benchmarks, the elevation of MHW for this area was calculated to be approximately 0.628 m. Knowing this value, GIS processing techniques were used to interpolate a 2-D contour line from the TIN giving the location of MHW.



This graphic displays an oblique 3-D perspective of the Hammonasset area using a Digital Elevation Model (DEM) to display the terrain. A DEM is a another type of model that presents a surface as a regularly spaced grid of squares, each with its own elevation value.

The 2004 MHW shoreline (shown in dark gray) created from the TIN is draped over the DEM. As in the above graphic, the color scheme also displays elevation values in meters with reds representing higher areas and blues representing low lying areas.

This illustrates one of the many benefits of working with GIS, which is the ability to integrate and display different types data. Here a 2-D line is shown with a 3-D surface, both of which can be adjusted to display the viewing perspective in ways that more traditional methods (such as maps or orthophotography) do not permit.

4. Shoreline Change Analysis 1884 to 2004 - Pulling It All Together:

In addition to the 1884s T-Sheet and 2004 LIDAR shorelines, OLISP used two other data sources for the Hammonasset Beach shoreline change analysis: T-Sheet shoreline from 1933, and a 2002 GPS site survey of MHW. Thus, OLISP has 4 sources of MHW shoreline data spanning 120 years. These data are displayed to the right over low-tide coordinated digital color infrared coastal orthophotography taken during the summer of 2005.

Before beginning, sources of error were identified and quantified. The matrix to the right shows the errors and overall accuracy for the shoreline data used.

Measurement Errors (m)	Time Period: 1880s	1920s-1940s	2002	2004
Error in location of planetable relative to true position	4.00	4.00	0.00	0.00
Error in location of plotted rodded points relative to planetable	1.00	1.00	0.00	0.00
Error in field interpreation of HWL at rodded points	4.00	4.00	0.00	0.00
Inaccuracies in location of control points	4.00	4.00	0.00	0.00
Error in digitizing inner to outer margin of plotted lines	4.00	4.00	0.00	0.00
Digitizer error	2.50	2.50	0.00	0.00
Operator error	2.50	2.50	0.00	0.00
GPS position error	0.00	0.00	2.19	0.00
LIDAR Shoreline Offset Error	0.00	0.00	0.00	2.29
LIDAR PositionError	0.00	0.00	0.00	0.50
LIDAR Shoreline Interpolation Error	0.00	0.00	0.00	0.00
Square root of Sum of Squares (Accuracy) (m)	***8.80***	***8.80***	***2.19***	***2.34***

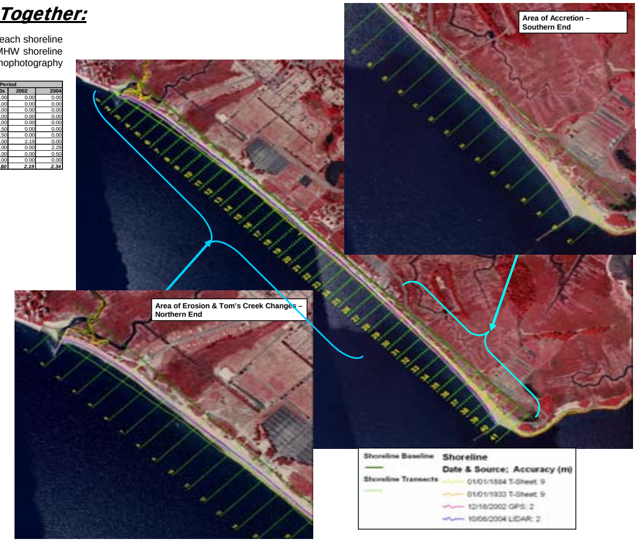
The analysis was performed in GIS using the Digital Shoreline Analysis System (DSAS) 3.0 for ESRI's ArcGIS 9.0. Transects spaced 250 feet apart perpendicular to an on-shore baseline were created to generate the results shown in the table to the right. These included:

- **End Point Rate:** relating the difference between the oldest and newest shoreline to the time elapsed;
- **Linear Regression Rate:** fitting a least squares regression line to all shorelines at each transect; and
- **Weighted Linear Regression Rate:** using the accuracy values from the error calculations as a weighting factor in the regression equations

Both the spatial and tabular data show Hammonasset Beach has changed considerably over the last 120 years. While the statistics differ slightly for each method, we can note the following:

- The maximum erosion rates (shown in red) occur around transects 3 through 6, while transects 38 and 39 show the greatest accretion rates (shown in black.)
- The rates of change steadily decrease from the maximum erosion rate to a more rapid increase in accretion rates from the northern to the southern end of the beach. Generally speaking, the northern 2/3 of the beach (transects 2 to ~27 through 30) has trended toward erosion, while the southern 1/3 (transects ~31 through 41) has trended toward accretion.
- The net effect can be thought of as a clockwise rotation of the beach around a stationary point in the vicinity of transects 28-29.
- The inlet of Tom's Creek at the northern end of the beach has radically altered its configuration from the late 19th/early 20th century to its present state in 2005.

Transect ID	End Point Rate (ft/yr)	Linear Regression Rate (ft/yr)	Weighted Linear Regression Rate (ft/yr)
1	0.000	0.000	0.000
2	(0.623)	(0.656)	(0.558)
3	(0.919)	(0.919)	(0.820)
4	(1.017)	(0.984)	(0.919)
5	(1.017)	(1.017)	(0.951)
6	(0.951)	(0.886)	(0.853)
7	(0.853)	(0.820)	(0.787)
8	(0.689)	(0.754)	(0.754)
9	(0.656)	(0.722)	(0.689)
10	(0.656)	(0.722)	(0.689)
11	(0.623)	(0.656)	(0.656)
12	(0.558)	(0.623)	(0.623)
13	(0.525)	(0.558)	(0.590)
14	(0.459)	(0.492)	(0.525)
15	(0.525)	(0.525)	(0.525)
16	(0.623)	(0.656)	(0.623)
17	(0.689)	(0.689)	(0.689)
18	(0.590)	(0.623)	(0.623)
19	(0.426)	(0.525)	(0.558)
20	(0.394)	(0.525)	(0.525)
21	(0.394)	(0.558)	(0.558)
22	(0.459)	(0.558)	(0.590)
23	(0.361)	(0.459)	(0.492)
24	(0.328)	(0.328)	(0.361)
25	(0.295)	(0.361)	(0.394)
26	(0.131)	(0.230)	(0.262)
27	(0.066)	(0.164)	(0.164)
28	0.066	(0.164)	(0.164)
29	0.098	(0.098)	(0.131)
30	0.066	0.000	(0.066)
31	0.328	0.230	0.164
32	0.426	0.230	0.197
33	0.558	0.328	0.262
34	0.722	0.459	0.394
35	0.689	0.492	0.459
36	0.722	0.656	0.623
37	0.853	0.754	0.754
38	1.017	0.984	1.017
39	1.345	1.411	1.476
40	0.426	0.426	0.000
41	0.262	0.262	0.000



It is important to remember that these results illustrate trends over time, so even though a statistic may indicate erosion, the shoreline itself may have eroded and/or accreted significantly. Additionally, changes may be indicative of both natural and/or man-made effects. For example, there was a severe hurricane in 1938, and in 1955 the U.S. Army Corps of Engineers constructed two 300 ft training walls at Tom's Creek, the 800 ft long groin at the southern tip of the beach, and added approximately 380,000 cubic yards of sand to the beach.

5. Visualizing Sea Level Rise from 2004 to 2080 - A Potential Look Ahead:

In addition to showing the past and present, GIS data and technology available to Connecticut's coastal managers can also offer a glimpse into the future. The graphics below attempt illustrate what sea level rise means by showing where the shoreline might end up as a result. The data used to estimate future MHW shorelines were derived from Gornitz, et. al., "Bracing for Climate Change in the Constitution State: What Connecticut Could Face," Environmental Defense, 2004.

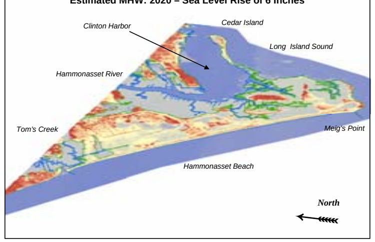
Based on data generated by the Goddard Institute for Space Studies (GISS) A2-CTL climate model, sea levels in Connecticut are expected to rise above the 1961-1990 mean by 4 to 8 inches by 2020; 7 to 17 inches by 2050; and 9 to 35 inches by 2080. While these values tend to be greater than more conservative metrics based solely on historic sea level rise (which do not specifically address certain climatological or localized human-use impacts) they may still underestimate the effects due to recent forecasts on global ice-melt. As with any model, these results are only as good as the data and assumptions used. Nevertheless, the values can be used to illustrate potential sea level rise with some simple GIS analysis.

Sea Level Rise projections for CT based on GISS A2-CTL (rise above 1961-1990 mean sea level (MSL))				
Source: http://pubs.giss.nasa.gov/docs/2004/2004_GornitzHale.pdf				
	Estimates			
Year	*Low (inches)*	*High (inches)*	*Average (inches)*	*Average (meters)*
2020	4	8	6	0.152
2050	7	17	12	0.304
2080	9	35	22	0.558
Current MHW Elevation	***Projected Elevation of MHW (in meters above NAVD88)***			
2004		**2020**	**2050**	**2080**
0.627		0.779	0.931	1.185
(assuming current difference between MSL and MHW is constant over time)				

To display how Hammonasset may change over the next 76 years, the high and low sea level rise estimates for each year were averaged for 2020, 2050, and 2080. MHW elevations for these years were derived by increasing the 2004 MHW by the calculated average. These values were then used to interpolate the shoreline contours from the TIN. The graphics below show the predicted shoreline location for each year draped over a DEM. For comparison, the 2004 LIDAR shoreline is included as a reference in each graphic.

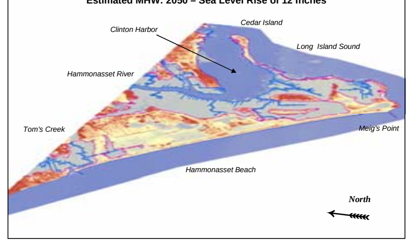
In general, the trends show a loss of tidal wetlands behind (east of) Hammonasset Beach and a fracturing of the barrier that separates Clinton Harbor from Long Island Sound. These raise questions concerning the re-establishment of the wetlands in the present upland area, and impacts such as increased tidal action resulting from the fracturing of the land barrier.

Estimated MHW: 2020 – Sea Level Rise of 6 Inches



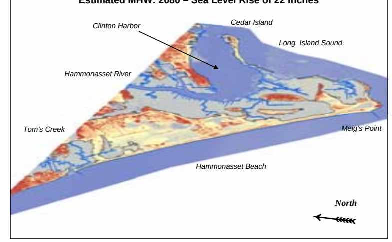
The blue shoreline represents MHW in 2004. The green indicates where MHW is predicted to be in 2020. Note that the Tom's Creek marsh and a large part of the marshes near the Hammonasset River are largely inundated.

Estimated MHW: 2050 – Sea Level Rise of 12 Inches



The blue shoreline represents MHW in 2004. The pink indicates where MHW is predicted to be in 2050. Note the the marshes between Meig's Point and Cedar Island are now inundated, and the southern shoreline behind (east) of Meig's Point is beginning to fracture into barrier islands.

Estimated MHW: 2080 – Sea Level Rise of 22 Inches



The blue shoreline represents MHW in 2004. The grey indicates where MHW is predicted to be in 2080. Note the southern shoreline behind (east) of Meig's Point is further fractured into smaller barrier islands and the area of inundation to the south of Tom's Creek has expanded.

6. Summary:

Identifying and analyzing shoreline is an important part of coastal management and planning activities. The State of Connecticut is fortunate to have several highly useful sources of shoreline data such as historic maps, site specific GPS ground surveys, LIDAR elevation data, and assorted aerial photography.

In conjunction with these data, the analytic capabilities provided by tools such as GIS are allowing Connecticut to explore coastal management issues in never before ways. Preliminary results of analyses such as these are encouraging as they provide valuable insights on coastal processes such as shoreline erosion, accretion, and the potential effects of sea level rise.

7. Credits:

- *T-sheet Data Processing: US National Geodetic Survey provided scanned images of the original T-Sheets. Martyn Smith & Dr. Robert Cromley (UCONN Center for Geographic Information and Analysis) completed the T-Sheet georeferencing and line vectorization. Mary DiGiacomo-Cohen (Long Island Sound Resource Center) provided data QA/QC reviews and feature attribution. Kevin O'Brien (OLISP) provided data QA/QC, feature attribution, edgematching, and geodatabase feature-class creation and validation. Ron Rozsa (OLISP) was project coordinator.*
- *2004 LIDAR data provided via a grant from the NOAA Coastal Services Center as part of a collaborative project with the University of Connecticut, Wesleyan University and the Connecticut Department of Environmental Protection. Data collection and processing was performed by EarthData International.*
- *DSAS software citation: Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., and Miller, T.L., Digital Shoreline Analysis System (DSAS) version 3.0; An ArcGIS© extension for calculating shoreline change: U.S. Geological Survey Open-File Report 2005-1304.*
- *2004 LIDAR processing & shoreline analysis by Kevin O'Brien, OLISP.*
- *2005 Connecticut Coastal Color Infrared Digital Orthophotography was compiled by James W. Sewall Co. and published by the State of Connecticut, Department of Environmental Protection.*

Long Island Sound Resource Center