Analysis of Shoreline Change in Connecticut

100+ Years of Erosion and Accretion:

Methodology and Summary Results

A cooperative effort between the Connecticut Department of Energy & Environmental Protection (DEEP), the Connecticut Sea Grant (CT Sea Grant) and the University of Connecticut Center for Land Use Education and Research (UCONN-CLEAR)

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Project Goal:

To conduct a Geographic Information System (GIS) time series analysis using maps of the Connecticut shoreline from several different time periods between 1880 and 2006 (100+ years) so as to provide a high-level, quantifiable data set describing CT shoreline trends from both a statewide, regional, and a localized perspective.

Disclaimers & Caveats:

Shoreline change data presented here may differ from those found in other sources; any differences do not necessarily indicate other data sources are inaccurate.

When considering other sources of shoreline change, discrepancies are to be expected considering the many possible ways of determining shoreline positions and rates of change, and the inherent uncertainty in calculating these rates.

The results from this analysis represent shoreline movement under past conditions and are not intended for use in predicting future shoreline positions or future rates of shoreline change.

The materials presented ***can*** be reasonably used to:

- *identify areas that have historically exhibited erosion or accretion trends;*
- *identify areas that have shown a "trend reversal" from the long term to the short term (either changing from erosion to accretion or vice-versa);*
- *generally assess the speed or magnitude of change; or*
- *support or direct research investigations or planning purposes* .

The materials presented ***should not*** be used to:

- *solely differentiate/explain the cause of change;*
- *state with absolute certainty the magnitude or speed of change at a given location;*
- *predict future rates and/or amount of change; or*
- *develop engineering or design plans.**

** Without a review of the underlying data*

Summary:

Shorelines are continuously moving in response to winds, waves, tides, sediment supply, changes in relative sea level, and human activities. As a result, shoreline changes are generally not constant through time and frequently switch from erosion (landward migration) to accretion (waterward migration) and vice versa. Cyclic and non-cyclic processes change the position of the shoreline over a variety of timescales, from the daily and seasonal effects of winds and waves, to changes in sea level spanning decades, or more. The shoreline "rate of change" statistics offered here reflect a cumulative summary of the processes that altered the shoreline for the time period analyzed, and cannot be attributed to any one (or more) drivers.

Long-term rates (ca. 1880s - 2006)

Long-term rates of shoreline change were determined using two methods. One approach fitted a least squares regression line to all shoreline positions from the earliest (ca. 1880s) to the most recent (2006). The rate of change is given by the slope of the regression line to the data. The calculation of linear regression rates uses all shoreline data at a given location, but requires a minimum of three shorelines. The rates calculated with many shoreline positions can increase confidence by reducing potential errors associated with the source data, and fluctuating short-term changes. (Dolan, Fenster, & Holme, 1991)

The linear regression method for determining shoreline change rates assumes a linear trend of change among the shoreline dates. However, in locations where shoreline change rates have not remained constant through time, a linear trend would not exist. For example, a shoreline may exhibit accretion over the first 100 years, but in later years, the shoreline may shift to an erosion trend. In these cases, it is expected that using a linear model provides a poor fit to the data, and as a result the uncertainty associated with these shoreline change rates is higher than those in which the trend is more linear.

A second approach calculated end-point rates representing the net change between the two shorelines divided by the elapsed time period. Unlike the linear regression method, end point rates do not have an associated expression (such as a confidence interval) of how scattered the shoreline positions are relative to an assumed linear trend, nor do they use any more than two shorelines. However, they can be used where the required number of shorelines will not support the linear regression approach and thus can provide a potentially more robust suite of data.

In both cases, negative rate values indicate erosion (movement of the shoreline away from a predefined baseline) and positive rate values indicate accretion (movement of the shoreline towards the baseline.) The baseline, described in more detail in the Data Processing section of this document, is simply a reference datum from which to measure change.

Short-term rates (1983 – 2006)

Typically, shoreline change occurring over a short time span can be characterized by cyclic or episodic non-linear behavior, such as storm-induced shoreline erosion. High short-term variability increases the shoreline change rate uncertainty and the potential for rates of shoreline change that are statistically insignificant. In many locations, the short-term trend is calculated with only 3 shorelines. As noted above, uncertainty generally decreases with an increasing number of shoreline data points; thus the small number of shorelines in the short-term calculation can result in higher uncertainty.

Since the short-term timeframe considers comparatively less data than the long-term, the rate calculation only used an end point rate. End point rates represent the net change between the two shorelines divided by the elapsed time period. Unlike the linear regression method, end point rates do not have an associated expression (such as a confidence interval) of how scattered the shoreline positions are relative to an assumed linear trend.

As with the long-term rates, negative rate values indicate erosion (movement of the shoreline away from the established baseline) and positive rate values indicate accretion (movement of the shoreline towards the established baseline.)

Data Compilation:

Vector based shoreline data was derived from the following sources:

1880s:

1) Connecticut Historic Shoreline 1880s* Vector layer derived from assorted scanned National Oceanic and Atmospheric Administration (NOAA) Topographic Survey sheets (T-sheet) images (ca. 1880s) provided to DEEP by NGS (http://tinyurl.com/l3obnfn) All shorelines (with the exception of the New Haven harbor area) were hand digitized from T-sheets georeferenced for this effort as part of a DEEP / UCONN collaboration
2) EC4B04-LIS* NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Used to fill in gaps of shoreline from missing T-Sheet scans for New Haven Harbor area

1900s:

1) CT1900A; CT1900B; CT1908A; CT1909A NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Vector data created by NOAA

1910s:

1) CT1915A NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Vector data created by NOAA

1930s:

1) CT132ELA; CT132FMA NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Vector data created by NOAA

1940s:

1) PH3148A; PH3148AZ; PH3148F; PH31B NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Vector data created by NOAA

1950s:

1) Connecticut Hydrography Line (1953)**; Connecticut Hydrography Line (1958)**; U.S. Geological Survey (USGS) Quadrangle Based Digital Line Graph (DLG) Hydrography Line Data provided by DEEP (http://tinyurl.com/lk5emx6) Coastal arcs extracted from statewide layer based on best available date of USGS quad compilation.
2) PH142A; PH142B NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Vector data created by NOAA

1960s:

1) Connecticut Hydrography Line (1960)**; Connecticut Hydrography Line (1961)**; Connecticut Hydrography Line (1964)**; Connecticut Hydrography Line (1967)**; Connecticut Hydrography

Line (1968)**; USGS Quadrangle Based DLG Hydrography Line Data provided by DEEP (http://tinyurl.com/lk5emx6) Coastal arcs extracted from statewide layer based on best available date of USGS quad compilation.

2) PH6002; PH6007; PH6815 NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Vector data created by NOAA

1970s:

1) Connecticut Hydrography Line (1970)**; USGS Quad Based DLG Hydrography Line Data provided by DEEP (http://tinyurl.com/lk5emx6) Coastal arcs extracted from statewide layer based on best available date of USGS quad compilation.

1980s:

1) Connecticut Hydrography Line (1983)**; Connecticut Hydrography Line (1984)**; USGS Quad DLG Hydrography Line Data provided by DEEP (http://tinyurl.com/lk5emx6) Coastal arcs extracted from statewide layer based on best available date of USGS quad compilation.
2) CM8312; CM8315 NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Vector data created by NOAA

1990s:

1) NOAA Environmental Sensitivity Index (ESI) data - CT* NOAA ESI Inventory (http://response.restoration.noaa.gov/esi) Vector data created by NOAA

2000s:

1) CT0401A**; CT0401B**; CT0410C**; CT0410D**; CT0410E** NOAA Shoreline Data Explorer (http://www.ngs.noaa.gov/NSDE/) Vector data created by NOAA

*** indicates the set itself provides coast-wide coverage.**
**** indicates a set, that when combined with others, provides coast-wide coverage.**

It is important to note that the variety of data sources used employed different methodologies for deriving a shoreline. Moreover, the representation of what the shoreline is relative to the actual mark on the ground also varied and can be classified into two characterizations:

1) Office of Coast Survey/NOAA T-Sheets (Topographic Survey Sheets – “T-Sheets”):
Mean High Water (MHW): By definition, this is the average of the two daily high water lines for areas in a diurnal tidal cycle. On T-sheets from the Atlantic coast it is interpreted by trained topographers using the physical appearance of the beach, usually a line from the preceding high water limit. (Shalowitz, 1962)

2) USGS 1:24K Topographic Quad Sheets:
Wet/Dry Line: These are best described as the “wet/dry line” or the intersection of land and water as interpreted from the source material - typically aerial photos. Depending on the tide stage when the photography was taken, the wet/dry line and MHW may not be exactly the same.

Discussions with USGS-Woods Hole validate the rationale to use shorelines taken from disparate sources and timeframes, with the increase in available data outweighing the drawbacks of using data derived from different methodologies or referencing different shorelines. (Thieler & Himmestoss, DEEP/UCONN meeting with USGS - Woods Hole, 2013) Successful integrations of such data were used in studies in California, with the caveat being to responsibly address issues of errors in uncertainty. This is addressed in a following section. (Hapke, Reid, Richmond, Ruggiero, & List, 2006)

General Shoreline Archive

All source material was first converted (when necessary) into a common coordinate system (CT State Plane (ft) NAD83.) The source material was then organized by grouping unique feature classes by decade. For NOAA shoreline data this designation was predicated on the stated survey date provided with the data attribution. For USGS data, the statewide line data was classified by a USGS Quadrangle Index cross referenced against source material dates from scans of the original Topographic map scans (Figure 1.) Next, the unique feature classes from each decade were imported in into a standardized data schema based on a combination of NOAA shoreline attributes as well as attributes required by the software package used to support the change analysis. Where needed, attribute values were transferred or reclassified based on comparable native values. The standardized layers were then merged into a data layer for each decade. The decadal layers were then merged into a statewide master coverage (Figure 2.) All variants – original source material, decadal-based merges, and the entire statewide datalayer - were stored within an Environmental Systems Research Institute (ESRI) Geodatabase format to serve as a master archive of data suitable for supporting a variety of possible uses.

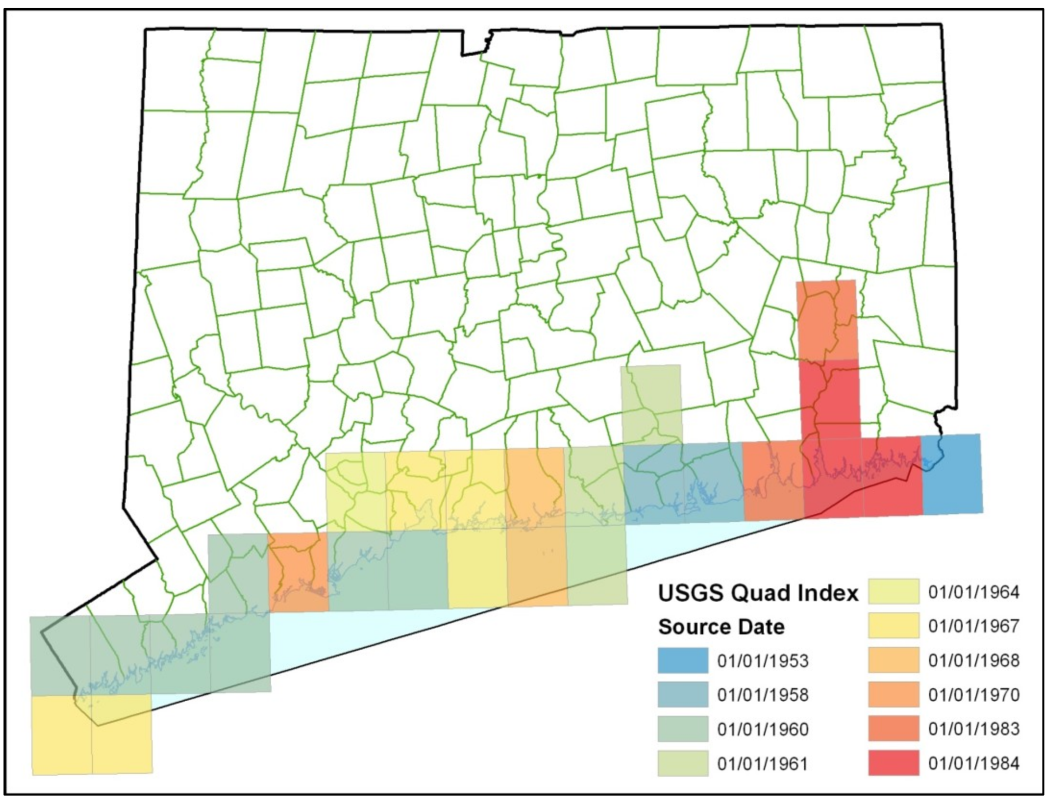


Figure 1: Coastal USGS Quads by Year

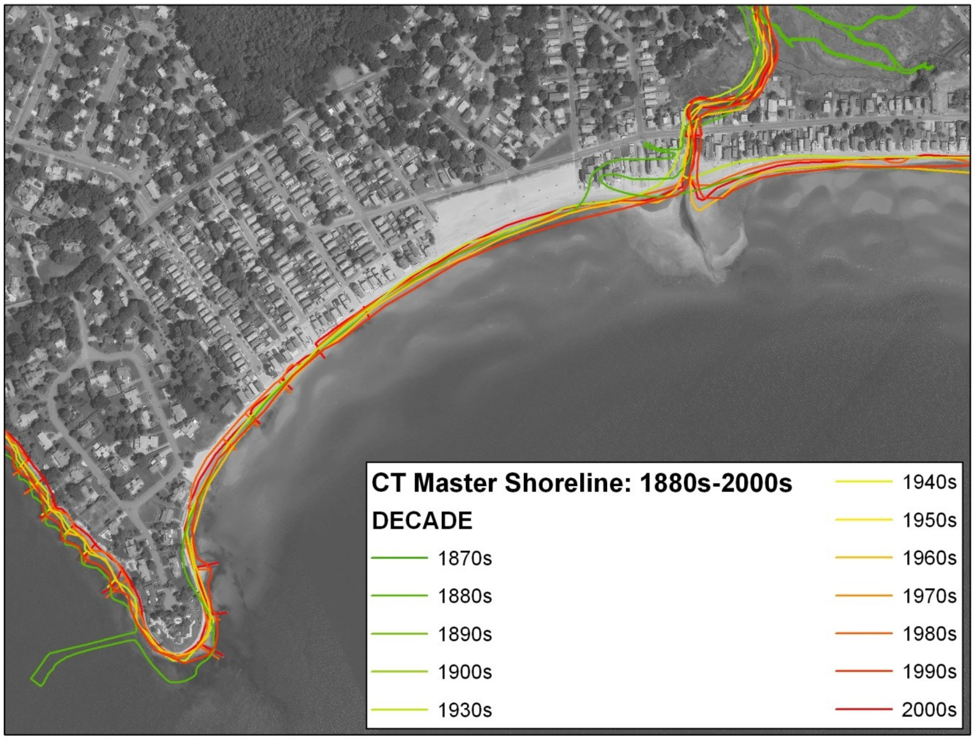


Figure 2: Sample shoreline data

Uncertainty Estimates

The numerous potential errors involved in deriving shoreline data make it necessary to provide a best estimate of the total positional uncertainty associated with each shoreline position. Uncertainties for shorelines include errors introduced by data sources as well as errors introduced by measurement methods and are well documented: (Anders & Byrnes, 1991) (Crowell, Leatherman, & Buckley, 1991) (Thieler & Danforth, 1994); (Moore, 2000) (Ruggiero, Kaminsky, & Gelfenbaum, 2003). The following five components are considered when estimating the positional uncertainty for shorelines:

1) georeferencing uncertainty;
2) digitizing uncertainty;
3) T-sheet survey uncertainty;
4) air photo collection and rectification uncertainty; and
5) the uncertainty of the high water line at the time of survey (Crowell, Leatherman, & Buckley, 1991)

For each shoreline, the position uncertainty is defined as the square root of the sum of squares (Taylor, 1997) of the relevant uncertainty terms, based on an assumption that each term is random and independent of the others (Hapke, Himmelstoss, Kratzmann, List, & Thieler, 2010). The average values for each uncertainty term and the total average positional uncertainty were estimated for each shoreline type (Table 1) using methods described in (Hapke, Himmelstoss, Kratzmann, List, & Thieler, 2010).

Measurement Errors (m)	Tsheets		UDGS DLG Topo		NOAA CT ESI		Air Photos
	1880s-1950s	1960s-1980s	1950s-1960s	1970s-1980s	1990s DOQQ / ESI Flights	1995 CTDEP	1970-2000s
Georeferencing	4	4	4	4	0	4	0
Digitizing	1	1	1	1	1	1	1
Tsheet survey	10	3	0	0	0	0	0
Air Photos	0	0	0	0	10**	3	3
USGS DLG Topo	0	0	22.5*	22.*	0	0	0
Shoreline location	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Square root of Sum of Squares (m)	***11.72***	***6.80***	***23.31***	***23.31***	***11.01***	***6.80***	***5.50***
Square root of Sum of Squares (ft)	***38.43***	***22.31***	***76.47***	***76.47***	***36.12***	***22.31***	***18.04***

Table 1: Uncertainty Terms

**** USGS DLG Topo uncertainty value based on review of CT data, above citations, and personal communication with USGS WHOI staff. Uncertainty value used is an average of upper and lower error bounds (15m and 30m)***

***** NOAA CT ESI source photo uncertainty taken from CT 1990 DOQQ positional accuracy assessments; assumes the same values for ESI overflights***

Shoreline Change Analysis Data

A separate version of the master archive was extracted to specifically support the shoreline change analysis described here. This dataset differs from the master archive in the following ways:

- Vectors only correspond to lines classified as "Shoreline" based on representative values from the standard attribute schema field describing the classification of the linework (i.e., this layer omits lines classified as upland marsh boundaries, transportation features, hazard areas, etc. that were included in some of the original source material).
- The coordinate system was converted to UTM Zone 18 (meters) to conform to the requirements of the software analysis package used.

Data Review/Assessment

The review of shoreline change analysis data began by creating a buffer around the shorelines using the appropriate error estimates. This provided a window of reasonable position to compare the shoreline to other sources of coastal information and assess whether or not to include it.

Visual inspection of buffered lines:

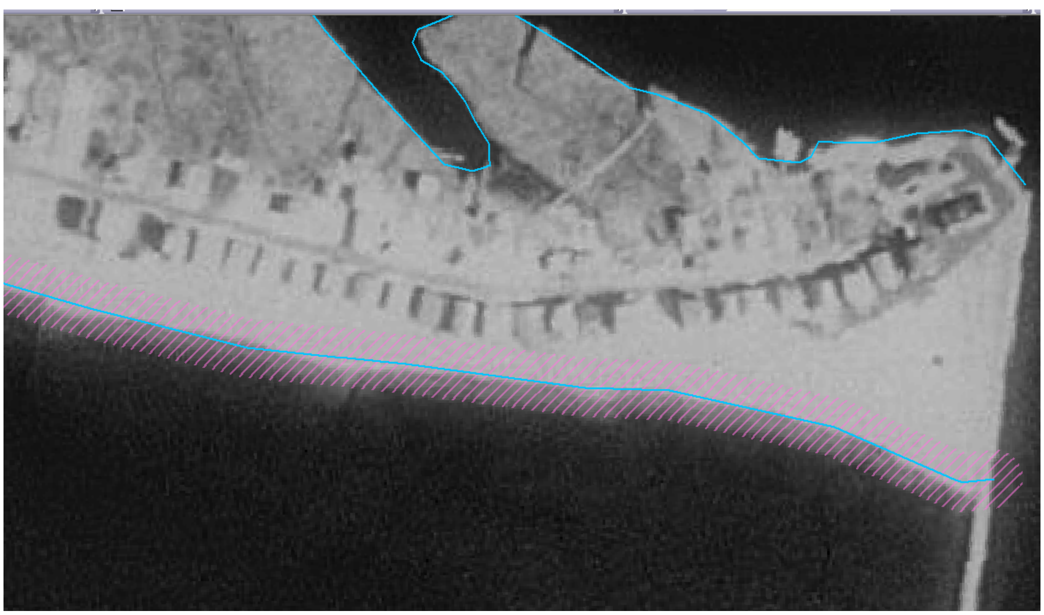
1. For shorelines 1990 – present, it was possible to compare the shorelines to the actual orthophoto imagery used to derive them (or to orthophotos taken within a year of the linework at a comparable level of detail) to confirm if the linework was suitable. "Suitable" areas were typically defined by:

- The error-bounded shoreline capturing what could best be determined as the "MHW vicinity" – i.e., an area that captures the land-water interface as well as a portion landward. In this way, we can be reasonably confident that the error-bounded shoreline is close to MH or a high-water mark and at least above low-water. This metric is typically applied to areas of open coastline such as beaches or marshes that do not have a well-defined point of reference such as jetties, groins, rocky outcrops, seawalls, rocky headlands, etc.
- For areas of the coast that do have well-defined points of reference such as jetties, groins, rocky outcrops, seawalls, rocky headlands, etc., the error-bounded shoreline needed to overlap or reasonably define the shape, extent, or orientation of these features.

Areas deemed "unsuitable" for this analysis generally corresponded to conditions such as:

- Misinterpretations of the vicinity of MHW shoreline (e.g., exposed tidal flats or other areas of obvious low water rather than a more appropriate area in the vicinity of the beach/water interface);
- Unknown/unexplainable digitizing errors such that the shorelines do not follow typical interpretations used to define similar areas within the data.

Any unsuitable areas were coded as such during the review and removed from the final version used in the analysis.



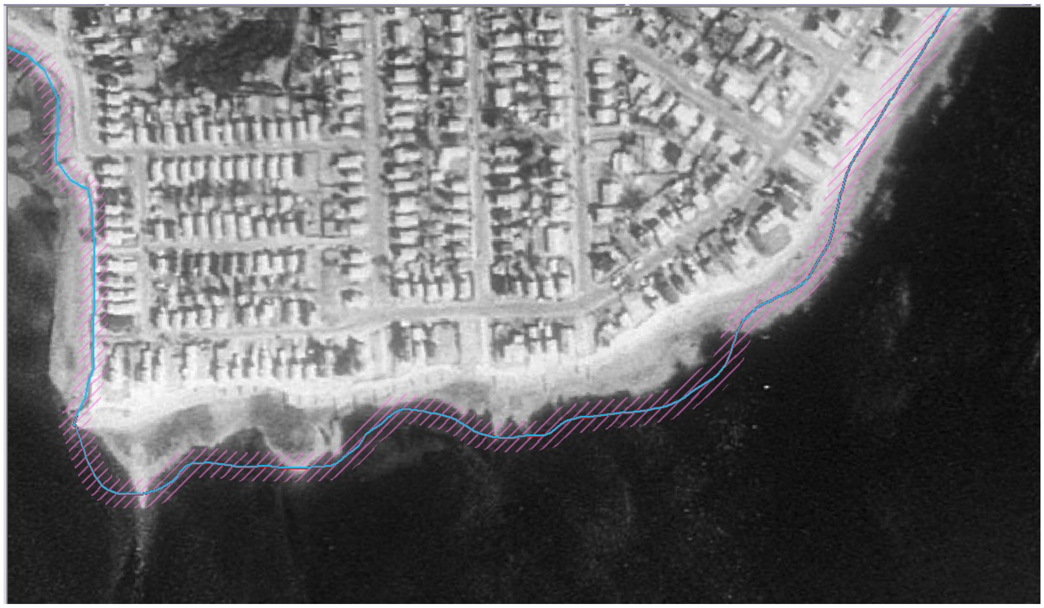


Figure 3: Examples of suitable (top) and unsuitable (bottom) shoreline vectors.

In the top image of Figure 3, the blue shoreline generally follows the photo trend but more importantly, the buffered area is also largely consistent. Below both the shoreline and the buffered area do not provide a good visual match along the southern section of the land form.

2. For shorelines pre-dating 1990, it was not possible to replicate the same methodology described above. Whereas the 1990-present shorelines were directly digitized from available (or comparable) orthophotos, the shorelines pre-dating 1990 were digitized from scans of hardcopy maps – T-sheets and USGS Topographic Quadrangle maps. These scanned maps required an intermediary step to georeference them (referencing the image coordinates of the scan to real-world coordinate locations,) which introduced an additional source of error. So while it was possible in many cases to access the scanned maps and assess whether the shoreline was interpreted and/or traced correctly, this alone was not sufficient to assess whether the georeferencing process accurately located the maps to correspond to a reasonable location on the ground. In order to assess the validity of the georeferencing, the error-bounded lines were displayed over ca. 2010 orthophotography and examined along areas of the coast with well-defined common points of reference such as jetties, groins, rocky outcrops, seawalls, rocky headlands, etc., that were assumed to be constant over time. Fortunately the Connecticut coastline has a well distributed set of these features enabling a coast-wide approach. The error-bounded shoreline needed to overlap or reasonably define the shape, extent, or orientation of these features in order to be considered suitable. In many cases, historic shorelines exhibited an offset from these "constants" such that the overall configuration of the shoreline was adequately represented, but the spatial location was shifted too far east, west, north or south - indicating positional accuracy exceeded the error bounds. In these cases, the discrepant shorelines were coded as unsuitable during the review and removed from the final version used in the analysis. It should be noted that while this approach was employed coast-wide, it was

necessarily limited in scope to areas that provided the means to assess the data; it is therefore possible that some shorelines included in the analysis may exceed their stated positional error boundary estimates. However, there was no conclusive way to identify or quantify these within the constraints of this study's time and funding, so taking a conservative approach in the analysis aspect of this effort was employed.

Data Processing:

Overview

Data processing used USGS Digital Shoreline Analysis System (DSAS) version 4.3 software extension for ESRI ArcGIS. (Thieler, Himmelstoss, Zichichi, & Ergul, 2009) DSAS generates geospatial data and statistical calculations for shoreline time-series data by analyzing the proximity and distribution of shorelines from an established baseline (starting point) at user-defined intervals (transects.) DSAS provides great flexibility in establishing parameters; consultations with USGS – Woods Hole staff (Thieler & Himmestoss, DEEP/UCONN meeting with USGS - Woods Hole, 2013) provided the following best-practices guidelines:

- Locating baselines:
  - Baselines should be oriented as close to shore as possible to minimize issues with multiple transect crossings and drawn to force transects to be as orthogonal to shoreline trends as possible. There is no "golden rule" and there will always be some interpretive work here. If the above two criteria are held to, there's very little difference in the resulting analyses – i.e., similar baselines will produce essentially similar results.
  - It is generally easier to create baselines for large stretches of shore and then edit/remove transects from analysis rather than a series of shorter baselines that ignore certain areas.
- Transect intervals:
  - A typical interval of 50m will produce suitable data. This is what was used in Massachusetts, could be more or less as needed.
- Statistical derivations;
  - Do not use WLR (weighted linear regression) calculations. Application of weighting parameters in the coding is not done well enough to provide defensible results.
  - Do not use EPR (end point rate) Confidence Interval values –values do not provide realistic meaning.
  - Ordinary least squares is the preferred statistic for anything >= 3 shorelines. Use EPR when you only have two shorelines.
- Other points of consideration
  - Using as many shorelines as possible, even if they do not match the datum exactly, is more useful in the data analysis. Adjusting the uncertainty values can help mitigate datum related inconsistencies. Shorelines from USGS topographic maps have been mixed in with NOAA shorelines in California – reports exist with the uncertainties used for those studies that we have adopted/modified. (Hapke, Reid, Richmond, Ruggiero, & List, 2006)

- Any photo derived shoreline can safely be assumed to use a wet/dry line which can be considered comparable to MHW. Care should be taken to account for additional uncertainty if there is any specific notation of only using a low-water line interface. Adjust uncertainty as needed.
- Better to adjust uncertainty values than edit lines that do not “match” known shoreline features like rocks, outcrops, etc. If data have systemic errors, then consider omitting all or parts. General rule is to keep what can reasonably be kept, and adjust uncertainty.
- Using LIDAR derived shorelines is typically only useful in areas of consistently sloping sandy beaches. For Connecticut, using LIDAR to fill in gaps of coverage in the eastern part of the state is not likely a good use of time/effort as results may not be optimal. Better to acquire USGS Topographic shorelines or NOAA ESI data as noted above.
- May want to consider looking at shorelines of similar type (i.e., sandy beach or marsh) to examine comparing apples to apples.
- Calculating an “average” rate for a given aggregation of shoreline (i.e., a town, a county, etc.) is doable, but this will likely be using shorelines of varying geologic characteristics. So for example, any area of geologic stability over time will drive values down from areas of actual erosion.

In general the outcome was to develop data for use in addressing two fundamental questions: **“How <u>much</u> has the shoreline changed?” (How far has it moved?)** and **“How <u>fast</u> has the shoreline changed?” (At what rate is it moving?)**

Baseline Development

A baseline is used in the DSAS model as a starting point to create transects which then cross through the individual shoreline vectors and provide measures of change over time. All baseline segments were created at a distance offshore of the furthest seaward shoreline vector for all of the available years yet oriented close enough to ensure that transects are reasonably perpendicular to the primary direction of change. Segments of the baseline contain attributes to identify sections for individual analysis and codes to provide a directional sequence for the model (west to east).

The baseline was created and edited within an ESRI file geodatabase (gdb) as a line feature. The file geodatabase format maintains curve topology and provides additional functionality to easily create and modify the line feature during the development and maintain a record of editing history. Once completed this file geodatabase feature was exported to an ESRI personal geodatabase (mdb) for compatibility with the DSAS modeling program.

An ESRI ArcGIS project was built for editing the baseline using additional feature layers for visible reference in the background. The primary background layers were the available shoreline vectors for each year, aerial imagery, and political boundaries helpful for identifying the attributes and positions of the existing shorelines. To improve computer performance all shoreline vectors were cropped (clipped) to a study zone created using a data layer that extends the town boundaries off shore far enough to include all islands associated with a political boundary. The 24 coastal towns were selected and the feature was modified to extend beyond the western and eastern most towns. The baseline and final analysis were contained within this clipped “zone”.

Before creating the baseline the shorelines were reviewed for what would eventually be included in the final analysis. The 2006 vector layer was more detailed than prior years and included islands and rock features not identified in earlier layers. These islands were removed from the analysis, as if they were not removed the output would have provided false rates of change where transects crossed these features. For larger island features not included in the time analysis, the baseline was drawn to fall between the island and the furthest seaward shoreline, essentially removing the island from the results. These offshore islands may affect the dynamics of the neighboring shoreline and provide a reason for change or stability yet do not contribute directly to the calculations of change. The baseline was also adjusted to avoid islands visible in the aerial imagery yet not identified in any of the vector datasets.

The Connecticut shoreline is very complex, it is not a simple linear feature where a baseline can easily remain perpendicular to all of the shoreline features. Curved arcs were used to best align around peninsulas and within embayments where straight-line baseline segments would not work. The DSAS software does interpolate a curve for quick changes in baseline direction, however, pre-setting the arcs allows for more control of the output transects, improving the odds the result transects would intersect the shoreline features properly. Testing with intermediate runs of the DSAS software, then adjusting the curves, improved the results.

Baseline Attributes: The attribute information within the baseline was coded to match political town boundaries based on the starting point of a given line segment moving from West to East. The shoreline towns were numbered west to east, starting in Greenwich with the number 1 and ending in Stonington as 24. These codes were entered as attributes and each segment within a town was numbered from 1 to the final segment count for that town (group sub-order). The segments were broken at significant changes in the land features and shoreline directions. If a segment extended into the next town the segment was broken, ensuring the attribute code changed at the boundary.

<u>Important baseline attributes</u>:

- **ID (LONG)** – Primary unique identifier for DSAS. 100 plus Town order concatenated with 100 plus group sub order. Adding 100 maintains a six digit format. Sample: Greenwich (Town 1) Segment # 3 = 101103
- **DSASGROUP (LONG)** – Group value for optional use in DSAS. Value is the town number as identified by DEEP.
- **CastDir (SHORT)** – Value tells DSAS if the baseline segment is offshore (0) or inland (1) of the shoreline vectors. In this study all values were set to 0.
- **townOrder (SHORT)** – Towns labeled as 1 to 24 from West to East. Value used in ID.
  grpSubOrder (LONG) – Values 1 to the last segment for a given town (west to east). Value used in ID.

Additional attributes were used during the build of the dataset to help maintain edit history, include town information, and provide suggested transect lengths for individual sections.

The draft baseline was converted to a personal geodatabase and reviewed for consistency and accuracy. A few segments were subsequently adjusted to extend selected features and better align sections to maximize perpendicular transects.

Transect & Statistical Generation

For both long-term data (i.e., shorelines from ca. 1880 to 2006) and short-term data (i.e., shorelines from 1983 to 2006) the following process steps were implemented within DSAS:

1. Transects were generated with 50m spacing.
2. Transect geometry reviewed; where necessary baselines were adjusted to correctly orient transects; transects regenerated with modified baselines.
3. Initial Statistics (using a Confidence Interval of 1.5 standard deviations) and intersect points based on revised transects were created. Confidence Interval was chosen to provide a balance of quantity of data and quality of data. Higher Confidence Interval values provide quality data at (generally) the expense of quantity and/or distribution of data; Lower Confidence Intervals will generally produce more data but of lower quality.
4. Reviewed revised transects and coded certain classes for removal:
    a. Transects that were too skewed (i.e., they did not sufficiently intersect the general trend of the shorelines in a more or less perpendicular fashion;
    b. Multiple transects hitting at or near the same location (e.g., around a point of land, or where one baseline ends and the next adjacent one begins.)
5. Reviewed intersection table and removed erroneous points (typically when transects were long enough to pick up inland shoreline arcs with distinctly different dates or in areas behind where parts of shorelines were removed due to accuracy issues.) This effectively sets a corrected inventory of shoreline intersections.
6. Clipped revised transects based on the corrected intersect points to produce a set showing only the envelope of change (limiting the transect length to just the area between the closest and furthest shorelines from the baseline)
7. Used the clipped transects to generate revised (final) statistics; joined statistics table to clipped transects to create a final analysis data set via the [ObjectId] field. Statistical output included:
    a. Net Shoreline Movement (NSM): The net shoreline movement reports a distance, not a rate. The NSM is associated with the dates of only two shorelines. It reports the distance between the oldest and youngest shorelines for each transect. This represents the total distance between the oldest and youngest shorelines.
    b. End Point Rate (EPR): The end point rate is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. The major advantages of the EPR are the ease of computation and minimal requirement of only two shoreline dates. The major disadvantage is that in cases where more data are available, the additional information is ignored.
    c. Confidence of End Point Rate (ECI): Generated, but ignored for this study per USGS-Woods Hole.

d. Shoreline Change Envelope (SCE): The shoreline change envelope reports a distance, not a rate. The SCE is the distance between the shoreline farthest from and closest to the baseline at each transect. This represents the total change in shoreline movement for all available shoreline positions and is not related to their dates.
e. Linear Regression Rate (LRR): A linear regression rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a particular transect. The regression line is placed so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. The method of linear regression includes these features: (1) All the data are used, regardless of changes in trend or accuracy, (2) The method is purely computational, (3) The calculation is based on accepted statistical concepts, and (4) The method is easy to employ (Dolan, Fenster, & Holme, 1991). However, the linear regression method is susceptible to outlier effects and also tends to underestimate the rate of change relative to other statistics, such as EPR (Dolan, Fenster, & Holme, 1991) (Genz, Fletcher, Dunn, Frazer, & Rooney, 2007).
f. The R-squared statistic, or coefficient of determination, is the percentage of variance in the data that is explained by a regression. It is a dimensionless index that ranges from 1.0 to 0.0 and measures how successfully the best-fit line accounts for variation in the data. In other words, it reflects the linear relationship between shoreline points along a given DSAS transect.
g. Standard Error of the Estimate: The standard error of the estimate measures the accuracy of the predicted values of y by comparing them to known values from the shoreline point data.
h. LRR 86.6% Confidence Interval: The standard error of the slope with confidence interval (LCI for ordinary linear regression) describes the uncertainty of the reported rate. The LRR rates are determined by a best-fit regression line through the sample data. The slope of this line is the reported rate of change (in meters/year). The confidence interval (LCI) is calculated by multiplying the standard error (also called the standard deviation) of the slope by the two-tailed test statistic at the user-specified confidence percentage (Zar, 1999). The specific confidence interval was chosen to provide a balance between quantity of data and quality of data.

8. Identified transects as:
    a. Not statistically valid (e.g., where the LRR Confidence interval exceeded the LRR value),
    b. Part of heavily industrialized harbors (Bridgeport, New Haven, Thames River) or areas of significant fill (largely localized in the western 6 coastal communities) based on a review of ca. 2010 aerial photographs and shoreline vectors.
    c. Suitable for analysis – effectively those that were not coded as ‘a’ or ‘b’ above.

NOTE: all transects were used to assess net shoreline movement to track and display the magnitude of shoreline change over time. The transects coded as described in 8a and 8b above were omitted from any rate-based assessments as we felt the changes derived from the obvious areas of heavy industrialization and fill would skew the overall results.

9. Added shoreline districts outlined in a 1979 CTDEP shoreline assessment to ID similar sections of shoreline for organization and comparative purposes. (Connecticut Coastal Area Management Program, 1979) (Figure 4) From west to east the following districts are defined as:
    a. Rock and Drift/Much Artificial Fill
    b. Glacial Drift and Beaches
    c. Glacial Drift and Rock
    d. Rock and Marshes
    e. Glacial Drift and Beaches
    f. Glacial Drift and Rock
    g. Rock and Marshes

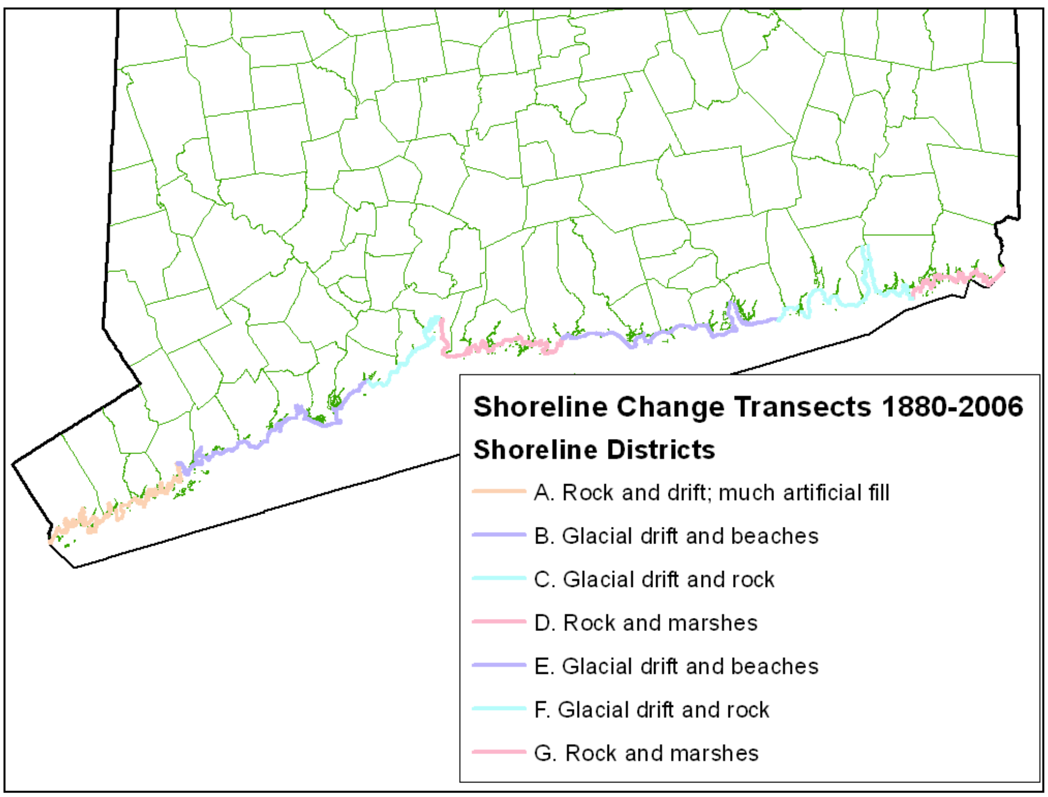


Figure 4: Connecticut Shoreline Districts

10. To account for a desire to address regional averaging of rates and uncertainties in the shoreline change data (e.g., by geologic categorization or by town/political boundaries) we needed to address how uncertainty values of each individual shoreline change value is used in the mean. (Hapke, Himmelstoss, Kratzmann, List, & Thieler, 2010) In shorelines generally dominated by long stretches of uniform orientation and geomorphology, it is possible to make use of automated processes such as spatially lagged autocorrelation tools in commercial off the shelf software packages. Given that the nature of the Connecticut shoreline does not match with

these conditions, discussions with USGS – Woods Hole (List, 2013) led to a manual best-professional judgment routine within ArcGIS to identify self-similar stretches of shoreline (typically defined by unique littoral cells such as pocket beaches and smaller stretches of beach or marsh-dominated shorelines.) The identification of these "reduced transect" estimators was used when determining regional uncertainty averages.

The resulting data show in Figures 5 – 7 were subsequently generated:

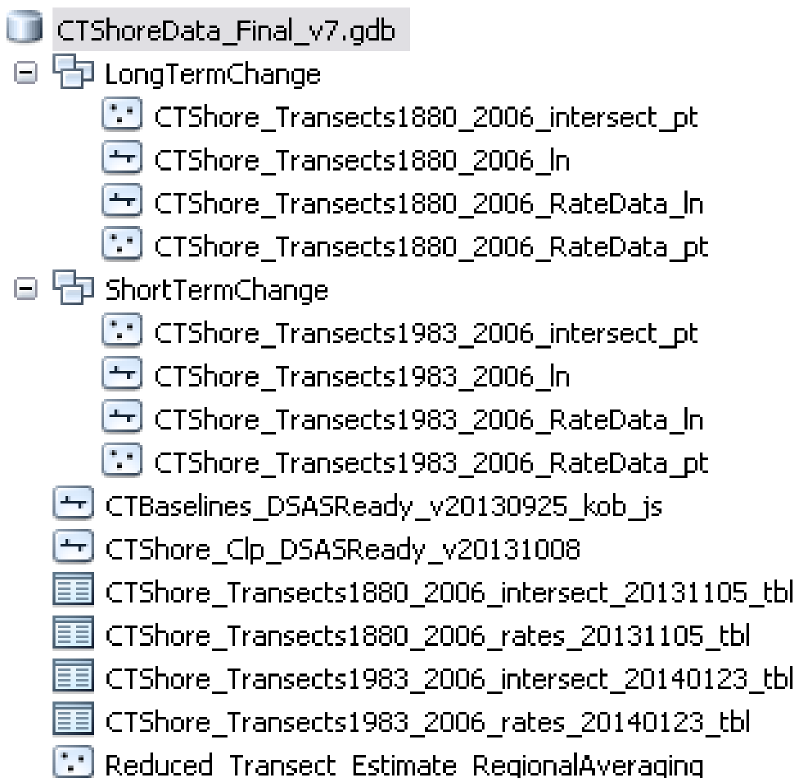


Figure 5: Final Data Structure output

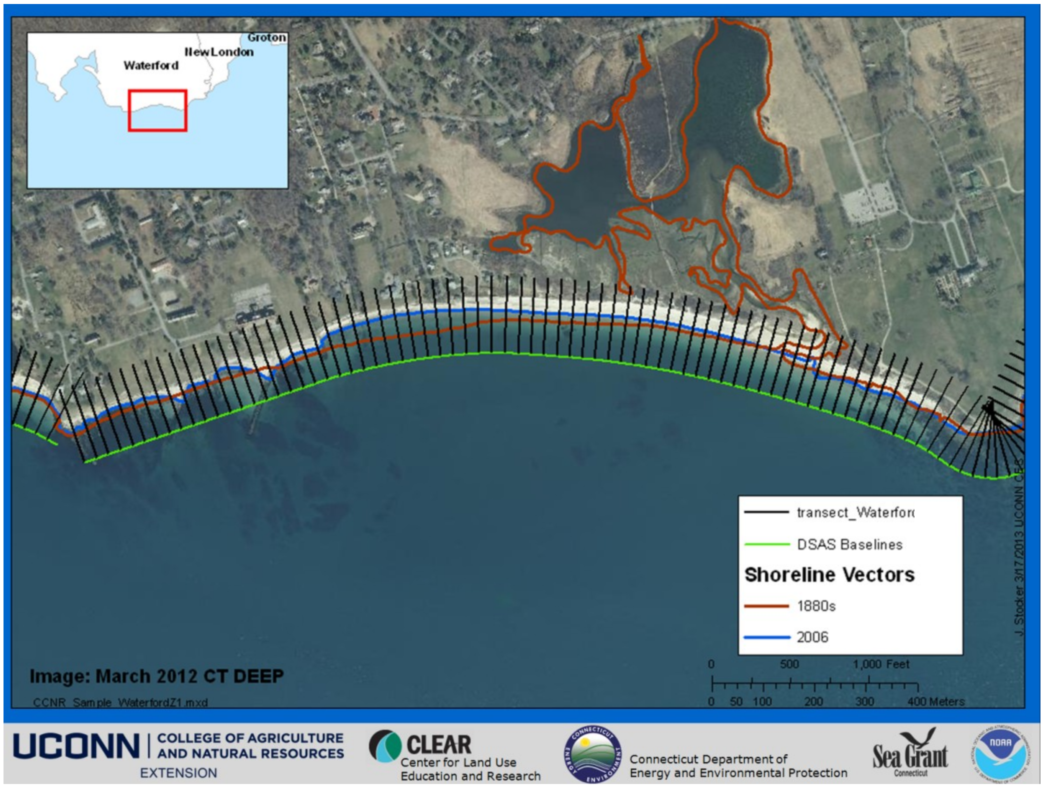


Figure 6: Example of baselines, shoreline vectors, and analysis transects

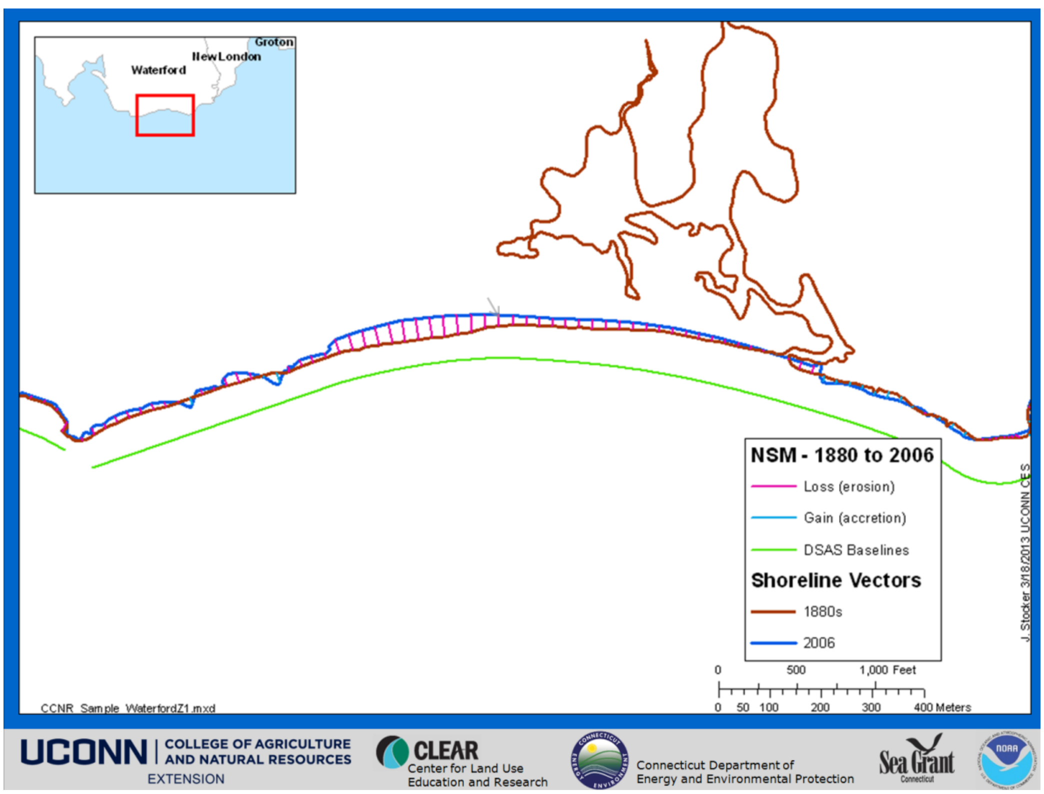


Figure 7: Example of shoreline transects clipped to the shoreline change envelope

Statistical Review and Processing:

Resulting data for both long and short-term rates were exported from ArcGIS into an MS Excel spreadsheet for processing and analysis. Data were exported on the basis of shoreline districts as defined above and organized using a combination of town identification codes and transect Ids to provide an organized progression of transect data along the Connecticut coastline from west to east. This enabled the generation of overall statistics for shoreline districts and the coastal communities contained within.

Short-Term Data (1983 – 2006)

For Short-term data (1983 – 2006), the following metrics were summarized on a per-town and district-wide basis. In the vicinity of the Connecticut River we identify sections as fronting Long Island Sound and the Connecticut River proper for towns on the western and eastern shores (Old Saybrook and Old Lyme, respectively.) Here we only include the EPR, as the density of shoreline data is limited by the temporal range and only small poorly distributed sections of the coast had the necessary number of shorelines required to compute LRR-based statistics.

- Net Shoreline Movement (how much has the shoreline moved): The Net Shoreline Movement calculations included data from all transects in order to portray the overall characteristics of change across the state and regions.
    - Minimum
    - Maximum
    - Average
- End Point Rate (how fast has the shoreline moved): The End Point Rate calculations excluded data from transects corresponding to those coded as heavily urbanized or the likely result of obvious fill in order to mitigate skewing the overall characteristics of rates of change across the state and regions.

With respect the End Point Rate calculations, the following pros and cons are worth noting:

End Point Rate Pros:

- A simple calculation that's easily understandable;
- Can be used essentially anywhere there are data (only need 2 shorelines.)
- Easily applied to both Long Term and Short Term analyses

End Point Rate Cons:

- Ignores other shorelines so the rate can be idealized;
- Assumes a linear fit; not always the case
- Can be highly influenced by the quality of either (or both) of the shorelines;
- Provides no measure of confidence in the rate.

The Short-term data results are summarized below (Table 2). In cases where a community is split across a shoreline district, we provide results for each component as well as a total:

Town	NSM Min	NSM Max	NSM Ave	EPR Ave
Greenwich	-23.88	45.43	1.21	0.06
Stamford	-29.28	50.57	-1.91	-0.10
Darien	-18.19	52.7	0.29	0.01
Norwalk - A	-16.36	36.25	1.89	0.09
Zone A	***-29.28***	***52.7***	***0.60***	***0.03***
Norwalk - A & B	-24.08	36.25	1.33	0.06
Norwalk - B	-24.08	19	-0.03	0.00
Westport	-52.13	20.16	-3.90	-0.18
Fairfield	-31.37	20.28	-5.12	-0.24
Bridgeport	-30.51	92.65	-3.33	-0.23
Stratford	-47.43	50.05	-5.56	-0.26
Milford - B	-82.67	289.45	17.24	0.81
Zone B	***-82.67***	***289.45***	***-1.14***	***-0.06***
Milford - B & C	-82.67	289.45	8.09	0.38
Milford - C	-64.07	37.08	-0.07	0.00
West Haven	-73.53	140.46	-6.21	-0.24
New Haven - C	-17.55	28.76	-4.55	N/A
Zone C	***-73.53***	***140.46***	***-3.54***	***-0.13***
New Haven - C & D	-18.05	28.76	0.03	0.02
New Haven - D	-18.05	27.48	2.48	0.02
East Haven	-7.78	32.33	1.15	0.05
Branford	-26.52	21.45	0.82	0.04
Guilford - D	-21.21	55.29	4.96	0.23
Zone D	***-26.52***	***55.29***	***2.45***	***0.10***
Guilford - D & E	-21.21	55.29	5.05	0.24
Guilford - E	-16.99	36.16	5.71	0.35
Madison	-40.11	11.88	-3.64	-0.17
Clinton	- 133.55	29.91	-3.33	-0.15
Westbrook	-12.12	19.51	2.14	0.10
Old Saybrook - LIS	-19.89	23.8	-2.60	-0.12
Old Saybrook - CT River	-20.51	25.83	6.18	0.28
Old Saybrook - All	-20.51	25.83	0.75	0.03
Old Lyme - CT River - E	-34.51	31.75	-9.81	-0.47
Old Lyme - LIS - E	- 152.22	30.57	-14.05	-1.92
Old Lyme - E	- 152.22	31.75	-12.28	-1.31
Zone E	***-***	***36.16***	***-3.04***	***-0.28***

Town	NSM Min	NSM Max	NSM Ave	EPR Ave
	152.22			
Old Lyme - E & F	-152.22	33.12	-9.41	-1.02
Old Lyme - F	-12.51	33.12	1.35	0.08
East Lyme	-36.44	32.53	-11.64	-0.50
Waterford	-120.77	19.63	-11.61	-0.56
New London	-35.28	22.99	-6.23	-0.60
Groton - F	-46.3	38.41	-3.34	-0.29
Zone F	***-120.77***	***38.41***	***-7.04***	***-0.42***
Groton - F & G	-46.3	38.41	-3.33	-0.25
Groton - G	-35.45	20.97	-3.32	-0.15
Stonington	-71.72	34.02	-3.75	-0.17
Zone G	***-71.72***	***34.02***	***-3.68***	***-0.17***

Table 2: Table of Short-term (1983 – 2006) statistics summary

Additional Short-Term products include the following (and are contained in Appendices)

- Average Short-Term NSM Chart (by Town and District)

Long-Term Data (ca. 1880 – 2006)

For Long-term data (ca. 1880 – 2006), the following metrics were summarized on a per-town and district-wide basis. As there was a greater density of data due to the longer time horizon, there are more data products. In the vicinity of the Connecticut River we identify sections as fronting Long Island Sound and the Connecticut River proper for towns on the western and eastern shores (Old Saybrook and Old Lyme, respectively.) As the long-term data generally have sufficient density across the entire coast, we are able to compute both EPR and LRR-based statistics.

- Net Shoreline Movement: The Net Shoreline Movement calculations included data from all transects in order to portray the overall characteristics of change across the state and regions.
  - Minimum
  - Maximum
  - Average
- Linear Regression Rate: The Linear Regression Rate calculations excluded data from transects corresponding to those coded as heavily urbanized or the likely result of obvious fill in order to mitigate skewing the overall characteristics of rates of change across the state and regions.
  - Minimum
  - Maximum
  - Average
- Ave. Uncertainty (via reduced transect estimates)

- End Point Rate: The End Point Rate calculations excluded data from transects corresponding to those coded as heavily urbanized or the likely result of obvious fill in order to mitigate skewing the overall characteristics of rates of change across the state and regions.
    - Minimum
    - Maximum
    - Average

With respect to the rate of change calculations, the pros and cons are regarding the use of the End Point rate are the same as those noted above in the Short-Term data section. Below are pro and con points that are relevant for Linear Regression rates that are applied to the long-Term data:

Linear Regression Rate Pros:

- Relatively easy to implement;
- Uses all shoreline data;
- Provides a rate and an estimate of confidence in it;
- Allows user to specify level of confidence (in this case, 86.5% or 1.5 Standard Deviations)

Linear Regression Rate Cons:

- Assumes a linear fit; not always the case
- Requires at least 3 data points (ideally more)
- Can return “inconclusive” results (e.g., where the measure of uncertainty is greater than the rate) – requires user to interpret results
- There may be areas where no output can be used.

The Long-term data results are summarized below (Table 3). In cases where a community is split across a shoreline district, we provide results for each component as well as a total:

Town	*NSM Min*	*NSM Max*	*NSM Ave*	*EPR Ave*	*LRR Ave*	*LRR CI Regional Ave. Uncertainty*	*LRR CI Ave Lower Bound*	*LRR CI Ave Upper Bound*
Greenwich	-91.45	340.77	15.04	0.04	0.05	0.01	0.03	0.06
Stamford	-64.3	416.78	17.34	0.05	0.06	0.03	0.03	0.08
Darien	-112.49	196.13	6.24	0.02	0.04	0.01	0.02	0.05
Norwalk - A	-49.63	436.05	19.15	0.05	0.05	0.02	0.03	0.07
Zone A	***-112.49***	***436.05***	***14.44***	***0.04***	***0.05***	***0.01***	***0.04***	***0.06***
Norwalk - A & B	-254.59	436.05	23.04	0.06	0.07	0.02	0.05	0.09
Norwalk - B	-254.59	383.92	32.61	0.07	0.12	0.04	0.08	0.17
Westport	-120.68	139.13	4.88	0.04	0.10	0.03	0.07	0.13
Fairfield	-30.69	104.86	8.87	0.07	0.12	0.04	0.08	0.16
Bridgeport	-51.62	343.97	42.82	0.22	0.28	0.05	0.23	0.33
Stratford	-102.56	162.42	-12.52	-0.10	-0.06454	0.06452	-0.13	0.00
Milford - B	-117.6	369.83	18.62	0.16	0.14	0.08	0.06	0.23

Town	NSM Min	NSM Max	NSM Ave	EPR Ave	LRR Ave	LRR CI Regional Ave. Uncertainty	LRR CI Ave Lower Bound	LRR CI Ave Upper Bound
Zone B	***-254.59***	***383.92***	***16.04***	***0.07***	***0.12***	***0.02***	***0.10***	***0.13***
Milford - B & C	-117.6	369.83	16.63	0.06	0.06	0.03	0.03	0.09
Milford - C	-95.07	42.95	-4.39	-0.04	-0.01	0.03	N/A	N/A
West Haven	-72.09	110.77	7.49	0.03	0.16	0.09	0.06	0.25
New Haven - C	11.96	791.13	430.63	0.03	N/A	N/A	N/A	N/A
Zone C	***-95.07***	***791.13***	***64.98***	***0.00***	***0.08***	***0.04***	***0.04***	***0.12***
New Haven - C & D	-36.75	791.13	166.23	0.10	0.16	0.05	0.11	0.20
New Haven - D	-36.75	353.85	43.59	0.10	0.16	0.06	0.10	0.21
East Haven	-82.21	84.58	5.06	0.05	0.08	0.05	0.03	0.12
Branford	-80.29	78.48	1.08	0.01	0.018	0.017	0.00	0.03
Guilford - D	-203.67	111.53	-2.47	-0.02	-0.03	0.02	-0.06	-0.01
Zone D	***-203.67***	***353.85***	***6.97***	***0.01***	***0.02***	***0.01***	***0.01***	***0.03***
Guilford - D & E	-203.67	111.53	-8.02	-0.07	-0.08	0.02	-0.11	-0.06
Guilford - E	-133.41	13.79	-43.43	-0.35	-0.39	0.13	-0.51	-0.26
Madison	-204.63	63.34	-8.78	-0.07	-0.05	0.03	-0.08	-0.03
Clinton	-183.71	45.96	-16.73	-0.14	-0.13	0.03	-0.16	-0.11
Westbrook	-39.68	80.88	2.47	0.02	0.019	0.023	N/A	N/A
Old Saybrook - LIS	-67.15	212.89	-4.28	-0.03	-0.018	0.023	N/A	N/A
Old Saybrook - CT River	-26.34	258.34	11.95	0.10	0.09	0.07	0.02	0.15
Old Saybrook - All	-67.15	258.34	1.86	0.01	0.022	0.024	N/A	N/A
Old Lyme - CT River - E	-77.74	65.36	-9.66	-0.08	-0.06	0.08	N/A	N/A
Old Lyme - LIS - E	-313.99	55.2	-43.26	-0.36	-0.31	0.09	-0.40	-0.21
Old Lyme - E	-313.99	65.36	-30.03	-0.25	-0.21	0.07	-0.28	-0.14
Zone E	***-313.99***	***258.34***	***-11.46***	***-0.09***	***-0.08***	***0.02***	***-0.10***	***-0.07***
Old Lyme - E & F	-313.99	65.36	-25.27	-0.21	-0.18	0.05	-0.23	-0.13
Old Lyme - F	-27.73	22.31	-6.90	-0.06	-0.064	0.058	-0.12	-0.01
East Lyme	-97.03	70.77	-1.39	-0.01	0.03	0.04	N/A	N/A
Waterford	-129.06	87.26	-4.92	-0.08	-0.04	0.05	N/A	N/A
New London	-30.02	316.52	19.05	0.02	0.059	0.064	N/A	N/A

Town	NSM Min	NSM Max	NSM Ave	EPR Ave	LRR Ave	LRR CI Regional Ave. Uncertainty	LRR CI Ave Lower Bound	LRR CI Ave Upper Bound
Groton - F	-74.01	249.38	10.74	-0.02	0.02	0.03	N/A	N/A
Zone F	***-129.06***	***316.52***	***5.96***	***-0.03***	***0.00***	***0.02***	***N/A***	***N/A***
Groton - F & G	-74.01	249.38	8.56	-0.01	0.03	0.02	0.00	0.05
Groton - G	-37.59	52.34	2.06	0.02	0.04	0.03	0.01	0.08
Stonington	-152.39	58.96	-5.89	-0.05	-0.02	0.01	-0.04	-0.01
Zone G	***-152.39***	***58.96***	***-4.53***	***-0.04***	***-0.01***	***0.012***	***N/A***	***N/A***

Table 3: Table of Long-term (ca 1880 – 2006) statistics summary

Additional Long-Term products include the following (and are contained in Appendices)

- Long-Term EPR &LRR and Short-Term EPR Averages Chart (by Town and District)
- Average Long-Term NSM Chart (by Town and District)
- District A:
  - Long-term NSM Chart
  - Long-term EPR Chart
- District B:
  - Long-Term NSM Chart
  - Long-term EPR Chart
  - Long-term LRR Chart
- District C:
  - Long-Term NSM Chart
  - Long-term EPR Chart
  - Long-term LRR Chart
- District D:
  - Long-Term NSM Chart
  - Long-term EPR Chart
  - Long-term LRR Chart
- District E:
  - Long-Term NSM Chart
  - Long-term EPR Chart
  - Long-term LRR Chart
- District F:
  - Long-Term NSM Chart
  - Long-term EPR Chart
- District G:
  - Long-Term NSM Chart
  - Long-term EPR Chart
  - Long-term LRR Chart

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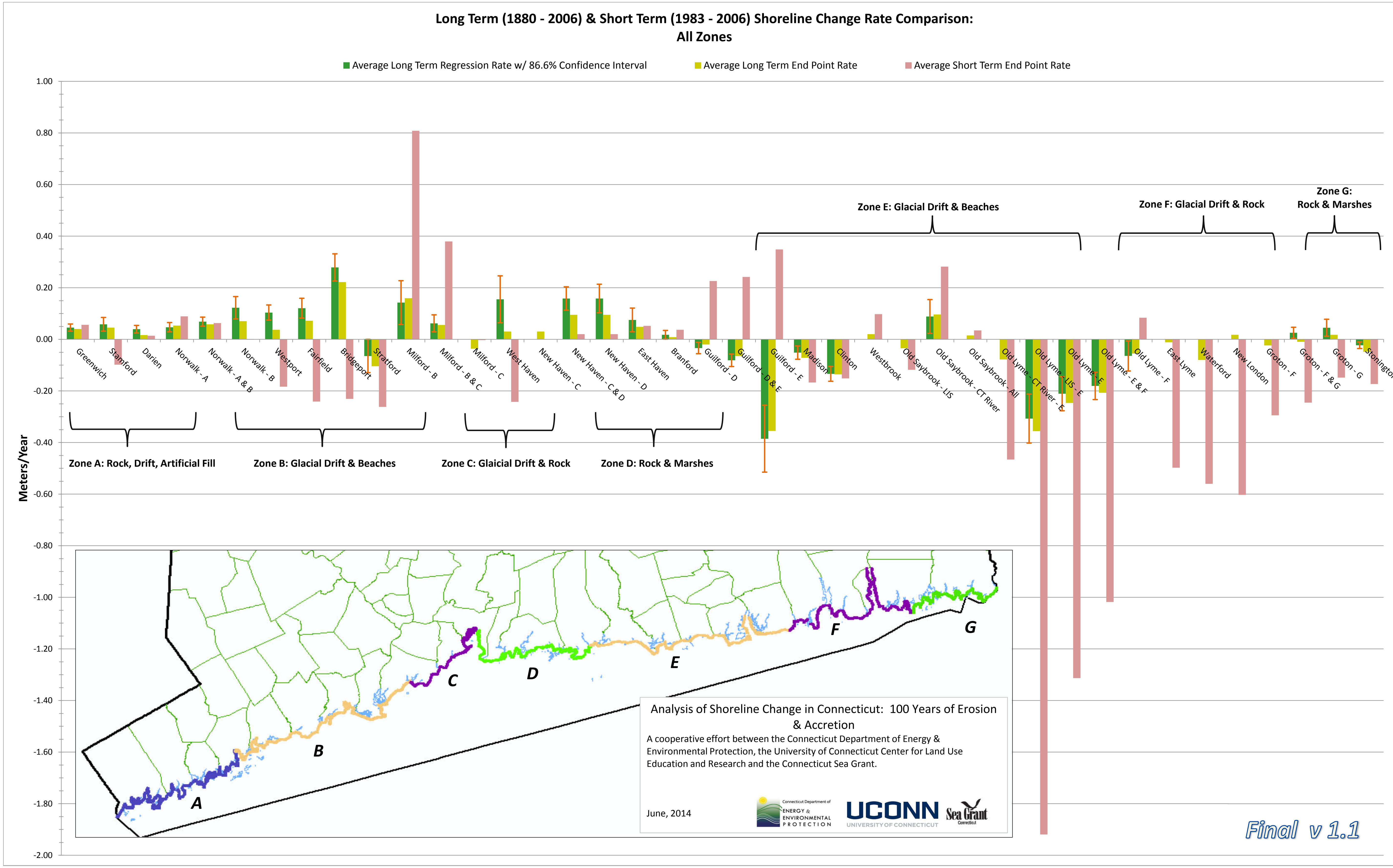
Appendices:

1) Long-Term EPR, Long Term LRR, and Short-Term EPR Averages Chart (by Town and District)
2) Average Long-Term NSM Chart (by Town and District)
3) Average Short-Term NSM Chart (by Town and District)
4) District A:
    a. Long-term NSM Chart
    b. Long-term EPR Chart
5) District B:
    a. Long-Term NSM Chart
    b. Long-term EPR Chart
    c. Long-term LRR Chart
6) District C:
    a. Long-Term NSM Chart
    b. Long-term EPR Chart
    c. Long-term LRR Chart
7) District D:
    a. Long-Term NSM Chart
    b. Long-term EPR Chart
    c. Long-term LRR Chart
8) District E:
    a. Long-Term NSM Chart
    b. Long-term EPR Chart
    c. Long-term LRR Chart
9) District F:
    a. Long-Term NSM Chart
    b. Long-term EPR Chart
10) District G:
    a. Long-Term NSM Chart
    b. Long-term EPR Chart
    c. Long-term LRR Chart



Long Term (1880 - 2006) & Short Term (1983 - 2006) Shoreline Change Rate Comparison:
All Zones
Average Long Term Regression Rate w/ 86.6% Confidence Interval
Average Long Term End Point Rate
Average Short Term End Point Rate
Meters/Year
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
-1.20
-1.40
-1.60
-1.80
-2.00
Greenwich
Stamford
Darien
Norwalk - A
Norwalk - A & B
Norwalk - B
Westport
Fairfield
Bridgeport
Stratford
Milford - B
Milford - B & C
Milford - C
West Haven
New Haven - C
New Haven - C & D
New Haven - D
East Haven
Branford
Guilford - D
Guilford - D & E
Guilford - E
Madison
Clinton
Westbrook
Old Saybrook - US
Old Saybrook - CT River
Old Saybrook - All
Old Lyme - CT River - E
Old Lyme - US - E
Old Lyme - E
Old Lyme - E & F
Old Lyme - F
East Lyme
Waterford
New London
Groton - F
Groton - F & G
Groton - G
Stonington
Zone A: Rock, Drift, Artificial Fill
Zone B: Glacial Drift & Beaches
Zone C: Glaicial Drift & Rock
Zone D: Rock & Marshes
Zone E: Glacial Drift & Beaches
Zone F: Glacial Drift & Rock
Zone G:
Rock & Marshes
A
B
C
D
E
F
G
Analysis of Shoreline Change in Connecticut: 100 Years of Erosion & Accretion
A cooperative effort between the Connecticut Department of Energy & Environmental Protection, the University of Connecticut Center for Land Use Education and Research and the Connecticut Sea Grant.
June, 2014
Connecticut Department of Energy & Environmental Protection
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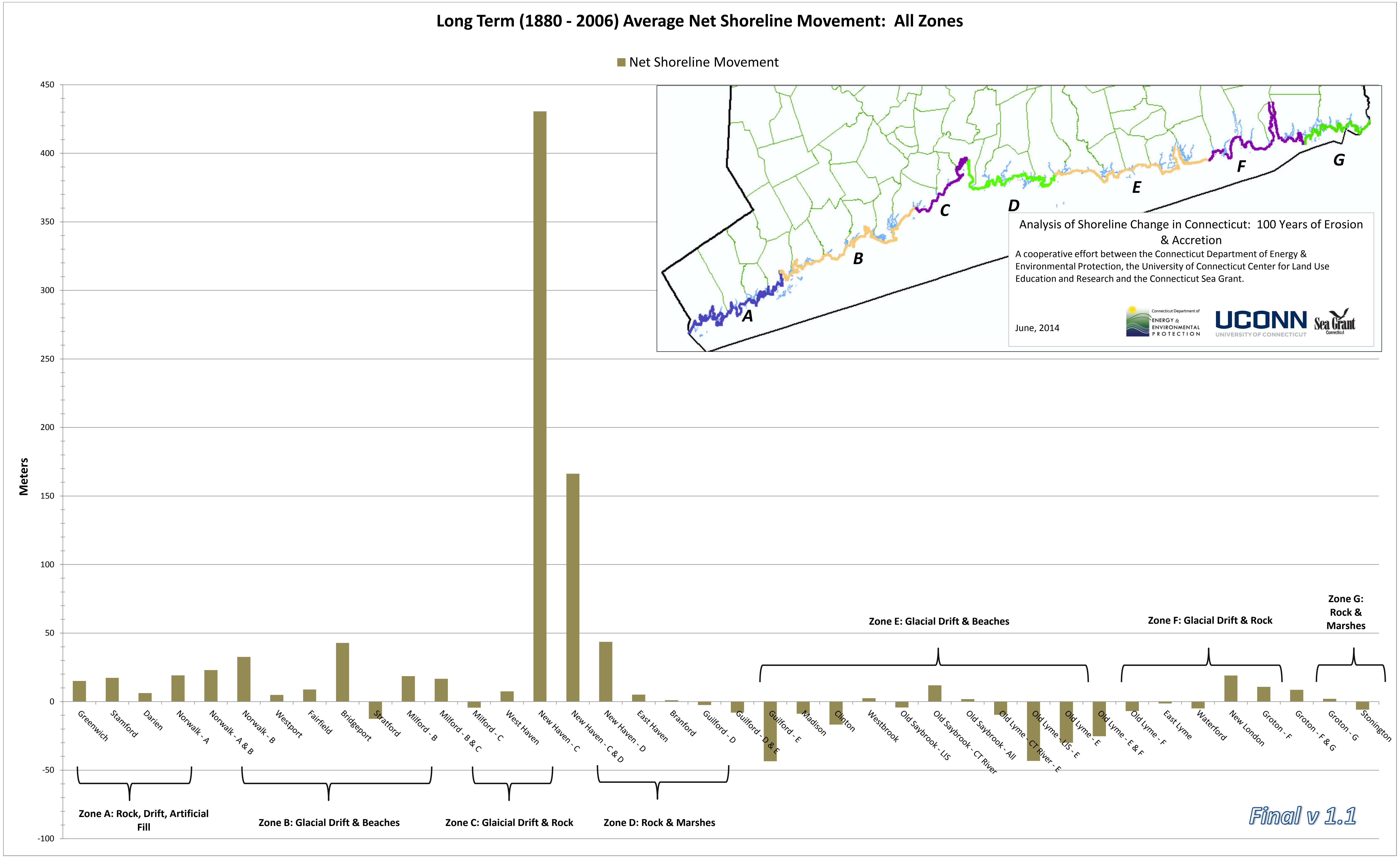
Long Term (1880 - 2006) Average Net Shoreline Movement: All Zones
Net Shoreline Movement
Meters
450
400
350
300
250
200
150
100
50
0
-50
-100
Greenwich
Stamford
Darien
Norwalk - A
Norwalk - A & B
Norwalk - B
Westport
Fairfield
Bridgeport
Stratford
Milford - B
Milford - B & C
Milford - C
West Haven
New Haven - C
New Haven - C & D
New Haven - D
East Haven
Branford
Guilford - D
Guilford - D & E
Guilford - E
Madison
Clinton
Westbrook
Old Saybrook - LIS
Old Saybrook - CT River
Old Saybrook - All
Old Lyme - CT River - E
Old Lyme - LIS - E
Old Lyme - E
Old Lyme - E & F
Old Lyme - F
East Lyme
Waterford
New London
Groton - F
Groton - F & G
Groton - G
Stonington
Zone A: Rock, Drift, Artificial Fill
Zone B: Glacial Drift & Beaches
Zone C: Glaicial Drift & Rock
Zone D: Rock & Marshes
Zone E: Glacial Drift & Beaches
Zone F: Glacial Drift & Rock
Zone G: Rock & Marshes
A
B
C
D
E
F
G
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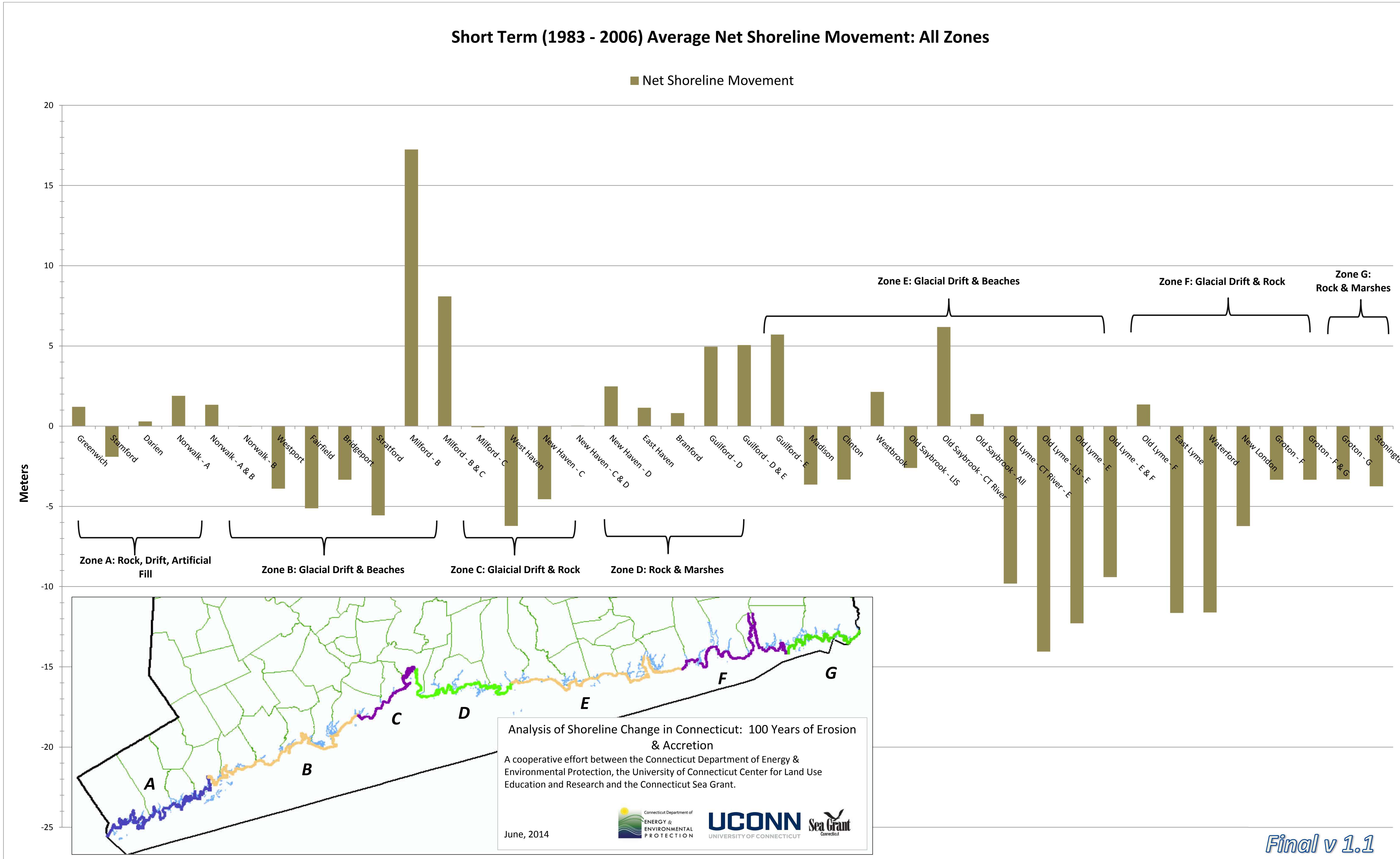

Short Term (1983 - 2006) Average Net Shoreline Movement: All Zones
Net Shoreline Movement
Meters
20
15
10
5
0
-5
-10
-15
-20
-25
Greenwich
Stamford
Darien
Norwalk - A
Norwalk - A & B
Norwalk - B
Westport
Fairfield
Bridgeport
Stratford
Milford - B
Milford - B & C
Milford - C
West Haven
New Haven - C
New Haven - C & D
New Haven - D
East Haven
Branford
Guilford - D
Guilford - D & E
Guilford - E
Madison
Clinton
Westbrook
Old Saybrook - LIS
Old Saybrook - CT River
Old Saybrook - All
Old Lyme - CT River - E
Old Lyme - LIS - E
Old Lyme - E
Old Lyme - E & F
Old Lyme - F
East Lyme
Waterford
New London
Groton - F
Groton - F & G
Groton - G
Stonington
Zone A: Rock, Drift, Artificial Fill
Zone B: Glacial Drift & Beaches
Zone C: Glaicial Drift & Rock
Zone D: Rock & Marshes
Zone E: Glacial Drift & Beaches
Zone F: Glacial Drift & Rock
Zone G: Rock & Marshes
A
B
C
D
E
F
G
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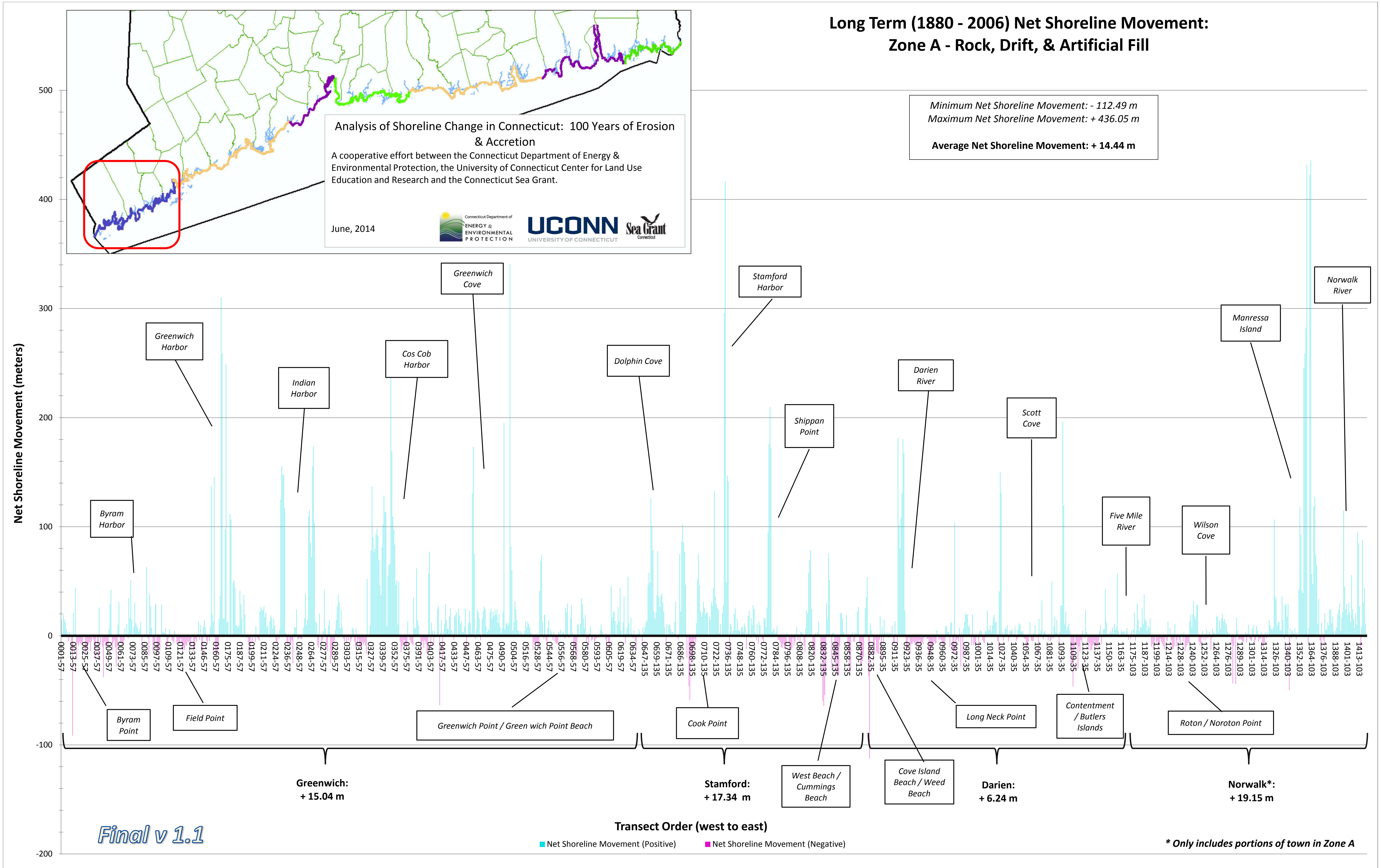

Long Term (1880 - 2006) Net Shoreline Movement:
Zone A - Rock, Drift, & Artificial Fill
Minimum Net Shoreline Movement: - 112.49 m
Maximum Net Shoreline Movement: + 436.05 m
Average Net Shoreline Movement: + 14.44 m
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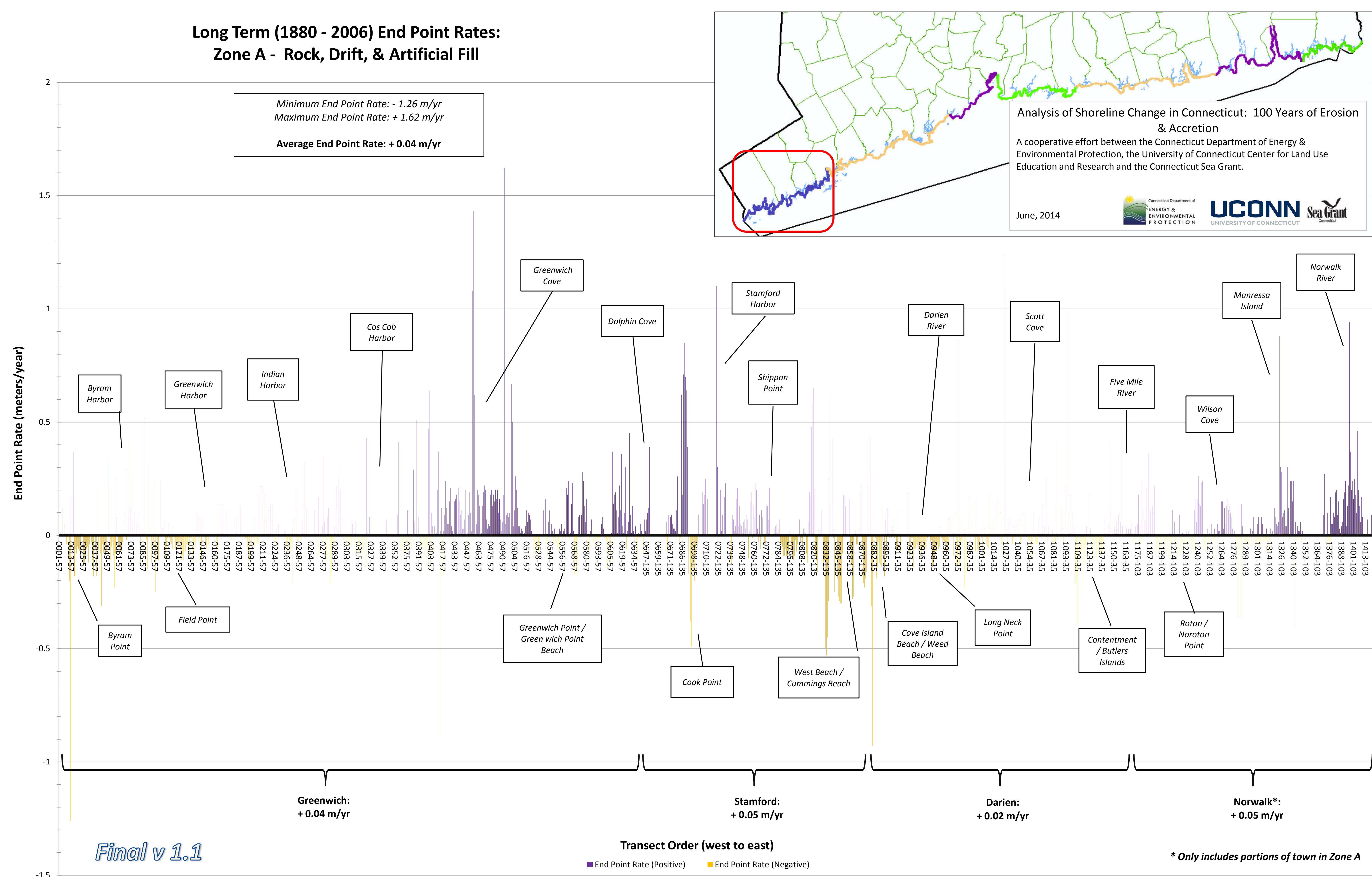
Net Shoreline Movement (meters)
500
400
300
200
100
0
-100
-200
Byram Harbor
Greenwich Harbor
Indian Harbor
Cos Cob Harbor
Greenwich Cove
Dolphin Cove
Stamford Harbor
Shippan Point
Darien River
Scott Cove
Five Mile River
Wilson Cove
Manressa Island
Norwalk River
Byram Point
Field Point
Greenwich Point / Green wich Point Beach
Cook Point
West Beach / Cummings Beach
Cove Island Beach / Weed Beach
Long Neck Point
Contentment / Butlers Islands
Roton / Noroton Point
Greenwich:
+ 15.04 m
Stamford:
+ 17.34 m
Darien:
+ 6.24 m
Norwalk*:
+ 19.15 m
Transect Order (west to east)
Net Shoreline Movement (Positive)
Net Shoreline Movement (Negative)
* Only includes portions of town in Zone A
Final v 1.1


Long Term (1880 - 2006) End Point Rates:
Zone A - Rock, Drift, & Artificial Fill
Minimum End Point Rate: - 1.26 m/yr
Maximum End Point Rate: + 1.62 m/yr
Average End Point Rate: + 0.04 m/yr
Analysis of Shoreline Change in Connecticut: 100 Years of Erosion & Accretion
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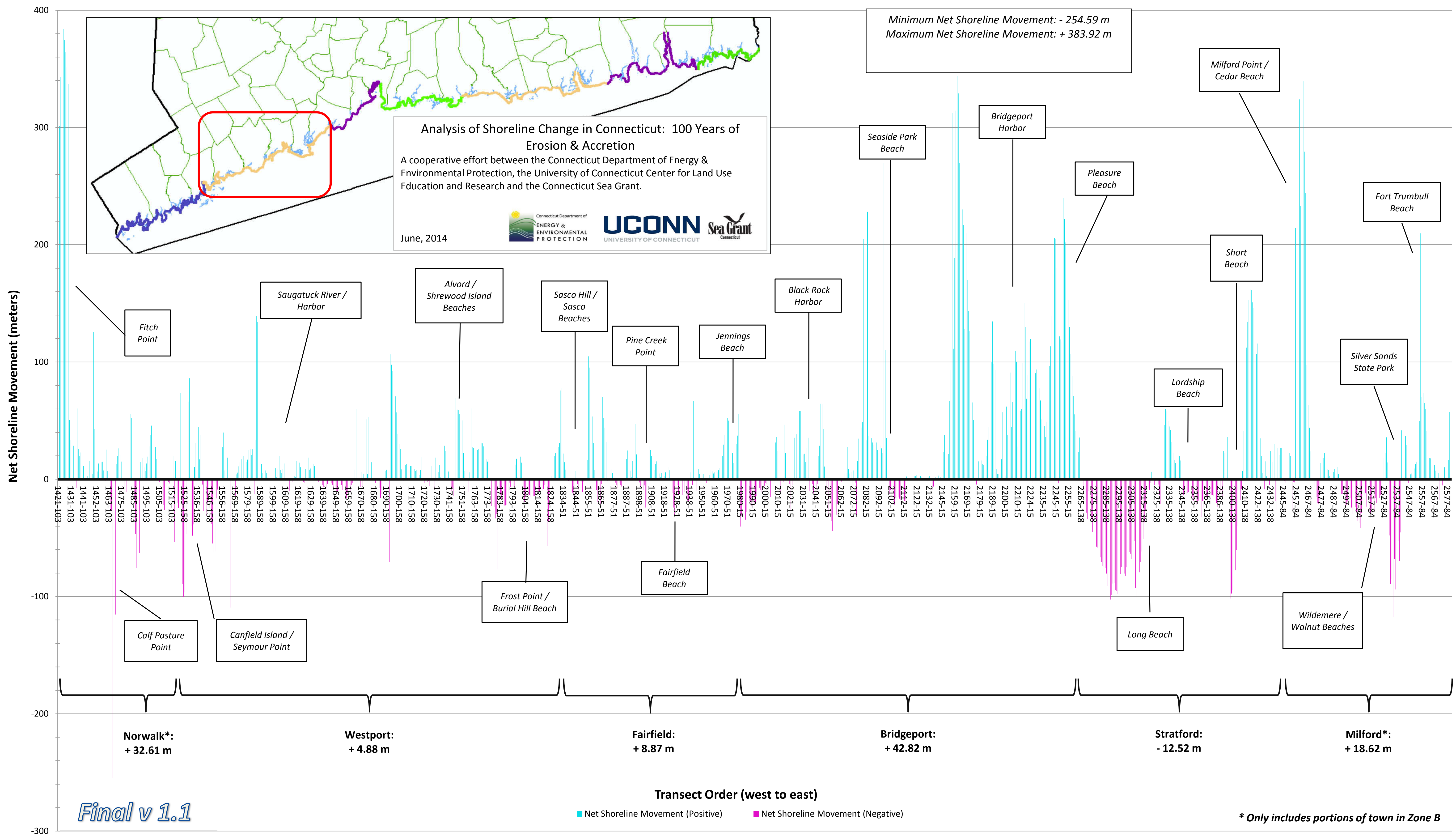
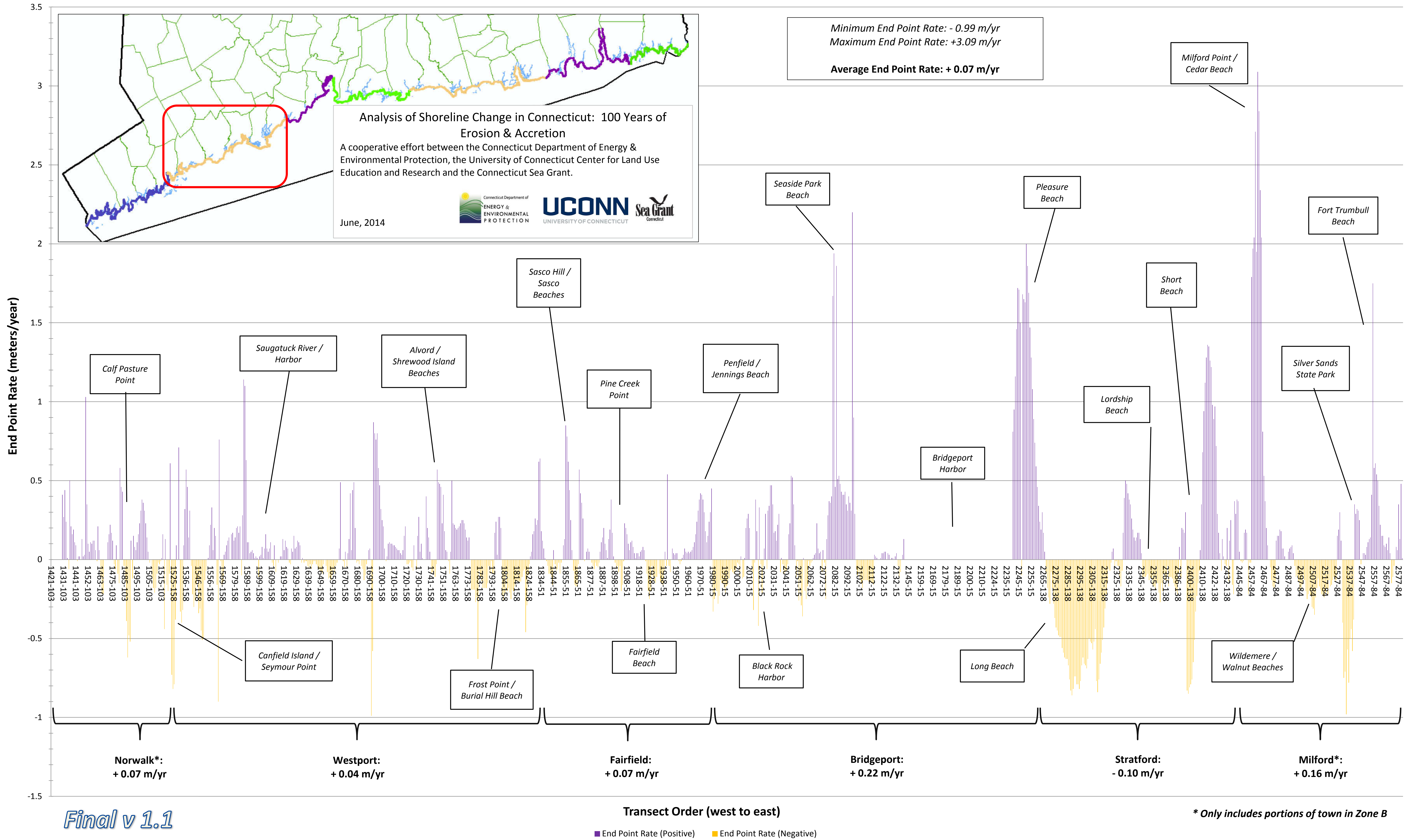
End Point Rate (meters/year)
2
1.5
1
0.5
0
-0.5
-1
-1.5
Byram Harbor
Greenwich Harbor
Indian Harbor
Cos Cob Harbor
Greenwich Cove
Dolphin Cove
Stamford Harbor
Shippan Point
Darien River
Scott Cove
Five Mile River
Wilson Cove
Manressa Island
Norwalk River
Byram Point
Field Point
Greenwich Point / Green wich Point Beach
Cook Point
West Beach / Cummings Beach
Cove Island Beach / Weed Beach
Long Neck Point
Contentment / Butlers Islands
Roton / Noroton Point
Greenwich: + 0.04 m/yr
Stamford: + 0.05 m/yr
Darien: + 0.02 m/yr
Norwalk*: + 0.05 m/yr
Final v 1.1
Transect Order (west to east)
End Point Rate (Positive)
End Point Rate (Negative)
* Only includes portions of town in Zone A

Long Term (1880 - 2006) Net Shoreline Movement:
Zone B - Glacial Drift & Beaches



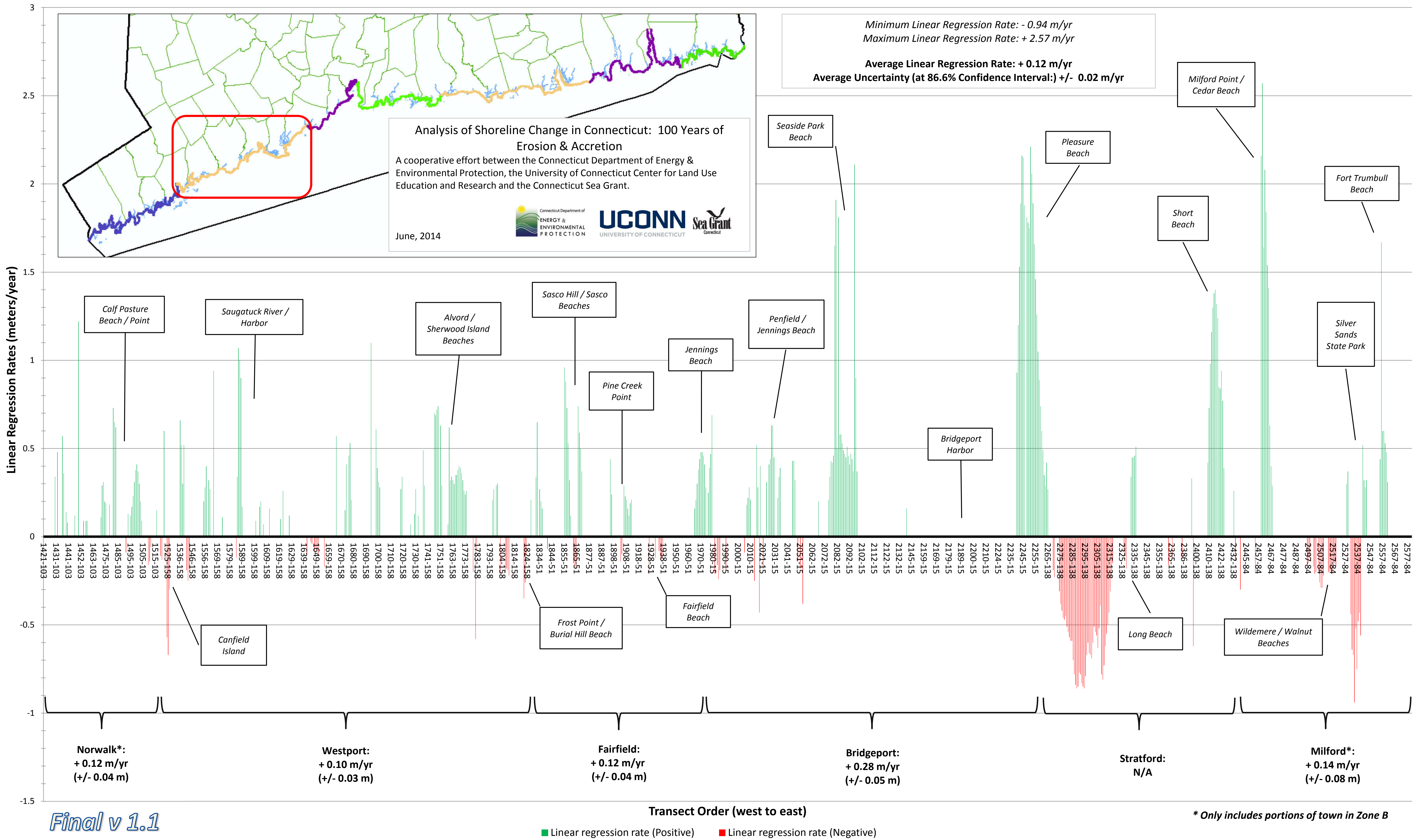
Long Term (1880 - 2006) End Point Rates:
Zone B - Glacial Drift & Beaches



Final v 1.1

*** Only includes portions of town in Zone B***

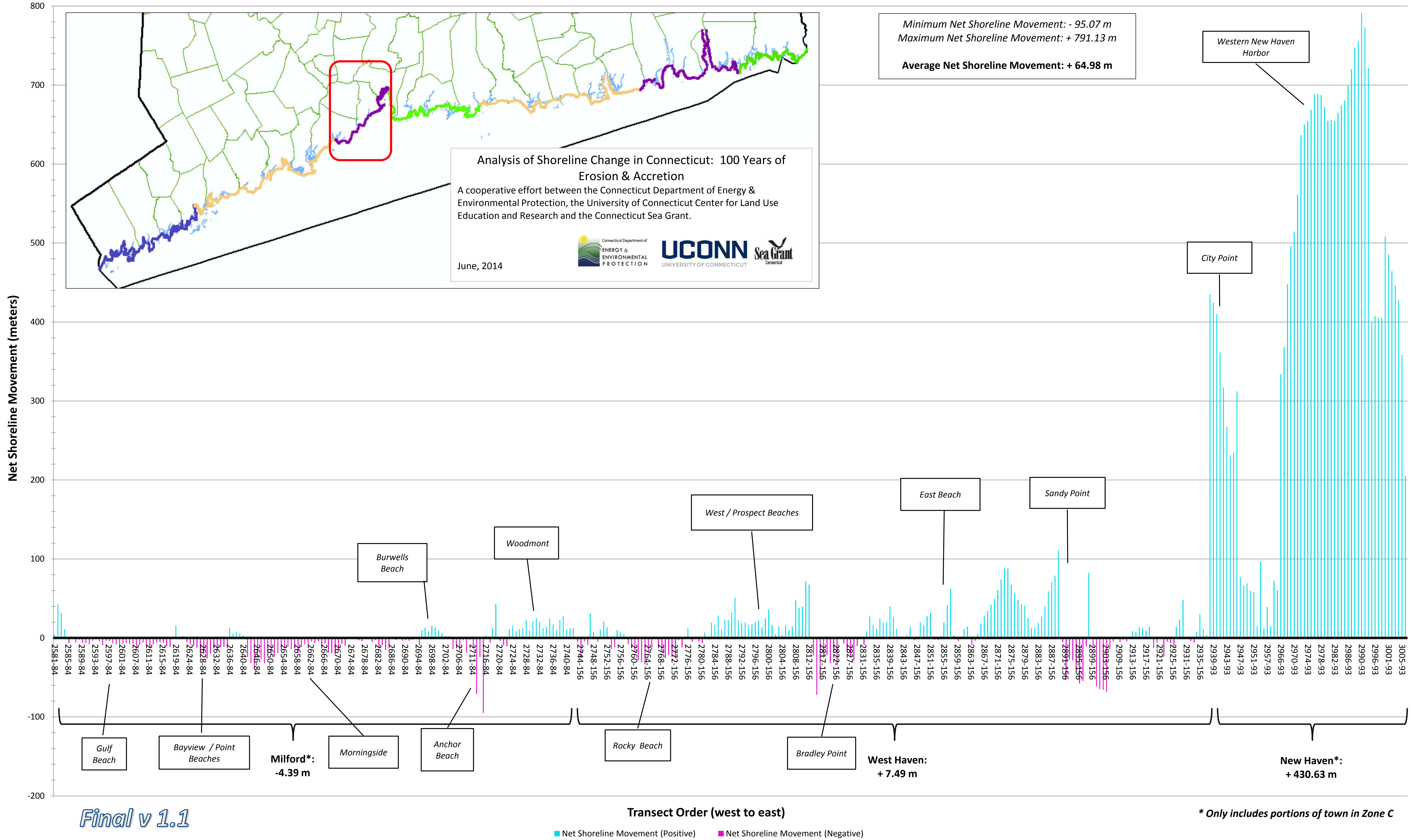
Long Term (1880 - 2006) Valid Linear Regression Rates:
Zone B - Glacial Drift & Beaches

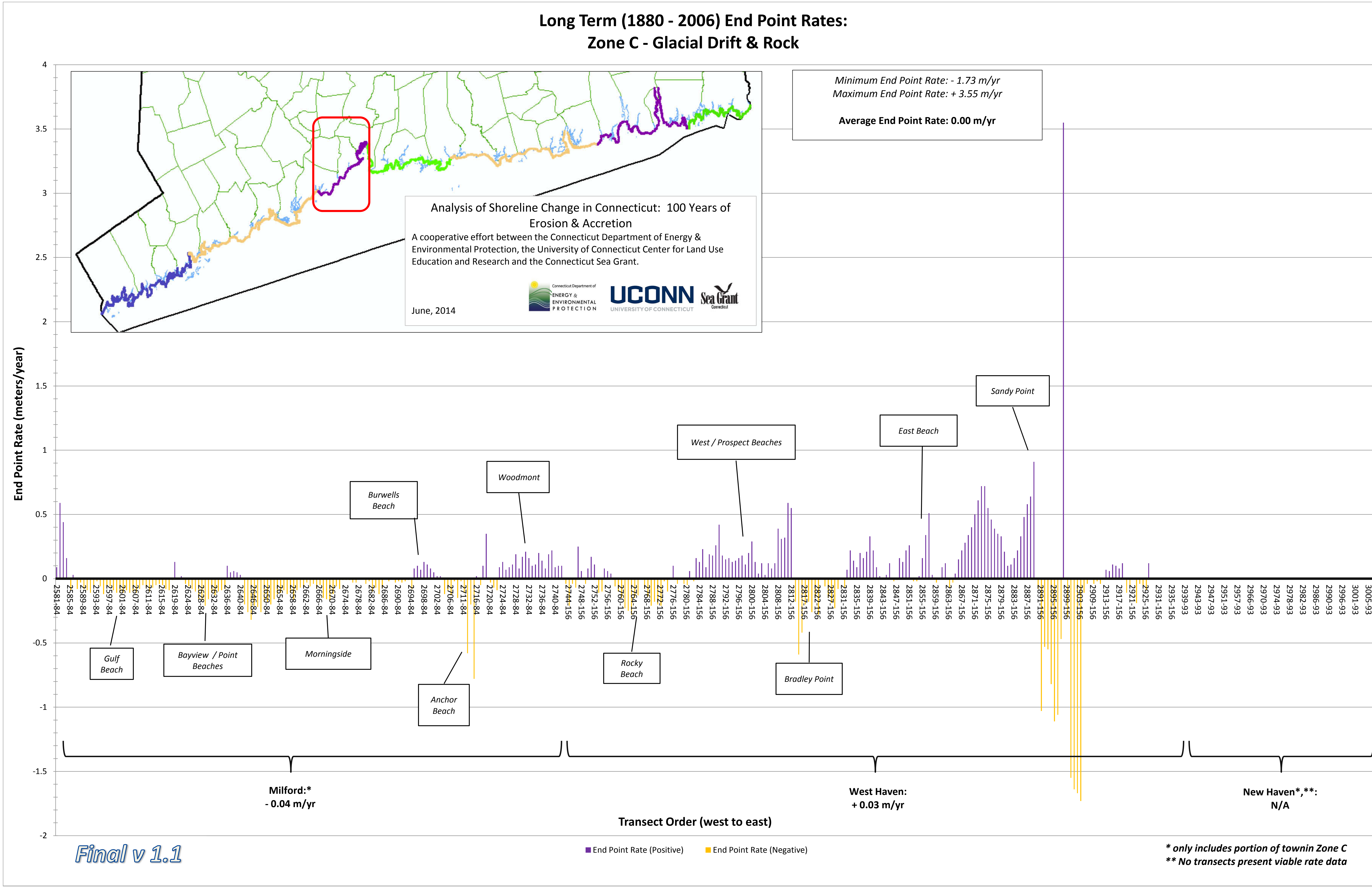


Final v 1.1

* Only includes portions of town in Zone B

Long Term (1880 - 2006) Net Shoreline Movement:
Zone C - Glacial Drift & Rock





Long Term (1880 - 2006) End Point Rates:
Zone C - Glacial Drift & Rock
Minimum End Point Rate: - 1.73 m/yr
Maximum End Point Rate: + 3.55 m/yr
Average End Point Rate: 0.00 m/yr
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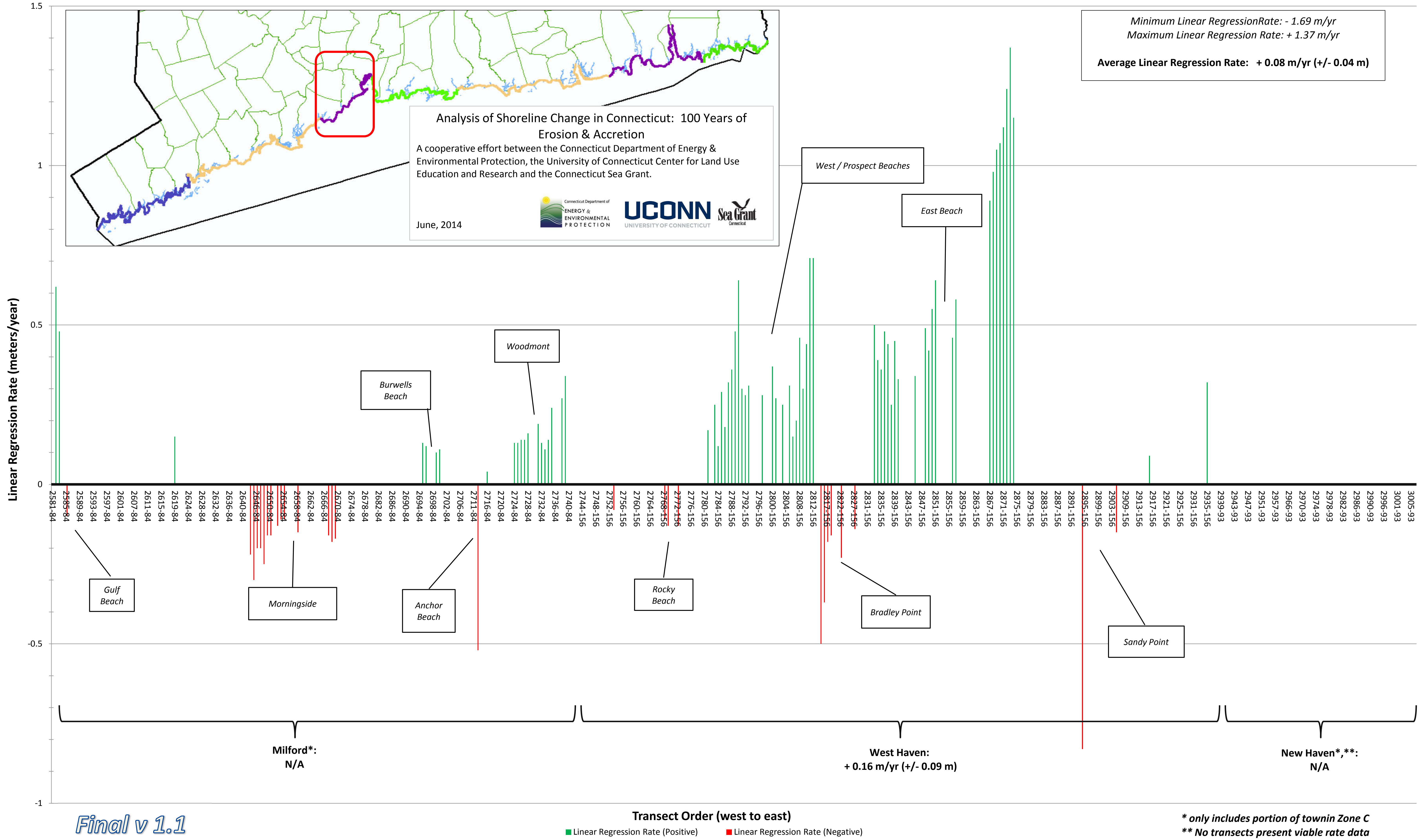
End Point Rate (meters/year)
Gulf Beach
Bayview / Point Beaches
Morningside
Anchor Beach
Burwells Beach
Woodmont
Rocky Beach
West / Prospect Beaches
Bradley Point
East Beach
Sandy Point
Milford:*
- 0.04 m/yr
West Haven:
+ 0.03 m/yr
New Haven*,**:
N/A
Transect Order (west to east)
Final v 1.1
End Point Rate (Positive)
End Point Rate (Negative)
* only includes portion of townin Zone C
** No transects present viable rate data

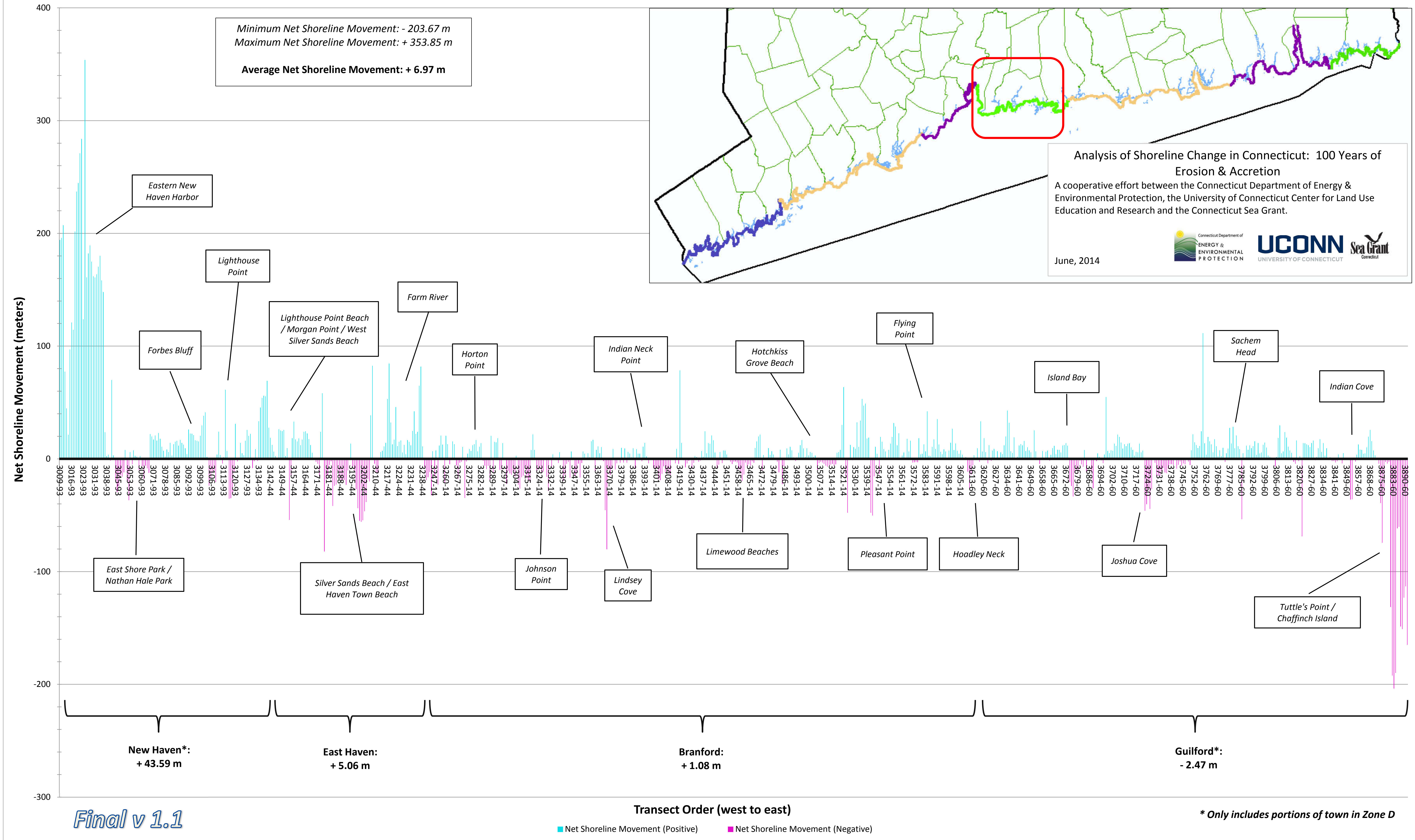
Long Term (1880 - 2006) Valid Linear Regression Rates:
Zone C - Glacial Drift & Rock



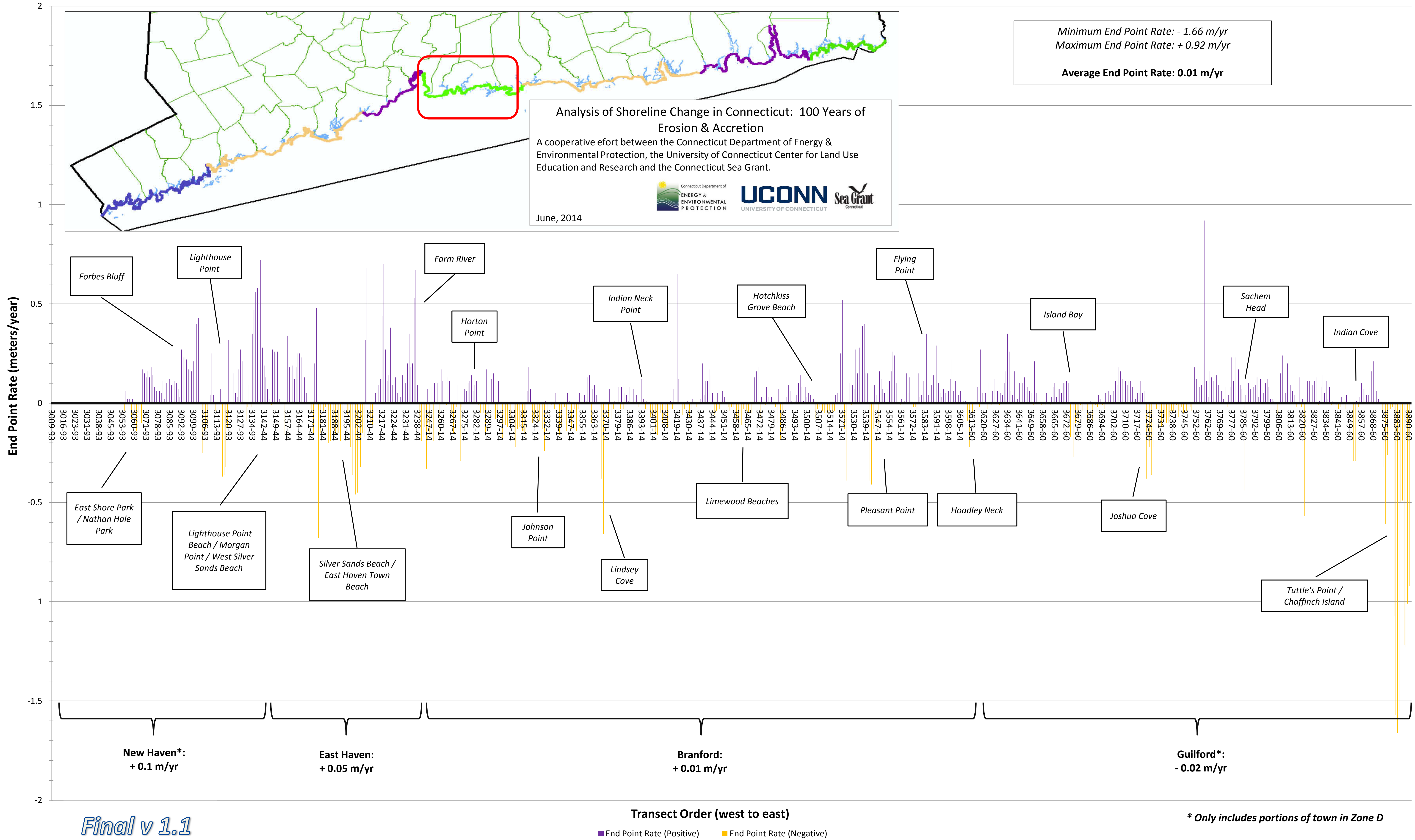
Final v 1.1

** only includes portion of townin Zone C*
*** No transects present viable rate data*

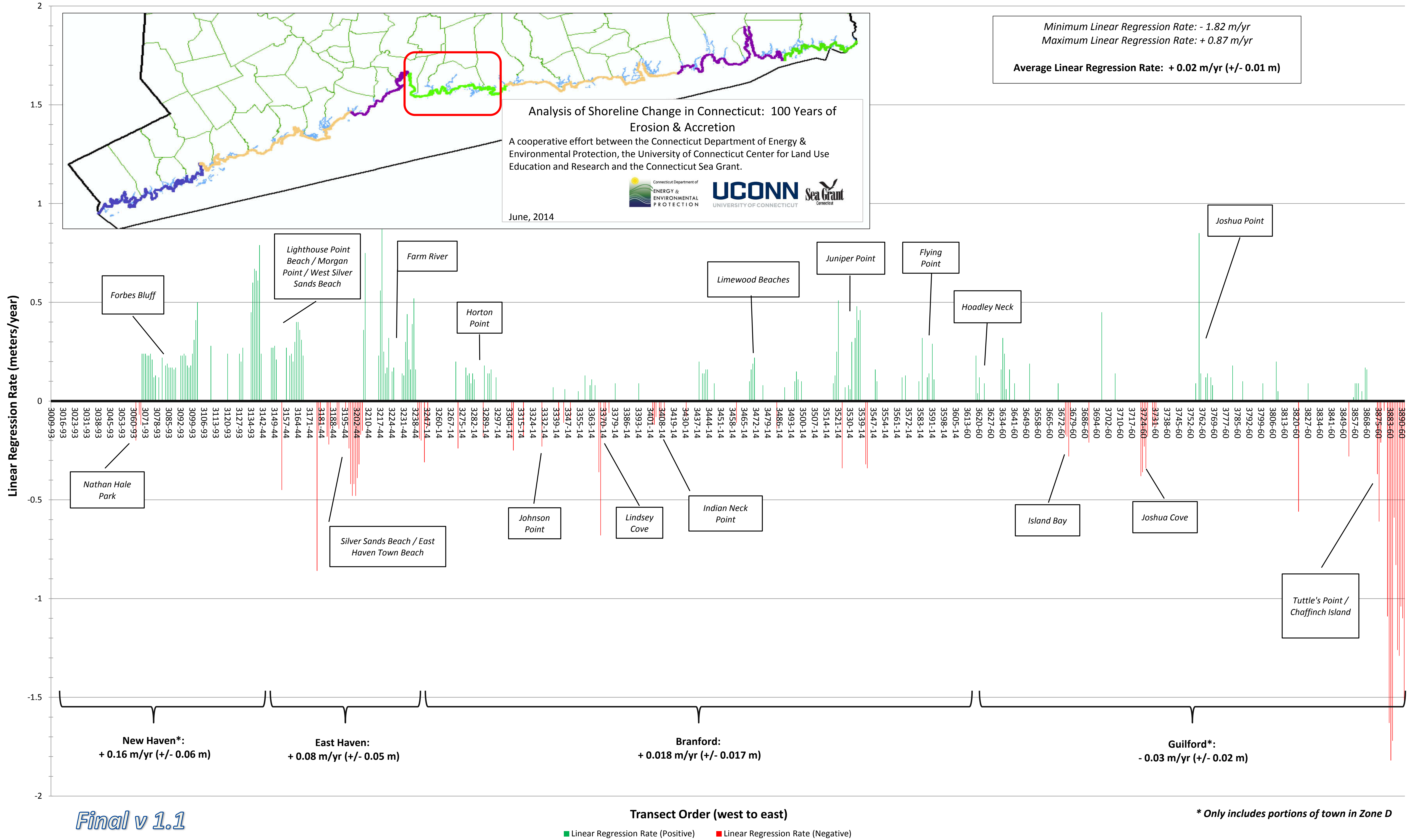
Long Term (1880 - 2006) Net Shoreline Movement:
Zone D - Rock & Marshes



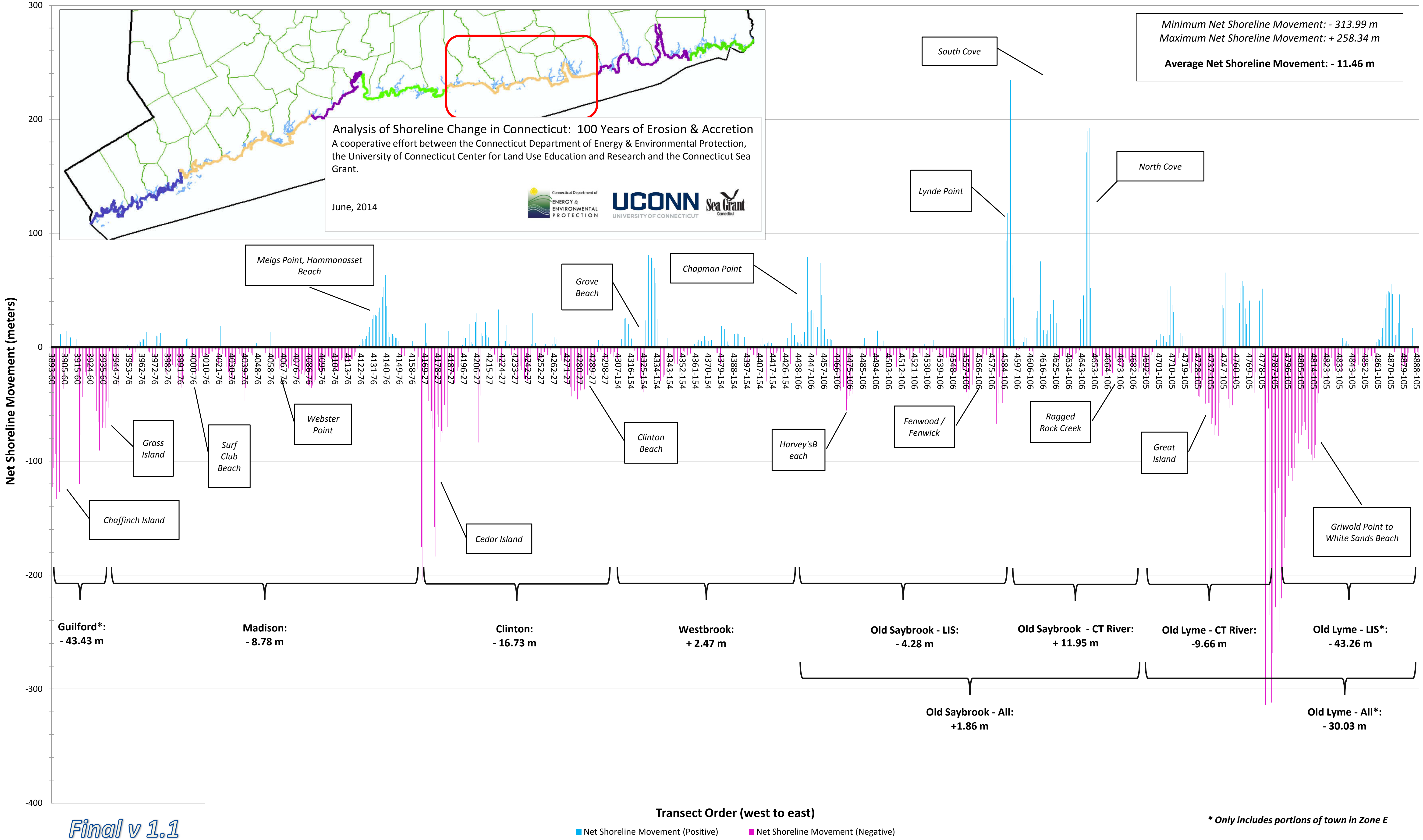
Long Term (1880 - 2006) End Point Rate:
Zone D - Rock & Marshes



Long Term (1880 - 2006) Valid Linear Regression Rates:
Zone D - Rock & Marshes



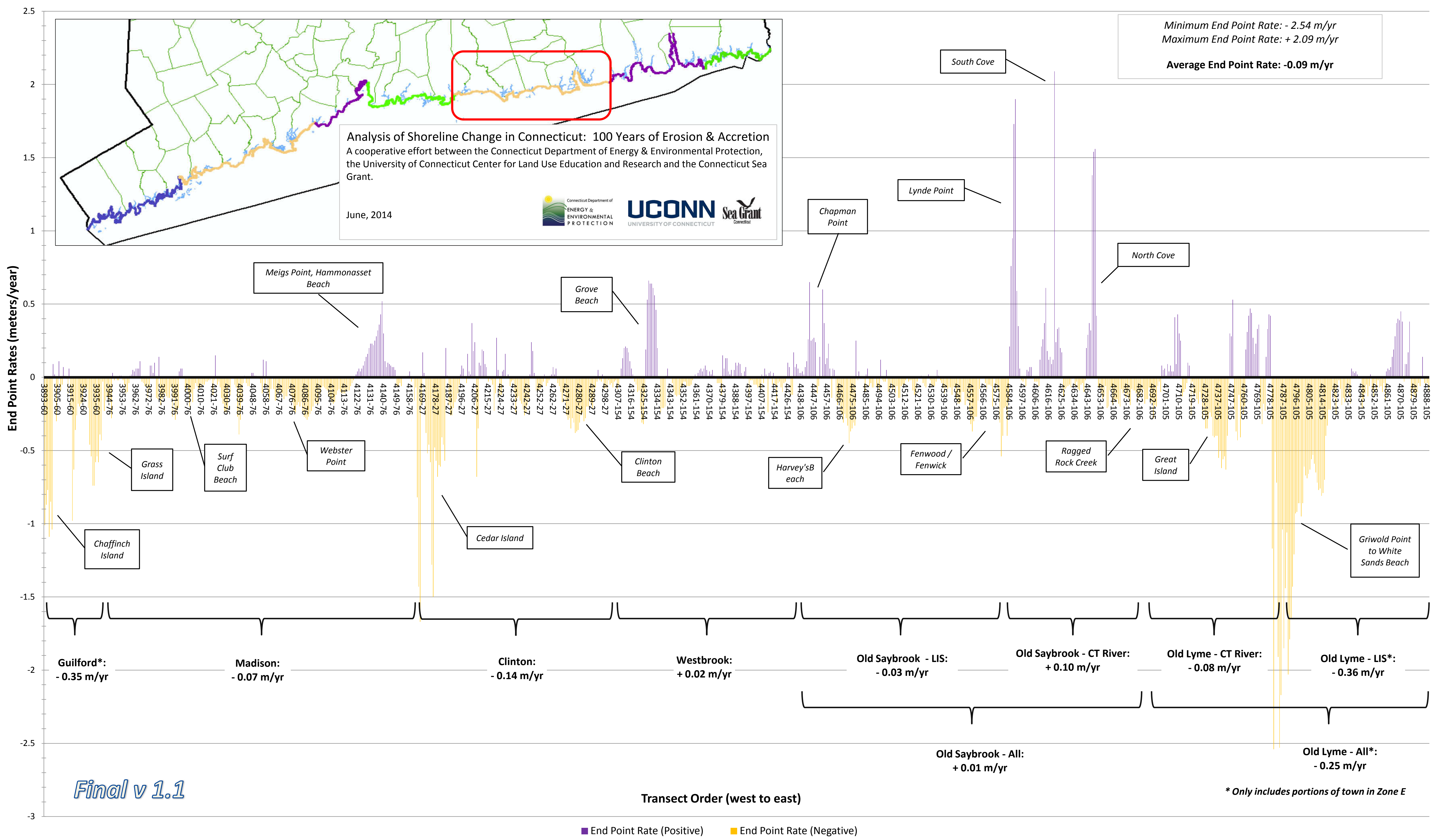
Long Term (1880 - 2006) Net Shoreline Movement:
Zone E - Glacial Drift & Beaches



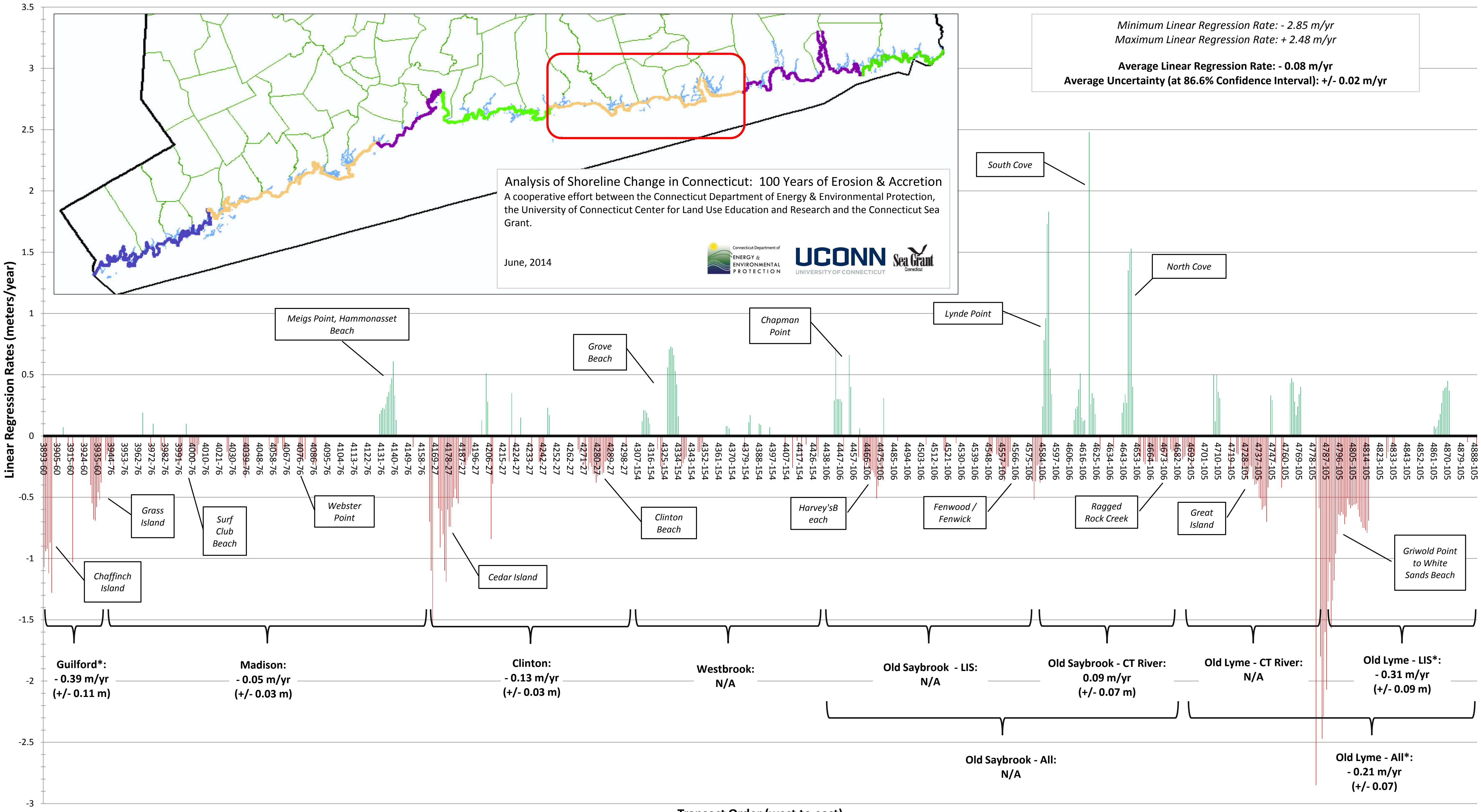
* Only includes portions of town in Zone E

Final v 1.1

Long Term (1880 - 2006) End Point Rates:
Zone E - Glacial Drift & Beaches



Long Term (1880 - 2006) Valid Linear Regression Rates:
Zone E - Glacial Drift & Beaches

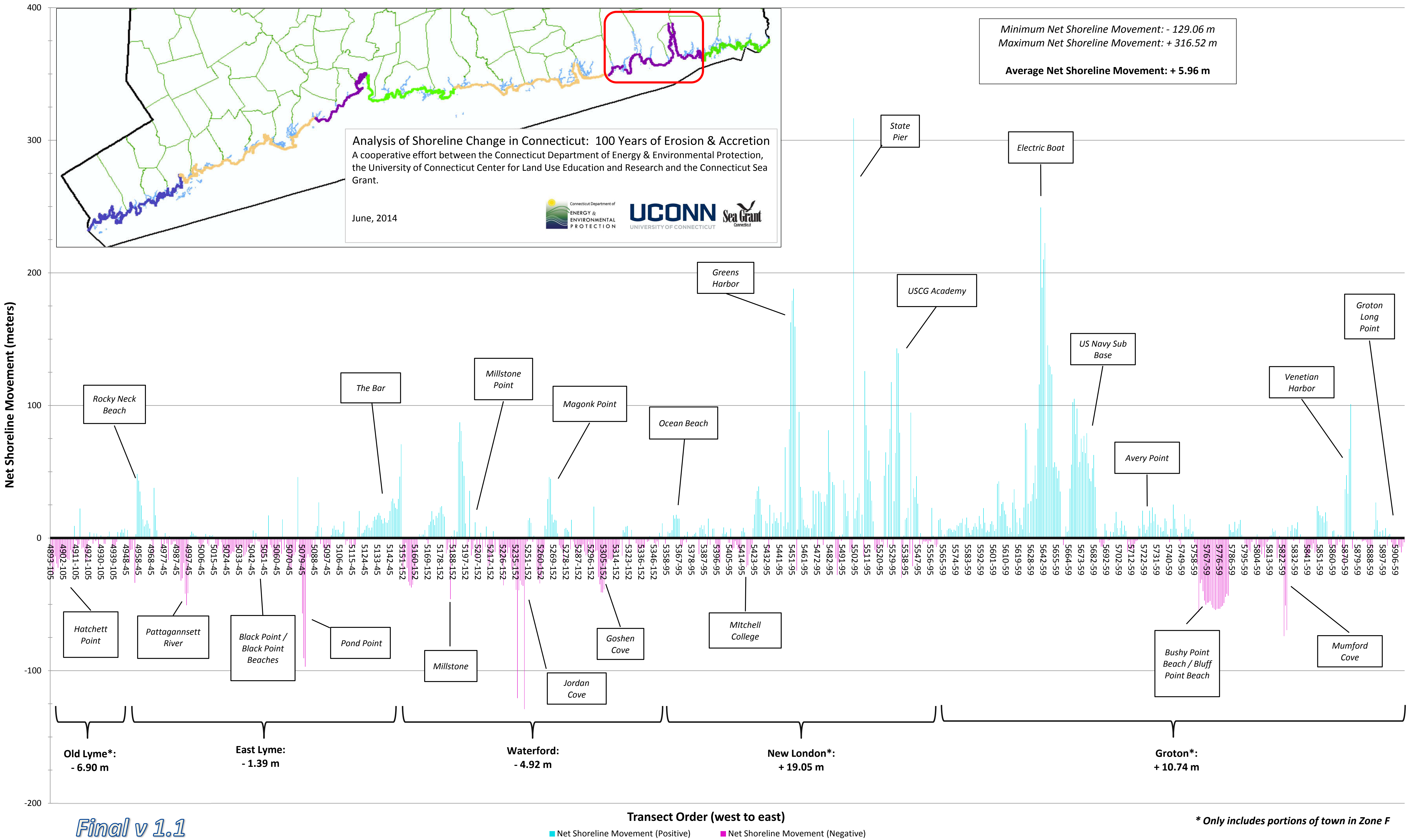


Final v 1.1

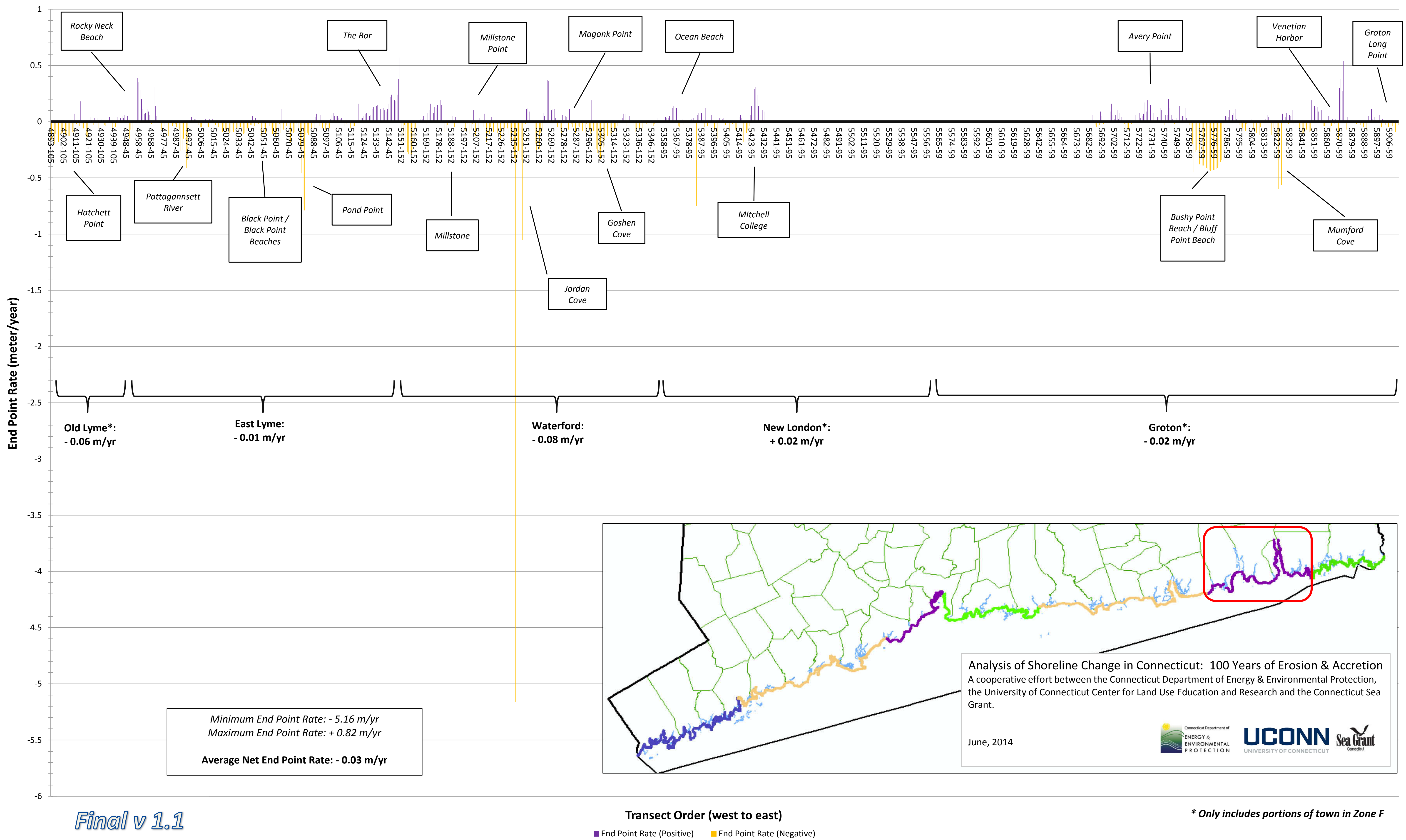
* Only includes portions of town in Zone E

■ Linear regression rate (Positive) ■ Linear regression rate (Negative)

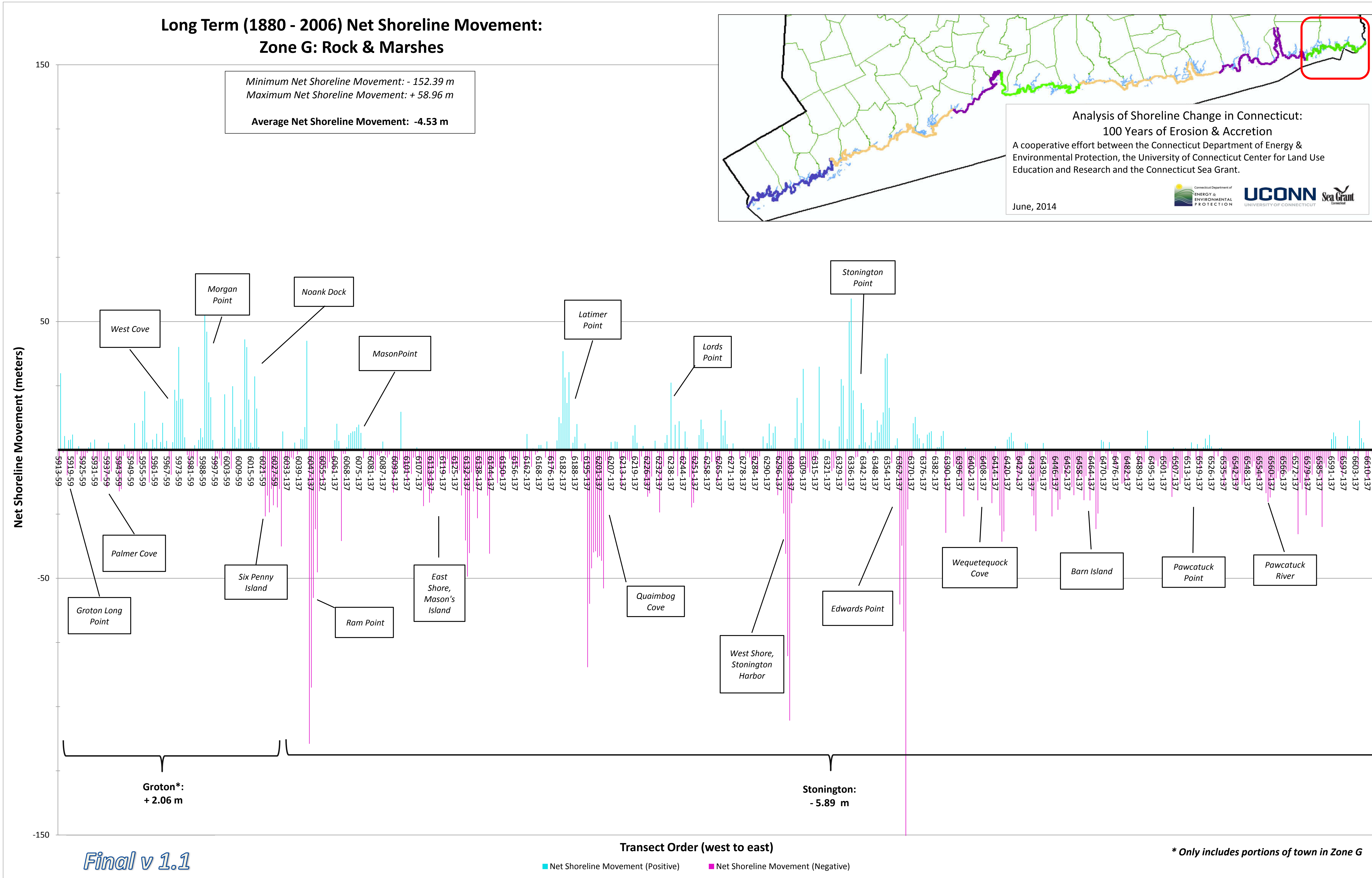
Long Term (1880 - 2006) Net Shoreline Movement:
Zone F - Glacial Drift & Rock



Long Term (1880 - 2006) End Point Rate:
Zone F - Glacial Drift & Rock



Final v 1.1


Long Term (1880 - 2006) Net Shoreline Movement:
Zone G: Rock & Marshes
Minimum Net Shoreline Movement: - 152.39 m
Maximum Net Shoreline Movement: + 58.96 m
Average Net Shoreline Movement: -4.53 m
Analysis of Shoreline Change in Connecticut:
100 Years of Erosion & Accretion
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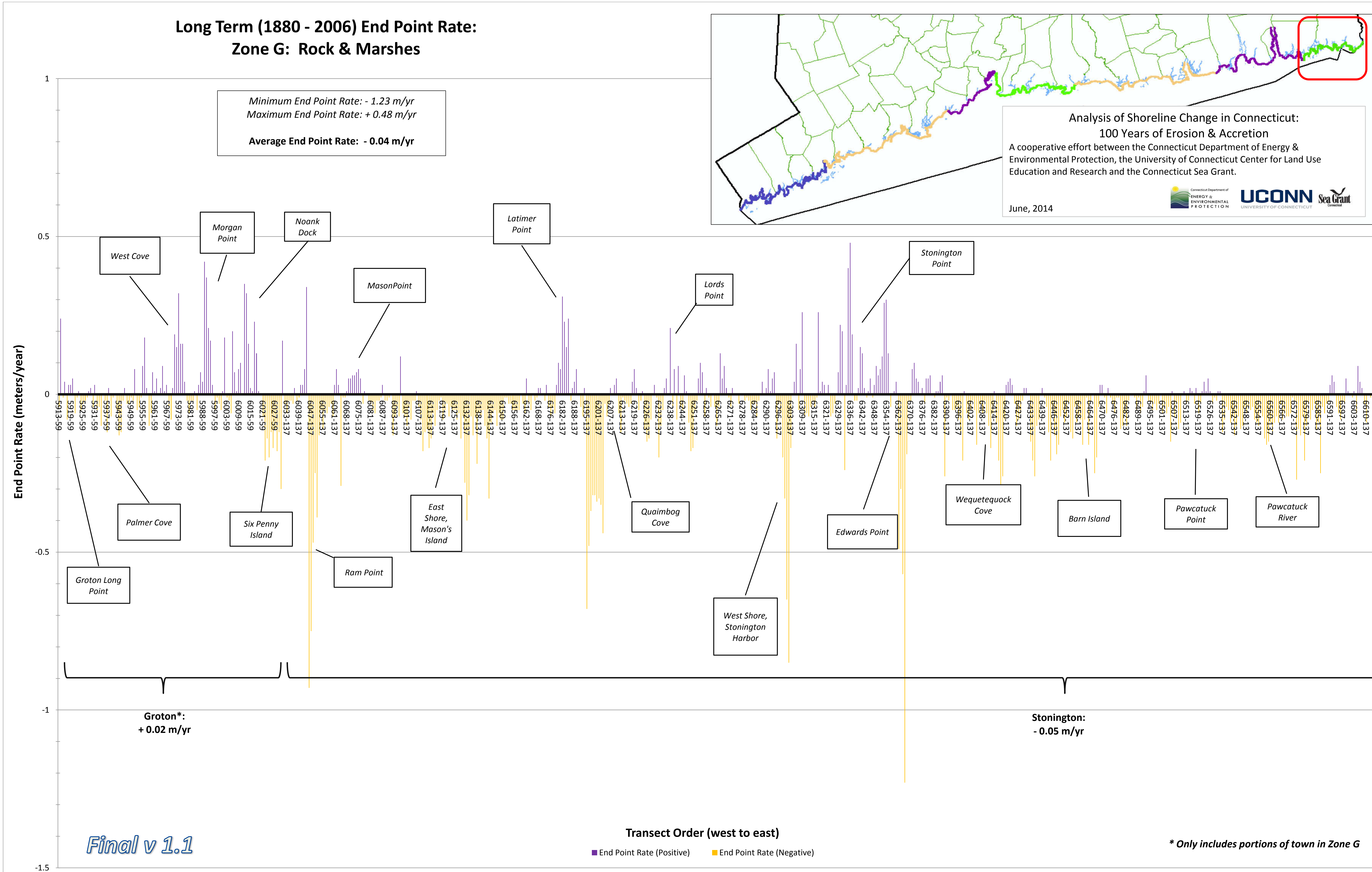
150
50
-50
-150
Net Shoreline Movement (meters)
West Cove
Morgan Point
Noank Dock
MasonPoint
Latimer Point
Lords Point
Stonington Point
Groton Long Point
Palmer Cove
Six Penny Island
Ram Point
East Shore, Mason's Island
Quaimbog Cove
West Shore, Stonington Harbor
Edwards Point
Wequetequock Cove
Barn Island
Pawcatuck Point
Pawcatuck River
Groton*:
+ 2.06 m
Stonington:
- 5.89 m
Transect Order (west to east)
Net Shoreline Movement (Positive)
Net Shoreline Movement (Negative)
* Only includes portions of town in Zone G
Final v 1.1


Long Term (1880 - 2006) End Point Rate:
Zone G: Rock & Marshes
Minimum End Point Rate: - 1.23 m/yr
Maximum End Point Rate: + 0.48 m/yr
Average End Point Rate: - 0.04 m/yr
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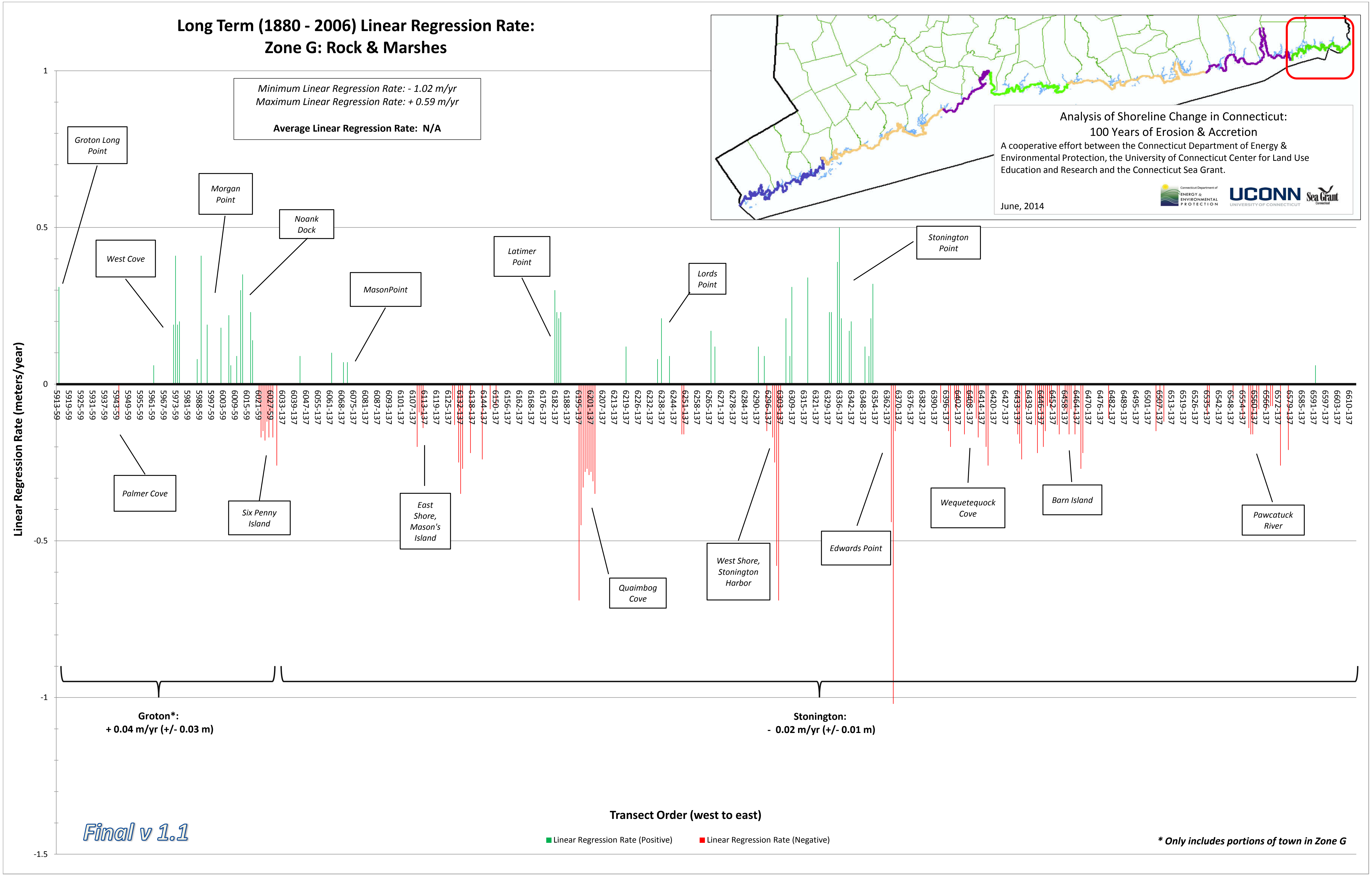
End Point Rate (meters/year)
1
0.5
0
-0.5
-1
-1.5
West Cove
Morgan Point
Noank Dock
MasonPoint
Latimer Point
Lords Point
Stonington Point
Groton Long Point
Palmer Cove
Six Penny Island
Ram Point
East Shore, Mason's Island
Quaimbog Cove
West Shore, Stonington Harbor
Edwards Point
Wequetequock Cove
Barn Island
Pawcatuck Point
Pawcatuck River
Groton*:
+ 0.02 m/yr
Stonington:
- 0.05 m/yr
Transect Order (west to east)
End Point Rate (Positive)
End Point Rate (Negative)
Final v 1.1
* Only includes portions of town in Zone G


Long Term (1880 - 2006) Linear Regression Rate:
Zone G: Rock & Marshes
Minimum Linear Regression Rate: - 1.02 m/yr
Maximum Linear Regression Rate: + 0.59 m/yr
Average Linear Regression Rate: N/A
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Linear Regression Rate (meters/year)
1
0.5
0
-0.5
-1
-1.5
Groton Long Point
West Cove
Morgan Point
Noank Dock
MasonPoint
Latimer Point
Lords Point
Stonington Point
Palmer Cove
Six Penny Island
East Shore, Mason's Island
Quaimbog Cove
West Shore, Stonington Harbor
Edwards Point
Wequetequock Cove
Barn Island
Pawcatuck River
Groton*:
+ 0.04 m/yr (+/- 0.03 m)
Stonington:
- 0.02 m/yr (+/- 0.01 m)
Transect Order (west to east)
Final v 1.1
Linear Regression Rate (Positive)
Linear Regression Rate (Negative)
* Only includes portions of town in Zone G