PSEG Power L.L.C.
Nuclear Development
P.O. Box 236, MC NDC-7, Hancocks Bridge, NJ 08038

PSEG
Power LLC

ND-2011-0026
May 11, 2011

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

Subject: **PSEG Early Site Permit Application**
Docket No. 52-043
Response to Request for Additional Information, RAI No. 20, Probable Maximum Tsunami Flooding

References: 1) PSEG Power, LLC letter to USNRC, Application for Early Site Permit for the PSEG Site, dated May 25, 2010

2) RAI No. 20, SRP Section: 02.04.06 – Probable Maximum Tsunami Flooding, dated April 11, 2011 (eRAI 5632)

The purpose of this letter is to respond to the request for additional information (RAI) identified in Reference 2 above. This RAI addresses Probable Maximum Tsunami Flooding, as described in Section 2.4.6 of the Site Safety Analysis Report (SSAR), as submitted in Part 2 of the PSEG Site Early Site Permit Application, Revision 0.

Enclosure 1 provides our response for RAI No. 20, Question No. 02.04.06-1 through 02.04.06-4. Responses to Questions No.02.04.06-1 (1)(2), 02.04.06-2, 02.04.06-3(1)(2), 02.04.06-4 (3)(4)(5)(6)(7) will result in revisions to the SSAR. Enclosure 2 includes the proposed revisions to the SSAR. Enclosure 3 provides one CD-ROM containing pdf files of the revised and new figures. Enclosure 4 includes the new regulatory commitment established in this submittal.

If any additional information is needed, please contact David Robillard, PSEG Nuclear Development Licensing Engineer, at (856) 339-7914.

D079
NRO

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 11th day of May, 2011.

Sincerely,

James Mallon
Nuclear Development
Early Site Permit Manager
PSEG Power, LLC

Enclosure 1: Response to NRC Request for Additional Information, RAI No. 20, Question No. 02.04.06-1 through 02.04.06-4, SRP Section: 02.04.06 – Probable Maximum Tsunami Flooding
Enclosure 2: Proposed Revisions Part 2 – Site Safety Analysis Report (SSAR) Section 2.4.6
Enclosure 3: CD-ROM Containing Figures 2.4.6-1 and 2.4.6-7 through 2.4.6-26
Enclosure 4: Summary of Regulatory Commitments

cc: USNRC Project Manager, Division of New Reactor Licensing, PSEG Site (w/enclosures)
USNRC, Environmental Project Manager, Division of Site and Environmental Reviews (w/enclosures)
USNRC Region I, Regional Administrator (w/enclosures)

ENCLOSURE 1

RESPONSE to RAI No. 20

QUESTIONS:

02.04.06-1
02.04.06-2
02.04.06-3
02.04.06-4

Response to RAI No. 20:

In Reference 2, the NRC staff asked PSEG for information regarding Probable Maximum Tsunami Flooding, as described in Section 2.4.6 of the Site Safety Analysis Report. The responses to the questions are presented following the same outline in which they were asked:

Response to RAI No. 20, Question 02.04.06-1:

In Reference 2, the specific requests for Question 02.04.06-1 were:

To meet the requirements of GDC 2, 10 CFR 52.17, and 10 CFR Part 100, PSEG should provide an assessment of the Probable Maximum Tsunami (PMT) for the proposed site. Section C.1.2.4.6.2 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to the historical tsunami record, including paleo-tsunami evidence. Provide additional information, evaluation and a discussion in the SSAR of the following:

(1) 1918 Puerto Rico Tsunami (SSAR 2.4.6.3). PSEG stated that the 1918 earthquake occurred within the Puerto Rico Trench and that it was responsible for the tsunami. It is believed that the earthquake actually occurred in the Mona Passage or just north of it and that the landslide likely contributed to the tsunami. Provide a clarification of the 1918 earthquake source location.

(2) Paleotsunami deposits (Missing from SSAR). Related information presented in 2.5.1. PSEG states that for the site no references to paleotsunamis have been found in existing literature, and no evidence of tsunami has been found in site borings. PSEG will provide reference to Section 2.5.1 and related conclusions in Section 2.4.6.

PSEG Response to NRC RAI:

(1) 1918 Puerto Rico Tsunami

Current research into the 1918 Puerto Rico Tsunami (Reference RAI-20-1) indicates that the October 11, 1918 Mona Passage earthquake triggered a tsunami that affected the western coast of Puerto Rico. The cause of the tsunami was previously suggested to be due to seafloor displacement by a normal fault on the eastern wall of the Mona Rift. Research, using newly available multibeam bathymetry and multichannel seismic reflection profiles, has identified a submarine landslide with steep headwall and sidewall scarps 15 km off the northwestern coast of Puerto Rico. Based on this new data it has been postulated that the landslide, which was induced by the earthquake, was responsible for the generation of the tsunami. SSAR Subsection 2.4.6.1.3 will be revised to reflect this change in source location.

References:

RAI-20-1, A.M. López-Venegas, U. S. ten Brink and E.L. Geist, "Submarine landslide as the source for the October 11, 1918 Mona Passage tsunami: Observations and modeling", Marine Geology, 254, 35-46, 2008.

(2) Paleotsunami Deposits

A tsunami deposit is usually identified by sedimentary context such as larger grain size than surrounding sediments, spatial distribution of the deposit and by ruling out other higher-energy depositional modes (Reference RAI-20-2).

Samples obtained from site borings were consistent with the fluvial and marine depositional conditions described in published literature and discussed in SSAR Subsection 2.5.1.2.3.2. The geologic strata at the PSEG Site consist of Lower Cretaceous, Upper Cretaceous, Lower Tertiary (Paleocene), Upper Tertiary (Neogene) and Quaternary formations above the basement rock. The dominant depositional processes for these strata were marine and fluvial over a series of regressive and transgressive events. The Cretaceous/Tertiary boundary was penetrated by the 16 borings performed for the PSEG Site exploration. Review of samples from the borings indicated strata or features that are consistent with the depositional environments described in SSAR Subsection 2.5.1.2.3.2, and the site samples were not interpreted to represent a paleotsunami occurrence.

Representatives of the New Jersey Geological Survey (NJGS) were contacted to determine if they have any knowledge of geologic evidence for paleotsunamis in the New Jersey area. As a result of the conversations with NJGS, Reference RAI-20-3 was identified as reporting evidence of tsunami deposits in the New Jersey area. Review of reference RAI-20-3 determined that boreholes drilled at Bass River, New Jersey (approximately 59 miles east of the PSEG Site) and at Ancora, New Jersey (approximately 40 miles northeast of the PSEG Site), as part of the Ocean Drilling Program, found a thin (<10 cm thick) clast unit above the Cretaceous/Tertiary boundary that appears to be related to a tsunami. The tsunami was not considered related to earthquakes, but is attributed, possibly, to a massive slumping on the Atlantic slope related to the bolide impact near Chicxulub, Mexico that marked the end of the Cretaceous (Reference RAI-20-3).

SSAR Sections 2.4.6, 2.5.1 and 2.5.4 will be revised to expand on the discussion of paleotsunamis.

References:

RAI-20-2. Jaffe, B. E., and G. Gelfenbaum, "Using Tsunami Deposits to Improve Assessment of Tsunami Risk", Solutions to Coastal Disasters "02 Conference Proceedings, ASCE, p. 836-847, 2002.

RAI-20-3. Miller, K.G., J. V. Browning, P. J. Sugarman, P. P. McLaughlin, M. A. Kominz, R. K. Olsson, J. D. Wright, B. S. Cramer, S. F. Pekar, and W. Van Sickel, 2003, 174AX leg summary: Sequences, sea level, tectonics, and aquifer resources: Coastal plain drilling, in Miller, K.G., P. J. Sugarman, J. V. Browning, et al., eds., Proceedings of the Ocean Drilling Program, Initial Reports, 174AX (Supplement): College Station TX (Ocean Drilling Program), 1-38.

RAI-20-4. Not Used

Associated PSEG Site ESP Application Revisions:

SSAR Subsection 2.4.6.1.3 will be revised to reflect this change in source location.

SSAR Subsection 2.4.6.1 will be revised to reference new text added to SSAR Section 2.5.4.1.3, relating to paleotsunamis.

SSAR Subsection 2.5.1.2.3.2 will be revised to include the following language after the first paragraph:

> The end of the Cretaceous was marked by a massive bolide event near Chicxulub, Mexico (Reference 2.5.1-266). Boreholes in New Jersey conducted approximately 40 miles northeast and 59 miles east of the PSEG Site as part of the Ocean Drilling Program recovered a continuous depositional record across the Cretaceous/Tertiary boundary. A thin (<10 cm.) layer in this sequence contains materials that appear to be from a tsunami. The tsunami may have been caused by submarine slumping on the Atlantic slope associated with the Chicxulub bolide impact (Reference 2.5.1-265).

The following references will be added to SSAR Subsection 2.5.1:

2.5.1-265 Miller, K.G., J. V. Browning, P. J. Sugarman, P. P. McLaughlin, M. A. Kominz, R. K. Olsson, J. D. Wright, B. S. Cramer, S. F. Pekar, and W. Van Sickel, 2003, 174AX leg summary: Sequences, sea level, tectonics, and aquifer resources: Coastal plain drilling, in Miller, K.G., P. J. Sugarman, J. V. Browning, et al., eds., Proceedings of the Ocean Drilling Program, Initial Reports, 174AX (Supplement): College Station TX (Ocean Drilling Program), 1-38.

2.5.1-266 Hildebrand, Alan R., Glen T. Penfield, David A. Kring, Mark Pilkington, Antonio Camargo Z., Stein B. Jacobsen and William V. Boynton, "Chicxulub Crater: a possible Cretaceous/Tertiary boundary impact crater on the Yucatan Peninsula, Mexico", Geology, v. 19 p.867, 1991.

SSAR Subsection 2.5.4.1 will be revised to include the following language in 2.5.4.1.3, after the first paragraph:

The dominant depositional processes for the strata were marine and fluvial over a series of regressive and transgressive events. Review of samples from the 16 soil borings performed in the area of the PSEG Site, all of which penetrated through the Cretaceous/Tertiary boundary, indicated strata or features that are consistent with the depositional environments described in the literature, and the samples are not interpreted to represent a paleotsunami occurrence at the PSEG Site.

Enclosure 2 provides the markups of the above described SSAR revision.

Response to RAI No. 20, Question 02.04.06-2:

In Reference 2, the specific request for Question 02.04.06-2 was:

> *To meet the requirements of GDC 2, 10 CFR 52.17, and 10 CFR Part 100, PSEG should provide an assessment of the Probable Maximum Tsunami (PMT) for the proposed site. Section C.1.2.4.6.1 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to determination of Probable Maximum Tsunami Flooding. This includes a discussion of the generation of tsunami-like waves from hill-slope failures and the stability of the coastal area. The range given in figure 2.4.6.1 of the SSAR is 0-2 degrees, and many of the slopes are at the maximum of the color scale, making it somewhat unclear if the slopes are actually higher (there appear to be some slopes greater than 2 degrees in the region).*
>
> *At the site audit, PSEG presented an updated figure showing maximum slope angle of 0.3 degrees. Provide updated figure and reference to related work in Section 2.5.5 in a revision of the SSAR.*

PSEG Response to NRC RAI:

Figure 2.4.6-1 has a scale of slope (i.e. dimensionless rise over run) ranging from 0 to 0.002. At the maximum scale value, the angle of the slope would equate to 0.115 degrees. In order to minimize any further confusion over this figure, the figure will be revised to have a dimensioned scale in angular degrees.

In SSAR Subsection 2.5.5, the analysis of slopes is described as being conducted during the COLA work. Subsection 2.5.5.1 discusses the general site slope characteristics and states that analyses will consider potential failure surfaces extending into the Delaware River. The text also states that portions of the site outside the new plant power block are relatively flat, and that there are no existing slopes on the site, either natural or manmade, that could affect the stability of the site. Subsection 2.4.6 will be revised to reflect this information.

Associated PSEG Site ESP Application Revisions:

SSAR Subsection 2.4.6.2 will be revised to reflect the following:

> Figure 2.4.6-1 shows the naturally occurring angular topography slopes on a grid in the vicinity of the PSEG Site, and shows a maximum slope value of 0.3° occurring inland of the site. Stability analysis will be conducted during the COLA phase of the project, and will include consideration of failure surfaces that extend into the Delaware River adjacent to the site as discussed in SSAR Subsection 2.5.5.1.

Figure 2.4.6-1, provided in Enclosure 3, will be revised to provide a scale in angular degrees.

Enclosure 2 provides the markups of the above described SSAR revision.

Response to RAI No. 20, Question 02.04.06-3:

In Reference 2, the specific requests for Question 02.04.06-3 were:

> *To meet the requirements of GDC 2, 10 CFR 52.17, and 10 CFR Part 100, PSEG should provide an assessment of the Probable Maximum Tsunami (PMT) for the proposed site. Section C.I.2.4.6.3 of Regulatory Guide 1.206 (RG 1.206) provides specific guidance with respect to the source characteristics needed to determine the PMT. These characteristics include detailed geo-seismic descriptions of the controlling local tsunami generators, including location, source dimensions, and maximum displacement. Provide additional information, evaluation and a discussion in the SSAR of the following:*
>
> *(1) Other Regional Landslide Sources (Missing from SSAR). Provide description, parameters, and tsunami estimates of other mapped landslide sources which might impact the site, as well as a discussion of how the Currituck was chosen as the primary landslide tsunami source on the continental shelf.*
>
> *(2) Activity of Offshore Portugal Seismic Zone (SSAR 2.4.6.2 2nd Paragraph). Discuss what the applicant means by "inactive" as applied to the seismic zone offshore Portugal. This is an important consideration with regard to the historical tsunami record and tsunami generating potential from that region.*

PSEG Response to NRC RAI:

(1) Other Regional Landslide Sources

The Currituck slide is one of several apparent Paleolithic slide events occurring on the outer slope of the U.S. East Coast continental shelf. Landslide-generated tsunamis typically cause the greatest levels of inundation on shorelines immediately landward of the slide event. Therefore, it is most relevant to consider additional historical or potential slides in the Mid-Atlantic Bight region, spanning from the Hudson Canyon to Cape Hatteras. Review of morphological studies of slide deposits in this region (Reference RAI-20-5) concludes that the most prominent slides are fluvial in origin, being linked to river delta deposits formed during the late Quaternary low stand of sea level, when the major rivers of the regions reached across the present shelf. In particular, the Currituck slide is associated with the delta of the Susquehanna River. Additional deltas of the Delaware and Hudson Rivers also have associated slide deposits. Information provided in Reference RAI-20-6 on the distribution of slide volumes shows that the Currituck slide is the largest slide occurring in the region, making it the most logical candidate for study. SSAR Subsection 2.4.6 will be revised to include this discussion.

References:

RAI-20-5, Twichell, D. C.,J. D. Chaytor, U. S. ten Brink and B. Buczkowski, B., "Morphology of late Quaternary submarine landslides along the U. S. Atlantic continental margin", Marine Geology, 264, 4-15, 2009.

RAI-20-6, Chaytor, J. D., U. S. ten Brink, A. R. Solow, and B. D. Andrews, "Size distribution of submarine landslides along the U. S. Atlantic margin", marine Geology, 264, 16-27.

(2) Activity of Offshore Portugal Seismic Zone

The word "inactive" was not intended to minimize the tsunami generating potential from the offshore Portugal region and SSAR Subsection 2.4.6 will be revised to delete the term.

Associated PSEG Site ESP Application Revisions:

SSAR Subsection 2.4.6.1.1 will be revised to add the following paragraph to the end of the subsection:

The Currituck slide is one of several apparent Paleolithic slide events occurring on the outer slope of the U.S. East Coast continental shelf. Landslide-generated tsunamis typically cause the greatest levels of inundation on shorelines immediately landward of the slide event. Therefore, it is most relevant to consider additional historical or potential slides in the Mid-Atlantic Bight region, spanning from the Hudson Canyon to Cape Hatteras. Review of morphological studies of slide deposits in this region (Reference 2.4.6-30) concludes that the most prominent slides are fluvial in origin, being linked to river delta deposits formed during the late Quaternary low stand of sea level, when the major rivers of the regions reached across the present shelf. In particular, the Currituck slide is associated with the delta of the Susquehanna River. Additional deltas of the Delaware and Hudson Rivers also have associated slide deposits. Information in Reference 2.4.6-31 on the distribution of slide volumes shows that the Currituck slide is the largest slide occurring in the region, making it the most logical candidate for study.

The following references will be added to SSAR Subsection 2.4.6:

2.4.6-30 Twichell, D. C.,J. D. Chaytor, U. S. ten Brink and B. Buczkowski, B., "Morphology of late Quaternary submarine landslides along the U. S. Atlantic continental margin", Marine Geology, 264, 4-15, 2009.

2.4.6-31 Chaytor, J. D., U. S. ten Brink, A. R. Solow, and B. D. Andrews, "Size distribution of submarine landslides along the U. S. Atlantic margin", marine Geology, 264, 16-27.

SSAR Subsection 2.4.6.2 2nd Paragraph will be revised to delete the word “inactive”.

Enclosure 2 provides the markups of the above described SSAR revision.

Response to RAI No. 20, Question 02.04.06-4:

In Reference 2, the specific requests for Question 02.04.06-4 were:

> *To meet the requirements of GDC 2, 10 CFR 52.17, and 10 CFR Part 100, PSEG should provide an assessment of the Probable Maximum Tsunami (PMT) for the proposed site. 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 the theoretical bases of the models, their verification and the conservatism of all input parameters. Specifically, for this site, PSEG provide additional information, evaluation and a discussion in the SSAR of the following:*
>
> (1) *Appropriateness of Shallow Water Wave Models (SSAR 2.4.6.4.1). Reference to NUREG/CR-6966 and physics-based discussion on possible limitations of MOST model for this application.*
> (2) *Water Levels for Bottom Friction Experiment (SSAR 2.4.6.4.1 and 2.4.6.4.5). Resolve the discrepancy between water levels shown in Figure 2.4.6-2 with the water levels stated in the last paragraph of Section 2.4.6.4.5. Reference to section presenting 10% exceedence tidal levels, and repeat tidal values when presenting runup/rundown in SSAR Section 2.4.6.4.5.*
> (3) *Input Parameters and Results for all Water Level Models (SSAR 2.4.6.2). Provide images of initial conditions and snapshots of the wave field in time in a revised version of the SSAR.*
> (4) *Determination of Simulation Time (SSAR 2.4.6.4.4). Provide information in the updated SSAR that results of a long-time Currituck simulation, out to 40 hours of real elapsed time, showed no evidence of seiche.*
> (5) *Sensitivity Experiments for Atlantic Marin Landslides (SSAR 2.4.6.4.5 2nd Paragraph). Information regarding whether other locations of the slides used in the sensitivity experiments are in a geologically similar environment compared to the actual Currituck slide location.*
> (6) *Landslide Initial Conditions (SSAR 2.4.6.4.5 and 2.4.6.4.6). Discussion of conservativeness of the TOPICS method of determining initial conditions for the Currituck and the N-wave for the Canary Islands. Provide all input parameters.*
> (7) *Effective Filtering of Delaware Bay (SSAR 2.4.6.4.5 3rd Paragraph, 2.4.6.4.6 1st Paragraph, and SSAR 2.4.6.4.7 3rd Paragraph). Additional simulation results for a case or cases with a finer resolution, to test the numerical effect of high frequency filtering and to ensure that the model is not unrealistically damping these components. Provide results in a reading room*
> (8) *Hispaniola Earthquake Source Parameters (SSAR 2.4.6.4.7 2nd Paragraph). Discussion on how the source parameters are derived.*

PSEG Response to NRC RAI:

(1) Appropriateness of Shallow Water Wave Models

Tsunami wavelengths are large compared to the depth of the water, and therefore are often called long waves or shallow water waves. The term shallow water waves refers to the shallowness of the water compared to the wavelength. Detailed behavior of tsunami-wave dynamics is determined using numerical simulations. U.S.NRC NUREG/CR-6966, *Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America* (March 2009), Section 5.3.4, Wave Propagation Simulation, references two tsunami-community numerical models. These are (1) Method of Splitting Tsunami (MOST) and (2) the set of models TSUNAMI-N1, TSUNAMI-N2, and TSUNAMI-N3 for simulation of near field tsunamis and TSUNAMI-F1 and TSUNAMI-F2 for far field tsunamis, collectively known as TSU.

Both of these models provide numerical solutions for the same underlying physical equations, based on the shallow water theory for nondispersive wave propagation. Of these two choices, the MOST model is more widely used by the U.S. tsunami community, and was therefore chosen for use in this study. Tsunamis produced by underwater landslides can be short enough in period and length to introduce dispersive effects, making weakly dispersive Boussinesq models more appropriate for modeling details of tsunami waveforms in these instances. However, it is unlikely that the use of a Boussinesq model instead of the MOST model would affect computed values of maximum runup or drawdown at the PSEG Site. Therefore, the MOST model, which meets the requirements of NUREG-CR-6966, is an acceptable method and is appropriate for this analysis.

(2) Water Levels for Bottom Friction Experiment

Figure 2.4.6-2 is presented in the context of the discussion contained in Subsection 2.4.6.4.1, which focuses on how the use of bottom friction coefficients affected the water surface elevations computed at the PSEG Site. Due to this focus, the effects of tides were not considered in presenting Figure 2.4.6-2.

Subsection 2.4.6.4.2 presents how the models were setup, including discussion of tidal conditions and associated values (e.g. 10% exceedence tidal levels), which are used in each of the three primary cases evaluated.

Subsection 2.4.6.4.5 presents the results of the analysis associated with Currituck Landslide case. This analysis included the tidal effects and does not include bottom friction to provide the most conservative (highest for runup and lowest for drawdown) water surface elevation at the PSEG Site as noted in Subsection 2.4.6.4.8.

During the course of the review, a typographical error was discovered in SSAR Subsection 2.4.6.4.8. A negative sign is missing from the elevation of the 90% exceedance low tide. This negative sign will be added in the first paragraph of SSAR Subsection 2.4.6.4.8: line 6, so that the text reads -5.08 ft NAVD.

(3) Input Parameters and Results for all Water Level Models

During the NRC audit, reviewers requested to see figures showing time series model output starting at the initial condition and the progression of that wave field through time. In addition to a figure illustrating source conditions, a set of four time series figures will be added for each of the three modeling scenarios. A figure illustrating wave heights through time at six stations along Delaware Bay for each modeling scenario is also included.

SSAR Subsection 2.4.6.4.5 will be revised to reference new Figures 2.4.6-8, 2.4.6-9, 2.4.6-10, 2.4.6-11, 2.4.6-12, 2.4.6-13, and 2.4.6-14 illustrating the progression of the wave field for the Currituck Landslide.

SSAR Subsection 2.4.6.4.6 will be revised to reference new Figures 2.4.6-15, 2.4.6-16, 2.4.6-17, 2.4.6-18, 2.4.6-19, and 2.4.6-20 illustrating the progression of the wave field for the La Palma Landslide.

SSAR Subsection 2.4.6.4.7 will be revised to reference new Figures 2.4.6-21, 2.4.6-22, 2.4.6-23, 2.4.6-24, 2.4.6-25, and 2.4.6-26 illustrating the progression of the wave field for the Hispaniola Trench Earthquake.

(4) Determination of Simulation Time

Model calculations were carried out for a simulated elapsed time of 40 hours after the initial tsunami generation event. No evidence was found of significant seiching effects within Delaware Bay after the initial arrival of the tsunami front at the PSEG site.

SSAR Subsection 2.4.6.4.4 will be revised to reflect this information.

Figure 2.4.6-7 will be added to the SSAR showing the results of this simulation.

(5) Sensitivity Experiments for Atlantic Margin Landslides

The analysis of the primary landslide tsunami source, the Currituck Landslide, included an evaluation of sensitivity to location. For the original Currituck event, the landslide center is located at 36.4°N, 74.5°W, and oriented in the direction of slide motion at 100 degrees clockwise from north. Three alternate events, each with a source moved progressively further north, have been considered, in order to investigate the hydrodynamic sensitivity of simulated runup results to the exact location of the slide event. The alternate source centers are located at 36.6°N, 74.49°W; 36.9°N, 74.48°W; and 37.2°N, 74.47°W. Numerical experiments with the four landslide locations do not indicate that wave height predictions in Delaware Bay are sensitive to the choice of landslide location, because offshore shelf bathymetry, rather than source location, controls wave height distribution and focusing patterns. Therefore, remaining simulations for this site are performed using the historic landslide location. Further numerical examples also indicate that Delaware Bay wave conditions are not sensitive to the chosen width of the landslide, given a constant total landslide volume.

The tests carried out here were done primarily to address questions on how the shelf geometry controls hydrodynamic behavior of tsunamis associated with slides in the region of the PSEG Site. Although there has been some recent literature suggesting that the region covered by the alternate slide locations may be vulnerable to failure (Reference 2.4.6-4), more recent literature (Reference 2.4.6-21) suggests that slides would be less likely at the additional source locations since these locations move out of the vicinity of old river delta deposits. The intent of the parametric study was to determine the hydrodynamic sensitivity of the tsunamis to geographical location. With this intent, and considering that the alternate sites are less likely sources of a landslide, the location of the original Currituck Landslide is the appropriate source location for the analysis.

SSAR Subsection 2.4.6.4.5 will be updated to reflect this additional information.

(6) Landslide Initial Conditions

Input parameters used for modeling tsunamis generated by landslides came from "Evaluation of Tsunami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts" (Reference 2.4.6-21). The source for the Currituck slide simulations were developed with the TOPICS program (References. 2.4.6-27 and 2.4.6-28) using the source geometry provided in Reference.2.4.6-21. TOPICS itself is based on a set of parameterized curve fits to calculated sea surface displacements based on numerical solutions of a fully nonlinear potential flow model. The model has been validated against extensive laboratory data obtained using rigid models for translating slide masses (Reference RAI-20-7). TOPICS has recently been validated against field measurements for the Papua New Guinea landslide event of 1998 (Reference RAI-20-8). TOPICS has thus been shown to be an appropriate means for prescribing initial conditions for landslide tsunamis.

For the Canary Islands, the N-wave source, based on initial displacement estimated from Ward and Day (Reference 2.4.6-25), represents the largest estimate of the tsunamigenic event appearing in the literature to date. Since that initial Ward and Day displacement estimate, additional investigations by Mader (Reference 2.4.6-8), Lovholt et al (Reference 2.4.6-7) and SAIC corporation (Reference 2.4.6-5) have been performed that have refined the estimate. These investigations show the initial displacement, caused by a volcanic cone collapse at La Palma, to be significantly less than suggested in the original Ward and Day estimate (Reference 2.4.6-25), which was used as the basis for the source modeling in the SSAR submittal in May 2010. Thus, the use of the Ward and Day initial estimate is conservative in that it produces a tsunami which is presently thought to be excessively large by subsequent investigators (References 2.4.6-5, 2.4.6-7, 2.4.6-8).

SSAR Subsection 2.4.6.4.5, second paragraph will be revised and a third paragraph added to better describe sensitivity experiments for Atlantic Margin Slides.

SSAR Subsection 2.4.6.3.1 will be revised to describe landslide initial conditions for Currituck and Section 2.4.6.3.2 will be revised to describe N-wave source for Canary Islands.

References:

RAI-20-7, Enet, F. and Grilli, S. T., 2007, “Experimental study of tsunami generation by three-dimensional rigid underwater landslides”, J. Waterway, Port, Coastal and Ocean Engineering., 133, 442-454.

RAI-20-8, Tappin, D. R., Watts, P. and Grilli, S. T., 2008, “The Papua New Guinea tsunami of 17 July 1998: anatomy of a catastrophic event”, Natural Hazards and Earth Systems Science, 8, 243-266.

(7) Effective Filtering of Delaware Bay

Simulations performed in the development of the Tsunami analysis found that high frequency waves were filtered at the mouth of the Delaware Bay. Additional runs using finer spatial grid resolution were performed and show a greater penetration of high frequency energy into the upper reaches of the Bay. However the results of this additional analysis do not change the conclusions on the dominance or magnitude of the lower frequency components. Therefore the results of the amplitude of the Runup and Drawdown of the Tsunami analysis shown in SSAR Subsection 2.4.6.4 are not affected. The data showing this analysis will be made available for review in the reading room.

Text will be added in Subsection 2.4.6.4.5 describing effective filtering of Delaware Bay.

(8) Hispaniola Earthquake Source Parameters

Hispaniola earthquake source parameters are based on "Pre-Defined Unit Sources" developed in the project of the forecast propagation database for NOAA's short-term inundation forecast for Tsunamis (Reference RAI-20-9). Unit sources for the Atlantic subduction zone were used to construct the Hispaniola earthquake source for the simulation.

Reference
RAI-20-9, Gica, E., M. Spillane, V.V. Titov, C. Chamberlin, and J.C. Newman (2008): Development of the forecast propagation database for NOAA's Short-term Inundation Forecast for Tsunamis (SIFT). NOAA Tech. Memo. OAR PMEL-139, 89 pp.

Associated PSEG Site ESP Application Revisions:

SSAR Subsection 2.4.6.4.8: line 6, first paragraph will be revised to add the negative sign in front of -5.08 ft NAVD.

Time series figures will be added for each of the model runs. These figures will be referenced in SSAR Subsections 2.4.6.4.5, 2.4.6.4.6, and 2.4.6.4.7.

A sentence will be added to end of SSAR Subsection 2.4.6.4.4 and a figure showing seiche effects (Figure 2.4.6-7) will be added.

SSAR Subsection 2.4.6.4.5, second paragraph will be revised and a third paragraph added to better describe sensitivity experiments for Atlantic Margin Slides.

SSAR Subsection 2.4.6.3.1 will be revised to describe landslide initial conditions for Currituck and Section 2.4.6.3.2 will be revised to describe N-wave source for Canary Islands.

Text will be added in Subsection 2.4.6.4.5 describing effective filtering of Delaware Bay.

Enclosure 2 provides the markups of the above described SSAR revision.

Enclosure 3 provides the new and revised figures.

PSEG Letter ND-2011-0026, dated May 11, 2011

ENCLOSURE 2
Proposed Revisions
Part 2 – Site Safety Analysis Report (SSAR)

Subsection 2.4.6, Tsunami
Subsection 2.5.1, Geology
Subsection 2.5.4 Geotechnical

<u>Marked Up Pages</u>
2.4-85
2.4-86
2.4-88
2.4-90
2.4-91
2.4-92
2.4.95
2.5-64
2.5-91
2.5-213

RAI-20 Supplement to SSAR Mark-up

2.4.6 PROBABLE MAXIMUM TSUNAMI FLOODING

This subsection develops the geohydrological design basis to ensure that potential hazards to the safety-related SSC important to safety due to the effects of a PMT are considered in the new plant design. NUREG/CR-6966, *Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America*, is used to support the conclusions described below.

Determination of PMT is based on evaluation of multiple source locations of the worst possible submarine landslide, volcanic cone flank failure, and submarine fault displacement that could affect the PSEG Site. The volume of material displaced causing the tsunami is based on recent research contained in "*Evaluation of Tsunami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts,*" USGS Administrative Report to the NRC (Reference 2.4.6-21). The Method of Splitting Tsunami (MOST) model, originally developed at the University of Southern California and currently maintained by NOAA's Pacific Marine Environmental Laboratory is used to propagate the tsunami from its source to the PSEG Site.

2.4.6.1 Historical Tsunami Record

Table 2.4.6-1 provides a list of recorded tsunamis affecting the eastern United States (U.S.) and Canada from 1755 to 2009 (Reference 2.4.6-15). Four potential tsunamigenic sources are identified that could affect the new plant location and include the following:

- A submarine landslide on the continental shelf along the U.S. East Coast.
- Seismic or volcanic tsunamigenic sources along the Atlantic Ocean's eastern boundary, including those near the Portuguese coast and Canary Islands.
- Co-seismic activity associated with subduction zones in several Caribbean trenches.
- Earthquake zones in the northern Atlantic Ocean, primarily near Newfoundland, Canada.

Of these, historical records and published studies indicate that the greatest severity of tsunami waves in the Mid-Atlantic region of the U.S. East Coast, including Delaware Bay, would most likely stem from the first three sources (Reference 2.4.6-15). The historical record does not contain detailed earthquake source parameters. Estimates of such parameters as displacement volume, focal depth, and fault dimension and orientation are based on anecdotal accounts and resulting impacts on shorelines and coastal populations.

Insert A from RAI-20 supplement here.

2.4.6.1.1 Currituck Landslide

Mapping and geological analysis of the sea floor indicates that a large submarine mass failure (SMF) event took place off the coast of NC in the late Pleistocene era. This slide is known as the Currituck slide. The slide is surmised to have happened in either one or two stages, with a total slide volume of around 2.16E11 cubic yards (cu. yd.) (165 cubic kilometers). Simulations of a number of scenarios based on the one- or two-stage partitioning of the event and on a range of slide velocities for each state indicate that coastlines immediately facing the slide location could experience tsunami amplitudes on the order of 20 ft. (6 meters [m]). Impact on regions upcoast or downcoast is mainly through refracted portions of the main generated waves or to edge waves propagating out of the immediately impacted areas, and effects are determined to be on the order of 6.6 feet. (Reference 2.4.6-21)

Insert B from RAI-20 supplement here.

2.4.6.1.2 1755 Lisbon, Portugal Earthquake and Tsunami

One significant Atlantic Ocean tsunami that affected the U.S. East Coast was generated off the coast of Portugal in 1755. The tsunami was generated at the Gorringe Bank, approximately 125 mi. (200 kilometers [km]) from the Portuguese coast, due to a displacement in the submarine fault. The highest runup from this tsunami was approximately 100 ft. (30.0 m), near Lagos, [illegible]. At Lisbon, Portugal, runup reached a height of app[illegible] m). [illegible]nce 2.4.6-15) Numerical simulations indicate that ma[illegible]udes along [illegible] East Coast could have reached 9.8 ft. (3 m) (Refer[illegible]

DELETE: "tsunamigenic"

INSERT: "and subsequent landslide"

2.4.6.1.3 Tsunami from 1918 Puerto Rico Earthquake

Puerto Rico experienced a ~~tsunamigenic~~ earthquake event in 1918 with a moment magnitude (M_w) of 7.3. The M_w is a logarithmic scale of 1 to 10 (a widely used successor to the Richter scale) that enables seismologists to compare the energy released by different earthquakes on the basis of the area of the geological fault that ruptured in the quake. The epicenter of the Puerto Rico earthquake was located 9.4 mi. off the northwest coast of the island, within the ~~Puerto Rico Trench~~. The resulting tsunami created runup ranging from 13 ft. to 20 ft. (4 m – 6 m) along the Puerto Rican coast. The tsunami had transatlantic reach, with effects of the tsunami recorded as a surge of 0.2 ft. at a ~~tide~~ gage in Atlantic City, NJ, located 40 mi. northeast of the mouth of Delaware Bay (Reference 2.4.6-15).

REPLACE WITH "Mona Passage"

INSERT "landslide and"

[illegible] Tsunami Due to 1929 Earthquake at G[illegible]land, Canada

The 1929 earthquake which generated the Grand Banks landslide had an M_w of 7.2; producing the largest recorded tsunami in the northern part of the North American east coast. The recorded damage attributed to this tsunami was mostly confined to the Newfoundland coast. The epicenter of the earthquake was located near the mouth of the Laurentian Channel, south of the Burin Peninsula and on the south coast of Newfoundland. The earthquake triggered an underwater landslide that generated a tsunami with a runup height of 89 ft. (27 m) at the Burin Peninsula. Water level records at Atlantic City show that the maximum tsunami amplitude at this location from the tsunami was 2.2 ft. (0.68 m) (Reference 2.4.6-15).

2.4.6.2 Probable Maximum Tsunami

Tsunami events that could affect the Delaware Bay environs and the PSEG Site could be generated by a range of local or distant geoseismic activities. Local sources include SMF events associated with slope failures on the continental shelf margin, or large sediment movements in the form of turbidity currents. These occur on the shelf margin or in submarine canyons that incise the shelf at locations along the eastern coast of the United States. Delaware Bay is a low-lying coastal plain estuary bounded by nearly flat terrain on both shores (Reference 2.4.6-24). Therefore, the occurrence of locally-generated waves due to subaerial or submarine landslide events is unlikely. ~~Figure 2.4.6-1 shows that the slopes near the PSEG Site are largely in the range of 1(vertical):500(horizontal).~~

Replace crossed out sentence with Insert C from RAI-20 supplement

Distant sources include co-seismic activity in s[illegible] Puerto Rico trenches, or ~~inactive~~ faulting zones such as the region west and south of Portugal. In addition, large scale SMF events have been identified along the Mid-Atlantic Ridge and British Isles. Possible catastrophic failure of volcanic cones and the subsequent generation of

DELETE "inactive"

2.4.6.3 Tsunami Source Characteristics

Simulations of tsunami events (Subsection 2.4.6.4) require a specification of properties of the tsunamigenic sources, including physical size, location and magnitude of ground movement. Values used in this study have been taken from available literature sources. Information about the source description for each of the three events considered is contained in Subsections 2.4.6.3.1 through 2.4.6.3.3.

2.4.6.3.1 Currituck Landslide

For the Currituck landslide, a total slide volume of 2.16E11 cu. yd. (165 cubic kilometers [km^3]), and a vertical slide displacement of 5740 ft. (1750 m) are used (Reference 2.4.6-21). The source for the tsunami motion is given in the form of a static surface displacement, specified using the equations and procedure outlined in two sources (References 2.4.6-27 and 2.4.6-28). The tsunami source location is taken as being the location of the actual Currituck landslide. Three additional sites to the north were tested in order to determine sensitivity to slide location at the study site.

Insert D from RAI-20 supplement at end of this section

2.4.6.3.2 La Palma Landslide in Canary Islands

The source for this event is a possible volcanic cone collapse on the flank of the Cumbre Vieja volcano on the island of La Palma, in the Canary Islands. This hypothetical event has been extensively studied with a variety of techniques. The main input to the choice of a source is based on scientific literature. The Science Applications International Corporation (SAIC) SAIC Adaptive Grid Eulerian (SAGE) program multimaterial model has previously been applied to simulate the propagation of the landslide (Reference 2.4.6-5). SAGE is a geodynamic model used to model a moving landslide (Reference 2.4.6-5). Recently, a Boussinesq model was used to simulate near-field tsunami wave propagation across the Atlantic Ocean (Reference 2.4.6-7). The results indicate that the maximum predicted WSEL in the Canary Islands range from 33 ft. to 590 ft. (10 m to 188 m) for landslide depths between 895 ft. and 5363 ft. (273 m and 1695 m) (Reference 2.4.6-7). The recent Boussinesq model predicts smaller WSEL than Ward and Day previously predicted (Reference 2.4.6-25), but larger than the predicted results of Mader (Reference 2.4.6-8). Although these results represent qualitatively improved dynamics, as they included the full 3-dimensional representation of the wave generation, a more conservative larger surface displacement is used.

INSERT:
"The N-wave source, based on initial displacement estimated from Ward and Day (Reference 2.4.6-25), represents the largest estimate of the tsunamigenic event appearing in the literature to date and is thus conservative in that it produces a tsunami which is presently thought to be excessively large by most investigators."

2.4.6.3.3 Hispaniola Trench

The source for this event is a subduction [illegible] Hispaniola Trench. This event is modele[illegible] displacement is then determined for eac[illegible] (Reference 2.4.6-17) to obtain an M_w equ[illegible] sources are shown in Table 2.4.6-2. The model is initialized with a static surface displacement corresponding to the superposed displacements resulting from the seven sources taken together.

the datum for NOAA National Geophysical Data Center (NGDC) Coastal Relief Model (CRM) and NOAA National Ocean Service (NOS) Arc Global Relief Model (ETOPO 1) bathymetry data sets. ETOPO 1 is a 1 arc-minute global relief model of the earth's surface that integrates land topography and ocean bathymetry. Mean sea level (msl) is -0.049 ft. NAVD (-0.015 m) at Reedy Point (Reference 2.4.6-13). Resulting runup and drawdown levels are reported relative to NAVD in Subsection 2.4.6.4.8.

2.4.6.4.3 Bathymetry and Topography Sources

Topography and bathymetry data for the model domains are obtained from NOAA NOS ETOPO 1, NOAA NGDC CRM, and NJ and DE Digital Elevation Grids.

Atlantic domain grids (Grid A for the Canary Island case and Grid A for the Hispaniola earthquake case) are generated based on ETOPO 1 (Reference 2.4.6-1). ETOPO 1 uses msl as a vertical datum origin. The Currituck Grid A includes the continental shelf and offshore areas in the Atlantic Ocean. Each case employs a different Grid A.

Grids for regional scale domains (Grid B) are based on CRM with 3 arc-second resolution (Reference 2.4.6-2). Data is available from NOAA (Reference 2.4.6-11). CRM also uses msl as the vertical datum origin. The Canary Island case and Hispaniola earthquake case use the same Grid B. The Currituck case uses a different Grid B.

All three cases studied here use the same local Grid C, developed from the CRM for bathymetry and NJ and DE digital elevation grids, and for subaerial topography (References 2.4.6-16 and 2.4.6-23). NJ and DE digital elevation data are extracted from the USGS 30 m DEM data (7.5-minute DEM, horizontal North American datum NAD83, UTM-18N, and vertical datum NAVD 88 [NAVD]).

INSERT:
"Model calculations were carried out for varying simulated elapsed times depending on the source location. The Currituck slide tsunami model ran calculations for elapsed times up to 40 hours after the initial tsunami generation event. No evidence was found of significant seiching effects within Delaware Bay after the initial arrival of the tsunami front at the PSEG site. Results from this simulation are shown in Figure 2.4.6-7."

2.4.6.4.4 Model Grids

Areas of grid coverage and spatial resolution for the three cases studied are given in Tables 2.4.6-3, 2.4.6-4, and 2.4.6-5 and shown in Figures 2.4.6-4, 2.4.6-5, and 2.4.6-6. Numerical simulations are performed for each of the cases using a Manning's *n* value of 0.01, and calculations are repeated with no bottom friction for the Currituck landslide case (Reference 2.4.6-6). Results for water levels are discussed for each case.

2.4.6.4.5 Currituck Landslide Results

Parameters used for the Currituck landslide case include a slide volume of 2.16E11 cu. yd. (165 km^3), a depth of middle slide of 5740 ft. (1750 m), and a slope along the failure plane of 2.5

degrees (Reference 2.4.6-21). Initial water surface displacements based on these parameters are generated using formulae and methodology for SMF (References 2.4.6-27 and 2.4.6-28).

~~For the original Currituck event, the landslide center is located at 36.4°N, 74.5°W, and oriented in the direction of slide motion at 100 degrees clockwise from north. Recent studies indicate, however, that the region of the continental margin just to the north of the historic landslide may be vulnerable to failure. Thus, it is reasonable to consider landslide events somewhat to the north of the historic landslide (Reference 2.4.6-4). Three additional events, each with a source moved progressively further north, have been considered. The additional source centers are located at 36.6°N, 74.49°W; 36.9°N, 74.48°W; and 37.2°N, 74.47°W. Numerical experiments with the four landslide locations do not indicate that wave height predictions in Delaware Bay are sensitive to the choice of landslide location, because offshore shelf bathymetry, rather than source location, controls wave height distribution and focusing patterns. Therefore, remaining simulations for this site are performed using the historic landslide location. Further numerical examples also indicate that Delaware Bay wave conditions are not sensitive to the chosen widt of the landslide, given a constant total landslide volume.~~ ←

Insert E from RAI-20 supplement here

Model outputs compare time series of surface elevation at Cape May, NJ, and the PSEG Site for the cases with and without bottom friction. Model results indicate that Delaware Bay effectively filters high frequency components of the tsunami signal, leaving only a low frequency response at the PSEG Site. These results occur for each of the cases studied. Low frequency waves propagate up the bay like flood waves in a river, experiencing less damping. ←

Insert F from RAI-20 supplement at end of this paragraph

Model output indicates that there is a region of high waves in the Delaware Bay entrance extending from Cape May towards the shipping channel in the mid-bay area. This region area of large sandbanks which extends 3.1 mi. in each direction. The high wave energy over this area is persistent for all the cases studied, and the high wave energy does not continue into the bay itself. ←

ADD:
"Figures 2.4.6-8, 2.4.6-9, 2.4.6-10, 2.4.6-11, 2.4.6-12, 2.4.6-13, and 2.4.6-14 illustrate model results for the Currituck Landslide through time."

The simulated WSEL relative to ... simulations with and without bot... he simulation reduces both the ma... ncy components. The effect on drawdown, computed using the 90 percent exceedance low tide water level, is more accentuated. Runup values with friction are reduced by 0.15 ft. Maximum runup at the site (computed with 10 percent exceedance high tide water level and no friction) is +5.65 ft. NAVD. Maximum drawdown (computed with 90 percent exceedance low tide water level and no friction) is -6.16 ft. NAVD.

2.4.6.4.6 La Palma (Canary Islands) Landslide Results

A simulation of the La Palma event is conducted using an N-wave source. An N-wave represents the geometry of a wave crest in tsunami models (Reference 2.4.6-20). This source is introduced in the model as a static initial condition. The incident wave at Cape May, NJ, is more organized than the wave in the Currituck example. This incident wave represents a wave train that has dispersed from an initial pulse over oceanic distances. The incident wave has a dominant wave period of approximately 25 minutes. This wave is filtered by the lower Delaware Bay, as in the Currituck example. There is a residual low frequency motion at the PSEG Site producing a runup elevation of 0.26 ft., with a leading wave of elevation, or positive surge at the site. The wave heights experienced from this event do not exceed 6.6 ft. in amplitude in the area covered by Grid B. Maximum runup at the site is +4.76 ft. NAVD. Maximum drawdown is -5.30 ft. NAVD. ←

ADD:
"Figures 2.4.6-15, 2.4.6-16, 2.4.6-17, 2.4.6-18, 2.4.6-19, and 2.4.6-20 illustrate model results for the La Palma Landslide through time."

2.4.6.4.7 Hispaniola Trench Earthquake Case

The last case considered is the Hispaniola Trench, w zone co-seismic event.

The tsunami source chosen for this case is based on a composite source utilizing seven individual Okada (1985) elastic sources with a total M_w equaling 9.0. The trench segment is located between longitudes 68°W and 62°W, and stretches for a distance of 419 mi. (675 km) (Reference 2.4.6-17). Properties of the individual Okada sources are given in Table 2.4.6-2.

Time series of WSEL for the Hispaniola Trench case for Cape May, NJ, and the PSEG Site indicate that maximum runup elevations within the boundaries of the A and B grids are up to 11.5 ft. (3.5 m). This is higher than values obtained for the La Palma case. As in all cases studied here, refraction directs waves away from the Delaware Bay entrance, reducing wave heights entering the bay to the 3 ft. – 5 ft. (1 m – 1.5 m) range, except for a concentration of energy over the shoal area south of Cape May. As in previous cases, results indicate that the bay effectively filters the high frequency components of the tsunami signal, leaving only a low frequency signal at the PSEG Site. Maximum runup at the site is +5.22 ft. NAVD. Maximum drawdown is -5.56 ft. NAVD. ←

ADD:
"Figures 2.4.6-21, 2.4.6-22, 2.4.6-23, 2.4.6-24, 2.4.6-25, and 2.4.6-26 illustrate model results for the Hispaniola Trench earthquake through time."

2.4.6.4.8 Summary of Tsuna

REPLACE WITH: "-5.08 ft."

Runup values calculated during si which serves as the static initial water level in the simulations. Maximum runup values are reported in Table 2.4.6-6 relative to the 10 percent exceedance high tide elevation. Drawdown values are reported in Table 2.4.6-6 relative to the 90 percent exceedance low tide elevation. The 10 percent exceedance high tide is 4.5 ft. NAVD and 90 percent exceedance low tide is ~~-5.00 ft.~~ NAVD based on values from the NOAA tidal gage at Reedy Point (Reference 2.4.6-13). This provides an approximation for extreme water levels reached for wave runup events arriving coincident with high astronomical tide, or for drawdown events arriving coincident with low astronomical tide. The PMT at the PSEG Site is caused by the Currituck Landslide. In the most conservative model without bottom friction, maximum runup at the PSEG Site is 5.65 ft. NAVD and maximum drawdown is -6.16 ft. NAVD.

These results indicate that a landslide tsunami on the U.S. East Coast continental shelf margin represents the PMT case.

2.4.6.5 Effects of Runup on Safety-Related Facilities

The new plant grade will be established at an elevation at least 1 ft. above the DBF of 35.9 ft. NAVD. As indicated in Table 2.4.6-6, none of the maximum predicted runup elevations obtained in this study overtop this elevation. Therefore, PMT events do not constitute a limiting design basis for the new plant nor do hydrodynamic and hydrostatic forces impact any safety-related structures. The DBF caused by storm surge and associated wave runup caused by the PMH, described in Subsection 2.4.5, governs the design to protect safety-related structures from wave runup.

2.4.6-18 Pararas-Carayannis, G., "Evaluation of the Threat of Mega Tsunami Generation from Postulated Massive Slope Failures of Island Stratovolcanoes on La Palma, Canary Islands, and on the Island of Hawaii," Science of Tsunami Hazards, 20: p. 251 – 277, 2002.

2.4.6-19 Synolakis, C.E., E.N. Bernard, V.V Titov, U. Kanoglu and F.I. Gonzalez, "Standards, Criteria and Procedures for NOAA Evaluation of Tsunami Numerical Models," NOAA Technical Memorandum OAR PMEL-135, Pacific Marine Environmental Laboratory, Seattle, WA, 2007.

2.4.6-20 Tadepalli, S. and C.E. Synolakis, "Model for the Leading Waves of Tsunamis," Physical Review Letters, 77, p. 2141 – 2144, 1996.

2.4.6-21 ten Brink, U., D. Twichell, E. Geist, J. Chaytor, J. Locat, H. Lee, B. Buczkowski, R. Barkan, A. Solow, B. Andrews, T. Parsons, P. Lynett, J. Lin and M. Sansoucy, "Evaluation of Tsunami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts," USGS Administrative report to the U.S. Nuclear Regulatory Commission, 300 pp., August 22, 2008.

2.4.6-22 Titov, V.V. and F.I. Gonzalez, "Implementation and Testing of the Method of Splitting Tsunami (MOST) Model," NOAA Technical Memorandum ERL PMEL-112, 1997.

2.4.6-23 University of Delaware Spatial Analysis Lab, Website, http://www.udel.edu/FREC/spatlab/dems/, accessed July 15, 2009.

2.4.6-24 U.S. Geological Survey, "Delaware River Study Unit Description," National Water-Quality Assessment Program, Website, http://nj.usgs.gov/nawqa/delr/su.descrpt.html, accessed June 16, 2009.

2.4.6-25 Ward, S.N. and S. Day, "Cumbre Vieja Volcano – Potential Collapse and Tsunami at La Palma, Canary Island," Geophysical Research Letters, 28(17), p. 3397 – 3400, 2001.

2.4.6-26 Ward, S.N., "Landslide Tsunami," Journal of Geophysical Research, 106: p. 11,201 – 11,215, 2001.

2.4.6-27 Watts, P., S.T. Grilli, D.R. Tappin, G.J. Fryer, "Tsunami Generation by Submarine Mass Failure. II: Predictive Equations and Case Studies," Journal of Waterway, Port, Coastal and Ocean Engineering, 131(6), p. 298 – 310, 2005.

2.4.6-28 Watts, P., S.T. Grilli, J.T. Kirby, G.J. Fryer, D.R. Tappin, "Landslide Tsunami Case Studies Using a Boussinesq Model and a Fully Nonlinear Tsunami Generation Mode l," Natural Hazards and Earth System Science, 3(5), 391 – 402, 2003.

2.4.6-29 Whitney, M.M. and R.W. Garvine, "Estimating Tidal Current Amplitudes Outside Estuaries and Characterizing the Zone of Estuarine Tidal Influence", Continental Shelf Research, 28: p. 380 – 390, 2008.

Add Insert I from RAI-20 Supplement

Therefore, the basement complex may contain crystalline components that may record Neoproterozoic to Cambrian igneous activity followed by deposition of sedimentary sequences that could be as late as Ordovician. Crystalline components may also be present and record Neoproterozoic deposition followed by Ordovician intrusion and metamorphism. The two components form the Pangean crust subsequently rifted to form extensional basins and synrift depositional sequences. Over the site vicinity, the rifting was followed by a long period of erosion to form a regional unconformity.

2.5.1.2.3.2 Deposition of North American Sedimentary Sequences

Following development of Atlantic Ocean crust in the Jurassic, thermal relaxation of the crust resulted in subsidence and aggradation on the pre-Cretaceous unconformity surface. In the PSEG Site vicinity, the aggradational sequence is represented by the Early Cretaceous Potomac Group (Formation). Following aggradation over the pre-Cretaceous erosional surface, the establishment of widespread continental shelf marine conditions resulted in deposition of the Upper Cretaceous section, first the Magothy Formation, which is characterized by beach and estuarine environments, and then several glauconite-rich transgressive-regressive cycles. The Upper Cretaceous section is indicative of low clastic input and bioturbation.

Add Insert G from RAI-20 Supplement

Widespread marine conditions persisted into the Eocene, at which time continental ice sheets in Antarctica by the earliest Oligocene marked the beginning of the onset of cyclic continental glaciation. Oscillation of the earth's water-ice budget resulted in associated glacio-eustatic sea level changes. In the PSEG Site vicinity, glacio-eustasy resulted in several transgressive-regressive cycles that are recorded in the Oligocene and early Miocene stratigraphic sequence stratigraphy (Reference 2.5.1-165). However, no Oligocene sediments are present in the site area or site location having been cut out by the sub-Miocene unconformity at the base of the Kirkwood Formation. The Middle Miocene also marked the beginning of increased clastic input that continues to the Quaternary (Reference 2.5.1-169). This has probably resulted in drainage divide migration (Reference 2.5.1-29) and has components of climate change and increased weathering (Reference 2.5.1-28).

During the Pliocene, the onset of continental glaciation in the northern hemisphere began with a major glacial event at 2.4 Ma and settled into an orbital cyclic pattern with a 41-ka period with relatively low amplitude events (Reference 2.5.1-105). This condition persisted until the Middle to Late Pleistocene with the onset of large amplitude glacial-interglacial cycles (Reference 2.5.1-28). In the vicinity of the PSEG Site these events have resulted in the deposition of fluvial sequences and the formation of estuarine terraces that were formed during the transition to interglacial periods and the resulting rise in sea level. Transition into glacial periods and the resulting fall in sea level and base level resulted in incision of the terraces and fluvial sequences that were deposited in the preceding transgressive event and the development of unconformities.

However, the relatively nearby location of the Laurentide ice sheet to the site vicinity makes correlation of relative sea levels to landforms complicated, due to near-field effects on relative sea level. These effects include, in addition to relative sea level changes associated with glacio-eustasy, the effects of glacio-isostasy and hydro-isostasy (Reference 2.5.1-41). Deconvolution of the contributions of these effects from the relative sea level signal depends on the horizontal distance to the ice load on the crust and poorly known parameters, such as mantle rheology and elastic strength of the crust (Reference 2.5.1-246).

2.5.1-255 Woodruff, K.D. and A.M. Thompson, "Geology of the Wilmington Area, Delaware," Delaware Geological Survey Geologic Map Series 4, scale 1:24,000, 1975.

2.5.1-256 Wu, P., "Effect of Viscosity Structure on Fault Potential and Stress Orientations in Eastern Canada," Geophysical Journal International 130: p. 365 – 382, 1997.

2.5.1-257 Wu, P. and H.S. Hasegawa , "Induced Stresses and Fault Potential in Eastern Canada Due to a Disc Load: A Preliminary Analysis," Geophysical Journal International 125: p. 415 – 430, 1996.

2.5.1-258 Wyer, P. and A.B. Watts, "Gravity Anomalies and Segmentation at the East Coast, USA Continental Margin,". Geophysics Journal International 166: p. 1015 – 1038, 2006.

2.5.1-259 Zimmerman, R.A., "Apatite Fission Track Age Evidence of Post-Triassic Uplift in the Central and Southern Appalachians," Geological Society of America, Abstracts with Programs 11: p. 219, 1979.

2.5.1-260 Zoback, M.L., "Stress Field Constraints on Intraplate Seismicity in Eastern North America," Journal of Geophysical Research, 97(B8): p. 11,761 – 11,782, 1992.

2.5.1-261 Zoback, M.D. and M.L. Zoback, "Tectonic Stress Field of North America and Relative Plate Motions," Geology of North America, Decade Map 1(19): p. 339 – 366, 1991.

2.5.1-262 Zoback, M.L. and M.D. Zoback, "Tectonic Stress Field of the Continental United States," in Geophysical Framework of the Continental United States, Geological Society of America Memoir, 172: p. 523 – 539, 1989.

2.5.1-263 Zoback, M.L., M.D. Zoback, J. Adams, M. Assumpcao, S. Bell, E.A. Bergman, P. Blumling, N.R. Brereton, D. Denham, J. Ding, K. Fuchs, N. Gay, S. Gregersen, H.K. Gupta, A. Gvishiani, K. Jacob, R. Klein, P. Knoll, M. Magee, J.L. Mercier, B.C. Muller, C. Paquin, K. Rajendran, O. Stephansson, G. Suarez, M. Suter, A. Udias, Z.H. Xu and M. Zhizhin, "Global Patterns of Tectonic Stress," Nature, v. 341, p. 291 – 299, 1989.

2.5.1-264 Tarr A.C., P. Talwani, S. Rhea, D. Carver, and D. Amick, "Results of Recent South Carolina Seismological Studies," Bulletin of the Seismological Society of America, 71(6): 1883-1902, 1981.

Add Insert J from RAI-20 Supplement

Hope Creek and Salem generating stations are similar to the stratigraphic layers, relationships, and conditions identified for the ESPA investigation. ← Add Insert H from RAI-20 Supplement

The stratigraphic units overlying the Vincentown Formation are of low strength and are deemed unsuitable to serve as competent layers based on their physical properties. The Vincentown Formation will serve as the competent layer for any future nuclear units at the PSEG Site (as it is for the existing units at the site). The sediments immediately underlying the Vincentown Formation, and extending to the depths investigated, are composed of very dense, silty or clayey sands and hard silts and clays.

Observations during the drilling and sampling and review of the geophysical electrical logging, as discussed in Subsection 2.5.4.1.2.3.2, indicate the cementation of Vincentown Formation sediments is variable and ranges from non-cemented sands to discontinuous layers of indurated, calcareous sandstone. Calcium carbonate is present throughout the unit based on the weak to strong reaction of the samples to 10 percent hydrochloric acid observed during the ESPA investigation. Previous petrographic studies of the Vincentown Formation (Reference 2.5.4.1-7) indicate that the entire formation has been subjected to some degree of cementation and that, in some instances, samples visually classified as being uncemented in the field have been found to be partially cemented in the laboratory. Presence of these calcareous cemented sands would not have an impact on the concrete foundations because the Vincentown Formation is not in contact with the concrete.

The upper surface of the Vincentown Formation is somewhat variable due to subaerial exposure, weathering, and fluvial erosion of this unit prior to deposition of the overlying units, as illustrated on the structure contour map (Figure 2.5.4.1-6). The relief displayed by the upper surface of the Vincentown Formation is interpreted and concluded to be consistent with an erosional mechanism and not as the result of active dissolution of the unit. Post-depositional subaerial exposure and weathering of the upper portions of the Vincentown Formation, prior to deposition of the overlying units, resulted in zones of oxidation generally observed in the previous and present borings across the PSEG Site.

Previous studies conclude that some dissolution of the uppermost, oxidized portions of the Vincentown Formation is likely to have occurred during this period of subaerial exposure and weathering. Also, previous studies report that conditions favorable to dissolution of the Vincentown Formation are considered to have ended with the deposition of the overlying Kirkwood Formation, approximately 25 million years ago (Reference 2.5.4.1-7). The information obtained during this ESPA investigation is consistent with these previously reported conclusions and observations. No evidence of karst conditions or zones of dissolution has been found from the large number of geotechnical borings performed at the PSEG Site, or from the mapping of the foundation excavation conducted during construction of Hope Creek Unit 1. It is concluded there is no potential for karst conditions or presence of zones of dissolution at the PSEG Site.

Based on the results of the ESPA investigation geotechnical borings and geophysical logs, specifically the P-S velocities, the oxidized portion of the Vincentown Formation shows no significant divergence in density, composition, or cementation, to that observed in the unoxidized portions of the Vincentown Formation. Additional data to be collected during the combined license phase of field investigations will be used to further evaluate the nature of the oxidized Vincentown Formation.

RAI-20 Supplement to Markups for SSAR Subsections 2.4.6, 2.5.1.2.3.2 and 2.5.4.1.3

Insert A at end of 2.4.6.1:
As discussed in Subsection 2.5.1.2.3.2, there is geologic evidence for a tsunami event occurring at the end of the Cretaceous Period (paleotsunami). The geologic record discussed in Section 2.5.4.1.3 indicates that review of samples from the 16 soil borings performed in the area of the PSEG ESPA site indicated strata or features that are consistent with the depositional environments described in the literature, and the site deposits are not interpreted to represent a paleotsunami occurrence.

Insert B at end of 2.4.6.1.1
The Currituck slide is one of several apparent Paleolithic slide events occurring on the outer slope of the U.S. East Coast continental shelf. Landslide-generated tsunamis typically cause the greatest levels of inundation on shorelines immediately landward of the slide event. Therefore, it is most relevant to consider additional historical or potential slides in the Mid-Atlantic Bight region, spanning from the Hudson Canyon to Cape Hatteras. Review of morphological studies of slide deposits in this region (Reference 2.4.6-30) concludes that the most prominent slides are fluvial in origin, being linked to river delta deposits formed during the late Quaternary low stand of sea level, when major rivers of the regions reached across the present shelf. In particular, the Currituck slide is associated with the delta of the Susquehanna River. Additional deltas of the Delaware and Hudson Rivers also have associated slide deposits. Information in Reference 2.4.6-31 on the distribution of slide volumes shows that the Currituck slide is the largest slide occurring in the region, making it the most logical candidate for study.

Insert C at end of 2.4.6.2
Figure 2.4.6-1 shows the naturally occurring angular topography slopes on a grid in the vicinity of the PSEG Site, and shows a maximum slope value of 0.3° occurring inland of the site. Stability analysis will be conducted during the COLA phase of the project, and will include consideration of failure surfaces that extend into the Delaware River adjacent to the site as discussed in SSAR Section 2.5.5.1.

Insert D at end of 2.4.6.3.1
The source for the Currituck slide simulations were developed using the TOPICS program (References 2.4.6-27 and 2.4.6-28) using the source geometry as given in Reference 2.4.6-21. TOPICS itself is based on a set of parameterized curve fits to calculated sea surface displacements based on numerical solutions of a fully nonlinear potential flow model, which in turn has been validated against extensive laboratory data obtained using rigid models for translating slide masses (Reference 2.4.6-32). TOPICS has recently been validated against field measurements for the Papua New Guinea landslide event of 1998 (Reference 2.4.6-33). TOPICS has thus been shown to be an appropriate means for prescribing initial conditions for landslide tsunamis.

Insert E in 2.4.6.4.5

For the original Currituck event, the landslide center is located at 36.4°N, 74.5°W, and oriented in the direction of slide motion at 100 degrees clockwise from north. Three additional events, each with a source moved progressively further north, have been considered, in order to investigate the sensitivity of simulated runup results to exact location of the slide event. The additional source centers are located at 36.6°N, 74.49°W; 36.9°N, 74.48°W; and 37.2°N, 74.47°W. Numerical experiments with the four landslide locations do not indicate that wave height predictions in Delaware Bay are sensitive to the choice of landslide location, because offshore shelf bathymetry, rather than source location, controls wave height distribution and focusing patterns. Therefore, remaining simulations for this site are performed using the historic landslide location. Further numerical examples also indicate that Delaware Bay wave conditions are not sensitive to the chosen width of the landslide, given a constant total landslide volume.

The tests carried out here were done primarily to address questions on how the shelf geometry controls hydrodynamic behavior of tsunamis associated with slides in the region of the PSEG Site. Although there has been some recent literature suggesting that the region covered by the additional slide locations may be vulnerable to failure (Reference 2.4.6-4), more recent literature (Reference 2.4.6-21) suggests that slides would be less likely at the additional source locations since these locations move out of the vicinity of old river delta deposits.

Insert F in 2.4.6.4.5 at end of paragraph ending:

Additional model runs using finer spatial grid resolution show a greater penetration of high frequency energy into the upper reaches of the Bay, but do not change the conclusions on the dominance or magnitude of the lower frequency components. Model results using the chosen grid resolution have thus been shown to be appropriate.

Insert G in 2.5.1.2.3.2 at end of first paragraph:

The end of the Cretaceous was marked by a massive bolide event near Chicxulub, Mexico (Reference 2.5.1-266). Boreholes in New Jersey conducted approximately 40 miles northeast and 59 miles east of the PSEG Site as part of the Ocean Drilling Program recovered a continuous depositional record across the Cretaceous/Tertiary boundary. A thin (<10 cm.) layer in this sequence contains materials that appear to be from a tsunami. The tsunami may have been caused by submarine slumping on the Atlantic slope associated with the Chicxulub bolide impact (Reference 2.5.1-265).

Insert H in 2.5.4.1.3, after the first paragraph:

The dominant depositional processes for the strata were marine and fluvial over a series of regressive and transgressive events. Review of samples from the 16 soil borings performed in the area of the PSEG Site, all of which penetrated through the Cretaceous/Tertiary boundary, indicated strata or features that are consistent with the depositional environments described in the literature, and the samples are not interpreted to represent a paleotsunami occurrence at the PSEG Site.

Insert I at end of references for SSAR Subsection 2.4.6

2.4.6-30 Twichell, D. C.,J. D. Chaytor, U. S. ten Brink and B. Buczkowski, B., "Morphology of late Quaternary submarine landslides along the U. S. Atlantic continental margin", Marine Geology, 264, 4-15, 2009.

2.4.6-31 Chaytor, J. D., U. S. ten Brink, A. R. Solow, and B. D. Andrews, "Size distribution of submarine landslides along the U. S. Atlantic margin", marine Geology, 264, 16-27.

2.4.6-32 Enet, F. and Grilli, S. T., 2007, "Experimental study of tsunami generation by three-dimensional rigid underwater landslides", J. Waterway, Port, Coastal and Ocean Engineering., 133, 442-454.

2.4.6-33 Tappin, D. R., Watts, P. and Grilli, S. T., 2008, "The Papua New Guinea tsunami of 17 July 1998: anatomy of a catastrophic event", Natural Hazards and Earth Systems Science, 8, 243-266.

Insert J at end of references for SSAR Subsection 2.5.1

2.5.1-265 Miller, K.G., J. V. Browning, P. J. Sugarman, P. P. McLaughlin, M. A. Kominz, R. K. Olsson, J. D. Wright, B. S. Cramer, S. F. Pekar, and W. Van Sickel, 2003, 174AX leg summary: Sequences, sea level, tectonics, and aquifer resources: Coastal plain drilling, in Miller, K.G., P. J. Sugarman, J. V. Browning, et al., eds., Proceedings of the Ocean Drilling Program, Initial Reports, 174AX (Supplement): College Station TX (Ocean Drilling Program), 1-38.

2.5.1-266 Hildebrand, Alan R., Glen T. Penfield, David A. Kring, Mark Pilkington, Antonio Camargo Z., Stein B. Jacobsen and William V. Boynton, "Chicxulub Crater: a possible Cretaceous/Tertiary boundary impact crater on the Yucatan Peninsula, Mexico", Geology, v. 19 p.867, 1991.

PSEG Letter ND-2011-0026, dated May 11, 2011

ENCLOSURE 3
CD-ROM Containing Figures 2.4.6-1 and 2.4.6-7 through 2.4.6-26

PSEG Letter ND-2011-0026, dated May 11, 2011

ENCLOSURE 4
Summary of Regulatory Commitments

ENCLOSURE 4

SUMMARY OF REGULATORY COMMITMENTS

The following table identifies commitments made in this document. (Any other actions discussed in the submittal represent intended or planned actions. They are described to the NRC for the NRC's information and are not regulatory commitments.)

COMMITMENT	COMMITTED DATE	COMMITMENT TYPE	
		ONE-TIME ACTION (Yes/No)	Programmatic (Yes/No)
PSEG will revise SSAR Sections 2.4.6, 2.5.1 and 2.5.4.1 and Figure 2.4.6-1 and add Figures 2.4.6-7 through 2.4.6-26 to incorporate the changes in Enclosure 2 in response to NRC RAI No. 20.	This revision will be included in the next update of the PSEG Site ESP application SSAR.	Yes	No