<u>Scenic Hudson GIS Methodology for Mapping Sea Level Rise</u>

The Hudson River Estuary is tidally influenced from New York City to the Troy dam. The 2100 NYS Commission Report has projected that sea level in the rivercould rise up to 72” by the year 2100. In order to better understand the impact of rising Hudson River water levels, Scenic Hudson has prepared a GIS modeltomapthe extent of predicted future inundation and flooding, and to identify potential natural and cultural features at risk.

Sea Level Rise Projections

While there is a strong consensus that the Hudson River will rise, there is disagreement among different scientific models on the exact amount of that rise for specific locations and timeframes.Inundation depths below show the central range (middle 67%) of model-based probabilities and a rapid ice melt scenario,[i] as identified in the NYS Sea Level Rise Task Force Report (2010) and the NYS 2100 Commission Report (2013).[ii]

North of Kingston	*2020's*	*2050's*	*2080's*	*2100*
Central Range	1"-4"	5"-9"	8"-18"	11-26"
Rapid Ice Melt	4"-9"	17"-26"	37"-50"	52"-68"
Kingston & South	*2020's*	*2050's*	*2080's*	*2100*
Central Range	2"-5"	7"-12"	12"-23"	15-30"
Rapid Ice Melt	5"-10"	19"-29"	41"-55"	56"-72"

Beyond the lack of consensus among different models, sea level rise projections are also likely to change over time with new data and improvements in scientific models. Because of that, Scenic Hudson’s model identifies water levels at multiple depth steps that can correlate to different models. Scenic Hudson maps current Hudson River water levels and 6” incremental increases up to 72,” covering current projectionsto the year 2100. The web mapper graphically depicts howtimeline projections overlap with differentinundation depth levels.

Water level datum information

Prior to inundation modeling, it is important to identify a consistent water level datum to be used in future projections. There are multiple water level datum variables, as the Hudson River experiences significant tidal variations. In some locations, there is a tidal range of more than 6’ between low and high tide. Mean higher-high water (MHHW)datum elevations are also inconsistent along the river, ranging from a low of 2.29’ at West Point to a high of 4.29’at the Troy dam.[iii]

Tidal Datum Data in Feet (NAVD88)[iv]

	Latitude	MHHW	Tidal Range[v]
The Battery	40.70033484	2.754	4.773
West Point	41.38480889	2.288	3.429
Poughkeepsie	41.65108596	2.644	3.676
Kingston	41.91819771	3.001	4.087
Athens	42.27712907	3.330	4.650
Albany	42.64524235	4.181	5.966
Troy	42.73455781	4.290	6.117

Scenic Hudson models inundation levels from a base condition of MHHW. MHHW is the mean value for the highest tide each day, averaged over a 19-year period. In loose terms, this reflects the farthest recurring inland extent of water for any location. Plant communities and infrastructure patterns are significantly different under regular inundation than those that are consistently dry. In that respect, MHHW is a logical starting point for modeling sea level rise over time.

Inundation modeling

Scenic Hudson's inundation layer is a "modified-bathtub" model of current and potential future Hudson River inundation zones.[vi]The extent of each vertical 6" increase in inundation above MHHW is modeled up to a level of 72." These levels can be directly related to sea level rise timeline projections.

Methodology:

The inundation zones were created using the following steps:

1) Create a continuous surface for MHHW elevation
2) Overlay MHHW surface with high resolution LiDAR data to map the current extent of MHHW
3) Model each 6" increase above MHHW to an elevation of 72"
4) Distinguish and remove non-contiguous low-lying areas

Scenic Hudson created a continuous surface of MHHW elevations using research from Roger Flood of Stony Brook University. In his research, Roger identified tidal datum elevations at 11 locations along the Hudson River from Manhattan to the Troy dam. Scenic Hudson mapped MHHW levels at those locations and interpolated vertical elevations throughout the estuary using data from those points.

Scenic Hudson then calculated the difference between the MHHW elevation surface and 2012 LiDAR elevation data provided by the NYS DEC – Hudson River Estuary Program. The result is a consistent elevational model of MHHW, where values of zero and below depict the current geographic exact extent of MHHW, and positive values reflect the elevational difference of any location above MHHW. Those positive values were then reclassified to represent each 6" incremental water level up to 72." Raster values of 6-72 represent inches above MHHW, while 0 represents the current extent of MHHW.

Because the model is based on elevation, there is the possibility for low-lying areas that are not contiguous with the river to be identified as inundation. If areas do not become connected to the larger river, however, they are not likely to be inundated at high tide, and should not be considered inundated in the model. LiDAR data provides excellent high-resolution elevation data, but it does not account for culverts and underground water connections. If there is a culvert connecting the larger river to a seemingly non-contiguous adjacent area, then that area would be inundated in the same way as the larger river. To account for this, Scenic Hudson completed a remote investigation of all mapped non-contiguous low-lying areas using LiDAR data, high resolution aerial photographs, and bird's-eye perspective photographs. In locations where the data appeared to indicate an underground water connection, the data was artificially connected in the model, allowing adjacent areas to be considered contiguous and inundated. Non-contiguous unconnected areas were distinguished as separate low-lying areas and have been removed from this data set.

Floodplain modeling

Beyond the risk of permanent inundation, the estuary also faces risk of increased coastal flooding associated with sea level rise. Scenic Hudson's flood layer is a model of current and potential future 1% risk (100 year) floodplain zones matching corresponding levels of inundation predicted due to sea level rise. The model identifies the current extent of flooding using FEMA Base Flood Elevations (BFE's) and models the extent of each 6" vertical increase up to a level that would correspond with 72" of inundation. Raster values of 6-72 represent the extent of the flood zone at the corresponding level (in inches) of inundation, while 0 represents the modeled current extent of the 1% risk flood zones. These levels can be directly related to sea level rise timeline projections outlined in the NYS Sea Level Rise Task Force Report (2010) and the NYS 2100 Commission Report (2013) as summarized below.

Scenic Hudson modeled potential flood zones using the following steps:

1) Create a continuous elevational surface of current FEMA Base Flood Elevations (BFE's)
2) Overlay BFE continuous surface with high resolution LiDAR data to map the current extent of flooding
3) Model each 6" increase above current BFE's to an elevation of 72."

Scenic Hudson created a continuous elevational surface for current FEMA BFE's. BFE's represent the current elevations at any location that have a 1% risk of flooding. Scenic Hudson created a complete dataset of Hudson River BFE's.[vii] FEMA data identifies BFE's by county for the Hudson River and for significant tributaries. For the purposes of the model, only the BFE's associated with the Hudson River were used. While there are components of climate change that may affect tributaries, the scope of this study focuses specifically on the geography and impacts of the rising Hudson River. In that regard, river BFE's were extended outward from the river and a consistent current BFE surface was interpolated. A continuous Hudson River BFE elevational surface was created by interpolating elevations between the combined BFE data points from FEMA flood data.

Scenic Hudson then calculated the difference between the BFE elevational surface and 2012 LiDAR elevation data provided by the NYS DEC. The result is a consistent elevational model of 1% risk flood elevations, where values of zero and below depict the current geographic exact extent of flooding, and positive values reflect the elevational difference of any location above current flood zones. Those positive values were then reclassified to represent each 6” incremental flood level up to 72.” The result is a series of 1% risk flood zones that correspond with each 6” incremental step in inundation due to predicted sea level rise. Please note that this data set is an elevational model for the purpose of estimating sea level rise impacts only. This data set is completely independent from current FEMA 100-year floodplain polygon data and should not be used as a substitute or replacement for any floodplain mapping done by FEMA.

Cultural and Infrastructure Overlays

Scenic Hudson’s GIS model maps 13 different incremental steps for inundation and for increased coastal flooding. Using the geographic extent of that data, it is easy to identify the potential natural and cultural resources at riskfor each of those steps based on the impacts of sea level rise.

2010 Census block data was overlain with modeled inundation and 1% risk flood zones to estimate the number of people and households at risk for inundation and flooding at each 6" increase in sea level rise.[viii]The spatial extent of census blocks does not match cleanly at the boundaries of the inundation and flood zones, however. To estimate census data for small areas, Scenic Hudson used areal weighting from census block polygons. Areal weighting allocates census data to target zones based on their proportion of the source zone's area. This method assumes an even distribution of population across the source and target zones.[ix] From this method of interpolation, population and household counts were estimated in each census block for 13 levels of inundation and flooding (corresponding with 0-72" inundation steps in 6" increments). Data from individual blocks were then summed by community. In the spatial overlay for flooding at each depth step, Scenic Hudson specifically excluded those areas inundated at that depth step. For example, at 36" of sea level rise, the census estimates for inundation include all block statistics from an overlay with inundation. At the same 36" of sea level rise, the census data for flooding includes all block statistics from an overlay with flooding, except for areas that are already inundated at 36." This manner allows a combined estimation of all people and households at risk without duplicating statistics.

Additional data shown on Scenic Hudson’s Sea Level Rise Web Mapper includes submerged aquatic vegetation, tidal wetlands, libraries, schools, and hazards (DEC brownfields, EPA regulated facilities, and wastewater treatment plants). Each of these data sets can be overlain with modeled inundation and flood zones to identify resources at risk to sea level rise.[x]

Summary

Scenic Hudson’s GIS model uses high resolution LiDAR data, current datum information, sea level rise projections, and overlays with natural and cultural resources to identify some of the Hudson Valley resources at risk by the year 2100 based on sea level rise. As the results indicate, there are many important resources at risk. With this data, communities can begin to assess the extent of these risks, and plan for options in coastal resiliency and adaptation. Each community and every situation is different, and this data is just the first part of the equation. For more information on the data, risks, and adaptation options, please contact Dr. Sacha Spector (Director of Conservation Science) or Jason Winner (Conservation GIS Manager) at Scenic Hudson.

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[i] The rapid-ice melt scenario is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic Ice sheets and paleoclimate studies.

[ii] The NYS Sea Level Rise Task Force Report is available at http://www.dec.ny.gov/energy/67778.html and the NYS 2100 Commission Report is available at http://www.rockefellerfoundation.org/blog/nys-2100-commission-report-building.

[iii] Elevations in feet, NAVD88.

[iv] All numbers derived from tidal datum data of September-October 2006, as identified by "Determining a MLLW Datum and Merging of Fugro and Bathymetric Coverages in the Upper Hudson River Estuary," Roger Flood, Stony Brook February 2011.

[v] Tidal range in this case refers to the great diurnal tidal range, which calculates the difference between MHHW and MLLW.

[vi] Thanks to the NOAA Coastal Services Center who use a similar methodology for inundation modeling and helped Scenic Hudson in the development of this model.

[vii] Linear lines for BFE's gathered from Digital Flood Insurance Rate Maps (DFIRM's) where available and from Q3 Digital Flood Zone Data in other locations. DFIRM's (2007-2013) include Dutchess, Greene, Orange, Putnam, Ulster, and Westchester Counties. Q3 data (published 1996 from 1979-1989 original maps) include Albany, Columbia, Rensselaer, and Rockland Counties.

[viii] 2010 census block data for people and households downloaded in March 2013 from http://factfinder2.census.gov/.

[ix] From "A Comparative Analysis of Areal Interpolation Methods," Cartography and Geographic Information Science, 32:411–423, Hawley and Moellering, 2005.

[x] Data sources as follows: Submerged Aquatic Vegetation (NYS DEC Hudson River Estuary Program) http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1208, Tidal Wetlands (NYS DEC Hudson River Estuary Program) http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1210, NYS Towns, Cities, and Villages (NYS Office of Cyber Security) http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=927, Libraries (NYS Education Department) http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=410, Schools (NYS Education Department) http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=415 and (NYS Office of Real Property Services) http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=431, Remediation Sites (NYS DEC) http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=1097, and EPA Regulated facilities (US EPA) http://www.epa.gov/region02/gis/data.htm#facilities.