Greg Gibson
Vice President, Regulatory Affairs

750 East Pratt Street, Suite 1600
Baltimore, Maryland 21202

UniStar
NUCLEAR ENERGY

10 CFR 50.4
10 CFR 52.79

August 24, 2009

UN#09-349

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject: UniStar Nuclear Energy, NRC Docket No. 52-016
Response to Request for Additional Information for the Calvert Cliffs Nuclear Power Plant, Unit 3,
RAI No. 99, Probable Maximum Tsunami Flooding, Questions 02.04.06-10, 02.04.06-12 through 02.04.06-17

Reference:
1) John Rycyna (NRC) to Robert Poche (UniStar Nuclear Energy), "RAI No 99 RHEB 2090.doc (PUBLIC)" email dated April 16, 2009

2) UniStar Nuclear Energy Letter UN#09-290, from G. Gibson to Document Control Desk (NRC), Updated Response Schedule to RAI No. 99, Probable Maximum Tsunami Flooding; RAI No.101, Groundwater; RAI No. 103, Probable Maximum Surge and Seiche Flooding, dated June 16, 2009

The purpose of this letter is to respond to the request for additional information (RAI) identified in the NRC e-mail correspondence to UniStar Nuclear Energy, dated April 16, 2009 (Reference 1). This RAI addresses Probable Maximum Tsunami Flooding, as discussed in Section 2.4.6 of the Final Safety Analysis Report (FSAR), as submitted in Part 2 of the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 3 Combined License Application (COLA), Revision 5.

Reference 2 stated that responses to Questions 02.04.06-15 and 02.04.06-16 would be provided by August 25, 2009 and responses to Questions 02.04.06-10, 02.04.06-12 through 02.04.06-14 and 02.04.06-17 would be provided by September 1, 2009.

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The enclosure provides our responses to RAI No. 99, Questions 02.04.06-10, 02.04.06-12 through 02.04.06-17 and includes revised COLA content. A Licensing Basis Document Change Request has been initiated to incorporate these changes into a future revision of the COLA. Our responses to Questions 02.04.06-10, 02.04.06-12 through 02.04.06-17 do not include any new regulatory commitments.

As previously communicated, a new computer code, TSU_NLSWE Version 1.0, has been developed that combines the NLSWE and TSU codes and is validated to the requirements of NQA-1-1983. This new code was developed and used to provide responses that should be treated as preliminary for your review until validation of the code is confirmed to comply with the requirements of NQA-1-1994, Subpart 2.7. The validation process will be completed by December 8, 2009. At that time UniStar Nuclear Energy will request the NRC to consider the enclosed response to RAI No. 99 as final.

If there are any questions regarding this transmittal, please contact me at (410) 470-4205, or Mr. Michael J. Yox at (410) 495-2436.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on August 24, 2009

Greg Gibson

Enclosure: Response to NRC Request for Additional Information RAI No. 99, Question 02.04.06-10, 02.04.06-12 through 02.04.06-17, Probable Maximum Tsunami Flooding, Calvert Cliffs Nuclear Power Plant, Unit 3

cc: Surinder Arora, NRC Project Manager, U.S. EPR Projects Branch
Laura Quinn, NRC Environmental Project Manager, U.S. EPR COL Application
Getachew Tesfaye, NRC Project Manager, U.S. EPR DC Application (w/o enclosure)
Loren Plisco, Deputy Regional Administrator, NRC Region II (w/o enclosure)
Silas Kennedy, U.S. NRC Resident Inspector, CCNPP, Units 1 and 2
U.S. NRC Region I Office

GTG/SFW/kat

Enclosure

Response to NRC Request for Additional Information RAI No. 99, Question 02.04.06-10, 02.04.06-12 through 02.04.06-17, Probable Maximum Tsunami Flooding, Calvert Cliffs Nuclear Power Plant, Unit 3

RAI No. 99

Question 02.04.06-10

Section C.I.2.4.6.4 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to tsunami analysis. This includes providing a complete description of the analysis procedure used to calculate tsunami wave height and period at the site, including verification of all models used in the analysis. Provide runup validation and/or field comparisons of the hydrodynamic model codes (NLSWE and TSU) used in the model simulations, in addition to the Gaussian hump comparison with analytic solutions.

Preliminary Response

The combined code TSU_NLSWE was used to simulate tsunami propagation in the Chesapeake Bay for both linear and nonlinear model simulation scenarios. Tsunami run-up on the Chesapeake Bay shore near the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 3 site was estimated independently and added to the simulated maximum tsunami water level to obtain the probable maximum tsunami (PMT) water level. Run-up was estimated independently because the TSU_NLSWE model code does not allow for flooding or drying of computational cells and therefore cannot be used to compute tsunami wave run-up. The methodology used to estimate the tsunami run-up is described in the response to RAI 99 Question 02.04.06-13.

The maximum tsunami water level at the CCNPP Unit 3 site was selected from linear simulation of tsunami propagation. The linear simulation model was developed following the procedure described by Yoon.[1] Linear model results for Gaussian hump propagation show good comparison with the analytical solution for a range of constant water depth conditions. Yoon applied the linear model to simulate the propagation of the 1983 Nihonkai-Chubu tsunami. This earthquake-generated tsunami originated near the east rim of the Sea of Japan and impacted the Japanese coast. A comparison of model results with measured data along the Japan Sea coast showed that satisfactory agreement was obtained using the linear model.

The nonlinear model including bottom friction was developed using the methodology given by the Intergovernmental Oceanographic Commission.[2] Nonlinear model simulations were compared qualitatively with analytical Gaussian hump solutions for a constant water depth that was similar to the average water depth of the Chesapeake Bay. The numerical simulation results appropriately predicted nonlinear wave deformation and dissipation by bottom friction, although a quantitative comparison against an analytical solution was not possible. However, the linear model results are bounding in terms of maximum and minimum water levels, and the nonlinear model results are not used in the Final Safety Analysis Report (FSAR) to establish the PMT amplitude or drawdown.

Given that the linear model has been validated against field observations and the fact that tsunami runup on the Chesapeake Bay shore is estimated independently and added to the maximum simulated water level at the site, the hydrodynamic model code used to estimate the PMT (the TSU model) is considered validated.

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[1] S. Yoon, 2002, "Propagation of Distant Tsunamis over Slowly Varying Topography," *Journal of Geophysical Research*, Volume 107, Number C10 (2002).

[2] Intergovernmental Oceanographic Commission (IOC), "Numerical method of tsunami simulation with the leap-frog scheme," *IUGG/IOC Time Project, Manuals and Guides*, (1997) UNESCO.

COLA Impact

The COLA changes due to the response to RAI 99 Question 02.04.06-10 are shown as part of the RAI No. 99 Question 02.04.06-17 response.

Question 02.04.06-12

Section C.I.2.4.6.4 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to tsunami analysis. This includes providing a complete description of the analysis procedure used to calculate tsunami wave height and period at the site. Clarify the phrase "waves quickly dispersed" in the updated FSAR and provide a surface contour map of maximum tsunami wave height in Chesapeake Bay.

Preliminary Response

Tsunami propagation in the Chesapeake Bay was simulated using both linear (TSU) and nonlinear (NLSWE) models. Three tsunami sources were considered, representing local and distant tsunami generators. The resultant tsunami waves entering the bay were applied at an internal model boundary near the mouth of the bay and propagated in the bay towards Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 3 by model simulation. Model results show that the waves entering the bay would undergo significant dissipation as they reached the CCNPP Unit 3 site, which is approximately 90 mi (145 km) inside the bay from the model boundary. For the Case 1 nonlinear simulation, the 4 m (13.1 ft) tsunami amplitude entering the bay was reduced in magnitude to about 0.155 m (0.51 ft) at the site, a 96 percent reduction in amplitude. For the Case 1 linear simulation, the tsunami amplitude was reduced in magnitude to 0.326 m (1.07 ft), a 92 percent reduction in amplitude. Figures 1 and 2 represent contour maps of maximum tsunami wave height in the bay for the Case 1 nonlinear and linear simulations, respectively. As shown in these results, most tsunami amplitude dissipation occurs within about the first 50 mi (80 km) of the boundary. This occurs because the bay is relatively shallow. These results provide the basis of the phrase "waves quickly dispersed" that is included in the FSAR.

Figure 1. Contour of Maximum Tsunami Amplitude for Case 1 with Nonlinear Simulation Option

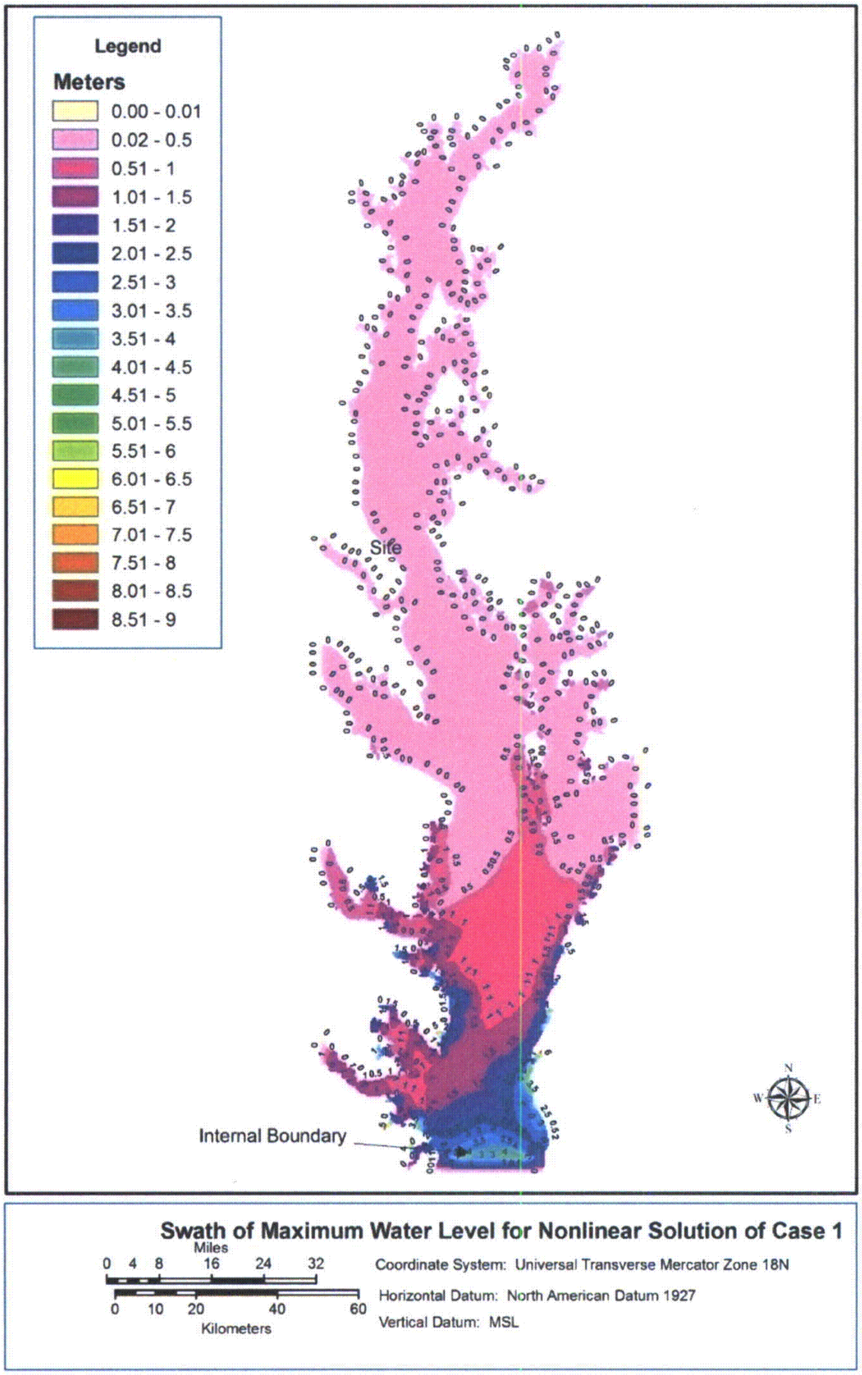
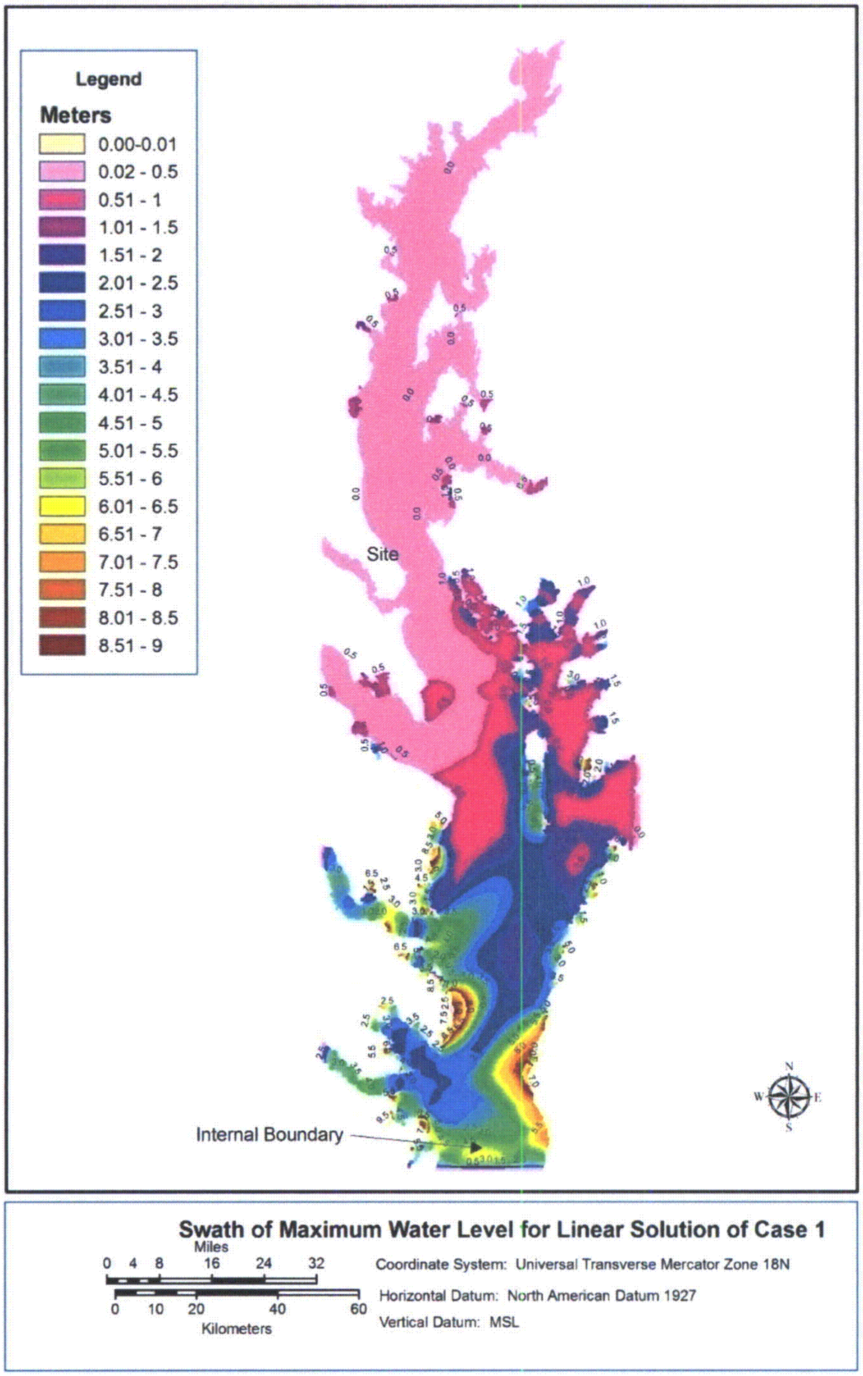


Figure 2. Contour of Maximum Tsunami Amplitude for Case 1 with Linear Simulation Option



COLA Impact

The COLA changes due to the response to RAI 99 Question 02.04.06-12 are shown as part of the RAI No. 99 Question 02.04.06-17 response.

Question 02.04.06-13

Section C.I.2.4.6.4 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to tsunami analysis. This includes providing a complete description of the analysis procedure used to calculate tsunami wave height and period at the site. Indicate how tsunami run-up on land is estimated from near-shore tsunami amplitude in the updated FSAR.

Preliminary Response

The numerical model TSU_NLSWE was used to simulate tsunami propagation in Chesapeake Bay using both linear and nonlinear simulation models. While the effects of nonlinear wave dissipation and bottom friction are considered in the NLSWE model, tsunami run-up on land is not accounted for in either model. Land boundaries in both models are assumed to be fixed and flooding of initially dry land cannot be simulated. However, tsunami run-up at the site was estimated independently and added to the maximum simulated tsunami amplitude to obtain the probable maximum tsunami (PMT) water level.

Several semi-empirical methods are available in literature that estimate short period wind-wave run-up on land. However, estimation of tsunami run-up is still a subject of research. The Coastal Engineering Manual (CEM) provides methodologies for estimating wind-wave run-up on plane beaches or coastal structures based on the surf similarity parameter.[1] The surf similarity parameter defines wave deformation and type of breaking based on beach slope, wave period and a representative wave height. CEM indicates that the run-up on structures generally ranges from 1 to 3 times the wave height.

Madsen proposed a similar methodology employing the surf similarity parameter for estimating tsunami run-up on plane beaches based on the assumption that tsunamis can be assumed as a quasi-periodic event.[2] Madsen and Fuhrman and Didenkulova et al. proposed analytical relationships for tsunami run-up on plane beaches using linear wave approximation.[3] However, because tsunami waves propagate a long distance in the shallow Chesapeake Bay before reaching the shoreline near the site, characteristic tsunami parameters are not comparable to the parameters on plane beaches and would likely result in a smaller tsunami run-up estimate for CCNPP Unit 3.

Mader indicated the tsunami run-up amplification at a site would be about 2 to 3 times the deep-water tsunami amplitude.[4] This is in addition to tsunami amplification in shallow water due to shoaling. The average Chesapeake Bay water depth is small and remains nearly unchanged over the bay length. As a result, shoaling effect in the Chesapeake Bay would be low and dissipation of tsunami waves would be predominant. Therefore, a tsunami run-up of 3 times the maximum tsunami amplitude in the Chesapeake Bay is conservative.

Based on above discussion, a maximum tsunami run-up amplification of 3 times the maximum tsunami amplitude in Chesapeake Bay near the CCNPP Unit 3 site is considered for the Ultimate Heat Sink (UHS) makeup water intake structure. The run-up height therefore is

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[1] Coastal Engineering Manual, EM 1110-2-1100, U.S. Army Corps of Engineers, 2008

[2] P. A. Madsen, and D. R. Fuhrman, "Analytical and Numerical Models for Tsunami Run-up," *Tsunami and Nonlinear Waves,* A. Kundu (Ed.), 2007

[3] Didenkulova, E. Pelinovsky, T. Soomere, and N. Zahibo, "Run-up of Nonlinear Asymmetric Waves on Plane Beach," A. Kundu (Ed.), 2007

[4] C. L. Mader , "Modeling the 1755 Lisbon Tsunami," *Science of Tsunami Hazards,* Volume 19, Number 2, (2001), pages 93-95

estimated as (3 x 1.5 ft) or 4.5 ft. Model simulation results show that the tsunami amplitude remains nearly the same over the width of the Chesapeake Bay near the CCNPP Unit 3 site.

COLA Impact

The COLA changes due to the response to RAI 99 Question 02.04.06-13 are shown as part of the RAI No. 99 Question 02.04.06-17 response.

Question 02.04.06-14

Section C.I.2.4.6.4 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to tsunami analysis. This includes providing a complete description of the analysis procedure used to calculate tsunami wave height and period at the site. Describe the source of data and method used to develop the bathymetric grid for the tsunami model. Also provide a description of the grid-size sensitivity test in the updated FSAR.

Preliminary Response

The bathymetry data for the Chesapeake Bay was obtained from the National Oceanic and Atmospheric Administration (NOAA) National Ocean Services program.[1] NOAA provides the data in the form of a digital elevation model (DEM) having a spatial resolution of 30 m by 30 m (98.4 ft by 98.4 ft) and coverage in 7.5-minute-by-7.5-minute blocks. The planer coordinates use the Universal Transverse Mercator (UTM) Zone 18N projected coordinate system based on the North American Datum of 1927 (NAD27). Vertical elevations are referenced to the local mean low water (MLW). The MLW is the average of all low water tides at a given location over a 19-year span referred to as the tidal epoch.

Bathymetric data were converted from local MLW datums to a global datum that is applicable for the entire model domain. Mean sea level (MSL) from the 1983-2001 tidal epoch for the NOAA tide station at the Chesapeake Bay Bridge Tunnel, Virginia (station 8638863) is used as the reference datum for the model, which also serves as MSL for the CCNPP Unit 3 site. Among the more than 30 tidal stations within the Chesapeake Bay, the Chesapeake Bay Bridge Tunnel station has the largest difference between MLW and MSL. Using the conversion factor derived from this station therefore results in an overestimation of water depths in other areas of the bay, which would lead to conservative estimates of tsunami amplitude in the bay.

The grid size for the Chesapeake Bay model bathymetry was selected based on the consideration that tsunami wavelengths include sufficient number of grid points, as described in Section 2.4.6.4.1 of the CCNPP Unit 3 FSAR. The selected 360 m square grid spacing encompasses about 92 grid points for one wavelength. Water depths were assigned to each 360 m by 360 m grid cell by sampling the 30 m NOAA DEM data at an appropriate interval. For example, the 360 m grid model bathymetry was developed by sampling every 12th data point from the 30 m NOAA DEM data. The original 30 m NOAA bathymetry and 360 m model bathymetry are shown on Figures 1 and 2, respectively.

To assess the sensitivity of model results to grid size, model sensitivity tests with grid sizes of 240 m, 300 m, and 360 m were performed for Case 1 using both nonlinear and linear simulation models. The maximum and minimum water levels produced by different grid sizes are listed in Table 1. Figures 3 and 4 show the simulated water levels at the CCNPP Unit 3 site for nonlinear and linear models, respectively, as a function of grid size. The results indicate that the maximum water level at the site decreases with the reduction of grid size for nonlinear solutions, whereas there is no clear trend for the minimum water level. For the linear solutions, there is no clear trend for the maximum and minimum water levels with the grid size. The 360 m grid produces a slightly lower maximum water level than the 300 m grid, but a higher maximum water level than does the 240 m grid. It can be concluded that grids finer than 360 m do not

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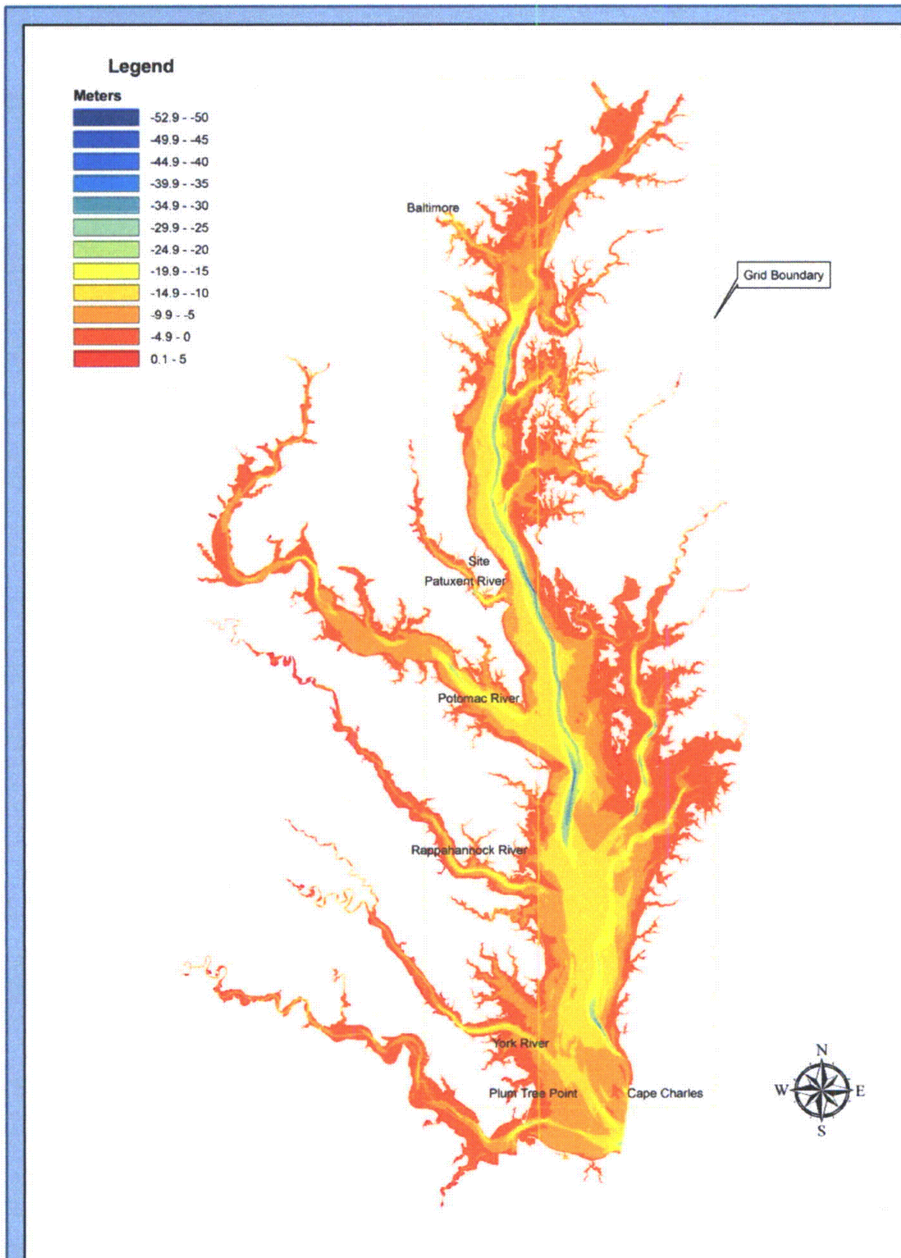
[1] Website: http://egisws01.nos.noaa.gov/servlet/BuildPage?template=bathy.txt&parm1=M130&B1=Submit: Bathymetry Data of the Chesapeake Bay, Date Accessed: 09/06/2006

necessarily improve the accuracy of the linear and nonlinear models, nor do they lead to more conservative results.

Table 1. Tsunami maximum and minimum water levels at the site for different grid sizes

Description	Maximum Water Level (m MSL)	Minimum water Level (m MSL)
360m Grid (Case 1, Nonlinear Solution)	0.155	-0.051
300m Grid (Case 1, Nonlinear Solution)	0.151	-0.052
240m Grid (Case 1, Nonlinear Solution)	0.140	-0.042
360m Grid (Case 1, Linear Solution)	0.326	-0.186
300m Grid (Case 1, Linear Solution)	0.365	-0.231
240m Grid (Case 1, Linear Solution)	0.306	-0.179

Figure 1: 30-m Square Grid DEM from NOAA National Ocean Service



Chesapeake Bay Bathymetry
(Data Source: NOAA)

Miles: 0 4.5 9 18 27 36
Kilometers: 0 10 20 40 60

Coordinate System: Universal Transverse Mercator Zone 18N
Horizontal Datum: North American Datum 1927
Vertical Datum: Mean Low Water Local Tidal Datum

Figure 2: 360-m Square Grid Model Bathymetry and Model Boundary Locations

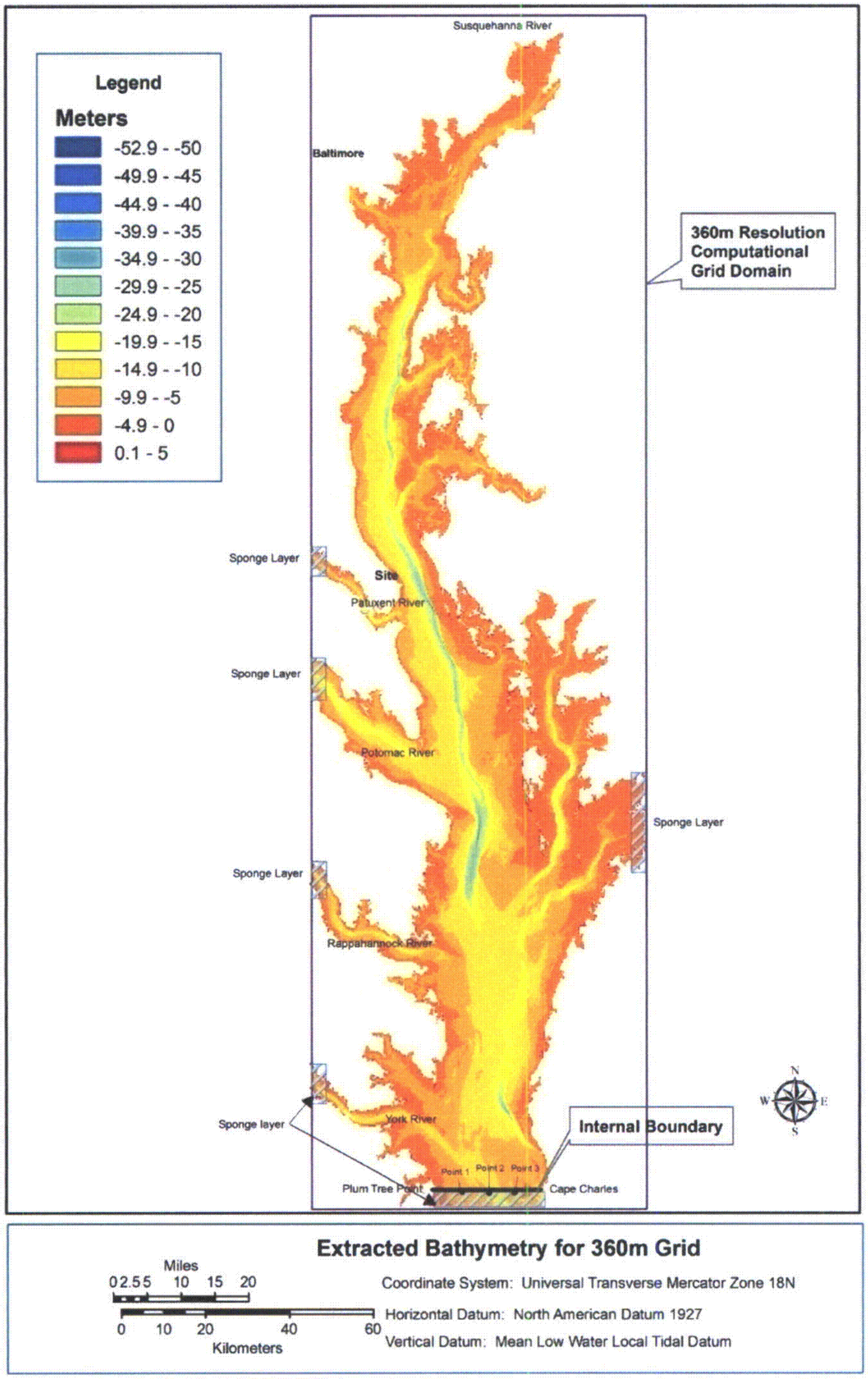


Figure 3: Comparison of Simulated Water Levels at the Site for Different Grid Sizes for the Nonlinear (NLSWE) Model, Case 1

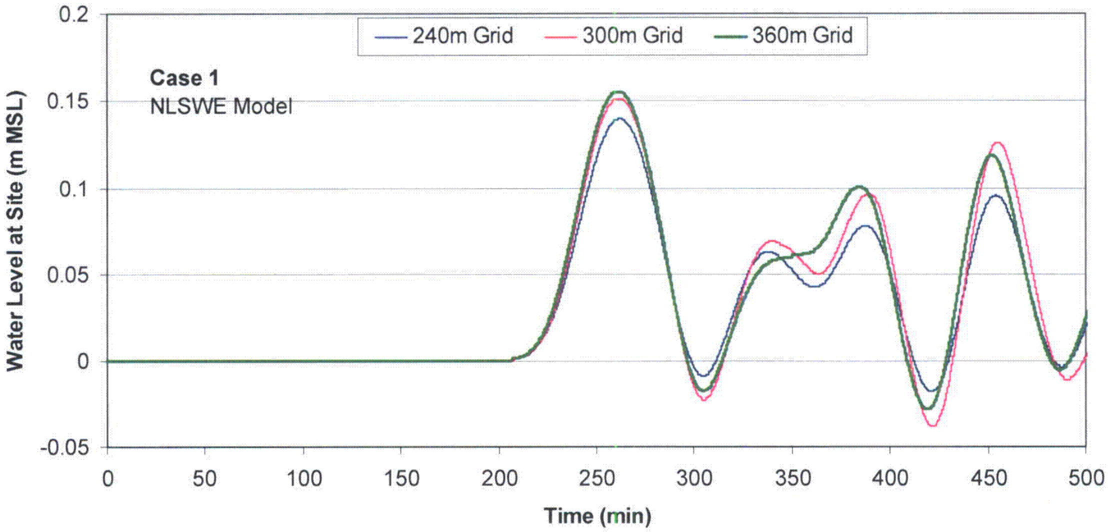
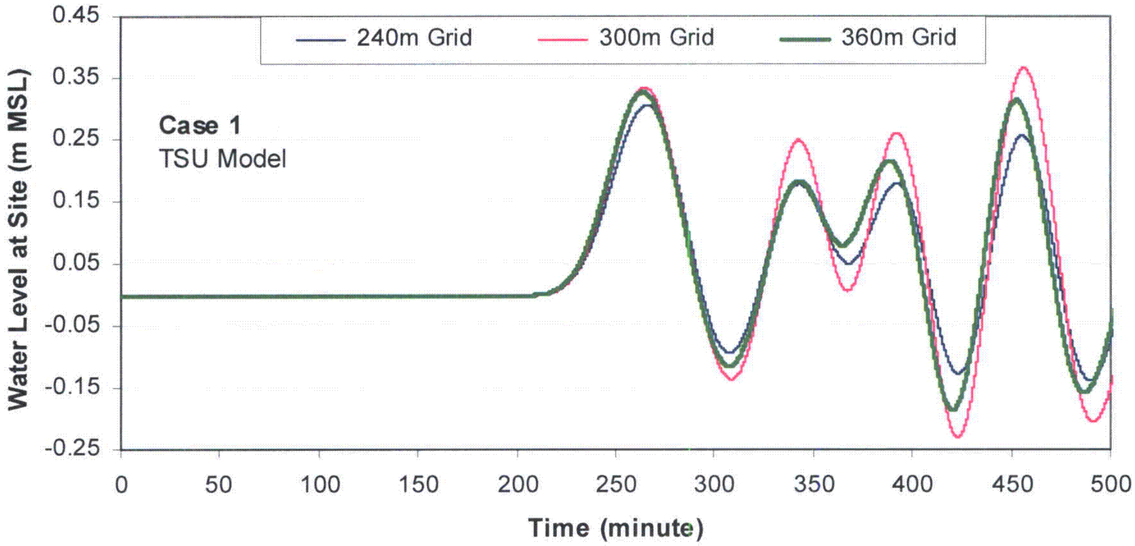


Figure 4: Comparison of Simulated Water Levels at the Site for Different Grid Sizes for the Linear (TSU) Model, Case 1



COLA Impact

The COLA changes due to the response to RAI 99 Question 02.04.06-14 are shown as part of the RAI No. 99 Question 02.04.06-17 response.

Question 02.04.06-15

Section C.I.2.4.6.5 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to tsunami water levels. This includes providing estimates of maximum and minimum (low water) tsunami wave heights from both distant and local generators. Provide a discussion in the updated FSAR of the water levels for all simulations (NLSWE and TSU models), so that the limiting water levels can be confirmed.

Preliminary Response

Simulations of tsunami propagation in the Chesapeake Bay for different tsunami generator sources were performed for both linear and nonlinear models as described in the response to RAI 99 Question 02.04.06-12. The TSU_NLSWE model code combines the NLSWE (nonlinear) and TSU (linear) models where the selection of model type is provided as input.

The maximum tsunami amplitude and drawdown at the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 3 site obtained from the simulations are summarized in Table 1. Tsunami amplitudes and drawdowns in Table 1 are referenced to the mean sea level (MSL) as established at the National Oceanic and Atmospheric Administration (NOAA) Chesapeake Bay Bridge Tunnel tide station (Station 8638863). The results show that the maximum amplitude is obtained for Case 1 with linear TSU model. The maximum drawdown is obtained for Case 3 also with linear TSU model

Table 1: Simulated Maximum Tsunami Amplitude and Drawdown for Different Cases with Linear and Nonlinear Simulation Options

Cases	Maximum Tsunami Amplitude (m)	Maximum Tsunami Drawdown (m)	Comments
1	0.155	0.051	Norfolk Canyon submarine landslide; nonlinear simulation option
	0.326	0.186	Norfolk Canyon submarine landslide; linear option
2	0.131	0.049	Canary Islands landslide; nonlinear option
	0.245	0.139	Canary Islands landslide; linear option
3	0.127	0.103	Haiti Earthquake; nonlinear option
	0.262	0.237	Haiti Earthquake; linear option

COLA Impact

The COLA changes due to the response to RAI 99 Question 02.04.06-15 are shown as part of the RAI No. 99 Question 02.04.06-17 response.

Question 02.04.06-16

Section C.I.2.4.6.5 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to tsunami water levels. This includes providing estimates of maximum and minimum (low water) tsunami wave heights from both distant and local generators. Provide a discussion in the updated FSAR of how uncertainty in simulated tsunami water levels was determined.

Preliminary Response

Part 2, Section 2.4.6.5 of the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 3 COLA, indicates the maximum amplitude and drawdown from the PMT, obtained from the linear simulation model, were each 0.5 m (1.64 ft), including a margin for uncertainties. The simulated values were increased by approximately 20 percent based on engineering judgment. No sensitivity or uncertainty analyses were conducted to quantitatively establish the margin.

Additional work has been conducted to assess the sensitivity of model results and the PMT estimate to model inputs and assumptions. Results of this assessment indicate that significant modeling uncertainty is associated with simulating wave propagation in very shallow water depths near land boundaries. In particular, Synolakis indicates that run-up estimates from linear models are accurate provided that the ratio of tsunami amplitude to water depth is small.[1] Ward recommends that tsunami computations using linear models be confined to grid points where the water depth is greater than the amplitude of incoming tsunamis.[2] At shallower water depths, Ward argues that waves no longer amplify because of increasing bottom friction, and that the limiting amplitude approximates the tsunami run-up height. Because the Chesapeake Bay model includes water depths less than the amplitude of incoming tsunamis, the simulated maximum amplitude and drawdown, taken from the linear model, were increased to provide assurance that these values are not underestimated. The basis for the factor used to increase the maximum amplitude and drawdown is described below.

To quantitatively assess the effects of confining the tsunami computations to grid points where the ratio of tsunami amplitude to water depth is relatively large, a series of model sensitivity simulations were performed wherein the minimum allowable water depth (cutoff depth) was varied in the model. Three simulations with cutoff depths of 0.5 m, 1.0 m, and 2.0 m for both linear and nonlinear models were conducted using the Case 1 tsunami generator. In each simulation, portions of the domain having water depths less than the cutoff depth were eliminated from the model domain. The shallow water areas of the Chesapeake Bay affected by imposing cutoff depths include the western shoreline near the Potomac River mouth and upstream of the CCNPP Unit 3 site. The simulated water levels at the site are shown on Figures 1 and 2. The relative increases in maximum amplitude at the site as a function of cutoff depth are summarized in Table 1.

The results from these simulations show that the amplitudes of the tsunami wave peaks and troughs at the CCNPP Unit 3 site generally increase with increasing cutoff depth for both linear and nonlinear models. Note that the maximum relative increase in amplitude (77 percent) occurred in the linear simulation with a 1.0 m cutoff depth; however, the maximum water level for this simulation appeared during the third wave peak, unlike other cases wherein the relative increase was greatest for the first peak. Excluding this apparently anomalous case, the 2.0 m

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[1] C.E.Synolakis, "The Runup of Solitary Waves," *Journal of Fluid Mechanics*, Volume 185 (1987), pages 523-545.
[2] S.N. Ward, "Landslide Tsunami," *Journal of Geophysical Research*, Volume 106, Number B6 (2001), pages 11,201–11,215.

cutoff depth resulted in the maximum water level. Consequently, the selected maximum water level from the Case 1 linear simulation was increased by 60 percent to obtain the PMT water level at the Unit 3 site. The same factor was also adopted for the PMT drawdown level.

Table 1. Maximum tsunami water levels at the site as a function of cutoff depth

Model	Cutoff Depth (m)	Maximum Amplitude (m)	Amplitude Change (%)
Case 1 Nonlinear	0m (Case 1, Nonlinear)	0.155	-
	0.5m (Case 1, Nonlinear)	0.175	12.9
	1m (Case 1, Nonlinear)	0.198	27.7
	2 m (Case 1, Nonlinear)	0.244	57.4
Case 2 Linear	0m (Case 1, Linear)	0.326	-
	0.5m (Case 1, Linear)	0.423	29.8
	1m (Case 1, Linear)	0.577	77.0 (Note 1)
	2m (Case 1, Linear)	0.524	60.7

Note 1: This apparently anomalous peak occurred on the third peak of the simulated tsunami wave (see Figure 2). The establishment of an appropriate margin for uncertainties is based on first peak values

Figure 1. Comparison of Water Level at the Site for Different Cutoff Depths, Nonlinear Model Simulation Option

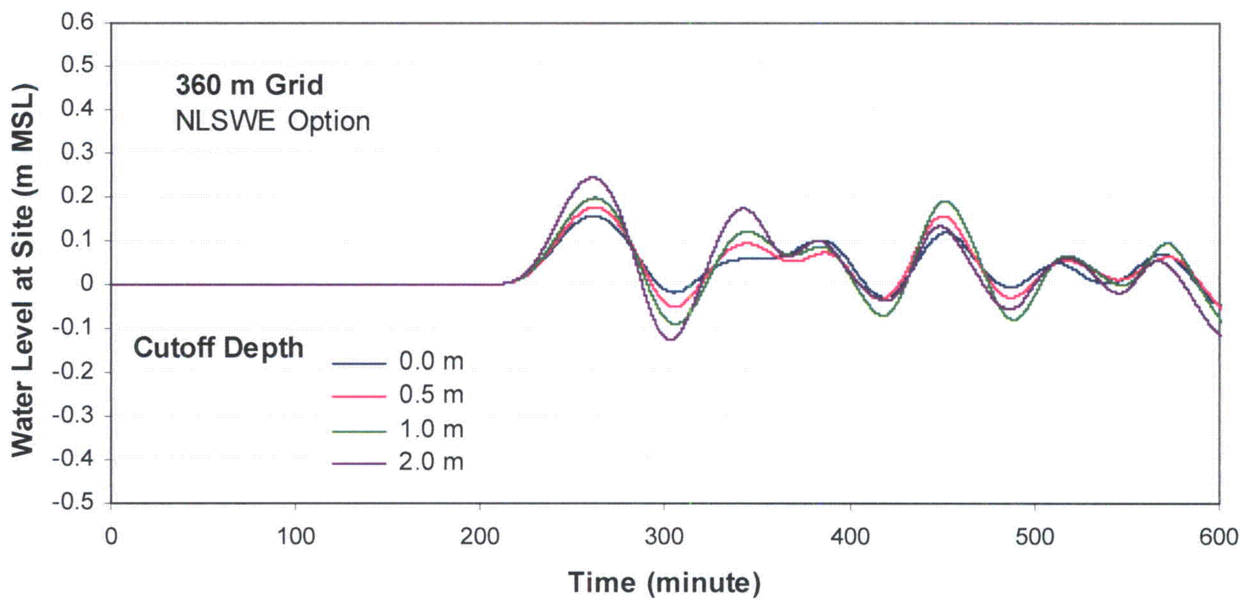
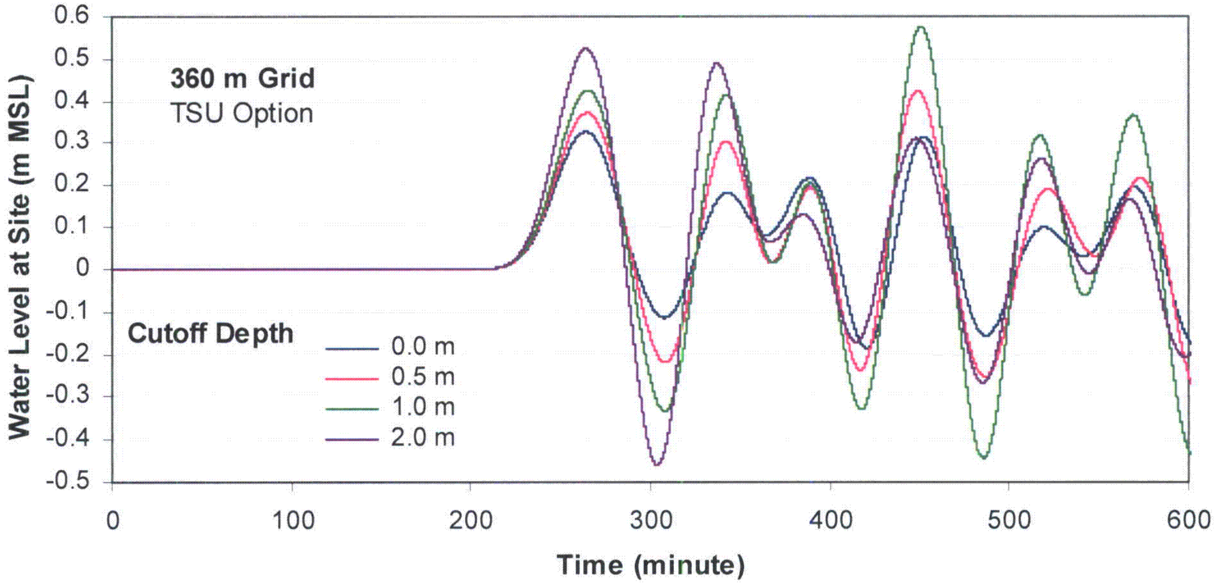


Figure 2. Comparison of Water Level at the Site for Different Cutoff Depths, Linear Model Simulation Option



COLA Impact

The COLA changes due to the response to RAI 99 Question 02.04.06-16 are shown as part of the RAI No. 99 Question 02.04.06-17 response.

Question 02.04.06-17

Section C.I.2.4.6.5 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to tsunami water levels. This includes describing the ambient water levels, including tides, sea level anomalies, and wind waves assumed to be coincident with the tsunami. Provide a discussion in the updated FSAR of long-term sea level rise that may be coincident with tsunami water levels.

Preliminary Response

Based on 1902-1999 tidal records from the National Oceanic and Atmospheric Administration for Baltimore, MD, the estimated mean sea level increased at a rate of about 1.02 ft/century or 3.12 mm/year. At Solomons Island, MD, the mean sea level from 1937-2006 is estimated to be rising at 1.12 ft/century or 3.41 mm/year. Assuming that the sea level at the site would rise at the average rate of these stations for the next 100 years, a long-term sea level increase of 1.07 ft has been selected for FSAR Section 2.4.6 in the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 3 COLA.

Long-term sea level rise in the Chesapeake Bay near the CCNPP Unit 3 site is estimated in FSAR Section 2.4.5 of COLA Revision 5 as a nominal increase of 1.0 ft in sea level for the design period of the plant.

COLA Impact

FSAR Sections 2.4.6.4 to 2.4.6.10 will be replaced in their entirety with the following in a future COLA revision.

2.4.6.4 Tsunami Analysis

Tsunami simulations were performed within the Chesapeake Bay using a two-dimensional, depth-averaged numerical model, TSU_NLSWE, Version 1.0. Because the water depth in the Chesapeake Bay is relatively shallow compared to the wavelength and amplitude of incident tsunamis, nonlinearity of waves and bottom friction effects are considered in the model formulation. The model is capable of simulating wave propagation in shallow waters using the nonlinear shallow water wave equations with bottom friction (NLSWE model), where the bottom friction term is taken as a function of the fluxes in the two horizontal directions and Manning's roughness coefficient. The model can also simulate wave propagation using the linear shallow water wave equations without bottom friction (TSU model). The model uses a leap-frog finite-difference scheme to numerically solve the governing partial differential equations. Tsunami simulations were conducted using both linear and nonlinear simulation models for both local and distant tsunami generators. Results were then compared to obtain the bounding tsunami amplitude at the CCNPP Unit 3 site.

2.4.6.4.1 Governing Equations

The governing equations used in the TSU_NLSWE model are shown below (Imamura, 2006; IOC, 1997):

$$\frac{\partial \eta}{\partial t}+\frac{\partial P}{\partial x}+\frac{\partial Q}{\partial y}=0 \qquad \text{Eq. 2.4.6-1}$$

$$\frac{\partial P}{\partial t}+\frac{\partial}{\partial x}\left(\frac{P^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{PQ}{h}\right)+gh\frac{\partial \eta}{\partial x}+\frac{gn^2}{h^{7/3}}P\sqrt{P^2+Q^2}=0 \qquad \text{Eq. 2.4.6-2}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{Q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{PQ}{h}\right)+gh\frac{\partial \eta}{\partial y}+\frac{gn^2}{h^{7/3}}Q\sqrt{P^2+Q^2}=0. \qquad \text{Eq. 2.4.6-3}$$

Where:

- η represents the free surface displacement from still-water level;
- P and Q are the depth-averaged volume fluxes in the x and y directions, respectively;
- t is time;
- g is the acceleration of gravity;
- h is the water depth below the still-water level; and
- n is Manning's roughness coefficient.

Linearization of the governing equations in the TSU model option neglects the effect of convective terms in the equations of motion (second and third terms in Eq. 2.4.6-2 and Eq. 2.4.6-3). Additionally, bottom friction effects (the last term in Eq. 2.4.6-2 and Eq. 2.4.6-3) are neglected in the TSU model option. As a result, simulation results using the TSU model option provide a conservative upper bound solution for tsunami propagation in a shallow water environment such as the Chesapeake Bay.

A leap-frog, finite-difference scheme is employed to solve both the nonlinear and linear shallow water equations on a staggered grid in time and space, as shown in Figure 2.4-29. The equation of the continuity is approximated with an explicit, central-difference scheme. Approximation of the linear terms in the equations of motion also uses a central-difference scheme. An upwind scheme is applied to approximate the convection terms in the equations of motion. An implicit scheme is utilized for the bottom friction terms, as the friction term becomes a source of instability if it is represented using explicit scheme (Imamura, 2006; IOC, 1997).

Discretization of linear governing equations in finite-difference form generates numerical dispersion, which is a form of numerical error (Yoon, 2002). This numerical dispersion can be used as a surrogate for the physical dispersion neglected in the linear form of the shallow water equation by appropriately selecting the computational time step and grid spacing. For a fixed grid model with varying water depth, the accuracy of the linear model, therefore, is limited because of inherent model requirements of different grid sizes for different water depths. Yoon overcomes this limitation by separately calculating the computational grid spacing (termed as "the hidden grid spacing") at each time step, based on the dispersion criterion provided as input to the model. The computations are then performed on the hidden grids. At the end of each time step, the results are interpolated back at user-specified grid locations from the hidden grids. This technique has shown a considerable improvement in the accuracy of the solution of linear shallow water equations. This hidden grid approach was employed in developing the TSU_NLSWE model. The finite-difference schemes used in the models are represented in Figures 2.4-30 and 2.4-31.

2.4.6.4.2 Model Simulations

Verification of TSU_NLSWE Code

Prior to using the TSU_NLSWE code for simulating tsunami propagation in Chesapeake Bay, it was necessary to verify the code. Verification was performed by comparing model simulation results against an analytical solution of Gaussian hump propagation developed by Carrier (2003). Comparison of the both the linear and nonlinear numerical solutions against the analytical solution resulted in good agreement for deep water. The model was also tested for a constant water depth of 10 m (32.8 ft) and the grid size of 360 m by 360 m (1181 ft by 1181 ft), which represents the relatively shallow depths of the Chesapeake Bay. The shallow water results for the linear simulation showed good agreement with the analytical solution. For the nonlinear simulation, a qualitative comparison showed that the numerical results appropriately predicted the nonlinear wave deformation and dissipation by bottom friction. A quantitative comparison for the nonlinear option was not possible as no analytical solution is available for the general nonlinear case. Yoon (2002) applied the linear model to simulate the propagation of the 1983 Nihonkai-Chubu tsunami. This earthquake-generated tsunami originated near the east rim of the Sea of Japan and impacted the Japanese coast. A comparison of model results with measured data along the Japan Sea coast showed that satisfactory agreement was obtained using the linear model (Yoon, 2002). Based on these results, the TSU_NLSWE code is considered verified.

The Chesapeake Bay Model Extent and Boundary Conditions

The TSU_NLSWE model code was used to provide estimates of maximum and minimum (low water) tsunami wave heights at the CCNPP Unit 3 site from both distant and local generators. Simulations were performed within the Chesapeake Bay for three potential tsunami sources generating the Probable Maximum Tsunami (PMT). The potential tsunamigenic sources are discussed in Section 2.4.6.1, and the source characteristics are described in Section 2.4.6.3. The characteristics of the incident tsunami waves at the entrance of the Chesapeake Bay and the computational cases for linear and nonlinear model simulation options are summarized in Table 2.4-26. Simulations were performed to obtain tsunami amplitude and drawdown for an initial water level condition corresponding to mean sea level (MSL) at the Chesapeake Bay Bridge Tunnel tide gauge. The PMT was then determined considering the simulated maximum tsunami amplitude at the CCNPP Unit 3 site, an antecedent water level condition based on the 10% exceedance high spring tide, sea level anomaly, and long-term sea level rise, as adopted in Section 2.4.5.

The Chesapeake Bay model domain extends approximately 180 mi (290 km) from near Plume Tree Point, Virginia to near the mouth of the Susquehanna River, including portions of the major river channels. Stream flow in the rivers and tidal variations were ignored in the tsunami simulations. A zero-flux condition was applied across fixed land boundaries. Flooding and drying of grid cells was not considered in the model.

Incoming tsunami amplitudes and periods for different cases, as presented in Table 2.4-26, were applied as regular sinusoidal waves along an internal boundary between Plume Tree Point, Virginia and Cape Charles, Virginia, as shown in Figure 2.4-32. The internal boundary was based on implementing a radiation boundary (Larsen, 1983). Implementation of the internal boundary, where the incoming tsunami is applied as a perturbation, requires that all outgoing waves are absorbed at the external boundaries of the model without reflection. This requirement was enforced by implementing non-reflective, absorbing layers (defined as "sponge" layers) for 10 grid lines along the boundaries. The procedure for defining a sponge layer is described by Larsen (1983). All outgoing waves, in terms of surface displacement and volume fluxes, are absorbed over the thickness of the sponge layers. Sponge layers were also implemented for the Patuxent, Potomac, Rappahannock and York Rivers along the west and Pocomoke Sound along the east boundary of the domain. Locations of the sponge layers are also shown in Figure 2.4-32. Boundaries for the other rivers, including the northern end of the Chesapeake Bay, were considered closed (no-flux) and fully reflective.

The Chesapeake Bay Bathymetry and Model Grid

Bathymetric data for the Chesapeake Bay were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Ocean Services program (NOAA, 2006b). The digital elevation model (DEM) data have a spatial resolution of 98.4 ft by 98.4 ft (30 m by 30 m) with coverage in 7.5-minute by 7.5-minute blocks (NOAA, 2006b). The depth soundings used to generate the bathymetry were surveyed over a period from 1859 to 1993. Thirty-six surveys were conducted in the 1859-1918 period, 37 in the 1930s, 91 in the 1940s, 66 in the 1950s, 25 in the 1960s, 24 in the 1970s, 14 in the 1980s, and 4 in the 1990s (NOAA, 2006b). The total range of sounding data is from 12.1 to -165.4 ft (3.7 to -50.4 m) at mean low water (MLW) with depths below MLW represented as negative values. The DEM data use the Universal Transverse Mercator (UTM) Zone 18N projected coordinate system with the North American Datum of 1927 (NAD27) for the horizontal coordinate system. The vertical datum is relative to MLW, where MLW is the average of all low water tides at a location over a 1983-2001 19-year period (or tidal epoch). The NOAA bathymetric data for the Chesapeake Bay are shown in Figure 2.4-200.

Bathymetric data were converted from local MLW datums to a global datum applicable for the entire model domain. MSL at Chesapeake Bay Bridge Tunnel (CBBT), which corresponds to the 1983-2001 tidal epoch, was adopted as the reference datum for the model and also assumed to be MSL for the CCNPP Unit 3 site. This assumption is conservative as the difference between the MSL and MLW at the CBBT station is the maximum inside the Chesapeake Bay. The MLW–MSL relationship at CBBT is given on the NOAA website (NOAA, 2007). Note that model results were converted to National Geodetic Vertical Datum of 1929 (NGVD 29) elevations for comparison with elevations of safety-related systems, structures, and components. The datum conversion relationship at the NOAA Cove Point, Maryland tide station (station 8577188) was used for this purpose. At the Cove Point station, MSL is 0.64 ft (0.195 m) higher than the NGVD 29 datum.

A square grid spacing of 360 m by 360 m (1181 ft by 1181 ft) was used to analyze tsunami wave propagation in the Chesapeake Bay. Typically, 10 to 20 grid points per wave length are recommended to accurately represent wave propagation in models based on the shallow water equations. Given a tsunami wave length of 33,260 m (109,093 ft), estimated based on the amplitude and period of the tsunami wave incident to the bay, the tsunami wave internal to the bay would be represented by about 92 grid points using the 360 m by 360 m grid and therefore adequately resolved. The effect of grid size on simulated tsunami water level at the CCNPP Unit 3 site was evaluated by comparing simulated results for grid sizes of 240 m by 240 m (787 ft by 787 ft) and 300 m by 300 m (984 ft by 984 ft). Figure 2.4-201 shows the variation of simulated water level at the CCNPP Unit 3 site for the three different grid sizes using the nonlinear model. These results show that the maximum water level at the CCNPP Unit 3 site are essentially the same for the 300 m by 300 m and 360 m by 360 m grids, while the maximum water level for the 240 m by 240 m was slightly lower. Based on this sensitivity analysis and a computational time requirement to satisfy dispersion criteria, a grid size of 360 m by 360 m was adopted for the computational domain. The numbers of grids in the two horizontal directions are 223 (east-west direction) and 790 (north-south direction). The bathymetric data used in the model, based on the 360 m by 360 m grid, are shown in Figure 2.4-32.

Numerical Simulation Cases

Numerical simulations were performed for three cases corresponding to the three tsunami generator sources identified in Section 2.4.6.1 and Table 2.4-26. For each case, simulations were performed with both linear (TSU) and nonlinear (NLSWE) models. The nonlinear NLSWE model includes the effects of wave dissipation due to bottom friction. To represent bottom friction, a constant Manning's roughness coefficient of 0.025 was used for the entire model domain for all three cases. The selected value represents natural channels in a good condition, as reported by Imamura (2006). Table 2.4-27 summarizes the model simulation conditions.

Model simulations were performed for a period of about 10 hours, which was selected by considering the tsunami travel time from the entrance of the Chesapeake Bay to the CCNPP Unit 3 site and the incoming tsunami period. A simulation time step of 5 seconds was selected based on a numerical stability criterion.

Wave characteristics generated along the internal boundary are shown in Figures 2.4-33, 2.4-202, 2.4-34, 2.4-203, 2.4-35, and 2.4-36. These figures show that the water levels at three locations along the boundary agree reasonably well with the assumed incoming sinusoidal tsunami waves from the three potential tsunami sources. The three locations on the boundary are shown in Figure 2.4-32.

2.4.6.5 Tsunami Water Levels

The numerical simulation results of tsunami propagation in the Chesapeake Bay for different cases are summarized in Table 2.4-28. Contour maps of maximum computed water levels in the Chesapeake Bay for Case 1 for the nonlinear and linear simulations are shown in Figures 2.4-204 and 2.4-205, respectively. These results show that the incoming tsunami waves dissipate quickly as they propagate up the Chesapeake Bay. The amounts of dissipation are similar in both the non-linear and linear simulations. The effects of wave non-linearity and bottom friction, accounted for in the nonlinear (NLSWE) model, result in additional dissipation of wave heights within the Chesapeake Bay. Therefore, simulation results from the liner (TSU) model are more conservative, providing greater amplitude and drawdown at the CCNPP Unit 3 site.

Variations in simulated water levels with time at the CCNPP Unit 3 site for the selected tsunami scenarios are shown in Figure 2.4-37 and Figure 2.4-38. These results show that the maximum tsunami amplitude at the CCNPP Unit 3 site is associated with Case 1, the Norfolk Canyon submarine landslide scenario, while the maximum tsunami drawdown that would occur is associated with Case 3, the Haitian earthquake scenario. Both maximum tsunami amplitude and drawdown were obtained with the linear (TSU) model. As shown in Table 2.4-28, the maximum tsunami amplitude and drawdown elevations at the CCNPP Unit 3 site are 1.07 ft (0.326 m) and 0.78 ft (0.237 m), respectively, as referenced to MSL. The results indicate that the linear solution of the shallow water equations provides bounding estimates of tsunami amplitude and drawdown at the CCNPP Unit 3 site.

An assessment of the sensitivity of model results and the PMT estimate to model inputs and assumptions indicated that there is uncertainty associated with simulating wave propagation in very shallow water depths near land boundaries. In particular, Synolakis (1987) indicates that run-up estimates from linear models are accurate provided that the ratio of tsunami amplitude to water depth is small. Ward (2001a) recommends that tsunami computations using linear models be confined to grid points where the water depth is greater than the amplitude of incoming tsunamis. At shallower water depths, Ward (2001a) argues that waves no longer amplify because of increasing bottom friction, and that the limiting amplitude approximates the tsunami run-up height. Because the Chesapeake Bay model includes water depths less than the amplitude of incoming tsunamis, the simulated maximum amplitude and drawdown, taken from the linear model, were increased to provide assurance that these values are not underestimated. The basis for the factor used to increase the maximum amplitude and drawdown is described below.

To quantitatively assess the effects of confining the tsunami computations to grid points where the ratio of tsunami amplitude to water depth is relatively large, a series of model sensitivity simulations were performed wherein the minimum allowable water depth (cutoff depth) was varied in the model. Three simulations with cutoff depths of 1.64 ft (0.5 m), 3.28 ft (1.0 m), and 6.56 ft (2.0 m) for both linear and nonlinear models were conducted using the Case 1 tsunami generator. In each simulation, portions of the domain having water depths less than the cutoff depth were eliminated from the model domain. The shallow water areas of the Chesapeake Bay affected by imposing cutoff depths include the western shoreline near the Potomac River mouth and upstream of the CCNPP Unit 3 site. The simulated water levels at the CCNPP Unit 3 site are shown on Figures 2.4-206 and 2.4-207. The relative increases in maximum amplitude at the CCNPP Unit 3 site as a function of cutoff depth are summarized in Table 2.4-100.

The results from these simulations show that the amplitudes of the tsunami wave peaks and troughs at the CCNPP Unit 3 site generally increase with increasing cutoff depth for both linear and nonlinear models. Note that the maximum relative increase in amplitude (77 percent) occurred in the linear simulation with a 1.0 m cutoff depth; however, the maximum water level for this simulation appeared during the third wave peak, unlike the other cases wherein the relative increase was greatest for the first peak. Excluding this apparently anomalous case, the 2.0 m cutoff depth resulted in the maximum water level. Consequently, the selected maximum water level from the Case 1 linear simulation was increased by 60 percent to obtain the PMT water level at the CCNPP Unit 3 site. The same factor was also adopted for the PMT drawdown level. Therefore, the maximum tsunami amplitude and drawdown at the CCNPP Unit 3 site were determined to be 1.71 ft (0.522 m) and 1.24 ft (0.379 m), respectively.

The PMT water level at the CCNPP Unit 3 site was determined by adding an appropriate antecedent water level and a tsunami run-up height to the computed tsunami amplitude. The antecedent water level was established as 4.34 ft NGVD 29, which accounts for the 10% exceedance high spring tide (2.17 ft or 0.66 m NGVD 29), a sea level anomaly (1.1 ft or 0.34 m NGVD 29), and long-term sea level rise (1.07 ft or 0.33 m NGVD 29) as described in Section 2.4.5. The PMT water level is therefore (1.71 ft + 4.34 ft =) 6.05 ft (1.84 m) NGVD 29.

Mader (2001b) indicates that tsunami run-up is about 2 to 3 times the deep-water tsunami amplitude. Madsen and Fuhrman (2007) describe a methodology to estimate tsunami run-up on plane beaches employing the surf similarity parameter. Because the Chesapeake Bay bathymetry varies considerably from natural beaches, Madsen and Fuhrman's method may underestimate tsunami run-up at the CCNPP Unit 3 site. Therefore, a tsunami run-up of 3 times the maximum tsunami amplitude in the Chesapeake Bay near the site, as recommended by Mader (2001b), was used to provide a conservative estimate of run-up. The run-up height therefore was estimated as (3 x 1.71 ft =) 5.13 ft (1.563 m).

The PMT high-water level, considering the maximum tsunami amplitude, antecedent conditions and run-up, was therefore estimated as (6.05 ft + 5.13 ft =) 11.18 ft (3.408 m) NGVD 29 or rounded up to 11.5 ft (3.5 m) NGVD 29.

The PMT low-water level was estimated by combining the adjusted drawdown with mean lower-low water (MLLW) datum at the NOAA Cove Point, MD station. Because incoming tsunamis were assumed to have a sinusoidal wave shape that likely estimates the tsunami trough, use of MLLW as the antecedent water level for the low-water PMT estimate was considered adequate. The MLLW level at the CCNPP Unit 3 site is 0.01 ft (0.003 m) NGVD 29 as given in Section 2.4.11. Consequently, the PMT low-water level at the CCNPP Unit 3 site was estimated as (0.01 ft – 1.24 ft =) -1.23 ft (-0.375 m) NGVD 29 or rounded down to -1.5 ft (-0.46 m) NGVD 29.

The numerical simulation indicates that the tsunami waves would experience significant dissipation when propagating up the Chesapeake Bay. Incoming tsunami waves with an amplitude of 13 ft (4 m) at the internal boundary dissipated over a distance of about 90 mi (144 km) to an adjusted wave amplitude of 1.71 ft (0.522 m) at the CCNPP Unit 3 site when propagating over relatively shallow water depths.

The simulated travel time for the tsunami to arrive at the CCNPP Unit 3 site from the model boundary near the Chesapeake Bay entrance was found to be about 3.5 hours. Note that the periods of the incoming tsunami wave were selected to be 1 hour (3,600 seconds) for Cases 1 and 2, and 1.44 hours (5,200 seconds) for Case 3.

Because the PMT maximum water level of 11.5 ft NGVD 29 is much less than the probable maximum storm surge still-water level of 21.7 ft NGVD at the CCNPP Unit 3 site, as established in Section 2.4.5, the PMT maximum water level would not constitute the design basis flood elevation at the CCNPP Unit 3 site. As described in Section 2.4.11.2.3, the design basis low-water level in the Chesapeake Bay near the site is the result of a Probable Maximum Hurricane along the eastern shore.

2.4.6.6 Hydrography and Harbor or Breakwater Influences on Tsunami

The Dominion Cove Point Liquefied Natural Gas (LNG) facility near Cove Point has a platform that is approximately 1,500 ft (457 m) long. The platform is located approximately 4 mi (6.4 km) southeast of the CCNPP Unit 3 site. The platform is aligned with the main flow direction in the Chesapeake Bay and, therefore, will not cause any obstruction to tsunami propagation. The effect of the platform was not considered in tsunami model simulations. The bathymetric influence on tsunami propagation was included in the model simulation by the water depth.

2.4.6.7 Effects on Safety-Related Facilities

Because the CCNPP Unit 3 project area elevation is set at approximately 85.0 ft (25.9 m) NGVD 29, the safety-related facilities on the power block will not be affected by the PMT.

By comparing the probable maximum storm surge (as discussed in Section 2.4.5) and the PMT at the CCNPP Unit 3 site, it is evident that the maximum water level at the safety-related UHS makeup water intake structure would be governed by the probable maximum storm surge height. The minimum water level at this location also is governed by storm surge events as shown in Section 2.4.11. Therefore, probable maximum tsunami events will not constitute the governing design basis for the safety-related UHS makeup intake system and associated shore protection structures.

2.4.6.8 Hydrostatic and Hydrodynamic Forces

The hydrostatic forces are proportional to the water depth below the still-water level. Comparing still-water levels due to the PMT and probable maximum storm surge (PMSS) at 10% exceedance high tide antecedent condition at the CCNPP Unit 3 site, the PMSS water level (21.7 ft or 6.6 m NGVD 29) is about 10.2 ft or 3.1 m higher than the PMT water level (11.5 ft or 3.5 m NGVD 29).

The PMT maximum water level including run-up will be at the deck elevation of the safety-related UHS makeup water intake structure at 11.5 ft (3.5 m) NGVD 29 as described in Section 2.4.1.1. Coincident wind-wave runup is unlikely to reach the UHS makeup water intake structure as the intake structure is offset from the shoreline. Consequently, there would be insignificant dynamic wave forces on the UHS intake structure from the PMT wave. The hydrodynamic wave force on the UHS makeup water intake structure is controlled by the PMSS event, as described in Section 3.8.4.

2.4.6.9 Debris and Water-Borne Projectiles

The tsunami water level including tsunami amplitude, antecedent water level and run-up is estimated to be 11.5 ft (3.5 m) NGVD 29. The elevation of the UHS intake operating deck and pump room floor providing foundation for safety-related equipment including pumps are 11.5 ft (3.51 m) NGVD 29. The PMT at the CCNPP Unit 3 site will not affect the operation of the UHS makeup water intake structure because the tsunami water level is at the deck and pump floor elevation. Therefore, debris and water-borne projectiles are not expected to affect the UHS intake structure. The CCNPP Units 1 and 2 forebay baffle wall, CCNPP Unit 3 intake sheet pipe wall and inlet protection screen, protect the inlets of intake pipes that convey water to the UHS intake structure from debris and water-borne projectiles.

2.4.6.10 Effects of Sediment Erosion and Deposition

Because the PMT amplitude is 1.71 ft (0.522 m), the UHS makeup water intake structure is not affected by PMT. Because the Units 1 and 2 baffle wall and Unit 3 sheet pile wall protect the CCNPP Unit 3 intake pipe inlet area, erosion effects near the intake pipe inlet would be negligible.

The estimated PMT amplitude is small compared to the water depth in the CCNPP Units 1 and 2 intake forebay and is not expected to produce high sediment transport capacity. Suspended sediments flowing towards the CCNPP Unit 3 intakes would travel through the opening underneath the Units 1 and 2 forebay baffle wall and would likely deposit in the CCNPP Unit 3 inlet area sheltered by the baffle wall and the sheet pile wall. Because the inlets of the intake pipes are located at about 10 ft (3.05 m) above the bed elevation, blockage of intake pipes due to sediment deposition is unlikely as a result of the PMT.

Table 2.4-26 will be revised as follows in a future COLA version.

Table 2.4-26—{Tsunami Wave Characteristics at the Entrance of the Chesapeake Bay}

Case	Amplitude	Period (seconds)	Source location
1	13 ft (4 m)	3,600	Norfolk Canyon submarine landslide
2	10 ft (3 m)	3,600	Canary Island submarine landslide
3	3.1 ft (0.9 m)	5,200	Haitian earthquake
~~4~~	~~13 ft (4 m)~~	~~3,600~~	~~Same as Case 1~~

Table 2.4-28 will be revised as follows in a future COLA version. For clarity, only the revised values are shown

Table 2.4-28 — {Simulated Maximum and Minimum Tsunami Magnitude}

Case No.	Tsunami Magnitude		Remarks
	Maximum Amplitude	Minimum Drawdown	
1	0.51 ft (0.155 m)	0.17 ft (0.051 m)	Nonlinear and bottom friction
	1. 07 ft (0.326 m)	0.61 ft (0.186 m)	Linear without bottom friction
2	0.43 ft (0.131 m)	0.16 ft (0.049 m)	Nonlinear and bottom friction
	0.80 ft (0.245 m)	0.46 ft (0.139 m)	Linear without bottom friction
3	0.42 ft (0.127 m)	0.34 ft (0.103 m)	Nonlinear and bottom friction
	0.86 ft (0.262 m)	0.78 ft (0.237 m)	Linear without bottom friction

Table 2.4-100 will be added in a future COLA version.

Table 2.4-100 — {Simulated Maximum Tsunami Magnitude at Site for Various Cutoff Depths for Case 1}

Simulation Condition		Maximum Amplitude	% Amplitude Change
Cutoff Depth	Model Option		
0.0 m	Nonlinear	0.51 ft (0.155 m)	-
	Linear	1.07 ft (0.326 m)	-
0.5 m	Nonlinear	0.57 ft (0.175 m)	12.9
	Linear	1.39 ft (0.423 m)	29.8
1.0 m	Nonlinear	0.65 ft (0.198 m)	27.7
	Linear	1.89 ft (0.577 m)	77.0
2.0 m	Nonlinear	0.80 ft (0.244 m)	57.4
	Linear	1.72 ft (0.524 m)	60.7

Figure 2.4-32 will be replaced as follows in a future version of the COLA. For clarity, only the revised figure is shown.

Figure 2.4-32—{Computational Domain and Model Bathymetry for Tsunami Simulation in Chesapeake Bay}

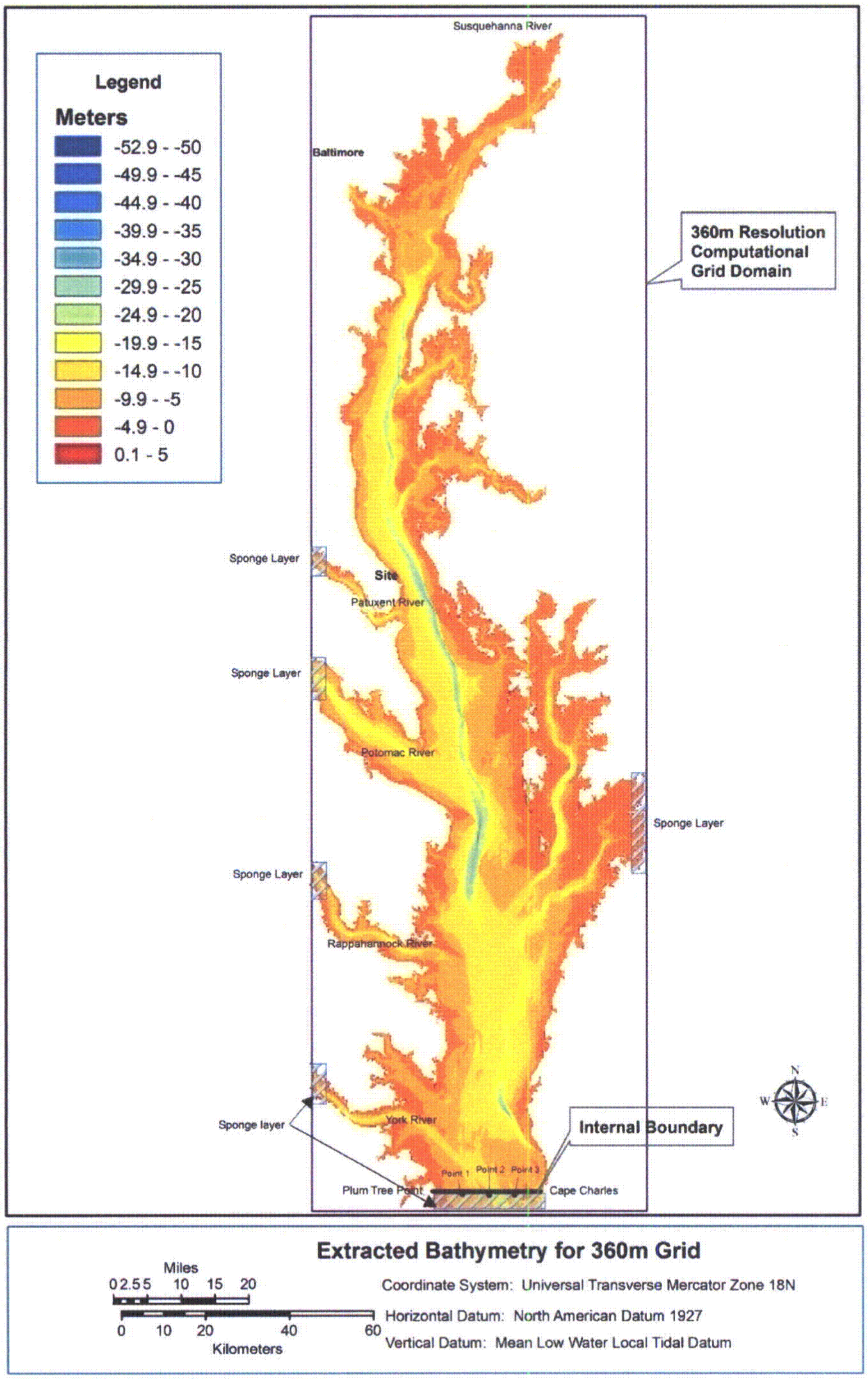


Figure 2.4-200 will be added in a future version of the COLA.

Figure 2.4-200—{Chesapeake Bay Digital Elevation Model from NOAA}

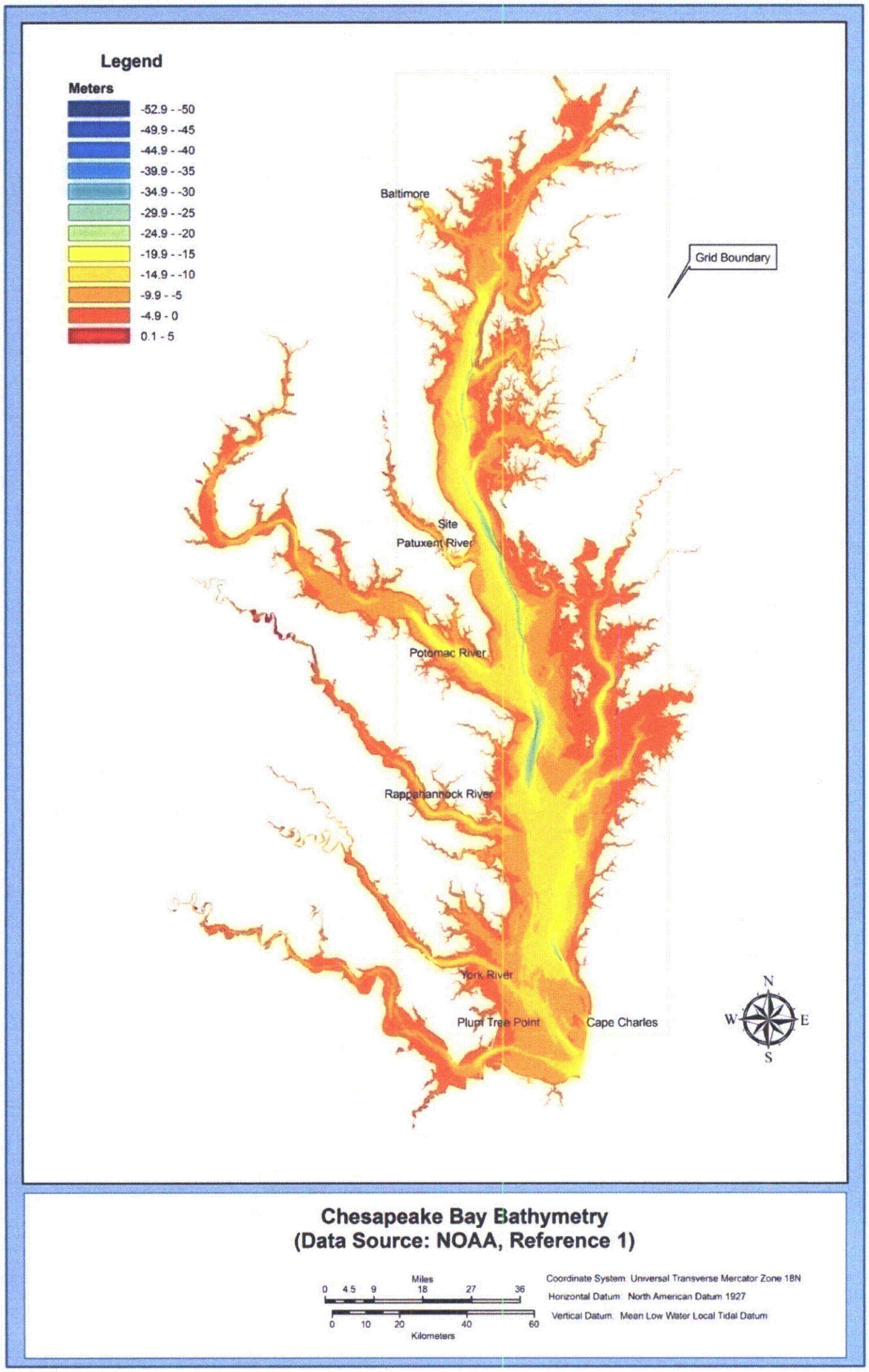


Figure 2.4-201 will be added in a future version of the COLA.

<u>Figure 2.4-201—{Comparison of Simulated Water Levels at the Site for Different Grid Sizes for Case 1, Nonlinear Model}</u>

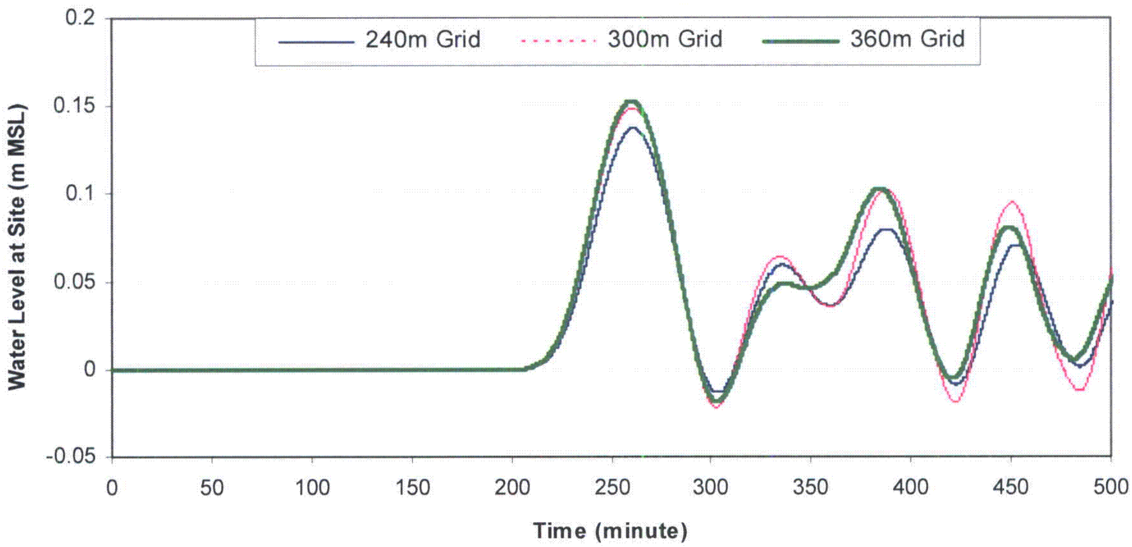


Figure 2.4-33 will be replaced as follows in a future version of the COLA. For clarity, only the revised figure is shown.

Figure 2.4-33—{Water Levels along Internal Boundary <u>for Case</u> 1, <u>Nonlinear Model</u>}

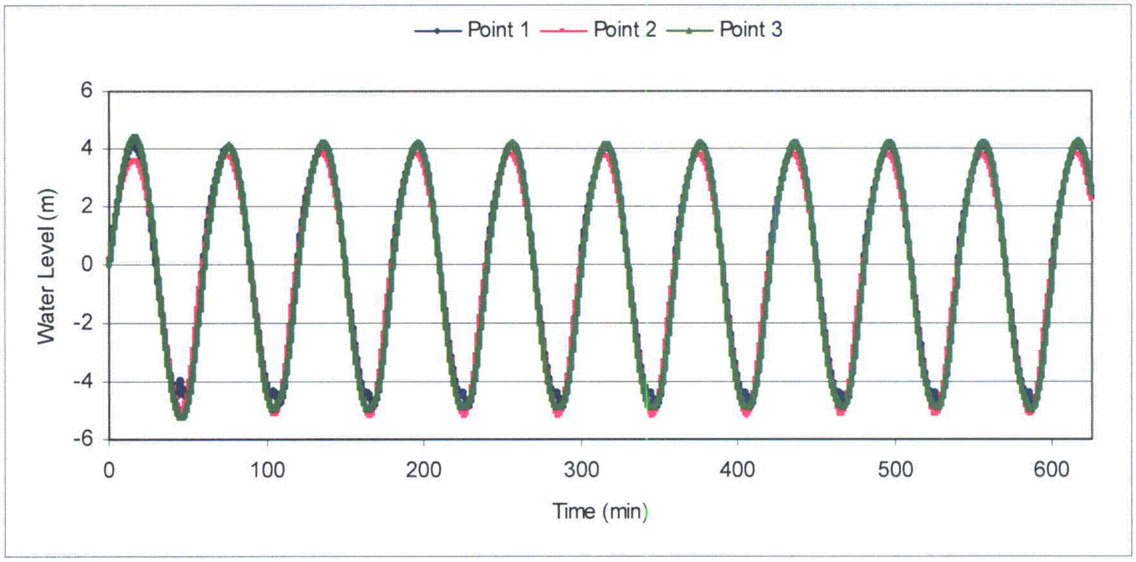


Figure 2.4-202 will be added in a future version of the COLA.

Figure 2.4-202—{Water Levels along Internal Boundary for Case 1, Linear Model}

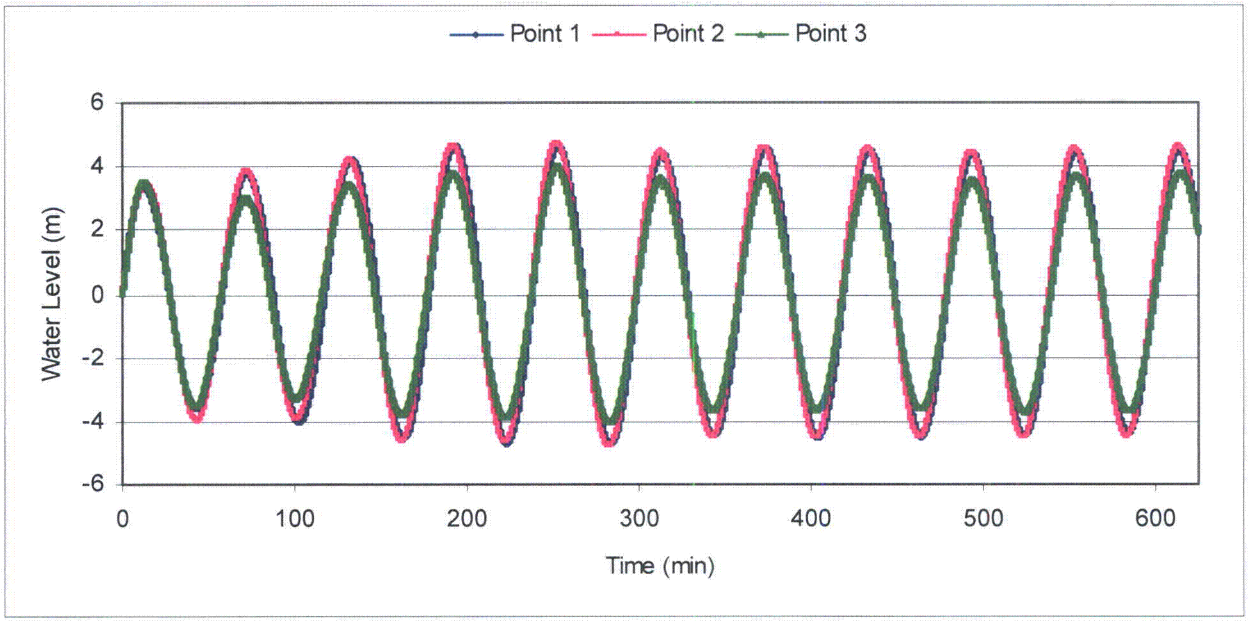


Figure 2.4-34 will be replaced as follows in a future version of the COLA. For clarity, only the revised figure is shown.

Figure 2.4-34—{Water Levels along Internal Boundary for Case 2, Nonlinear Model}

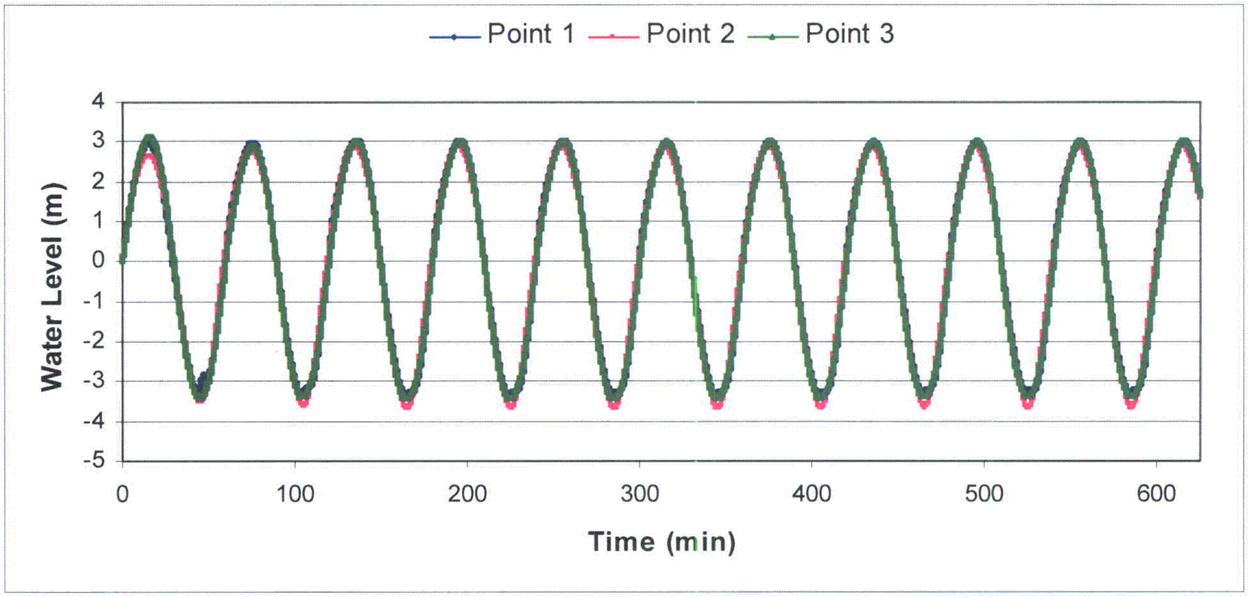


Figure 2.4-203 will be added in a future version of the COLA.

Figure 2.4-203—{Water Levels along Internal Boundary for Case 2, Linear Model}

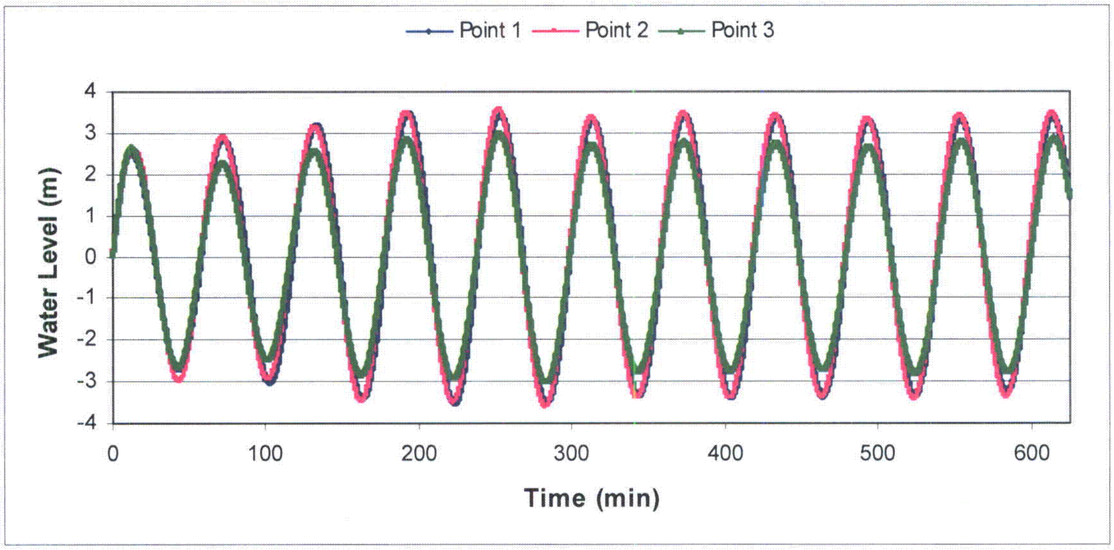


Figure 2.4-35 will be replaced as follows in a future version of the COLA. For clarity, only the revised figure is shown.

Figure 2.4-35—{Water Levels along Internal Boundary for Case 3, Nonlinear Model}

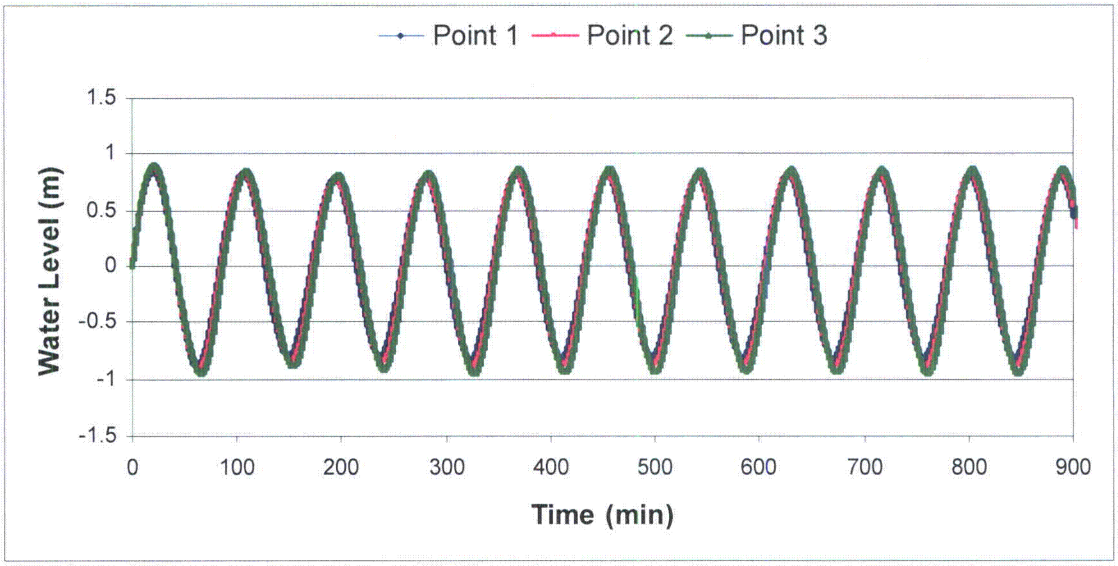


Figure 2.4-36 will be replaced as follows in a future version of the COLA. For clarity, only the revised figure is shown.

Figure 2.4-36—{Water Levels along Internal Boundary for Case 3, Linear Model}

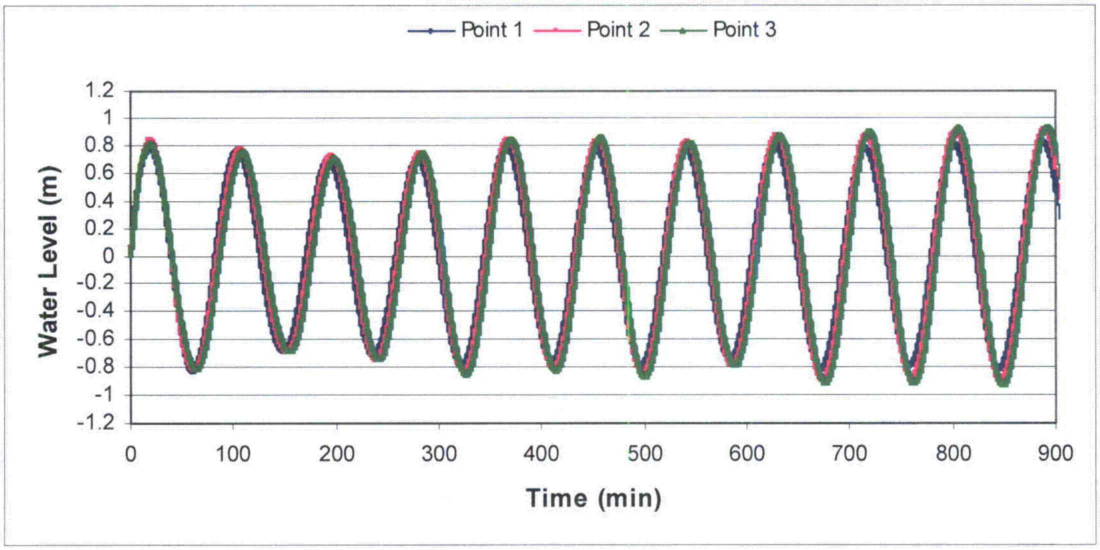


Figure 2.4-204 will be added in a future version of the COLA.

Figure 2.4-204 - {Contour of Maximum Water Levels for Case 1, Nonlinear Model}

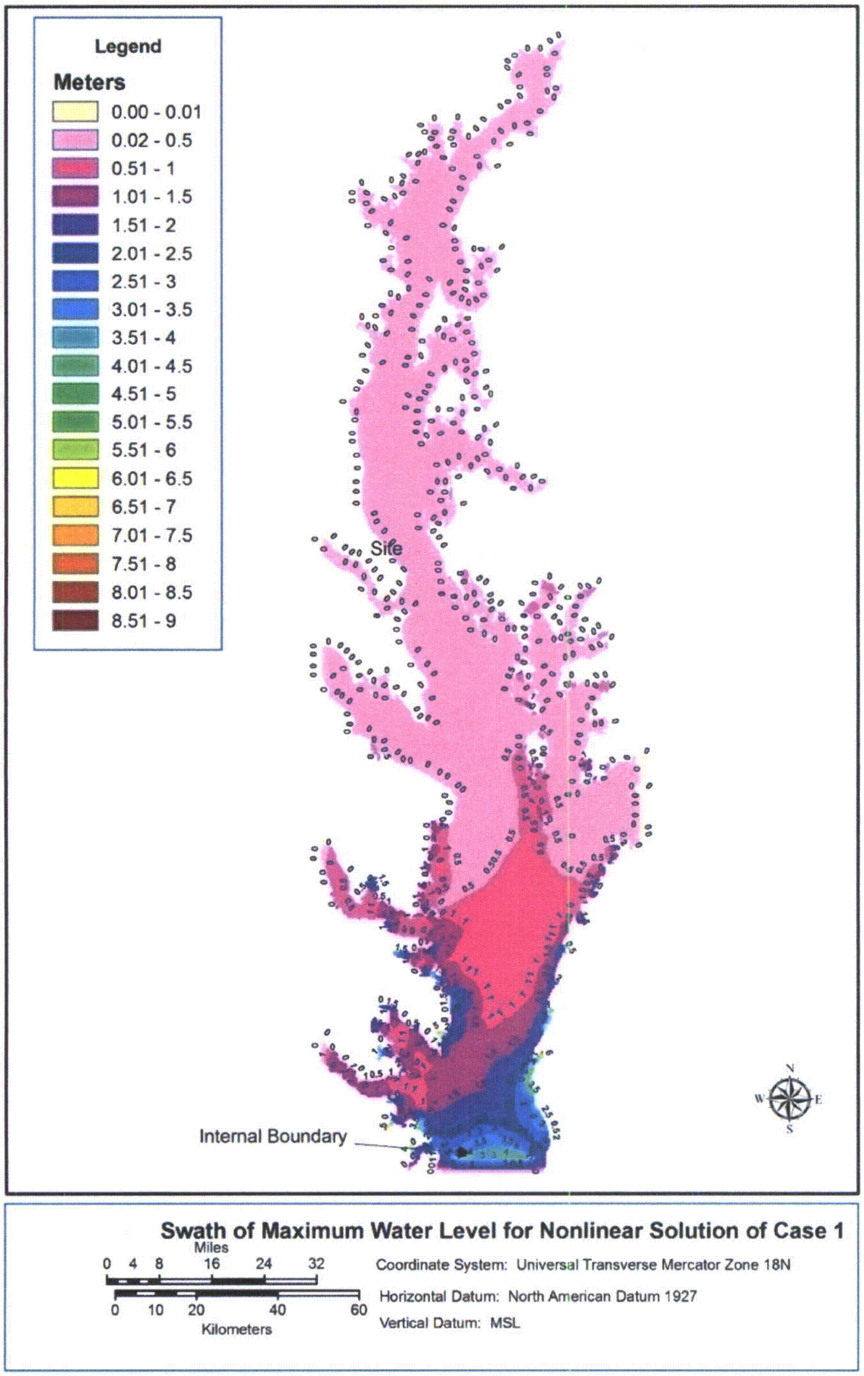


Figure 2.4-205 will be added in a future version of the COLA.

Figure 2.4-205 - {Contour of Maximum Water Levels for Case 1, Linear Model}

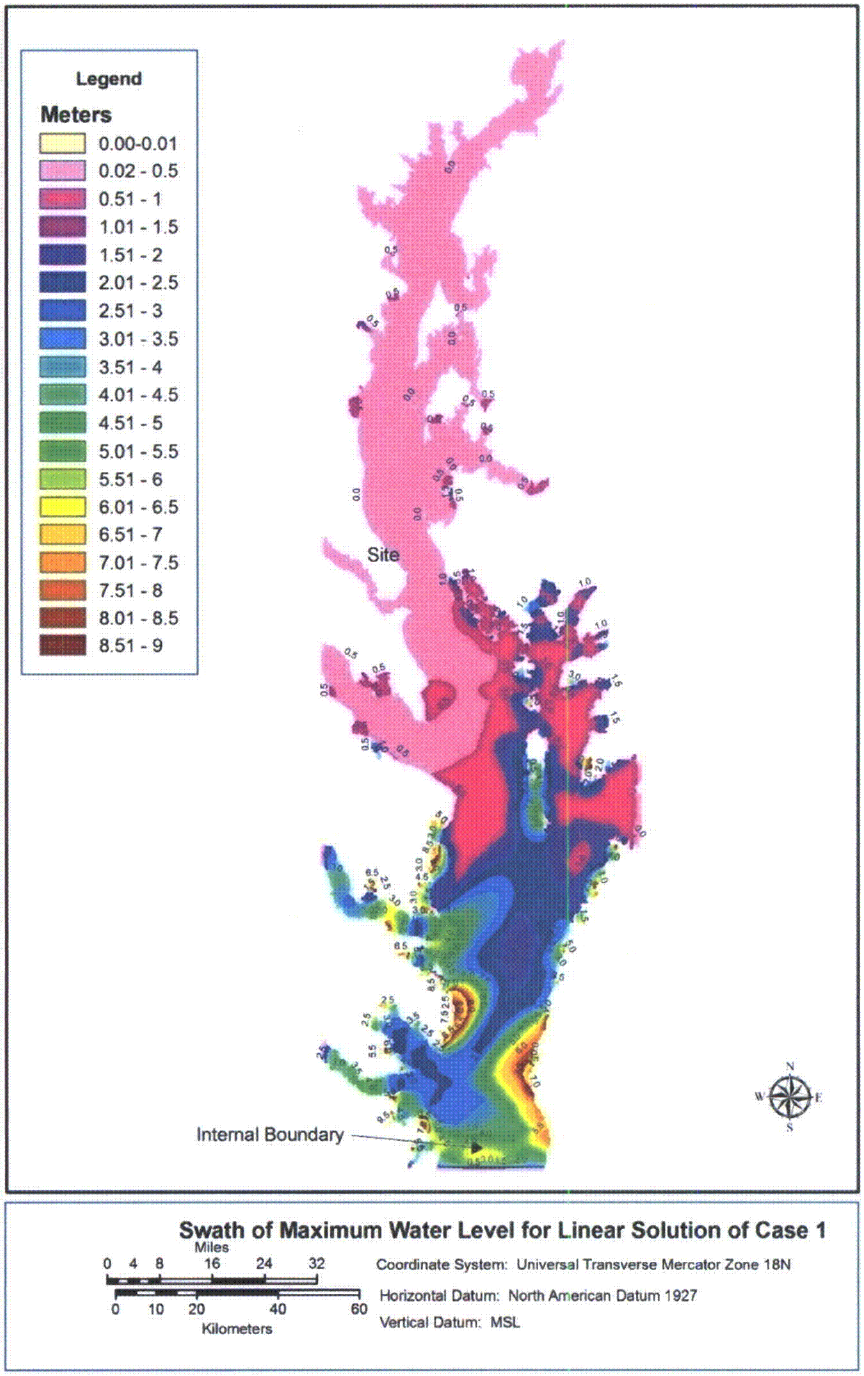


Figure 2.4-37 will be replaced as follows in a future version of the COLA. For clarity, only the revised figure is shown.

Figure 2.4-37—{Time History of Tsunami Water Levels ~~At The Site~~, Case 1 through 3, Nonlinear Model}

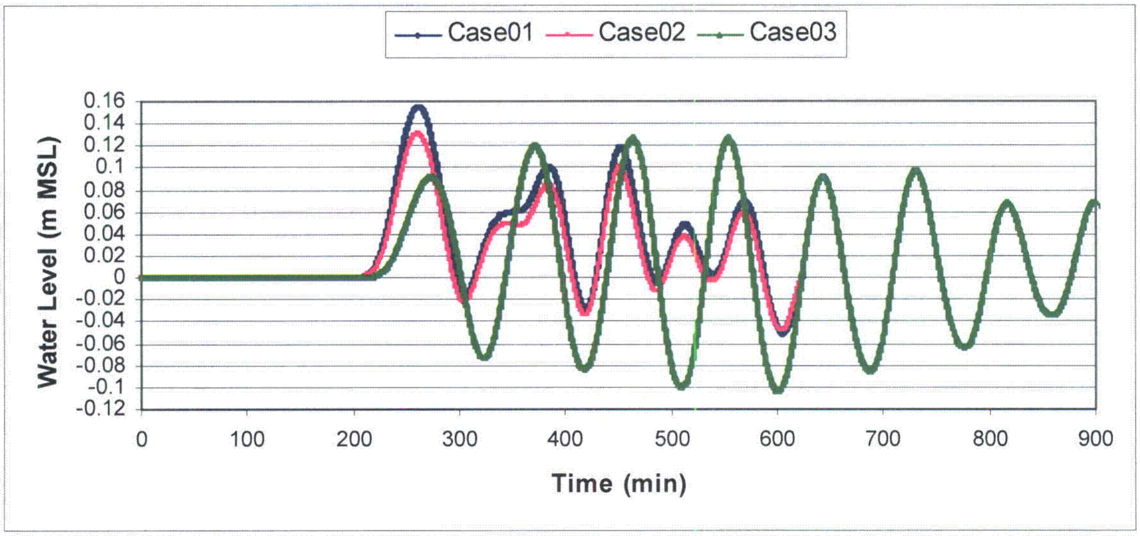


Figure 2.4-38 will be replaced as follows in a future version of the COLA. For clarity, only the revised figure is shown.

Figure 2.4-38 - {Time History of Tsunami Water Levels a~~t The Site, Case 2~~, Cases 1 through 3, Linear Model}

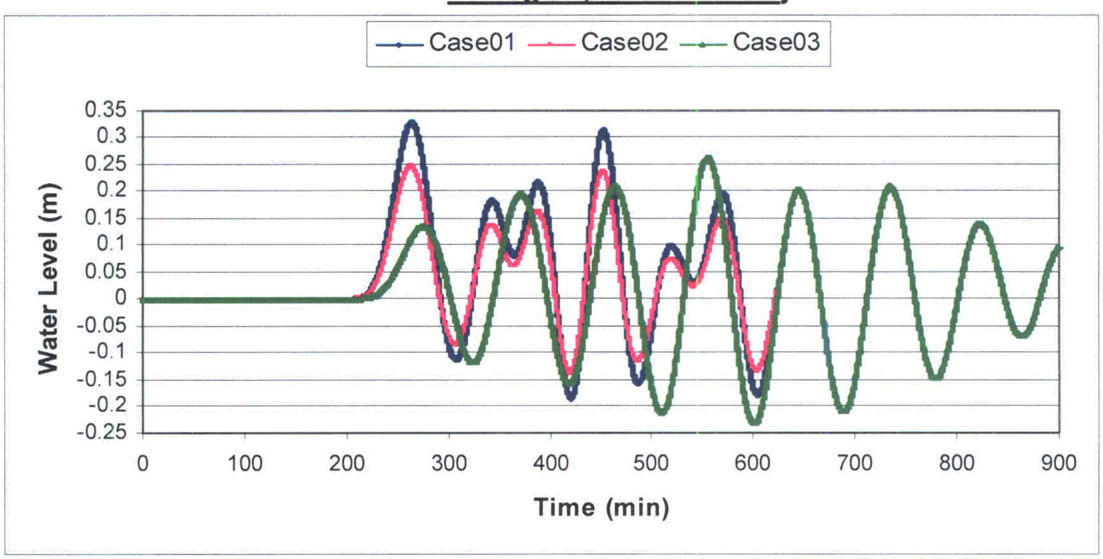


Figure 2.4-206 will be added in a future version of the COLA.

Figure 2.4-206 - {<u>Time History of Tsunami Water Levels at Site for Different Cutoff Depths, Case 1, Nonlinear Option</u>}

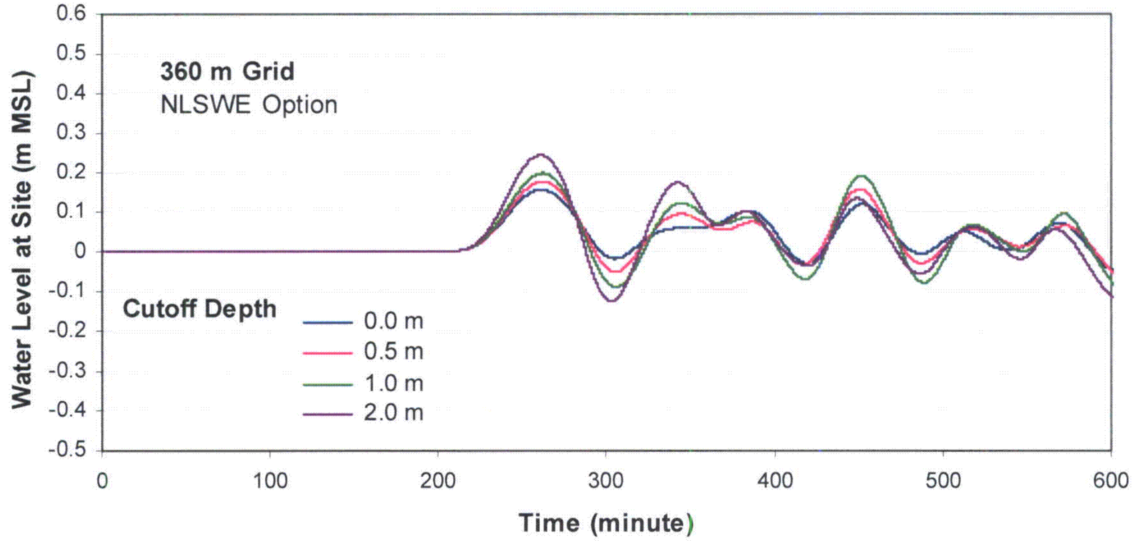
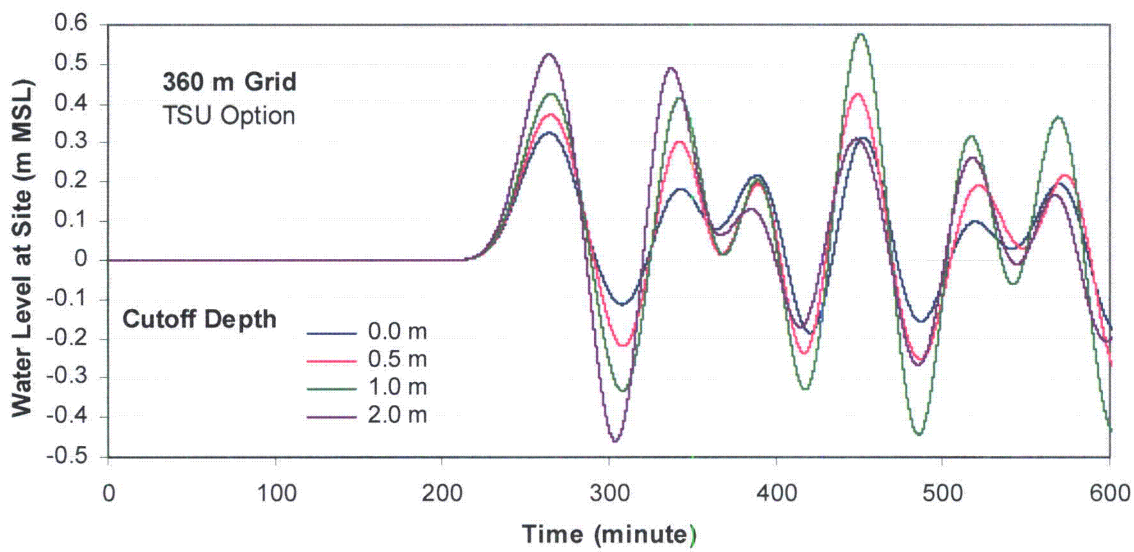


Figure 2.4-207 will be added in a future version of the COLA.

Figure 2.4-207 - {<u>Time History of Tsunami Water Levels at Site for Different Cutoff Depths, Case 1, Linear Option</u>}



The following figures will be deleted in a future COLA revision.

Figure 2.4-39—{<u>Not Used</u> ~~Time History Of Tsunami Water Levels At The Site, Case 3~~}

Figure 2.4-40—{<u>Not Used</u> ~~Time History Of Tsunami Water Levels At The Site, Case 4~~}

FSAR Section 2.4.6.12 will be supplemented as follows in a future COLA revision:

2.4.6.12 References

Madsen and Fuhrman, 2007. Analytical and Numerical Models for Tsunami Run-up, In Tsunami and Nonlinear Waves, A. Kundu (Ed.), Springer.

Synolakis, 1987. The Run-up of Solitary Waves, Journal of Fluid Mechanics, Volume 185, pages 523-545