Applied Coastal Research and Engineering, Inc.
766 Falmouth Road, Suite A-1
Mashpee, MA 02649
508-539-3737

PROPOSAL

Date: **February 13, 2014**

To: **Jonathan L. Carter, Town Manager, Town of Wells, Maine**

From: **Sean W. Kelley, P.E.**

Subject: **Proposal for initial assessment of FEMA flood map appeal**

Applied Coastal is pleased to provide this proposal to perform an initial evaluation of the wave climate along the Wells coastline in support of the Town's appeal of the Preliminary FEMA floods maps. The analysis effort will focus on the determination of appropriate wave setup values that would be appropriate for 100-year storm conditions along the ocean shoreline of the Town. Wave setup is a phenomenon where the still water elevation along a coastline is elevated due to wave breaking. Setup increases as wave period increases and as the slope of the sea bottom becomes steeper.

It has been demonstrated that the empirical method adopted by FEMA to determine setup (the DIM) in the New England region over-predicts the magnitude of water level increase, compared to physics-based modeling approaches. In some areas, the DIM overpredicts setup by 4 feet, which greatly impacts the elevation and landward extent of the flood zones delineated by FEMA.

The proposed scope of work is divided into two main tasks; 1) an analysis to determine a representative 100-year wave condition and setup magnitude along the Wells shoreline and 2) the running of a single WHAFIS transect to demonstrate how the alternate setup value would change flood zone delineations.

The results of these tasks will provide useful information concerning the merit of pursuing a wider scale appeal of the preliminary maps based on the application of the DIM to determine wave setup.

Task 1. 100-year Wave Climate Determination

Techniques and software tools approved by FEMA will be utilized to determine 100-year wave characteristics and setup along the coastline of Wells.

A directional analysis of extremal wave conditions will be performed using a 20-year hindcast record available from the USACE WIS database. The 100-year offshore wave height and period will be computed for the range of compass sectors that approach the Town's shoreline.

These wave conditions will then be used as input to the wave model SWAN (developed by the Delft University of Technology) to calculate setup at the shoreline at one cross-shore transect (corresponding to an existing FEMA analysis transect). SWAN will be run in 1-dimensional mode, since the 1-D formulation of the model determines an exact setup magnitude. The cross-shore 1-D wave model transect will be developed using available sources of topography and bathymetry (e.g.,USACE LiDAR and NOAA soundings).

A technical memorandum that provides details on the analysis methods and results will be provided.

Cost of Task 1 Analysis: $7,500

Task 2. WHAFIS Model Run Using Updated Wave Setup

As an optional task, it is proposed that a single WHAFIS model run be performed along an existing FEMA transect in order to demonstrate how the new value of setup, determined in Task 1, would affect the delineation of flood zones. WHAFIS is the official FEMA wave model used to propagate waves from the ocean across flooded upland areas.

The results of this model run will be very useful to demonstrate in a quantifiable manor to the public how the new value of wave setup would potentially change flood zones in Town.

For the selected transect, the WHAFIS input data (made available form FEMA for the appeal) would be used to recreate the FEMA analysis, but using the value of wave setup determined in Task 2.

If this task is approved, details on the analysis methods and results will be added to the memo provided for Task 1.

Cost of Task 2 Analysis: $5,000

RANSOM Consulting, Inc.

Memo

400 Commercial Street, Suite 404, Portland, Maine 04101, Tel (207) 772-2891, Fax (207) 772-3248
Byfield, Massachusetts □ Portsmouth, New Hampshire □ Hamilton, New Jersey □ East Providence, Rhode Island
www.ransomenv.com

Date: Feb. 4, 2014
To: Municipal Clients
From: Bob Gerber, PE
Subject: FEMA flood mapping status

A lot of things are happening (or not happening) in the world of flood mapping. To recap a few:

1) Preliminary coastal flood maps for York and Cumberland Counties were released Nov. 4th. The Cumberland County CCO meeting for municipal officials was held in Portland in January 8, 2014. The York County CCO meeting was held in Kennebunk on January 9th.
2) A meeting was held immediately after the Cumberland County CCO meeting among FEMA, STARR, Tom Hall of Scarborough, Larry Mead of Old Orchard Beach, and me to discuss the differences between the new FEMA maps in the towns for which I appealed in 2010 and the maps for those towns that I did not work for in 2010. I calculated the wave setup term differently in 2010 than FEMA is calculating it now and this is resulting in differences between adjacent towns in estuarine areas of 2 to 3 feet (FEMA's new maps being higher). This is particularly clear in the Scarborough Marsh area where I compared FEMA's current calculations with the way I would have calculated the wave setup by my 2010 approach. Both Maine Senators and Representative Pingree have sent letters to FEMA head Fugate pointing these facts out and asking that FEMA establish a procedure that will level the playing field. FEMA told us on January 8th that my old methodology could not be used in appeals, even in towns where FEMA had accepted my 2010 work.

   Like a bar room brawl that spills into the street, the fight has spread into Massachusetts where I challenged the DIM methodology for extending wave setup into estuaries in Scituate and Marshfield. FEMA had summarily dismissed my appeal, but I submitted a reply that pointed out how it had been accepted in the new Preliminary maps in 8 towns in southern Maine and that high water mark survey data from the blizzard of 1978 supported much lower wave setup transmission into marsh areas than suggested by the FEMA calculation methodology. FEMA released a letter to my Massachusetts towns Feb. 3rd stating that the resolution of the appeals would be delayed (essentially by a year) while they considered the appeals further.

3) Information essential to support FEMA's York and Cumberland County Preliminary Maps was not released with the Preliminary Maps on November 4th as was promised to the towns last winter when we requested the data then after seeing the Work Maps. FEMA said that all our requested data would be delivered with the Preliminary Maps. After going through the engineering data disk in detail and drilling down to its lowest levels, I discovered that new wave conditions and wind data had been applied but without any technical backup. I requested this data immediately but it took until January 8th before FEMA hand-delivered a thick paper document that provided the needed backup. By detailed study of that document I discovered that there was a detailed STWAVE model for Saco Bay that had not been delivered with the York County engineering data disk. I then requested that and received it January 22nd. I now feel that we have all of the technical data that went into the Cumberland and York County maps but that data was not delivered until two and a half months after the Preliminary Maps were released. I have asked Senator Collins' office to request an extension of time before the start of appeals due to the late delivery of the documents and she has requested more time from Fugate. If extra time is not granted, the Municipal Appeal Period for York and Cumberland Counties will start on or about March 1st.
4) The Waldo County Preliminary coastal flood maps were released about 2 weeks ago. The Knox County Preliminary coastal flood maps were released on February 3rd. These new maps are based on some new complex FEMA circulation and wave models that will have to be examined closely.
5) I received preliminary confirmation last week and final confirmation Feb. 3rd that the BOUSS-2D wave model has been approved for use in FEMA flood mapping. Thanks to Senator Collins' staffer Alec Porteous who provided essential support in obtaining acceptance of these models by FEMA. I began the FEMA approval process for both STWAVE and BOUSS-2D a little over a year ago. STWAVE was approved within several months but BOUSS-2D took much longer (most of the lag was not FEMA's fault; it took a long time for the license holder to sign documents giving FEMA use of the model). BOUSS-2D is a 2nd-order, 2-dimensional wave model that carries waves above the still water level and can be used to calculate wave setup and wave runup as well as wave heights. It is a multi-phase model capable of simulating diffraction and reflection. This type of model, which uses the Boussinesq method of solving differential equations, is the only type of model sanctioned by FEMA Guidelines and Specifications beyond the DIM method (DIM is only a 1-dimensional model) to produce accurate estimates of wave setup. I have applied this model to three different analyses with good results. Unfortunately, it is an expensive and difficult model to use.

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Memo

400 Commercial Street, Suite 404, Portland, Maine 04101, Tel (207) 772-2891, Fax (207) 772-3248
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Date: 3 Feb. 2014
To: Jon Carter, Town Manager, Town of Wells
From: Robert Gerber, PE
Subject: Preliminary review of FEMA Preliminary Coastal Flood Maps

Introduction

As agreed with the Town, I have undertaken a preliminary review of the Preliminary coastal flood maps and underlying calculations produced by FEMA that support the Nov. 2013 Preliminary York County Flood Map release.

I have printed out pertinent information from the "engineering data disk" and annotated it in places. The Town probably does not have the software to load and print out a lot of the material that I have printed, so this will give you a good record of what calculations underlie the maps.

The set of attachments appended to this report includes some basic town-wide information and then groups most of the underlying technical calculations by transects. FEMA uses some broad-based modeling approaches to develop characteristic wave-related inputs to "transects". It then calculates a number of things along these linear transects and then turns that into a flood map that incorporates that data and interpolates that data between transects. This report and attachments are bookmarked in Adobe PDF format so turn on the bookmarks in the vertical menu bar on the left and you can navigate quickly through the document.

Basic Mapping and Underlying Wave Data

Attachment 1 is a town-wide map showing the wave transects and proposed FEMA zones overlain on USGS topographic base maps. That is followed by a printout (**Attachment 2**) of the pertinent parts of the FEMA "Engineering Summary" Excel spreadsheet contained on the data disk. This consists of 5 pages that reference the FEMA transects as shown on the maps. The wave transects in Wells are numbered sequentially from YK-64 in the south to YK-77 in the north.

The next page (**Attachment 3**) is the location of bathymetric and topographic data points used to develop a bathymetric map for a 2-dimensional wave model (the ACOE model STWAVE) used to generate and propagate the 100-year wave condition to the Wells shoreline. Where the points are very closely-spaced the red zone is a solid mass of red and these represent LiDAR-acquired points. More toward the open ocean you can see discrete red dots that represent NOAA soundings that are used to construct navigation charts. Notice that there are very few data points on the Wells shoreline beaches, which results in the bathymetry underlying the wave model interpolating from the ocean side to the marsh side and ignoring the height of the land along the beach.

Attachment 4 shows the contoured output of FEMA's detailed STWAVE wave model. The red lines are contours of equal wave height in feet (as shown by the labels). This wave height is the "significant" wave height which is used in many of the FEMA calculations. The significant wave height is the average of the 1/3rd highest waves during the peak of the 100-year storm condition. Where the wave contours are close together it indicates that the large offshore waves are breaking due to shoaling on the bottom. In the southern part of Wells, 20-ft high waves reach the shore before starting to break. In some other areas to the north, behind offshore ledges, the wave height is reduced to as little as 15' before it starts breaking on its final approach to the shore. Notice that because the topography of the area behind the beaches are not properly considered that the waves are shown to go straight through the beaches as if the topography was less than the 100-year storm surge elevation, which is defined in FEMA's tables and the draft FIS as elevation 8.9' NAVD88 vertical datum. However, FEMA's wave model assumes a slightly higher elevation on which the waves are superimposed of 9.5' NAVD88 (because that is what the future SWEL will be after the new maps are adopted—but it is not what these Preliminary maps should be based on).

Wave Transect Calculations

Beginning with **Attachment 5** and proceeding through **Attachment 38** the FEMA model printouts are arranged by transect going from south to north. There are several sets of documents for each transect. The first document is a set of pages that constitute a "MathCAD" printout in which is calculated wave setup on the open coast, as well as any steep banks or structures that might occur on that transect, and the wave runup on that transect if the "TAW" method or "SPM" method of runup is applicable. The second set of documents for each transect consists of CHAMP model wave profile printouts which may include cases for both the "intact" and "failed" conditions if the transect goes through a shoreline protection structure.

The total wave setup is entered as input to the FEMA CHAMP model, which has a set of modules that calculate the erosion profile of an unprotected sand dune (using certain assumptions on the slope of the final eroded surface), then the wave crest profile (based on the elevation of the top of the wave crests for the average of the 1% highest waves), and if the beach slope is less than 12.5% the RUNUP2 module would be used to calculate runup rather than the TAW or SPM method. The RUNUP2 and SPM programs final outputs are based on the average of the 2% highest wave runup positions (they actually calculate runup based on mean wave height characteristics then multiply the result by 2.2 to get the 2% runup level). The TAW method is generally applied to steep banks and riprap. The SPM method is applied to only vertical walls. For riprap and bulkhead walls, FEMA usually calculates the intact case (for the wall profile the way it currently exists) and the "failed" case where FEMA assumes certain standard modes of failure and the MathCAD sheet is used to construct the "failed" wall profile. If a property owner's flood zone and Base Flood Elevation (BFE) is based on the assumption of a "failed" wall and the owner can obtain a Licensed Professional Engineer to "certify" that the wall can withstand the 100-year storm, then an appeal could be filed on that basis.

FEMA uses the results from the "intact" versus "failed" structure analyses to choose which of the two cases—intact or failed—produces the higher of the two runups and then uses that value to set the Base Flood Elevations (BFE) on the ocean side of the structures. If the top of the structure elevation is less that the surge elevation plus runup, then the runup is capped at top of structure (or top of bank in case of failed structure) plus 3'. Splash zones 30' wide may be included behind intact structures or behind the top of a bank. There is a special case where FEMA defines a "Primary Frontal Dune" (PFD) (**Attachment 39**). Wells only has a few small areas in the northern section of its coast so defined but where that designation occurs, the calculated VE zone BFE is carried to the back or landward side of the frontal dune and all the intervening area is defined as a VE zone regardless of whether the analysis shows a runup overtopping the dune. This is a requirement of the Code of Federal Regulations wherever a PFD is defined.

The New Issue: Wave Setup and its transmission into the Estuarine Areas

One additional feature of the new Preliminary Maps must be pointed out because the carrying of the calculated term "wave setup" into the back estuary areas is something new on these maps that did not occur on the 2009 Preliminary FEMA maps. The basis for doing this comes from a section buried deep in FEMA's Guidelines and Specifications (G&S), Appendix D, Section 2.6.3.4 of the *Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update* (Feb. 2007). Unless expensive modeling of a type that FEMA did not include in its budget to map York County is done, the following guideline controls:

D.2.8.3.4.3 Decay of Wave Setup across Flooded Lands

> Some previous Flood Insurance Studies have been completed using the assumption that wave setup will decay in the inland direction at some prescribed rate (e.g., one foot of wave setup decay per 1,000 ft of inland flooding, or all wave setup will decay across the barrier island width, etc.). These rules of thumb should not be used. Absent the types of 2-dimensional effects described in the previous section, wave setup at the inland limit of flooding will be equal to or greater than the wave setup at the +/- MSL shoreline

We can illustrate the effect of this by looking at **Attachment 11**. As a simple example, I have attached three sheets that pertain to wave transect YK-67 where the flood elevation behind the barrier beach was calculated by FEMA to be 16' NAVD88. The first sheet shows the local mapping around this transect. The second sheet shows the data inputs to the FEMA module called "WHAFIS" which is within the CHAMP program. Notice that the calculated wave setup component (taken from the MathCAD sheet, **Attachment 12**) is 5.68' (**Attachment 2** shows 5.3') based on a 29.86' high wave. All of the Wells transects have an assumed offshore significant wave height of 29.9' and a wave period of 11.4 seconds which is what the Direct Integration Method (DIM) methodology of calculating open ocean wave setup requires, according to FEMA. The third sheet is the model wave profile (a cross section through the wave and the shore) showing that the offshore 1% wave crest elevation is about 22' and because of the rapid drop near shore of the wave crest elevation and the fact that FEMA calculated a runup of 8' using the TAW method (contained in **Attachment 12**) on a stone revetment assumed to fail so that the wave crest drops to elevation 15', the offshore VE elevation was chosen to be 17'. Now the sum of the surge elevation and the wave setup is 14.6' (called the Total Water Level or TWL), which is rounded up to 15' and carried across the barrier beach in what is assumed to be a marsh flooded to elevation 14.6', allowing a 1' high (average of 1% highest waves) wave to form about 1200' behind shore. With all the numerical rounding, this results in an area in the marsh behind the shore with an AE elevation of 16' as shown in the profile.

So the assumption is that any piling up of the water level on the ocean side (as contained in the wave setup term) is transmitted across the dune to the back estuarine areas. Although minor overtopping of the dunes by the waves during the peak of the storm might occur, the main mechanism by which water enters the estuarine area in the vicinity of YK-67 is from the Ogunquit River from the south. Along the Ogunquit River the main elevation of the 100-year flood is AE-15, based on an average of the wave setup terms for the transects YK-64 through YK-67 which are typically about 5 feet. The Surge Elevation of 8.9 plus 5' equals 14' Total Water Level, then WHAFIS calculates a one foot wave height in part of the estuary behind the beach, to bring the BFE to 15'. The small 16' BFE zone around YK-67 is based on the extra high wave setup of 5.68' for that transect, which produces a TWL of 14.58' for the transect behind the beach and with the one-foot inland wave on top of that it rounds to elevation 16'. We come back to the original question now of whether the tidal flow into the Ogunquit River, with any wave setup super-elevation of the wave crest elevations due to wave setup at the entrance of the River added, can cause the water elevation within the Ogunquit River to actually reach 14-15' elevation during the peak of the 100-year storm. The only way that question can be answered is through using a routing or circulation-type model to move the water into and out of the Ogunquit River during the period just before, during, and after the peak of the 100-year storm. And that is the modeling work that FEMA did not do as part of its mapping, so they fell back on the simple instruction in Appendix D.2.6.3.4.3 to carry the whole wave setup term into the estuary.

Summary of Issues found that may warrant Follow-up

1. STWAVE model improvement and better incident wave selection for WHAFIS and TAW. The wave model does not properly reflect the topography of Wells Beach in the area above normal tidal fluctuation as shown in **Attachment 3**. Putting in the actual topography on Wells Beach would result in improved wave modeling. LiDAR and 2-ft contours for that area are now available on the MEGIS website. Although FEMA insists on using the deepwater wave characteristics to calculate wave setup, smaller near-shore waves should be used as inputs to WHAFIS, TAW and SPM. The surge elevation of 8.9' should be used in the STWAVE model, not 9.5'. The nearshore wave heights that vary from 15 to 20 feet, depending on the transect, should be used for WHAFIS and TAW.

   We note that FEMA used the full deepwater (e.g., ≥300' water depth) wave heights in both WHAFIS and wave runup calculations. As noted in Section D.2.7.1 of the February 2007 Guidelines and Specifications for Flood Hazard Mapping Partners (Atlantic Ocean and Gulf of Mexico Coastal Guidelines Update) (**Attachment 40**) WHAFIS is not intended to use a wave characteristic derived from 10 miles offshore if the wave is transformed by "refraction, diffraction, or bottom dissipation effects." The section goes on to state that "the Mapping Partner should perform separate wave transformation calculations if these effects will cause the incident wave height to depart markedly from the value generated (WHAFIS originally generated the wave characteristics by simulating a wind of constant velocity blowing across a fetch of defined length) by WHAFIS." This is a benefit of using the STWAVE model to create a distribution of significant wave heights and periods across the coastal area being mapped. It does take into account refraction and bottom dissipation effects and, to a mild degree, diffraction.

   Similarly, FEMA used the deepwater wave height for its TAW runup calculations. See **Attachment 41,** Page 2 of the "Technical Report, Wave Run-Up and Wave Overtopping at Dikes" published by the Technical Committee on Flood Defence at Delft in May 2002 (which documents the TAW methodology), "the wave height that is always used in wave run-up and wave overtopping calculations is the incident wave height that should be expected at the end of the foreshore (and thus at the toe of the dike)." This is definitely *not* the deepwater wave of 29.9'.

I want to caution you, however, that making these changes may not change the final calculated BFE at any particular transect. That result is based more on the wave setup calculation and capping runup on top of walls and dune tops. WHAFIS and TAW also are really governed by breaking wave depths and since these may be smaller than a recalculated incident wave height, it may not change the wave profile or runup result by a significant amount. The overall FEMA Preliminary Map looks reasonable when compared with other locations with similar conditions where we have done the modeling ourselves. Despite the fact that FEMA has done a rather sloppy job in defining the nearshore bathymetry/topography and used overly conservative inputs to the WHAFIS and TAW models, the ocean side flood mapping would probably not benefit much by cleaning up the model and recalculating all the transects, which would cost on the order of $10,000.

2. Dune erosion assumption seems overly conservative. FEMA has postulated a large amount of erosion at transects YK-74, YK-75, and YK-77 that seems excessive to me. This drives the VE zones back and allows overtopping of the dunes. Using different incident wave assumptions and a different assumption on how erosion would occur at these locations will affect the location of the VE zones and possibly the Base Flood Elevations. Some research would be required but the assumed erosion slope of 2% may be too flat. There are data on the profiles along Wells beaches taken by Maine Geological Survey over time and these could be compiled and analyzed and a report prepared to document a more appropriate assumed erosion slope. However, since most of the transects are through areas with seawalls of some type and since the areas of these three transects have relatively light density, you should determine first whether it is worth the Town's effort to work on the erosion assumption at these three transect locations, an effort that might cost about $5000.

3. Transmission of Wave Setup into Estuaries. This is clearly the most important issue because it results in adding much more area to the 100-year flood zones. Due to the flatness of the land in the estuarine areas, a reduction of BFE by one or two feet would make a big difference to the area impacted. This is probably the issue that the most effort should be focused on, yet obtaining changes through the appeal process or LOMRs could prove to be very expensive.

   The BFEs in the estuarine areas behind the main shoreline have higher elevations than ever previously seen on FEMA coastal flood maps of Wells for three reasons: a) most estuaries in the past did not have any wave setup from the front shore carried back into the estuaries; b) most estuaries did not have any assumed wave action that could raise a static BFE; and c) the DIM model and its deepwater wave assumptions create what I consider to be a conservative wave setup value for even the ocean-side shoreline, let alone in the estuaries behind the shore. To properly account for transmission of wave setup into the estuaries behind the shore requires a fairly sophisticated "circulation model" (driven by a surge and wave model) that simulates how much water can actually move into an estuary during the hypothetical 100-year storm and how it then spreads out in a distribution of elevations behind the estuary entrance. In round numbers, it would cost about $25,000 to $35,000 per estuary to model this.

Short of doing a circulation model, it may be worthwhile to try to simulate the February 1978 storm conditions and compare the single measured Total Water Level (data point 96) in the Webhannet River estuary[1] with a value predicted by reconstructing the wave conditions from the February 1978 storm and then calculating the wave setup at wave transect YK-70. This could then be used to argue that the classic DIM calculations over-predicted the wave setup that was carried into the Webhannet River estuary. Such a demonstration might only cost about $5000 for the Webhannet, but the problem remains of how to translate this to the theoretical 100-year storm. It may be possible to develop a defensible way of scaling up the results of measured storm TWL measurements to the theoretical 100 year storm, but we have not thought through that process in enough detail yet to determine what would be required, short of a full-blown wave-driven circulation model.

Attachments: 1-41

[1] There were no 1978 storm high water mark surveyed points in the Ogunquit River, but perhaps there are data from another storm that could be used.