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MEMORANDUM

Date: May 16,2016
> **To:**   Mr. Art Leventis
> **From:** Lee Weishar, Ph.D.; PWS
> **Re:**   Task 5A Shoreline Change and Memorandum

Introduction

A computer-based shoreline mapping methodology, within a Geographic Information System (GIS) framework, was used to compile and analyze changes in historical shoreline position in the vicinity of Coughlin Park in the Town of Winthrop, Massachusetts. The purpose of this task was to quantify changes in shoreline and coastal bank positions using the most accurate data sources and compilation procedures available, and to evaluate long-term rates of shoreline and bank change. Because this information is critical to most coastal zone management decisions, emphasis has been placed on data accuracy and clear presentation of results. The following section provides a detailed description of the methods and data sources used in this study.

Data Sources

Shoreline change can be determined from accurately overlying historical vertical aerial photography with recent digital orthoimagery. The shoreline, as defined by the high water line, can then be extracted from each of the photos; the high water line is evidenced by a change in gray tone on black and white and color aerial photographs, and the position of this wetted boundary is identifiable on most air photos (Stafford and Langfelder, 1971).

Given the timeframe of interest, this study used only digital orthoimagery (DOQQs) to evaluate historical changes in shoreline (Table 1). There was shoreline data from the Office of Coastal Zone Management (CZM) starting as early as 1839, but only years present in this analysis were used. We started with 1995 to avoid any misinterpretation of shoreline change rates due to the Boston Harbor dredging activities that artificially extended the land on which Coughlin Park is located. Since the primary focus of this project is to mitigate erosion along the western shoreline of Coughlin Park, the more recent data was more appropriate and would provide a more accurate representation of the conditions that exist at the park.

Shoreline position information was obtained from a series of large-scale digital aerial photographs for the following time periods: 1995, 2001, 2005, 2008, and 2013 (Table 1). Photographs from these years were selected based on availability of orthoimagery from the MassGIS data base. An additional year of aerial imagery was also obtained from Google Earth for 2015. The time series

of photographs selected for this study represents the highest quality and most reasonable spaced photographic data available.

Table 1.   Summary of Shoreline Source Data Characteristics for Study Area

Date	Data Source	Comments
1995	MassGIS	1.6 ft/pixel resolution
2001	MassGIS	1.6 ft/pixel resolution
2005	MassGIS	1.6 ft/pixel resolution
2008	MassGIS	1 ft/pixel resolution
2013	MassGIS	1 ft/pixel resolution
2015	Google Earth	1 ft/pixel resolution

Data Compilation and Analysis Methods
The aerial photographs shown in Table 1 provide a synoptic view of the Coughlin Park coastline with a temporal coverage ranging from 2 to 6 years. Orthoimagery from 1995-2013 were retrieved with completed geo-referenced spatial information. The georeferencing tool available within ESRI's ArcMap was used to transform, resample and rectify the 2015 image retrieved from Google Earth against the 2013 MassGIS orthoimagery.

The next analysis step involved identification of a reference shoreline for each of the aerial- and orthophoto years. Air photo interpretation along a shoreline is an art based on science, supported by familiarity with the area and its processes, and includes a certain amount of error and interpretative subjectivity. Delineation of the reference shoreline is the most important and most subjective part of shoreline change analysis, particularly in areas where relief distortion can compound problems. The horizontal position of the high water shoreline as recognized on the beach and on photography was determined using a hierarchy of criteria dependent on morphologic features present on the subaerial beach. The primary criterion was a well-marked limit of uprush by waves associated with the most recent high tide. This generally was recognized as a beach scarp or debris line, marking the upper limit of the foreshore. If a scarp could not be identified, a debris line usually was identified. Reference shorelines for each of the photographs were captured through heads-up digitizing, and stored digitally in GIS.

A second reference line representing the top of bank at the subject property (the west side of Coughlin Park) was also captured through heads-up digitizing. The top of bank is easily visible on most aerial photographs. This additional data was useful in comparing with the high water shoreline to verify temporal changes in bank erosion. For coastal management purposes, the erosion rate of the top of bank also represents the factor most important in determining short-term risk to the park infrastructure.

Once the shoreline and bank data were compiled spatial and temporal changes in the data were quantified. This was accomplished by identifying a series of shore normal transects along the coastline where discrete measurements of shoreline and top of the coastal bank change could be made and could be computed to calculate rates of change. A total of 50 shore normal transects were established at 25 foot evenly-spaced intervals along the shoreline which covered approximately a quarter mile (Figure 1A). The area directly west of the tennis and basketball courts is the immediate area of concern and incorporates the area that was used for the shoreline change

analysis (Transects 29-47). This area west of the tennis courts was of high concern because of the client's observations of rapid erosion of this area. For the rate of bank change analysis, a total of 19 shore normal transects were established at 25 foot evenly-spaced intervals at the area of concern (Figure 1B) which runs approximately 455 feet.
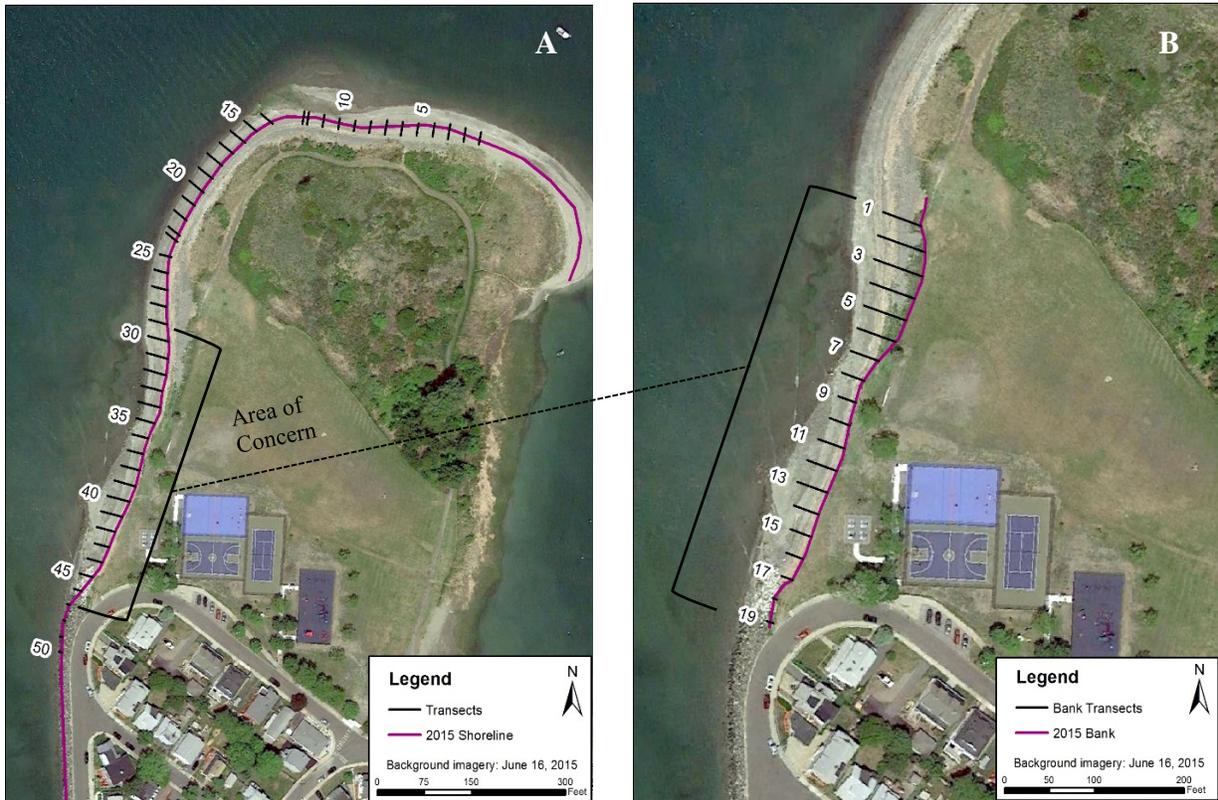

Figure 1.   Area in of Coughlin Park, Town of Winthrop, MA selected for analysis of historical shoreline change (A). A small area pertinent to the study area was selected for analysis of historical shoreline change. (B). Evenly spaced transects represent points where bank change statistics were computed.

At each transect, distances of shoreline movement were calculated, and annual rates of shoreline change were determined using the various time intervals between shorelines. A matrix of long-term and incremental shoreline change rates was developed using all of the available shoreline data. The rates of shoreline change were calculated using two different methods. The shoreline change rates were calculated using the end point method, which uses the distance over which the shoreline position changed (measured along the transect), divided by the number of years over which the change occurred. This method was used to compare successive shoreline dates. Shoreline change rates were also calculated using linear regression. The linear regression method was used to determine the rates of change for the entire data set (1995 to 2015) as well as two shorter time periods, 1995 to 2005, and 2005 to 2015. In this method, an average rate of change is based on a best-fit line to a series of points representing shoreline position over a period of time. The linear regression method is most applicable when looking at long-term averages in the rate of shoreline change, and is the method most often used for planning purposes and for management decisions.

Synthesis of Changes in Shorelines and Top of Bank
To evaluate the trends in shoreline change at Coughlin Park, a variety of graphical representations have been developed. Three time periods were chosen to address specific questions concerning the shoreline change. The longer term shoreline change period (1995-2015) was chosen to show the rate of change over the entire period of data available. The longer term data provides the most reliable quantification of the shoreline response because it smooths out the effects of large erosion and accretion events. The shorter time periods analyzed reflect a greater influence of either a large accretion or erosion event may have on the shoreline change rate and are instructive when determining the effect that large storm events have on the shoreline. To analyze whether recent rates of change have been different or similar to longer range trends, two additional periods were also selected (1995 to 2005, and 2005 to 2015). Figures 2, 3 and 4 show the historical shoreline positions from 1995 to 2015, 1995 to 2005, and 2005 to 2015. Graphs showing rates of shoreline change, calculated using both linear regression and end point methods, are displayed along with the shoreline position data in Figures 2, 3, and 4. Thus, trends of shoreline change at any given point along the coast can be visualized and quantified by comparing the three graphs shown in Figures 2, 3, and 4.

For the bank analysis, Figure 5 shows the historical bank positions from 1995 to 2015, and Figures 6 and 7 show the bank positions between two shorter time periods, 1995 to 2005 and 2005 to 2015. The graph showing rates of bank change, calculated using both linear regression and end point methods are displayed next to the bank position data in Figures 5, 6, and 7.

Shoreline Change Results
The data sets in Figures 2 - 4 shows the important longer term trends in shoreline change for this section of coast of Coughlin Park. The rates presented on the map itself are linear regression results in ft/yr, while both linear regression and end point results are shown on the graphs beside each map. Longer term accretion rates between 1995 and 2015 are highest (+0.8 ft/yr) at Transect 5 (approximately 620 feet north of the tennis courts), while erosion rates were highest (-1.7ft/yr) at Transects 32-34 (approximately 220 feet north-west of the tennis courts). Longer term trends at the area of concern (Transects 29 through 47) show that the shoreline was eroding at an average of -1.2 ft/yr (-0.4 ft/yr using endpoint analysis).

To see whether recent shoreline change rates have followed longer term trends, shoreline change rates were also analyzed for 1995 to 2005 and 2005 to 2015. Between 1995 and 2005, the entire shoreline was accreting at an average of 0.1 ft/yr differing from the longer term average erosion rate of -0.3 ft/yr as noted in Table 2[1]. An interesting observation was seen between transects 13 to 26, where the shorter term trends (1995-2005) showed average accretion rates of 1.2 ft/yr which differs from long term erosion rates of -0.2 ft/yr for the same transects (13-26) (Figure 1A) indicating a transition from accretion to erosion. Erosion rates between 1995 and 2005 were highest (-1.8 ft/yr) at Transects 33 and 41. The observed highest erosion rates at Transect 41 was different from the longer term rates where highest erosion rates were located between Transects 32 and 34. Additionally, for the 1995 to 2005 time frame, the highest accretion rates (+1.5 ft/yr) were seen at Transect 16 (approximately 600 feet north of the tennis courts); again, this was a different area where highest accretion rates were observed in the longer term analysis (1995 to 2015). In fact, the long-term trends at Transect 16 showed erosion of -0.4 ft/yr.

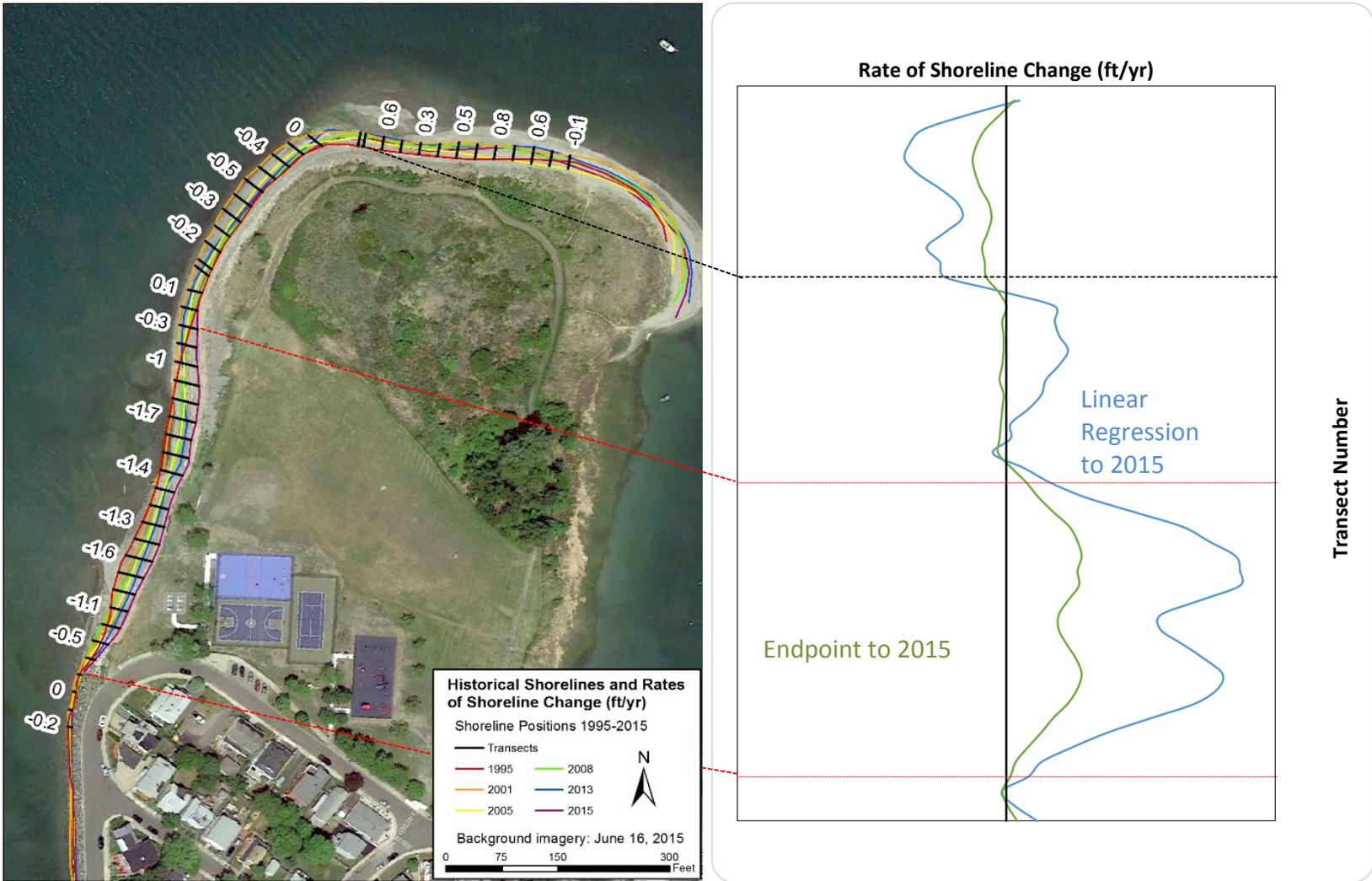[1] The erosion and accretion rates were averaged across all transects.

Figure 2. Historical shoreline (high water line) positions from 1995 to 2015 and long-term rates of shoreline change computed using linear regression and end point methods. Red lines denote area of concern.
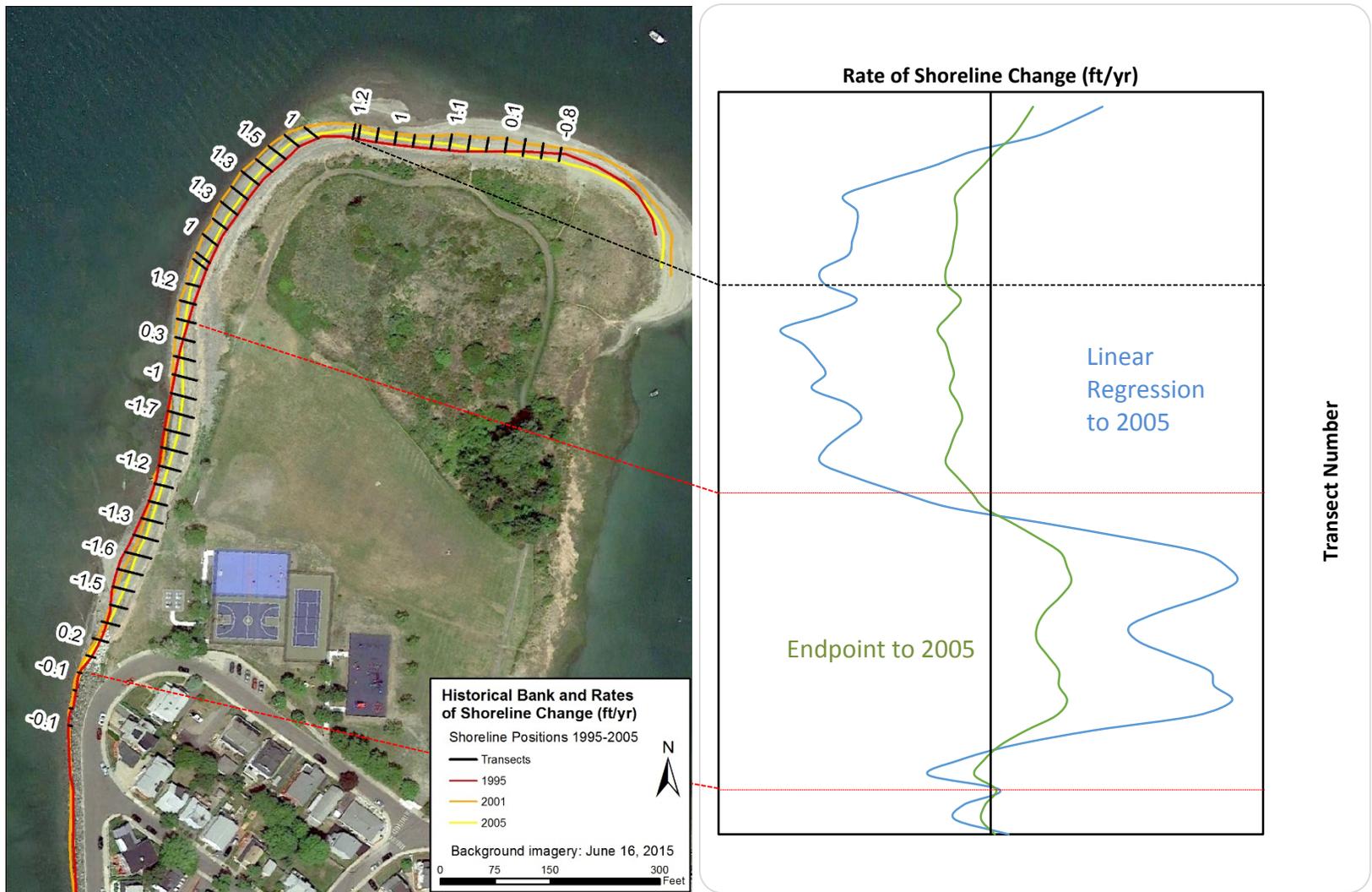
Figure 3. Historical shoreline (high water line) positions from 1995 to 2005 and shorter term rates of shoreline change computed using linear regression and end point methods. Red lines denote the area of concern.
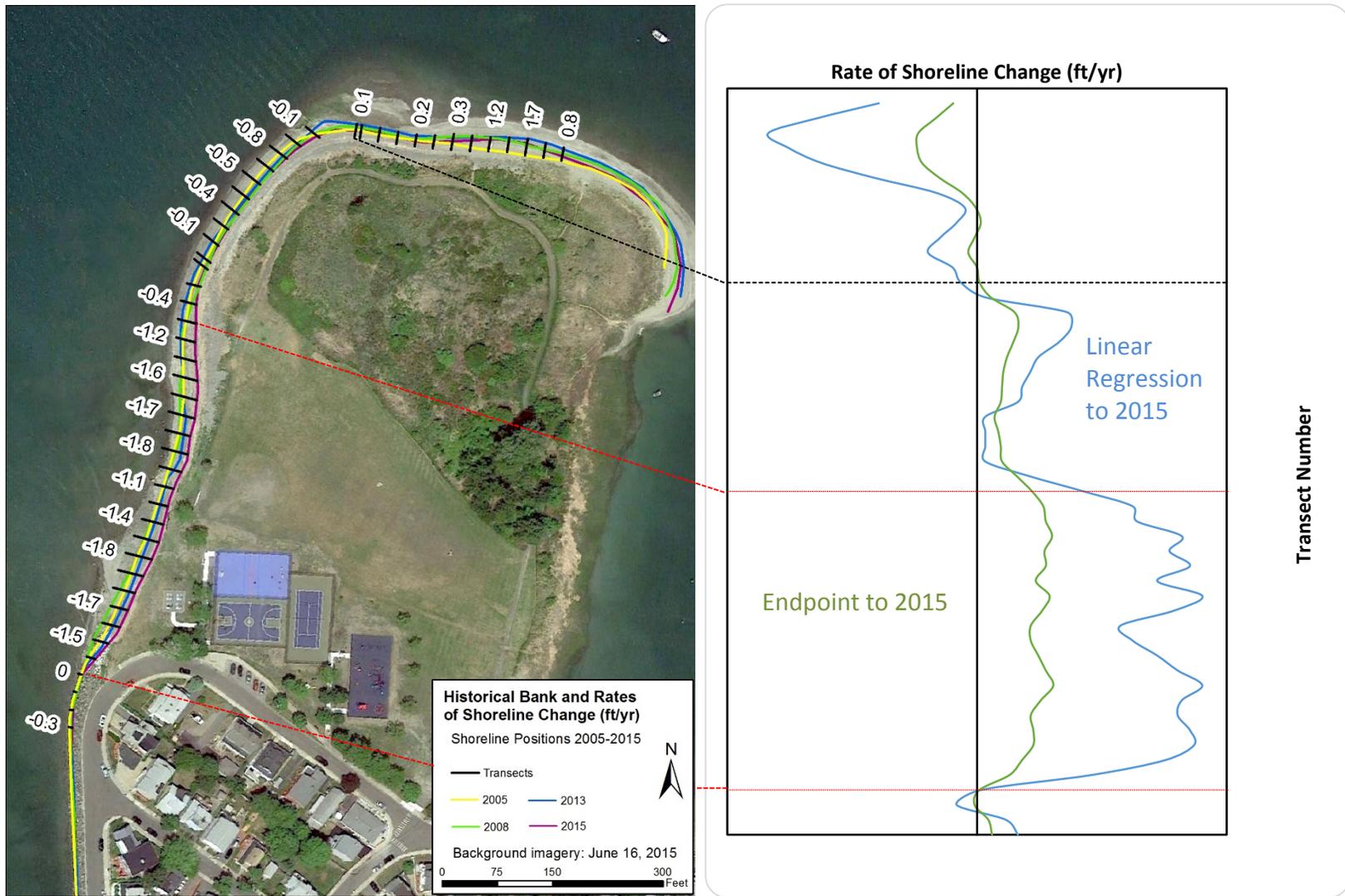
Figure 4. Historical shoreline (high water line) positions from 2005 to 2015 and shorter term rates of shoreline change computed using linear regression and end point methods. Red lines denote area of concern.

Table 2. Average shoreline accretion and erosion rates (ft/yr) (Linear Regression)

Transects	1995-2015	1995-2005	2005-2015
1 to 12	0.5	0.5	0.7
13 to 26	-0.2	1.2	-0.3
27-47	-1.2	-1.0	-1.4
All	-0.3	0.1	-0.5

Shorter and longer term erosion rates for the park shoreline (Transects 27-47) were -1.0 ft/yr and -1.2 ft/yr respectively (Table 2), indicating the erosion rates at the area of concern have been steadily increasing. On the contrary, the area in the northern section of the shoreline (Transects 1-12) showed the same accretion rate of 0.5 ft/yr for both the longer term and shorter term analysis (1995-2005), indicating this area was stable and accreting sand.

Evaluating the recent shoreline change rates from 2005 and 2015, however, showed a transition to a more erosional phase throughout almost the entire study area with the exception of the most northern section of the shoreline (Transects 1 to 12). Between 2005 and 2015, the area between Transects 1 and 12 showed an accretion rate of 0.7 ft/yr (Table 2). Compared to the longer term accretion rate of 0.5 ft/yr for Transects 1 to 12, this area, in recent years, has been accreting sand at a faster rate. In the recent shorter term analysis (2005-2015), the northwest section of the shoreline (Transects 13 to 26) was eroding at a rate of -0.3 ft/yr which differed from the accretion phase this area was enduring during the 1995 to 2005 time period, indicating a change from accretion to erosion from the early to recent time period. This erosion rate of -0.3ft/yr for the 2005-2015 time period was similar to the long-term trend of -0.2 ft/yr for the same area (Transects 13-26). The area of concern (Transects 27-47) had an erosion rate of -1.4 ft/yr for the time period between 2005 and 2015, which was greater than the longer term average of -1.2 ft/yr and the 1995-2005 time period average of -1.0 ft/yr, indicating that in recent years, erosion of the area of concern has increased.

End point rates, for both the shorter and longer term analyses, were generally lower in magnitude compared to the linear regression rates throughout the site (Figure 2, 3, and 4). This indicated that larger morphological changes were occurring between the endpoint year limits (1995 and 2015).

Long-Term Top of Bank Changes
As discussed earlier in this section, in addition to the shoreline change analysis, we also evaluated the rate of change of the top of the bank in the area of concern (west side of Coughlin Park). The locations of the top of bank as it was delineated from each of the data sources and rate of change data are pictured in Figure 5 -7. Like the shoreline change analysis, the rate of bank change was quantified along shore perpendicular transects. Figure 5 shows the linear regression rates of change of the top of the bank from 1995 to 2015 for the 19 transects at the area of concern. The longer term trend for the entire length of the bank showed the area eroding at an average rate of -1.5 ft/yr (-0.5 ft/y using end point analysis).
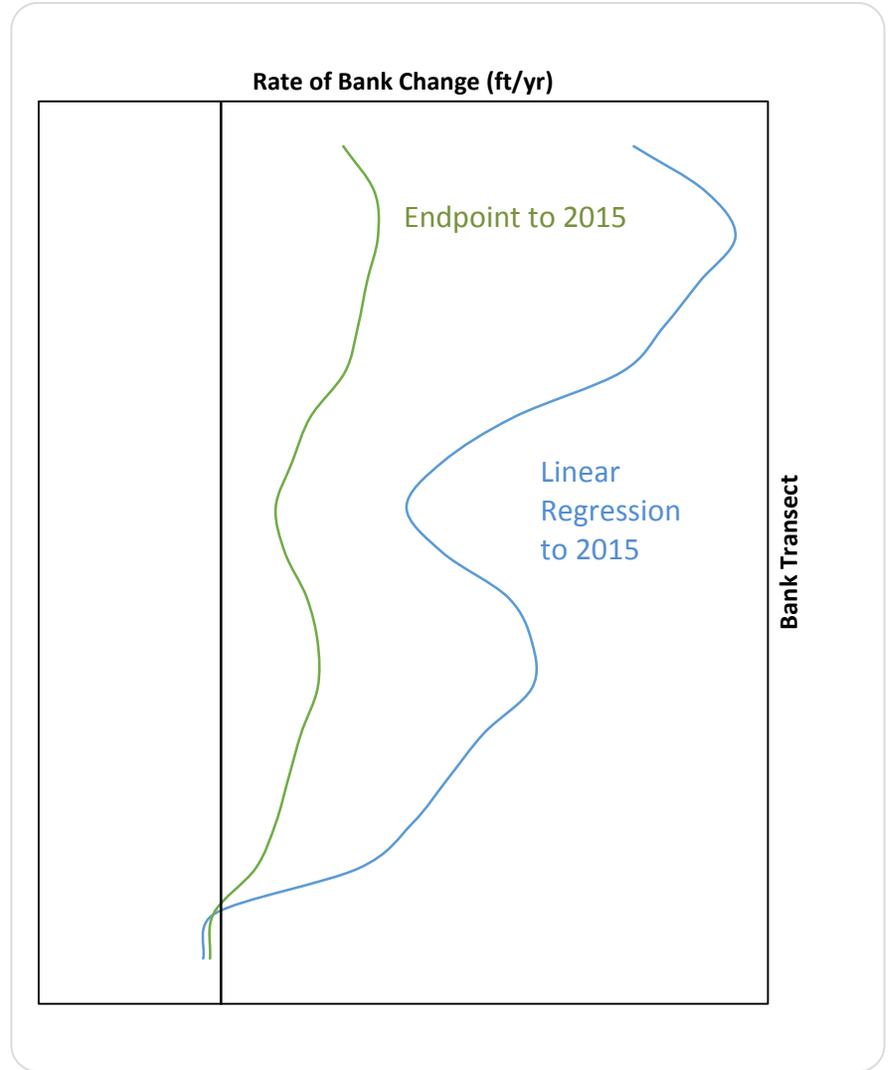
Figure 5. Historical bank positions from 1995 to 2015 and long-term rates of bank change computed using linear regression and end point methods.
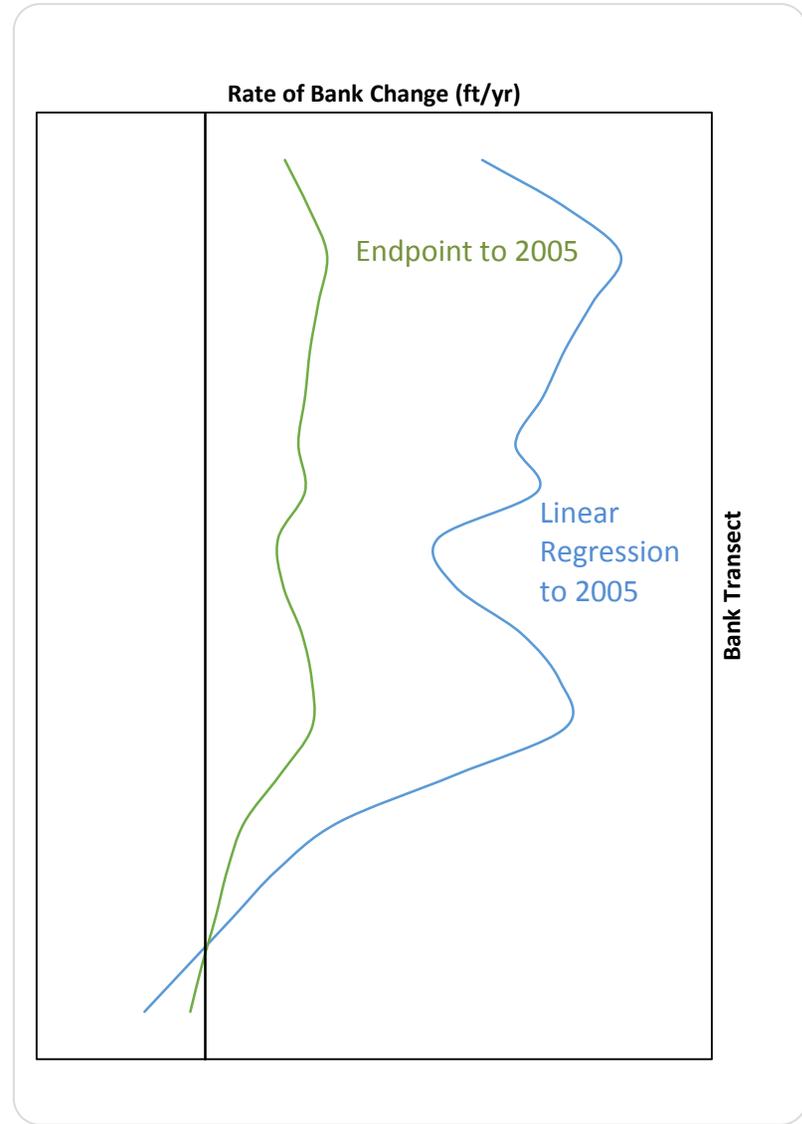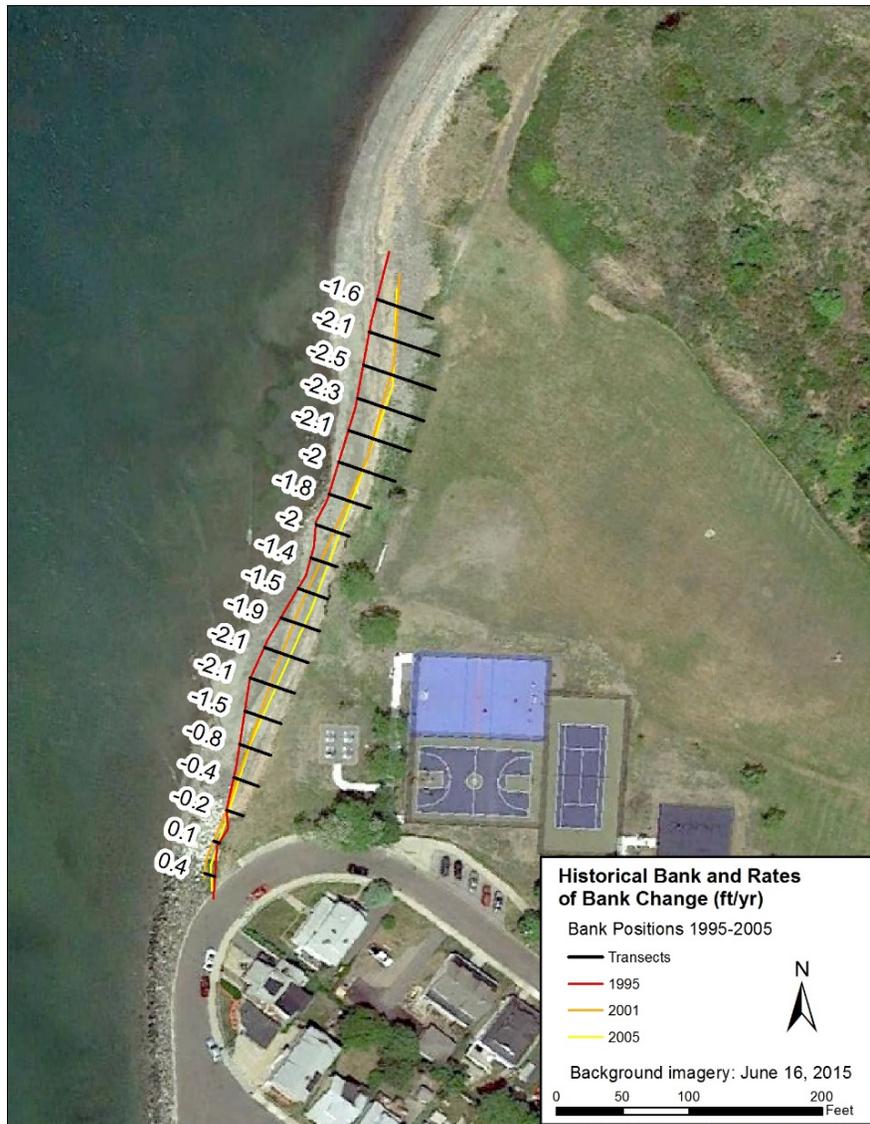
Figure 6. Historical bank positions from 1995 to 2005 and short-term rates of bank change computed using linear regression and end point methods.
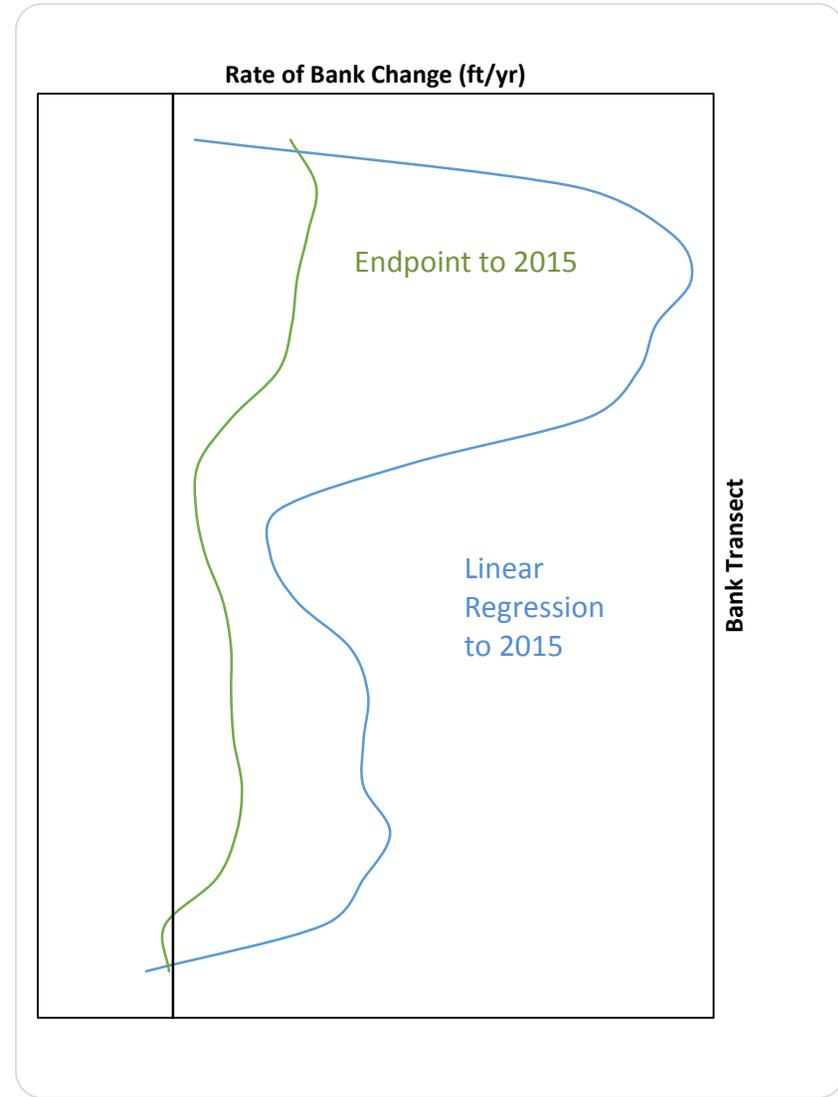
Figure 7. Historical bank positions from 2005 to 2015 and short-term rates of bank change computed using linear regression and end point methods.

Again, it was important to understand whether the shorter term trends followed the longer term trends of bank erosion. The locations of the top of bank as it was delineated from each of the data sources and rate of change data for the two shorter time periods (1995-2005 and 2005-2015) are shown in Figures 6 and 7. The average bank erosion rates for the time periods 1995-2005 and 2005-2015, measured -1.5 ft/yr and -1.8 ft/yr, (-0.4 ft/yr and -0.5 ft/yr using endpoint analysis) respectively. Similar, to the shoreline change analysis, the most recent time period (2005-2015) had a rate of bank change slightly higher than both the earlier time period (1995-2005) and longer term average, indicating an acceleration of bank erosion in recent years.

For both the shorter and longer term analyses, the end point rates were generally lower in magnitude compared to the linear regression. This indicates there were large changes occurring between the first and last years of the analysis time period (1995 and 2015).

Conclusions
Given the rates of shoreline and bank change resulting from these analyses, general conclusions about the future state of the area of concern (Transects 27-47; Figure 1A) can be made. The recent 2015 shoreline is approximately 42 feet from the picnic table area, which is directly adjacent to the basketball courts. Assuming the given rates of shoreline erosion continue (-0.4 and -1.2 ft/yr; endpoint-linear regression), the picnic area to the left of the basketball courts could be negatively impacted sometime between 35 to 105 years from present day. Currently (2015), the top of the bank is 32 feet away from the picnic area. If bank erosion rates continue as they are (-0.5 and -1.5 ft/yr; endpoint-linear regression), it would be expected that in 21-64 years the picnic area could be negatively impacted. Based on the analysis, the top of bank is eroding faster than the shoreline and expected negative impacts will occur sooner compared to impacts to the shoreline.

However, it should be pointed out that the area between the top of the coastal bank and the tennis courts is the location of a scenic path that is heavily used by residents to walk their dogs, play with their children, and/or to just enjoy the outdoors. The path and the ability to use the path for recreational purposes is and extremely important use of the Park for the Town. Therefore, the current erosion of the top of the coastal bank will begin to adversely affect the path in the next 2 to 4 years.

References
Stafford, D.G. and J. Langfelder. 1971. Air photo survey of coastal erosion. Photogramm. Eng., 37: 565-575.