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A CHANGE IN TIDE: A NEW APPROACH FOR TIDE FORECASTS AND COASTAL FLOOD WARNINGS

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ABSTRACT

Tide forecasts have been a crucial component for marine navigation for centuries, and more recently greater attention has been placed on impacts of coastal inundation due to population increases along the immediate shoreline and concerns over potential sea level rise. The National Weather Service (NWS) issues Coastal Flood Warnings, but the process has lacked consistency and specificity. This paper addresses a multifaceted process designed to enhance the value of Coastal Flood Warnings.

This work has been an offshoot of an initiative sponsored by the North Atlantic Regional Team (NART) and has focused on New England pilot communities. However, the techniques described in this paper are more broadly applicable. Extratropical storms (mostly nor'easters) have a more frequent impact on the New England coastline, and this work has focused primarily on coastal flooding from nor'easters.

An important premise of this paper is that forecasters can and do add value over model data in making coastal flood decisions. The process for routine tide forecasts and non-routine coastal flood warnings favor forecaster interaction with model surge forecast data via the Gridded Forecast Editor (GFE). Forecasters use GFE to modify model surge predictions as appropriate and then employ a GFE SmartTool that produces a total water level by combining astronomical tide with the forecaster-modified surge predictions. An internal Total Water Level (TWL) product highlights any coastal flood impacts by checking customized tables of impacts as a function of both predicted wave height and water level (derived from prior studies and forecasters' anecdotal experience). The definitions of minor, moderate, and major coastal flooding impacts have been developed with the aim of standardizing terminology from one office to another.

A reference library of inundation maps is being developed for the southern New England coastline to help personalize the risk to the coastal population for various water level scenarios. Future work will involve the development of real time mapping with depictions of uncertainty, incorporation of wave run-up information, and seamless application to tropical scenarios.

1. Introduction

For centuries, mariners have depended upon day-to-day tide forecasts for various purposes, but especially for navigation. The day-to-day tide forecasts have generally been limited to astronomical tide predictions without consideration for weather induced departures. For decades, NOAA's National Weather Service has issued Coastal Flood Watches and Warnings. The warnings have covered long reaches of coastline with limited specificity. Through a North Atlantic Regional Team (NART) project to enhance coastal resiliency, there has been an effort to address these shortcomings of the legacy tide and coastal flood program.

This paper will describe a new process for routine tide forecasting that incorporates weather-based tidal departures and an entirely new process for producing Coastal Flood Warnings. Vallee and Notchey (2001) broke new ground by use of the Hydroview/RiverPro Software that allowed for more specific water level forecasts when a Coastal Flood Watch or Warning was issued. Building upon that success, the NWS Graphical Forecast Editor (GFE) has been employed to produce more meaningful tide forecasts and Coastal Flood Watches and Warnings. In addition, Geographic Information System (GIS) technology has been applied to highlight specific areas at risk through visualization techniques.

Coastal inundation risks have received increased attention recently as a consequence of high impact hurricanes such as Katrina in 2005 and documentation on both observed sea level rise (NOS 2006) and projected sea level rise (Pachuri and Reisinger [2007])'s contribution to the Intergovernmental Panel on Climate Change [IPCC] 4th assessment report). In addition, technology has advanced to enable better visualization of locations subject to inundation. For example, the Coastal Services Center (CSC) developed a series of reference library inundation maps for the Tar Heel Basin in the wake of Hurricane Floyd. More recently, the collaborative Chesapeake Bay Inundation Prediction System (CIPS) has demonstrated success with a hydraulic model that can provide street level inundation maps for both tropical and extratropical events (Stamey et al. 2007). This model correlated well with the inundation observed from Hurricane Isabel.

The work described in this paper is focused on extratropical cyclones that have impacted the New England coastline. New England, especially the south coast of Rhode Island and Massachusetts, is also vulnerable to tropical cyclones, even category 3 major hurricanes. Major hurricanes (e.g. hurricanes in 1635, 1867, 1815, 1938, and 1954) have wrought great havoc along the south coast of New England. There are some tools developed to assist with the tropical threat through the multi-agency (NWS, FEMA, and Corps of Engineers) Hurricane Evacuation Study (USACE 1995 and 1997), based on the Sea Lake Overland Surge from Hurricanes (SLOSH) model (see Jelesnianski et al. 1992). The Hurricane Evacuation Study identifies land areas that should be subject to evacuation for various intensities of hurricanes. A comparable tool does not exist for extratropical cyclones. Furthermore, wave action can be an important component to New England extratropical coastal flood events, and the sample of extratropical cyclone inundation events is significantly higher than that for tropical counterparts. For these reasons, our focus is on the extratropical storm surge threat along the New England coast.

2. Monitoring and guidance

Observed tide data are available from the National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) in addition to supplemental tide data from a select number of U.S. Army Corps of Engineers gages, and a relatively new and economical tide gage designed and installed by the Charybdis Group LLC (http://charybdisgroup.com) at Scituate Harbor, MA. Real-time storm surge guidance originates from gridded storm surge predictions from the NWS operational Extratropical Storm Surge (ETSS) model (Kim and Shaffer 1996 and Glahn et al. 2009). There is a plan, however, to also undertake a comparative verification study of water level forecasts that will include an Advance Circulation (ADCIRC) model for Coastal Ocean Hydrodynamics (employed at the University of Massachusetts at Boston; http://www.harbor1.umb.edu/forecast/model.html) and The Unstructured Grid Finite Volume Coastal Ocean Model or FVCOM (employed at the University of Massachusetts at Dartmouth; http://fvcom.smast.umassd.edu/research_projects/NECOFS/index.html). The ETSS model is available every six hours and incorporates input from the NWS Global Forecast System (GFS) atmospheric model (EMC 2003). The ETSS model has been observed to have a systemic low bias along the entire Rhode Island and Massachusetts coastline. The bias has been most pronounced in Narragansett Bay which on occasion has exceeded 1.5 feet. The ETSS model is also constrained by the accuracy of the surface GFS pressure and wind flux envelope. Thus, during critical storm surge episodes, forecasters can and do make improvements over the ETSS model guidance, and so it is imperative the storm tide prediction process consists of a human-machine mix.

3. Routine forecast process

Routine tide forecasts have value to some customers, especially those with marine navigation responsibilities. The process begins with the ingestion of gridded astronomical tide predictions and the gridded forecast tide departure from the ETSS model. A challenging aspect of the entire process has been the ability to begin with reliable gridded astronomical tide fields. A combination of commercial off-the-shelf software and homegrown scripts produce gridded astronomical tide data. The commercial off-the-shelf program, XTide, generates the point astronomical tide forecasts at hourly intervals. The hourly data generated for about 30 locations from Maine to Delaware are known to have good harmonics. Modifications to the XTide source code allow the hourly output to be easily parsed by the local scripts designed to use the data.

Once the hourly data are generated, a local script takes the point data and creates an AWIPS-ready netCDF grid file. The point data read by the program are handed to "natgrid", a natural neighbor objective analysis routine (extracted from PyNGL, another commercial off-the-shelf package). Once the gridding is complete, land areas are masked out, and the data are saved in the netCDF file. The data are now ready to be displayed in AWIPS and ingested into GFE. Even this method can result in errors up to a half foot and thus requires at least a cursory review by the forecaster.

During routine conditions (when there is no threat of coastal flooding) forecasters will typically import the ETSS gridded departure without any intervention. The addition of the gridded astronomical and departure tide fields (or storm surge fields when atmospheric conditions produce positive departures) produce the total water level grid. Figure 1 displays images of astronomical tide, departure from predicted astronomical tide (referred to as "storm surge" when positive), and storm tide as viewed in the NWS internal GFE system. A GFE Procedure accomplishes the ingestion and summation of surge and astronomical tide fields. It is this total water grid that forms the basis for the tide predictions that customers and partners access from the NWS Advanced Hydrologic Prediction System (AHPS). The total water level forecast data for select locations are encoded in the SHEF format and sent by the forecaster to the AHPS database. The user can choose a select number of points with real-time tide data and view a time series projection of tide amplitude out to 96 hours (Fig. 2).

4. Non-routine forecast process

When there is any threat of coastal flooding, the forecast process begins the same as during benign situations. A GFE Procedure is invoked to ingest and combine astronomical gridded tide data with the tide departure or storm surge grids from the ETSS model. That procedure produces a total water level grid. When there is a threat of coastal flooding, the forecaster becomes more engaged in reviewing and modifying the storm surge grid from the ETSS model. The forecaster will adjust the ETSS storm surge grid based upon experience with the synoptic pattern, any adjustments to the expected synoptic pattern as depicted by the GFS model (since that model provides the wind driver for the ETSS model), and any known (or perceived) systemic bias associated with the ETSS model itself. Upon adjusting the storm surge field, the forecaster will invoke another GFE Procedure to recalculate the total water level grids.

The issue at hand now is to determine which, if any, areas should be subject to a Coastal Flood Watch, Coastal Flood Warning, or Coastal Flood Advisory. A Coastal Flood Advisory is issued for expected minor coastal flooding, and a Coastal Flood Watch/Warning is issued for potential/expected moderate or major coastal flooding.

In an attempt to standardize terminology, the Taunton, MA and Gray, ME Weather Forecast Offices, in collaboration with area emergency management officials, define minor, moderate, and major coastal flooding as follows:

Minor Coastal Flooding – Flooding of the most vulnerable shore roads and/or basements due to height of storm tide or wave splash-over. Majority of roads remain passable with only isolated closures. There is no significant threat to life and any impact on property is minimal. This type of event is covered by a **Coastal Flood Advisory.**

Moderate Coastal Flooding – Widespread flooding of vulnerable shore roads and/or basements due to height of storm tide and/or wave action. Numerous road closures are needed. Lives may be at risk for people who put themselves in harm's way. Isolated damage of very vulnerable structures such as docks or house decks/porches near the high tide line may be observed. This type of event is covered by a **Coastal Flood Warning.**

Major Coastal Flooding – Coastal flooding severe enough to cause *at least* scattered structural damage along with widespread flooding of vulnerable shore roads and/or basements. Some vulnerable homes or businesses are severely damaged or destroyed. Numerous roads are impassable, some with washouts severe enough to be life threatening if one attempted to cross on foot or by vehicle. Some neighborhoods are isolated. Evacuation of some neighborhoods is necessary. This type of event is covered by a **Coastal Flood Warning** with additional language to indicate that the flooding will be major, severe, destructive, damaging, etc.

Coastal flooding is primarily a function of total water level (astronomical tide plus storm surge) and wave action. To help ascertain the impact of wave action, the wave amplitude is considered, although the wave period is undoubtedly of significance as well. A set of empirical tables was developed for various points along the coast to define probable magnitude of impact (minor, moderate, or major) based on forecast total water level and wave amplitude. See Tables 1 and 2 for examples. The tables were established from two studies (Nocera et al. 2005 for the east coast and Moker and Nocera 2011 for the south coast) as well as collective forecaster experience at WFO Taunton. The tables are not set in stone but are intended to be adjusted with time as forecasters gain new experience with critical wave/water level thresholds from new storms and new studies. An item for future work would be to replace the tables with a multi-variant regression analysis that provides a forecast of impact based on screened predictors, which would likely include forecast water level, wave amplitude and period, strength of onshore wind component, and possibly even forecast wave or swell direction.

In a potential coastal flood scenario, the forecaster will run the Total Water Level (TWL) product from the GFE Product Formatter. This is essentially a work product for the forecasters. Referencing the tables, the TWL product will check for a first cut at coastal flood impact based upon the information gleaned from the total water level and the forecast wave heights offshore from the GFE grids. Up to three sample areas determine the information in the TWL product. First, surge and tide level information is sampled at/very near the coast. Second, wave information that will appear in the final public product is normally sampled within 5 miles of the shoreline (and thus more representative of the wave activity one would view from shore). A third sample area is for *wave impact* and may be sampled up to 20 miles offshore. The sampling of wave heights is dependent upon the exposure of the location in question. The sampling for wave heights for Boston and Providence extend only a mile or two into Boston Harbor and Narragansett Bay, respectively. In contrast, wave sampling to assess wave impact at a more exposed location such as Scituate extends to 15 miles offshore to maintain better consistency with historical buoy wave data and correlations from past studies/experience. Note that some locations are much more sensitive to wave action than others, dependent upon open ocean exposure.

The first cut impact from the TWL product highlights those locations which may need watch/warning/advisory issuances. The forecaster is encouraged to review this work product and adjust subjectively where he/she believes that the impact may be more or less than that indicated in the raw TWL product. See Figure 3 for an example of the TWL product. Note that the far right column displays the wave heights sampled to assess impact and are not the values that will be displayed in the public warning product. At this point the forecaster edits the TWL product as necessary, saves, and then prepares the Coastal Flood Warning (CFW) product via the Graphical Hazard Generator (GHG) software associated with the GFE. The CFW product will contain the matrices found in the final TWL work product for any reach of coastline that was listed with at least minor coastal flooding. The forecaster will edit the final CFW product and transmit it via the GHG software. Figures 4a and 4b illustrate a CFW product produced by this new methodology.

5. Information to partners and customers

One of the founding objectives behind the NART Coastal Inundation Project is to better communicate locations where people could potentially be at risk from a storm. This has been achieved via time series tidal forecasts for select locations in AHPS. Also, NOAA's Coastal Services Center (CSC) employed GIS technology and Google Internet applications to produce a series of reference maps for the pilot communities of Scituate, MA and Saco, ME using techniques described in CSC's Coastal Inundation Mapping Guidebook (2009). Based on digital elevation mapping derived from light detection and ranging (LIDAR) data sets, these maps illustrate static water level inundation for various storm tide levels that might affect these communities. In addition, the FEMA 100 year (or 1% chance of occurring in a year) velocity zone has been superimposed as an additional layer on these maps to infer the potential impact of wave action. Under the guidance of CSC, Taunton WFO staff has begun to expand the visualization mapping to other vulnerable eastern Massachusetts coastal communities. To access the reference map library for the pilot communities of Scituate and Saco, go to: http://www.erh.noaa.gov/box/coastalInundation.php?sid=scituate and http://www.erh.noaa.gov/box/coastalInundation.php?sid=saco. Figure 5 and Figure 6 (a and b) provide examples. In the future, it is planned to further stratify the inundation maps to depict the velocity zone as a function of both wave amplitude and storm tide. This requires an assimilation of wave set-up and run-up information in either a direct or indirect manner. Since the establishment of necessary shoreline cross-sections to dynamically simulate wave set-up and run-up can be very resource intensive to both construct and execute in real time, a more stochastic process might be pursued, such as described by Cannon (2007) and implemented in a real time Gulf of Maine Ocean Observing System (GOMOOS) nomogram (see www.gomoos.org), functional for both the Saco, ME and Scituate, MA pilot communities. The nomogram essentially correlates predicted wave heights and storm tide to historical impact from similar wave heights and storm tides.

The importance of communicating the forecast uncertainty with the TWL cannot be overemphasized. Storm surge models are subject to the uncertainty associated with the atmospheric forcing models and ensemble output may prove useful to better establish the range of uncertainty for specific storm events. There is a need to establish an effective means of communicating the uncertainty to partners and customers of this forecast information. One method is to simply add a disclaimer on the reference inundation maps to urge users to add at least an additional foot of water level to accommodate for what might be a worst case scenario. A more sophisticated process might be to identify on a storm-by-storm basis a worst case scenario. If dynamic mapping based on actual real time forecasts is employed, then a different type of shading might be added to depict a "reasonable" worst case scenario for that event, possibly computed from ensemble results or subjectively derived by the forecaster. There may be different ways to communicate uncertainty, but it needs to be easily understandable to evoke an appropriate response for those potentially at risk.

No standard and clear link to either routine tide forecasts or coastal flood forecasts has existed. To remedy this, the WFO Taunton ITO has developed an experimental web page portal for tide and coastal flood information. An experimental interactive map has been developed to allow partners and customers to easily link to tide forecasts (the AHPS time series), coastal flood statements, and reference inundation maps where available. This part of the web page is patterned after and has the look and feel of the extremely popular surf zone forecast map. See the real-time display of the water level forecast and coastal flood threat product in real time at: http://www.erh.noaa.gov/box/cfwGMdisplay.php or the example shown in Figure 7.

6. Early experience with the new procedure

Several minor to moderate coastal flood episodes during the 2009-2010 winter allowed the opportunity to test and evaluate the new procedure. The results have been favorable. Forecasters have been able to produce coastal flood advisories and warnings that have been accurate. The procedure has allowed forecasters to adjust the model storm surge values along various reaches of the coast. Anecdotally, forecasters state that they are able to improve upon the ETSS guidance provided in GFE far more often than not. Forecasters have the ability to adjust the ETSS guidance based on their adjustments to the GFS generated wind field. Also, forecasters do not see the "anomaly" component from the ETSS model. Adjusting the raw surge guidance from the ETSS model with the "anomaly" would provide higher quality guidance as input for the forecaster. The biggest operational issue has been the gridded astronomical tide forecast errors. In theory, forecasters should not have to worry at all about the astronomical tide forecast. That should be a given and solid reference level. In actuality, forecasters have had to double-check the astronomical tide predictions and more often than not make adjustments to that field. It is hoped that further refinements of the gridded astronomical tide predictions will allow forecasters to maintain primary focus on the storm surge field.

7. Conclusions

Coastal flooding along the New England coast from both extratropical and tropical cyclones can wreak major impact to lives and property. The coastal flood warning program has traditionally provided warning information for extratropical cyclones on a very broad scale, often leading to ambiguity as to locations at risk. The process of producing coastal flood warnings has traditionally been awkward, whenever it is necessary to adjust storm surge guidance. The coastal flood warning process has also resided outside of the gridded forecast process, which is now employed for most weather elements and constitutes the keel for the future next generation suite of NWS forecast information.

The Taunton WFO in conjunction with a NART coastal resiliency initiative has developed a new process for formulating tide forecasts, which incorporates model departures over the expected astronomical predictions, as well as a more efficient means for producing and disseminating coastal flood warning information. Furthermore, through the partnership of the National Ocean Service, NWS, and other NOAA line offices, Web interfacing and inundation visualization have been added to enhance the accessibility and understanding of coastal flood risk information. These efforts serve to better delineate and communicate the coastal flood threat, expected to become more serious and frequent during an era of continued sea level rise.

Much more work remains to be done. A comparative verification of several storm surge models (the operational ETSS, a FVCOM model, and an ADCIRC model) is planned. The water level/wave height tables will need to be refined as forecasters gain more experience. A few iterations were needed to ensure that forecast wave height sampling is appropriate for the impact location. For example, the tide gage for Newport, RI is located in the harbor. Flooding in Newport Harbor is primarily a function of water level, since sufficient protection exists to dampen wave energy at that location. Along Second Beach in Newport, however, the shore is very vulnerable to wave activity in Rhode Island Sound. In some instances, the impact really is not inundation per se but erosion. The Sconset neighborhood on Nantucket is one such example, where erosion from successive storms threatens the longevity of houses perched perilously on bluffs. Much more needs to be done to forecast erosion impact in a scientifically sound manner.

Finally, a means for communicating uncertainty with potential inundation events needs to be established. The vision is to produce real time visualization mapping that more explicitly incorporates wave action and communicates uncertainty in an understandable manner for all concerned.

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Disclaimer

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Tables:

Table 1. Coastal flood matrix developed for Boston Harbor.

Boston Harbor

Storm Tide (ft.) Wave Height (ft.)

	1	2	3	4	5
11.0	-	-	-	-	Minor
11.5	-	-	-	Minor	Minor
12.0	-	-	-	Minor	Moderate
12.5	-	-	Minor	Moderate	Moderate
13.0	-	Minor	Minor	Moderate	Major
13.5	Minor	Minor	Moderate	Moderate	Major
14.0	Minor	Moderate	Moderate	Major	Major
14.5	Moderate	Moderate	Major	Major	Major
15.0	Major	Major	Major	Major	Major

Table 2. Coastal flood matrix developed for Scituate. Note the differences in wave heights for the more exposed shoreline of Scituate.

Scituate

Storm Tide (ft.) Wave Height(ft.)

	10	15	20	25	30	35
9.5	-	-	-	-	Minor	Minor
10.0	-	-	-	Minor	Minor	Moderate
10.5	-	Minor	Minor	Moderate	Moderate	Moderate
11.0	Minor	Minor	Moderate	Moderate	Moderate	Major
11.5	Minor	Moderate	Moderate	Moderate	Major	Major
12.0	Moderate	Moderate	Moderate	Major	Major	Major
12.5	Moderate	Moderate	Major	Major	Major	Major
13.0	Moderate	Moderate	Major	Major	Major	Major
13.5	Moderate	Major	Major	Major	Major	Major
14.0	Major	Major	Major	Major	Major	Major

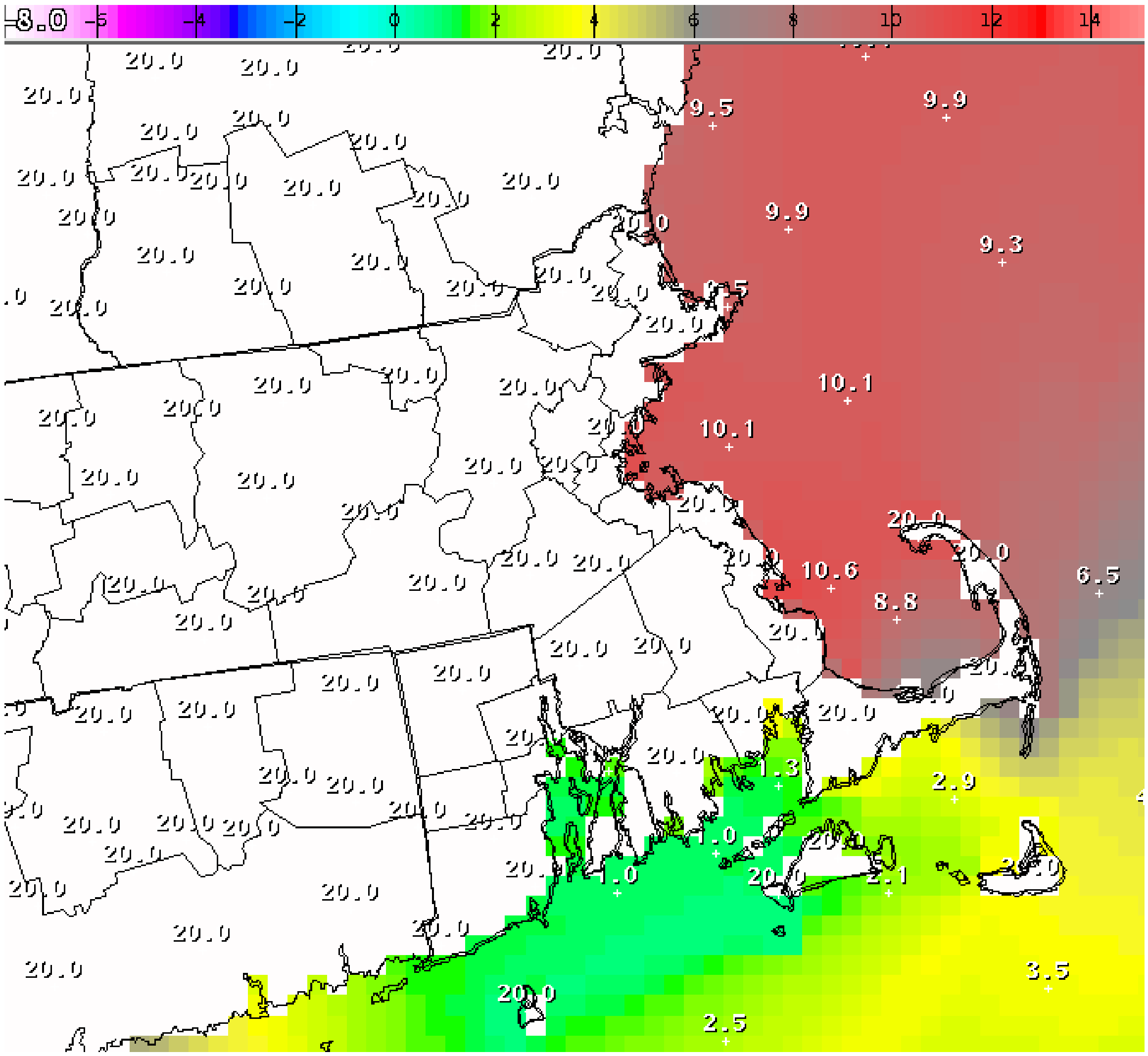

Figure 1a. GFE image of astronomical tide (ft.)

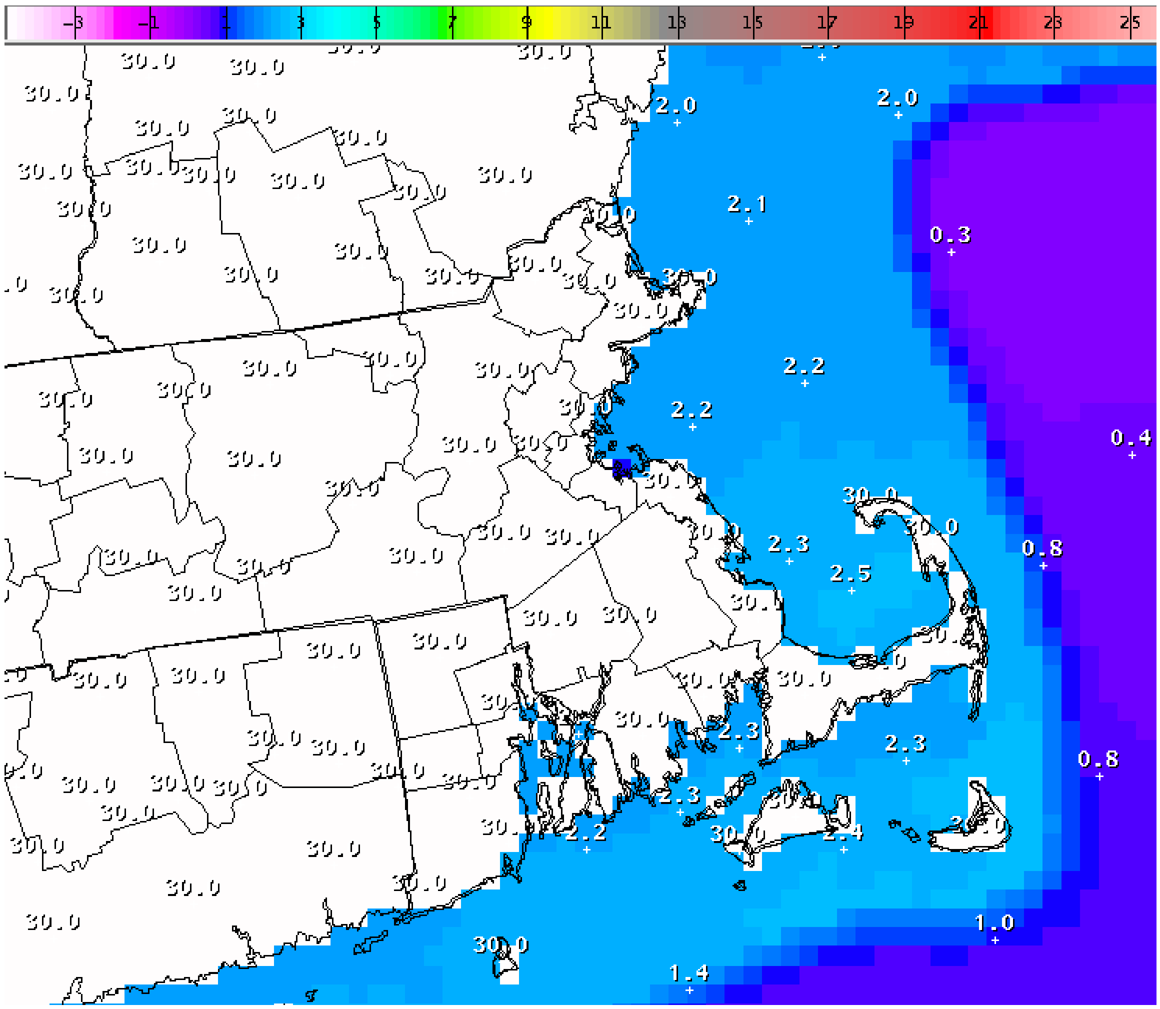

Figure 1b. GFE image of tidal departure (forecaster editable). Positive tidal departures equate to storm surge (ft.).

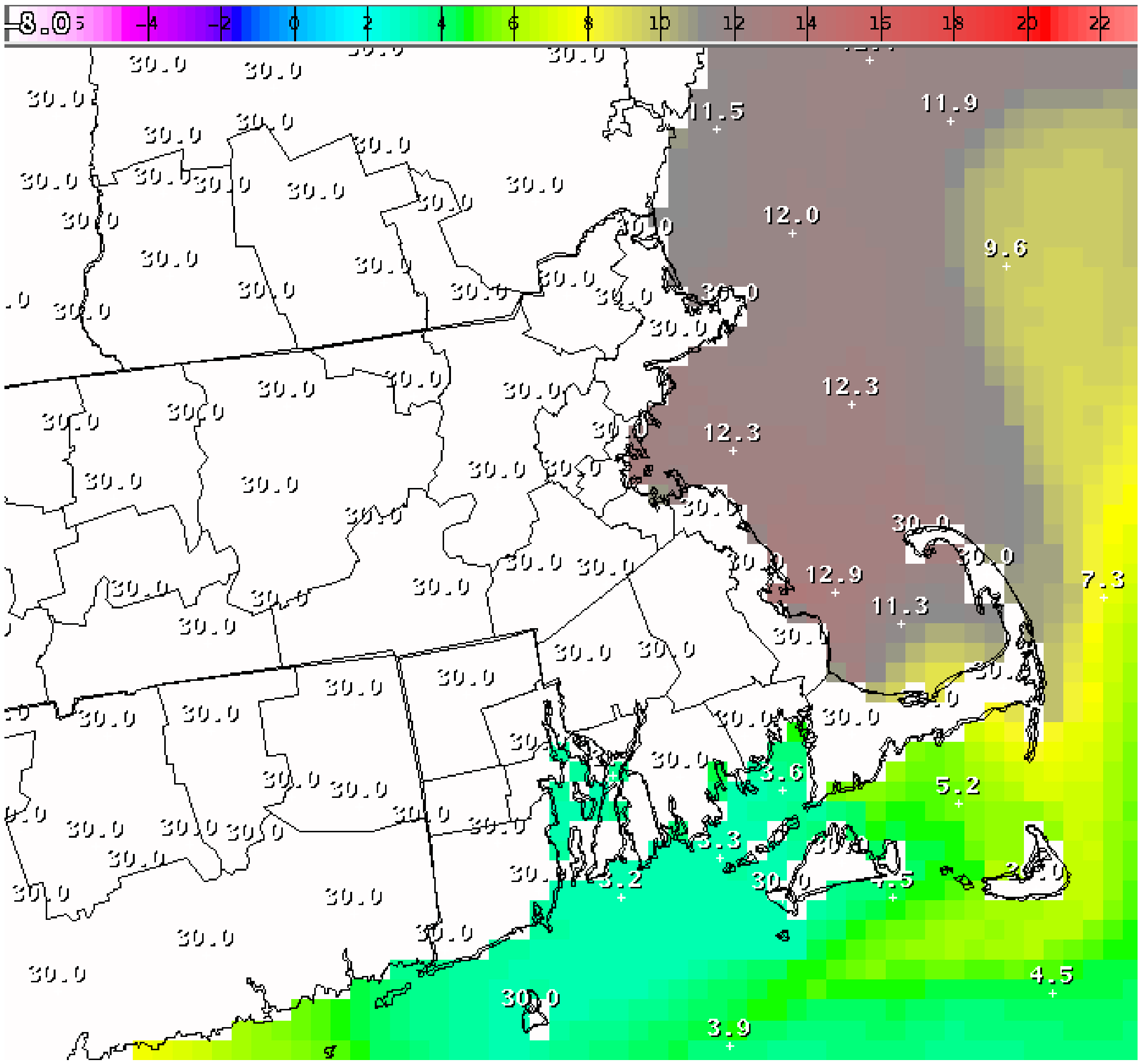

Figure 1c. GFE image of storm tide (ft.), which is calculated by adding tidal departure (storm surge) to astronomical tide

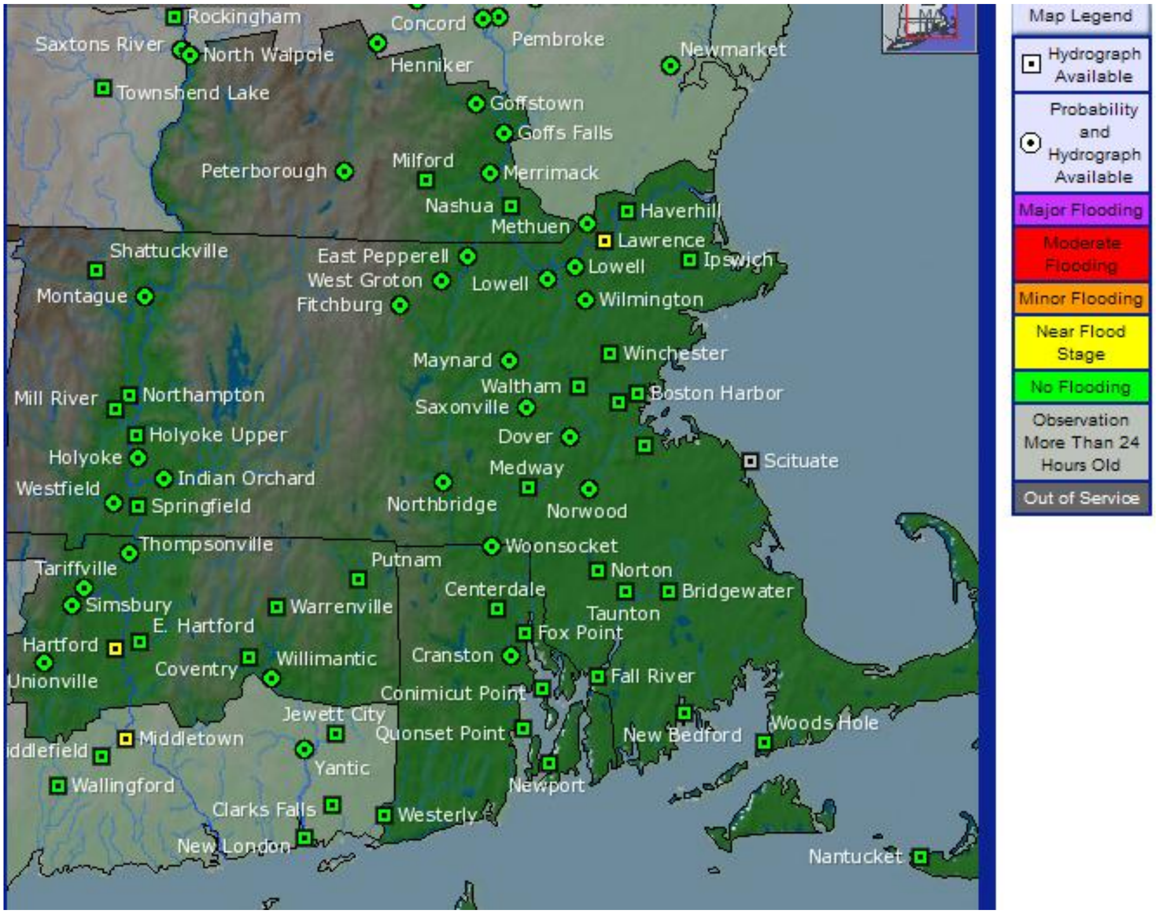

Figure 2a. Advanced Hydrologic Prediction System (AHPS) portal. Available at http://water.weather.gov/ahps/

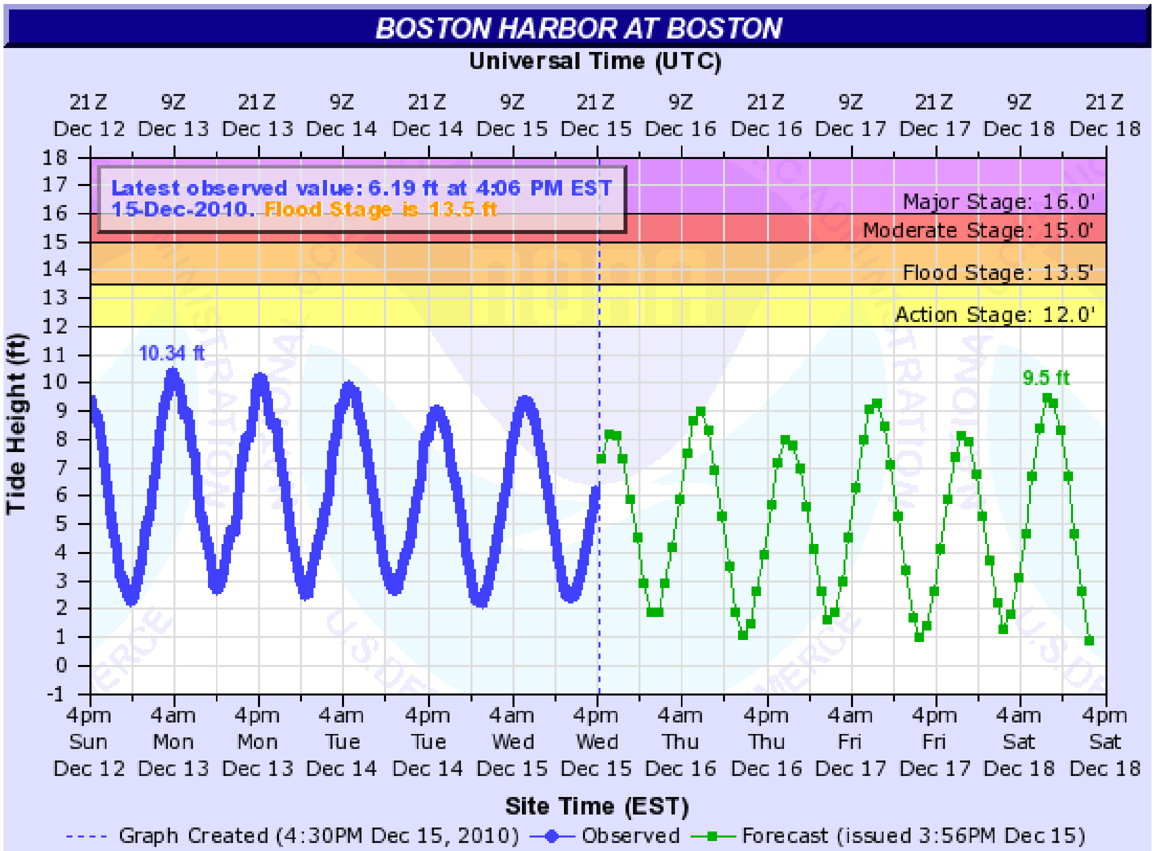

Figure 2b. AHPS hydrograph time series for Boston Harbor, MA.

TOTAL COASTAL WEATER LEVEL FORECAST
NATIONAL WEATHER SERVICE TAUNTON MA
935 AM EST MON NOV 8 2010

ALL TIDE HEIGHTS ARE REFERENCED TO MEAN LOWER LOW WATER.
TIME OF HIGH TOTAL TIDE IS APPROXIMATE TO NEAREST HOUR.

BOSTON HARBOR

TOTAL TIDE /FT/	DAY/TIME	ASTRO TIDE /FT/	SURGE /FT/	WAVES /FT/	FLOOD CATEGORY	RISK WAVES /FT/
13.3	08/12 PM	11.5	1.8	2	MINOR	2
10.8	09/01 AM	9.9	0.9	1-2	NONE	1-2
11.7	09/01 PM	11.1	0.6	1-2	NONE	1-2
10.6	10/02 AM	9.5	1.1	2	NONE	2
11.9	10/02 PM	10.6	1.3	2	NONE	2
10.0	11/02 AM	9.0	1.0	2	NONE	2

SCITUATE

TOTAL TIDE /FT/	DAY/TIME	ASTRO TIDE /FT/	SURGE /FT/	WAVES /FT/	FLOOD CATEGORY	RISK WAVES /FT/
12.7	08/12 PM	10.9	1.8	12-16	MODERATE	16-18
10.3	09/01 AM	9.4	0.9	6-7	NONE	8-10
11.2	09/01 PM	10.6	0.6	7	NONE	7-9
10.1	10/02 AM	9.0	1.1	8-10	NONE	10-11
11.3	10/02 PM	10.0	1.3	10	MINOR	11-12
9.6	11/03 AM	8.6	1.0	10-11	NONE	12-14

Figure 3. Sample of the internal Total Water Level (TWL) product used to construct tables in the Coastal Warning Product. Note the “waves” column refers to waves expected within about 5 miles of the coast. The “risk waves” in contrast refers to wave amplitudes sampled further offshore for those exposed reaches of coastline. “Risk waves” more closely represent activity in the sampling area of past studies, typically buoys located 15 to 20 miles offshore.

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URGENT - IMMEDIATE BROADCAST REQUESTED
COASTAL HAZARD MESSAGE
NATIONAL WEATHER SERVICE TAUNTON MA
347 AM EST MON MAR 1 2010

...POTENTIAL FOR MINOR TO MODERATE COASTAL FLOODING ALONG THE EAST
COAST OF MASSACHUSETTS WITHIN A FEW HOURS OF THIS MORNINGS HIGH
TIDE...

.THE COMBINATION OF HIGH ASTRONOMICAL TIDES...STRONG NORTHWEST TO
NORTH WINDS...AND ROUGH SEAS WILL LEAD TO MINOR TO MODERATE COASTAL
FLOODING OVER EAST COASTAL MASSACHUSETTS LATE THIS MORNING.

MAZ016-019-022-011700-
/O.UPG.KBOX.CF.A.0004.100301T1400Z-100301T1900Z/
/O.NEW.KBOX.CF.W.0003.100301T1400Z-100301T1900Z/
EASTERN NORFOLK MA-EASTERN PLYMOUTH MA-BARNSTABLE MA-
347 AM EST MON MAR 1 2010

...COASTAL FLOOD WARNING IN EFFECT FROM 9 AM THIS MORNING TO 2 PM
EST THIS AFTERNOON...

THE NATIONAL WEATHER SERVICE IN TAUNTON HAS ISSUED A COASTAL
FLOOD WARNING...WHICH IS IN EFFECT FROM 9 AM THIS MORNING TO 2 PM
EST THIS AFTERNOON. THE COASTAL FLOOD WATCH IS NO LONGER IN
EFFECT.

THIS WARNING COVERS THE EAST COAST OF MASSACHUSETTS SOUTH OF BOSTON.

A VERY INTENSE STORM SYSTEM LOCATED TO THE SOUTH OF NOVA SCOTIA WILL
DRIFT WESTWARD FOR A TIME THEN HEAD BACK OUT TO SEA LATER TODAY.
NORTHWEST WINDS WILL INCREASE TO 30 TO 40 MPH WITH HIGHER GUSTS ALONG
THE COAST. SEAS WILL BE BUILDING TO BETWEEN 10 AND 15 FEET OVER THE
OUTER COASTAL WATERS OFF OF EASTERN MASSACHUSETTS. ALTHOUGH THE
SURFACE WINDS WILL BE MAINLY FROM THE NORTHWEST...THE MAIN WAVE
ENERGY IS EXPECTED TO BE FROM THE NORTH AND NORTHEAST. THE COMBINATION
OF THE WINDS...ROUGH SEAS...AND A HIGH ASTRONOMICAL TIDE WILL LEAD TO
POCKETS OF MODERATE COASTAL FLOODING WITHIN A FEW HOURS OF THE LATE
MORNING HIGH TIDE.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

A COASTAL FLOOD WARNING IS ISSUED WHEN MODERATE OR MAJOR COASTAL
FLOODING IS EXPECTED.  MODERATE COASTAL FLOODING PRODUCES
WIDESPREAD FLOODING OF VULNERABLE SHORE ROADS AND/OR BASEMENTS
DUE TO THE HEIGHT OF STORM TIDE AND/OR WAVE ACTION.  NUMEROUS
ROAD CLOSURES ARE NEEDED. LIVES MAY BE AT RISK FOR PEOPLE WHO PUT
THEMSELVES IN HARMS WAY. ISOLATED STRUCTURAL DAMAGE MAY BE
OBSERVED.
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Figure 4a. Example of Coastal Hazard Message issued by WFO Taunton.

PROVINCETOWN HARBOR

TOTAL TIDE /FT/	DAY/TIME	ASTRO TIDE /FT/	SURGE /FT/	WAVES /FT/	FLOOD CATEGORY
12.5	01/12 PM	11.1	1.4	7	MINOR
11.6	02/12 AM	11.0	0.6	4-5	NONE
11.0	02/12 PM	10.8	0.2	3	NONE
11.3	03/01 AM	11.0	0.3	2	NONE
11.2	03/01 PM	10.5	0.7	3-4	NONE

CHATHAM - EAST COAST

TOTAL TIDE /FT/	DAY/TIME	ASTRO TIDE /FT/	SURGE /FT/	WAVES /FT/	FLOOD CATEGORY
9.6	01/12 PM	8.2	1.4	12-14	MODERATE
8.5	02/12 AM	8.0	0.5	9-10	MINOR
8.3	02/01 PM	8.1	0.2	5-6	NONE
8.4	03/01 AM	8.1	0.3	4-5	NONE
8.5	03/02 PM	7.7	0.8	7-8	MINOR

Figure 4b. Examples of coastal flood tables appended to the Coastal Hazard Message issued by WFO Taunton.

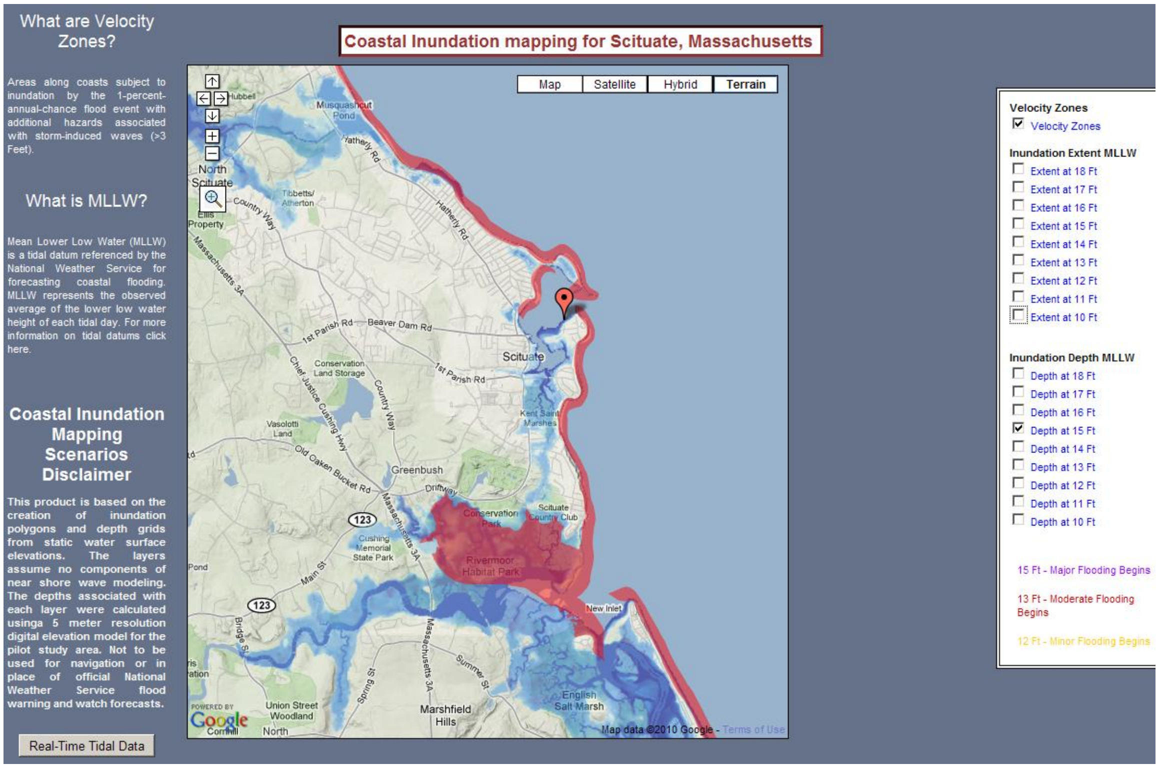

Figure 5. Example of an inundation graphic for Scituate, MA with a 15 foot storm tide.

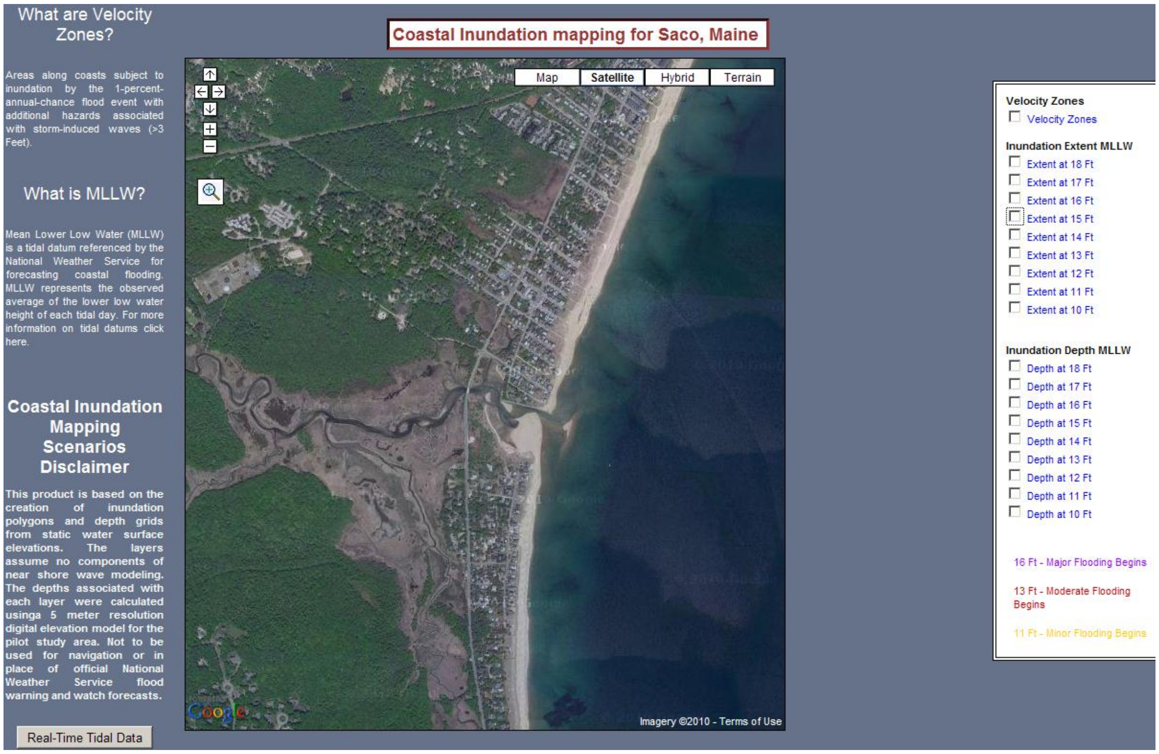

Figure 6a. Example of an inundation graphic for Saco, ME with no storm tide.

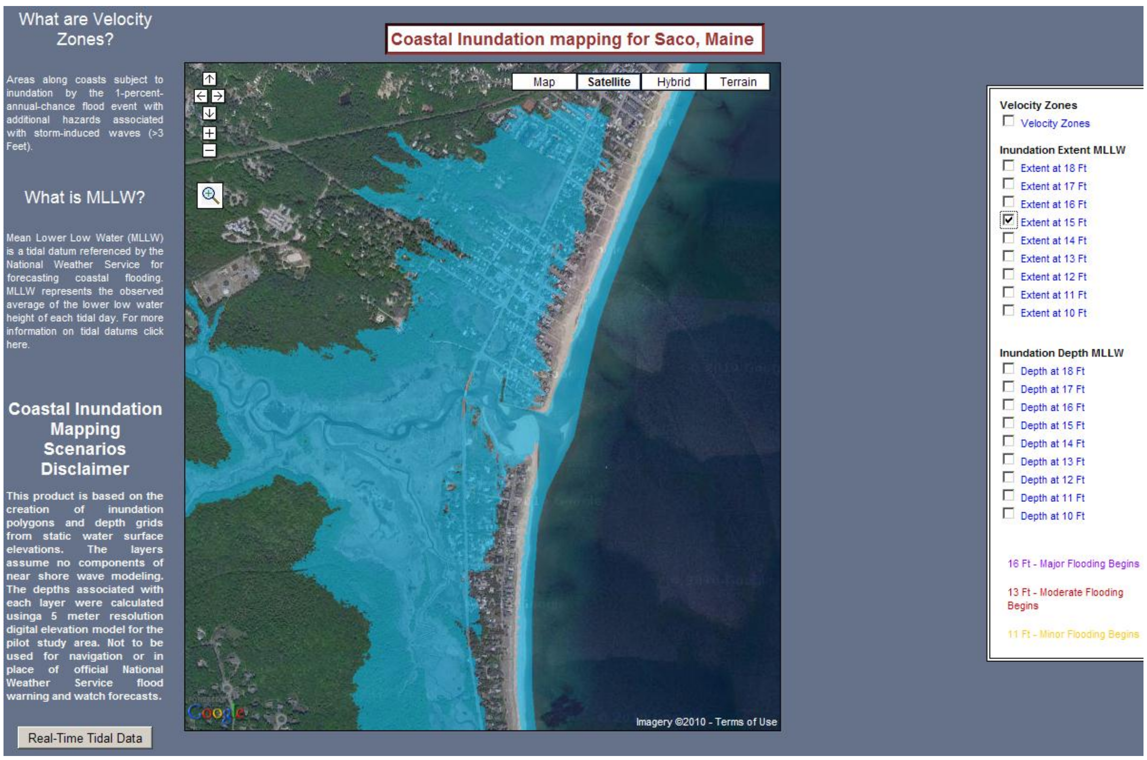

Figure 6b. Example of an inundation graphic for Saco, ME with a 15 foot storm tide.

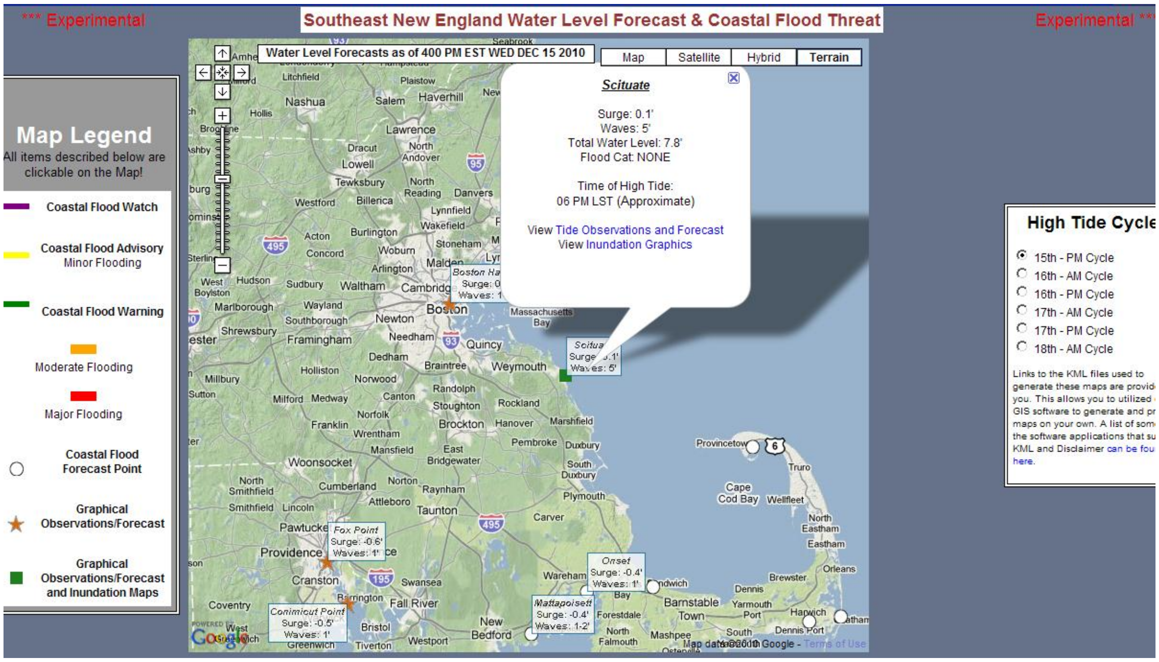

Figure 7. An example of the experimental tide and coastal flood forecast web portal developed at the Taunton WFO.