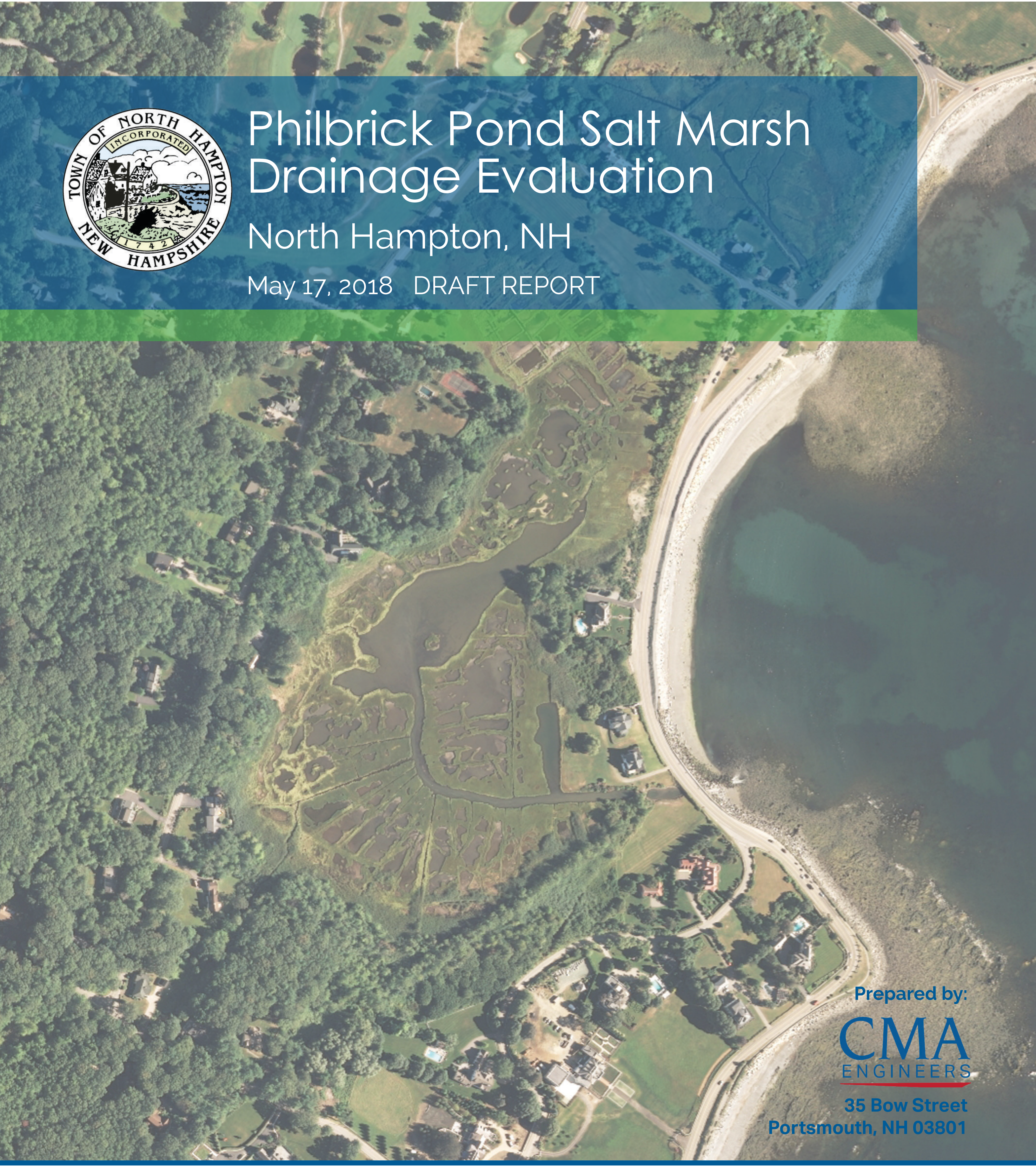
Philbrick Pond Salt Marsh Drainage Evaluation

North Hampton, NH

May 17, 2018 DRAFT REPORT



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1. Introduction

This report was prepared on behalf of the Town of North Hampton, New Hampshire by CMA Engineers, Inc., in association with Gomez and Sullivan Engineers; the Jackson Estuarine Laboratory of the University of New Hampshire; James Verra and Associates, Inc.; and Edward S. Kelly, P.E. The project was funded by the Town of North Hampton and by a grant from the State of New Hampshire Department of Environmental Services under the New Hampshire Coastal Program's (NHCP) "Design Solutions for Coastal Resilience" competitive grant program. Federal funds were provided by the National Oceanic and Atmospheric Administration (NOAA). The grant funding was approved by the New Hampshire Governor and Council.

The Philbrick Pond saltmarsh is a 29 acre marsh draining to the Atlantic Ocean in North Hampton, NH. Flow into and out of the marsh is through drainage structures beneath Ocean Boulevard (US Route 1A) and what was believed to be a partially crushed vitrified clay pipe beneath a 1900 vintage trolley berm. Both the trolley berm pipe and the Route 1A culvert constrain flow out of the marsh during normal tidal fluctuations and after precipitation events. . During the extreme "Mother's Day" storm of 2006, flow limitations due to the trolley berm culvert and other hydraulic constraints resulted in flood impacts to homes surrounding the marsh, and the isolation of more than 40 homes for more than three days from vehicular traffic, including ambulance and fire vehicles. The two culverts also limit flow into and out of the marsh during normal tidal cycles, and limit flood levels in the marsh during storm surge conditions. Storm surge flooding will increase with future sea level rise. As the project was initiated, it was believed that the trolley berm culvert needed to be replaced with an appropriately configured opening that would optimally minimize flood damage from both extreme precipitation events and storm surges, and that also would improve marsh health through increased daily tidal inundation and draining. The Town appropriation and Federal grant provided funds for the completion of topographic surveys, a complex hydrology and hydraulic analysis, a wetlands evaluation and alternatives analysis and conceptual design.

The marsh health and flooding issues described above have been deliberated in North Hampton for decades. Poor and declining health of the Philbrick Pond salt marsh was documented in 1984 by Dr. Frederick Short, Ph.D. of the Jackson Estuarine Laboratory ("North Hampton Salt Marsh Study") attributed both to mosquito control ditching completed in the 1950's that left significant areas of the marsh permanently inundated, and limited daily tidal variation due to culvert configurations that significantly limit outflow at each low tide. Both of these conditions continue to this day. Dr. Short, and several subsequent reviewers in the ensuing 20 years, had recommended removal of the trolley berm and creation of an open channel as a partial solution. Concern has been expressed by many residents over the years that removing the trolley berm and creating a channel would create a significant risk of flooding from storm surges, from the ocean. The 2006 Mother's Day storm and related isolation of homes has spurred on-going concern regarding flooding from extreme precipitation events, with flow coming from the westerly, upland direction. These competing concerns are both valid and were the reason for the need for this investigation.

In the early 2000's, the New Hampshire Coastal Program funded salt marsh vegetation monitoring, topographical surveys, and limited water level measurements and conducted public meetings to discuss the nature of the tidal restrictions and the process to better understand the nature of the flood risks. At that time, topographical surveys; assessment of the culvert structures; a hydrological and hydraulic study including precipitation events, storm surges and sea level rise; and analysis of alternatives were recommended. Initiating this process was controversial to some in North Hampton, and a consensus on moving forward was not yet clear at that time.

In about 2015, a neighborhood consensus appeared to have developed to have the “partially crushed” pipe in the old trolley berm replaced at the same size as a way to limit future flooding from extreme precipitation events. The Town of North Hampton agreed to apply for funding for this investigation to determine appropriate means of limiting flooding.

This report provides full detail on the survey information gathered, the assessment of the two culvert structures, further wetlands monitoring, an extensive hydrologic and hydraulic analysis of existing conditions and alternatives, conceptual designs of alternative solutions, and recommendations for future actions.

2. Survey

James Verra Associates (“Verra”) of Newington, NH was retained to provide detailed survey information to support the investigation. Verra had provided survey services to the New Hampshire Coastal Program in the early 2000’s to record spot elevations for house sills, septic system leachfields, and various spot elevations within Philbrick Pond. This previous survey was updated in 2017 to provide full detailed field survey of the channel and culverts in the vicinity of the trolley berm, to confirm key elevations at other locations in the watershed, and to provide spot elevations for use in preparing a one foot contour plan of Philbrick Pond using LIDAR based satellite imaging. The detailed survey information is presented in Appendix A. All survey information is on the 1929 NGVD datum.

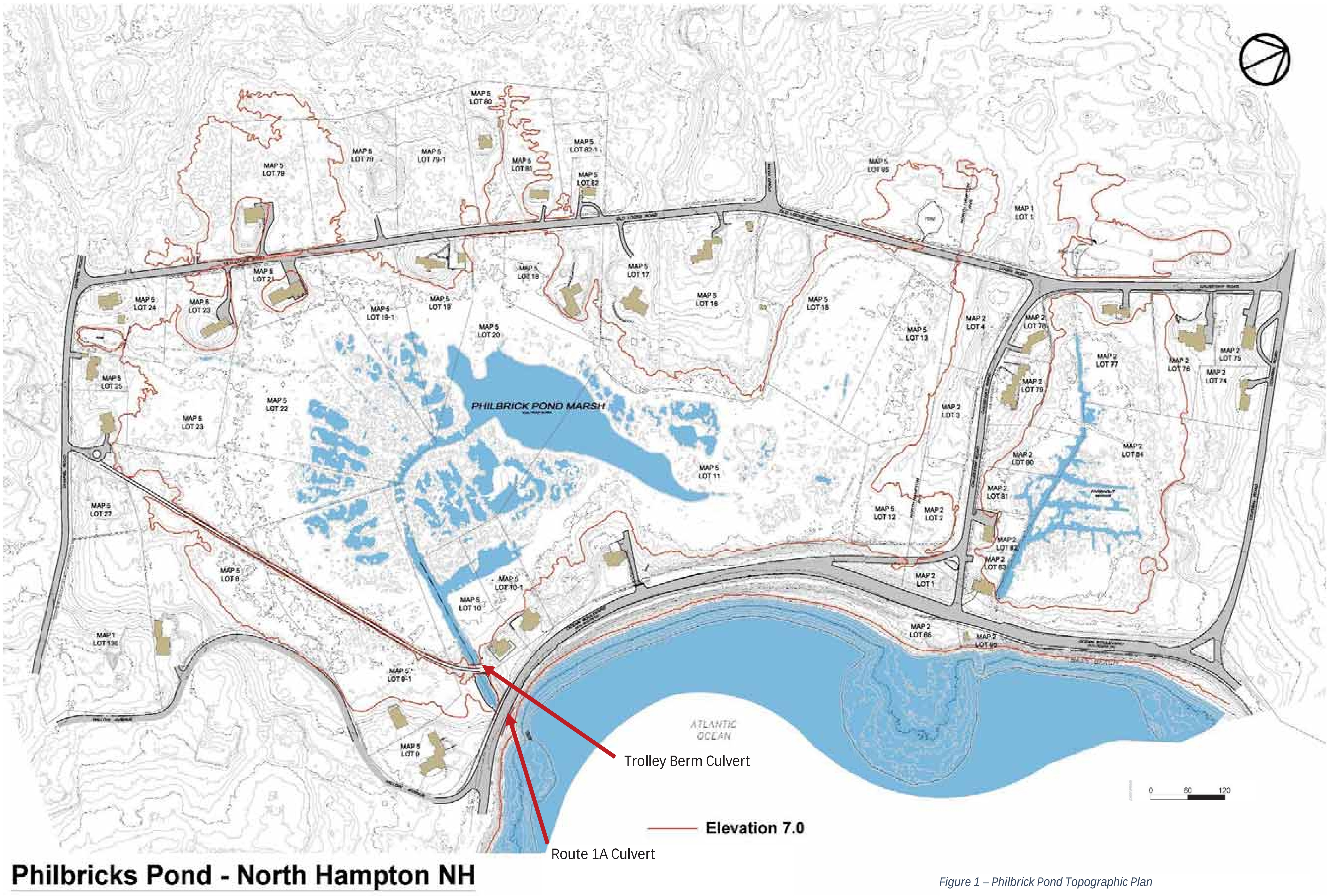
CMA Engineers used all of the survey information provided to prepare a base map, presented as **Figure 1** . This base map provides a one-foot contour map, detailed topography in the channels at the trolley berm, all sill and leachfield elevations, and property delineations based on Town of North Hampton tax maps. On this plan, the red line is Elevation 7.0, indicated as a “flood reference elevation” herein. This is the flood elevation in this drainage basin at which Old Locke Road to the west of Philbrick Pond floods and begins to be impassable to vehicles, and it is also the elevation above which the lowest basements, residential door sills and leachfields begin to be at risk. Throughout this report, the red line indicated on maps and graphs indicates this same Elevation 7, the flood level above which flood damage to properties and isolation of homes begins to occur. Water levels in Philbrick Pond below that red line generally do not pose risk to property or roadway access.

The survey information with spot elevations recorded at individual properties is presented in **Table 1**. Note that the lowest basement elevations are between 6.6 and 7.11 feet (five homes), and three septic leachfields are at elevation 6 and 7. These are subject to flooding when Philbrick Pond levels are at 7 or above, the “reference flood elevation” on the maps and graphs. The lowest first floor elevations are 8.1 and 9.4 feet. All other first floor elevations are well above flood levels under all circumstances evaluated herein. Roadway access to Old Locke Road, Pond Path and Bradley Lane begins to be limited at about elevation 7.

The invert elevations of the two culverts are significant factors. The invert elevation of the Route 1A culvert is 2.0. Typical high tide in the ocean is about 5.2 and typical low tide is about -4.2. The impact of that invert elevation is that water doesn’t begin to flow into Philbrick Pond until near the end of the rising tide cycle and at low tide, water levels in the pond can never be lower than a near-high tide elevation. This is further exacerbated by the presence of cobbles installed immediately upstream of the Route 1A culvert, with a bottom elevation of about 3. The cobbles are in the configuration of a "v-notch weir". This further limits the incoming tide to the very end of the tide cycle, and limits low tide elevations in Philbrick Pond as well. The 30 inch trolley berm culvert has invert elevations of 1.18 on the east side, and 1.11 on the west side. The effect of those elevations is that the trolley berm pipe is regularly full at low tide. The pipe is permanently submerged.

Table 1 Survey Information with Spot Elevations

Philbrick Pond Salt Marsh Drainage Evaluation			Property Elevations, Datum 1929 NGVD			
Map	**Lot**	**Street Address**	**Basement**	**Garage**	**First Floor**	**Septic Field**
2	78	44 Causeway Rd	9.9	13.9	14.5	11.6
2	79	60 Causeway Rd	8.7		17.7	10.2
2	82	70 Causeway Rd	7.8		11.4	6
2	83	2677 Ocean Boulevard	7.7	14.7	16.4	6
2	85	2680 Ocean Boulevard			15.31	
5	8	24 Willow Ave			12.5	
5	9	34 Willow Ave	8.6	16.9	17.3	7
5	10	88 Ocean Blvd	7.11		15.97	
5	10-1	90 Ocean Blvd	7.1		16.8	12.5
5	11	92 Ocean Blvd	10.5		18.7	17
5	15	31 Old Locke Rd	Access Denied			
5	16	29 Old Locke Rd	14.9	21.2	23.8	19.9
5	17	27 Old Locke Rd	8.8	14.8	17.4	14
5	18	23 Old Locke Rd	8	11.3	16.3	12.7
5	19	19 Old Locke Rd	7.8	8.7	15.6	13.1
5	21	9 Old Locke Rd		8.6	9.4	8.5
5	23	7 Old Locke Rd	6.6		14.7	11
5	24	21 Chapel Rd	9.9	9.5	8.1	11
5	25	19 Chapel Rd	6.9	10.6	15.1	12
5	26	15 Chapel Rd	7.6		16	12.6
5	78	8 Old Locke Rd	7.5		15.6	12.5
5	80	16 Old Locke Rd	9.55		13.3	12.9
5	81	18 Old Locke Rd	7.1		12.4	9.7
5	82	20 Old Locke Rd				10.5
5	9-1	34 Willow Ave			13.2	



Trolley Berm Culvert

Route 1A Culvert

Figure 1 – Philbrick Pond Topographic Plan

3. Culvert Assessments

Figure 2 1900 Vintage Trolley Berm Surface

Figure 2 shows a depression in the surface of the trolley berm that had led observers to believe that the vitrified clay pipe was partially crushed. An internal inspection of the pipe was needed to determine the nature of the blockage. Since the pipe was essentially fully submerged by seawater at all tide levels, TV inspection of the pipe condition was not possible. The pipe was inspected by tracing the crown and invert of the pipe, and the sides of the pipe at 90 and 180 degrees, using a 20 foot long fiberglass rod, accessed from both the upstream and downstream sides. **Figure 3** indicates the inspection method. As the rod traced up the pipe, each VC pipe joint could be "felt". There were no indications of any internal damage to the pipe, and there was no detritus in the bottom of the pipe, as substantial velocities occur in the pipe four times daily as tides go in and out. There is some limited damage to the bell of the pipe (see **Figure 4**) where cobbles have hit the top of the protruding pipe in the past, but these are limited to about an inch of damage in the top of the pipe. It was concluded that the 118 year old vitrified clay pipe is intact and functional. The surface depressions indicated in **Figure 2** have apparently been caused over the years by water flowing through the soil at high tide both on the incoming and outgoing tides. During and after the inspection, water was observed moving into the soil above the culvert pipe on the east side at high tide and exiting the berm through the soil on the west side. This movement of seawater through the soil has washed soil particles over the years, creating the observed depression. This will continue, and in the very long term, may result in re-establishment of a channel rather than a berm. The rate of soil erosion of the berm is likely to increase over time.

Figure 3 Testing the Trolley Berm Pipe

Accordingly, the initial objective of this investigation, to consider how to replace a partially crushed pipe, was determined not to be necessary. One alternative is that the trolley berm pipe can remain as is.

Figure 4 Chipped VC pipe, with voids over pipe

The Route 1A culvert required internal inspection in order to develop confidence in the hydraulic modeling of the system. The Ted Berry Company of Livermore, Maine was contracted to complete TV inspection of the 44 inch wide by 58 inch high box which transitions to a 4' diameter reinforced concrete pipe on the ocean side.

Figure 5

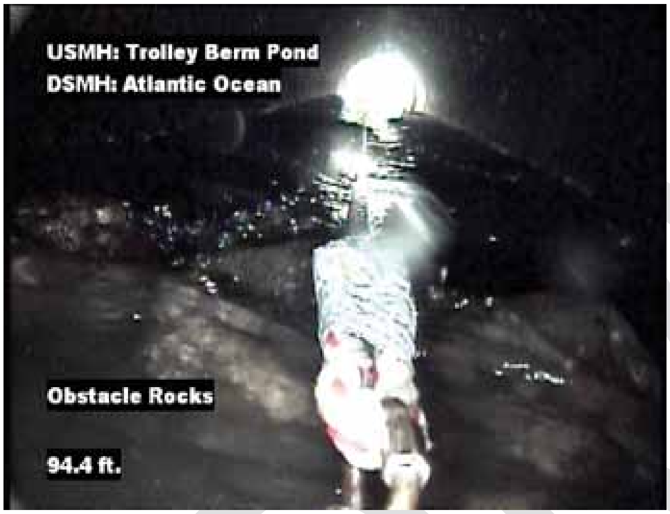


Figure 6

The summary inspection report is presented in Appendix B, and video logs have been provided to NH DOT Division 6 staff. The box section has a field stone side and concrete top.

The box section is about 47 feet long and was reported to be in fair condition (see **Figures 5 and 6**). There was one section of the concrete top that showed exposed and corroded reinforcing steel, coded as a defect that requires immediate attention. Otherwise, there were several cracks in the top, and indications of previous infiltration, but the box appeared to be fully functional with limited flow obstructions. The 4 foot diameter RCP pipe is 140 feet in length, in good condition with the exception of one joint separation about ten feet from the end of the pipe at the ocean discharge point. There were a number of “obstacle rocks” in the invert of the pipe in the manhole between the box and pipe sections, and in the invert of the pipe to the east of the transition. The nature of these flow obstructions was taken into account in the hydraulic modeling.

The full detail of the inspection records has been forwarded to NH DOT for their consideration of maintenance activities that may be necessary.

4. Hydrologic and Hydraulic Evaluation

4.1 Introduction

Gomez and Sullivan Engineers of Henniker, NH were subconsultants for the completion of the hydrologic and hydraulic analysis of Philbrick Pond. Their work is presented in a series of memoranda in Appendix C. The 118 pages of memoranda consist of the following:

Memorandum Date	**Topic**
C.1. September 29, 2017	Calibration Results
C.2. October 3, 2017	Existing Conditions Analysis
C.3. October 20, 2017	Alternative Conditions Analysis
C.4. October 30, 2017	Sea Level Rise Analysis under Existing Conditions
C.5. November 10, 2017	Sea Level Rise Analysis under Alternative Conditions

Each memorandum was prepared in sequence and reviewed in detail by Gomez and Sullivan and CMA Engineers, and modified as appropriate, prior to proceeding to the next set of modeling conditions. This is a complex, technical analysis. The reader has the choice of reviewing Appendix C in its full detail, reviewing the graphs included in the public presentation slides given at a neighborhood public meeting in December 2017, and included in Appendix D, and/or reading the following general summary of the analysis.

The hydrology and hydraulic analysis of Philbrick Pond was completed using the HEC-RAS modeling system. HEC-RAS is the US Army Corps of Engineers' "Hydrologic Engineering Center's River Analysis System", a standard computer model widely used for modeling river and stream flow in the US.

In all of the information to follow, the term "culvert pond" refers to the small body of water between the Route 1A culvert and the trolley berm culvert. The culvert pond elevations provided are not relevant to flooding conditions of properties around Philbrick Pond. The Philbrick Pond levels reported are the levels that would occur both on the west side of the trolley berm and in the full marsh system to and beyond Old Locke Road.

The tide levels used in this analysis are summarized in **Table 2** below. The ocean high tides used in the model are most relevant to note. Normal high tide is modeled as elevation 5.2, astronomical high tide is modeled as elevation 7.3 (this occurs periodically each year due to lunar influences), and the extreme storm surge condition (high tide with a storm with high northeasterly winds) as 9.2. The "100 year storm" was modeled using a 24 hour rainstorm of 9.06 inches as predicted by the Northeast Regional Climate Center's (NRCC) Extreme Precipitation Analysis. This assumes no significant prior precipitation. For comparison purposes, the 2006 "Mother's Day" storm may have resulted in slightly less rainfall in 24 hours in North Hampton, depending upon the data source used, but that storm had very significant precipitation in the days prior to the major event, such that the Mother's Day storm had an overall multi-day recurrence interval significantly greater than the 100 year storm. It is important to note that the "100 year storm" is the storm likely to recur once every hundred years based on the data recorded to date. The term describes the statistical likelihood of recurrence, but is not predictive of when this might occur. This storm might not recur for decades, or a much greater storm could occur in the very near future. The 100 year storm event is typically used for planning purposes.

Table 2: Tide Levels

Tide Scenario	Higher-High Tide	Lower-Low Tide	Basis
Observed	5.3	-3.5	-
Normal	5.2	-4.2	Historic Mean Higher-High and Lower-Low Water Levels
Astronomical	7.3	-6.3	Historic Highest and Lowest Observed Astronomical Tides
Extreme Storm Surge	9.2	-3.9	Higher-High Tide based on 100-Year Stillwater Elevation of Atlantic Ocean from Federal Emergency Management Agency's Flood Insurance Study for Rockingham County, NH. The Lower-Low Tide based on review of data at the Fort Point, NH gage during historical nor-easters.

4.2 Calibration

The first step in the process was to calibrate the model using continuously monitored water surface elevation data gathered for parts of June and July, 2017 (Appendix C.1). Water level loggers were installed on either side of the trolley berm. Using those two levels, and the tide levels reported for the mouth of Portsmouth Harbor, existing conditions as flow occurred through both pipes were monitored and compared with the output of the HEC-RAS model. The v-notch weir on the west side of the Route 1 A culvert was a particular challenge in calibrating the model. The determination was made that the best calibration results were obtained by using "weir coefficients" that were different between normal tide cycles and astronomical tide cycles when far more flow was entering and exiting the pond, diminishing the effect of the v-notch weir at these higher flows. With that modification, model runs reasonably matched observed conditions.

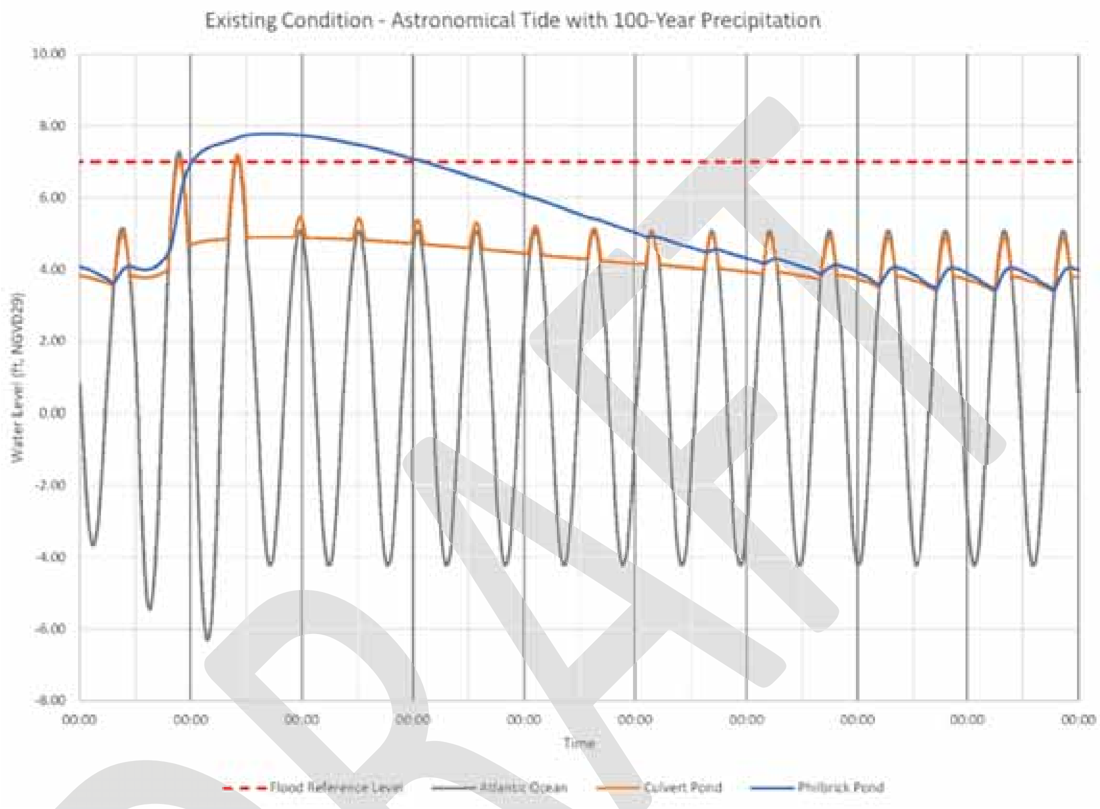
4.3 Existing Conditions

The next step was to evaluate existing conditions, with the 30 inch trolley berm culvert as is (Appendix C.2). **Figure 7** presents water levels under normal tidal cycles with existing conditions. The red line is elevation 7.0, where properties and roads begin to flood. The black lines are ocean tide levels. The brown line is the culvert pond elevation, and the blue line is the level in Philbrick Pond. That format will be the same for all graphs to follow. The significant point from this graph is the very limited daily tide variation in the level at Philbrick Pond. While typical tides are varying in the ocean by about 9 feet twice daily, the level in Philbrick Pond only varies by about 5 inches, from a typical high of 4.1 feet to a typical low of 3.7 feet. This is an unusual condition for a saltmarsh, as the level remains constantly within 5 inches of the high tide level.

Figure 7

The Philbrick Pond water level predicted by the model under existing conditions in the event of the 100 year storm event is indicated in **Figure 8**. Note that the Philbrick Pond level is above the red flood reference line. As occurred in the Mother's Day storm, this indicates Philbrick Pond would be at a maximum elevation of 7.8 and that the level would remain above the elevation 7 reference flood level for two days. This appears to be accurately modeling what occurred in the 2006 storm.

Figure 8



The flooding predicted to occur in the Philbrick Pond neighborhood in the 100 year storm is depicted in **Figure 9**. At the 7.8 level, some basements are subject to flooding, several septic leachfields are under water, but no first floors of houses are flooded. At this level, the primary impact of the flooding is the isolation of houses as Old Locke Road is flooded in several locations at a depth that is impassable to both personal and emergency vehicles. This isolates more than 40 homes for two plus days until water levels subside. That is what occurred in 2006, and that is what the model predicts. This situation will happen again in future major precipitation events, and will be exacerbated in the future by sea level rise.

Figure 10 presents the predicted Philbrick Pond level in the event of an extreme storm surge (nor'easter). Note that, under existing conditions (current sea levels, trolley berm pipe as is), the maximum level in Philbrick Pond is only 4.7, a level that does not threaten any properties in the neighborhood. Under current conditions, the flooding risk is solely from precipitation events, and not from ocean storms. Note that the culvert pond level in this circumstance is modeled as being quite high, in excess of elevation 8. However, there is insufficient time of high flow into the pond during a high tide cycle to raise the Philbrick Pond level higher than indicated in Figure 9. This phenomenon has been noticed by neighbors in recent ocean storm events.

Figure 9 – Flooding Extent Modeled during 100 Year Storm Event

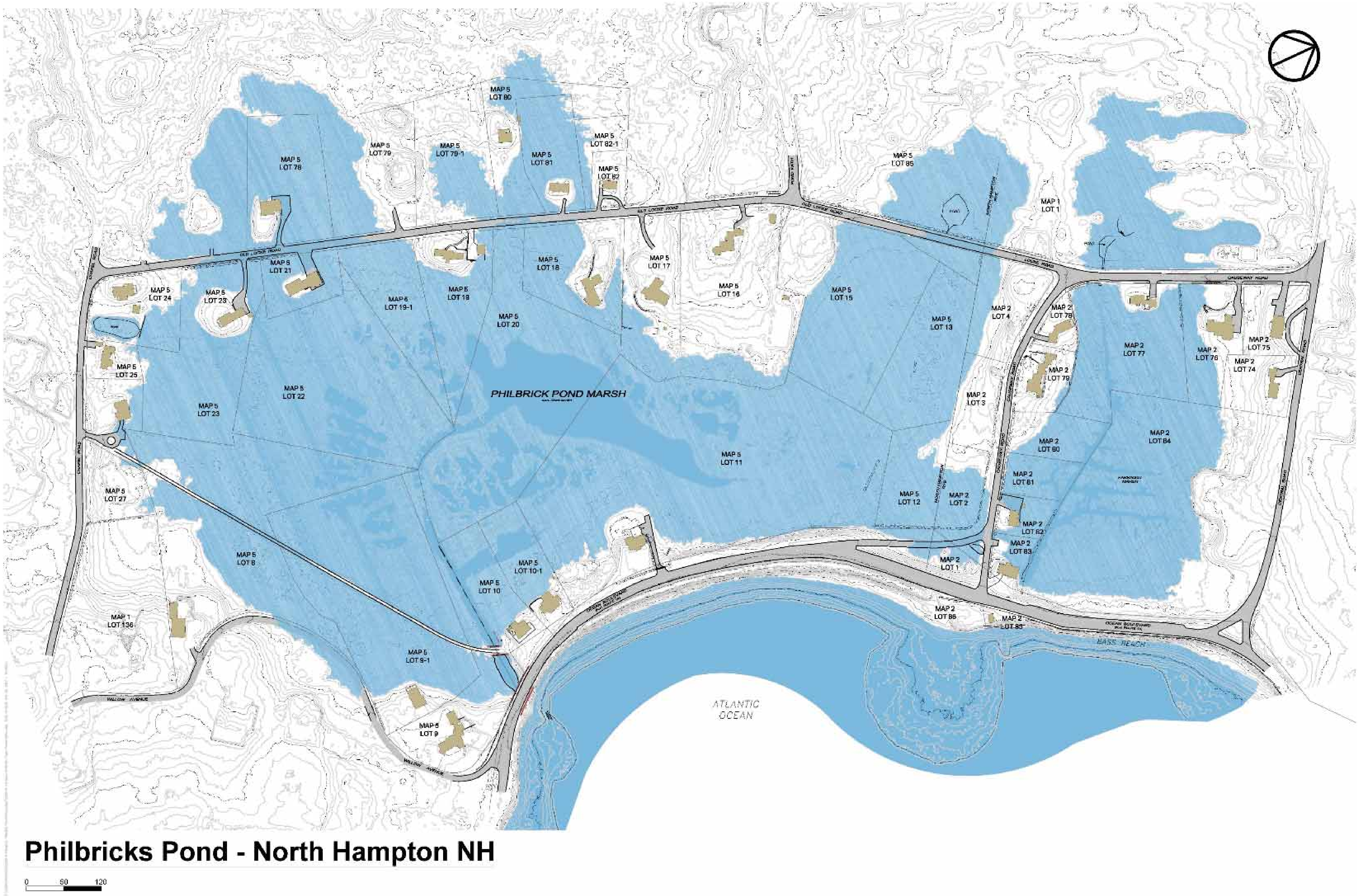


Figure 10

It should be noted that this investigation did not include the impact of wave height and overtopping of seawalls and “shale piles” on the ocean side of Ocean Boulevard. That occurs periodically now in major storm surges, and does introduce water, and rocks, across Ocean Boulevard. While that does introduce some ocean water to the Philbrick Pond watershed, it does not impact flood levels as evaluated herein. That is a topic that should be addressed separately, particularly in regard to future sea level rise scenarios.

4.4. Hydraulic Impact of Alternatives

Four alternatives were formulated and evaluated to investigate the impact of each alternative on Philbrick Pond water levels in the various events. The alternatives are characterized as follows:

Existing Conditions – Trolley berm pipe remains as is.

BOX – Replace the 30-inch diameter trolley berm pipe with a 30 inch high by 8 foot wide box to increase the outflow of water from Philbrick Pond in extreme precipitation events to help reduce flood levels.

SLAB – Replace the v-notch cobble weir at the entrance to the Route 1A culvert with a concrete slab at the culvert’s existing invert elevation to decrease water levels in Philbrick Pond at low tide, thus increasing daily tide variations in the pond and marsh system.

CHANNEL + SLAB – Remove the trolley berm in its entirety creating a continuous channel and replace the v-notch weir at the Route 1A culvert in order to both increase outflow of water from Philbrick Pond in extreme precipitation events and to decrease water levels in Philbrick Pond at low tide.

Each of these four alternatives were evaluated for normal daily tides, the 100 year precipitation event and extreme storm surges. Rather than reproduce many graphs in the body of this report, Table 3 presents the Philbrick Pond elevations, both max and min, for each of the alternatives, for each of the three weather events. Significant observations from Table 3 are presented below. In Table 3, and subsequent tables, elevations that result in the flooding of Old Locke Road and some basements and septic leachfields are shown in red.

Table 3 Philbrick Pond Water Levels with Alternatives – Existing Sea Level

Alternative	Normal Daily Tides		100 Year Precipitation		Extreme Storm Surge	
	Max	Min	Max	Min	Max	Min
Existing Pipe	4.1	3.7	7.8	4.0	5.2	4.4
BOX	4.2	3.7	7.2	4.0	6.0	4.8
SLAB	4.1	2.8	7.7	3.8	5.2	4.3
CHANNEL/SLAB	4.2	2.8	7.1	3.9	6.1	4.9

1. The impact on daily high tides in Philbrick Pond of the alternatives is similar. The slab has no impact. Constructing the BOX and CHANNEL each increases daily high tides by 0.1 feet.
2. The daily low tide level in Philbrick Pond is decreased by 0.9 feet by installing the slab and by the same 0.9 feet, by installing the slab and removing the trolley berm. Daily Philbrick Pond tide variations increase from the current 0.5 feet, by installing the slab, to 1.3 feet, and, by installing the channel and slab, to 1.4 feet. This compares to the current variation of only 0.4 feet.
3. In the 100 year precipitation event, the slab has no impact over existing conditions, and Old Locke Road floods to an elevation of 7.7. Installing a box or the channel reduces flood levels by about 0.5 feet, but Old Locke Road still floods, although the road flooding is to a lesser depth and the duration of flooding is for less than a day, rather than for several days with existing conditions.
4. Under extreme storm surge conditions, at current sea levels, the water level in Philbrick Pond with the installation of a box or the channel rises about 0.5 feet higher than existing conditions, although the resulting water levels, at 5.2 and 5.3 feet respectively are well below flood elevations that affect properties.
5. All alternatives evaluated result in flooding of Old Locke Road in a 100 year precipitation event, although increasing flow capacity at the trolley berm reduces both the magnitude and duration of flooding.

4.5. Effect of Sea Level Rise on Hydraulics of Alternatives

It is clear that sea level has risen in recent decades, and that it continues to rise. What is not clear, and is subject to debate and wide ranges of prediction, is the magnitude and rate of increase of future sea level rise. For this analysis the projections were used as presented in the New Hampshire Coastal Risk and Hazards Commission (NHCRHC) report entitled “Preparing New Hampshire for Projected Storm Surge, Sea Level Rise and Extreme Precipitation”, dated November 2016. These ranges were projected as indicated in Table 4.

Table 4. Assumptions of Ranges of Future Sea Level Rise

Scenario	Rise (ft)
Current	-
2050 Moderate	+1.3
2050 Highest	+2.0
2100 Moderate	+3.9
2100 Highest	+6.9

These ranges are based on a variety of assumptions, and the projections are subject to potential significant changes in the future based on additional data and further research.

The model results for the "existing conditions" of retaining the existing 30 inch diameter culvert at the trolley berm for the various sea level rise assumptions are presented in Table 5. In the 2050 ranges, normal high tides will continue to rise, the 100 year precipitation event water levels will rise by several inches, and storm surges will result in Philbrick Pond water levels of 6.0 to 6.5 feet, nearing the point at which some property and road flooding may occur due to ocean storms. The wider ranges for the 2100 projection, some 70 years in the future, predict that normal high tides would flood properties and roadways, within the range of the two projections. Flooding during the 100 year precipitation event would be substantially higher, and extreme storm surge events would flood roadways and properties.

Table 5. Hydraulic Impact of Sea Level Rise with Existing Trolley Berm Pipe on Philbrick Pond Water Levels – High Tides

Sea Level Scenario	Normal High Tide	100 Year Precipitation	Extreme Storm Surge
Current	4.1	7.8	5.2
2050 Moderate, +1.3 feet	4.5	8.0	6.0
2050 Highest, +2.0 feet	4.8	8.2	6.5
2100 Moderate, +3.9 feet	6.0	8.8	7.9
2100 Highest, +6.6 feet	8.5	10.3	10.3

The impacts of the sea level rise ranges on Philbrick Pond water levels for the three alternatives, (SLAB, BOX and CHANNEL) are summarized in Tables 6, 7 and 8. For these alternatives, the 2050 highest sea level rise scenario was not modeled because the results were so similar to the 2050 moderate projection.

Table 6 shows similar high tide data if only the v-notch weir at the Route 1A culvert is replaced by a slab, thus reducing low tide levels and increasing outgoing flow on each tide cycle. Comparing Table 6 to the Philbrick Pond tide levels in Table 5 indicates that the numbers are all virtually the same, except for a slight reduction in the 100 year precipitation event. Replacing the cobble v-notch weir with a slab has a slight positive impact on high tides (the pond drains slightly better at low tide after major rain events) and does not increase high tide levels in Philbrick Pond under any of the scenarios. The hydraulic benefit of the SLAB alternative is that it lowers low tide, as discussed later in this report.

Table 6. Hydraulic Impact of Sea Level Rise with existing pipe at Trolley Berm and SLAB at Route 1A Culvert on Philbrick Pond Water Levels – High Tides

Sea Level Scenario	Normal High Tide	100 Year Precipitation	Extreme Storm Surge
Current	4.1	7.7	5.2
2050 Moderate, +1.3 feet	4.4	8.0	5.9
2100 Moderate, +3.9 feet	6.0	8.8	7.9
2100 Highest, +6.6 feet	8.5	10.3	10.3

Table 7 indicates that replacing the 30 inch diameter trolley berm pipe with a box culvert decreases current and near term flooding in the 100 year precipitation event by 0.3 to 0.6 feet, but flooding of properties and roadways continues to occur to a lesser level and for a shorter period of time. With sea level rise, flood levels are higher during storm surges, creating flooding events from ocean surges at some point after 2050, based on the current sea level rise projections.

Table 7. Hydraulic Impact of Sea Level Rise with BOX at Trolley Berm on Philbrick Pond Water Levels – High Tides

Sea Level Scenario	Normal High Tide	100 Year Precipitation	Extreme Storm Surge
Current	4.2	7.2	6.0
02050 Moderate, +1.3 feet	4.8	7.7	6.7
2100 Moderate, +3.9 feet	6.3	8.7	8.2
2100 Highest, +6.6 feet	8.2	10.2	10.1

Table 8 presents the projected Philbrick Pond water levels with the complete removal of the trolley berm (CHANNEL) and the replacement of the v-notch weir at the Route 1A culvert with a concrete slab (SLAB). Comparing the projected water levels in Table 8 with Table 7 indicates that the CHANNEL results in very similar pond high tide levels to the BOX alternative, improved by 0.1 feet in several circumstances. Old Locke Road still floods in a 100 year storm event, but to a lesser depth and for a shorter period of time. As with the SLAB discussion, the CHANNEL + SLAB alternative has a much more dramatic hydraulic impact on low tides in Philbrick Pond than on high tides.

Table 8. Hydraulic Impact of Sea Level Rise with removal of Trolley Berm (CHANNEL) and installation of SLAB on Philbrick Pond Water Levels – High Tides

Sea Level Scenario	Normal High Tide	100 Year Precipitation	Extreme Storm Surge
Current	4.2	7.1	6.1
2050 Moderate, +1.3 feet	4.8	7.6	6.8
2100 Moderate, +3.9 feet	6.3	8.7	8.3
2100 Highest, +6.6 feet	8.0	10.1	10.0

In the long run, with the ranges of sea level rise projected for 2100, all alternatives evaluated result in significant flooding of homes and roads. The normal high tides and the extreme storm surge flooding events could be effectively controlled by the installation of a tide gate that is activated, and lowered, only in the event of astronomical high tides and/or extreme storm surge events. The 100 year precipitation event, in combination with long term sea level rise would be more challenging to resolve, likely requiring a major pumping facility to remove water from Philbrick Pond after major rain events.

It should be noted that all of the hydraulic analyses presented in this report exclude the impact of water overtopping seawalls on the ocean side of Ocean Boulevard. The analysis of the seawalls with respect to current function and sea level rise was beyond the scope of this report. This is an issue that will need to be addressed in the future, under a separate evaluation.

4.6 Hydraulic Impacts of Alternatives and Sea Level Rise on Diurnal Tide Fluctuations

The charts and tables presented above pertain to predictions of high tide levels in Philbrick Pond. The parameter that is more important with respect to Philbrick Pond marsh health is the twice daily, diurnal variation of water levels in the pond and saltmarsh. The level in the ocean varies twice daily by about 9 feet typically, while the level in Philbrick Pond under existing hydraulic conditions is typically 4.1 feet at high tide and 3.7 feet at low tide, a diurnal variation of only about 5 inches. Marsh health could be substantially improved if this diurnal variation was increased significantly, resulting in less submergence of the marsh system.

With existing sea levels, the typical high and low tide projections for the four alternatives are presented in Table 9. The removal of the cobble v-notch weir and installation of a concrete SLAB at elevation 2.0 increases the daily tidal variation from a modeled 4.8 inches to 15.6 inches, a very significant improvement. In addition to the SLAB, removing the trolley berm and creating a CHANNEL only adds an additional 1.2 inches to the daily water level fluctuation.

Table 9. Diurnal Philbrick Pond Variation with Existing Pipe at Trolley Berm and

Existing Sea Level

Alternative	Philbrick Pond		Diurnal Tide Variation (feet/inches)
	High Tide	Low Tide	
Existing Trolley Berm Pipe	4.1	3.7	0.4 feet (4.8 inches)
SLAB	4.1	2.8	1.3 feet (15.6 inches)
BOX	4.2	3.7	0.5 feet (6 inches)
CHANNEL + SLAB	4.2	2.8	1.4 feet (16.8 inches)

5. Wetlands Evaluation

Dr. David M. Burdick of the Jackson Estuarine Laboratory of the University of New Hampshire oversaw the 2017 evaluation of the Philbrick Pond saltmarsh. His report is presented in Appendix D, with its tables, **Figure**s and references. The wetlands report is summarized below.

Philbrick Pond is a lagoon type estuary that formed landward of barrier beach spits in North Hampton, NH. Its inlet was stabilized and restricted by the road that is now Route 1A or Ocean Boulevard. Water flow from the Gulf of Maine passes through a culvert running under Route 1A and into a small waterway and is further restricted as it runs through a clay pipe under an old trolley berm. The lagoon is characterized as a 29 acre tidal marsh. The overall drainage basin surrounding Philbrick Pond is small, comprising about 680 acres, or a little more than one square mile.

The goal of the project is to evaluate the condition and hydrology of the two restrictions recognizing the conflicting needs for improved drainage from upstream flooding and limiting tidal flooding associated with extreme (i.e., storm surge) and normal flooding events due to sea level rise. The tidal marsh itself is a resource held in the public trust and therefore should be protected from any negative impacts associated with current conditions or predicted impacts due to future alternatives that may be chosen by the Town and its residents. Ditching of the marsh in the mid twentieth century rerouted drainage paths (e.g. Chapel Brook) and has resulted in large areas of vegetation loss between ditches in the past 60 years, as first reported by Short in 1984.

Philbrick Pond was identified as having inadequate tidal exchange to support healthy marsh by the Soil Conservation Service in 1994 and this agency suggested both culverts needed to be replaced (SCS 1994). Current observations and modeling shows the large culvert under Route 1A does not impede water flow as much as the existing 30-inch culvert under the trolley berm. This round clay culvert constrains flow into the marsh during normal tidal fluctuations, and the restricted hydrology likely has negative impacts on salt marsh health (Burdick and Roman 2012). During the extreme "Mother's Day" storm in 2006, flow limitations due to the culvert exacerbated flood impacts to homes surrounding the marsh due to flow limitations on outgoing tides. The existing clay pipe also limits flow and flood levels into the marsh during storm surge conditions. If it is to be replaced, this trolley berm culvert needs an appropriately configured opening that optimally minimizes flood damage from both extreme precipitation events and storm surges, and that also improves marsh health through improved daily tidal inundation and draining.

The objectives of this report on the tidal marsh are threefold: 1) to evaluate the health of the tidal marsh by comparing existing and new data in Philbrick Pond with conditions found in the Little River tidal marsh just to the south; 2) characterize the relative benefits to the tidal marsh for the hydraulic alternatives evaluated by the hydrologic modeling; and 3) recommend management actions to restore marsh health using small scale drainage improvements (also known as runneling).

5.1 Methods

Philbrick Pond Marsh and Little River Marsh were both assessed as part of the Coastal Program's salt marsh monitoring program at the turn of the century, which involved collections of species composition and abundance of salt marsh plants along transects running from major tidal creeks to the upland edge at randomized locations. Using positions documented in the original database, we re-occupied four transects in each of the two marshes, and collected data in August from 0.5 m2 plots at 1, 10, 50 meters and every 50 meters thereafter up to 200 meters. After 200 meters, 50 or 100 meter intervals were used to obtain seven plots per transect. This resulted in 29 plots at PP (**Figure 11**) and 28 at LR (**Figure 12**).

Figure 11 Stations along four transects in Philbrick Pond sampled in 2017.
(Figure 2 in Appendix E David M. Burdick, Chris Peter and Gregg E. Moore Wetlands Report)

Figure 12 Stations along four transects in Little River Marsh Pond sampled in 2017.
(Figure 3 in Appendix E David M. Burdick, Chris Peter and Gregg E. Moore Wetlands Report)

In addition to the vegetation, plot elevations were determined by real time kinematic geographic positioning system and soil pore water was collected using sippers. Pore water salinity and chemical redox potential were measured in the field, whereas pH and sulfides (Cline 1969) were measured at the laboratory.

Data was entered into Excel spreadsheets and analyzed using analysis of variance and covariance, with Tukey's post hoc test for significant effects).

5.2 Results of Surveys (wetland evaluation)

Both marshes had severe tidal restrictions, with LR restored to 75% of potential tidal range in 2000 (Chmura et al. 2012) but the tidal restriction at PP Marsh remains to date. The elevation of the marsh surface was found to be higher at Little River (1.21 meters above NAVD) compared to PP (0.95 m) – a difference of about 10 inches (Table 10). Even when unvegetated pools were removed from the data, PP was 8 inches lower in elevation and the difference was highly significant.

Pore water salinity averaged 30 ppt, almost the strength of seawater, in Philbrick Pond Marsh (Table 1). In comparison, Little River Marsh was about 32 ppt, the typical value for seawater in the Gulf of Maine. The difference in salinity between the two marshes was not statistically significant. Both marsh soils showed fairly neutral pH values, about 6.6 pH.

Redox potential, or Eh, is a measure of the ability of the soil constituents to accept electrons produced during chemical reactions. Eh ranges from fully oxidized (+700 millivolts) to severely reduced (-400 mV), with oxygen disappearing at about +400 mV. The chemical reduction of the soils was much more severe at PP (-305 mV) than LR (-119 mV), indicating more stressful conditions for life. Similarly, the plant toxin H_2S was 4-fold greater at PP (Table 1). Both the Eh and sulfide concentration showed significant differences between the two sites, with PP having stress levels indicative of greater flooding and impaired drainage.

Lower elevations, impeded drainage and more stressful conditions were reflected in the vegetation of Philbrick Pond Marsh. In 2017 we found typical salt marsh plants (halophytes: *Spartina alterniflora*, *S. patens*, and others) covering about 55% of the plots and 40% bare sediment or dead grasses (**Figure 4**). Plant cover was similar to the original survey in 2002, with slightly less *S. patens* (salt hay). In 1984 Dr. Short interpreted the large unvegetated areas still seen today as: "an area of dead saltwater hay (*Spartina patens*) covered by a thick mat of blue green algae."

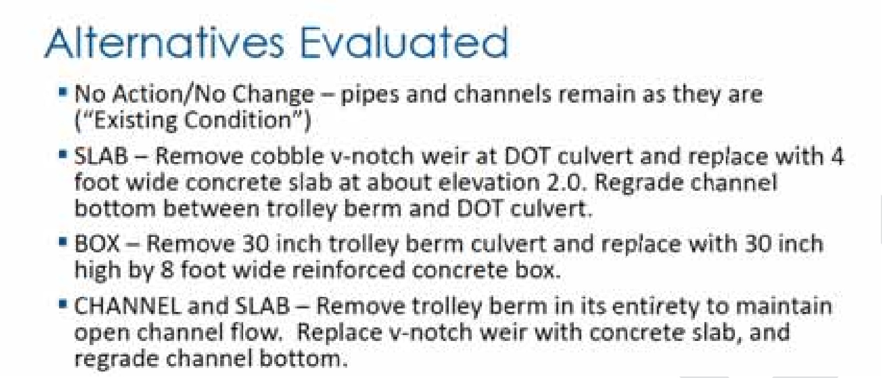
In comparison, Little River Marsh showed a dramatic recovery from the large tidal restoration completed in 2000, based on data from 2003 and 2005 in addition to 2017 (**Figure 11**). Dead plants and bare ground were dominant at 60% cover in 2003, but decreased to 20% cover in 2017 while *S. patens* and *S. alterniflora* both increased, contributing to a total of 76% halophyte cover in 2017. With Little River now largely restored (Chmura et al. 2012) it can serve as a reference marsh to compare conditions in Philbrick Pond Marsh.

In 2017, our reference site at Little River was dominated by salt hay (38%) but also had a variety of other halophytes summing to 21% cover **(Figure 12)**. In wetter areas tall cordgrass was found and contributed 17% cover. Only 20% cover was dead and bare and 2% cover of invasive species, notably *Phragmites australis* (common reed). In sharp contrast, Philbrick Pond Marsh showed 40% dead and bare, likely due to stressful conditions, and almost twice as much *S. alterniflora*, which is better adapted to the more stressful inundated conditions.

In summary, the lower elevations of Philbrick Pond marsh and impeded drainage has led to lower Eh and greater sulfides, all of which stress the vegetation and favor cordgrass over salt hay and other marsh plants typical of New Hampshire marshes. Many areas between ditches are too stressful for vegetation since extensive ditching 60 years ago and pools have replaced large portions of the vegetated marsh.

5.3 Evaluation of Alternatives with respect to potential impacts to salt marsh

Several management alternatives were examined using hydrologic modeling for present day conditions and several sea level rise scenarios (see inset). They were chosen to capture the range of options for hydrologic management of the system to reduce flooding for residents and preserve the functions and values of the natural resources of the system.



Alternatives Evaluated

- No Action/No Change – pipes and channels remain as they are ("Existing Condition")
- SLAB – Remove cobble v-notch weir at DOT culvert and replace with 4 foot wide concrete slab at about elevation 2.0. Regrade channel bottom between trolley berm and DOT culvert.
- BOX – Remove 30 inch trolley berm culvert and replace with 30 inch high by 8 foot wide reinforced concrete box.
- CHANNEL and SLAB – Remove trolley berm in its entirety to maintain open channel flow. Replace v-notch weir with concrete slab, and regrade channel bottom.

Under the NO ACTION alternative, the Philbrick Pond Marsh will continue on its path to complete degradation. The very small tides allow only a few inches of drainage every tide, leaving stagnant waters and stressful soil conditions that plants have difficulty surviving. With only intermittent flooding and no sediment sources, the marsh cannot perform its function of building through accretion and peat formation and so becomes lower relative to sea level as sea level rises.

Under the second alternative, SLAB, improved drainage is expected, leading to better growing conditions and a healthier marsh. Removal of the cobble V-notch weir and channel re-grading will allow waters that are currently trapped behind the weir to drain, increase the typical tidal range from less than 6 inches to about 15 inches (see **Table 3**). Plant productivity and cover is likely to increase following implementation of this alternative. However, the flooding and sediment marshes need to build will still not be carried into the marsh under this alternative and the marsh will likely continue on its path to degradation once sea levels rise substantially (1-2 feet). This alternative will likely have no impact on flooding due to significant rainfall or storm surge events.

BOX is the third alternative, which is limited to replacing the trolley berm pipe with a box culvert alone (no replacement of V-notch weir with slab). Modeling indicates this alternative would not change the tidal flooding or drainage significantly compared to current conditions. The cross-sectional area of tidal exchange would increase from 5 to 20 square feet at the trolley berm, but the V-notch weir and shallow area in the channel would limit normal tides to existing conditions. The BOX alternative therefore, would be unlikely to increase the functions and values of the salt marsh.

The fourth alternative, CHANNEL AND SLAB would result in unrestricted tides from the landward side of Route 1A throughout the marsh. The culvert under Route 1A would still partially restrict the full range of tides. This solution would increase the tidal range to 1.4 feet (inches). Removing the trolley berm in its entirety and removing the v-notch weir at the Route 1-A culvert would lower typical low tides by 0.9 feet from current levels and increase typical high tides by 0.1 feet. Flooding associated with significant rainfall events would be substantially reduced but not eliminated, and storm surges under assumed ranges of sea level rise would result in flooding conditions for homes and roads after 2050. Under current sea level conditions Philbrick Pond water levels during astronomical high tides would increase by about one foot. The greater flooding and flushing would likely bring substantial improvements to the healt of the marsh.

5.4 Recommendations for marsh restoration activities beyond culvert replacement

Important changes in the hydrology of Philbrick Pond Marsh occurred when natural drainages were replaced by ditches (sometime in the late 1950s according to USGS topographic maps). Hydrologic changes have led to impaired drainage and ponding, with loss of vegetation in areas surrounded by ditches. Since the turn of the last century, rising sea levels combined with altered hydrology, specifically old ditch systems, has led to patterns of vegetation loss in Rhode Island and Massachusetts salt marshes similar to those found at Philbrick Pond (Raposa et al. 2015). The loss of vegetation from the large impounded areas was reported by Dr. Short in 1984 and has slowly continued to the present, as indicated by our quantitative vegetation survey.

Vegetation loss could be reversed, but only if tidal drainage is increased for the system. If culvert or channel improvements are implemented for Philbrick Pond, additional steps could be taken to reverse the pattern of marsh loss caused by impoundments associated with the old ditches. The increased drainage predicted from the hydraulic models would justify establishing a small program to partially drain the impounded (ponded) areas between ditches using shallow drainage paths called runnels. Runnels are shallow drainages cut through unnatural impediments to drainage that drain the top six inches of sediment, but do not drain the peat deeply, which has led to loss of marsh elevation elsewhere (Burdick et al. 2017). Runnels have been used in Rhode Island, where low tidal ranges and rising sea levels have alarmed managers and the public (Ardito 2014; http://seagrant.gso.uri.edu/elevating-drowning-salt-marshes/). Runnels have also been tried in the Great Marsh of Massachusetts with documented success in reversing the expansion of the impoundments (Burdick et al. 2017).

Currently, there are over 20 impounded ponds in the southern portion of the marsh, 10 in the center and another 20 in the northern section representing a significant opportunity to enhance restoration benefits. Several of these impounded areas could be drained and monitored to track plant response to the increased drainage above and beyond the increased drainage from the hydrologic improvements to the system. The addition of runneling to a restoration program for Philbrick Pond Marsh represents a relatively low-cost strategy to enhance the benefits of restored hydrology. Futhermore, such a strategy is aligned with several current funding opportunities for developing innovative approaches to increasing coastal resilience in the State.(e.g., NHDES Coastal Resilience Grant).

5.5 Effect of Marsh Impoundments on Mosquito Breeding

The Town of North Hampton contracts with the firm Dragon Mosquito Control, Inc. of Brentwood, NH for monitoring and control of mosquitoes. Sarah McGregor of that firm reported that the impoundments in the Philbrick Pond marsh contain mosquito larvae and are treated regularly to control the propagation of mosquitoes. If runnels were installed to drain the berms adjacent to ditches, the effect of such an effort should be coordinated with monitoring to confirm effectiveness with respect to habitat for mosquito larvae. Installing runnels could serve a dual purpose of helping to re-establish marsh vegetation and better facilitating the control of mosquito populations.

6. Development and Evaluation of Alternatives

Conceptual designs and cost estimates were developed for two drainage improvements, and for two potential access improvements. Concept drawings and cost estimates are included in Appendix D. Each of these alternatives are discussed in the following sections.

6.1 Route 1A Culvert Inlet Improvements (SLAB)

This simple project at modest cost has the effect of increasing the daily tide level variation in the 29 acre Philbrick Pond saltmarsh from the current 5 inches to about 15 inches, with associated improvements to the marsh environment. The construction project would involve blocking both the Route 1A and trolley berm culverts for a short construction period, dewatering the culvert pond, removing existing cobbles at the entrance to the Route 1A box culvert, installing base materials, pouring a four-foot wide concrete slab extending the existing box culvert invert into the culvert pond, and placing cobbles in side slopes for erosion control. The project would also need to include dredging the existing "high bottom", presumed to be of unconsolidated sediments in the culvert pond between the two culverts. The high bottom is shown on Figure 9. This is simple "dredging" and can likely be accomplished with a land based excavator and in less than a day. Borings should be completed in design to confirm the base materials below the slab, and a test excavation should be completed to confirm the characteristics of the material to be dredged (i.e. the absence of ledge).

In similar drainage projects, NHDES typically prefers a natural bottom, of bottom muds or cobbles, to a concrete slab. This culvert entrance could be constructed of cobbles, however, even the ripples created by flow over cobbles would permanently increase low tide water levels in the 29 acres of marsh behind the culvert. A flat culvert entrance would best accomplish the environmental objectives of this improvement.

The project would require subsurface investigations, wetlands permitting, the preparation of final design, and opportunity for public input. In order for the project to proceed, the concurrence of two private property owners is required, as the State of New Hampshire right-of-way appears to be close to the existing culvert inlet and access to the site for construction work will require approval of the two property owners.

The project has an estimated cost of $60,000, as indicated in Appendix E.

We recommend that this be an NH DOT project, in cooperation with NH DES and the NH Coastal Program.

Following completion of the construction, monitoring of the culvert pond is recommended to assure that the "high bottom" does not re-form, limiting the low tide benefits of the improvement. The existing "high bottom" is formed due to both the water elevation at the v-notch weir, and the swirling of water entering and exiting the 30 inch trolley berm pipe which has a lower invert elevation at elevation 1.18.

6.2 Tide Gate Installation/Trolley Berm Removal

In the long term, a tide gate will be required to be installed at the inlet side of the Route 1A culvert, if sea level rise projections beyond those currently predicted for the year 2050 are experienced. This would need to be a tide gate that provides no head loss in the normal run of tide, but that can be lowered only in the event of an astronomical high tide, or an extreme ocean storm surge that threatens to flood homes and roads. A motor operated, remotely activated, rectangular, corrosion resistant tide gate would accomplish these objectives. It would be exercised periodically, but deployed only in extreme tide and/or weather events. The tide gate might be automatically actuated when the Portsmouth Harbor tide level exceeds a pre-set elevation, using multiple control systems. Such a tide gate would permanently provide effective control of tidal/ocean surge flooding. It should be noted that the hydraulic models presented herein do not predict the need for such a tide gate until sometime after the projected 2050 sea level rise ranges are exceeded.

At the time such a tide gate is installed, if the two property owners were in agreement, the trolley berm could be removed, re-establishing the original channel.

This combined project is the best engineering solution to the set of flooding and environmental issues at this location. It would result in a significant decrease in flood levels affecting properties and roads from major precipitation events, the tide gate would control flooding from the other direction from astronomical high tides and storm surges, and the diurnal Philbrick Pond water level variation would be maximized. However, in the 100 year storm, or greater, Old Locke Road would still flood.

Removing the trolley berm has been, and remains, highly controversial locally, and at least one of the two trolley berm property owners remains opposed as of this date to removal or other major modifications to the trolley berm.

If implemented, this would also most appropriately be an NH DOT project in cooperation with NH DES and the NH Coastal Program. As indicated in Appendix D, it has an estimated capital cost of $ 225,000 in 2018 dollars (See Appendix E).

6.3 Emergency Access Improvements

Under existing conditions, with the 30-inch trolley berm pipe in place, flooding of Old Locke Road in the event of the 100 year storm can be expected to occur, with a water depth sufficient to preclude emergency or personal vehicular passage, and for a duration of two days or more. This isolates more than 40 homes for the duration of the flooding, including ambulance, police, fire and personal vehicle access and egress. From a policy perspective, the Town of North Hampton should decide whether that magnitude and duration of isolation is acceptable from a public safety standpoint. CMA Engineers has briefly evaluated two means of providing permanent access in a flood event for both emergency and personal vehicles.

It should be noted that providing emergency access to the 40+ homes on Old Locke Road, Pond Path and Bradley Lane is necessary, regardless of the measures taken for drainage improvements evaluated herein. Even if a tide gate was installed at Ocean Boulevard, and the trolley berm was removed in the future as described above, Old Locke Road would still flood in the 100 year storm to a lesser extent, and the flood level would increase in the future with sea level rise, not with respect to storm surge events, but in the event of a 100 year precipitation event.

6.3.1 Gravel Emergency Access Road from Bradley Lane to Woodland Road

One alternative is to construct an emergency gravel access road, normally gated, to allow flood related emergency vehicular access from Bradley Lane to Woodland Road. The road would be about 1,000 feet in length, would traverse current woodlands, and would require wetlands permits to fill wooded wetlands. If this alternative is chosen, the gravel road might be constructed at a width sufficient for two cars to pass so that emergency access and egress could be provided for personal vehicles as well as public safety vehicles.

With respect to property acquisition, this alternative is challenging. It would require that the Town of North Hampton acquire rights of way from at least five different private property owners. A right of way from one of two Bradley Lane homeowners would be required. The road would then traverse three narrow lots, each of which has a house with limited frontage on Woodland Road. The road would then cross, in some fashion, a 6+ acre undeveloped lot to reach Woodland Road. Initial discussions with the six potential private property owners might yield an indication as to whether or not acquisition of these rights of way is potentially feasible. Five of the six property owners would need to be amenable.

A conceptual drawing of this alternative is presented in Appendix E. The project has an approximate estimated cost of $240,000, although land acquisition costs are indeterminate. The gravel road could be constructed at about half the width evaluated, at lesser cost, if it was solely for the use of emergency vehicles in the event of a flood event.

At the November 30, 2017 public meeting on this project, a North Hampton town resident indicated that there is a "grandfathered" access of some sort for fishermen to access the coast from Woodland Road to what is now Bradley Lane, described to be in the same location evaluated herein. The resident indicated that this access is used periodically at present. This informal grandfathered access might merit investigation by the Town staff.

If rights of way were reasonably attainable, this option would be effective in resolving the isolation of the neighborhood at a lesser cost to the Town of North Hampton in comparison to the cost of raising Old Locke Road.

6.3.2 Raising Old Locke Road

Raising Old Locke Road by up to three feet for a length of about 500 feet at the North Hampton/Rye Town line would provide permanent access for emergency and personal vehicles. This would require removal of existing pavement, placing and compacting of fill ranging in depth from about 3 feet tapering to 0 on each end, installing sub-base materials, and providing new pavement. A box culvert would be required at the low point. Guard rails would be required at the culvert location.

Sizing of the new culvert would require detailed calculations and balancing of the interests of property owners on both sides. On a project of this type, design procedures typically strive to maintain the same capacity to move the same flow of water after the project is completed so that the upstream property owner does not experience additional flooding. Downstream property owners have the right to expect that drainage improvements do not introduce greater peak event flows as a result of the project that damage their downstream property. In this instance, in the peak 100 year storm event, there is more than a foot of water flowing over Old Locke Road. The size of the proposed culvert indicated in Appendix D is a placeholder, as these calculations needed to balance the rights of the various property owners have not been prepared under this scope. This issue would need to be addressed properly if this alternative were to proceed to a design phase.

This project would be controversial. An abutter to the project site has recently indicated to the Town that this concept is unacceptable.

Cooperation of the Town of Rye would be required, as some of the construction would need to occur in Rye at the northern end of the road reconstruction.

A concept sketch of the project and a cost estimate is presented in Appendix E. The project has an estimated cost of about $475,000.

6.4 Other Emergency Access Options

Consideration was given to raising Old Locke Road on the southern side of Philbrick Pond, nearer Chapel Road. This was not evaluated in detail because a three foot grade increase would be required over 1,000 feet in length, and the new increased road grade would be inconsistent with the elevation of numerous driveways at lower elevations. From a variety of perspectives, this would not be preferable to the above alternative at the North Hampton/Rye Town line.

Consideration was also given to emergency vehicle use of an existing Aquarion watermain right of way from Pond Path to the end of Fairway Drive in Rye. However, a gravel road in this location would pass close to existing yards in North Hampton, the project would require a significant wetlands permit, and permission of Aquarion, the Town of Rye and the residents of Fairway Drive in Rye would need to be sought.

If all of the access alternatives outlined above are determined by the Town to be unfeasible or undesirable, the Town of North Hampton might consider discussing emergency access alternatives with the Abenaqui Country Club. With limited construction, it is possible that Abenaqui may be able to provide emergency access to Pond Path for an ambulance or a police vehicle in the event of a flood on existing cart paths that are largely high and dry even in the event of the 100 year storm. This would require cooperation of the Town and Abenaqui.

6.5 Flooding of Abenaqui Golf Course

In addition to the flooding of the Abenaqui golf course in the rare event of a 100 year storm, several holes of the golf course have been flooded during rainstorms in the last several years with a total rainfall of about 2 inches or more. This has resulted in closing of golf holes for days at a time after annual rainfall events. This flooding is not due specifically to the water level in the full Philbrick Pond marsh system. We believe that the limited drainage is due to conditions immediately downstream of the outlet of the Town's culvert under Old Locke Road. Very dense wetlands vegetation on private property parcels downstream of the pipe outlet constrain the flow of water, resulting in ponding within the golf course on the west side of Old Locke Road. Improving this drainage flow would require a channel to be cut through one of two privately owned wetlands parcels on the east side of Old Locke Road. The Town has worked with Abenaqui Country Club during the course of this project to clean the drainage pipe and assure that the outlet is unobstructed. This has not however limited the golf course flooding experienced. Creating a channel through the wetlands to improve drainage flow would require property owner approval and a significant wetlands permit.

Abenaqui has options available to raise cart paths and make alterations to tee locations to allow the golf course to function in the event of these annual storms.

In the long run, with sea level rise, low lying areas of the golf course in the vicinity of Old Locke Road will require substantial fill in order to remain above water levels and playable in all climatic events. The water levels predicted herein with future sea level rise should be reviewed by Abenaqui and a long range plan should be formulated to assure long term viability of the low-lying holes of the course in the vicinity of Old Locke Road.

6.6 Broader Implications of Sea Level Rise for the Town of North Hampton

If the sea level rise predictions beyond 2050 are realized, there are other significant challenges that will need to be addressed in North Hampton. NH DOT will need to evaluate Ocean Boulevard with respect to the adequacy of seawalls and road elevations, likely necessitating major improvements and capital investments. The Town of North Hampton will also need to evaluate and prioritize needs to raise other local roads to assure access for emergency vehicles and residents for local roads lower than elevations subject to flooding either from extreme precipitation or storm surge events. The need, eventually, at Philbrick Pond to raise Old Locke Road by three feet, and/or to install a relatively simple tide gate for emergency use, are minimal requirements compared to what will be required in other New Hampshire coastal areas where public infrastructure and residences are substantially more at risk than is the case at Philbrick Pond. Municipalities throughout the eastern seaboard are just beginning to plan for prioritized infrastructure improvements, the magnitude of which, at local, state and national levels, will be very substantial. In North Hampton, evaluation, planning and implementation of coastal infrastructure improvements will be necessary in the coming decades by the State of New Hampshire and the Town of North Hampton.

7. Public Participation

Two public meetings have been held to which Philbrick Pond abutters were invited. The first meeting held in June, 2017 provided a description of the scope of the investigation, prior to beginning of field work on this project. Residents in attendance participated in a free-ranging discussion of flooding problems experienced and concerns regarding their properties.

The second public meeting was held in January 2017. The PowerPoint presentation provided in Appendix F was made and discussed by those in attendance. This was a wide-ranging discussion of many facets of the problem and potential solutions. A summary of the questions/comments and the responses is included in Appendix F.

A third public meeting, at a North Hampton Board of Selectmen meeting, is scheduled for early June to discuss the evaluation of alternatives and the recommendations of this report.

8. Recommendations

8.1

The NH Department of Transportation and the NH Department of Environmental Services and its NH Coastal Program should consider proceeding with modifications to the inlet of the Route 1A Ocean Boulevard culvert to remove the existing cobble V-notch weir and install a concrete slab inlet to the existing culvert, with associated required dredging of a small quantity of sediment in the existing culvert pond. Agreement of the two private property owners should be sought and obtained.

8.2

With respect to emergency flood event access to Old Locke Road, Pond Path and Bradley Lane, North Hampton Town staff should consider having preliminary discussions with property owners in the vicinity of Bradley Lane and Woodland Road, with property owners adjacent to the north end of Old Locke Road, and with Abenaqui Country Club to report back to the Board of Selectmen on whether one of those alternatives should be pursued further by the Town to provide, at a minimum, emergency vehicle access to the isolated homes in the event of a flood. If one of the public access improvements is selected, the Town should contact FEMA to pursue potential grant funding for design and construction of those improvements.

8.3

The Town of North Hampton, its Conservation Commission, and the New Hampshire Coastal Program should consider a pilot program to install runnels at saltmarsh impoundments with the dual purpose of improving marsh vegetation and limiting mosquito propagation. Funding sources for such improvements should be sought. Any work in the marsh will require specific approval of the private property owner, as all of the marsh and pond areas are privately owned.

8.4

In the future, as the NH Department of Transportation considers improvements to Ocean Boulevard, its seawalls, and its drainage structures, consideration should be given to:

a. evaluating the adequacy of existing structural and rock pile seawalls in view of on-going storm experiences and future sea level rise, and;

b: when significant improvements to the Route 1A culvert are anticipated in the future: 1. consider lowering the invert elevation of the conduit on the west inlet in order to maximize diurnal tide level variations in Philbrick Pond; 2. consider increasing the culvert sizes to facilitate flow out of the pond after major precipitation events; 3. consider installation of a tide gate to be remotely activated and operated only in extreme storm surge events or astronomical high tides, and; 4. consider removal of the trolley berm, if property owner permission can be obtained. Fully resolving the flood risk to properties and maximizing marsh health would require the installation of a tide gate, the removal of the trolley berm, and the reconstruction of the Route 1A culvert at a lower elevation and with a larger opening size. Evaluating the hydraulics of replacing the Route 1A culvert was beyond the scope of this investigation and would need to be completed if such a replacement is contemplated in the future.

Appendix A

Survey

NOTES:

1. THIS PLAN IS BASED ON A FIELD SURVEY 6/30/2017 & 8/14/2017 BY JAMES VERRA AND ASSOC., INC.
2. HORIZONTAL DATUM: NAD 1983 (1986 ADJUSTMENT)
   HORIZONTAL BM: NHDOT 345–0220
   VERTICAL DATUM: NGVD 1929
   VERTICAL BM: NHDOT 397–0490
3. ENGINEER OR CONTRACTOR TO VERIFY SITE BENCHMARKS BY LEVELING BETWEEN 2 BENCHMARKS PRIOR TO THE SETTING OR ESTABLISHMENT OF ANY GRADES/ELEVATIONS. DISCREPANCIES ARE TO BE REPORTED TO JAMES VERRA AND ASSOC., INC.
4. THE LOCATION OF ALL UNDERGROUND UTILITIES SHOWN HEREON ARE APPROXIMATE AND ARE BASED UPON THE FIELD LOCATION OF ALL VISIBLE STRUCTURES (IE CATCH BASINS, MANHOLES, WATER GATES ETC.) AND INFORMATION COMPILED FROM PLANS PROVIDED BY UTILITY COMPANIES AND GOVERNMENTAL AGENCIES. ALL CONTRACTORS SHOULD NOTIFY, IN WRITING, SAID AGENCIES PRIOR TO ANY EXCAVATION WORK AND CALL DIG–SAFE @ 1–888–DIG–SAFE.
5. NO WETLANDS DELINEATION PERFORMED.
6. THE ROW SHOWN HEREON AS DASHED LINES IS BASED ON REFERENCE PLAN 3. RESEARCH AT THE RCRD AND NHDOT INDICATES THAT NO ROW WAS GRANTED TO THE STATE OF NH TO THE LAND BETWEEN THE TRAVELLED WAY OF OCEAN BOULEVARD AND SAID DASHED LINES.
7. DECREASE NGVD 1929 ELEVATIONS 0.781' TO CONVERT TO NAVD 1988 DATUM.

REFERENCE PLANS:

1. SURVEY COMPILATION PLAN, "PHILBRICK POND" – NORTH HAMPTON, N.H. AND "BASS BEACH" – RYE, N.H., FOR N.H. OFFICE OF STATE PLANNING, DATED 9/9/2002, PLAN NO. 21511, BY JAMES VERRA AND ASSOCIATES, INC., NOT RECORDED.
2. PLAT OF LAND, 88 OCEAN BOULEVARD, NORTH HAMPTON, N.H., FOR FRANCIS H. EARTHROWL, JR., DATED 9/21/1998, PLAN NO. 20935, BY JAMES VERRA AND ASSOCIATES, INC, NOT RECORDED.
3. STATE OF N.H. HIGHWAY DEPARTMENT, OCEAN BOULEVARD, TOWNS OF RYE, NORTH HAMPTON AND HAMPTON, COUNTY OF ROCKINGHAM, FILE# 31228, SHEETS 12 & 13, ON FILE AT NHDOT, CONCORD, N.H.

OWNERS OF RECORD

5–9
MICHAEL FALZONE
LAURA J HARPER FALZONE
34 WILLOW AVE
NO HAMPTON, NH 03862
3796/822

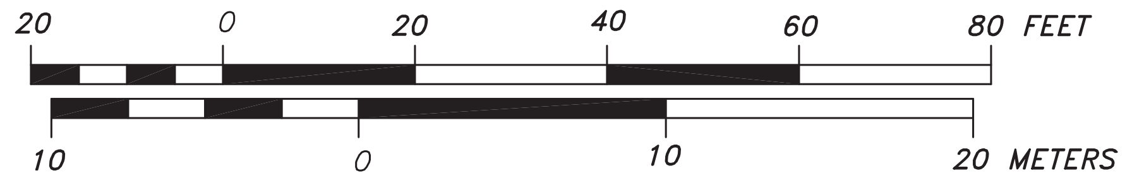
5–9–1 (32 WILLOW AVE)
MICHAEL FALZONE
LAURA J HARPER FALZONE
34 WILLOW AVE
NO HAMPTON, NH 03862
3818/2727

5–10 (88 OCEAN BLVD)
EARTHROWL FAMILY LTD PARTENRSHIP (44% INTEREST)
935 BEACON ST
NEWTON, MA 02459
4215/180

RUTH S. EARTHROWL, TRUSTEE (56% INTEREST)
FRANCIS H. EARTHROWL, JR FAMILY TRUST
935 BEACON ST
NEWTON, MA 02459
4191/2020

LEGEND:

110–5	TAX SHEET – LOT NUMBER
RCRD	ROCKINGHAM COUNTY REGISTRY OF DEEDS
EOP	EDGE OF PAVEMENT
RWM	MORTARED RETAINING WALL
RWS	STONE RETAINING WALL
▯	REFLECTOR
—o—	SIGN
▦	CATCH BASIN
⌒⌒⌒	TREE LINE/BRUSH LINE
—D—	DRAIN LINE
▨	CEMENT CONCRETE
⊠	RETAINING WALL
LA	LANDSCAPED AREA
ROW	RIGHT OF WAY
×12.5	SPOT GRADE



STATE OF NEW HAMPSHIRE
LICENSED LAND SURVEYOR
No. 625
JAMES VERRA
SIGNATURE

REV. NO.	DATE	DESCRIPTION	APPR'D
1	9/6/2017	ADD TOPOGRAPHIC INFORMATION FOR EARTHROWL PARCEL & REVISE TBM ELEVATIONS	JV

LIMITED TOPOGRAPHIC PLAN
OCEAN BOULEVARD
N.H. ROUTE 1–A
NORTH HAMPTON, NEW HAMPSHIRE
for CMA ENGINEERS, INC.

JAMES VERRA and ASSOCIATES, INC.
101 SHATTUCK WAY
SUITE 8
NEWINGTON, N.H. 03801–7876
603–436–3557

JCS
PROJECT MGR

JCS
DRAWN BY

DATE:	7/14/2017
JOB NO:	21511–A
SCALE:	1" = 20'
DWG NAME:	21511–A
PLAN NO:	21511–A
SHEET:	1 OF 1

Appendix B

Culvert Inspection

File 1028

Ted Berry Co. Inc.
521 Federal Road
Livermore, Maine 04253
Office: 207-897-3348 Fax: 207-897-3627
www.tedberrycompany.com

TED BERRY
COMPANY Inc.

CMA Engineers
Philbrick's/Trolley Berm
Ocean Blvd Culvert Inspection

Project Manager – Charlie Roberts
Field Supervisor – James S. Knowles III

SAFETY FOR ALL OF US
TED BERRY
Co. INC

PACP
NASSCO

i.t. pipes

TED BERRY

Ted Berry Company
521 Federal Rd
Livermore Maine 04253
207-897-3348

Project Summary

ect Name: CMA Engineers

US MH	DS MH	Pipe ID	Date	Street	Material	Size	Total	Insp
Trolley Berm Pond	Atlantic Ocean		8/31/2017	Ocean Blvd	Other	44	140.2	140.2
Trolley Berm Pond	Atlantic Ocean		8/31/2017	Ocean Blvd	Other	44	140.2	47.1

Pipe Size: 44 **Total Ln.:** 140.2 **Inspected Ln.:** 187.3

Project Total Ln.: 140.2 **Project Inspected Ln.:** 187.3

TED BERRY

Ted Berry Company
521 Federal Rd
Livermore Maine 04253
207-897-3348

Defect Listing Plot with Images

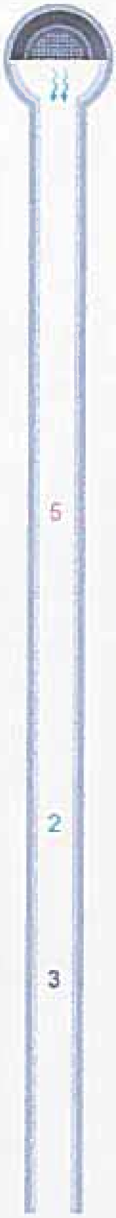
Customer CMA Engineers		City North Hampton	Street Ocean Blvd	Date 20170831
Surveyed By James_Knowles_III	Certificate Number U-912-16283	Work Order M-17-00597	Location Code Other	Weather Dry
Pre-Cleaning No Pre-Cleaning	Purpose of Survey Routine Assessment		Media label 1	Number of ...

Time: 12:52

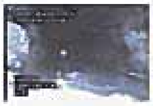
Year Laid		Upstream MH Trolley Berm Pond	Downstream MH Atlantic Ocean
Sewer Use	Other		
Length surveyed	47.1	Material Other	Shape Rectangular

Pipe Segment Refere...	Flow Control Not Controlled	Direction Downstream	Height 58	Width 44
Remarks Condition Assessment			US Rim to Invert	DS Rim to Invert

Trolley Berm Pond



0.0 ft. End of Pipe



Trolley Berm Pond

0.0 ft. Water Level

4.2 ft. Surface Reinforcement Corroded Chemical

13.9 ft. General Observation

Field Stone Side & Concrete Top

17.8 ft. Fracture Circumferential

28.1 ft. Obstacle Rocks

34.3 ft. Infiltration Stain

Defect Listing Plot with Images

Customer	City	Street	Date	Time
CMA Engineers	North Hampton	Ocean Blvd	20170831	12:52
Surveyed By	Certificate Number	Work Order	Location Code	Weather
James_Knowles_III	U-912-16283	M-17-00597	Other	Dry
Pre-Cleaning	Purpose of Survey		Media label	Number of ...
No Pre-Cleaning	Routine Assessment		1	

Year Laid		Upstream MH		Downstream MH
Sewer Use	Other	Trolley Berm Pond		Atlantic Ocean
Length surveyed	47.1	Material		Shape
		Other		Rectangular
Pipe Segment Refere...	Flow Control	Direction	Height	Width
	Not Controlled	Downstream	58	44
Remarks			US Rim to Invert	DS Rim to Invert
Condition Assessment				

42.2 ft. Obstacle Rocks

45.0 ft. General Observation

RCP Transition

47.1 ft. Survey Abandoned

Lost Video Reversal

Ted Berry Company
521 Federal Rd
Livermore Maine 04253
207-897-3348

PACP Conditions

Customer		City	Street	Date	Time
CMA Engineers		North Hampton	Ocean Blvd	20170831	12:52
Surveyed By	Certificate Number	Work Order	Location Code	Weather	
James_Knowles_III	U-912-16283	M-17-00597	Other	Dry	
Pre-Cleaning	Purpose of Survey		Media label	Number of ...	
No Pre-Cleaning	Routine Assessment		1		

Year Laid		Upstream MH		Downstream MH
		Trolley Berm Pond		Atlantic Ocean
Sewer Use	Other	Material		Shape
Length surveyed	47.1	Other		Rectangular
Pipe Segment Refere...	Flow Control	Direction	Height	Width
	Not Controlled	Downstream	58	44
Remarks			US Rim to Invert	DS Rim to Invert
Condition Assessment				

Normal Defects	Structural Ratings			O & M Ratings			Combined Ratings		
	Grade Rating	No. Occur.	Rating	Grade Rating	No. Occur.	Rating	Grade Rating	No. Occur.	Rating
	1	0	0	1	0	0	1	0	0
	2	1	2	2	0	0	2	1	2
	3	0	0	3	2	6	3	2	6
	4	0	0	4	0	0	4	0	0
	5	1	5	5	0	0	5	1	5
Continuous Defects									
	Subtotals	2		Subtotals	2		Subtotals	4	
SUMMARY	Pipe Rating	7		Pipe Rating	6		Overall Pipe Rating	13	
	Structural Index	3.5		O&M Index	3.0		Overall Index	3.3	
	Str. Quick Rating	5121		O&M Quick Rating	3200		Ovrl. Quick Rating	5132	

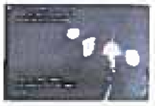
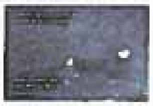
Code	ID	Length

Ted Berry Company
521 Federal Rd
Livermore Maine 04253
207-897-3348

Defect Listing Plot with Images

Customer	CMA Engineers
City	North Hampton
Street	Ocean Blvd
Date	20170831
Time	14:28
Surveyed By	James_Knowles_III
Certificate Number	U-912-16283
Work Order	M-17-00597
Location Code	Other
Weather	Dry
Pre-Cleaning	No Pre-Cleaning
Purpose of Survey	Routine Assessment
Media label	1
Number of ...	
Year Laid	
Sewer Use	Other
Length surveyed	140.2
Upstream MH	Trolley Berm Pond
Downstream MH	Atlantic Ocean
Material	Other
Shape	Rectangular
Pipe Segment Refere...	
Flow Control	Not Controlled
Direction	Downstream
Height	58
Width	44
Remarks	Resumed At RCP Connection
US Rim to Invert	
DS Rim to Invert	


Trolley Berm Pond

0.0 ft.	End of Pipe			Resumed at RCP Transition
0.0 ft.	Water Level			
0.0 ft.	General Observation			REsumed At RCP transition
82.8 ft.	Obstacle Rocks		3	
94.4 ft.	Obstacle Rocks		3	
130.6 ft.	Joint Separated Large		2	
130.6 ft.	General Observation			Last Stick of Pipe

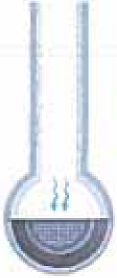
Defect Listing Plot with Images

Customer	City	Street	Date	Time
CMA Engineers	North Hampton	Ocean Blvd	20170831	14:28
Surveyed By	Certificate Number	Work Order	Location Code	Weather
James_Knowles_III	U-912-16283	M-17-00597	Other	Dry
Pre-Cleaning	Purpose of Survey		Media label	Number of ...
No Pre-Cleaning	Routine Assessment		1	

Year Laid		Upstream MH	Downstream MH	
		Trolley Berm Pond	Atlantic Ocean	
Sewer Use	Other	Material	Shape	
Length surveyed	140.2	Other	Rectangular	
Pipe Segment Refere...	Flow Control	Direction	Height	Width
	Not Controlled	Downstream	58	44
Remarks			US Rim to Invert	DS Rim to Invert
Resumed At RCP Connection				

140.2 ft. Discharge Point

Atlantic Ocean



Atlantic Ocean

PACP Conditions

Customer CMA Engineers		City North Hampton	Street Ocean Blvd	Date 20170831	Time 14:28
Surveyed By James_Knowles_III	Certificate Number U-912-16283	Work Order M-17-00597	Location Code Other	Weather Dry	
Pre-Cleaning No Pre-Cleaning	Purpose of Survey Routine Assessment		Media label 1		Number of ...

Year Laid		Upstream MH Trolley Berm Pond		Downstream MH Atlantic Ocean	
Sewer Use	Other				
Length surveyed	140.2	Material Other		Shape Rectangular	
Pipe Segment Refere...	Flow Control Not Controlled	Direction Downstream	Height 58	Width 44	
Remarks Resumed At RCP Connection			US Rim to Invert	DS Rim to Invert	

	Structural Ratings			O & M Ratings			Combined Ratings		
Normal Defects	Grade Rating	No. Occur.	Rating	Grade Rating	No. Occur.	Rating	Grade Rating	No. Occur.	Rating
	1	0	0	1	0	0	1	0	0
	2	1	2	2	0	0	2	1	2
	3	0	0	3	2	6	3	2	6
	4	0	0	4	0	0	4	0	0
	5	0	0	5	0	0	5	0	0
	Subtotals	1		Subtotals	2		Subtotals	3	
SUMMARY	Pipe Rating Structural Index Str. Quick Rating	2 2.0 2100		Pipe Rating O&M Index O&M Quick Rating	6 3.0 3200		Overall Pipe Rating Overall Index Ovrl. Quick Rating	8 2.7 3221	

Continuous Defects

Code	ID	Length

Appendix C

Gomez and Sullivan Final Memos

GOMEZ AND SULLIVAN
ENGINEERS

PO Box 2179
Henniker, NH 03424
T. (603) 428 - 4960
(513) 560 - 9715 (Kevin)

MEMO

To: Craig Musselman (CMA)

From: Kevin Miller, Rick Stewart, and John Hart (Gomez and Sullivan)

Date: September 29, 2017

Re: Philbrick Pond – Calibration Results

Background

In North Hampton, culverts passing under a berm for a former trolley line and State Route 1A, transfer flow between the Philbrick Pond Marsh and the Atlantic Ocean. A small pond (i.e. termed the culvert pond for the purposes of this memo) exists between the downstream end of the trolley berm culvert and the upstream end of the Route 1A culvert. Gomez and Sullivan has been tasked with evaluating the hydraulics of these culverts under existing conditions and potential future alternatives. Each condition is to be evaluated under various combinations of tidal and hydrologic scenarios including future sea level rise considerations.

Model Development

A LiDAR derived DEM was supplemented with bathymetric and topographic survey of the channel approaching the trolley berm culvert, and the culvert pond. A majority of the Philbrick Pond Marsh was modeled using a storage area, while cross sections were developed for the channel approaching the culvert pond. The DEM only provides above-water information, thus the stage-volume rating curve for the Philbrick Pond storage area had to be estimated for elevations below elevation 3.25 feet[1]. It was assumed that no storage was available below elevation 2.0 feet (i.e. approximately the lowest elevation at the Route 1A culvert, and storage between 2.0 and 3.25 feet was estimated through linear interpolation. The culverts were modeled based on the field survey. The culvert parameters are further discussed in the Calibration section of this memo, particularly the entrance condition to the Route 1A culvert which required the introduction of an inline structure (i.e. weir) into the model.

Manning's roughness values were estimated for the cross sections based on aerial imagery, and ineffective flow areas were assigned as appropriate in each cross section. Some interpolated cross sections were created to improve model stability. A lateral structure was introduced to transfer flow over the trolley berm to model flow which bypasses the culvert to downstream cross sections due to high water surface elevations in the Philbrick Pond. Although the lateral structure is unnecessary for the calibration runs, it is expected to play a role during some production runs, particularly the runs evaluating a precipitation event.

---

[1] All elevation in this memo refer to the National Geodetic Vertical Datum of 1929 (NGVD29). The conversion from the North American Vertical Datum of 1988 (NAVD88) used for this project was generally +0.781 feet (i.e. NGVD29 = NAVD88 + 0.781). However, the conversion used for data obtained from the NOAA station at Fort Pointe, NH utilized a conversion factor of +0.768 feet (i.e. NGVD29 = NAVD88 + 0.768).

Calibration

Water level loggers were installed upstream and downstream of the trolley berm culvert during most of June and July of 2017. These water levels were used during calibration by comparing these observations to the simulated model results in the Philbrick Pond storage area and the culvert pond (i.e. as represented by cross section 556). Tidal data from the NOAA station located at Fort Pointe, NH (Station ID: 8423898) was collected to be utilized as the downstream boundary condition during calibration. Additionally, to remove a possible calibration variable, daily precipitation data from the NOAA station at North Hampton, NH (GHCN ID: USC00276070) was utilized to identify time periods when significant inflow to Philbrick Pond was not expected. The upstream boundary condition during calibration utilized a constant baseflow of 1.4 cfs, based on a common assumption of 2 cfs per square mile (mi^2) for the 0.7 mi^2 drainage basin[2]. The model was found to be somewhat sensitive to the baseflow, however there is currently no basis for the use of a different value[3]. Calibration was primarily performed using data from the period Noon on June 8, 2017 through Midnight on June 17, 2017. Additional verification was performed by evaluating two periods (i.e. Noon on July 3, 2017 through Midnight on July 7, 2017 and Noon on July 20, 2017 through Midnight on July 23, 2017) without changing any calibrated parameters.

During calibration, the Manning's roughness used for the culverts was found to have little impact on model results. As such, a normal value was utilized for the vitrified clay pipe through the trolley berm (i.e. 0.014), and a high value was used for the Route 1A culvert (i.e. 0.02)[4]. While various other variables within the HEC-RAS culvert methodology were evaluated for the Route 1A culvert (e.g. FHWA chart and scales, blockage on culvert bottom), none of these methods came close to matching the water level in the culvert pond. Joseph F. Marrone published his Master's Thesis in December 1990, which includes an analysis of the hydraulics at the Route 1A culvert. The thesis posits that flow out of the culvert pond is not controlled by the Route 1A culvert but by a contraction and change in elevation six feet to the marsh side of the culvert, which acts like a weir causing a critical flow condition at this location. The thesis goes on to suggest that this constriction is most nearly triangular in nature and develops the following equation for flow:

$$Q = 6.5*h_w^{2.5}$$

Where,

- h_w is the head above the "weir" crest[5]

While HEC-RAS allows the user to define a rating curve at a cross section, this is only used for steady flow applications, and is ignored for unsteady runs such as those utilized in this calibration and the pending production runs. Therefore, the best option for implementing the constriction upstream of the Route 1A culvert is with a weir (i.e. inline structure). The HEC-RAS assumes that h_w is raised to the 1.5 power for all weirs. While HEC-RAS allows the user to define a rating curve at a weir, which could be based on a formula not raised to the 1.5 power, these rating curves do not consider tailwater effects and thus do not appropriately account for backwater during high tide. Since HEC-RAS does not allow for the weir coefficient to depend on h_w, there is no way to implement the exact flow estimation proposed by the thesis within HEC-RAS. Thus, the calibrated weir coefficient may not be completely valid for flow conditions outside those evaluated during calibration. However, it is suspected that this error does not apply for higher discharges as the hydraulic control is expected to move from the weir to the culvert. This transition is

---

[2] Drainage area obtained from the United States Geological Survey (USGS) StreamStats webtool.

[3] While the USGS provides various streamflow estimates for ungauged basins in New Hampshire, including seasonal flow duration statistics, the drainage area for this basin (0.7 mi^2) falls outside of the suggested range for these computations (i.e. 3.26 to 689 mi^2).

[4] The value of 0.02 is based on the maximum values of a concrete culvert with an unfinished, rough wooden form, since the upstream section of the culvert has stone sides and an occasional stone blockage on the bottom.

[5] The weir crest elevation is reported as 2.69 feet in the thesis. It is assumed that this elevation refers to NGVD29, as no datum is specified and NAVD88 was not established until 1991.

expected to occur for free flow culvert discharges in excess of approximately 34 cfs for the calibrated weir coefficient (i.e. 1.75)[6]. As a reference, the peak culvert flows during calibration are approximately 16 cfs.

Results

The average error for all three time periods evaluated during calibration is less than 0.1 feet, with the maximum error of each time period being less than 0.5 feet. Figures 1 through 3 provide a time series comparison of the observed and simulated water levels. While some features in each time period could likely be match better, the common set of parameters used in all three time periods does a relatively good job of matching water levels at each location for each time period. Of particular note is the discrepancy in water levels for Philbrick Pond seen in Figure 3. This is likely because of the higher water levels in the culvert pond compared to the other two calibration periods (i.e. lows around 4 rather than 3.5 feet). A sensitivity was performed which identified better results using a weir coefficient of 2.6 (i.e. rather than 1.75). Figures 4 through 6, show that despite better results for the third calibration period, they are worse for the other runs, particularly the first period. Since HEC-RAS is limited to a single weir coefficient, we should decide on what that coefficient should be used for the existing conditions runs. The normal high and low tidal scenario will be similar to the first calibration period, while the astronomical tidal range will be similar to the third calibration period, and the extreme tidal range will be wider than the third calibration period (i.e. approximately the same magnitude difference as the astronomical tides are from the normal high and low tides. As such it is proposed that a weir coefficient of 1.75 be used for the normal tide scenario, but a weir coefficient of 2.6 be used for the other two scenarios.

---

[6] The formula provided in the thesis suggests the transition of hydraulic control from the weir to the Route 1A culvert would occur for flows in excess of approximately 54.5 cfs.

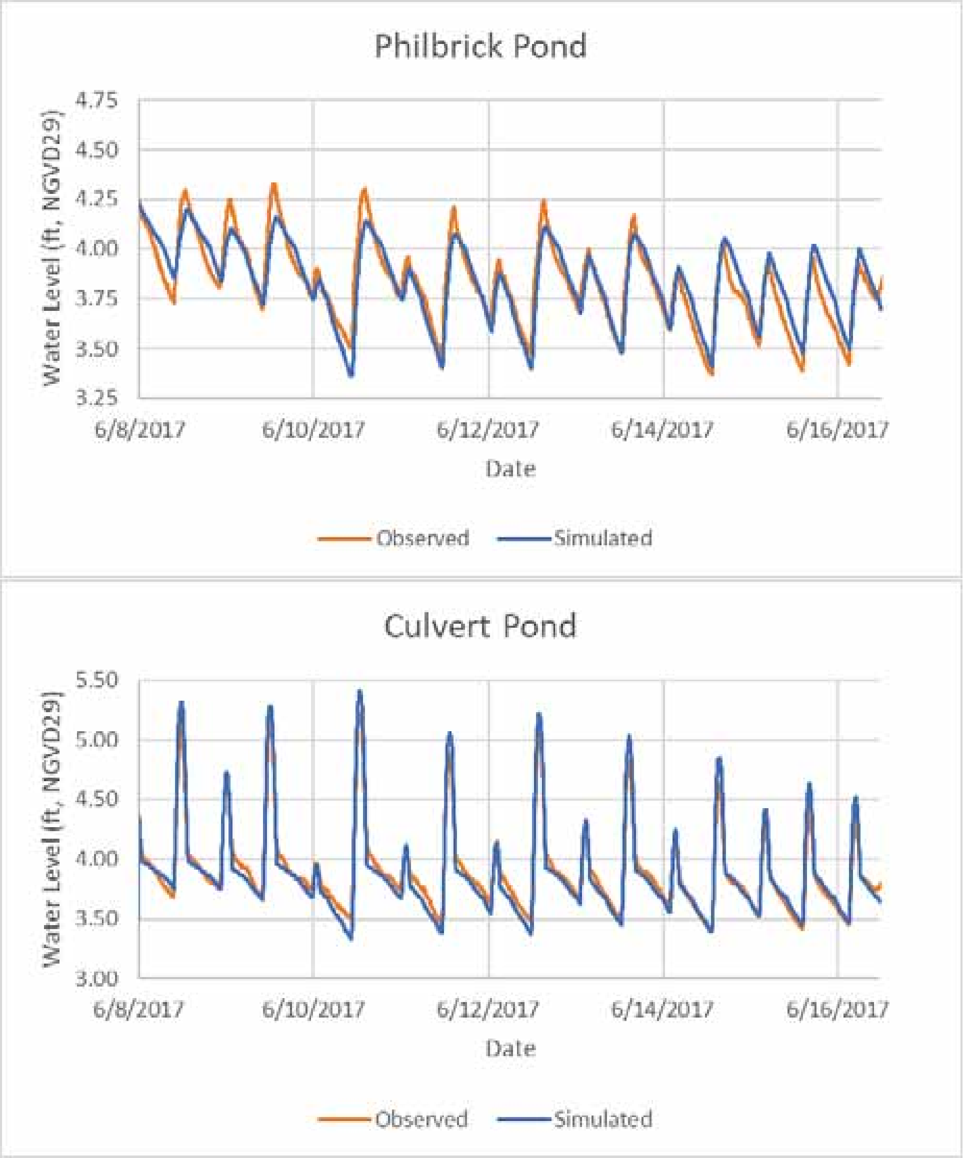


Figure 1: Calibration (Noon on 6/8/2017 through Midnight on 6/17/2017)

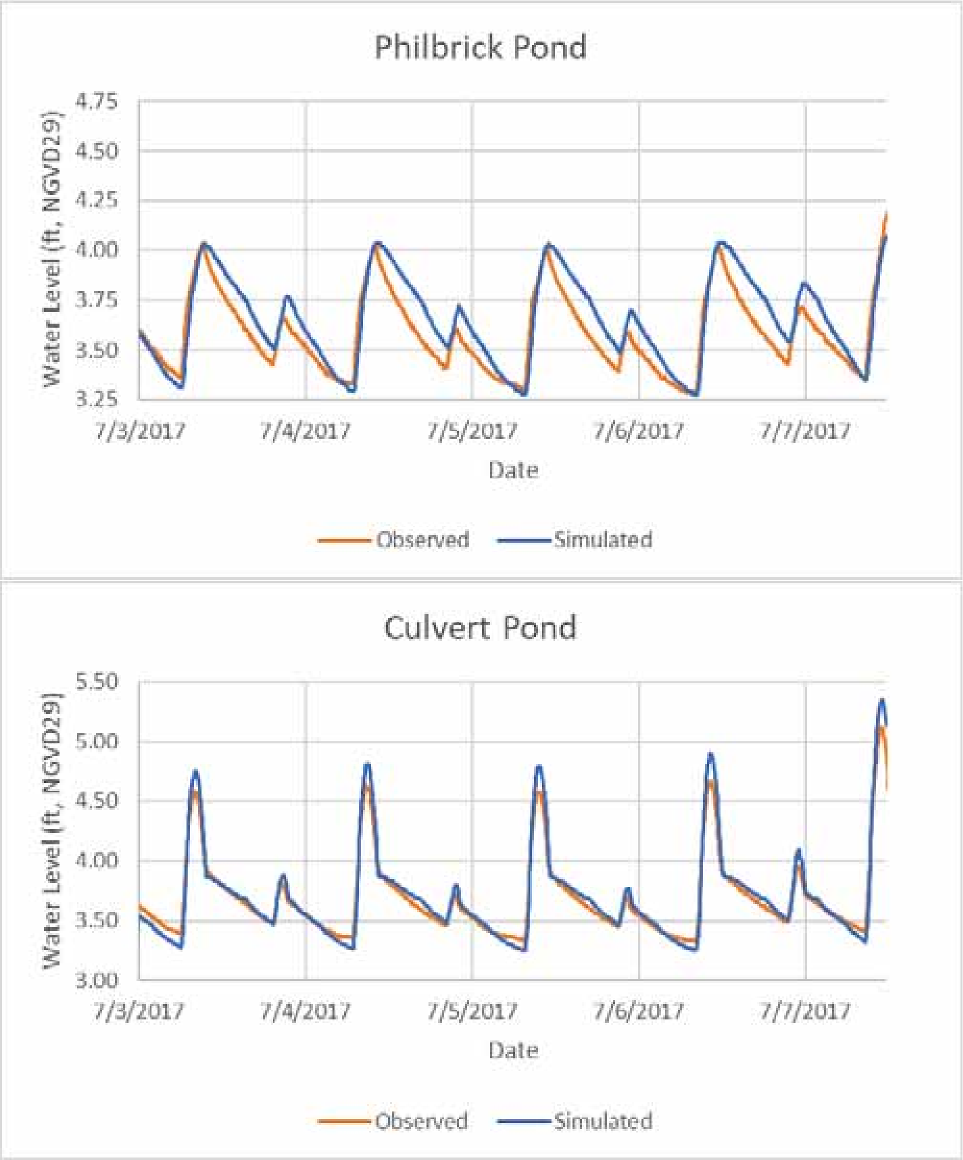


Figure 2: Verification (Noon on 7/3/2017 through Midnight on 7/8/2017)

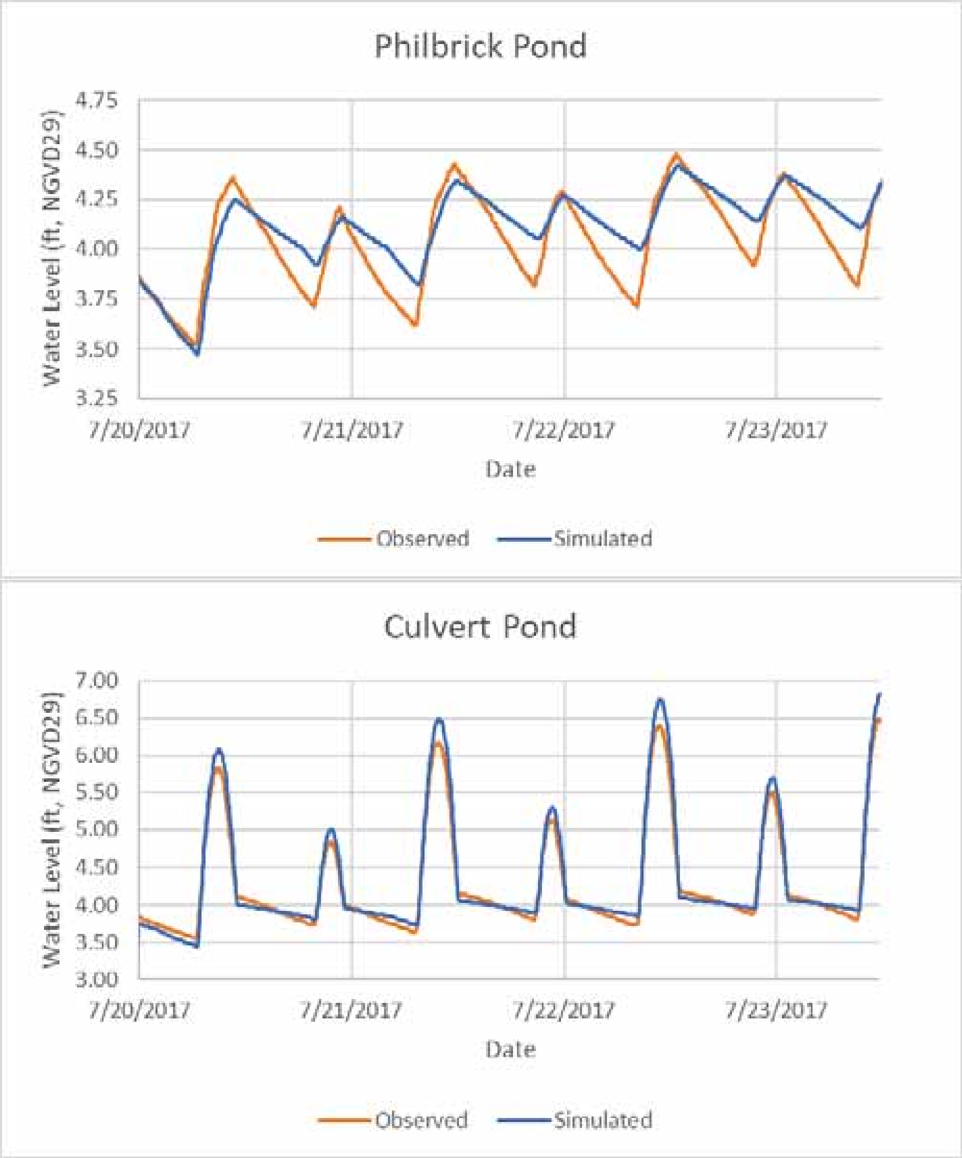


Figure 3: Verification (Noon on 7/20/2017 through Midnight on 7/23/2017)

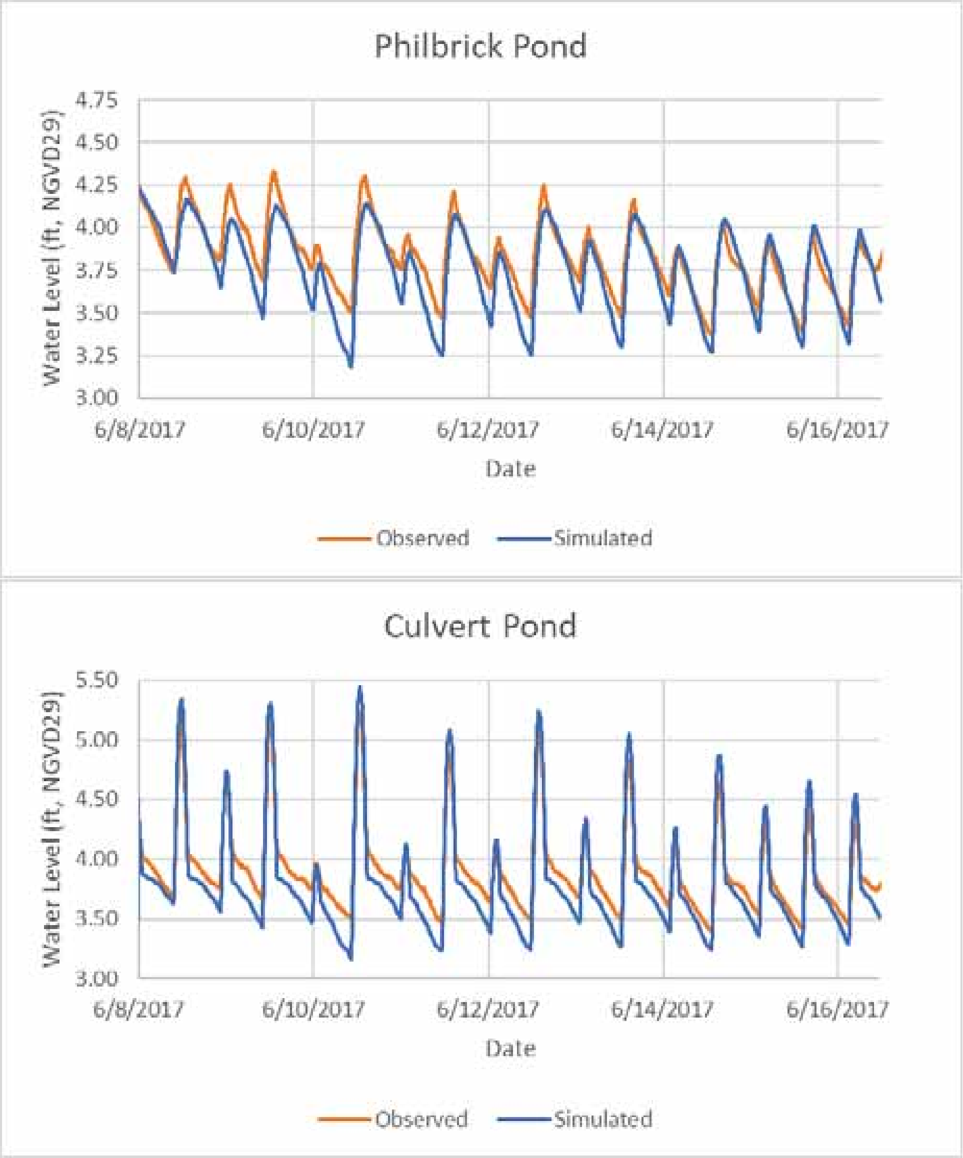


Figure 4: Calibration Sensitivity (Noon on 6/8/2017 through Midnight on 6/17/2017)

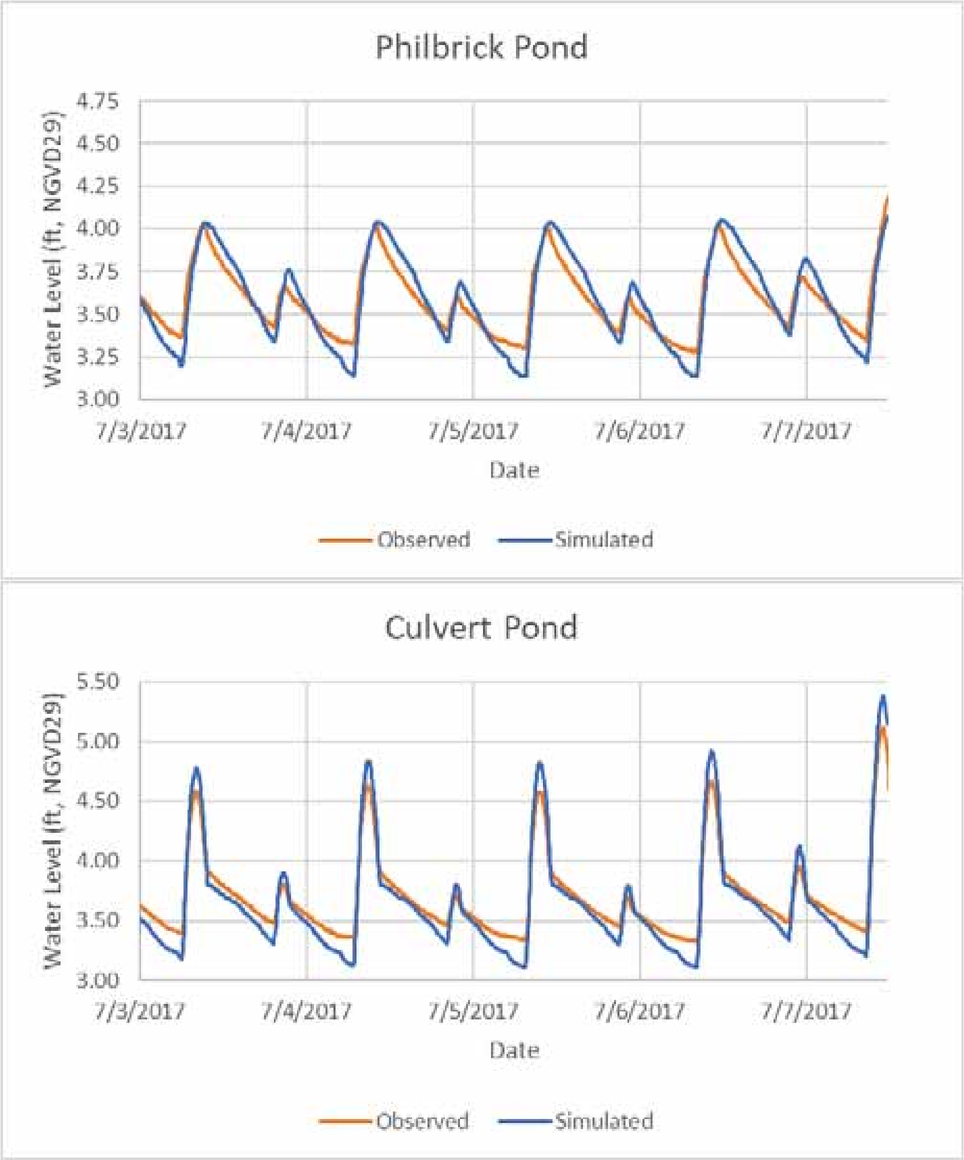


Figure 5: Verification Sensitivity (Noon on 7/3/2017 through Midnight on 7/8/2017)

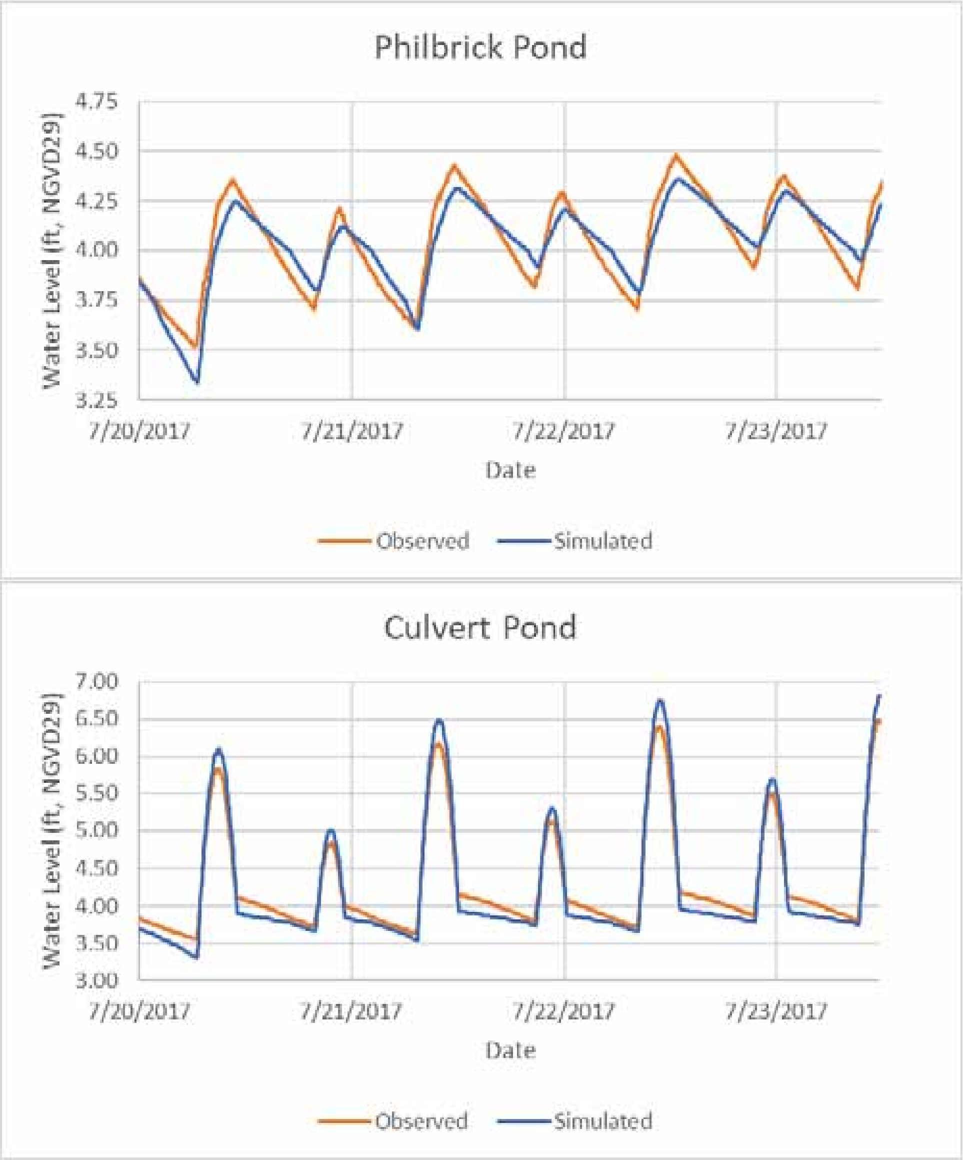


Figure 6: Verification Sensitivity (Noon on 7/20/2017 through Midnight on 7/23/2017)

GOMEZ AND SULLIVAN
ENGINEERS

PO Box 2179
Henniker, NH 03424
T. (603) 428 - 4960
(513) 560 - 9715 (Kevin)

MEMO

To: Craig Musselman (CMA)

From: Kevin Miller, Rick Stewart, and John Hart (Gomez and Sullivan)

Date: October 3, 2017

Re: Philbrick Pond – Existing Conditions Analysis

Background

In North Hampton, culverts passing under a berm for a former trolley line and State Route 1A, transfer flow between the Philbrick Pond Marsh and the Atlantic Ocean. A small pond (i.e. termed the culvert pond for the purposes of this memo) exists between the downstream end of the trolley berm culvert and the upstream end of the Route 1A culvert. Gomez and Sullivan has been tasked with evaluating the hydraulics of these culverts under existing conditions and potential future alternatives. Each condition is to be evaluated under various combinations of tidal and hydrologic scenarios including future sea level rise considerations. A memo dated September 29, 2017 outlined the development and calibration of a HEC-RAS model for the Philbrick Pond analysis. This memo outlines the assumptions and results surrounding the analysis of existing conditions under three hydrologic scenarios (i.e. normal tides, astronomical tides with precipitation, and extreme storm surge tides).

Boundary Condition Development

The downstream boundaries for each of the hydrologic scenarios evaluated in the existing conditions analysis were developed using tidal data from the NOAA station located at Fort Point, NH (Station ID: 8423898)[1]. The stage hydrograph from 6/1/2017 21:06 through 6/2/2017 21:06 was scaled using the ratio of the observed higher-high tide over the desired higher-high tide or the ratio of the observed lower-low tide over the desired lower-low tide. The scaling was done such that the observed values above zero feet[2] were multiplied by the ratio of higher-high tides, and the observed values below zero feet were multiplied by the ratio of lower-low tides. The observed and desired tide levels are presented in Table 1. The astronomical tide levels were defined such that the higher-high tide coincided with the peak inflow from a precipitation event. The runoff hydrograph for this precipitation event lasts multiple days, however, the tide levels were defined using normal tides for days other than the peak inflow.

The astronomical tides were evaluated in conjunction with the 100-year precipitation event. The United States Army Corps of Engineer's HEC-HMS program was used to develop the runoff hydrograph for this 0.7 mi^2 drainage area[3]. The 100-year 24-hour duration precipitation depths for Latitude 42.9711°N and Longitude 70.7812°W were obtained from the National Oceanic and Atmospheric Administration's Atlas

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[1] The Fort Point NOAA station is approximately 7 miles away from Philbrick Pond.

[2] All elevation in this memo refer to the National Geodetic Vertical Datum of 1929 (NGVD29). The conversion from the North American Vertical Datum of 1988 (NAVD88) used for this project was generally +0.781 feet (i.e. NGVD29 = NAVD88 + 0.781). However, the conversion used for data obtained from the NOAA station at Fort Point, NH utilized a conversion factor of +0.768 feet (i.e. NGVD29 = NAVD88 + 0.768).

[3] Drainage area obtained from the United States Geological Survey (USGS) StreamStats webtool.

No. 14 (8.48 inches) and the Northeast Regional Climate Center's (NRCC) Extreme Precipitation Analysis webtool (9.06 inches). The analysis used the larger value, and its associated temporal distribution for determining inflow to the Philbrick Pond. The Soil Conservation Service's (SCS) Curve Number methodology was used to account for infiltration losses. A Curve Number of approximately 78 was estimated for the drainage area using information from the Natural Resources Conservation Service's (NRCS) SSURGO soils database and the United States Geological Survey's National Land Cover Dataset. The standard SCS unit hydrograph was utilized within the model. A lag time of 130 minutes was estimated for this drainage area, based on the formulas for sheet flow, shallow concentrated flow, and channel flow from the NRCS National Engineering Handbook. Input information for these formulas were derived from a combination of sources, including the NRCC, USGS, and aerial imagery. The HEC-HMS model utilized a baseflow of 2 cfs/mi^2 (i.e. consistent with assumptions during calibration), and a recession constant and ratio of 0.3 and 0.2 respectively. These values are based on engineering experience and suggested values for smaller watersheds. The resulting runoff hydrograph resulted in a peak inflow to the Philbrick Pond of just over 450 cfs, as shown in Figure 1. This hydrograph was used as the upstream boundary condition for the Astronomical plus precipitation scenario, with a minimum flow of 1.4 cfs at all times.

Table 1: Tide Levels

Tide Scenario	Higher-High Tide	Lower-Low Tide	Basis
Observed	5.3	-3.5	-
Normal	5.2	-4.2	Historic Mean Higher-High and Lower-Low Water Levels
Astronomical	7.3	-6.3	Historic Highest and Lowest Observed Astronomical Tides
Extreme Storm Surge	9.2	-7.8	Higher-High Tide based on 100-Year Stillwater Elevation of Atlantic Ocean from Federal Emergency Management Agency's Flood Insurance Study for Rockingham County, NH. The Lower-Low Tide based on comparing ratio of Lower-Low Tide levels to Higher-High Tide levels for the Normal and Astronomical Tide Scenarios.

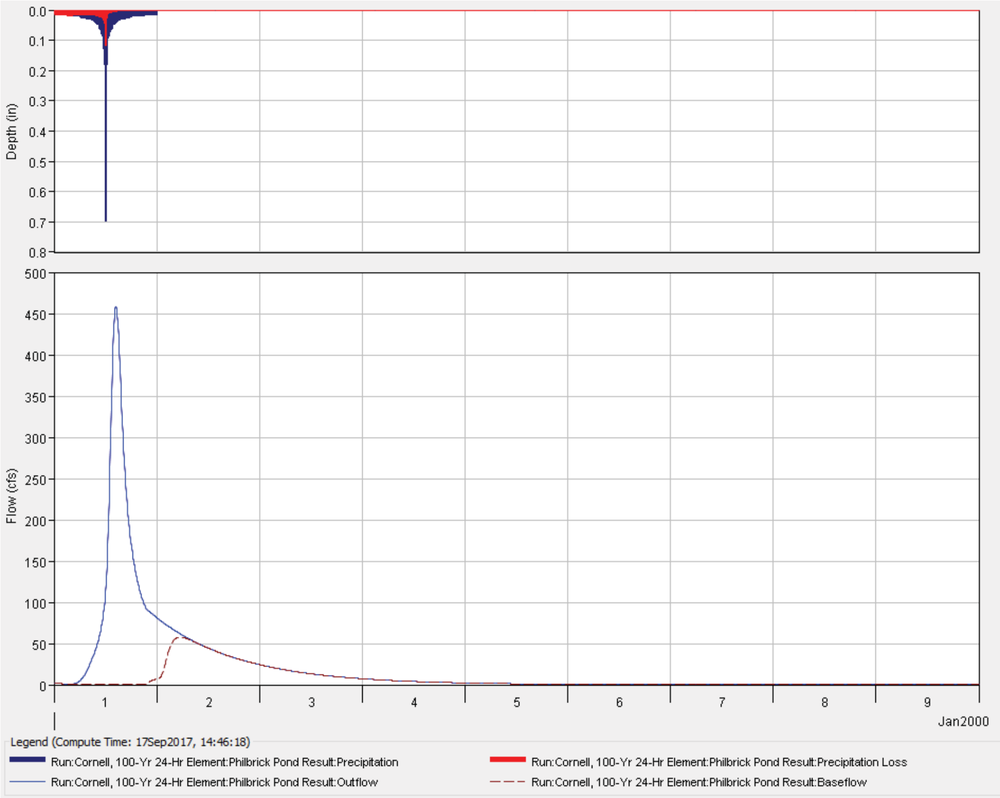

Figure 1: HEC-HMS Results

Results

Figures 2 through 4 show the resulting levels of the Atlantic Ocean, Culvert Pond, and Philbrick Pond for each of the three scenarios analyzed. A flood reference level is provided on each figure at 7.0 feet, which is approximately the elevation at which the Old Locke Road begins to flood. It should be noted in Figure 3, that the peak level in the Philbrick and Culvert Ponds are higher than the peak tide due to the inflow from the 100-Year Precipitation. Similar to field observations the model showed that it takes multiple days for the water in the Philbrick Pond to drain after a major rainfall event. The results of a sensitivity analysis, which extends the astronomical tides throughout the simulation, are presented in Figure 5. The sensitivity analysis only increases the peak water level in the Philbrick Pond by about 0.1 feet. It also shows that the duration of the astronomical tides could extend the time it takes to drain Philbrick Pond. While tidal fluctuations of this magnitude may be sustainable for more than one day, they would not last more than a week, as modeled in the sensitivity analysis.

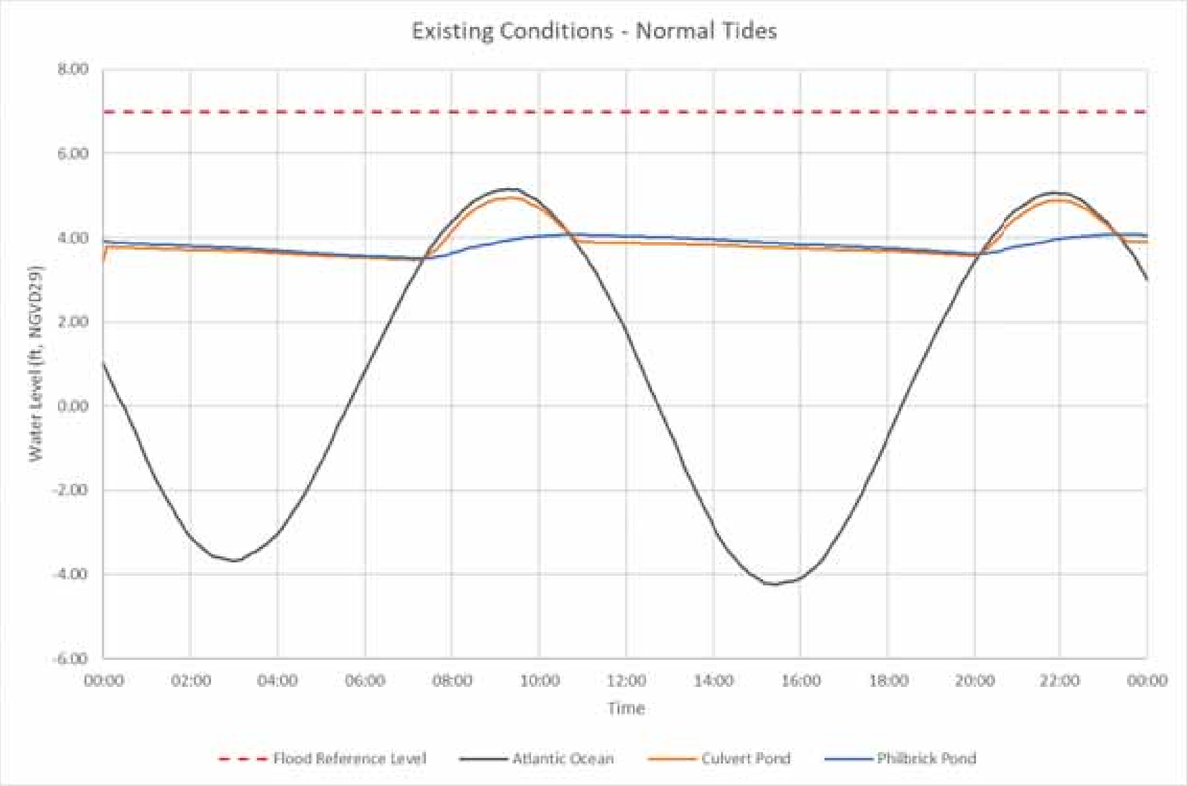

Figure 2: Existing Conditions - Normal Tides

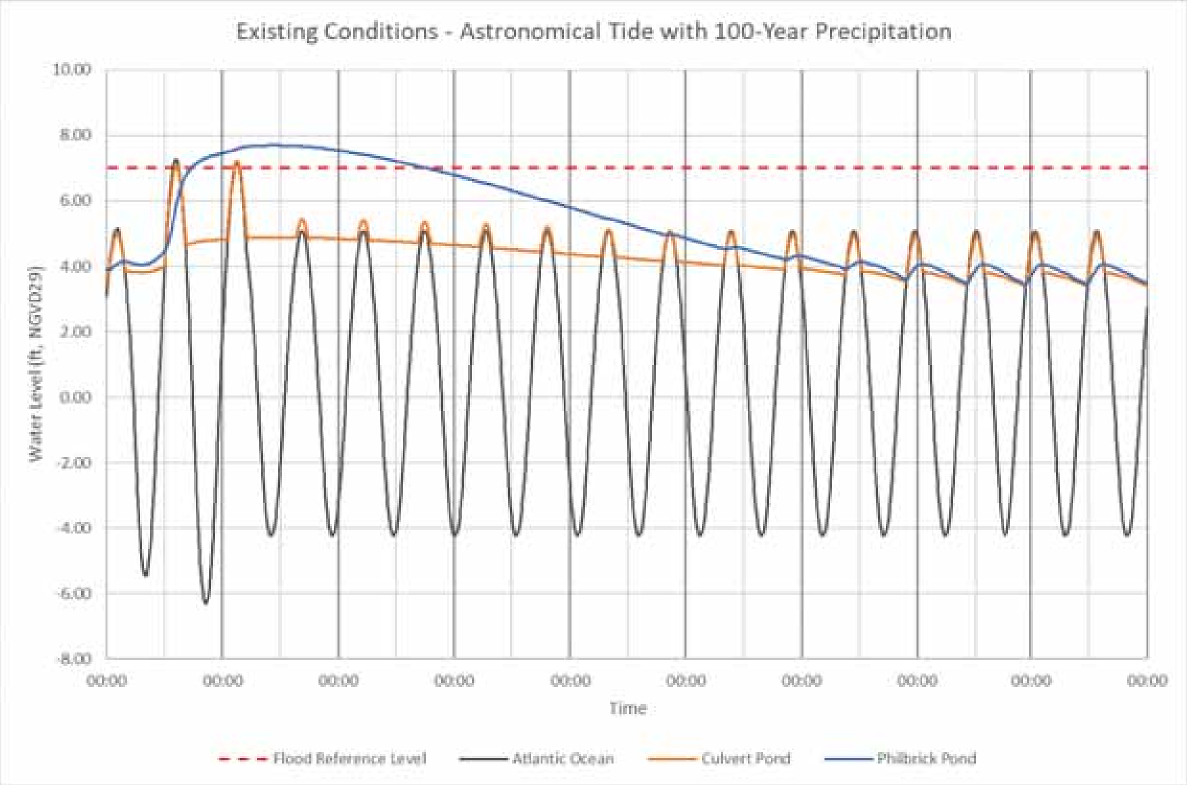

Figure 3: Existing Conditions – Astronomical Tides with 100-Year Precipitation

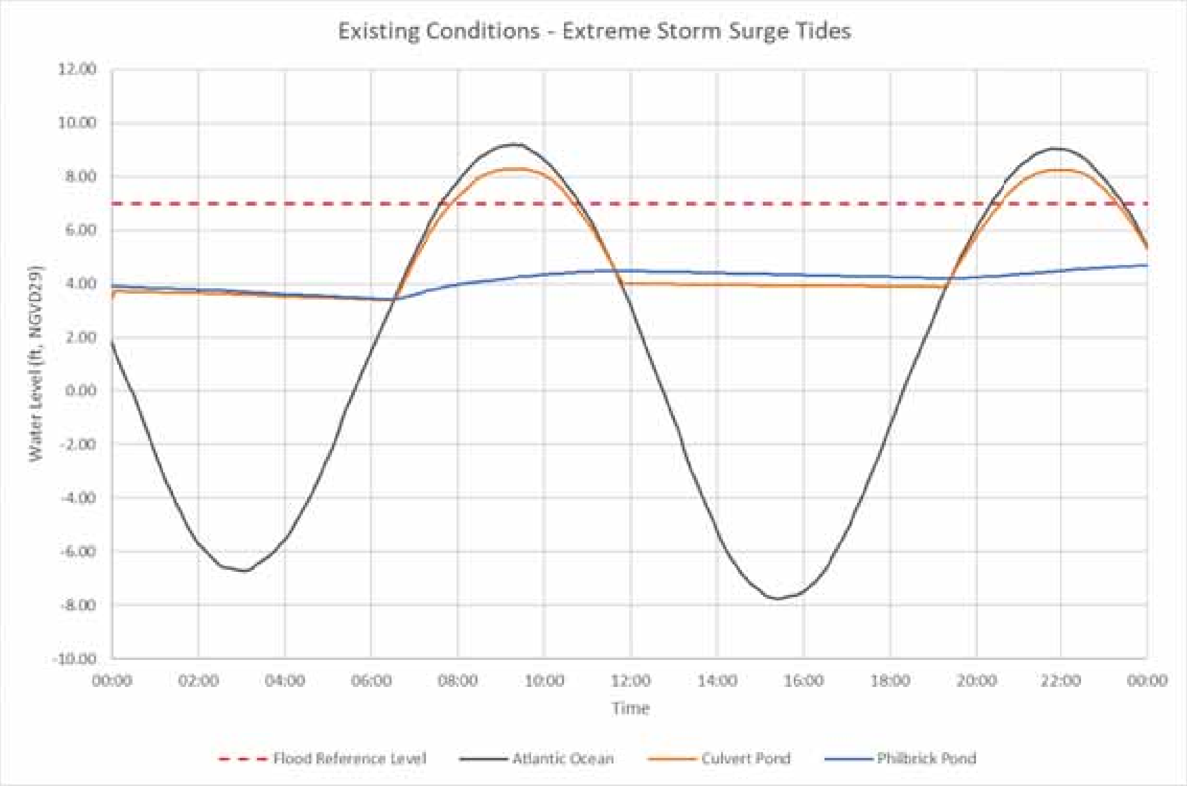

Figure 4: Existing Conditions – Extreme Storm Surge Tides

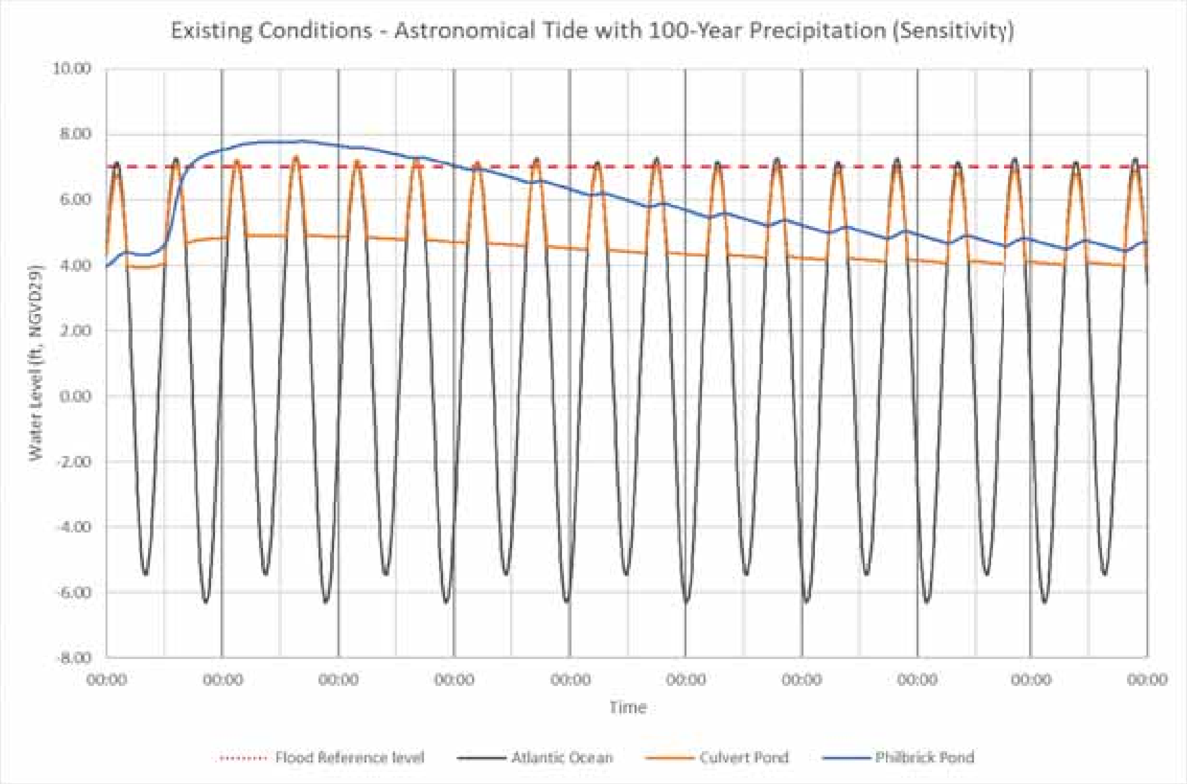

Figure 5: Existing Conditions – Astronomical Tides with 100-Year Precipitation (Sensitivity)

GOMEZ AND SULLIVAN
ENGINEERS

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Henniker, NH 03424
T. (603) 428 - 4960
(513) 560 - 9715 (Kevin)

MEMO

To: Craig Musselman (CMA)

From: Kevin Miller and John Hart (Gomez and Sullivan)

Date: October 20, 2017

Re: Philbrick Pond – Alternative Conditions Analysis

Background

In North Hampton, culverts passing under a berm for a former trolley line and State Route 1A, transfer flow between the Philbrick Pond Marsh and the Atlantic Ocean. A small pond (i.e. termed the Culvert Pond for the purposes of this memo) exists between the downstream end of the trolley berm culvert and the upstream end of the Route 1A culvert. Gomez and Sullivan has been tasked with evaluating the hydraulics of these culverts under existing conditions and potential future alternatives. Each condition is to be evaluated under various combinations of tidal and hydrologic scenarios including future sea level rise considerations. A memo dated September 29, 2017 outlined the development and calibration of a HEC-RAS model for the Philbrick Pond analysis. A memo dated October 3, 2017 presented the assumptions and results surrounding the analysis of existing conditions under three scenarios (i.e. normal tides, astronomical tides with precipitation, and extreme storm surge tides). This memo presents the assumptions and results surrounding the analysis of potential future alternatives under the same three scenarios as the existing conditions memo.

Model Revisions

The geometry of the model was revised to evaluate four potential alternatives as described below.

Box

This geometry replaces the existing 30" VCP culvert through the trolley berm with a 2.5' high by 8' wide concrete box culvert. The existing trolley berm culvert has an invert approximately 1' below the Route 1A culvert. However, the proposed culvert was modeled to have the same invert as the Route 1A culvert (i.e. 2.0 feet[1]). The entrance conditions were assumed to include a flush headwall with the inlet edges having a ¾" chamfer. The culvert roughness coefficient was assumed to be 0.011, and the culvert length was assumed to be the same as the existing culvert (i.e. 40 feet).

Slab

This geometry replaced the "weir" located upstream of the Route 1A culvert with a 4' wide concrete pad at the same elevation as the Route 1A culvert invert (i.e. 2.0 feet). The concrete pad was assumed to be unfinished with a roughness coefficient of 0.017. Additionally, this geometry re-graded the high channel bottom within the Culvert Pond (see Figure 1 below) as this also contributes to reduced outflow.

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[1] All elevation in this memo refer to the National Geodetic Vertical Datum of 1929 (NGVD29). The conversion from the North American Vertical Datum of 1988 (NAVD88) used for this project was generally +0.781 feet (i.e. NGVD29 = NAVD88 + 0.781).

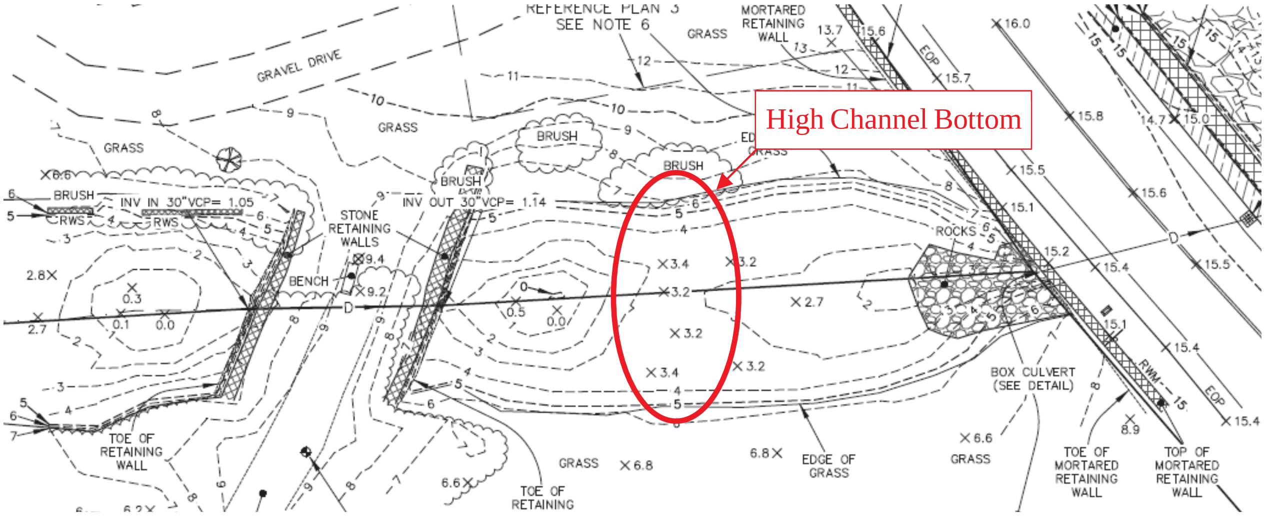

Figure 1: Survey of Culvert Pond

<u>Box + Slab</u>
This geometry combined all the changes of the Box and Slab geometries[2].

<u>Channel + Slab</u>
This geometry utilized all the changes of the Slab geometry, as well as removal of the trolley berm culvert/embankment to allow for natural channel conditions through this area[2].

Results

A number of figures are provided at the end of this memo which show results for the existing conditions and each of the four alternative conditions described above, for a total of five conditions. A flood reference level is provided on each figure at 7.0 feet, which is approximately the elevation at which the Old Locke Road begins to flood. Each of these five conditions includes a figure for each of the three scenarios, for a total of 15 figures. Some additional results are also presented in Tables 1 and 2, below. It should be noted that the minimum water surface elevations are computed as the minimum level to occur after the occurrence of the maximum high tide during the simulation.

Table 1: Maximum Water Surface Elevation

Condition	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Existing	4.1	5.0	7.7	7.2	4.7	8.3
Box	4.2	4.2	7.2	7.2	5.2	5.9
Slab	4.1	5.0	7.7	7.2	4.6	8.3
Box + Slab	4.2	4.4	7.2	7.2	5.3	5.9
Channel + Slab	4.3	4.3	7.1	7.1	5.3	5.3

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[2] Additional changes were also made to the interpolated cross sections downstream of the Route 1A culver to improve model stability. While some minor instability still exists, it is no longer expected to impact pertinent model results (i.e. those results located upstream of the Route 1A culvert). These changes were not made for the other model geometries, as they already ran without stability issues.

Table 2: Minimum Water Surface Elevation[1]

Condition	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Existing	3.6	3.6	3.4	3.4	4.2	3.9
Box	3.6	3.6	3.4	3.4	4.4	4.3
Slab	3.3	2.3	3.3	2.3	4.1	3.6
Box + Slab	3.2	2.3	3.1	2.3	4.4	4.3
Channel + Slab	2.8	2.3	2.8	2.3	4.4	4.4

Notes:

1. Minimum Elevation taken after maximum high tide.

Box

When compared to existing conditions, the decrease in Culvert Pond levels and increase in Philbrick Pond levels during tidal scenarios (i.e. normal and extreme storm surge) suggest that a larger volume of water is entering from the Atlantic Ocean during high tides. The model results also suggest that the Route 1A culvert limits the amount of water entering the Philbrick Pond, as the water level in the Culvert and Philbrick Ponds does not match that of the Atlantic Ocean, as shown in the figures. Further, the peak water surface elevation in the Philbrick Pond is decreased for significant rainfall events, and the pond drains faster as shown in the figures. Overall, the maximum water surface elevation results indicate that the use of a box culvert allows for greater transfer of flow between the Philbrick and Culvert Ponds than existing conditions.

Slab

Removal of the “weir” and high channel bottom in the Culvert Pond has little impact on peak water surface elevations. However, the minimum water surface elevation results indicate a greater ability to drain the ponds.

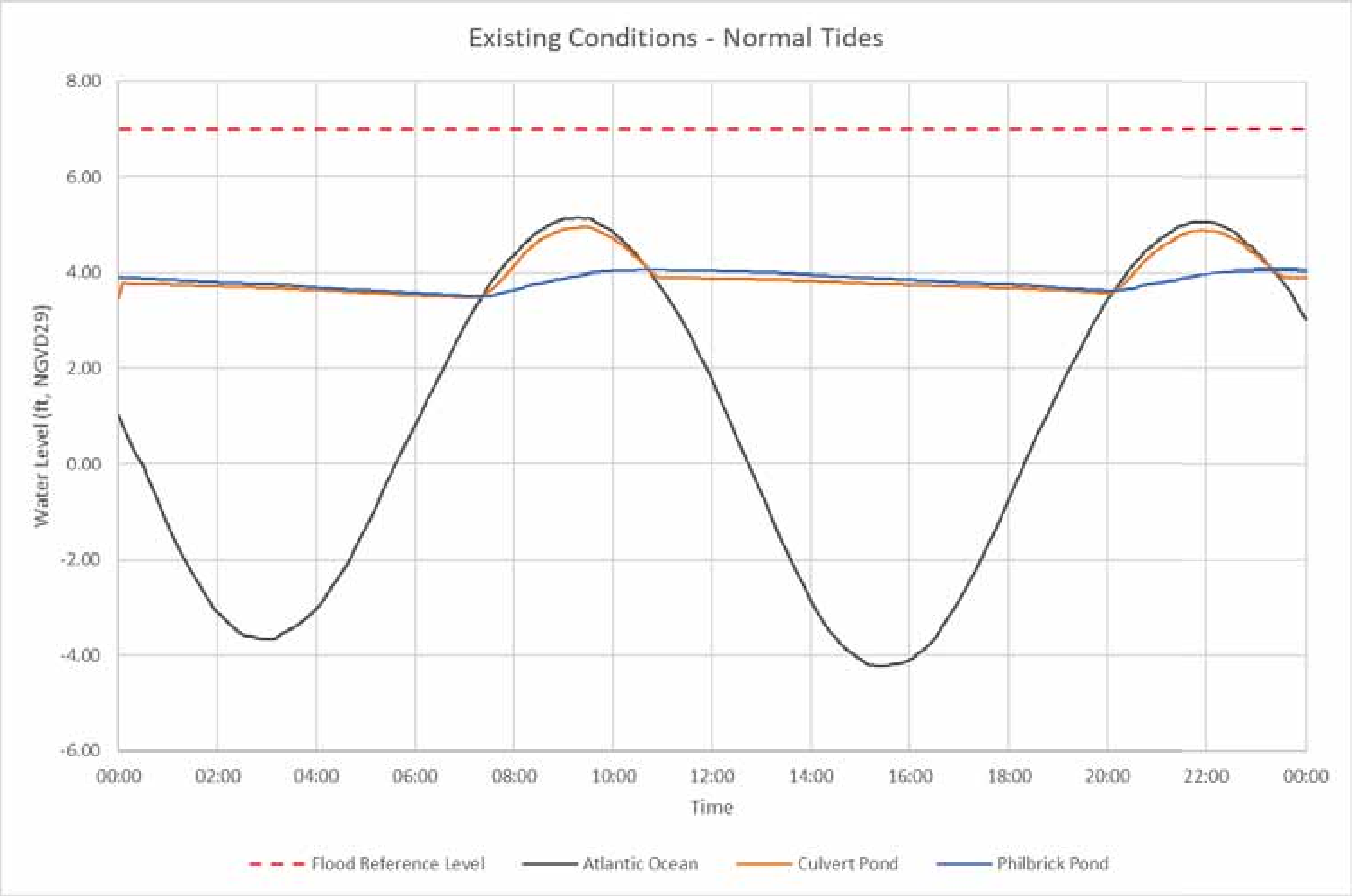
Box + Slab

The results for this condition exhibit a combination of features as the previous two conditions.

The maximum water surface elevation results indicate greater transfer of flow between the Philbrick and Culvert Ponds (i.e. similar to the Box condition), while the minimum water surface elevation results indicate a greater ability to drain the ponds (i.e. similar to the Slab condition). It should be noted that the minimum water levels are higher during than the Slab condition under extreme storm surge tidal events, because the box allows for a greater volume of inflow during high tide, and the time between high tides is not long enough to drain the extra volume.

Channel + Slab

The maximum water surface elevation results indicate that this condition provides even greater flow transfer between the Philbrick and Culvert Ponds than the Box + Slab condition, as it provides greater inflow during high tides and greater discharge during rainfall events.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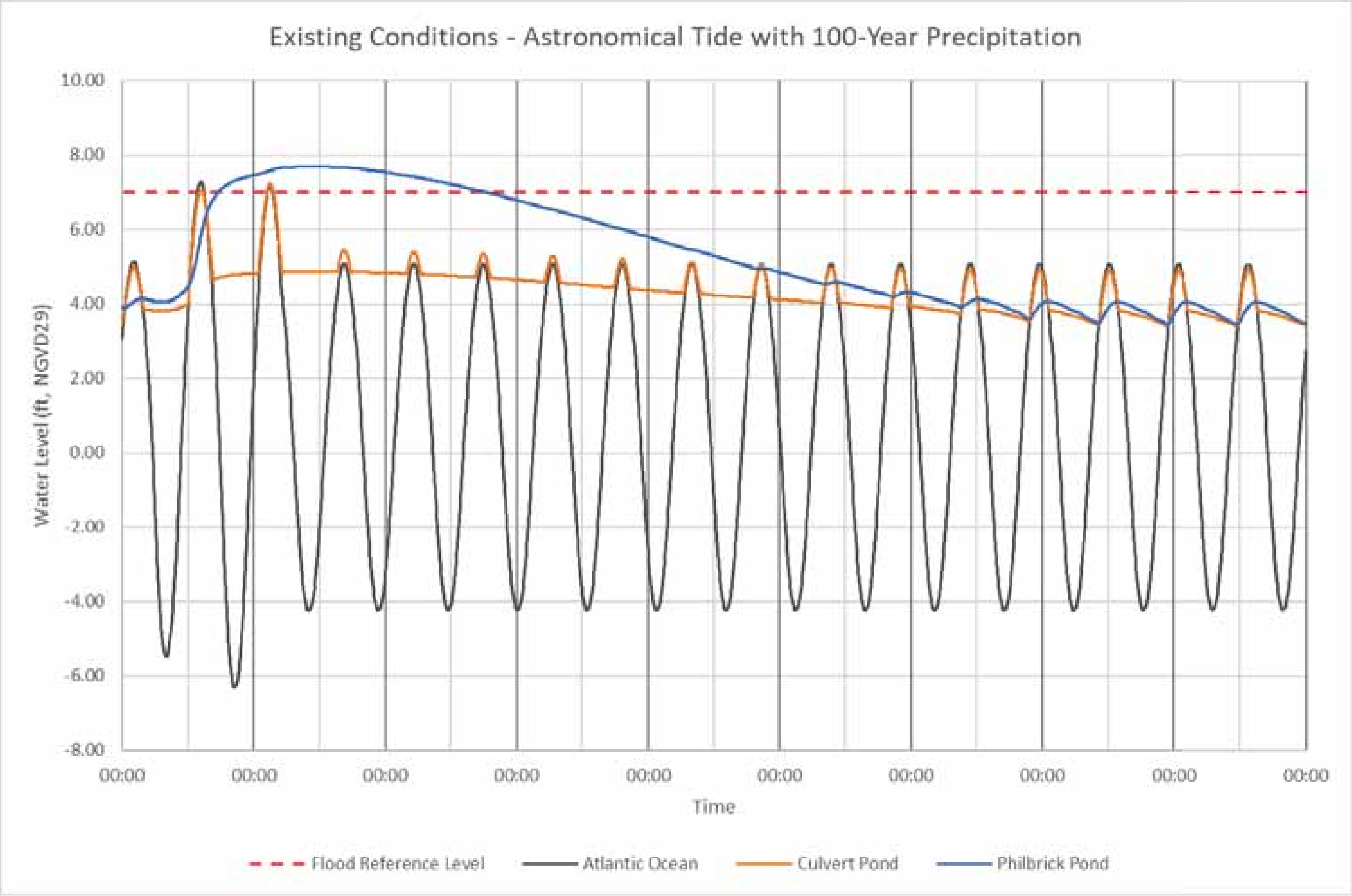
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Culvert Pond
Philbrick Pond


Existing Conditions - Extreme Storm Surge Tides
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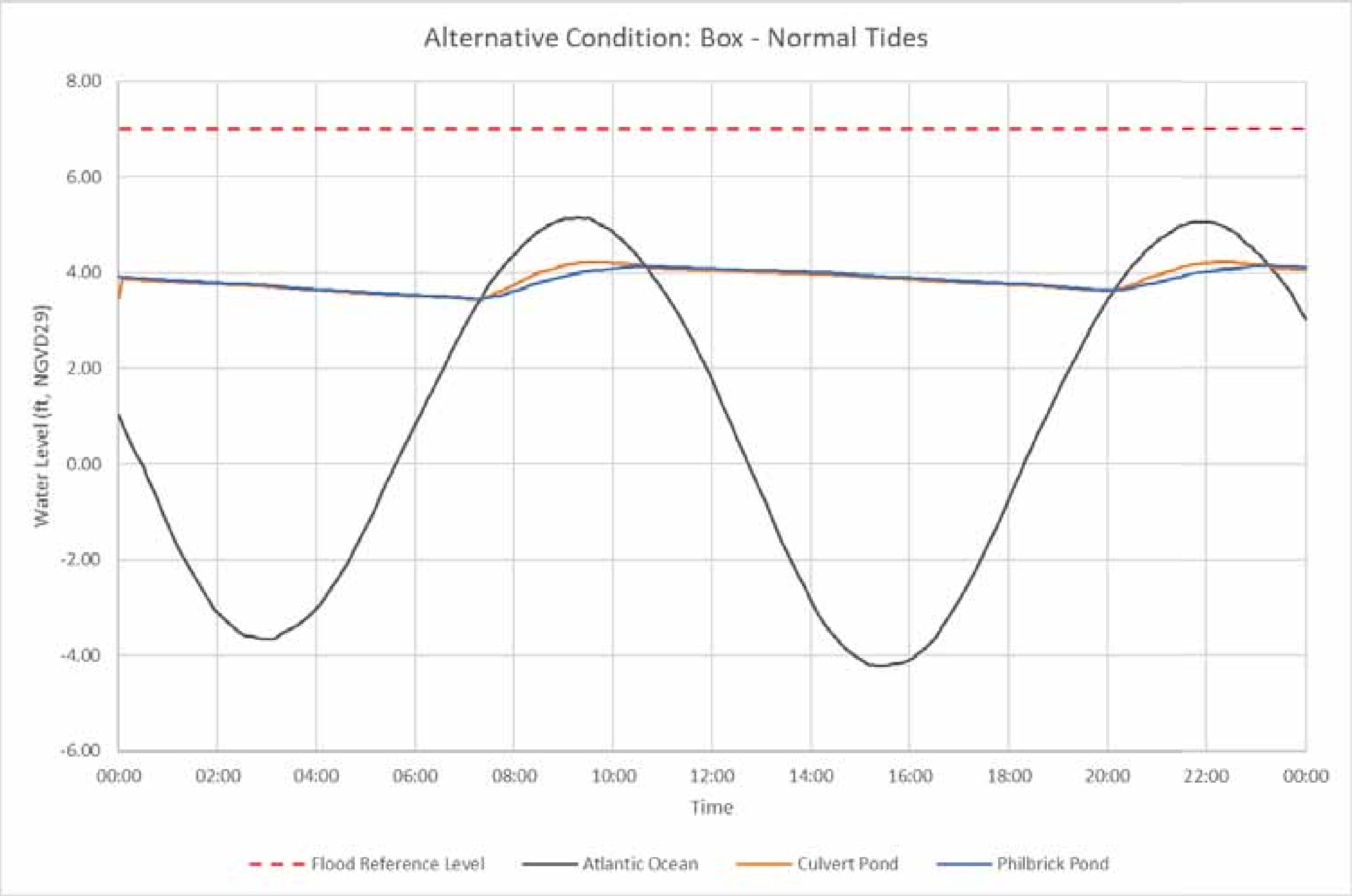
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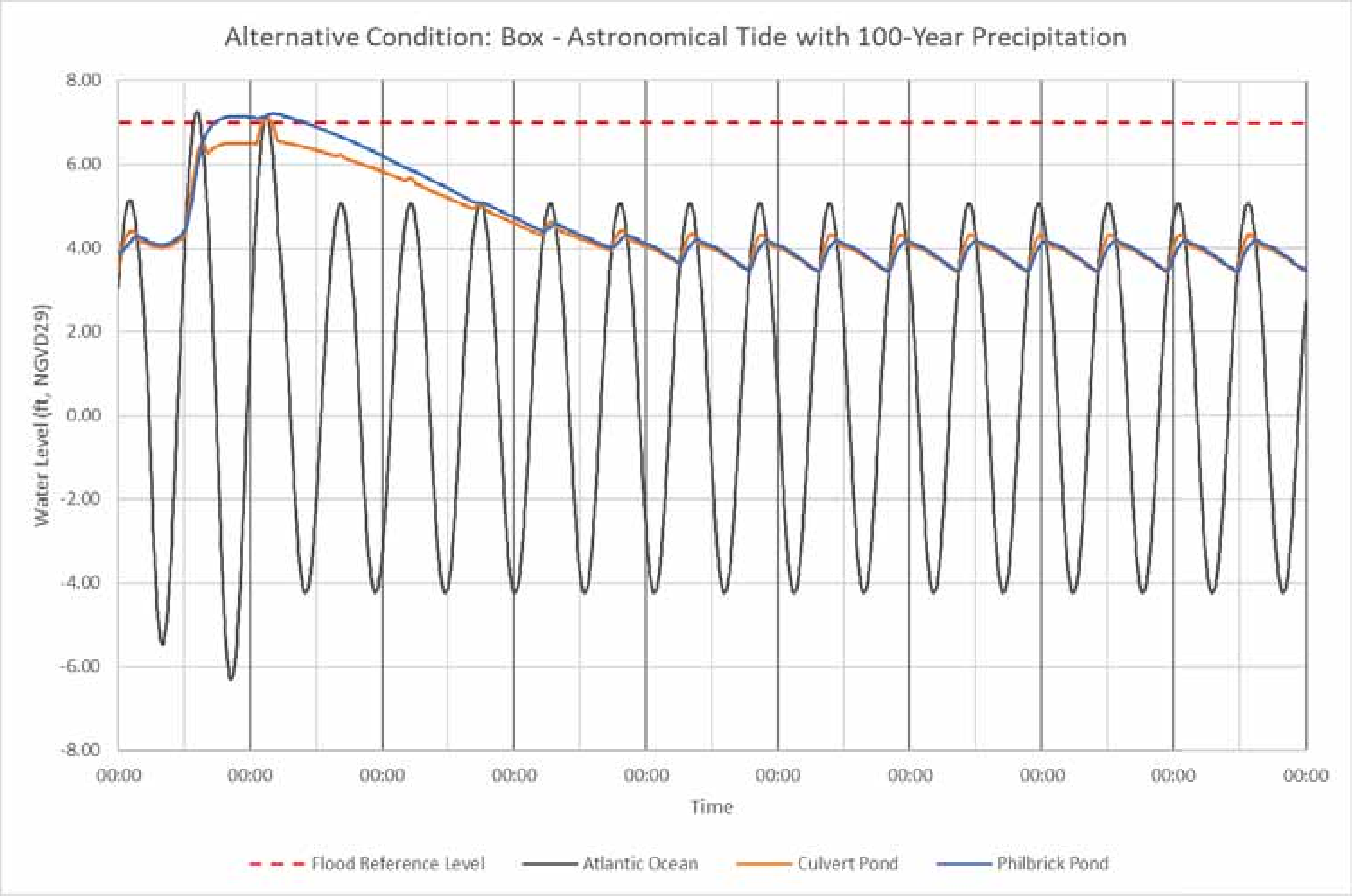
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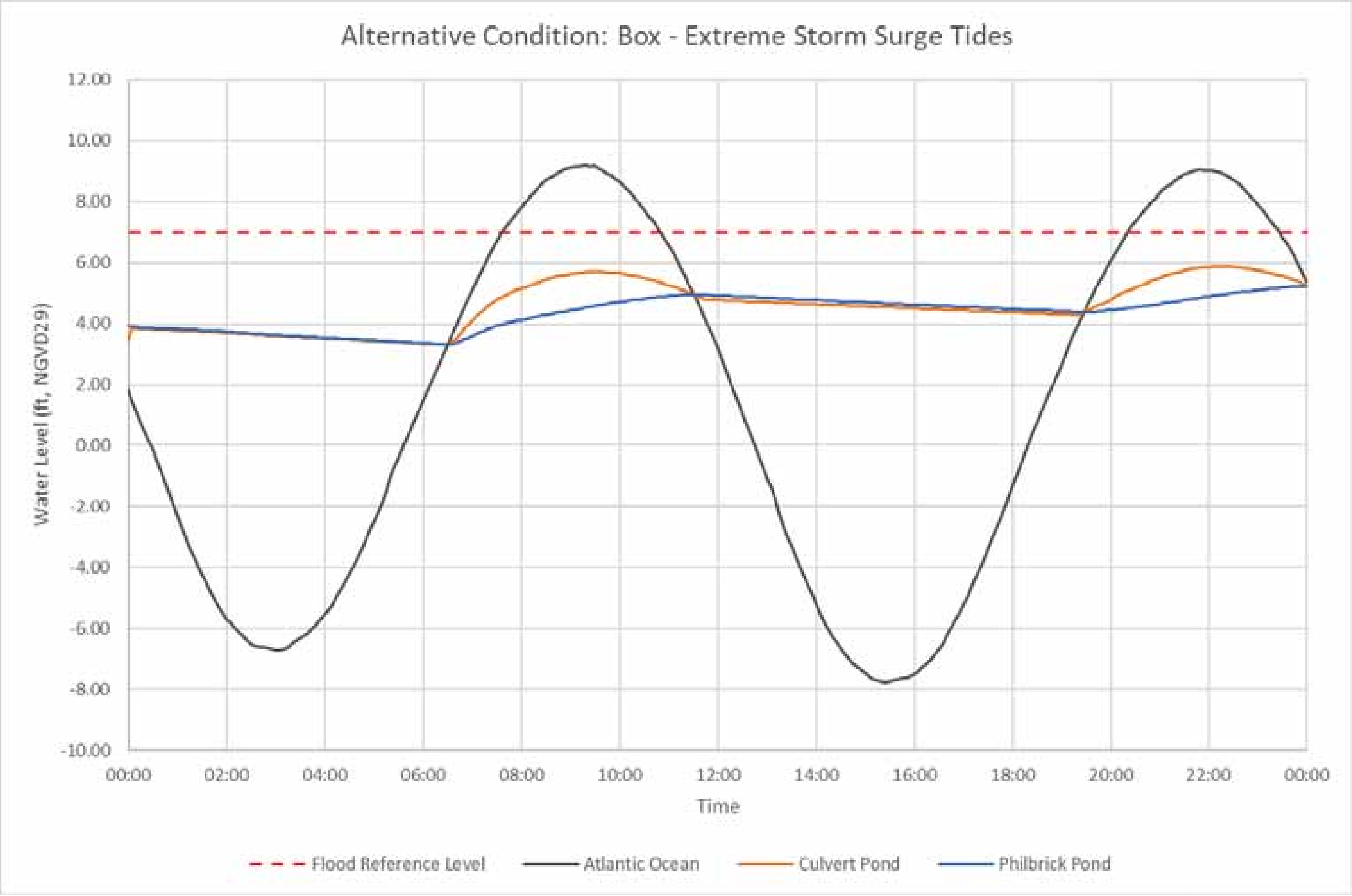
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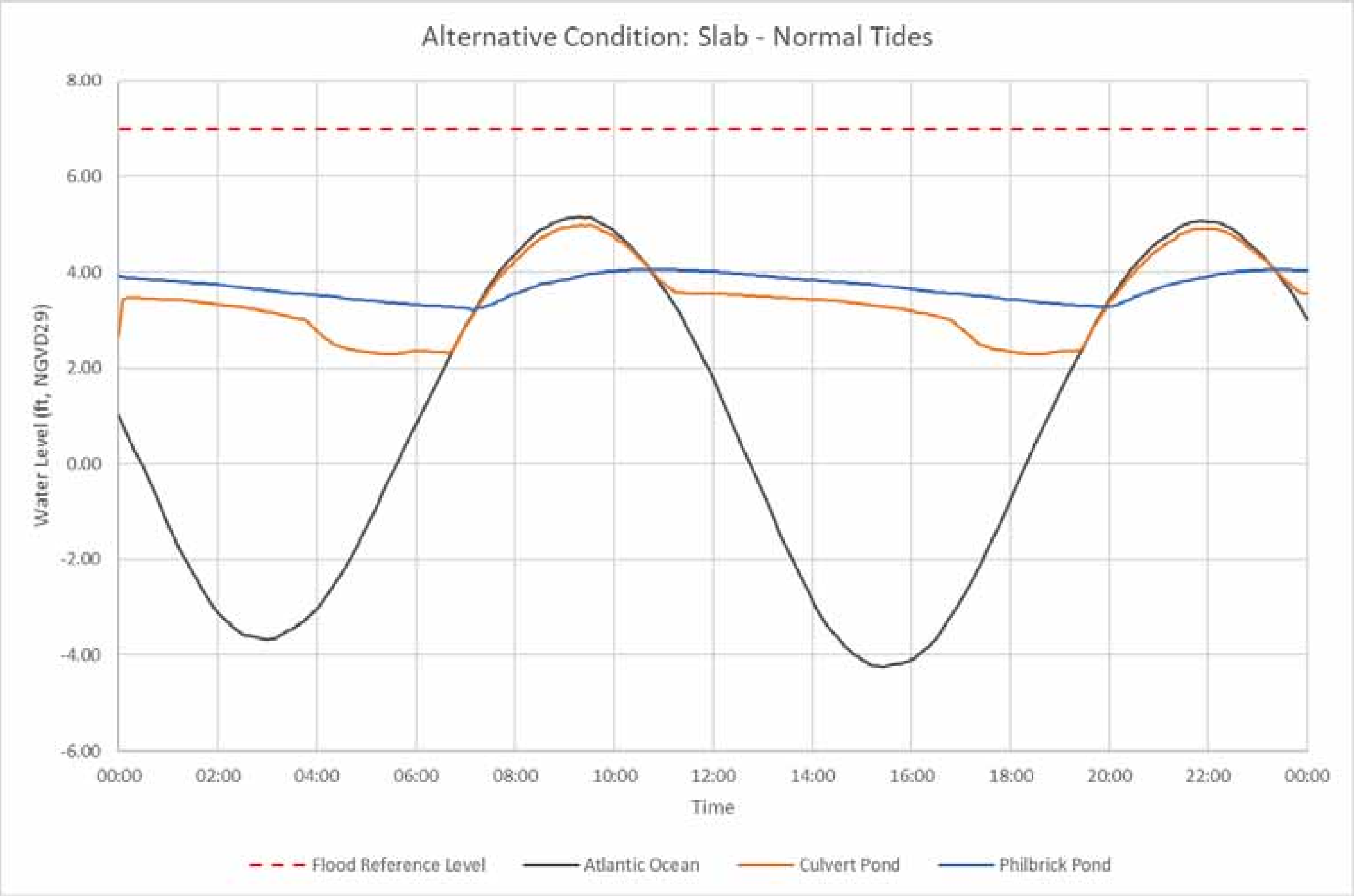
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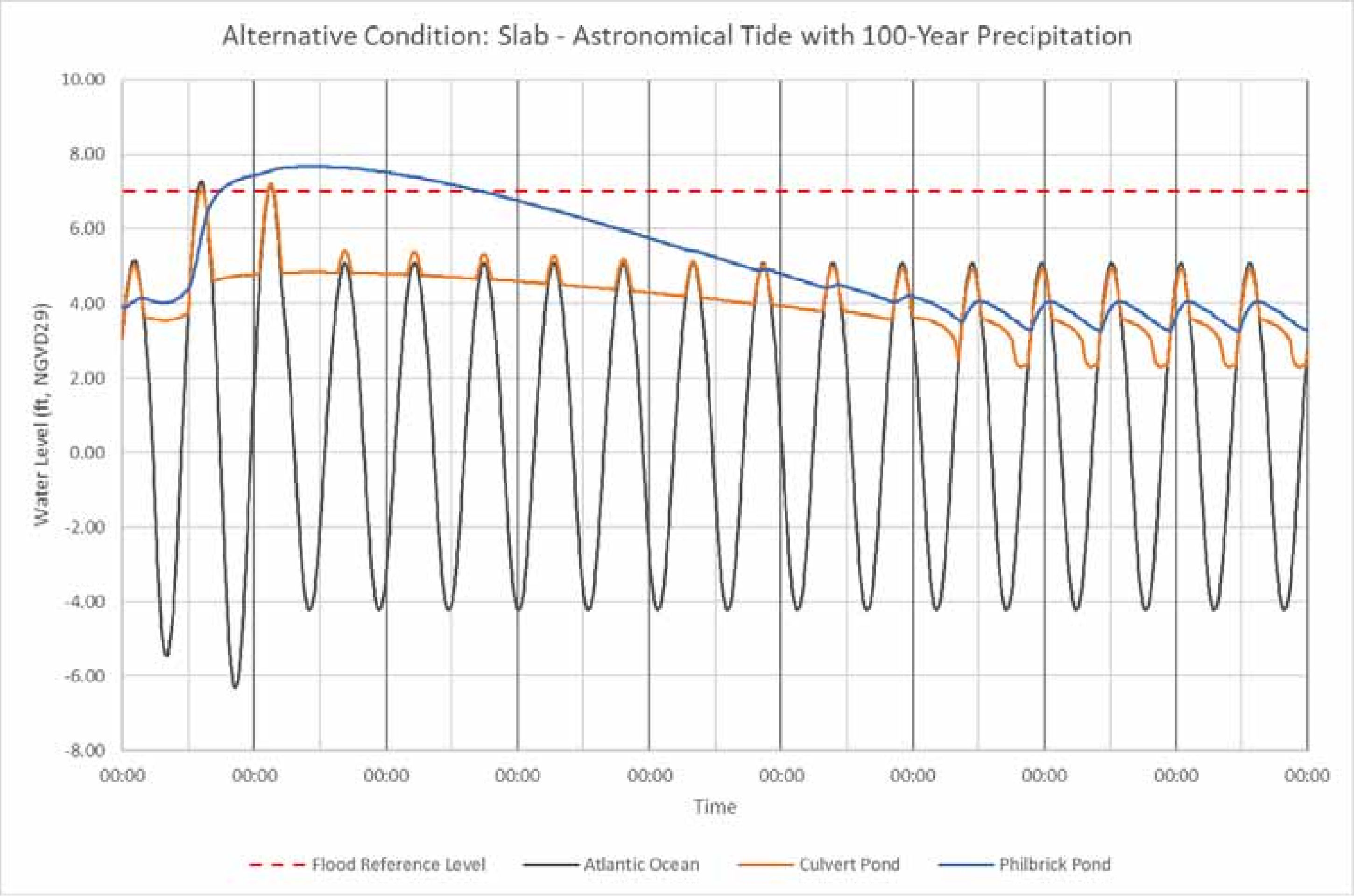
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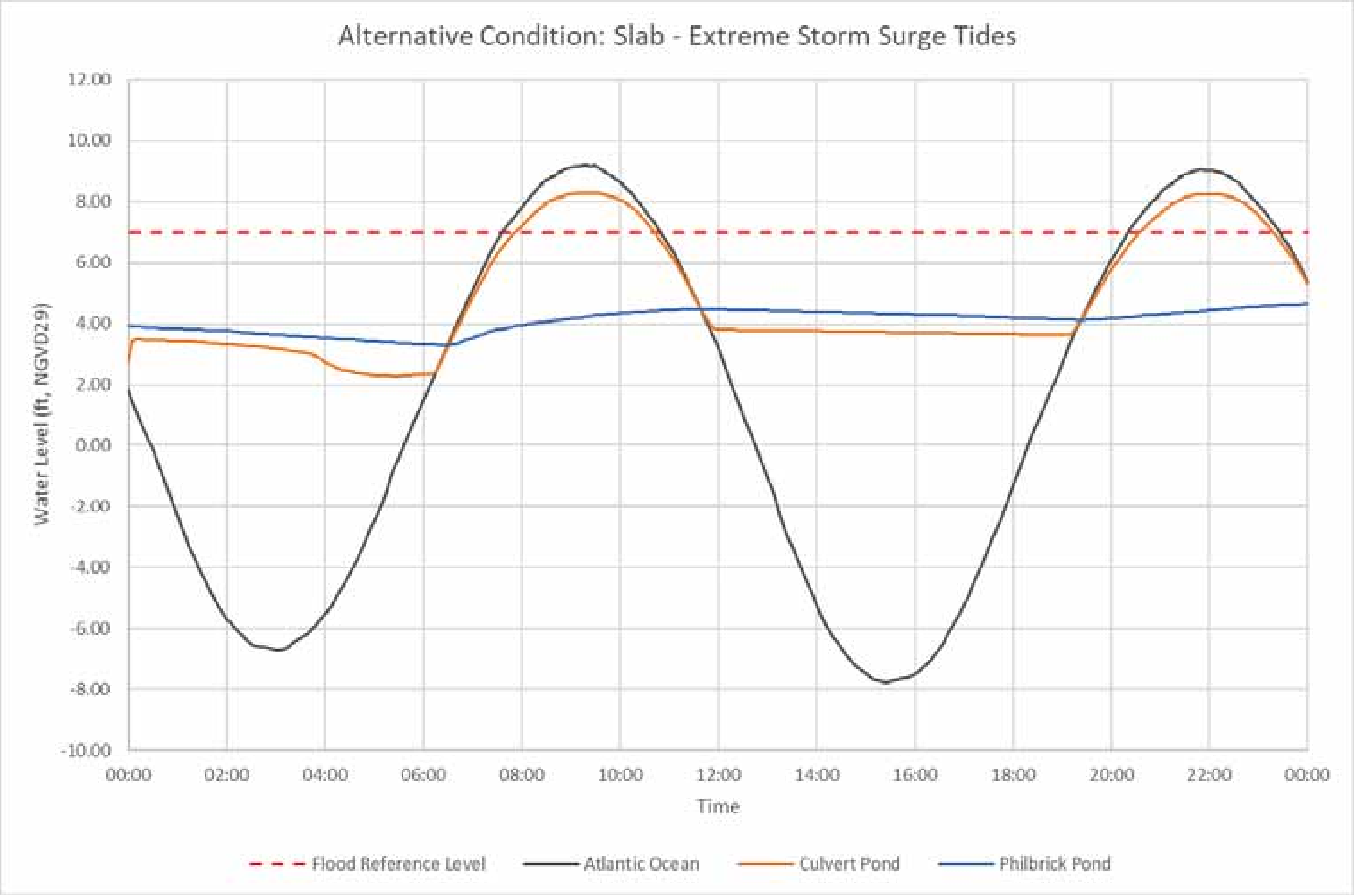
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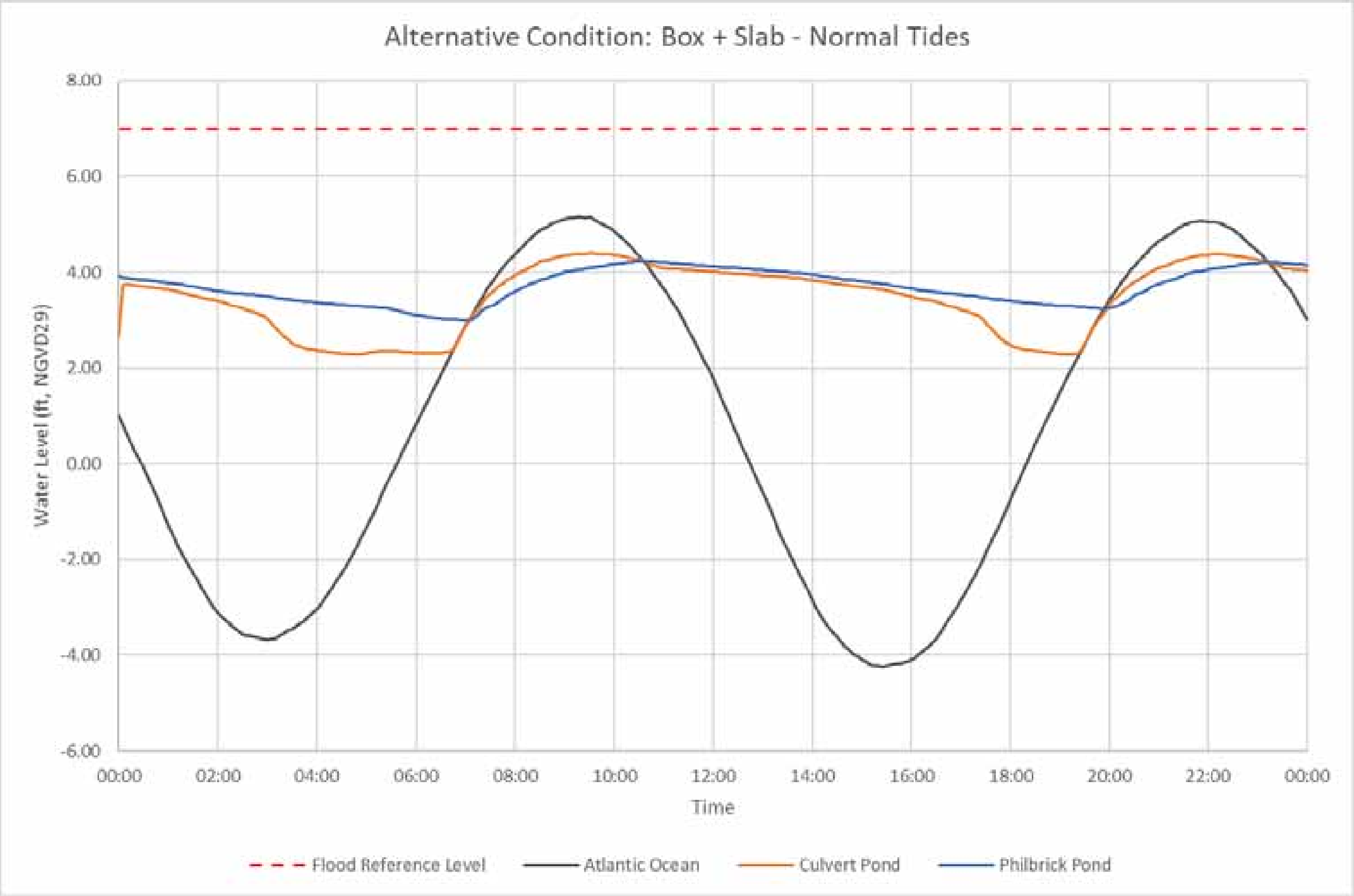
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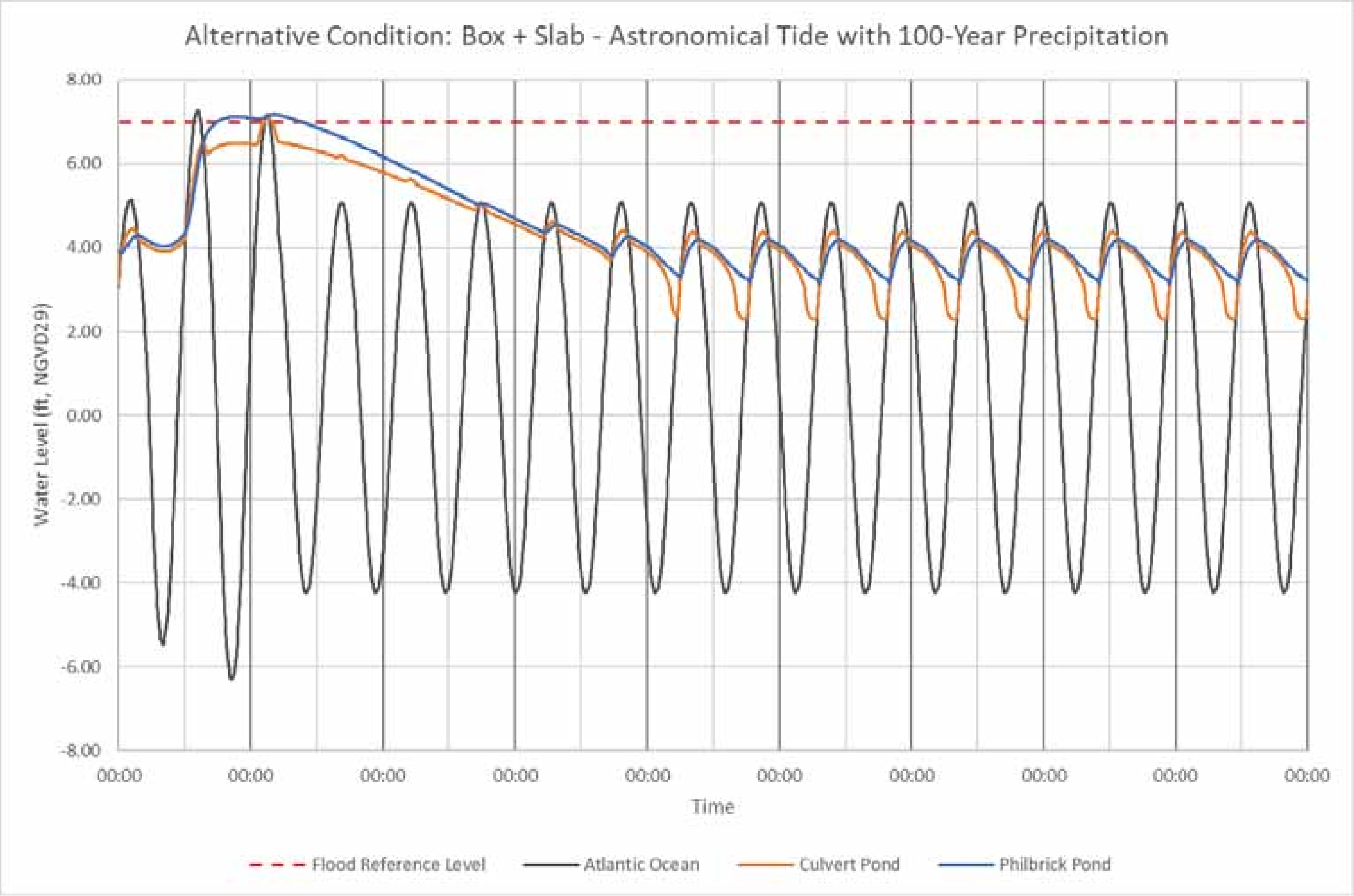
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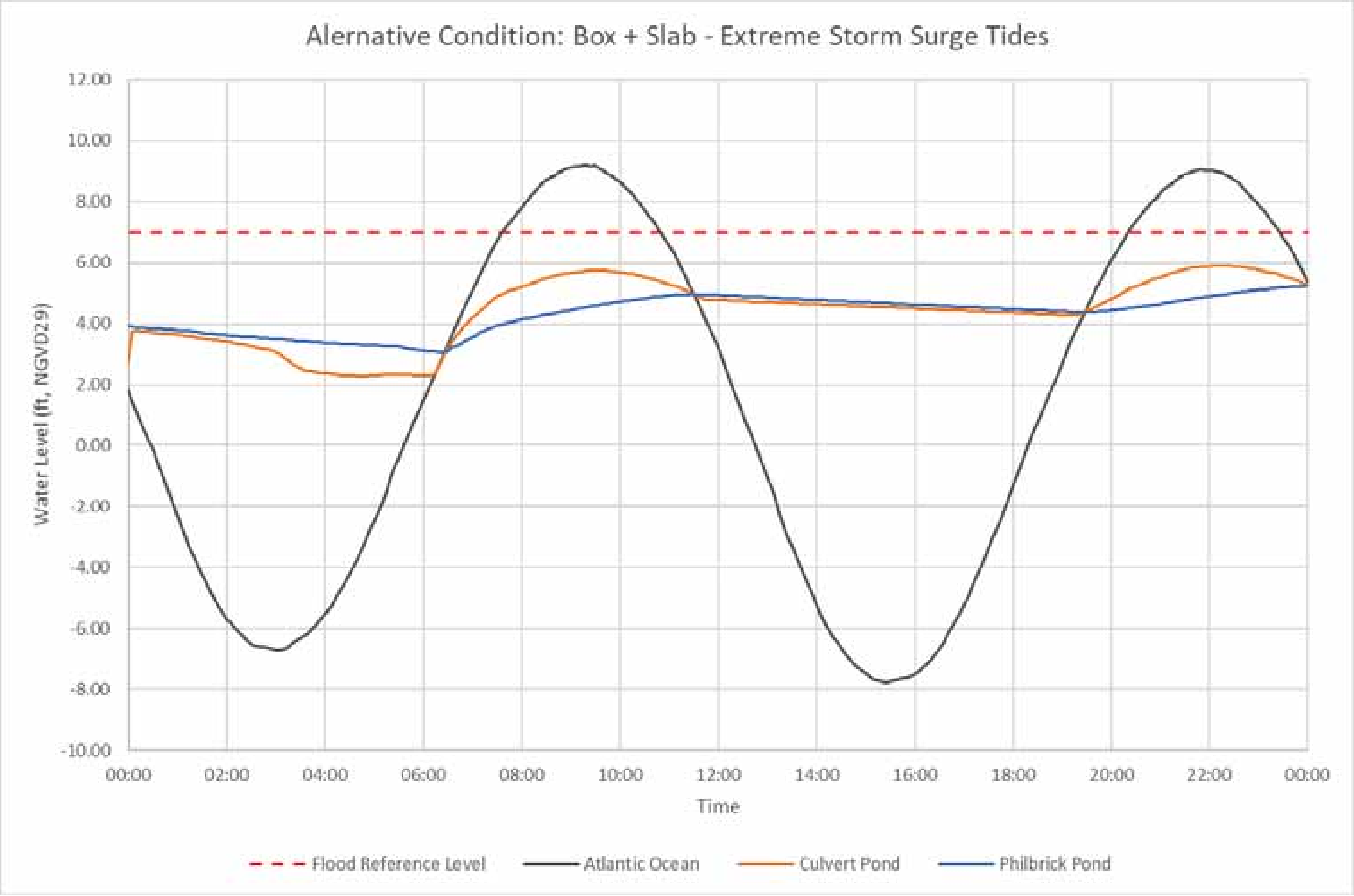
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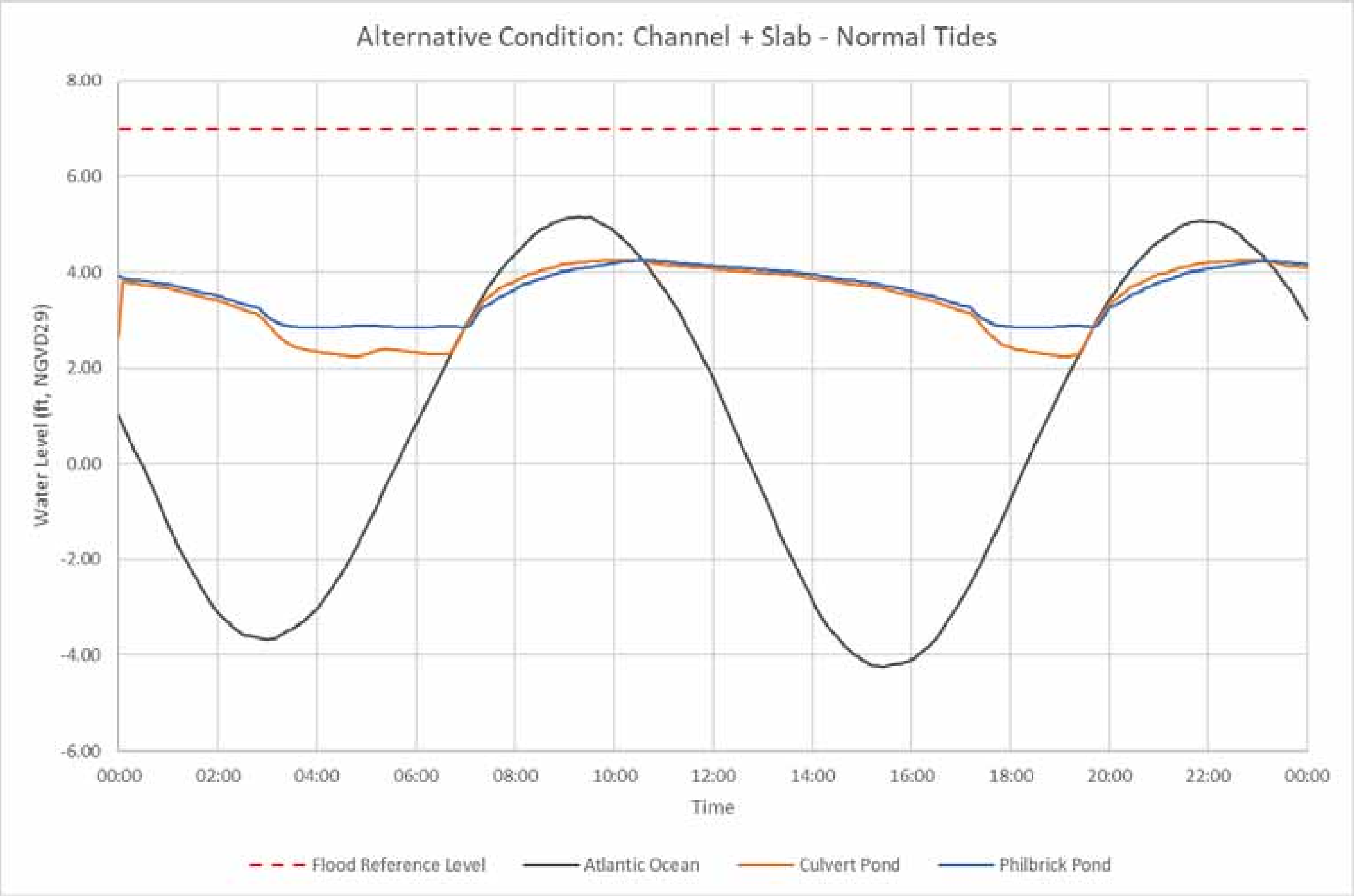
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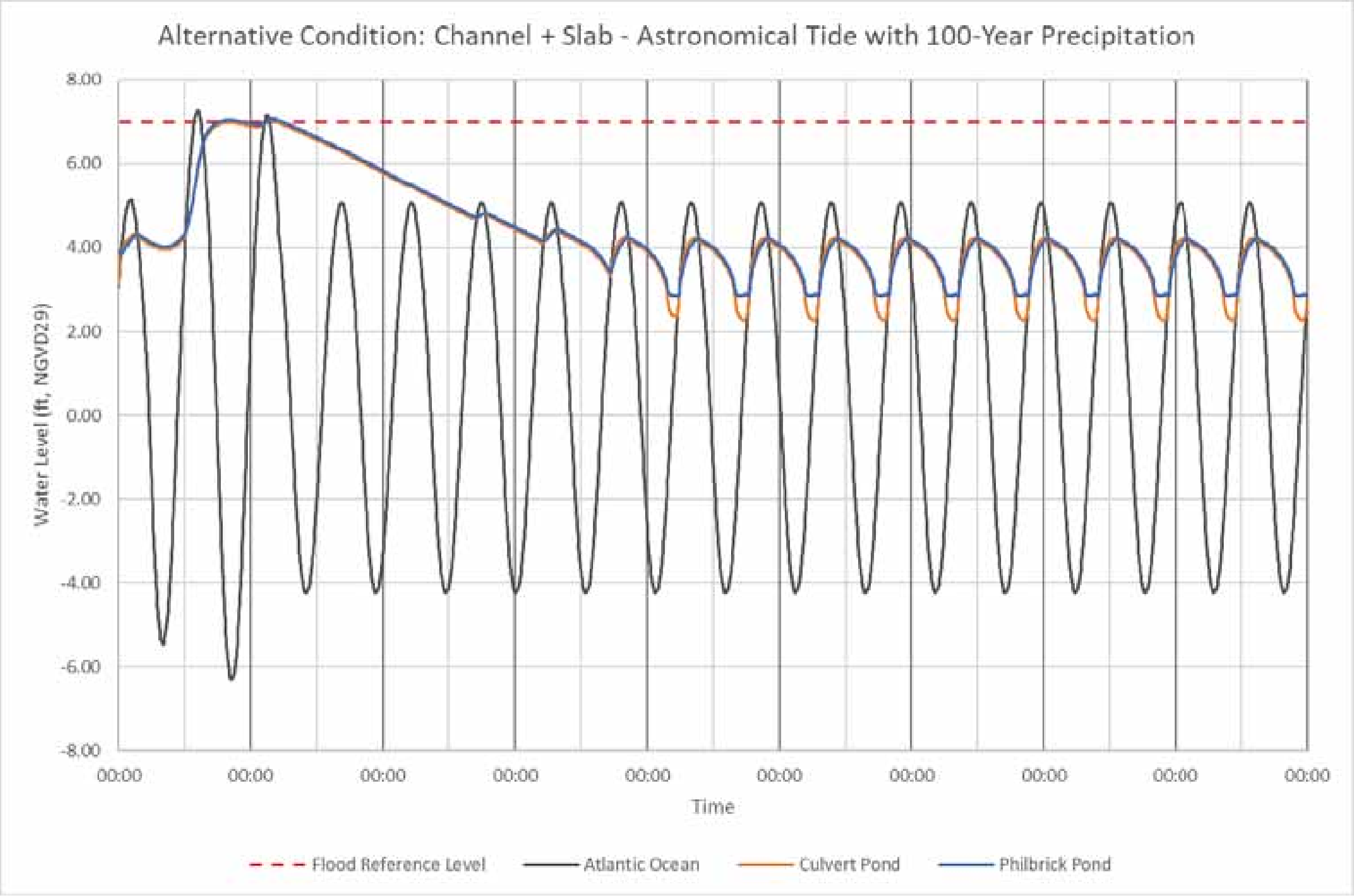
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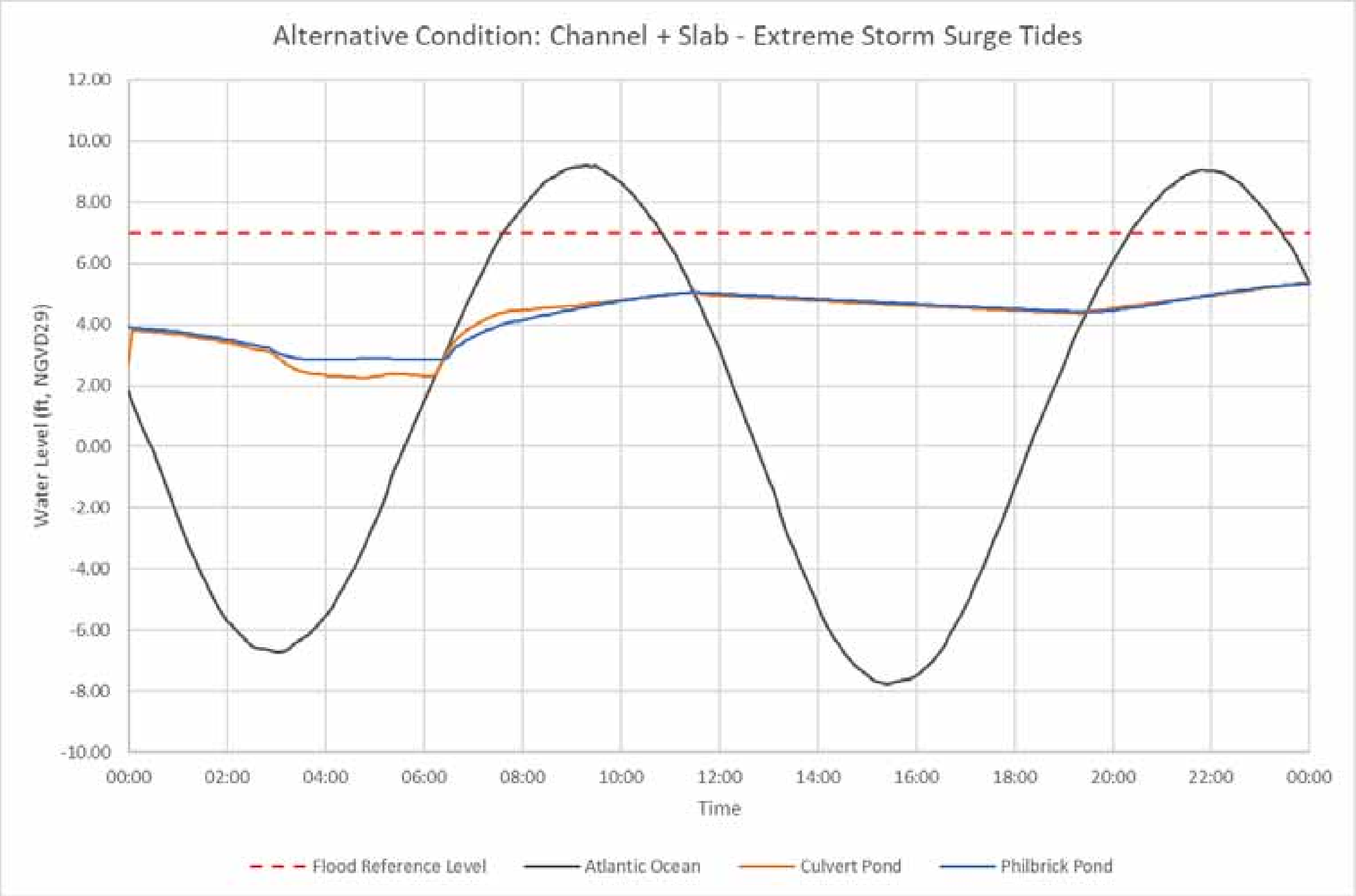
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Culvert Pond
Philbrick Pond

GOMEZ AND SULLIVAN ENGINEERS

PO Box 2179
Henniker, NH 03424
T. (603) 428 - 4960
(513) 560 - 9715 (Kevin)

MEMO

To: Craig Musselman (CMA)

From: Kevin Miller and John Hart (Gomez and Sullivan)

Date: October 30, 2017

Re: Philbrick Pond – Sea-Level Rise Analysis under Existing Conditions

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Background

In North Hampton, culverts passing under a berm for a former trolley line and State Route 1A transfer flow between the Philbrick Pond Marsh and the Atlantic Ocean. A small pond (i.e. termed the Culvert Pond for the purposes of this memo) exists between the downstream end of the trolley berm culvert and the upstream end of the Route 1A culvert. Gomez and Sullivan has been tasked with evaluating the hydraulics of these culverts under existing conditions and potential future alternatives. Each condition is to be evaluated under various combinations of tidal and hydrologic scenarios including future sea-level rise considerations. A memo dated September 29, 2017 outlined the development and calibration of a HEC-RAS model for the Philbrick Pond analysis. A memo dated October 3, 2017 presented the assumptions and results surrounding the analysis of existing conditions under three scenarios (i.e. normal tides, astronomical tides with precipitation, and extreme storm surge tides[1]). A memo dated October 20, 2017 presented the assumptions and results surrounding four potential future alternatives the same three scenarios as the existing conditions memo. This memo presents the assumptions and results surrounding the analysis of existing conditions under the same three scenarios as the existing conditions memo assuming four different sea-level rise scenarios.

Model Revisions

The sea-level rise scenarios were based on the New Hampshire Coastal Risk and Hazards Commission (NH-CRHC) report titled "Preparing New Hampshire for Projected Storm Surge, Sea-Level Rise and Extreme Precipitation: Final Report and Recommendations" dated November 2016. This report provided sea-level rise projections for the year 2050 and 2100 under three greenhouse gas emissions scenarios (i.e. Intermediate-Low, Intermediate-High, and Highest Conceivable). This study utilized the Intermediate-High Emissions and Highest Conceivable Emissions (i.e. termed Moderate Scenario and Highest Scenario for this memo). Table 1 provides the sea-level rise projections for each year and emission rate utilized in this study. These rises were applied directly to the tides utilized as the boundary condition thus far in the study. It should be noted that the report applies the sea-level rise projections to a base year of 1992. However, the normal tides for this study are based on 2017 data, the astronomical tides are based on the highest and lowest observed astronomical tides at the Fort Point, NH gage which occurred in 1995 and 1994 respectively, and the extreme storm surge tides are from the latest Federal Emergency Management Agency Flood Insurance Report dated May 17, 2005. These normal and astronomical tides would have already accounted for the estimated sea level rise of 1.3" per decade since 1992 as described in the NH-CRHC

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[1] The high tide for the Extreme Storm Surge Tides is based on the 100-Year Stillwater Elevation of the Atlantic Ocean reported in the Federal Emergency Management Agency's Flood Insurance Study for Rockingham County, NH.

report and thus the sea-level rises are considered slightly conservatively high. While it is unclear whether the extreme storm surge tides are based on any particular year, they are also considered conservatively high, since the report is dated 2005 and may have considered the small sea-level rise since 1992.

Table 1: Sea-Level Projections

Scenario	Rise (ft)
Current	-
2050 (Moderate Scenario)	+1.3
2050 (Highest Scenario)	+2.0
2100 (Moderate Scenario)	+3.9
2100 (Highest Scenario)	+6.6

The model includes two initial condition parameters: a) starting water surface elevation (i.e. stage) in Philbrick Pond, and b) starting flow in the channel between Philbrick Pond and the Atlantic Ocean (i.e. including flow through the trolley berm and Route 1A culverts). If, for example, the initial stage is too high the higher-high tide and lower-low tide for the first day of the normal tide simulation will also be too high. As such, the initial conditions are assessed such that the higher-high tide and lower-low tide are the same for each day of the simulation under normal tides.

It was noted during evaluation of sea-level rise on existing conditions, that each sea-level scenario required different initial conditions. However, each hydrologic scenario does not require different initial conditions, as each of these scenarios starts with the falling limb after a normal tide[2]. Table 2 provides the initial conditions for sea-level scenarios under existing conditions. It was also suspected and confirmed that each alternative condition may also need different initial conditions. As such a similar table with the new initial conditions for each alternative condition is provided in Attachment A.

Table 2: Initial Conditions

Sea-Level Scenario	Existing Conditions	
	Flow (cfs)	Stage (ft, NGVD 29)
Current	11	4.04
2050 (Moderate Scenario)	18	4.46
2050 (Highest Scenario)	22	4.80
2100 (Moderate Scenario)	31	5.98
2100 (Highest Scenario)	23	8.52

Additionally, based on preliminary results obtained during evaluation of sea-level rise under existing conditions, the model geometry was revised from the analysis presented in the October 20, 2017 memo. These revisions were to the layout of cross sections and storage areas upstream of the Route 1A culvert including Philbrick Pond. These model revisions did not have a significant impact on the calibration runs, and thus did not warrant re-evaluating the calibration parameters. The October 20, 2017 memo noted that the model required slight alterations to the model geometries for some alternative conditions to provide model stability[3]. However, the revised model geometry developed for this memo did not require similar slight alterations in model geometry to provide a stable model.

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[2] Two of the three hydrologic scenarios then transition to either an astronomical or extreme storm surge tide for a 24-hour period before returning to a normal tide.

[3] The differences in model geometry for model stability were to the interpolated cross sections downstream of the Route 1A culvert (i.e. in the Atlantic Ocean).

Finally, the tidal cycle for the extreme storm surge tides were changed after a review of data at the Fort Point, NH gage during historical nor'easters. This change involved increasing the extreme storm surge low tide such that the minimum tide was twice as high relative to a normal low tide as the extreme storm surge high tide is to a normal high tide. This is depicted in Figure 1 where the extreme storm surge high tide is approximately 4 feet higher than a normal high tide, and the extreme storm surge low tide is approximately 8 feet higher than the normal low tide.

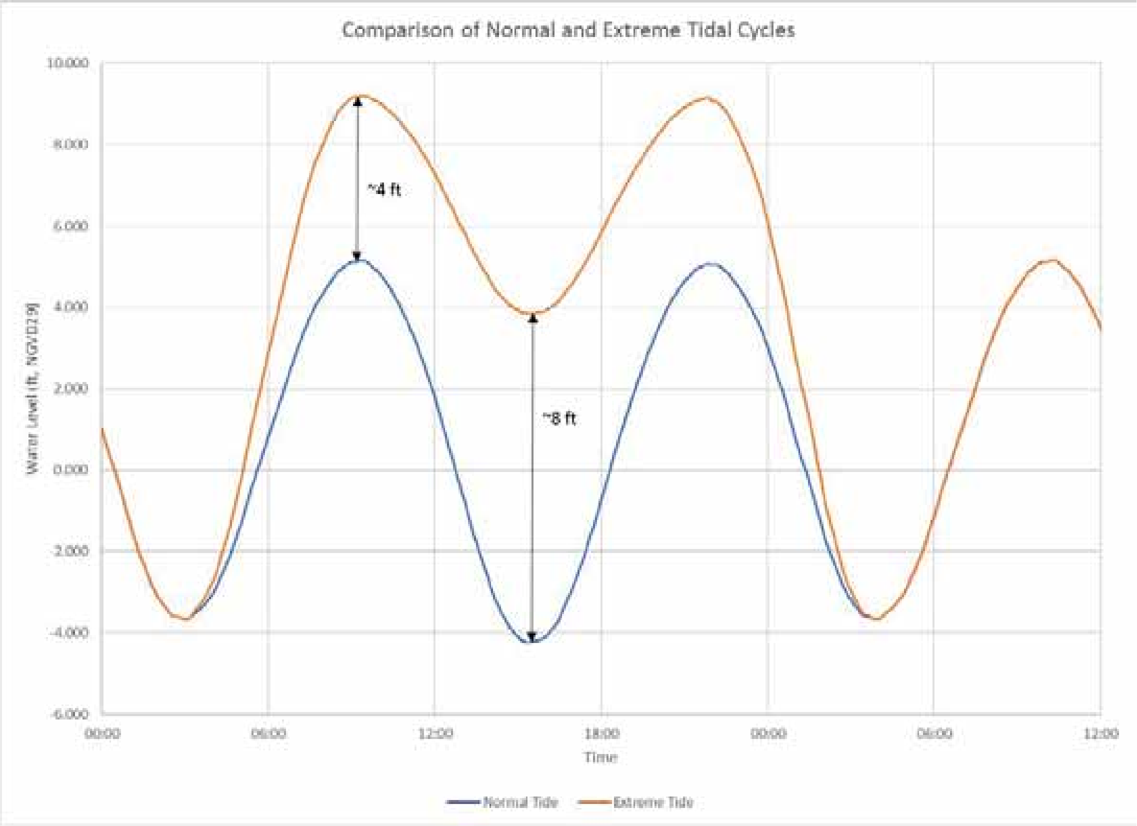

Figure 1: Comparison of Normal and Extreme Storm Surge Tidal Cycles

Results

The maximum and minimum water surface elevations reported in the October 20, 2017 memo were significantly impacted for the extreme storm surge tides scenario due to the change in tidal cycle. Additionally, due to the change in how the volume of off-channel storage available between the Route 1A and Trolley Berm culverts is computed, the revised model geometry resulted in significant impacts to the minimum water surface elevation of the Philbrick Pond under the Slab and Box + Slab conditions for the Normal Tides and Astronomical Tides + 100-Year Precipitation scenarios. Otherwise, the change in results was generally less than approximately 0.1 feet[4]. Attachment A provides updated tables and figures of the results presented in the October 20, 2017 memo. It should be noted that the figures depicting the extreme storm surge tide scenarios were somewhat altered to show the transition back to a normal tide.

A number of figures are provided in Attachment B, which show results for the existing conditions under current and projected sea-levels, for five sea-level scenarios. These figures utilize the same elevation scale to better compare results. Additionally, a flood referenced level is provided on each figure at 7.0 feet, which is approximately the elevation at which the Old Locke Road begins to flood. Each of these five sea-

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[4] It should be noted that the minimum water surface elevations are different from those reported in the October 20, 2017 memo for the Astronomical Tides + 100-Year Precipitation scenario due to a change in how this value is reported.

level scenarios includes a figure for each of the three hydrologic scenarios, for a total of 15 figures. Some additional results are also presented in Tables 3 and 4, below. It should be noted that the minimum water surface elevations are computed as the minimum level to occur between hour 10 and 24 in the simulation to evaluate drawdown after increased tides/initiation of inflow from rainfall, as the absolute minimum water surface elevations for the Astronomical Tides + 100-Year Precipitation and Extreme Storm Surge Tide scenarios is equal to that of the Normal Tides scenario because the ponds eventually stabilize back to levels corresponding to Normal Tides.

Table 3: Maximum Water Surface Elevation (ft, NGVD29) under Existing Conditions

Seal-Level Scenario	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current	4.1	5.0	7.8	7.2	5.2	8.1
2050 (Moderate Scenario)	4.5	6.2	8.0	8.1	6.0	8.3
2050 (Highest Scenario)	4.8	6.8	8.2	8.3	6.5	8.3
2100 (Moderate Scenario)	6.0	8.1	8.8	8.8	7.9	8.4
2100 (Highest Scenario)	8.5	8.5	10.3	10.3	10.3	10.3

Table 4: Minimum Water Surface Elevation (ft, NGVD29) under Existing Conditions [1]

Sea-Level Scenario	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current	3.7	3.6	4.0	3.8	4.4	4.1
2050 (Moderate Scenario)	4.2	3.9	4.4	4.0	4.7	4.3
2050 (Highest Scenario)	4.5	4.0	4.7	4.1	5.0	4.5
2100 (Moderate Scenario)	5.7	4.4	5.9	4.4	6.3	4.9
2100 (Highest Scenario)	8.0	5.6	8.2	6.0	8.8	8.9

<u>Notes</u>:

1. Water Surface Elevation taken between hour 10 and 24 in the simulation to evaluate drawdown after increased tides/initiation of inflow from rainfall, as the absolute minimum drawdown for Astronomical and Extreme Storm Surge Tide scenarios is equal to that of the Normal Tides scenario because the ponds stabilize back to normal condition after the extreme storm surge tides pass.

While sea-level rise results in higher water surface elevations, and longer time to drain after a rainfall event, there is not a 1:1 relationship between increase in sea-level and increase in pond water surface elevations. These results also show that Old Locke Road would always be inundated by the Philbrick Pond under existing conditions for a sea-level rise of 6.6 feet, corresponding to the 2100 (Highest Scenario) sea-level scenario.

The model shows that for extreme storm surge tides under the 2100 (Highest Scenario) scenario, water overtops Route 1A at a section of lower lying area approximately 550 feet in length. The roadway is overtopped for approximately 2 hours for each of the high tides, during which enough volume enters to increase the Philbrick Pond water level by approximately 0.2 to 0.3 feet during each high tide. It should be noted that additional flow may enter the Philbrick Pond during the extreme storm surge tides under the 2100 (Highest Scenario) scenario, as the model does not include approximately 215 linear feet of area along Route 1A which is lower than elevation 16 feet. This area is located approximately 0.5 miles north of the Route 1A culvert. However, this is not expected to significantly impact the results of the analysis.

Attachment A – Updated Results for Alternative Conditions under Current Sea-Levels

Table A-1: Initial Conditions

Condition	Current Sea-Levels	
	Flow (cfs)	Stage (ft, NGVD29)
Existing	11	4.04
Slab	19	4.05
Box	14	4.09
Box + Slab	19	4.09
Channel + Slab	27	4.09

Table A-2: Maximum Water Surface Elevation (ft, NGVD29) under Current Sea-Levels

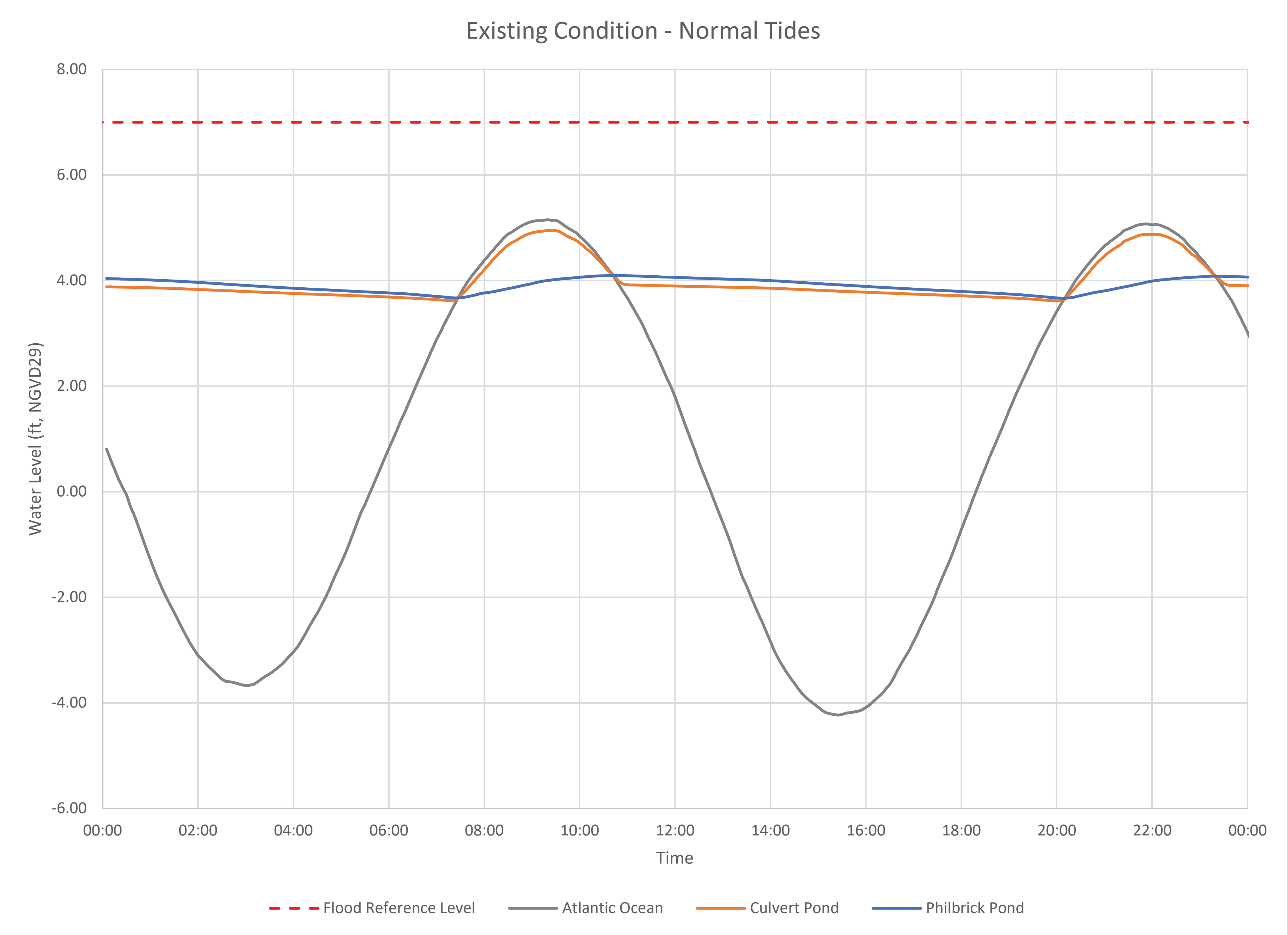
Condition	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Existing	4.1	5.0	7.8	7.2	5.2	8.1
Slab	4.1	5.0	7.7	7.2	5.2	8.1
Box	4.2	4.3	7.2	7.2	6.0	6.5
Box + Slab	4.2	4.4	7.2	7.2	6.0	6.5
Channel + Slab	4.2	4.3	7.1	7.1	6.1	6.1

Table A-3: Minimum Water Surface Elevation (ft, NGVD29) under Current Sea-Levels[1]

Condition	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Existing	3.7	3.6	4.0	3.8	4.4	4.1
Slab	2.8	2.3	3.8	3.5	4.3	4.0
Box	3.7	3.7	4.0	4.0	4.8	4.9
Box + Slab	2.8	2.3	3.9	3.8	4.8	4.9
Channel + Slab	2.8	2.3	3.9	3.9	4.9	5.0

Notes:

1. Water Surface Elevation taken between hour 10 and 24 in the simulation to evaluate drawdown after increased tides/initiation of inflow to Philbrick Pond due to rainfall, as the absolute minimum drawdown for Astronomical and Extreme Storm Surge Tide scenarios is equal to that of the Normal Tides scenario because the ponds stabilize back to normal condition after the extreme storm surge tides pass.


Existing Condition - Normal Tides
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6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
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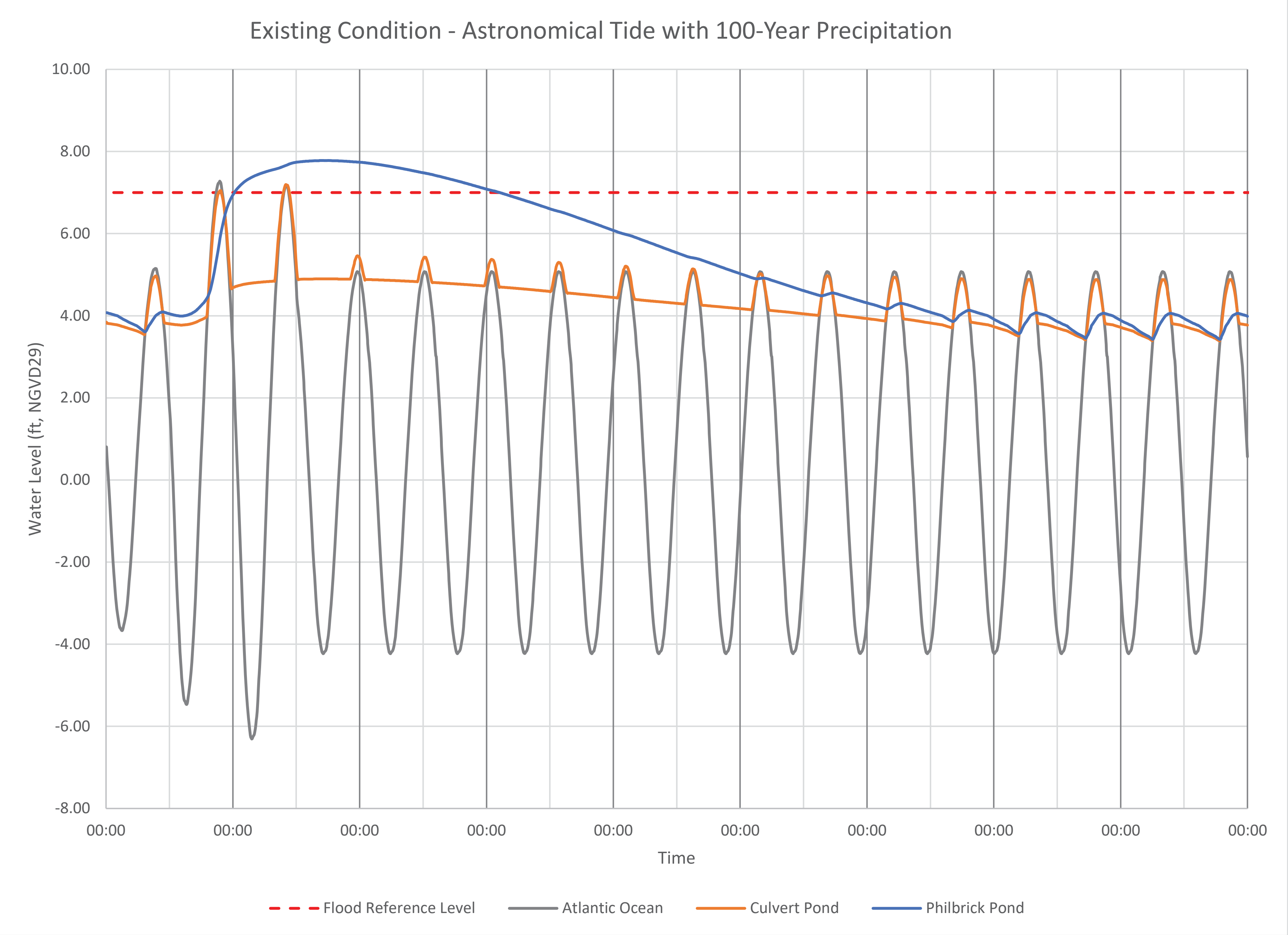
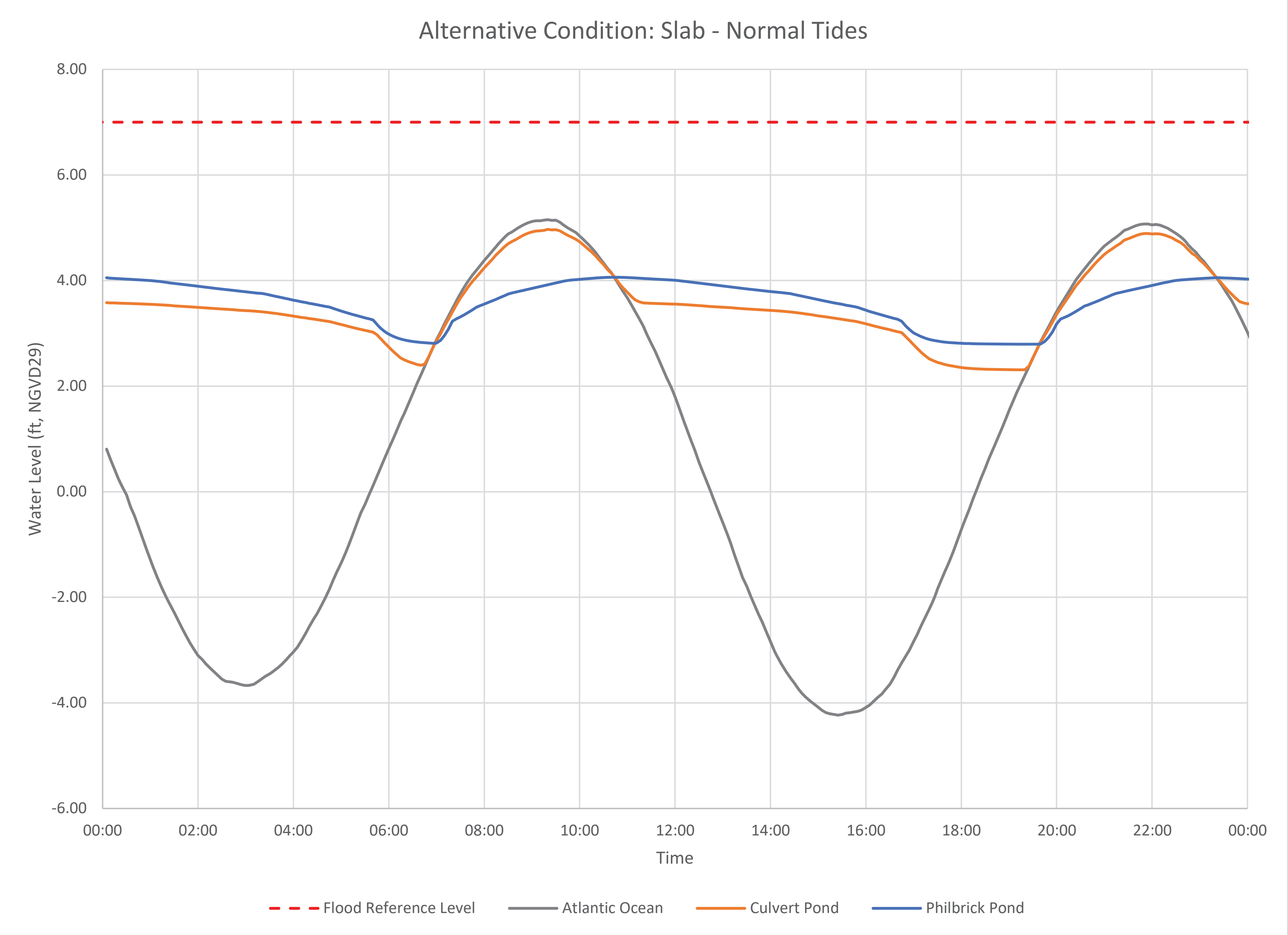
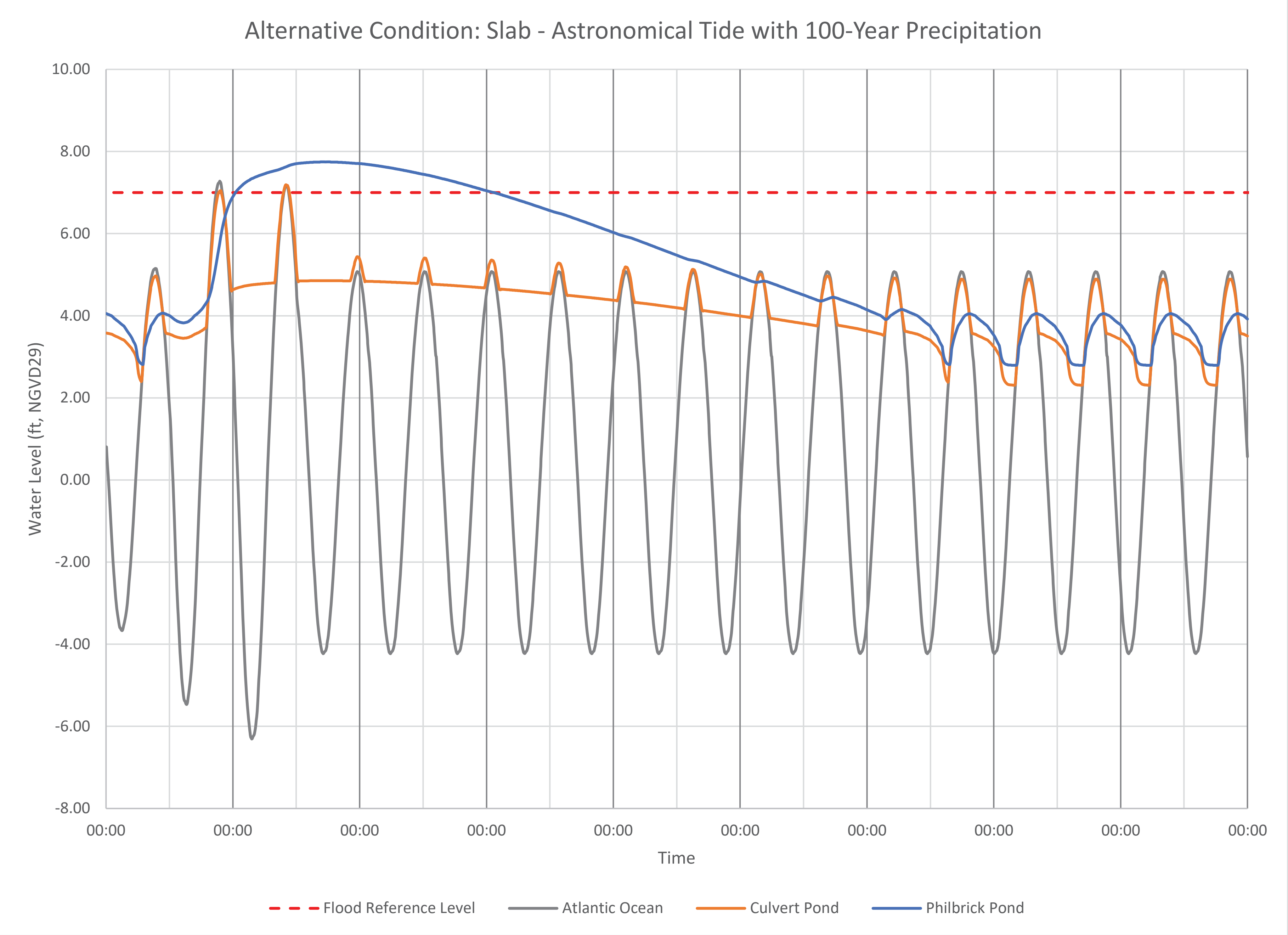
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond

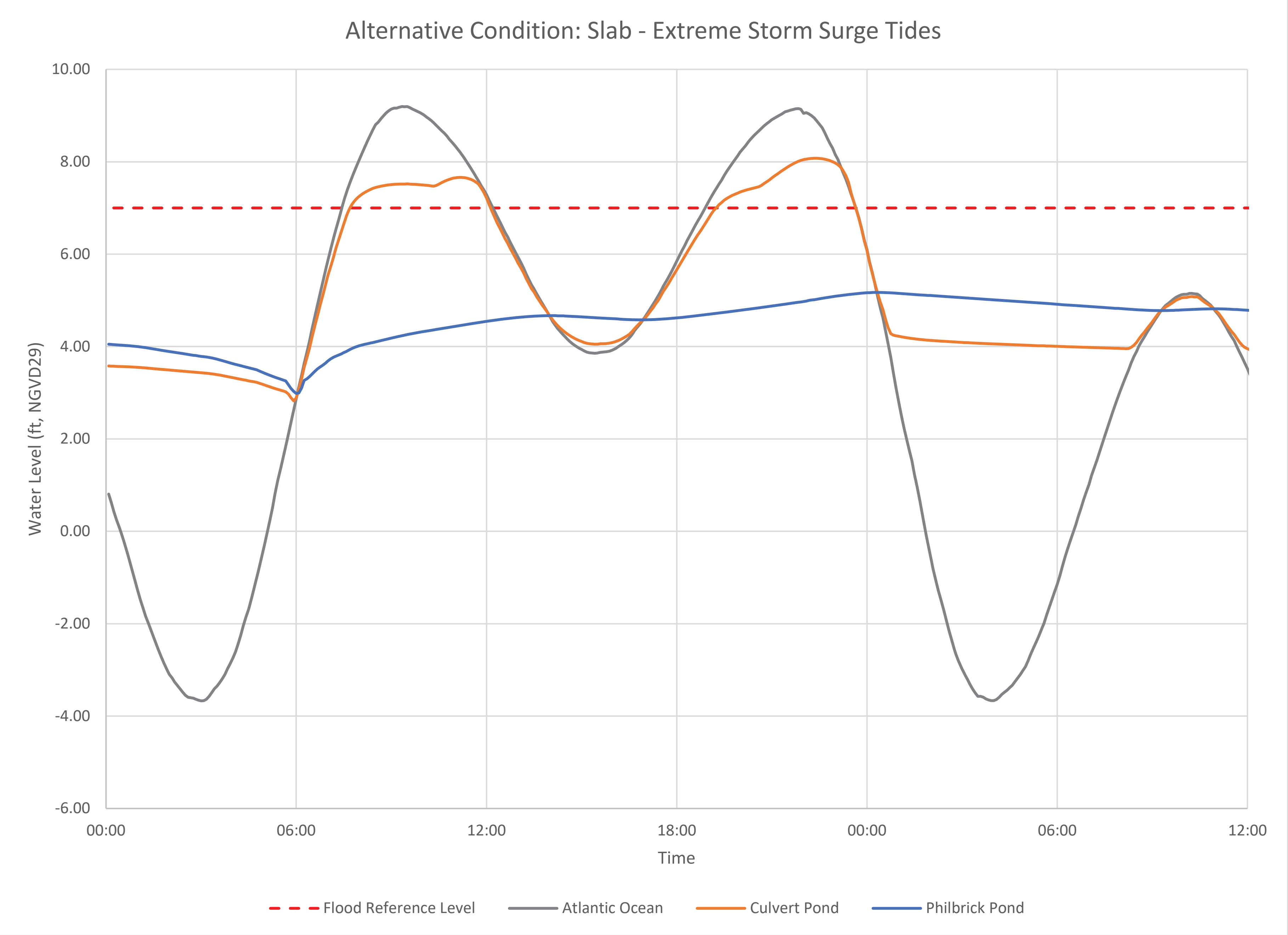


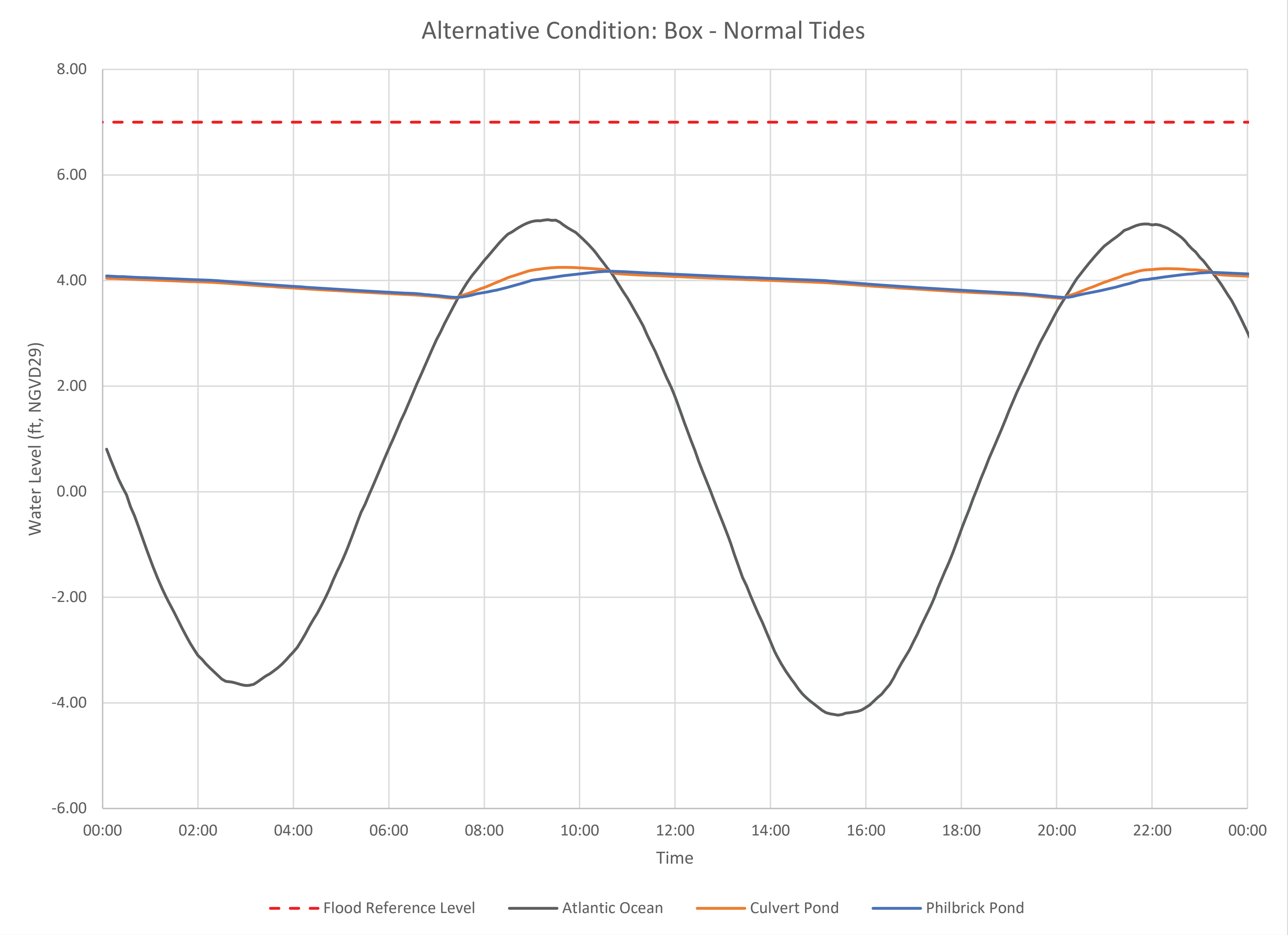
Existing Condition - Astronomical Tide with 100-Year Precipitation
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Existing Condition - Extreme Storm Surge Tides
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
00:00
06:00
12:00
18:00
00:00
06:00
12:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Normal Tides
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Astronomical Tide with 100-Year Precipitation
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Extreme Storm Surge Tides
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
00:00
06:00
12:00
18:00
00:00
06:00
12:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box - Normal Tides
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6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
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02:00
04:00
06:00
08:00
10:00
12:00
14:00
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18:00
20:00
22:00
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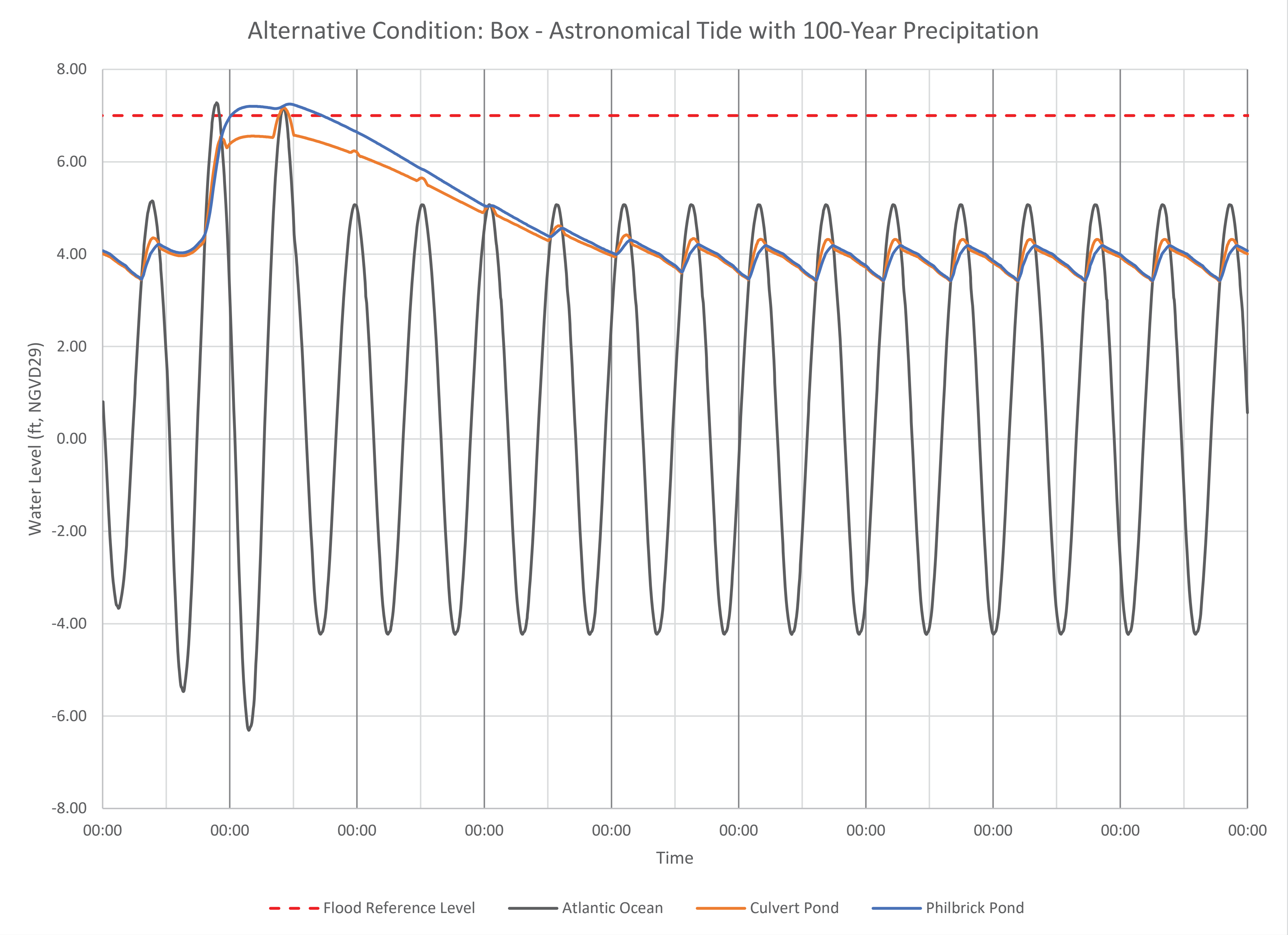
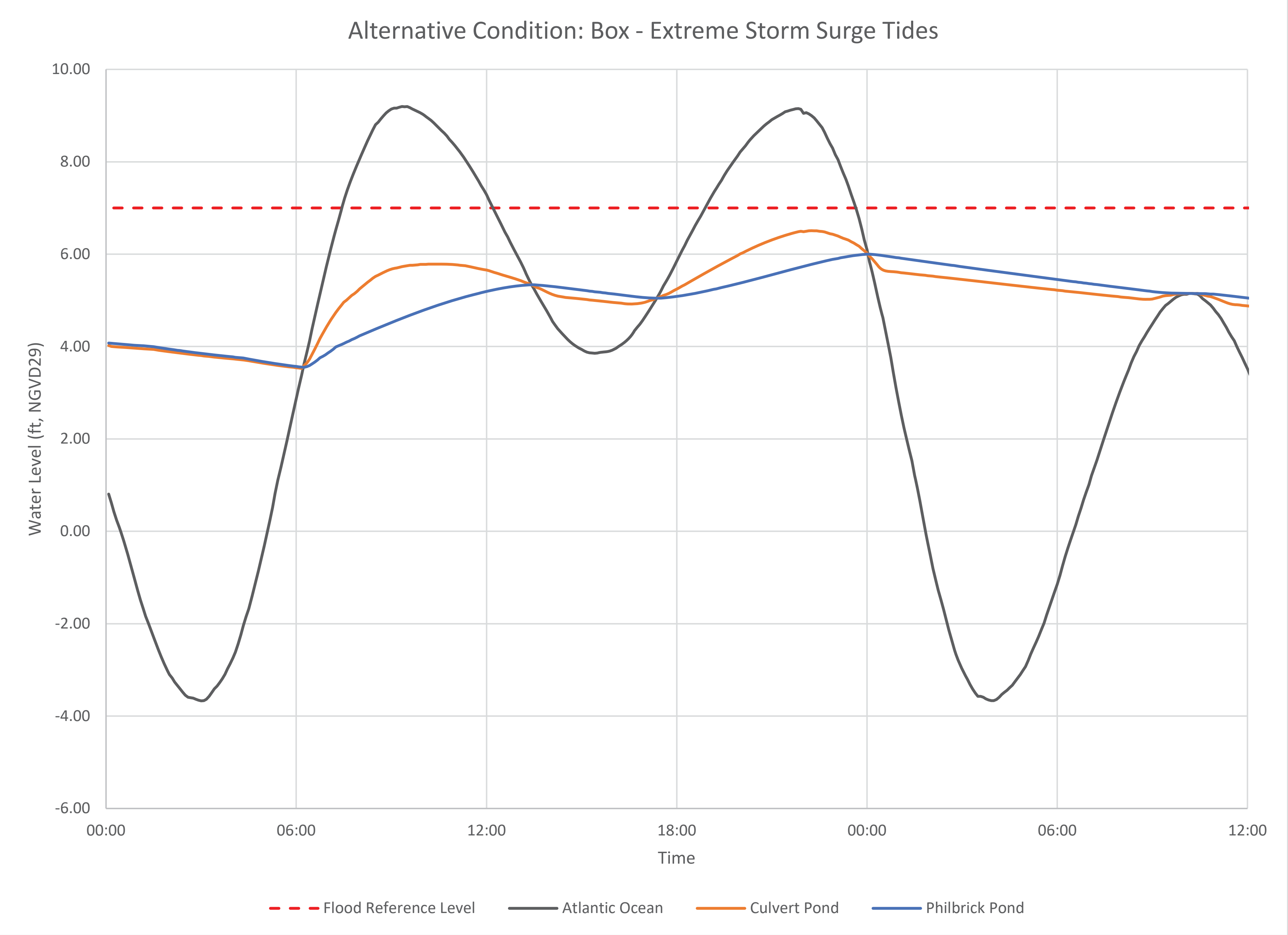
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box - Astronomical Tide with 100-Year Precipitation
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box - Extreme Storm Surge Tides
Water Level (ft, NGVD29)
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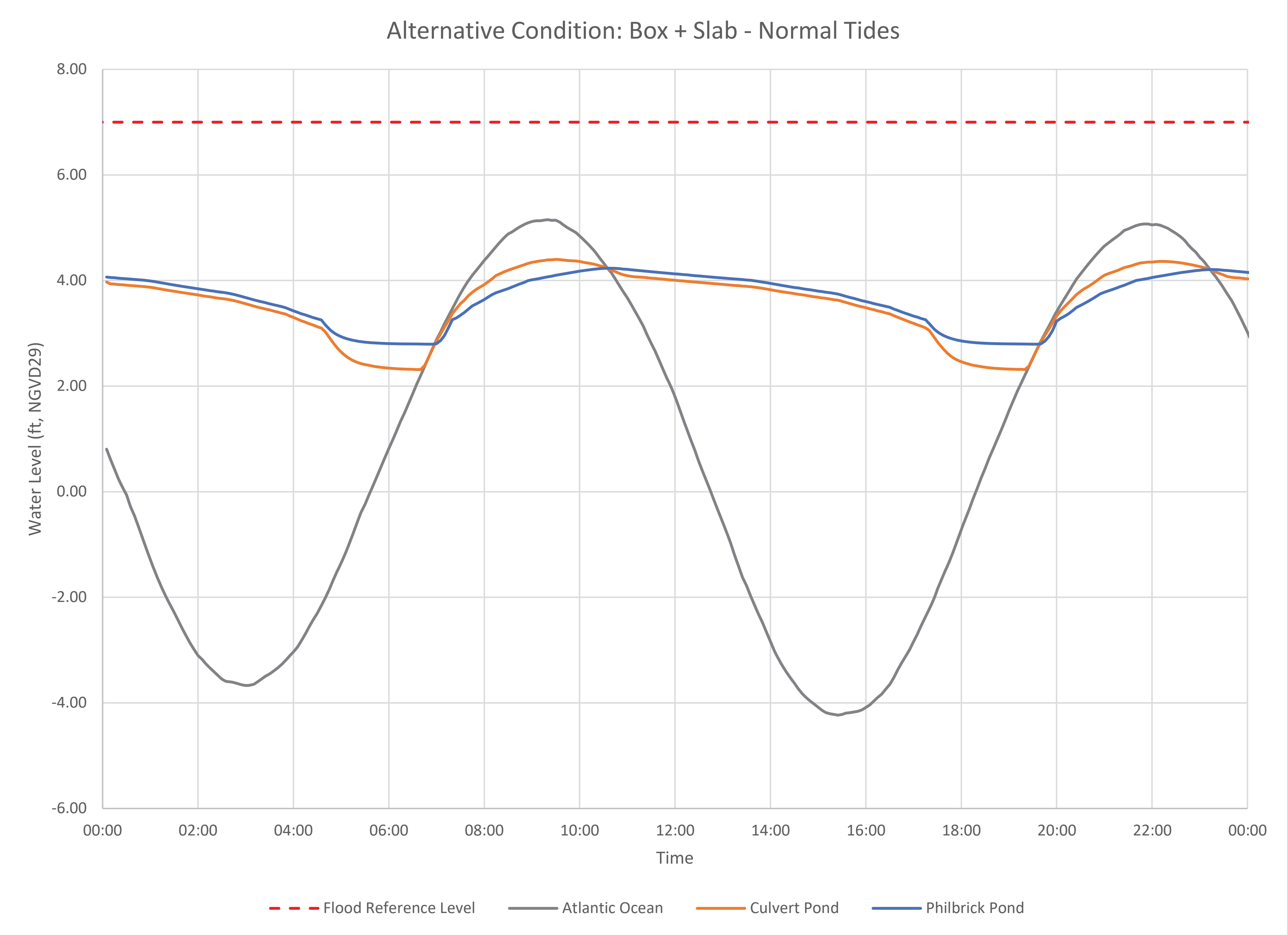
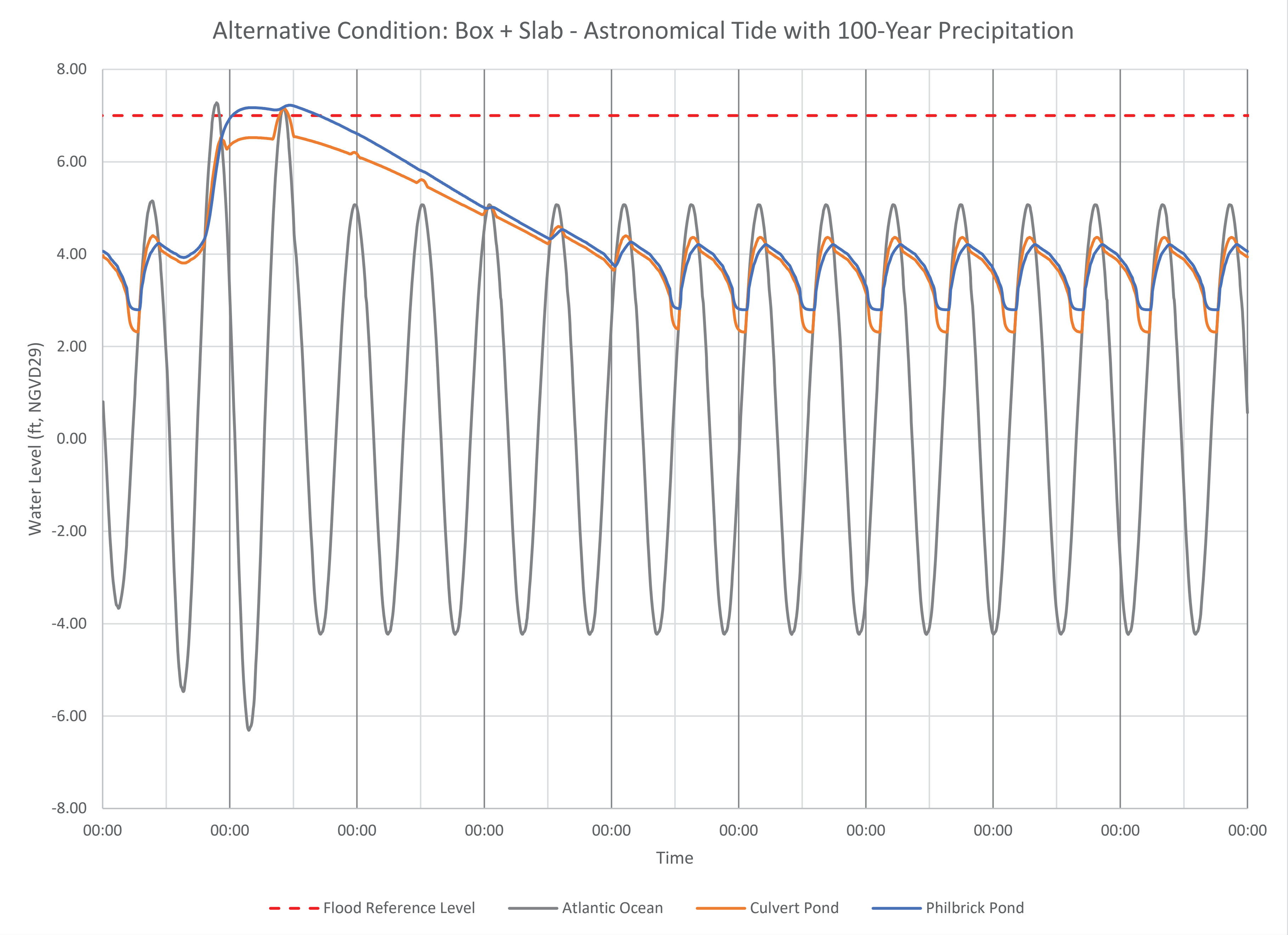
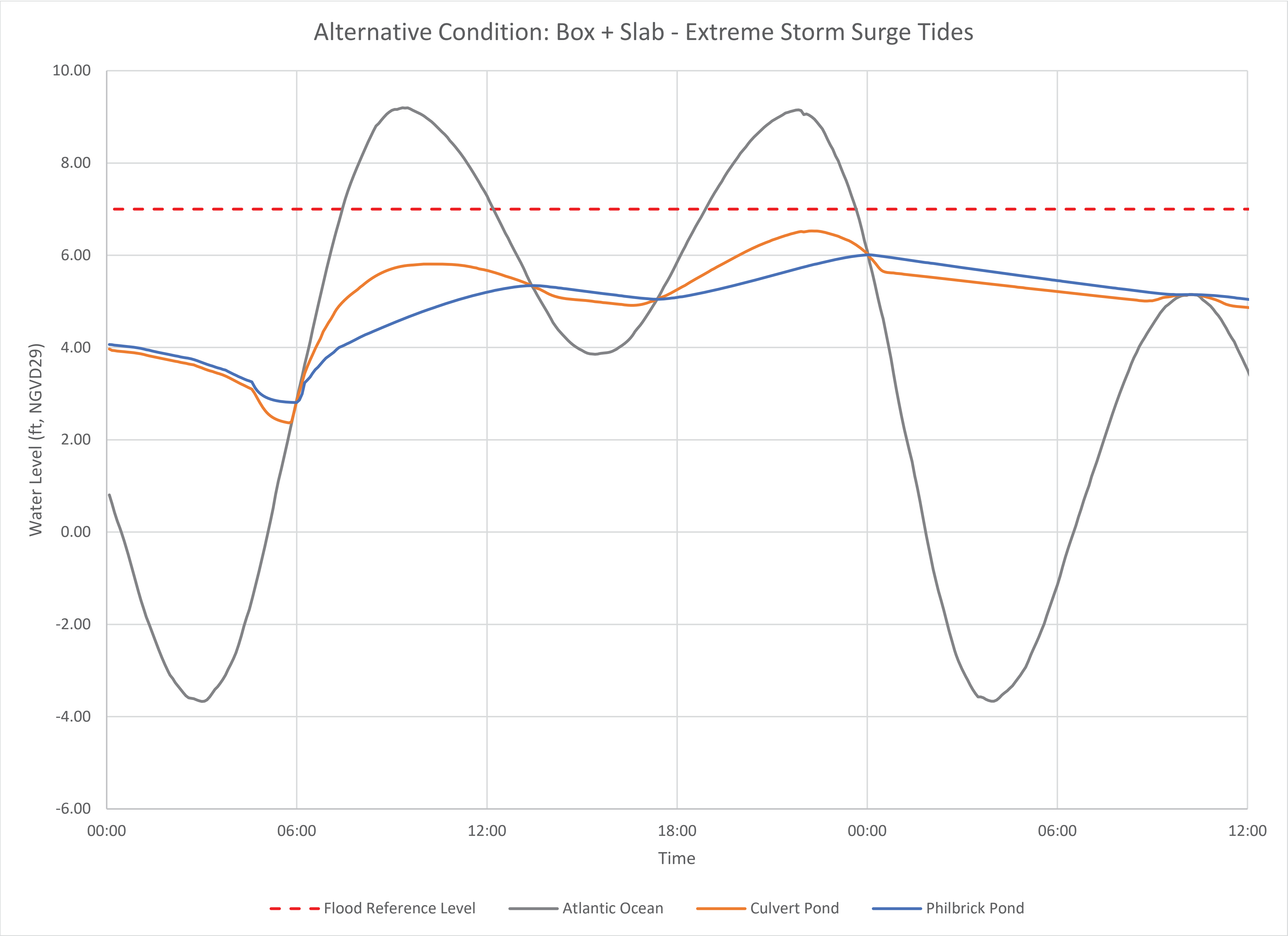
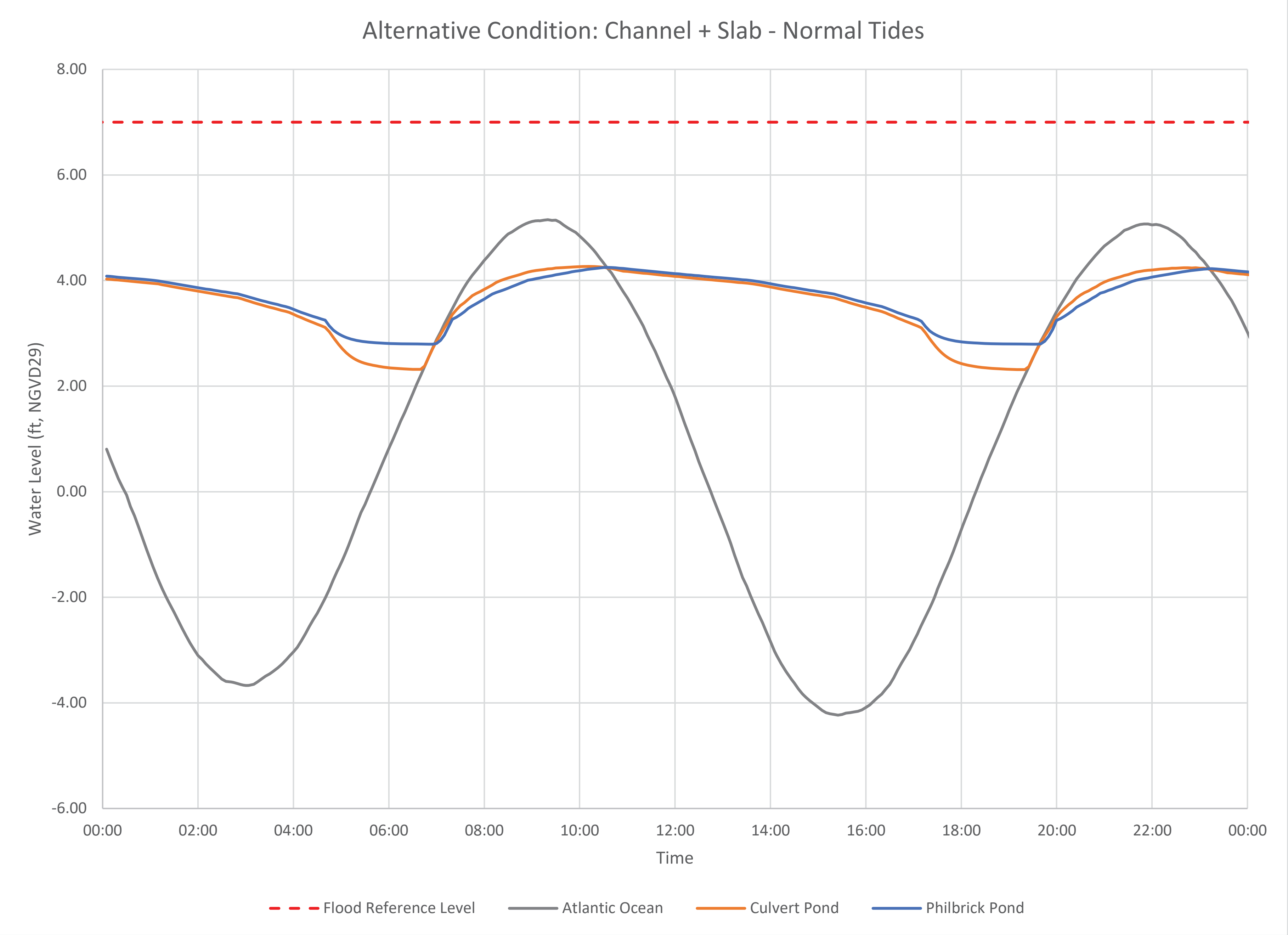
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
00:00
06:00
12:00
18:00
00:00
06:00
12:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box + Slab - Normal Tides
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box + Slab - Astronomical Tide with 100-Year Precipitation
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box + Slab - Extreme Storm Surge Tides
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
00:00
06:00
12:00
18:00
00:00
06:00
12:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Channel + Slab - Normal Tides
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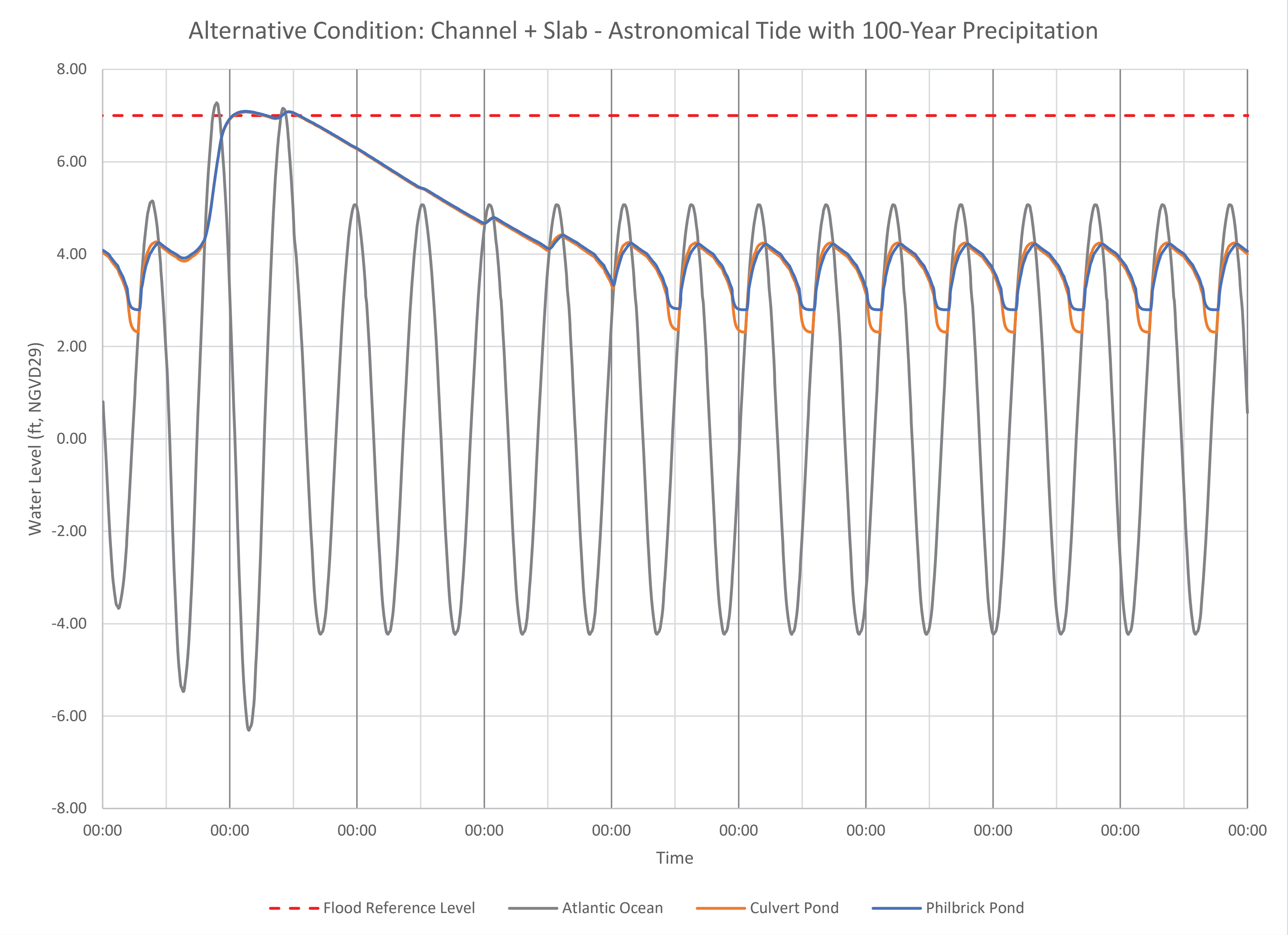
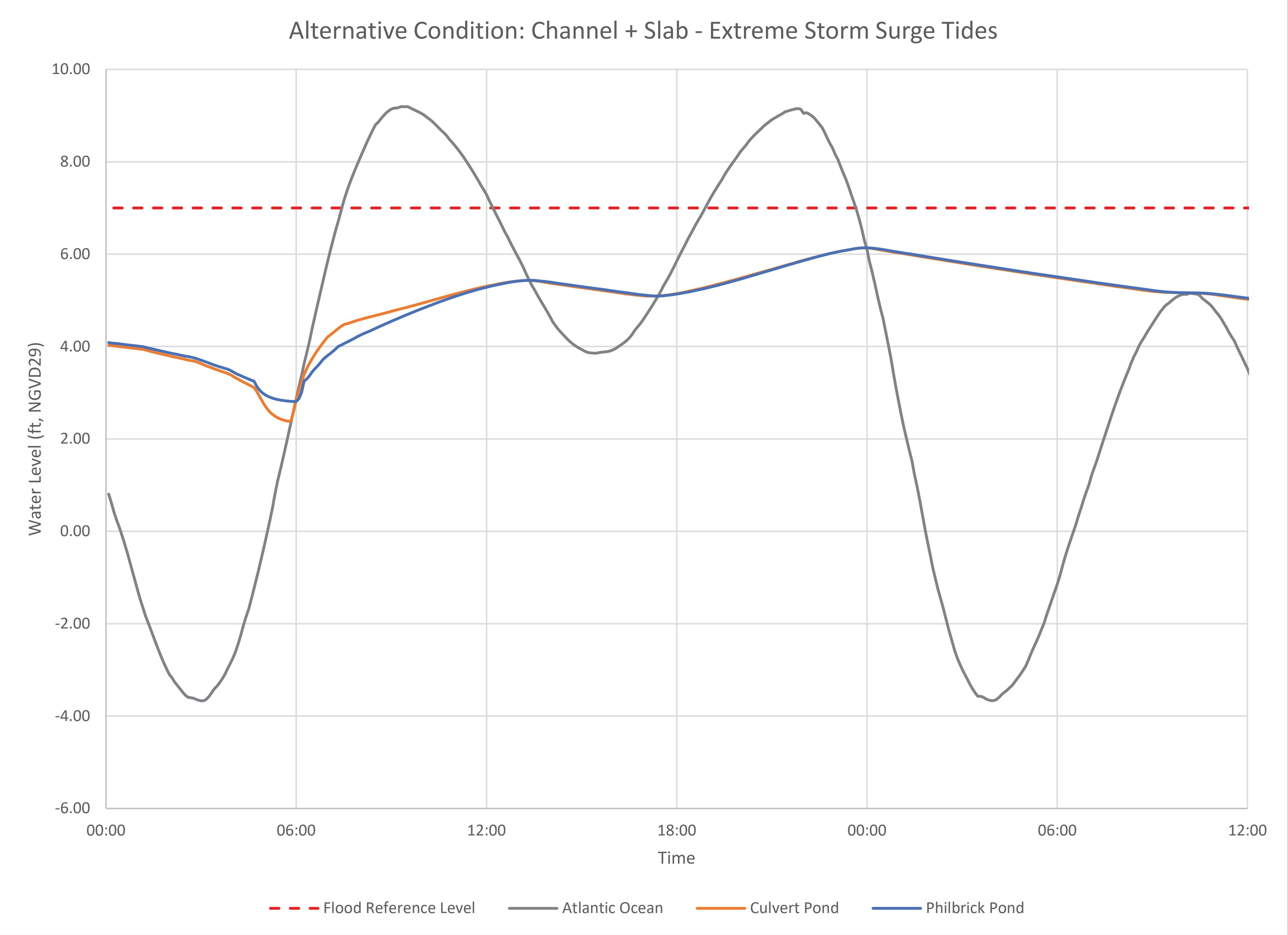
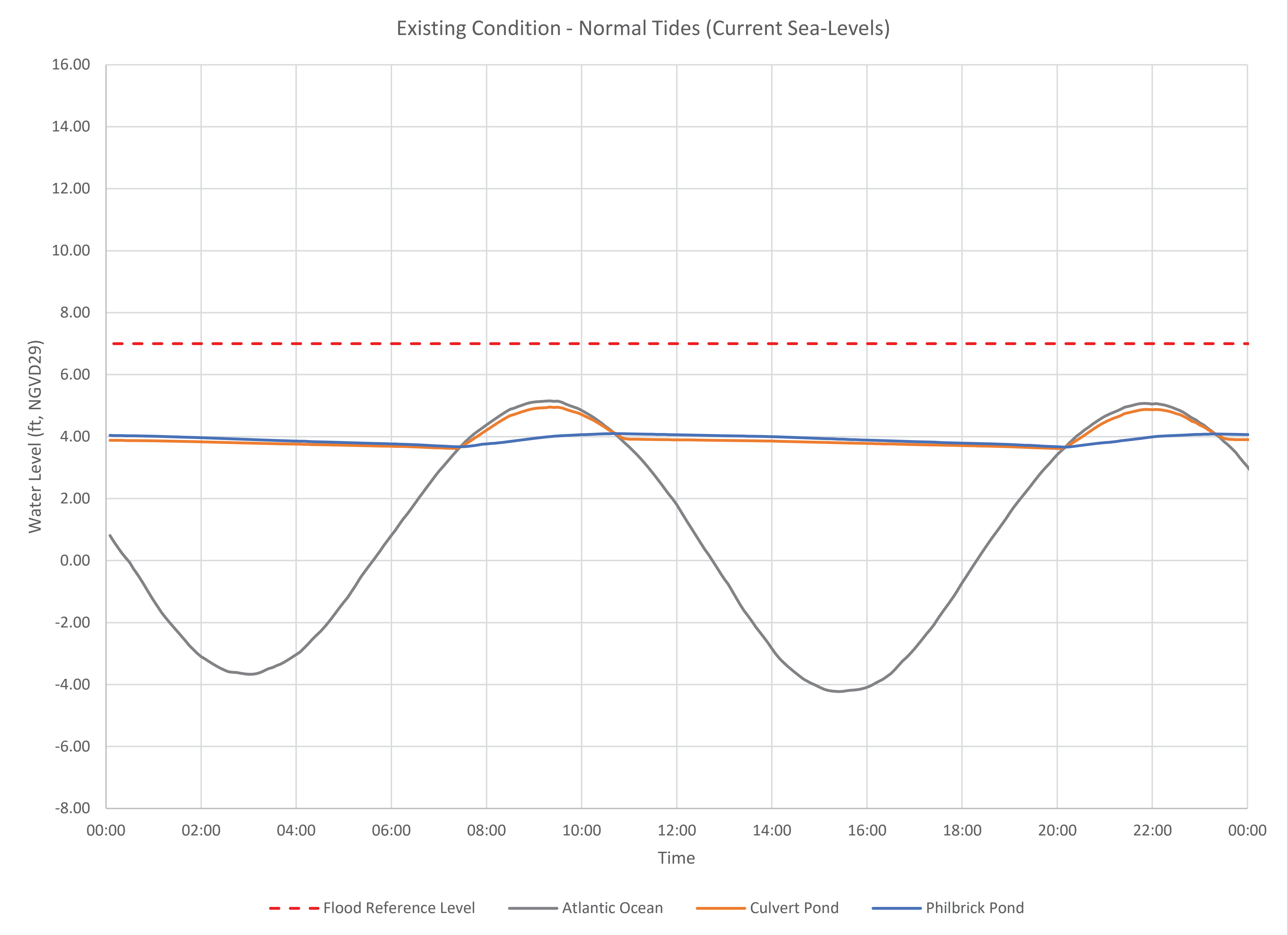
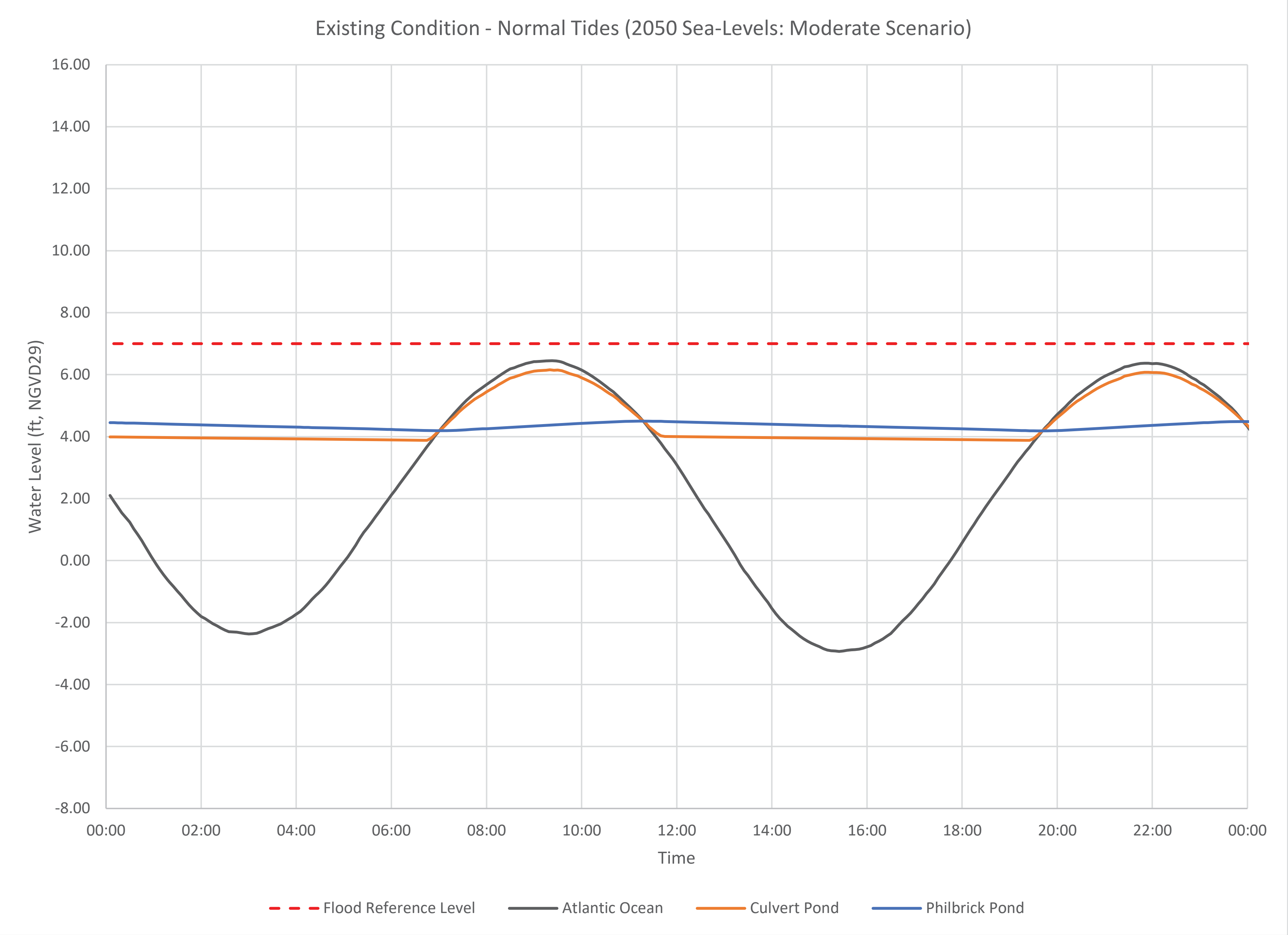
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Channel + Slab - Astronomical Tide with 100-Year Precipitation
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond

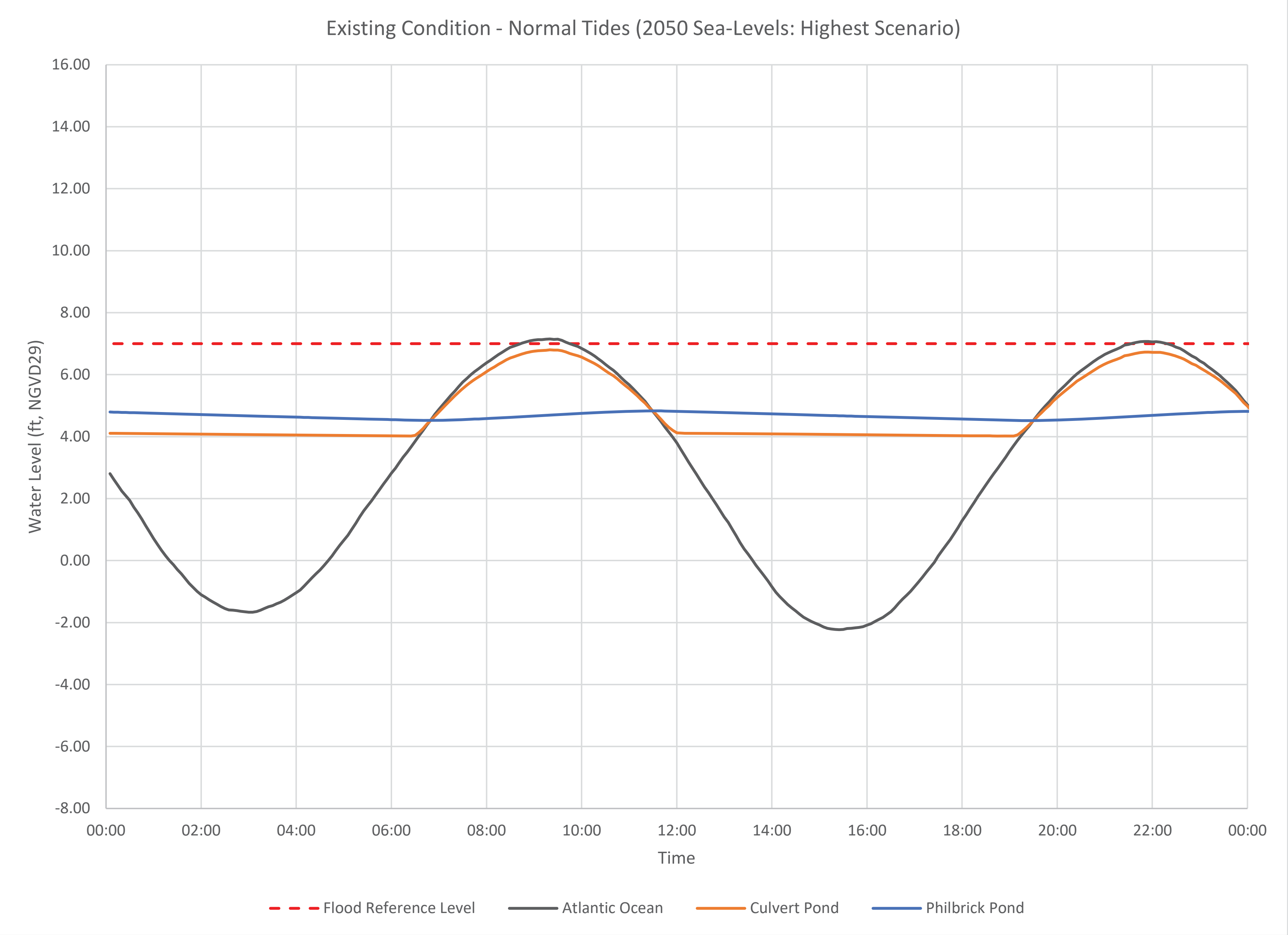

Alternative Condition: Channel + Slab - Extreme Storm Surge Tides
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
Water Level (ft, NGVD29)
00:00
06:00
12:00
18:00
00:00
06:00
12:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond

Attachment B –Results for Existing Conditions under various Sea-Levels


Existing Condition - Normal Tides (Current Sea-Levels)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond



Existing Condition - Normal Tides (2050 Sea-Levels: Moderate Scenario)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond



Existing Condition - Normal Tides (2050 Sea-Levels: Highest Scenario)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
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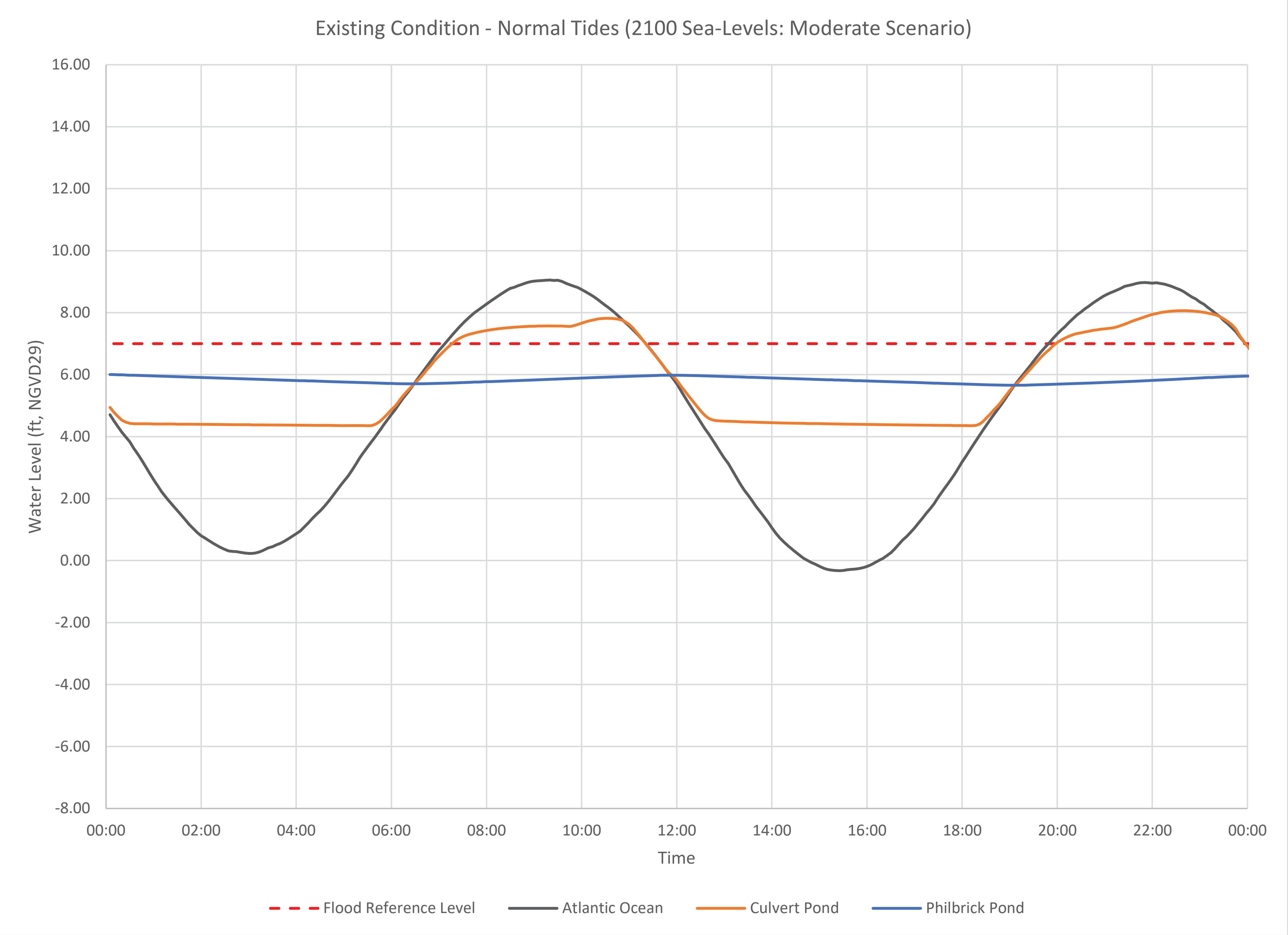
Philbrick Pond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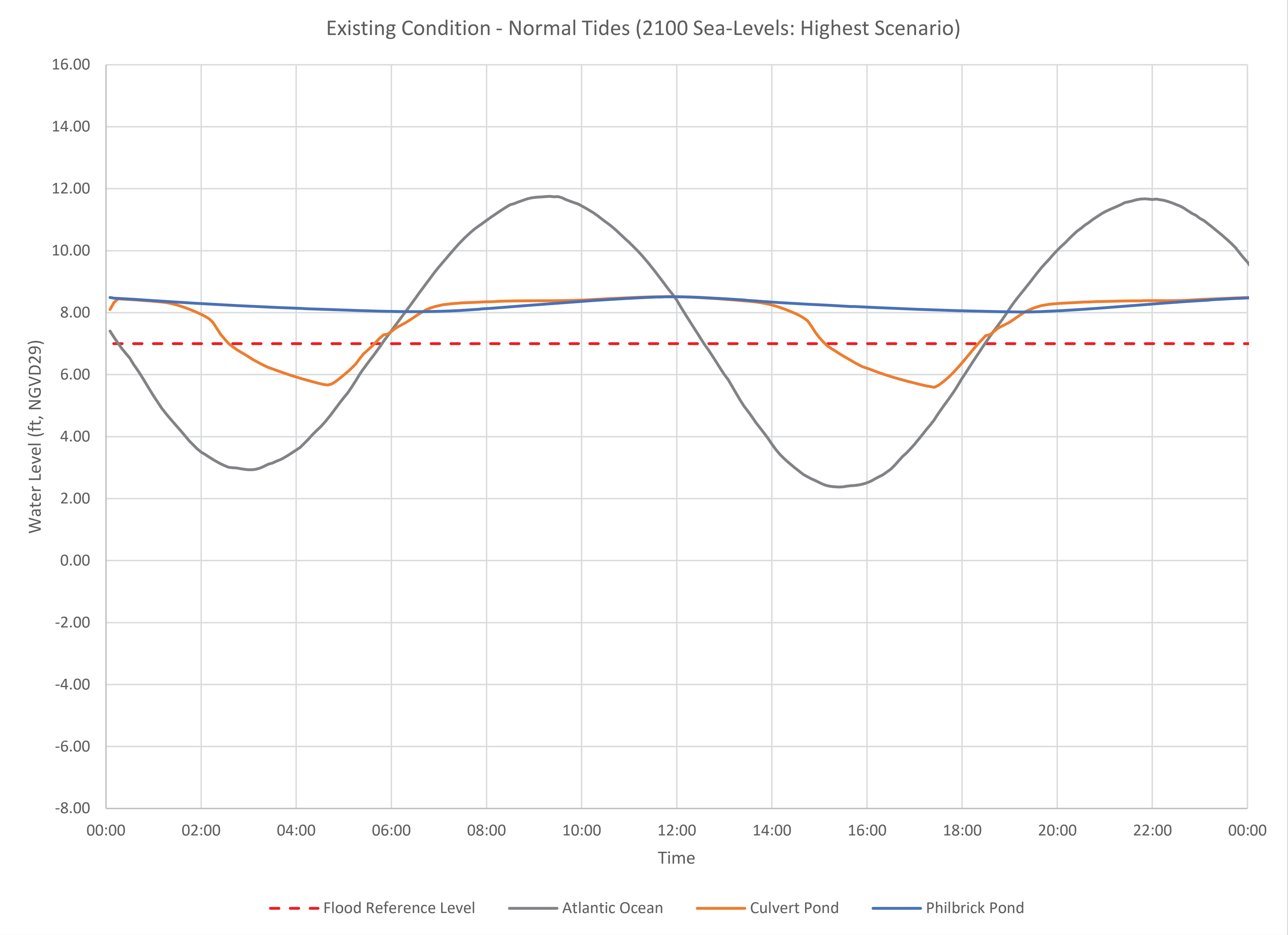
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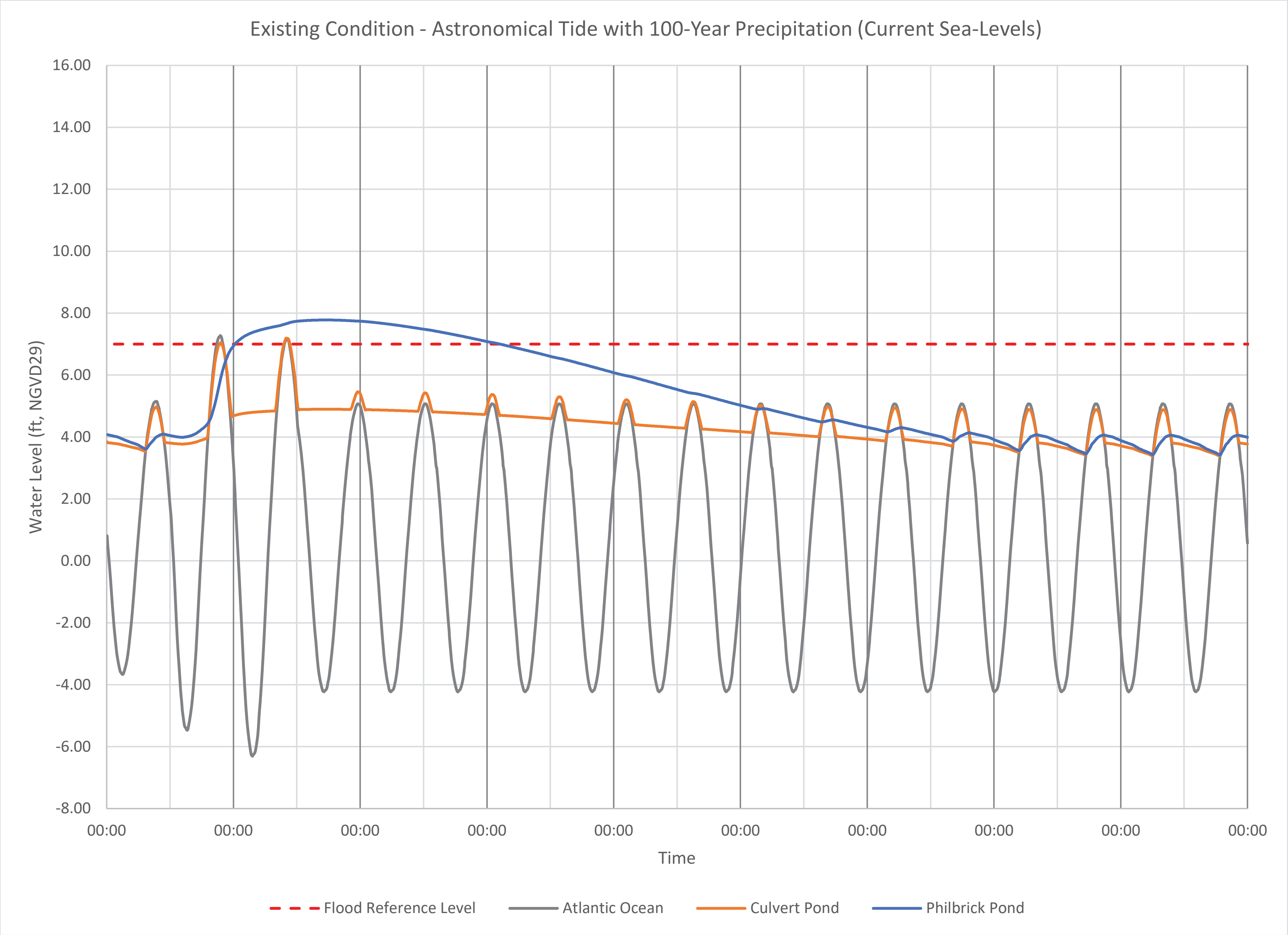
Philbrick Pond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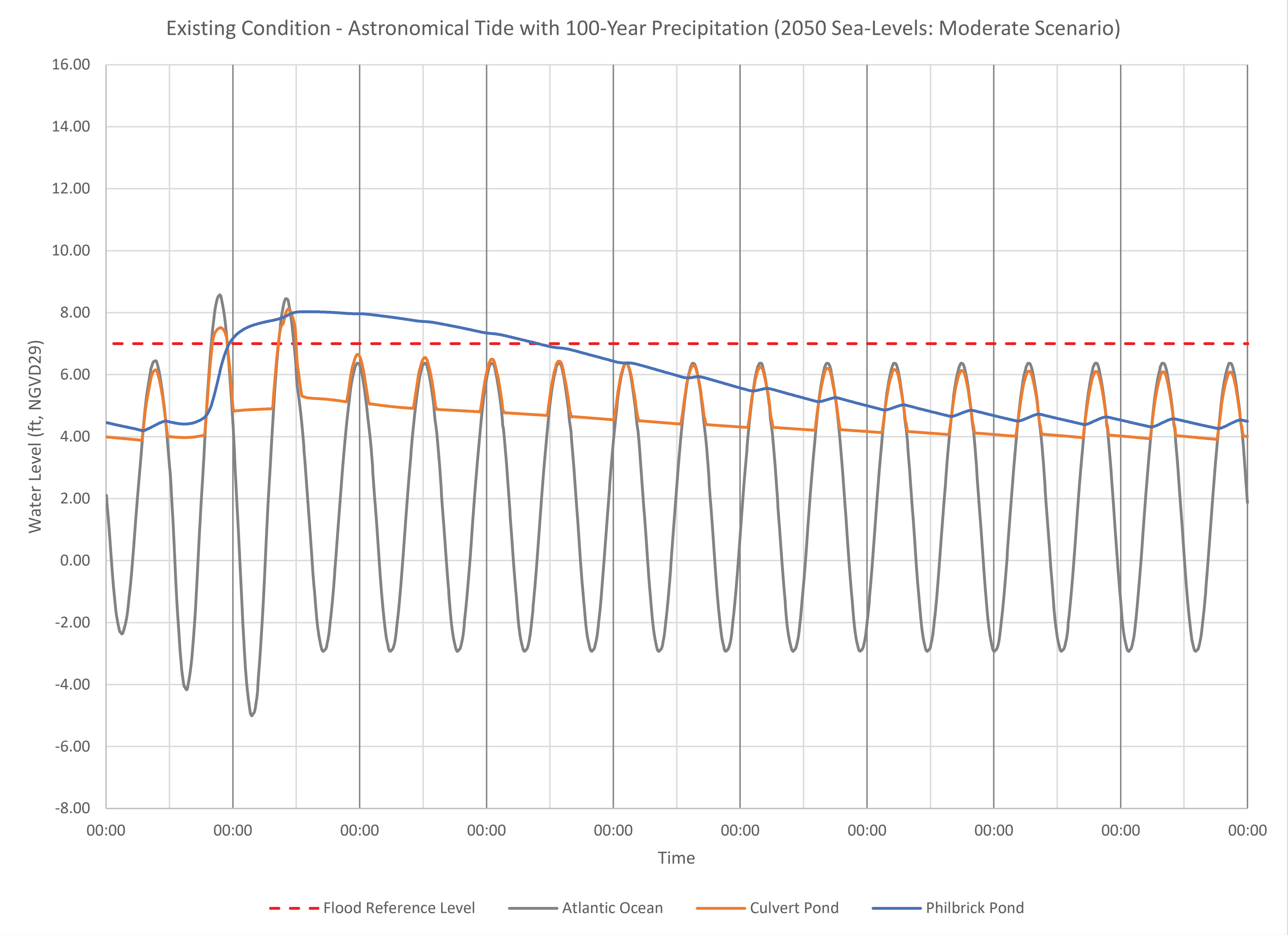
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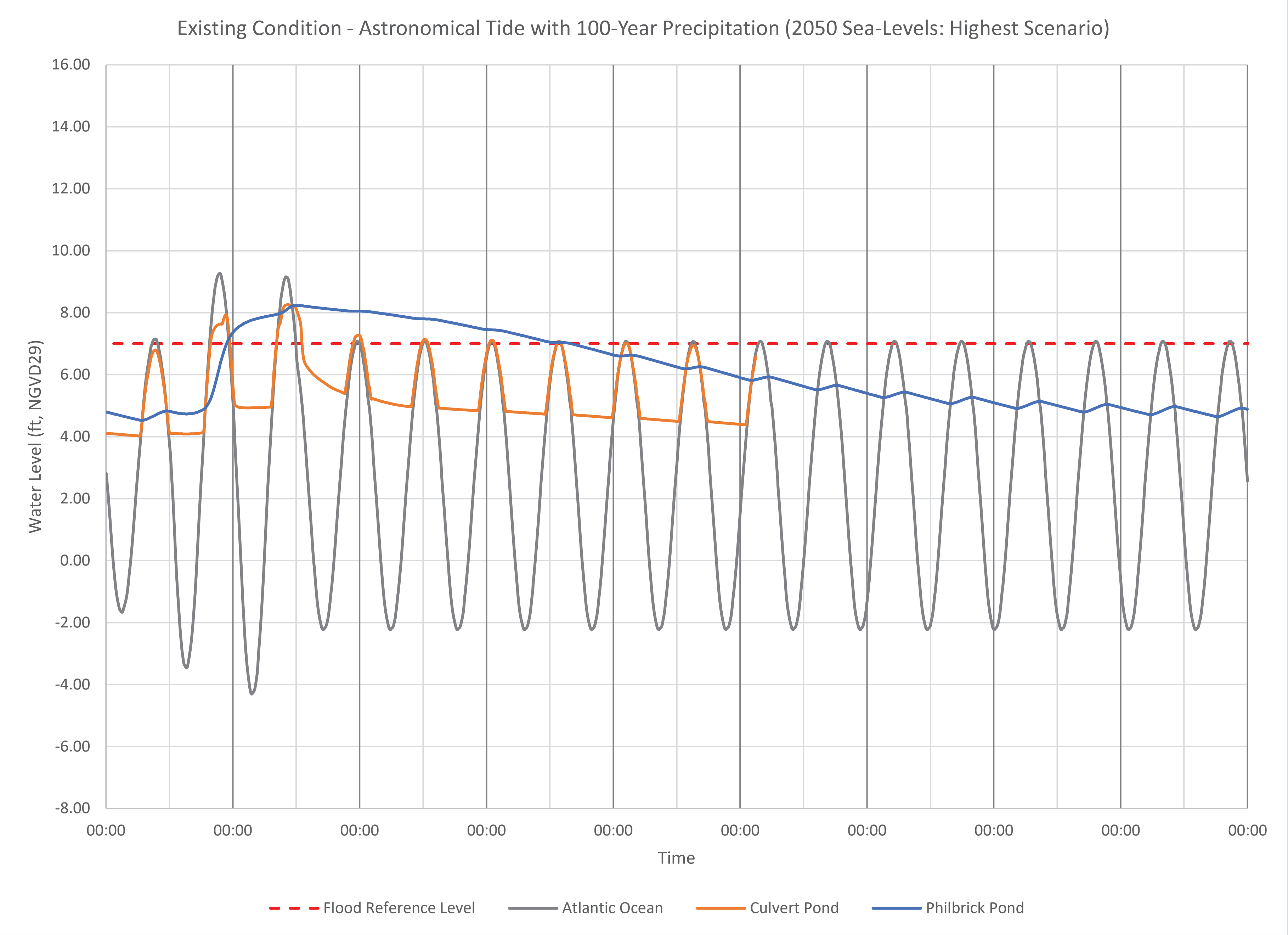
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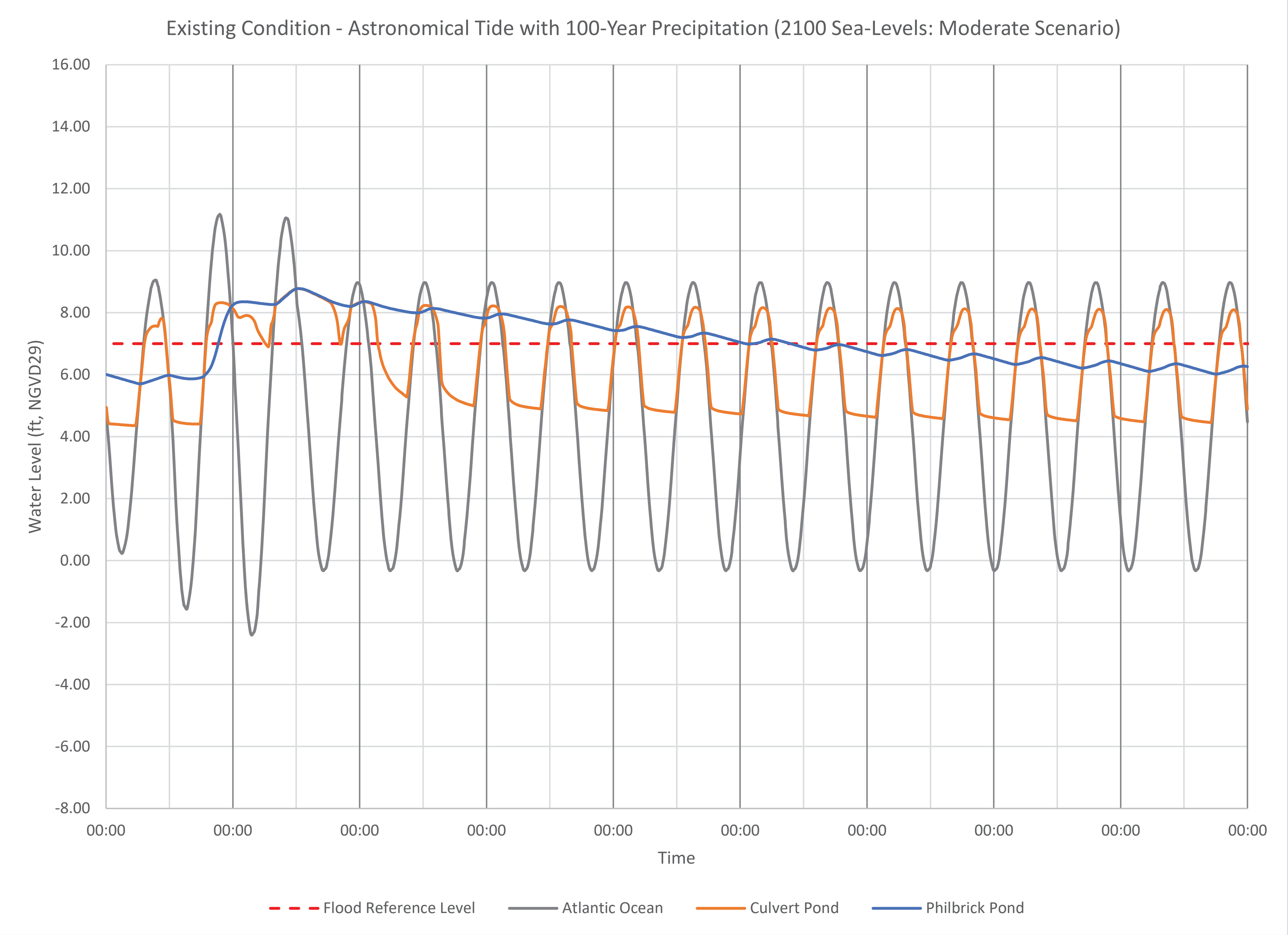
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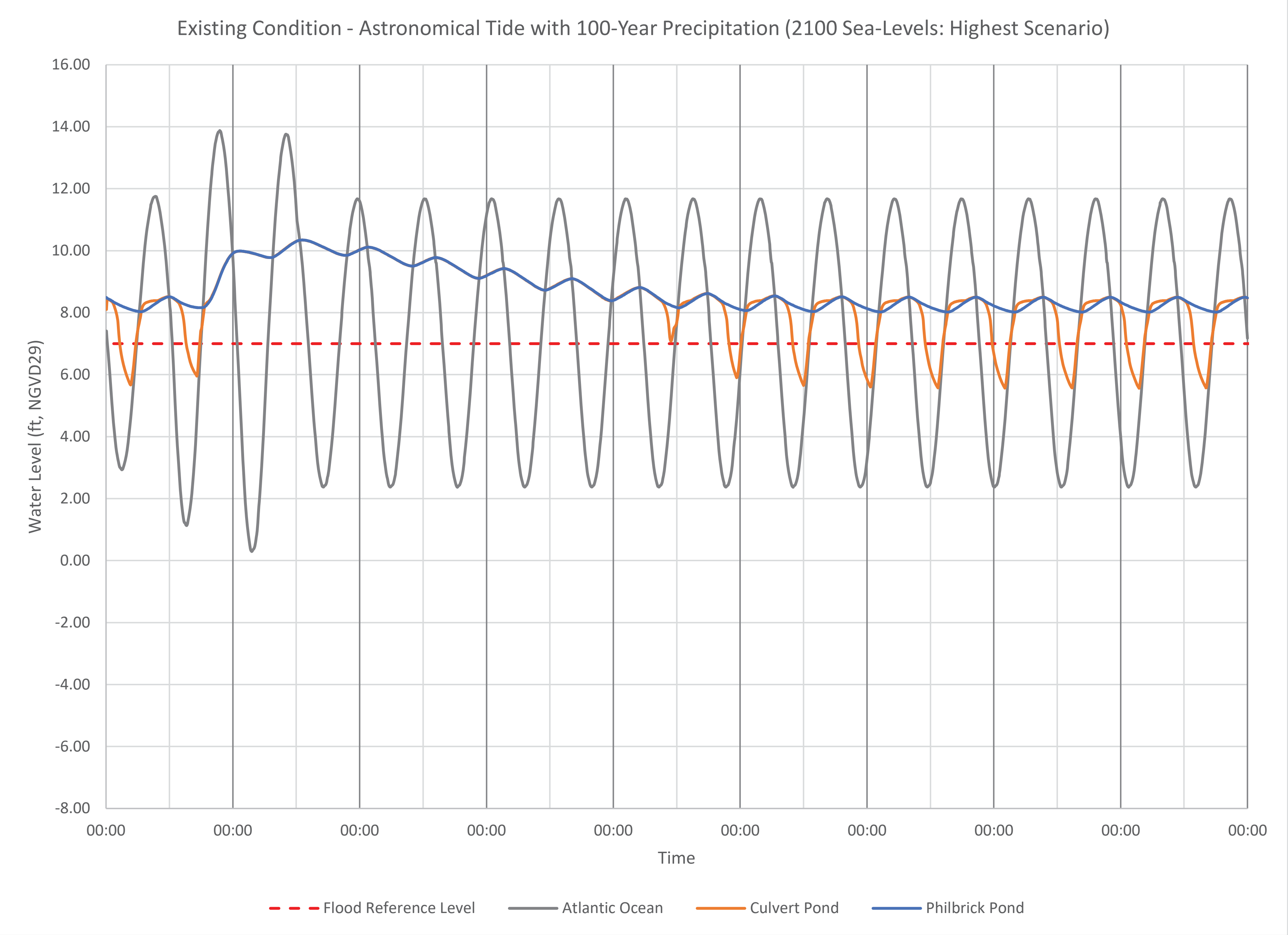
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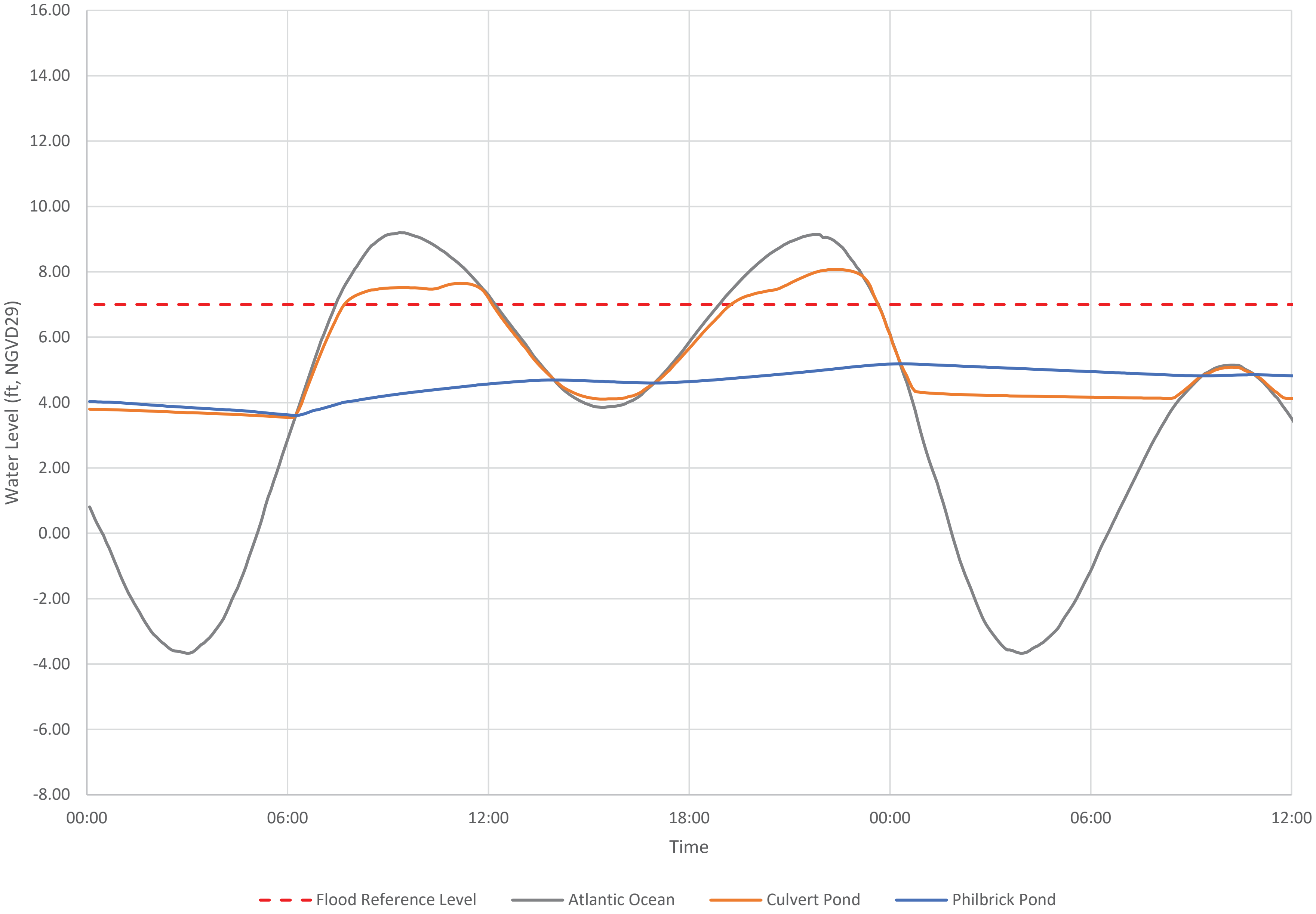

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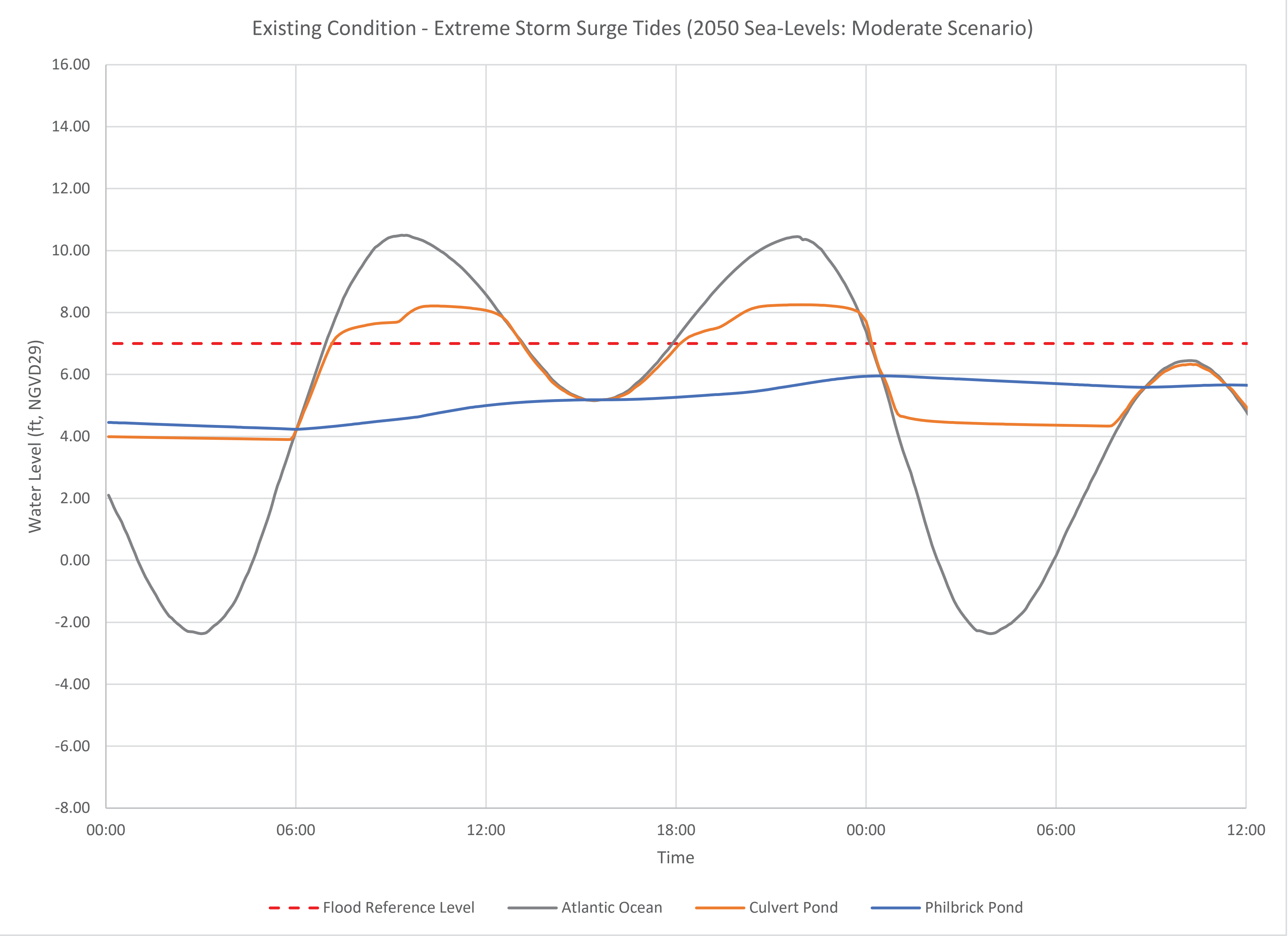

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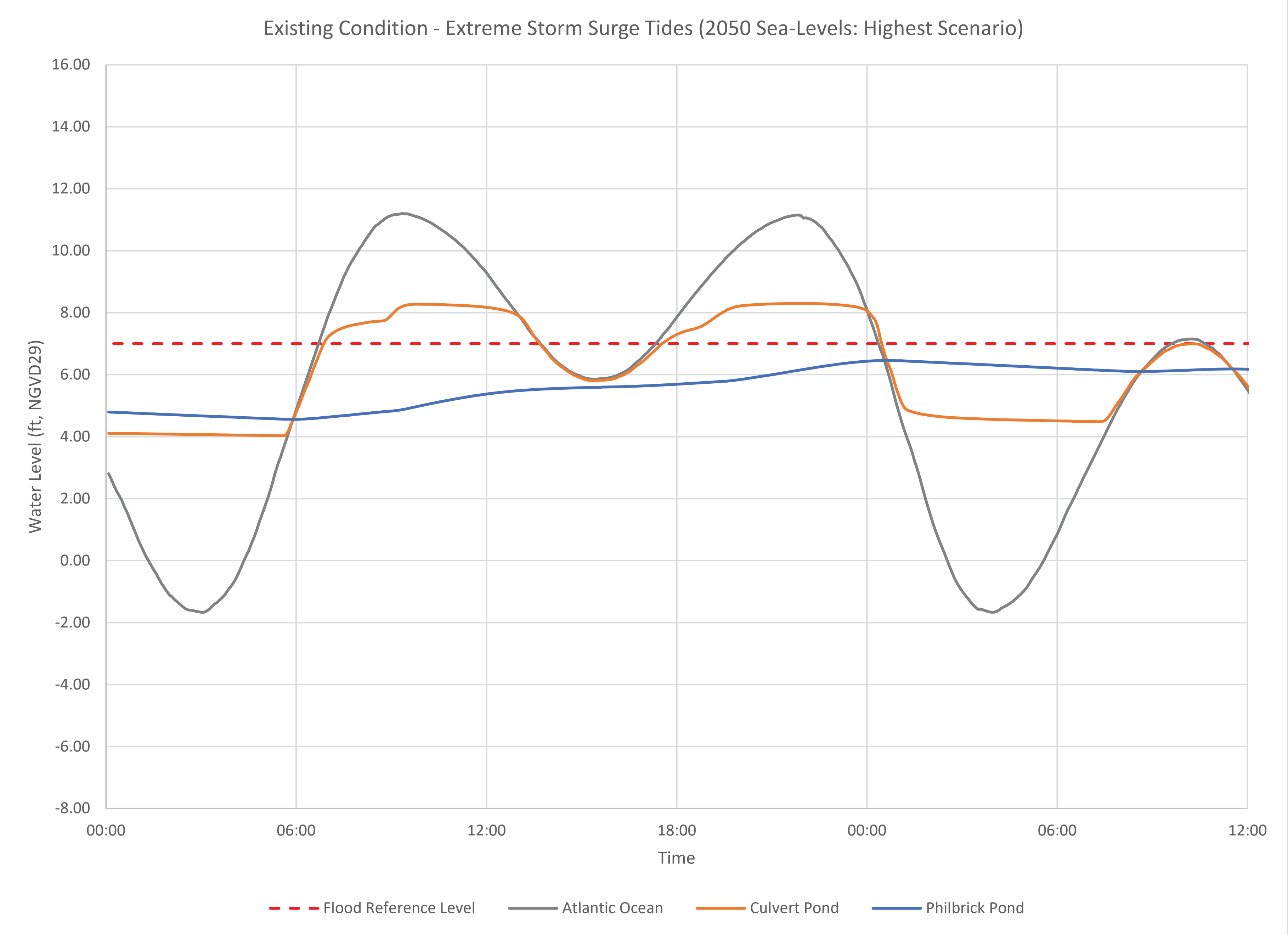
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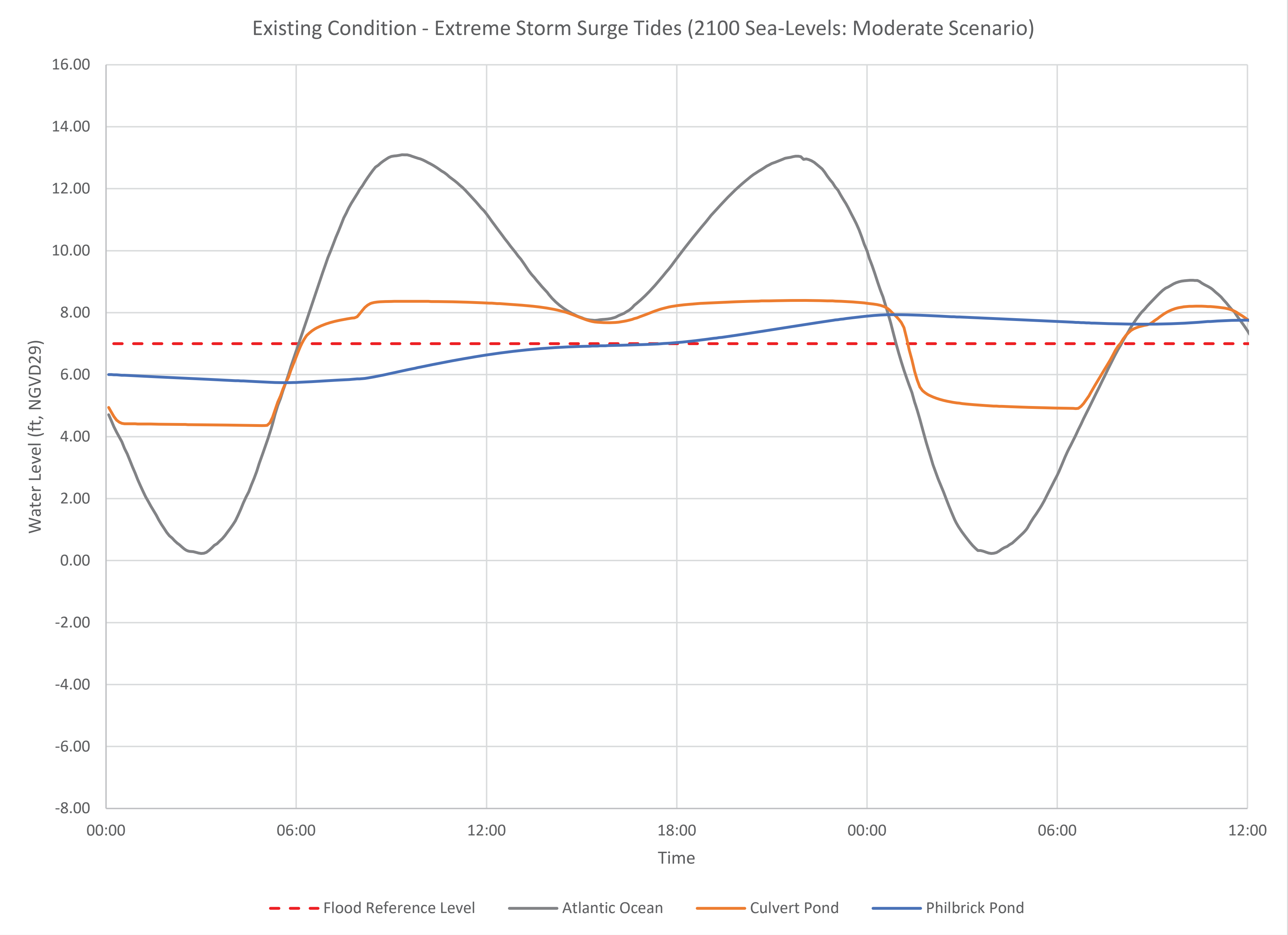
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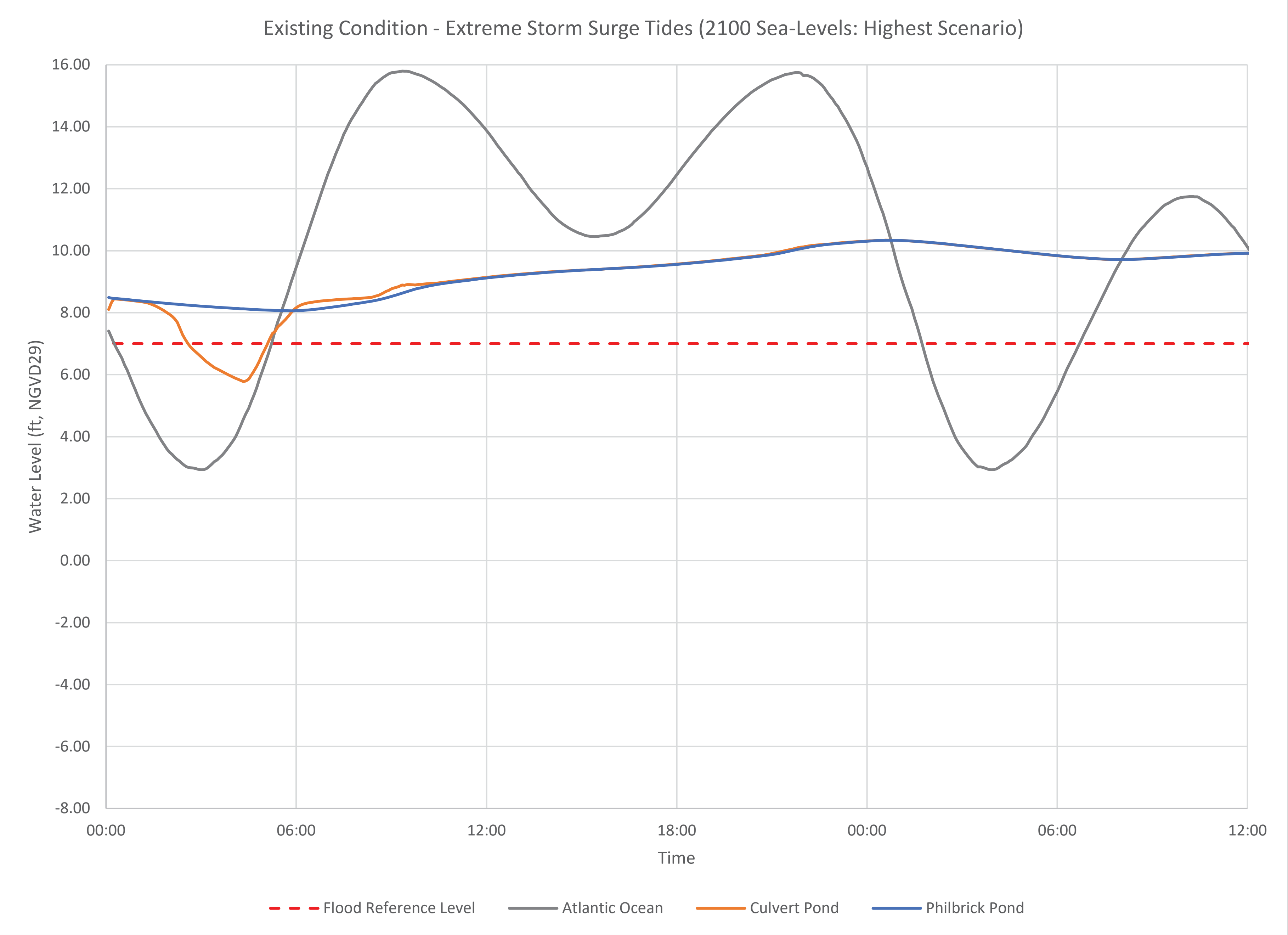
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Culvert Pond
Philbrick Pond

GOMEZ AND SULLIVAN
ENGINEERS

PO Box 2179
Henniker, NH 03424
T. (603) 428 - 4960
(513) 560 - 9715 (Kevin)

MEMO

To: Craig Musselman (CMA)

From: Kevin Miller and John Hart (Gomez and Sullivan)

Date: November 10, 2017

Re: Philbrick Pond – Sea-Level Rise Analysis under Alternative Conditions

Background

In North Hampton, culverts passing under a berm for a former trolley line and State Route 1A transfer flow between the Philbrick Pond Marsh and the Atlantic Ocean. A small pond (i.e. termed the Culvert Pond for the purposes of this memo) exists between the downstream end of the trolley berm culvert and the upstream end of the Route 1A culvert. Gomez and Sullivan has been tasked with evaluating the hydraulics of these culverts under existing conditions and potential future alternatives. Each condition is to be evaluated under various combinations of tidal and hydrologic scenarios including future sea-level rise considerations. A memo dated September 29, 2017 outlined the development and calibration of a HEC-RAS model for the Philbrick Pond analysis. A memo dated October 3, 2017 presented the assumptions and results surrounding the analysis of existing conditions under three scenarios (i.e. normal tides, astronomical tides with precipitation, and extreme storm surge tides[1]). A memo dated October 20, 2017 presented the assumptions and results surrounding four potential future alternatives (i.e. slab, box, box + slab, channel + slab) under the same three scenarios as the existing conditions memo. An October 30, 2017 memo presented the assumptions and results surrounding the analysis of existing conditions under the same three scenarios as the existing conditions memo assuming four different sea-level rise scenarios, as well as revised results for alternative conditions under current sea-levels. This memo presents the assumptions and results for three alternative conditions (i.e. slab, box, channel + slab) under three future sea-level scenarios (2050-Moderate, 2100-Moderate, 2100-Highest) for the same hydrologic scenarios as evaluated for existing conditions[2]. This memo also presents results for a sensitivity analysis regarding the tidal scenario coinciding with the 100-year precipitation event.

Model Revisions

The model includes two initial condition parameters: a) starting water surface elevation (i.e. stage) in Philbrick Pond, and b) starting flow in the channel between Philbrick Pond and the Atlantic Ocean (i.e. including flow through the trolley berm and Route 1A culverts). If, for example, the initial stage is too high the higher-high tide and lower-low tide for the first day of the normal tide simulation will also be too high. As such, the initial conditions are assessed such that the higher-high tide and lower-low tide are the same for each day of the simulation under normal tides. These initial conditions can be different for each alternative condition, and each sea-level scenario. Table 1 provides the initial conditions for each condition and sea-level scenario presented in this memo.

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[1] The high tide for the Extreme Storm Surge Tides is based on the 100-Year Stillwater Elevation of the Atlantic Ocean reported in the Federal Emergency Management Agency's Flood Insurance Study for Rockingham County, NH.

[2] The box + slab condition was dropped from this analysis as the resulting water surface elevations were not significantly different from other scenarios. Similarly, the 2050-Highest sea-level scenario was dropped from this analysis, as it did not present significantly different results from the 2050-Moderate sea-level scenario.

Table 1: Initial Conditions

Sea-Level Scenario (Sea-Level Rise in ft)	Existing Conditions		Alternative Condition: Slab		Alternative Condition: Box		Alternative Condition: Channel + Slab	
	Flow (cfs)	Stage (ft, NGVD 29)	Flow (cfs)	Stage (ft, NGVD 29)	Flow (cfs)	Stage (ft, NGVD 29)	Flow (cfs)	Stage (ft, NGVD 29)
Current (0.0)	11	4.04	19	4.05	14	4.09	27	4.09
2050 - Moderate Scenario (1.3)	18	4.46	20	4.31	37	4.67	39	4.67
2100 - Moderate Scenario (3.9)	31	5.98	33	5.95	70	6.21	80	6.27
2100 - Highest Scenario (6.6)	23	8.52	27	8.52	40	8.13	45	7.99

Additionally, a sensitivity analysis was performed regarding the occurring during the peak inflow of the 100-year precipitation event. The sensitivity analysis was evaluated under existing conditions and current sea-levels, but replaced the astronomical tides with normal tides.

Results

Figures 1 and 2 present results of the sensitivity analysis related to the tidal conditions during the peak inflow to Philbrick Pond caused by the 100-year precipitation event. These results show that the normal tides scenario provides a maximum water surface elevation of 7.6 feet as opposed to 7.8 feet under astronomical tides. Additionally, the water recedes below elevation 7 feet approximately 5 hours earlier under the normal tides scenario, which provides earlier access to residences via Old Locke Road.

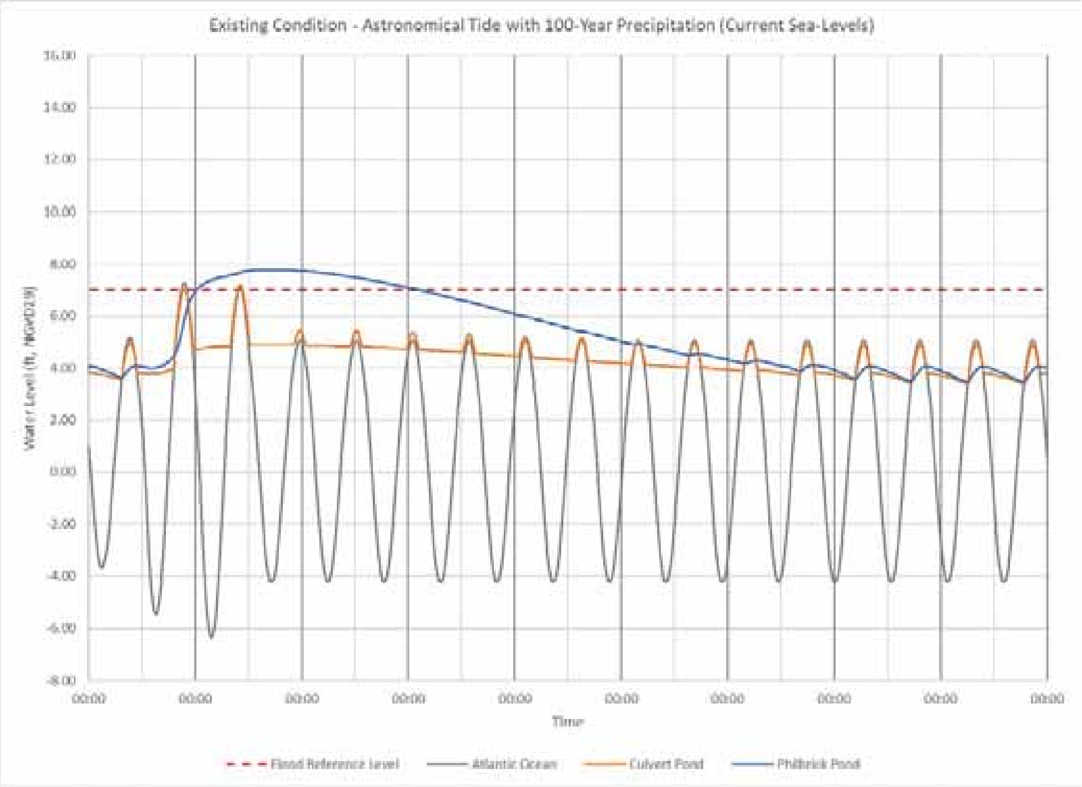


Figure 1: 100-Year Precipitation under Astronomical Tides

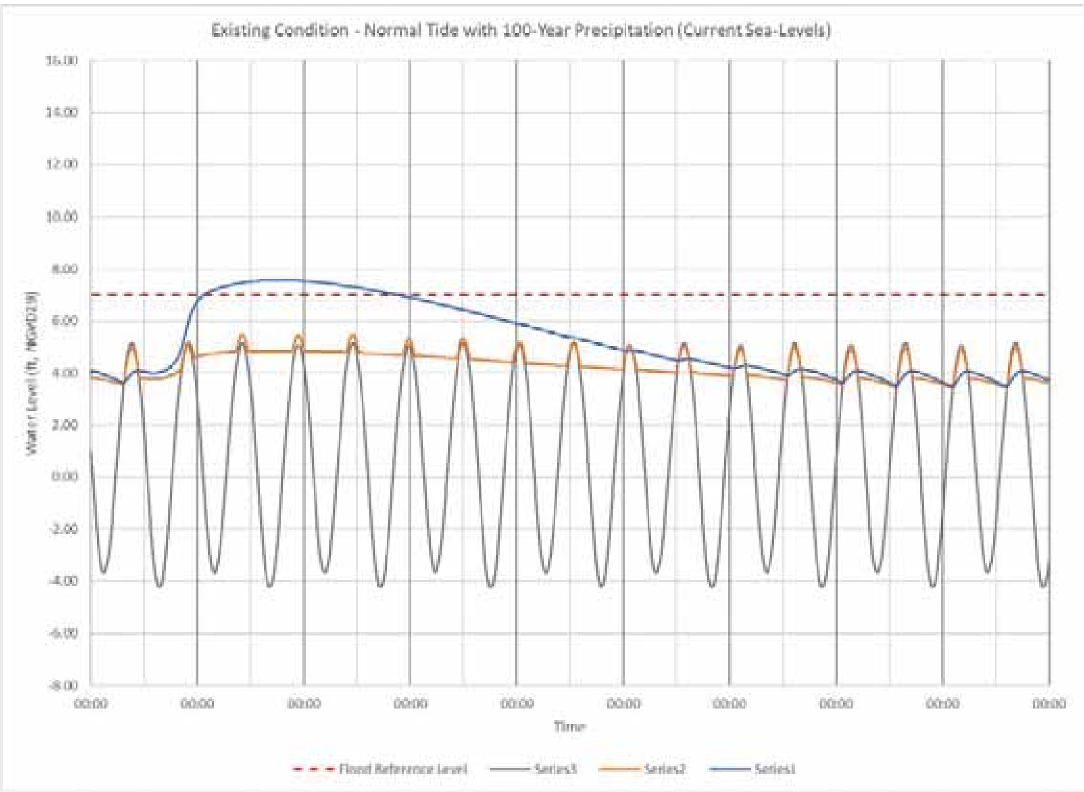


Figure 2: 100-Year Precipitation under Normal Tides

Attachment A provides tables of results in relation to maximum and minimum water surface elevations. It should be noted that the minimum water surface elevations are computed as the minimum level to occur between hour 10 and 30 in the simulation. These elevations were used to evaluate drawdown after increased tides/initiation of inflow from rainfall. The absolute minimum water surface elevations for the Astronomical Tides + 100-Year Precipitation and Extreme Storm Surge Tide scenarios is equal to that of the Normal Tides scenario because the ponds eventually stabilize back to levels corresponding to Normal Tides. Additionally, Attachment B provides figures which show results for the existing and three alternative conditions under current and three projected sea-levels. These figures utilize the same elevation scale to better compare results. Additionally, a flood referenced level is provided on each figure at 7.0 feet, which is approximately the elevation at which the Old Locke Road begins to flood. Each of the four conditions includes a separate figure for each of the four sea-level scenarios and three hydrologic scenarios, for a total of 48 figures. Similar to the results of the October 30, 2017 memo, the alternative conditions do not exhibit a 1:1 relationship between increase in sea-level and increase in pond water surface elevations.

Slab

The results indicate that the slab condition has minimal impact on maximum water surface elevations when compared to existing conditions, but does provide better drainage of the Philbrick and Culvert Ponds, as indicated by lower minimum water surface elevations. However, the drainage benefit is reduced under the higher sea-level scenarios.

Box

The box condition provides lower maximum water surface elevations in Philbrick Pond during rainfall events when compared to existing conditions, regardless of the sea-level scenario. However, this condition generally provides higher maximum water surface elevations under normal and extreme storm surge tidal conditions (i.e. except for the 2100-Highest sea-level scenario). Finally, the box condition only provides lower minimum water surface elevations under the 2100-Highest sea-level scenario.

Channel + Slab

The channel + slab condition provides lower maximum water surface elevations in Philbrick Pond during rainfall events when compared to existing conditions, regardless of the sea-level scenario. However, this condition generally provides higher maximum water surface elevations under normal and extreme storum surge tidal conditions (i.e. except for the 2100-Highest sea-level scenario). Finally, channel + slab conditions generally provides lower minimum water surface elevations in Philbrick Pond than existing conditions.

Attachment A –Maximum and Minimum Results for Current and Alternative Conditions under Current and Future Sea-Levels

Table A-1: Maximum Water Surface Elevation (ft, NGVD29) under Existing Conditions

Sea-Level Scenario (Sea-Level Rise in ft)	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current (0.0)	4.1	5.0	7.8	7.2	5.2	8.1
2050 - Moderate Scenario (1.3)	4.5	6.2	8.0	8.1	6.0	8.3
2100 - Moderate Scenario (3.9)	6.0	8.1	8.8	8.8	7.9	8.4
2100 - Highest Scenario (6.6)	8.5	8.5	10.3	10.3	10.3	10.3

Table A-2: Minimum Water Surface Elevation (ft, NGVD29) under Existing Conditions [1]

Sea-Level Scenario (Sea-Level Rise in ft)	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current (0.0)	3.7	3.6	4.0	3.8	4.4	4.1
2050 - Moderate Scenario (1.3)	4.2	3.9	4.4	4.0	4.7	4.4
2100 - Moderate Scenario (3.9)	5.7	4.4	5.9	4.4	6.3	4.9
2100 - Highest Scenario (6.6)	8.0	5.6	8.2	6.0	8.8	8.9

Notes:

1. Water Surface Elevation taken between hour 10 and 30 in the simulation. These elevations were used to evaluate drawdown after increased tides/initiation of inflow from rainfall. The absolute minimum water surface elevation for Astronomical Tides + 100-Year Precipitation and Extreme Storm Surge Tide scenarios is equal to that of the Normal Tides scenario because the ponds eventually stabilize back to levels corresponding to Normal Tides.

Table A-3: Maximum Water Surface Elevation (ft, NGVD29) under Alternative Condition: Slab

Sea-Level Scenario (Sea-Level Rise in ft)	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current (0.0)	4.1	5.0	7.7	7.2	5.2	8.1
2050 - Moderate Scenario (1.3)	4.4	6.1	8.0	8.1	5.9	8.3
2100 - Moderate Scenario (3.9)	6.0	8.1	8.8	8.8	7.9	8.4
2100 - Highest Scenario (6.6)	8.5	8.5	10.3	10.3	10.3	10.3

Table A-4: Minimum Water Surface Elevation (ft, NGVD29) under Alternative Condition: Slab[1]

Sea-Level Scenario (Sea-Level Rise in ft)	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current (0.0)	2.8	2.3	3.8	3.5	4.3	4.0
2050 - Moderate Scenario (1.3)	3.9	3.5	4.2	3.7	4.5	4.3
2100 - Moderate Scenario (3.9)	5.6	4.3	5.8	4.3	6.3	4.9
2100 - Highest Scenario (6.6)	8.0	5.6	8.2	5.9	8.8	8.9

Notes:

1. Water Surface Elevation taken between hour 10 and 30 in the simulation. These elevations were used to evaluate drawdown after increased tides/initiation of inflow from rainfall. The absolute minimum water surface elevation for Astronomical Tides + 100-Year Precipitation and Extreme Storm Surge Tide scenarios is equal to that of the Normal Tides scenario because the ponds eventually stabilize back to levels corresponding to Normal Tides.

Table A-5: Maximum Water Surface Elevation (ft, NGVD29) under Alternative Condition: Box

Sea-Level Scenario (Sea-Level Rise in ft)	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current (0.0)	4.2	4.3	7.2	7.2	6.0	6.5
2050 - Moderate Scenario (1.3)	4.8	5.0	7.7	7.7	6.7	7.2
2100 - Moderate Scenario (3.9)	6.3	6.7	8.7	8.7	8.2	8.3
2100 - Highest Scenario (6.6)	8.2	8.3	10.2	10.2	10.1	10.1

Table A-6: Minimum Water Surface Elevation (ft, NGVD29) under Alternative Condition: Box[1]

Sea-Level Scenario (Sea-Level Rise in ft)	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current (0.0)	3.7	3.7	4.0	4.0	4.8	4.9
2050 - Moderate Scenario (1.3)	4.2	4.1	4.5	4.4	5.2	5.6
2100 - Moderate Scenario (3.9)	5.6	5.4	5.9	5.6	6.4	6.9
2100 - Highest Scenario (6.6)	7.6	6.9	7.8	7.0	8.5	8.6

Notes:

1. Water Surface Elevation taken between hour 10 and 30 in the simulation. These elevations were used to evaluate drawdown after increased tides/initiation of inflow from rainfall. The absolute minimum water surface elevation for Astronomical Tides + 100-Year Precipitation and Extreme Storm Surge Tide scenarios is equal to that of the Normal Tides scenario because the ponds eventually stabilize back to levels corresponding to Normal Tides.

Table A-7: Maximum Water Surface Elevation (ft, NGVD29) under Alternative Condition: Channel + Slab

Sea-Level Scenario (Sea-Level Rise in ft)	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current (0.0)	4.2	4.3	7.1	7.1	6.1	6.1
2050 - Moderate Scenario (1.3)	4.8	4.8	7.6	7.6	6.8	6.8
2100 - Moderate Scenario (3.9)	6.3	6.3	8.7	8.7	8.3	8.3
2100 - Highest Scenario (6.6)	8.0	8.0	10.1	10.1	10.0	10.0

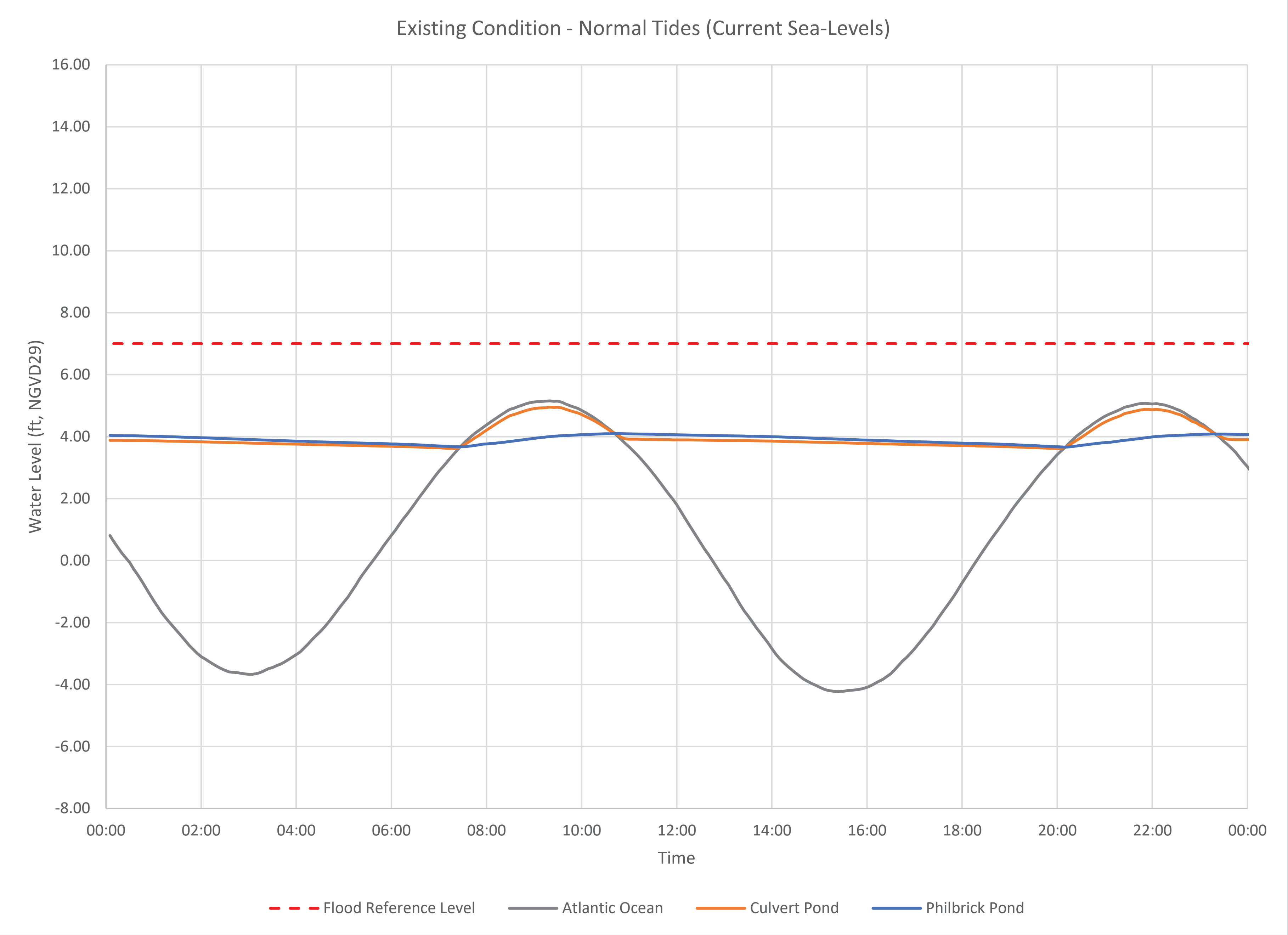
Table A-8: Minimum Water Surface Elevation (ft, NGVD29) under Alternative Condition: Channel + Slab[1]

Sea-Level Scenario (Sea-Level Rise in ft)	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Current (0.0)	2.8	2.3	3.9	3.9	4.9	5.0
2050 - Moderate Scenario (1.3)	4.1	4.1	4.5	4.5	5.3	5.3
2100 - Moderate Scenario (3.9)	5.6	5.6	5.9	5.8	6.6	6.6
2100 - Highest Scenario (6.6)	7.3	7.3	7.5	7.5	8.3	8.3

Notes:

1. Water Surface Elevation taken between hour 10 and 30 in the simulation. These elevations were used to evaluate drawdown after increased tides/initiation of inflow from rainfall. The absolute minimum water surface elevation for Astronomical Tides + 100-Year Precipitation and Extreme Storm Surge Tide scenarios is equal to that of the Normal Tides scenario because the ponds eventually stabilize back to levels corresponding to Normal Tides.

Attachment B –Figures for Existing and Alternative Conditions under Current and Future Sea-Levels


Existing Condition - Normal Tides (Current Sea-Levels)
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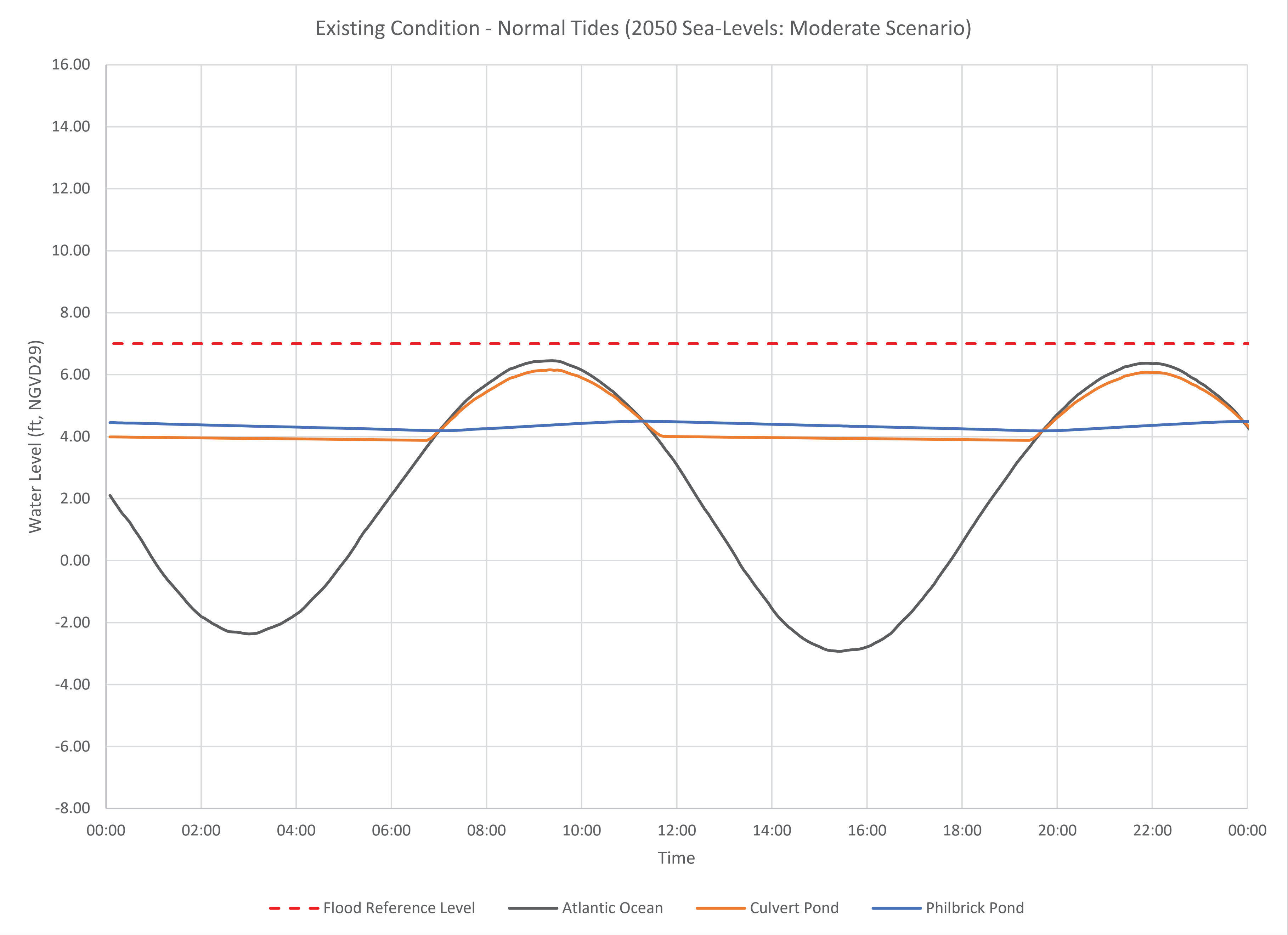
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Existing Condition - Normal Tides (2050 Sea-Levels: Moderate Scenario)
16.00
14.00
12.00
10.00
8.00
6.00
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2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
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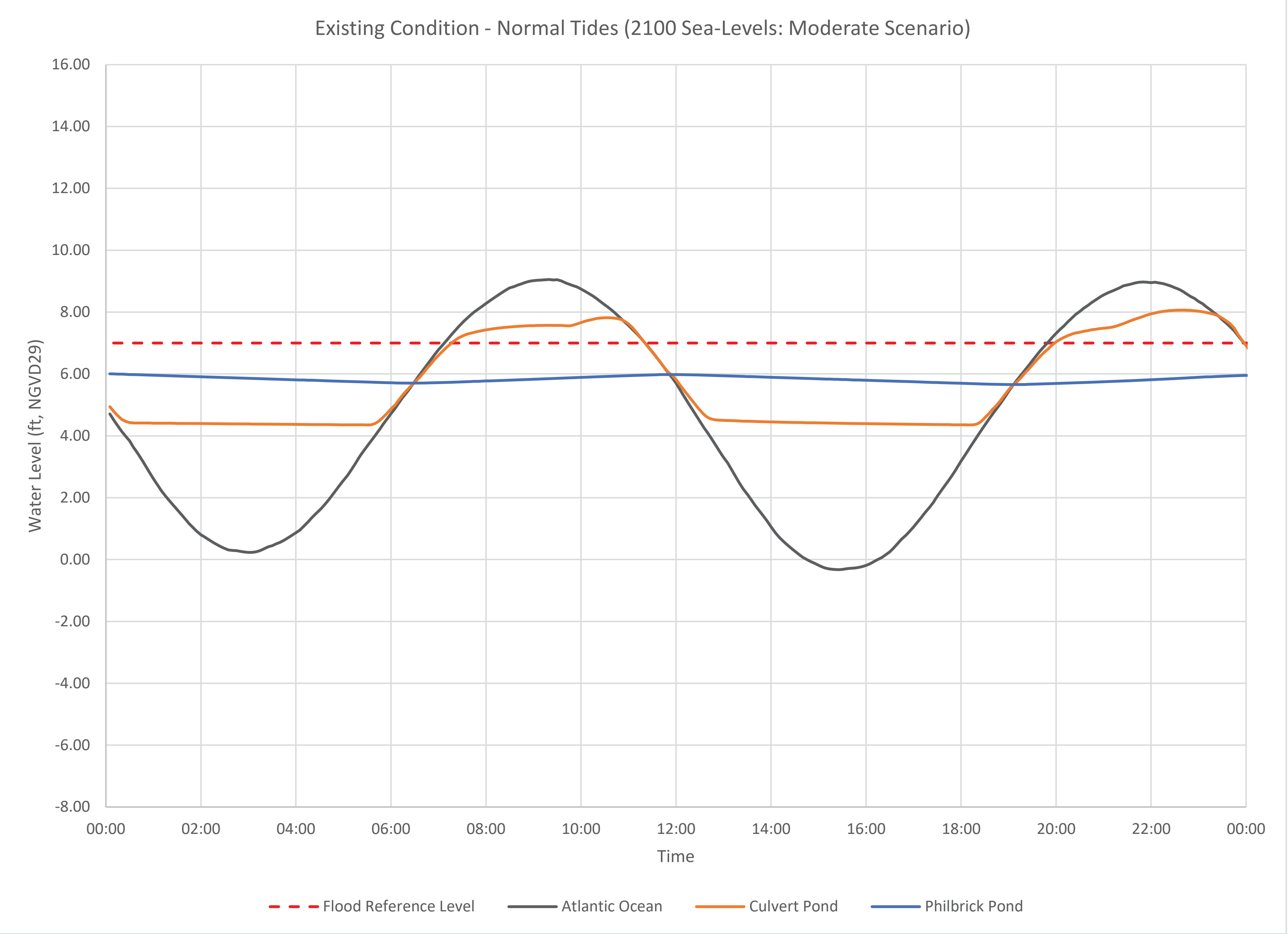
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
00:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond



Existing Condition - Normal Tides (2100 Sea-Levels: Moderate Scenario)
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14.00
12.00
10.00
8.00
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-2.00
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Water Level (ft, NGVD29)
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02:00
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18:00
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22:00
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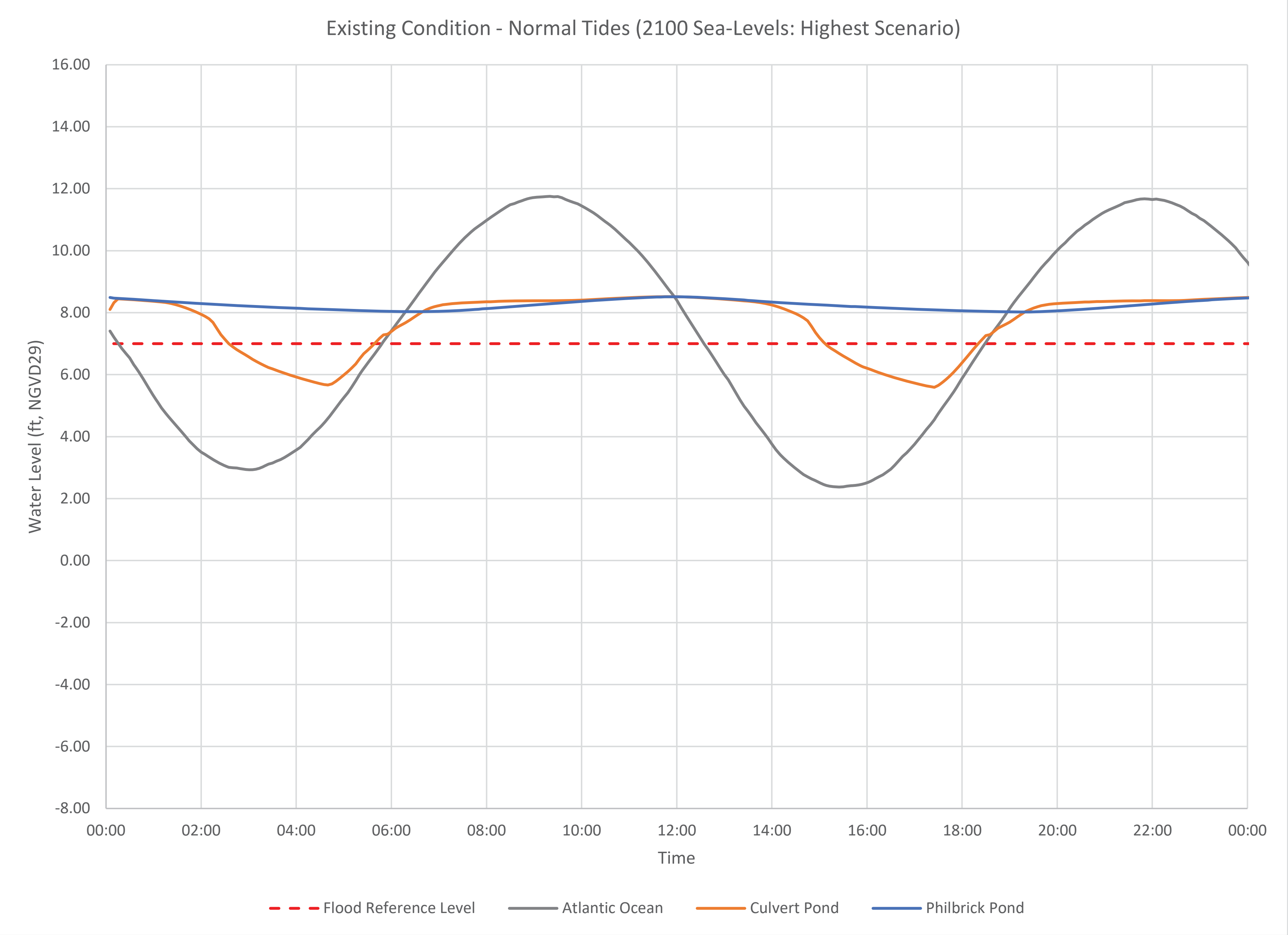
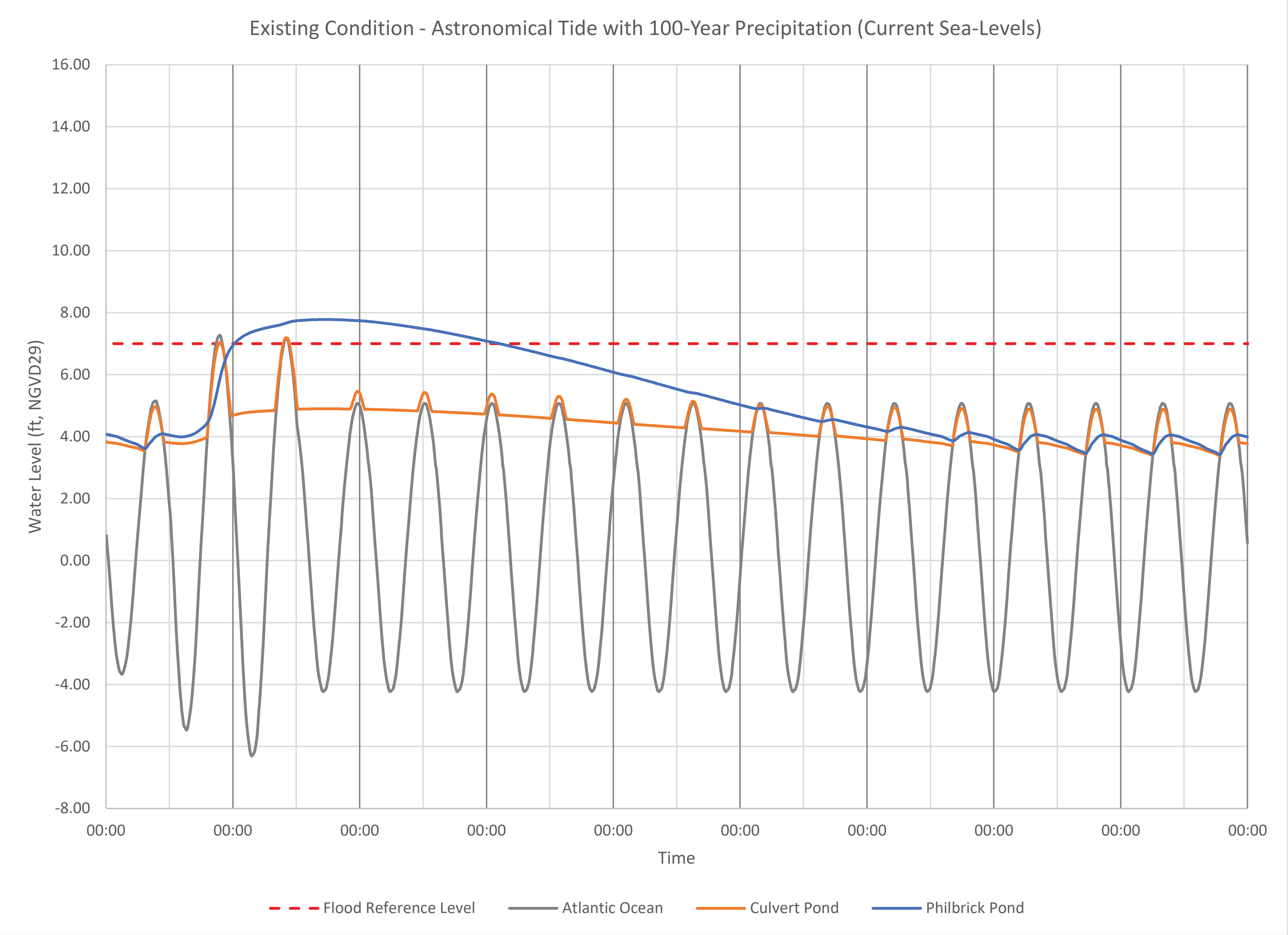
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond



Existing Condition - Normal Tides (2100 Sea-Levels: Highest Scenario)


Existing Condition - Astronomical Tide with 100-Year Precipitation (Current Sea-Levels)
Water Level (ft, NGVD29)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
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-2.00
-4.00
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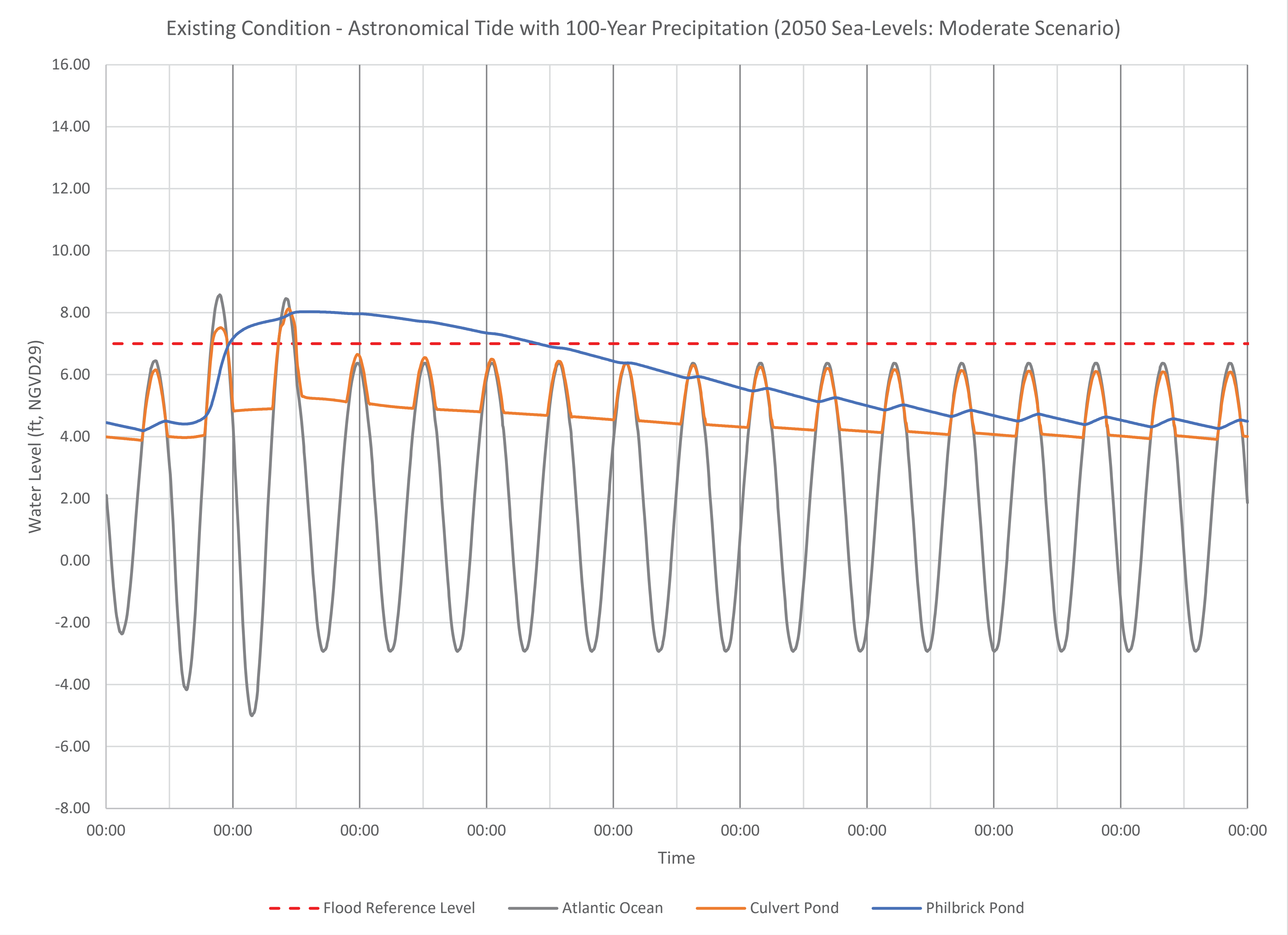
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Existing Condition - Astronomical Tide with 100-Year Precipitation (2050 Sea-Levels: Moderate Scenario)
Water Level (ft, NGVD29)
16.00
14.00
12.00
10.00
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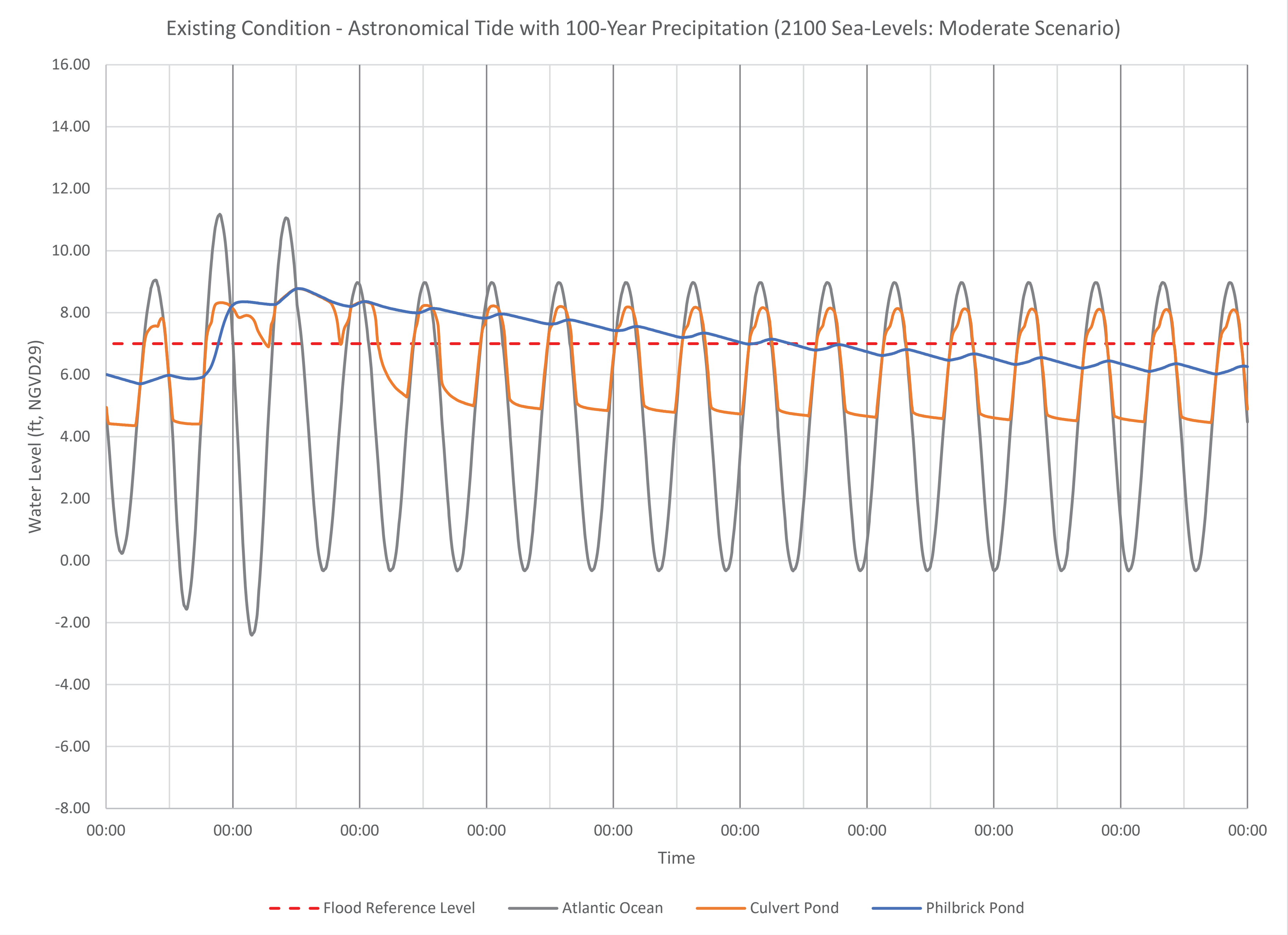
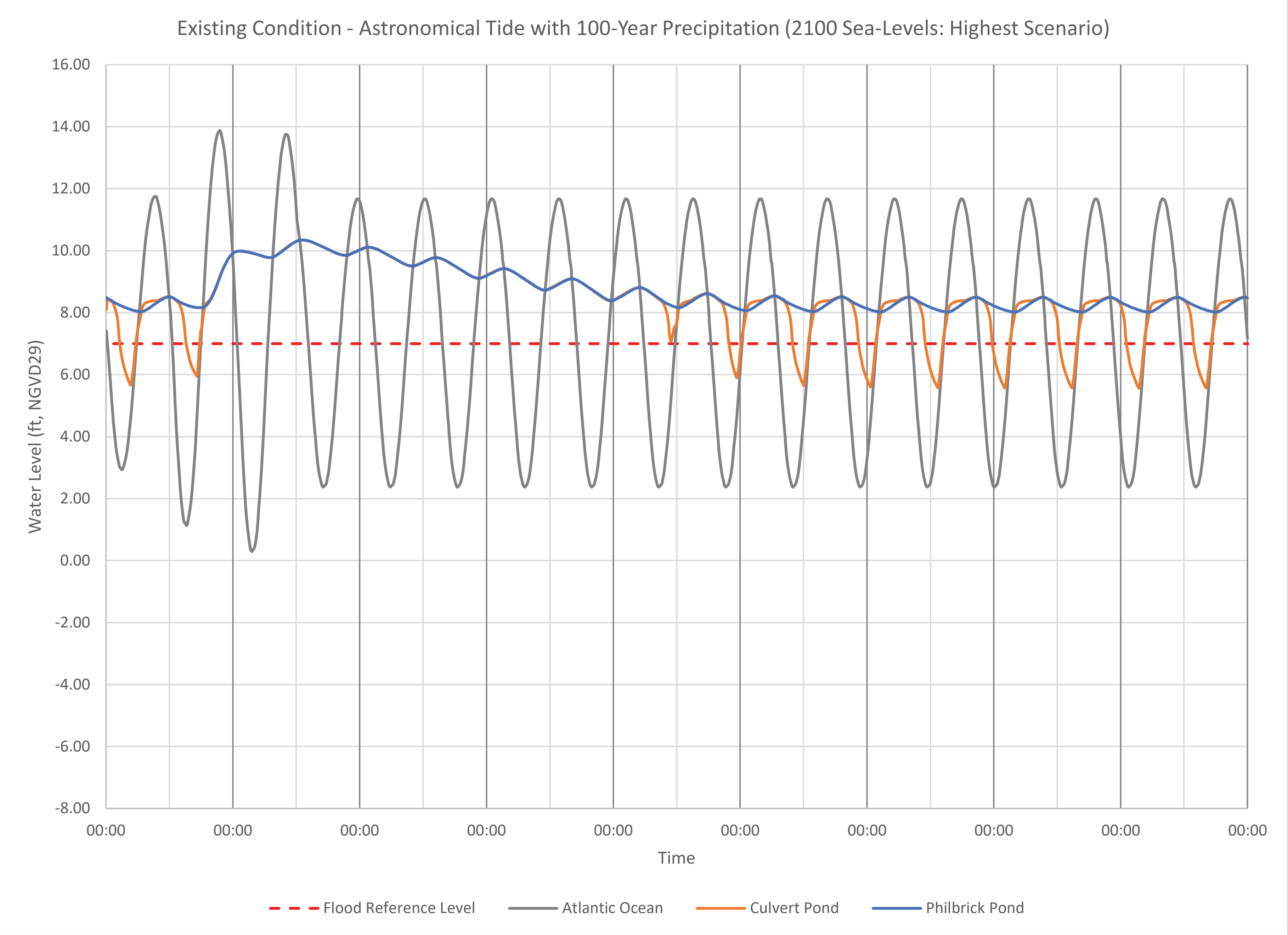
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond



Existing Condition - Astronomical Tide with 100-Year Precipitation (2100 Sea-Levels: Moderate Scenario)


Existing Condition - Astronomical Tide with 100-Year Precipitation (2100 Sea-Levels: Highest Scenario)
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-6.00
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Water Level (ft, NGVD29)
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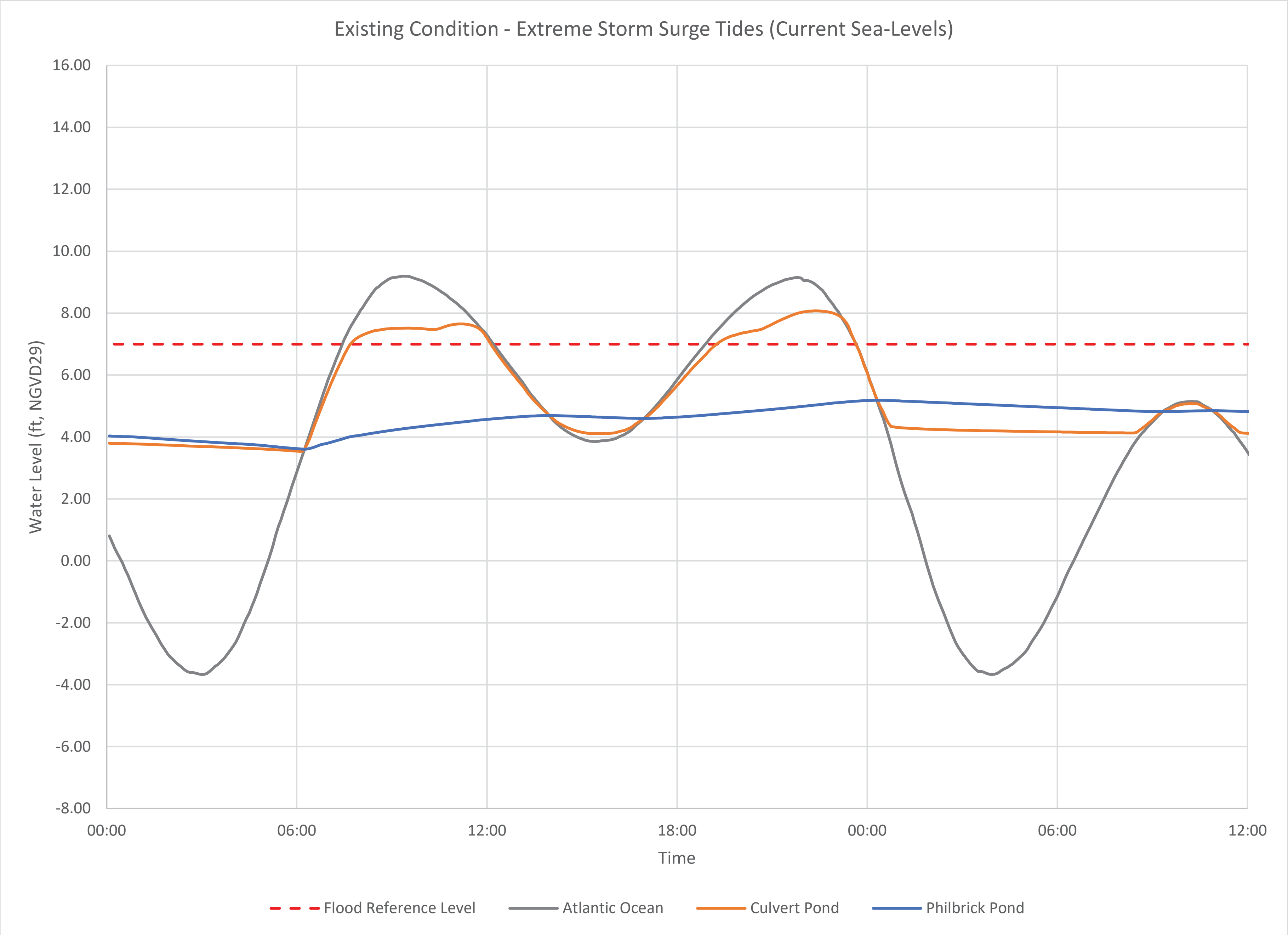
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Existing Condition - Extreme Storm Surge Tides (Current Sea-Levels)
Water Level (ft, NGVD29)
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
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-2.00
-4.00
-6.00
-8.00
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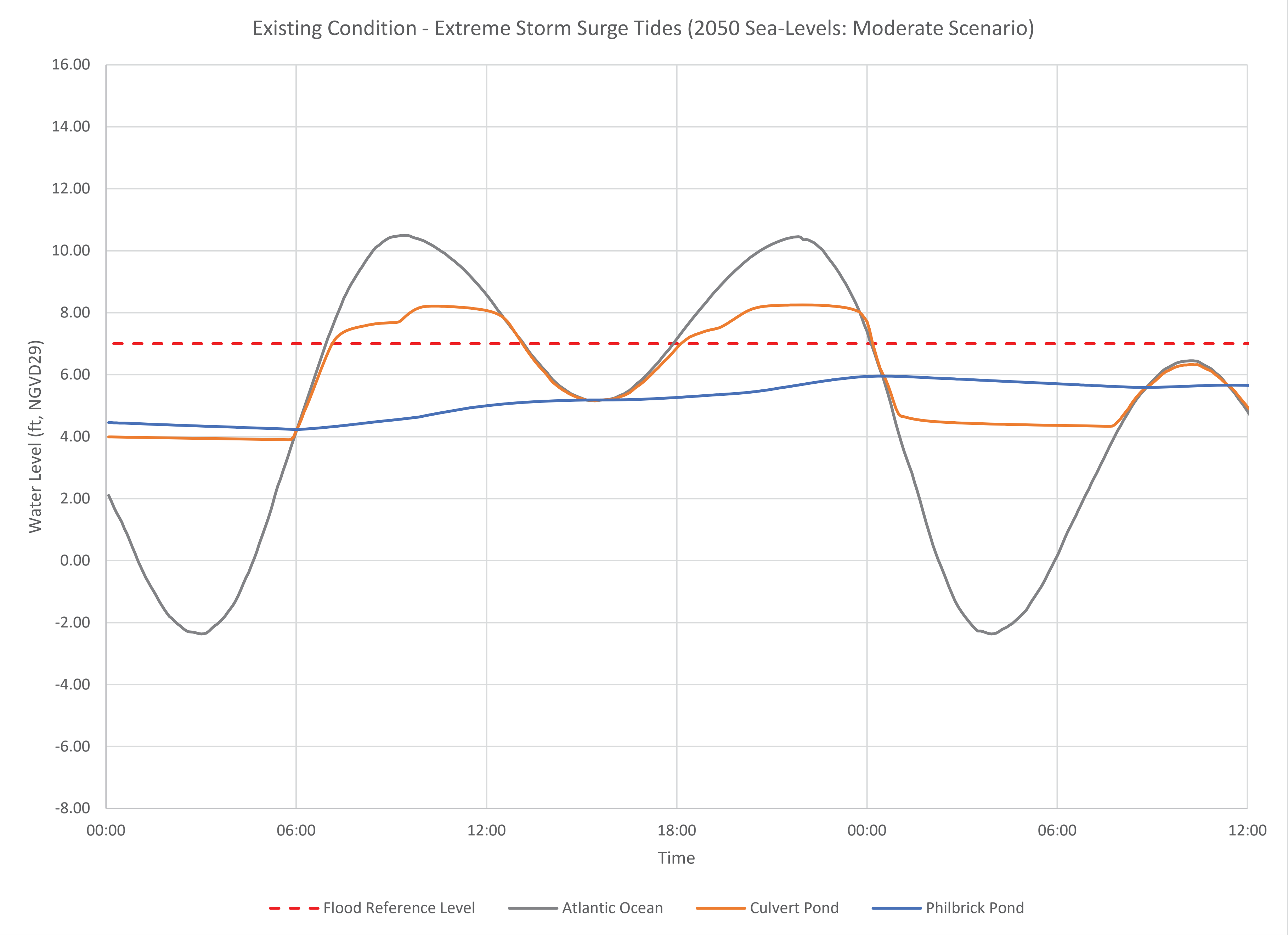
06:00
12:00
18:00
00:00
06:00
12:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Existing Condition - Extreme Storm Surge Tides (2050 Sea-Levels: Moderate Scenario)
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Water Level (ft, NGVD29)
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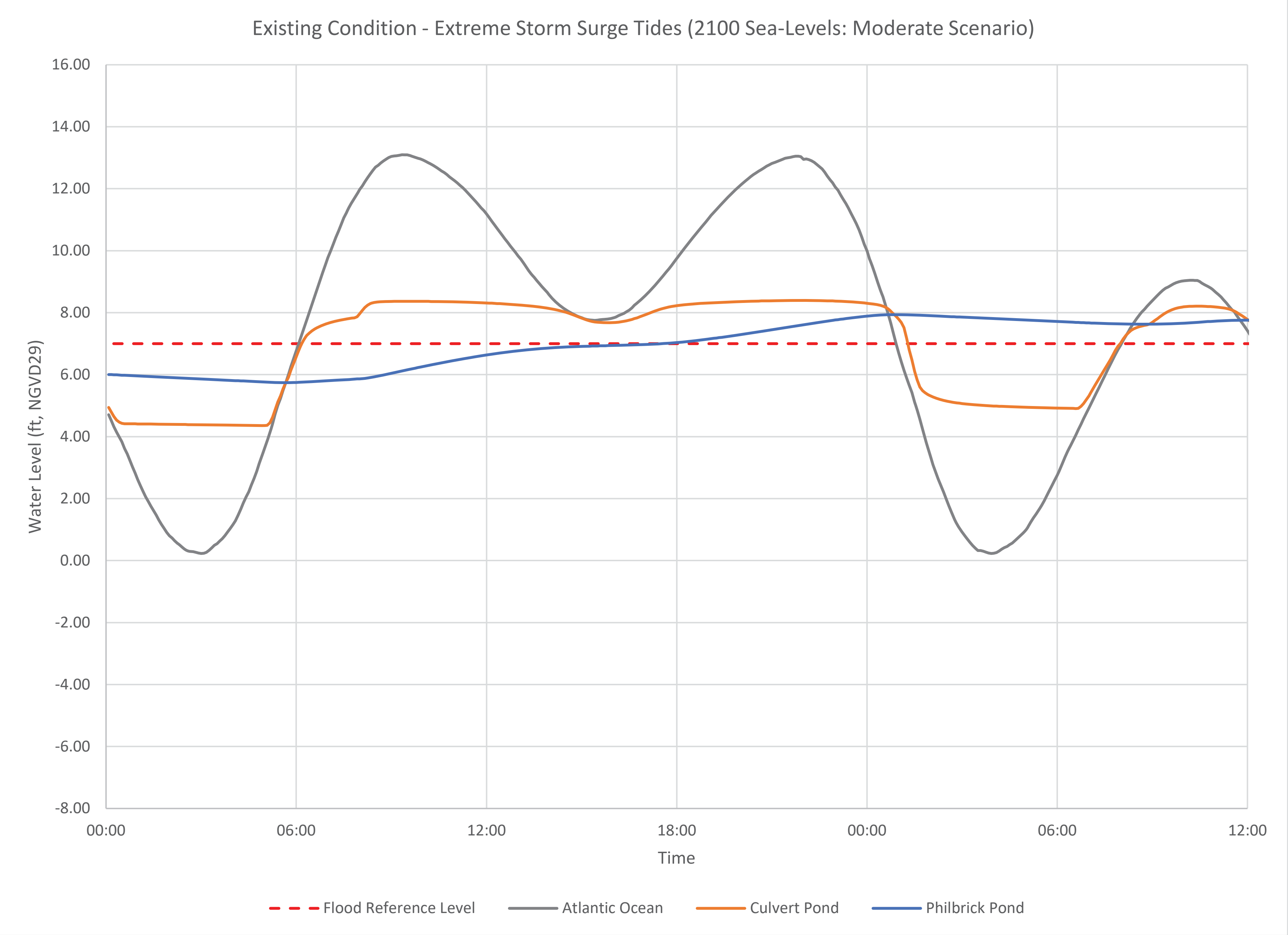
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Existing Condition - Extreme Storm Surge Tides (2100 Sea-Levels: Moderate Scenario)
16.00
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Water Level (ft, NGVD29)
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06:00
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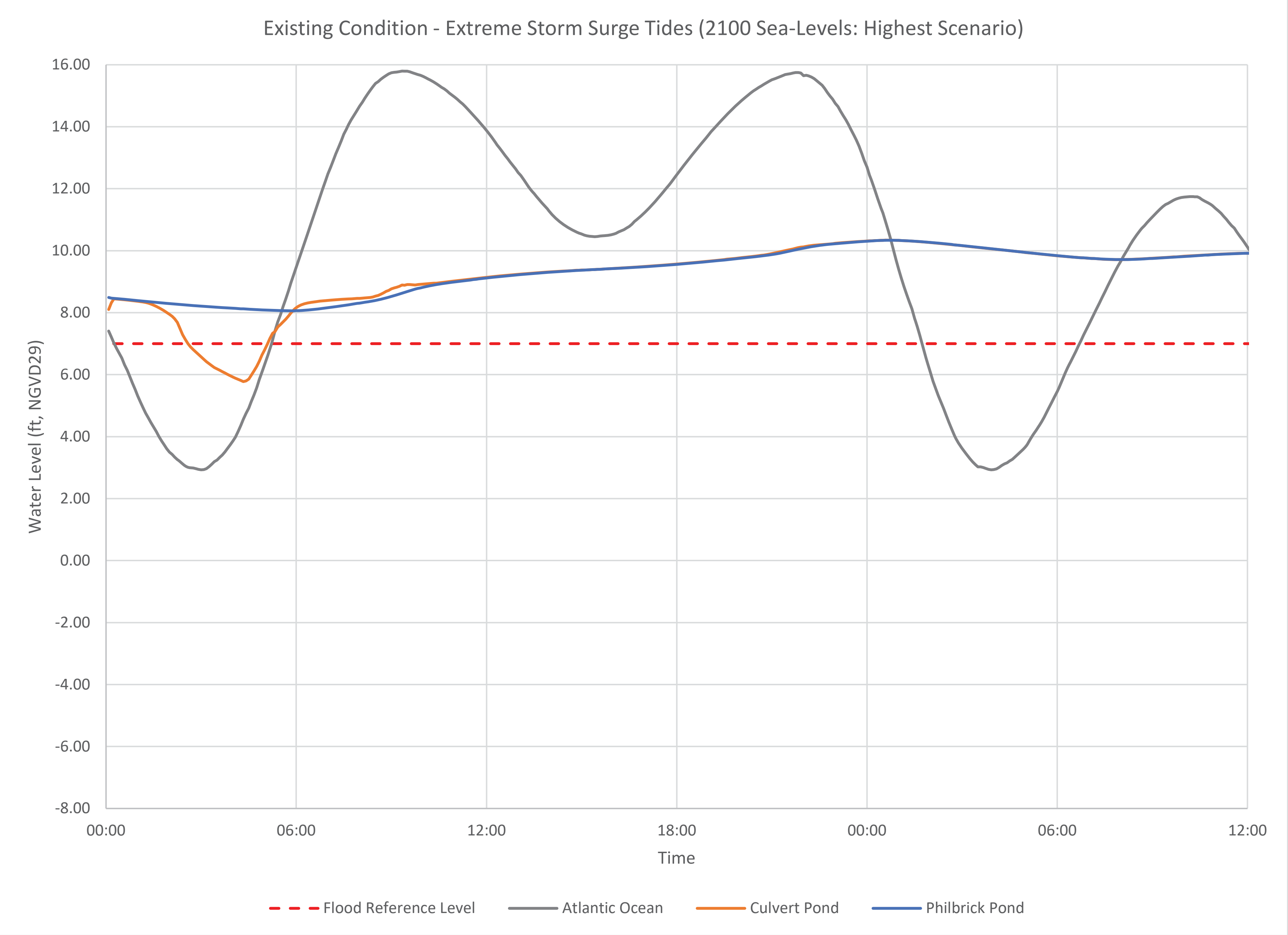
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Existing Condition - Extreme Storm Surge Tides (2100 Sea-Levels: Highest Scenario)
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Water Level (ft, NGVD29)
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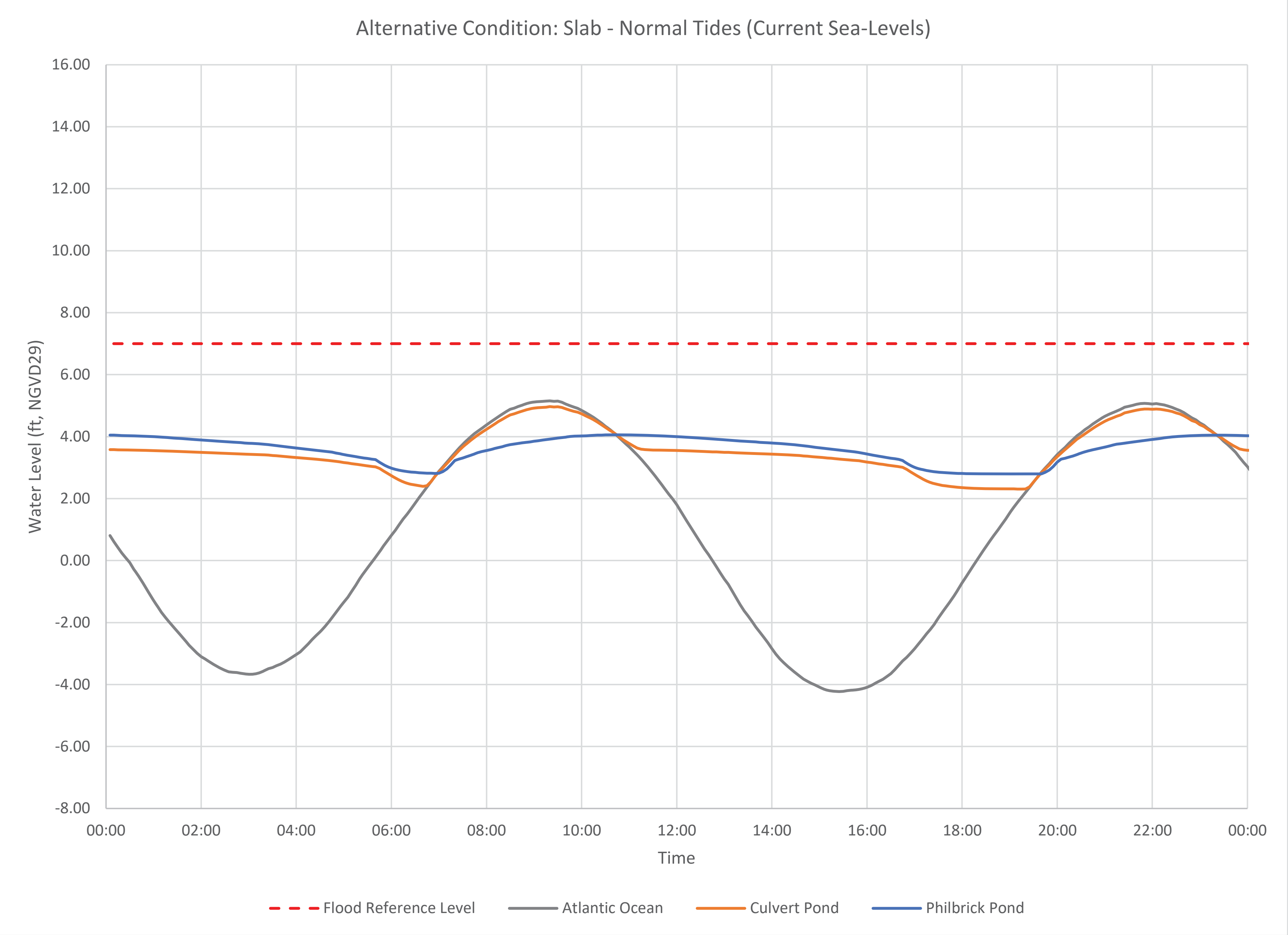
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Normal Tides (Current Sea-Levels)
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-6.00
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Water Level (ft, NGVD29)
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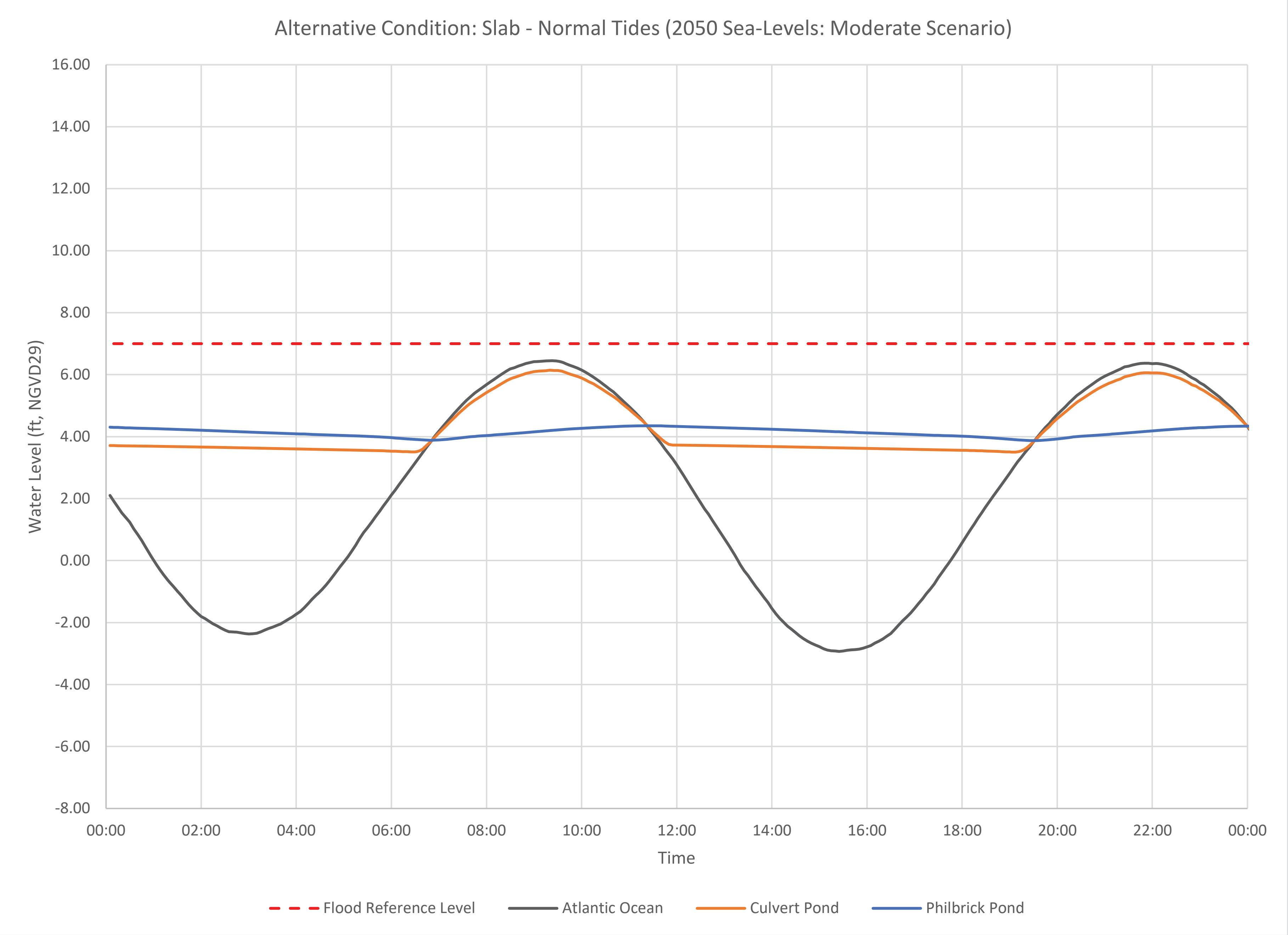
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Normal Tides (2050 Sea-Levels: Moderate Scenario)
Water Level (ft, NGVD29)
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14.00
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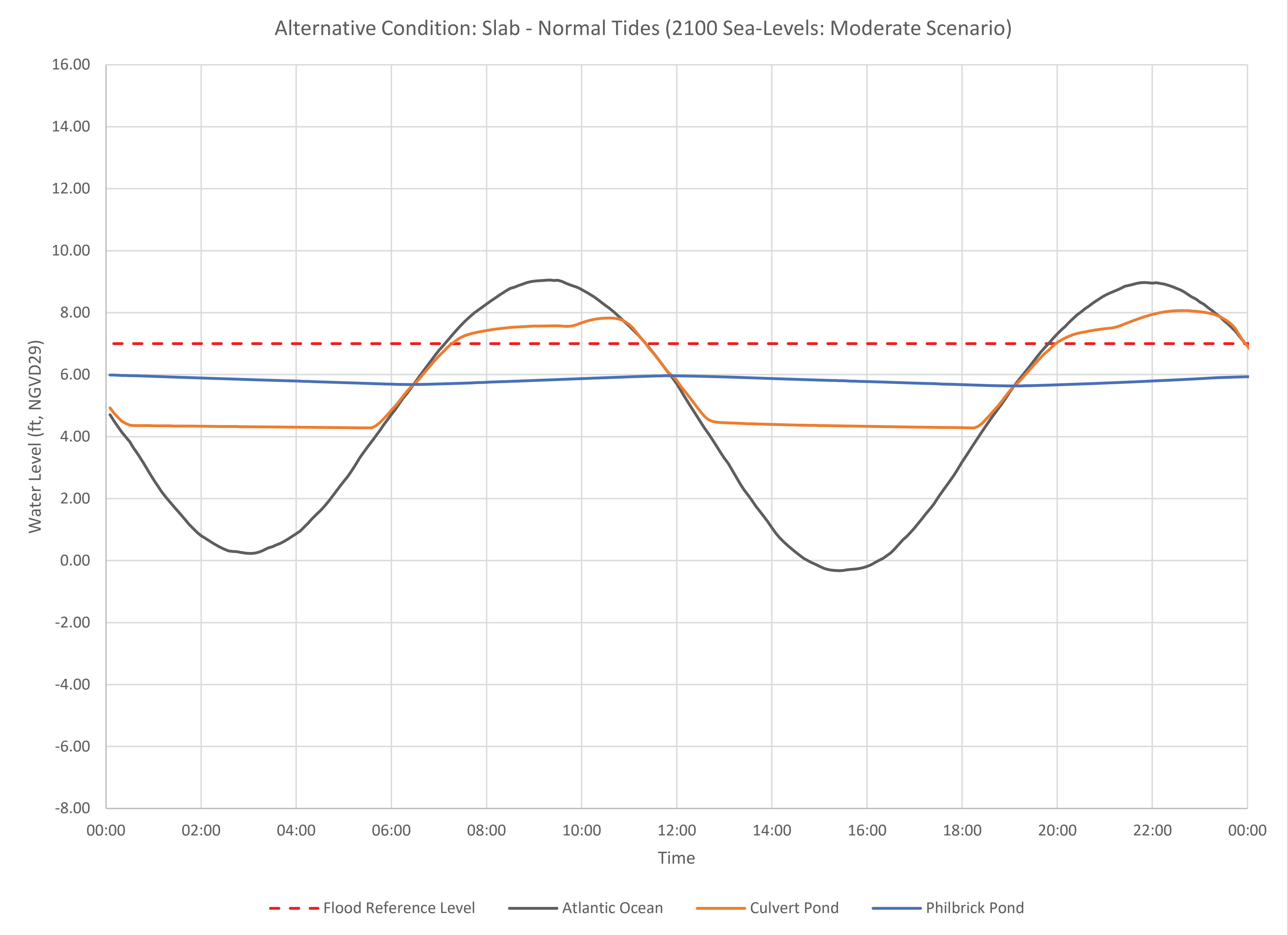
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Normal Tides (2100 Sea-Levels: Moderate Scenario)
Water Level (ft, NGVD29)
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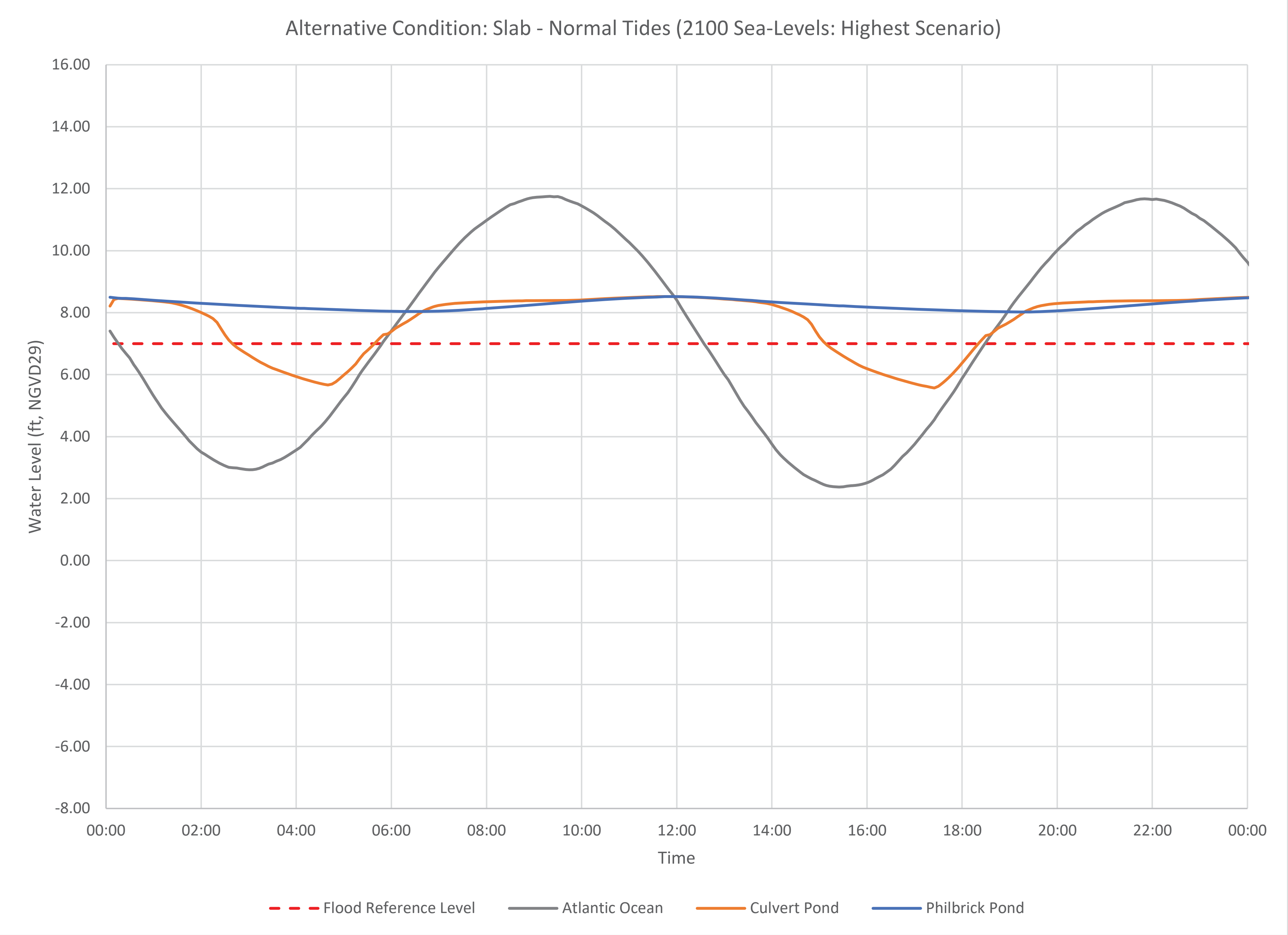
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Normal Tides (2100 Sea-Levels: Highest Scenario)
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Water Level (ft, NGVD29)
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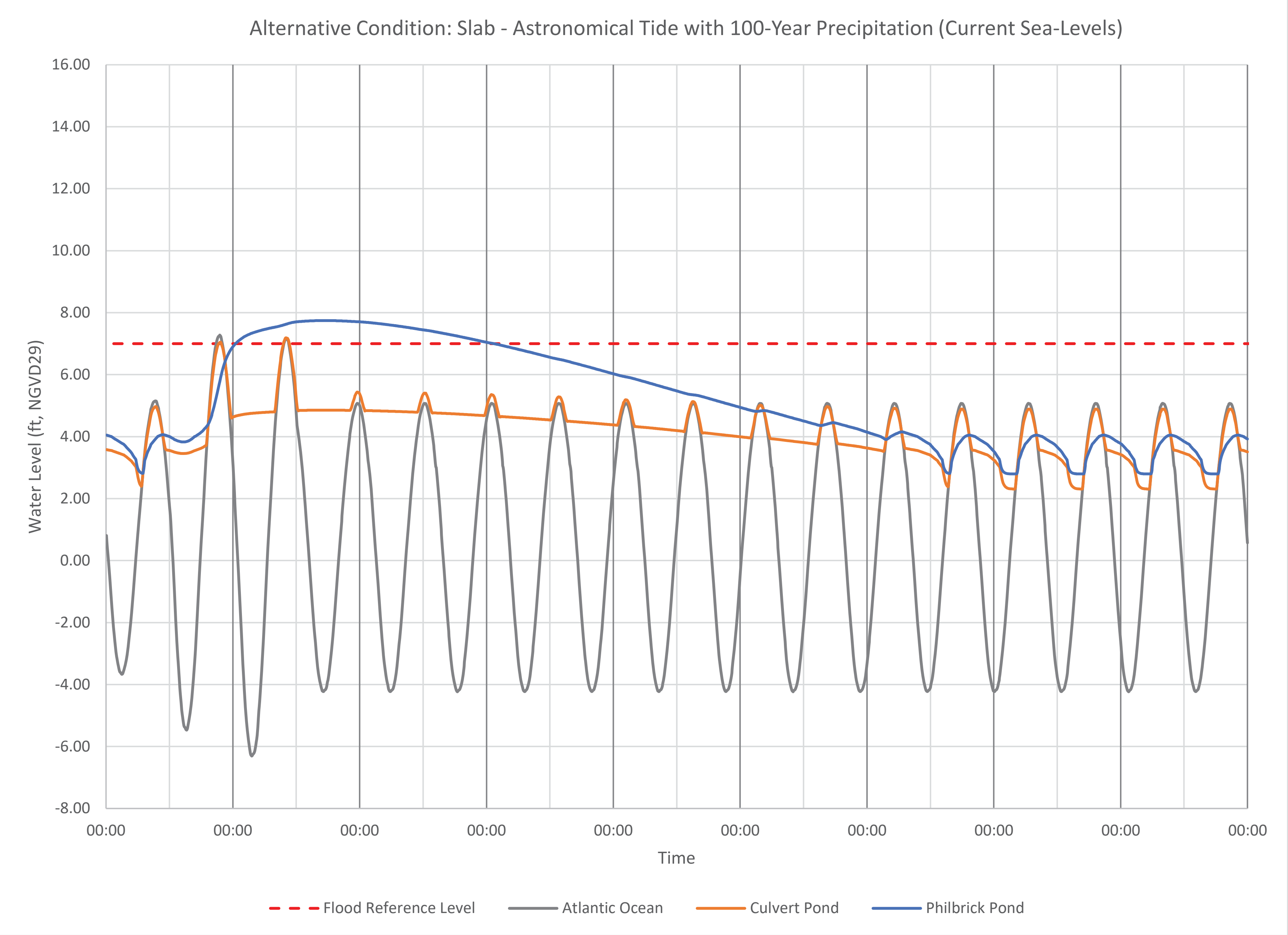
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Astronomical Tide with 100-Year Precipitation (Current Sea-Levels)
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Water Level (ft, NGVD29)
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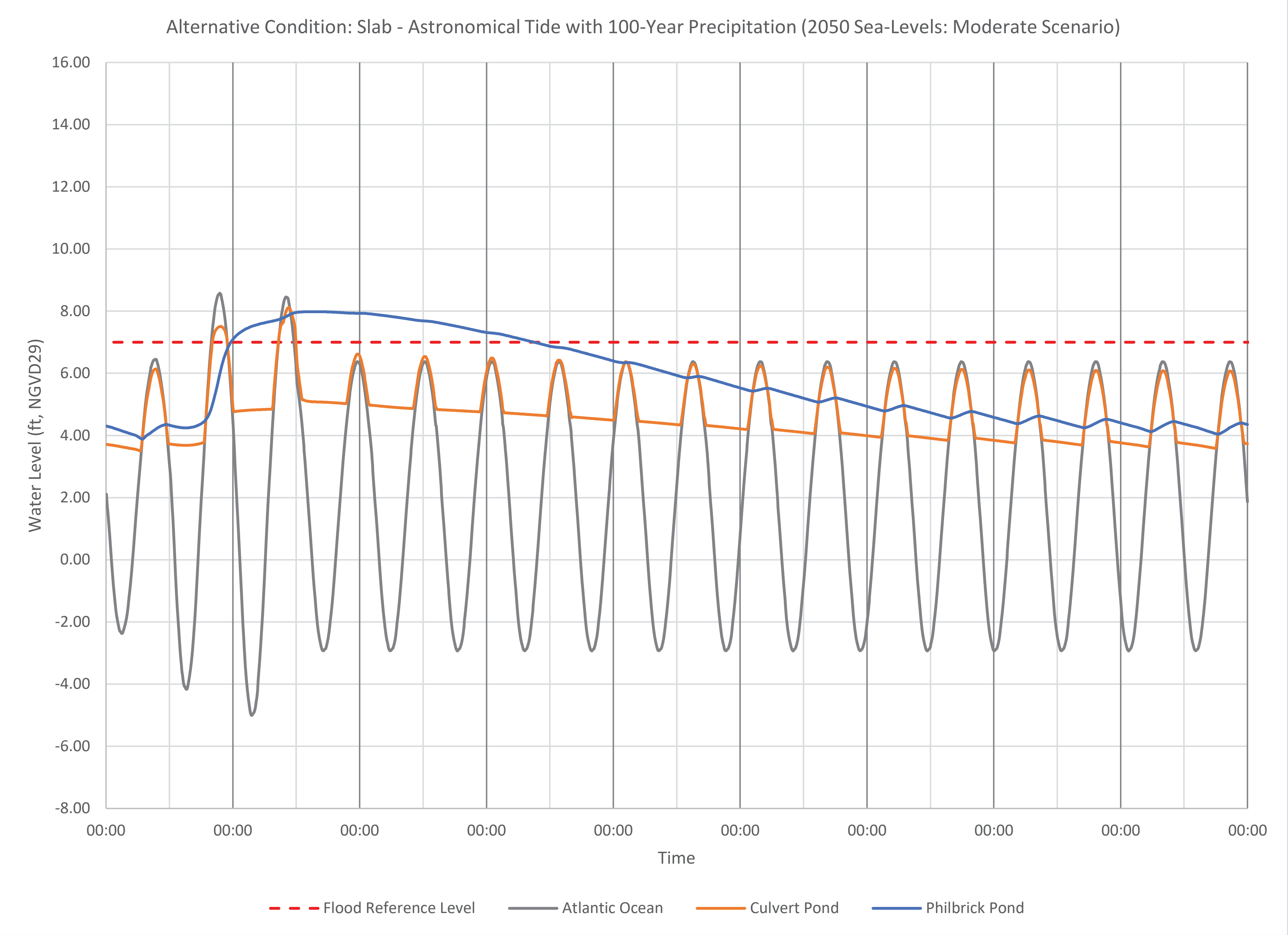
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Astronomical Tide with 100-Year Precipitation (2050 Sea-Levels: Moderate Scenario)
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14.00
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Water Level (ft, NGVD29)
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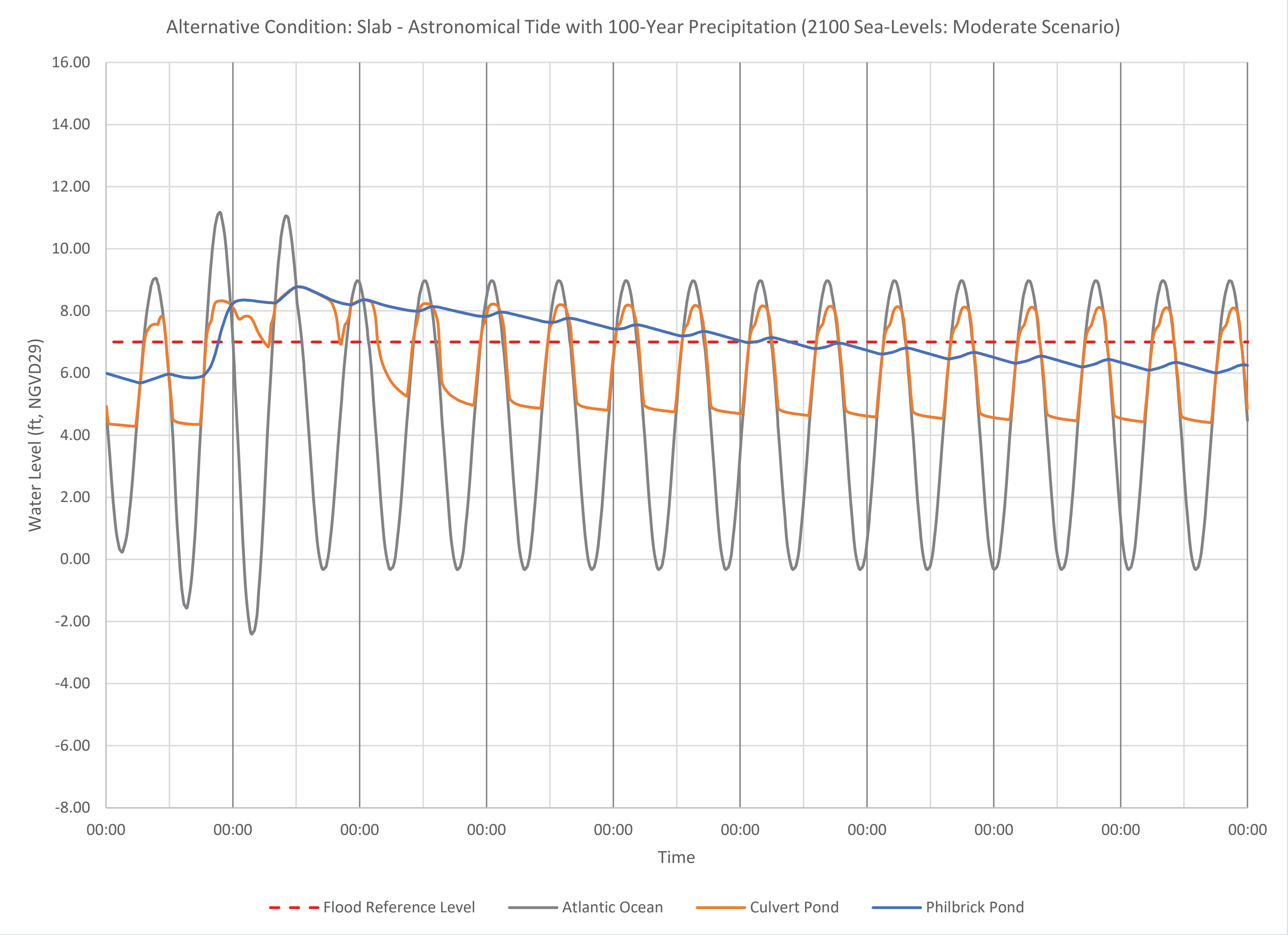
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Astronomical Tide with 100-Year Precipitation (2100 Sea-Levels: Moderate Scenario)
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14.00
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Water Level (ft, NGVD29)
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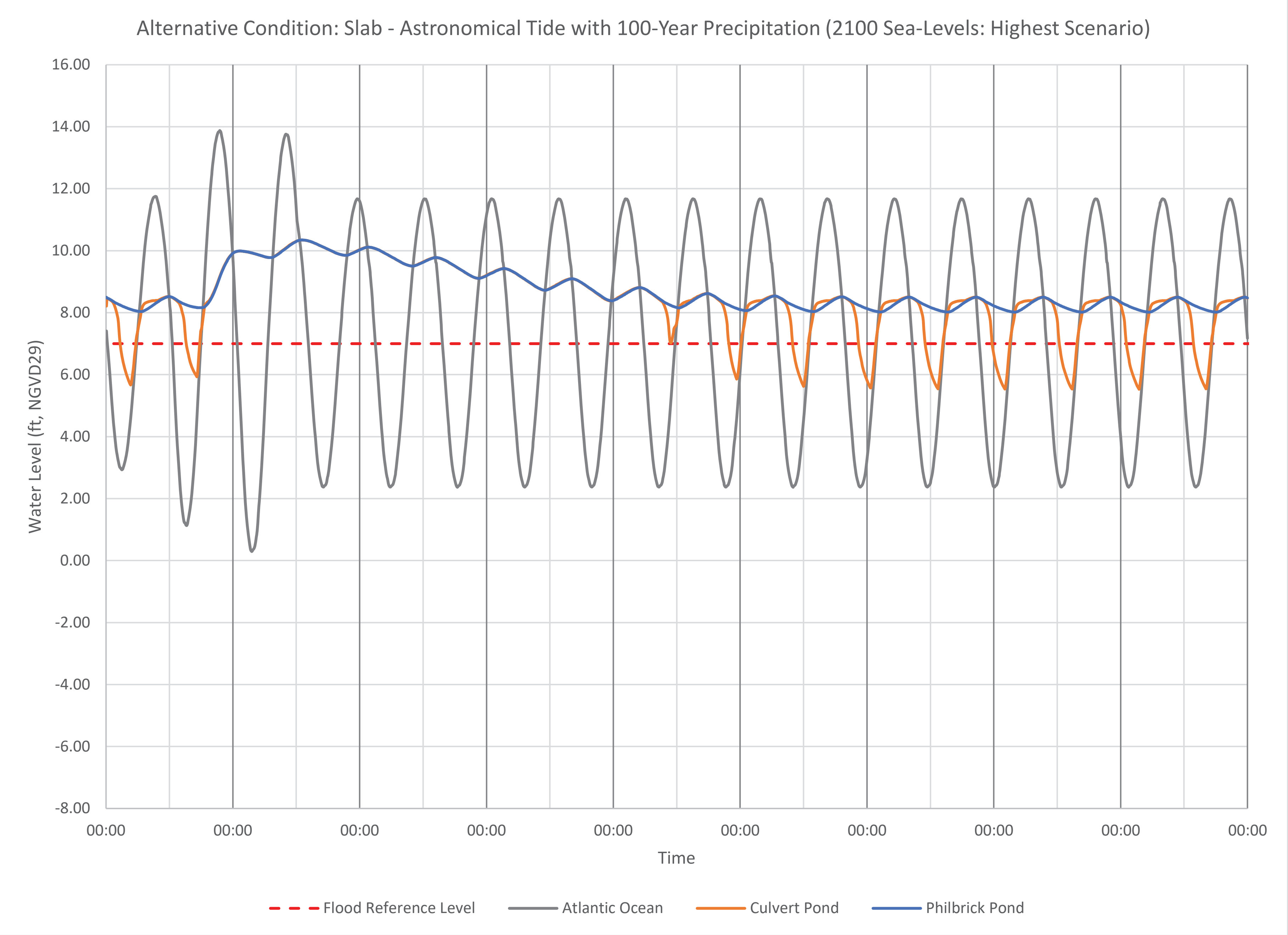
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Astronomical Tide with 100-Year Precipitation (2100 Sea-Levels: Highest Scenario)
Water Level (ft, NGVD29)
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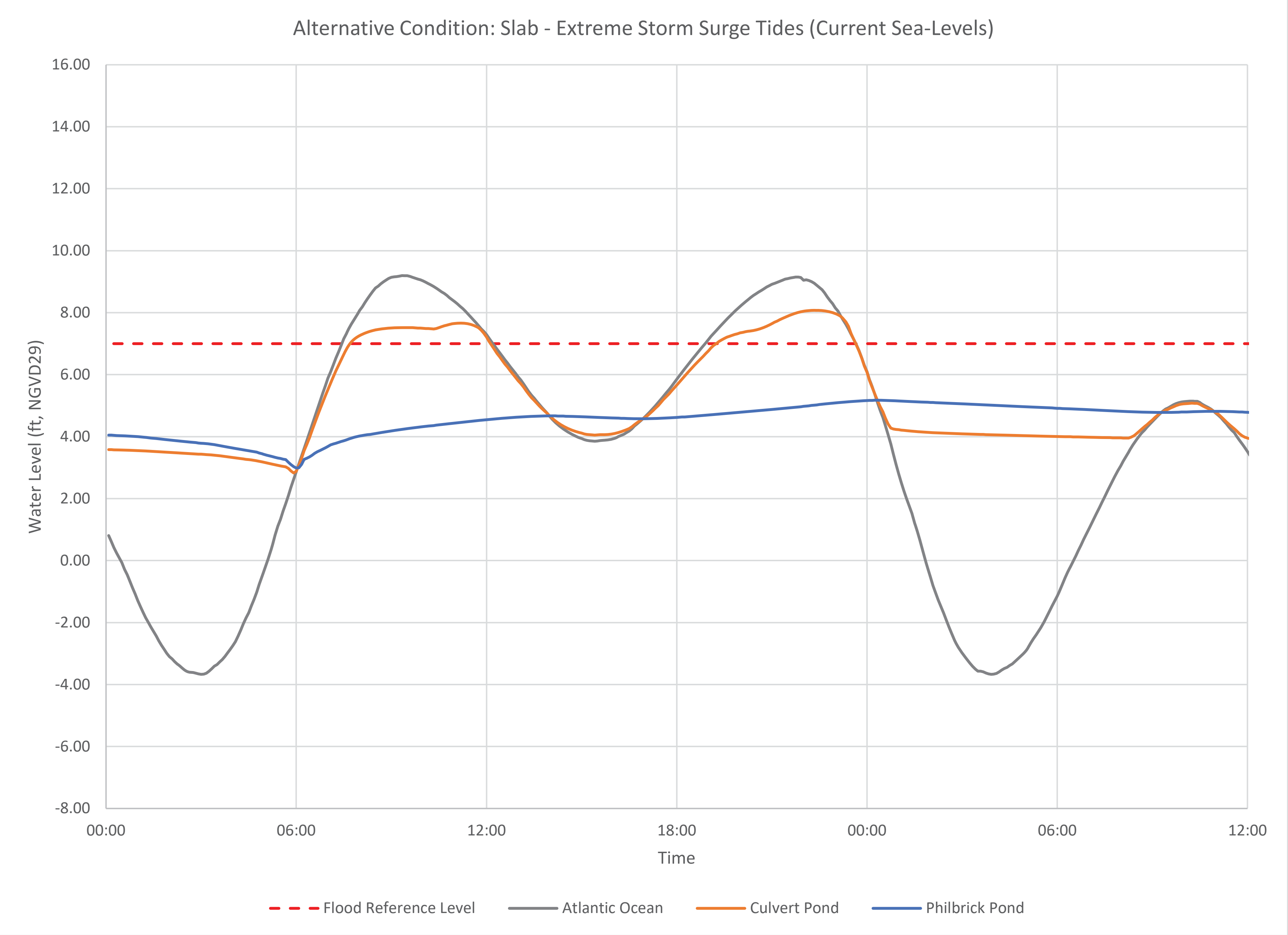
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Extreme Storm Surge Tides (Current Sea-Levels)
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12.00
10.00
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6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
Water Level (ft, NGVD29)
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06:00
12:00
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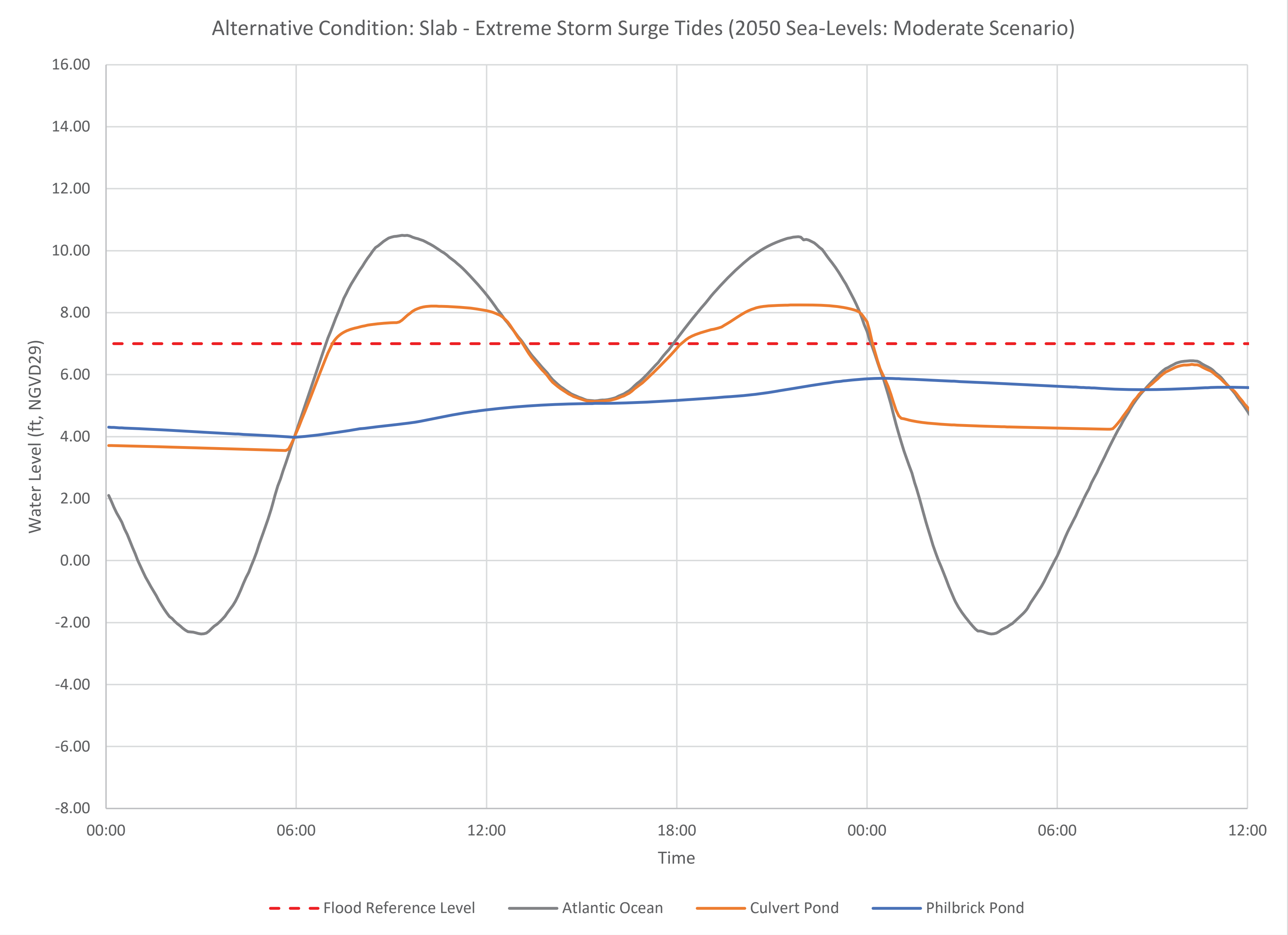
12:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Extreme Storm Surge Tides (2050 Sea-Levels: Moderate Scenario)
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12.00
10.00
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-6.00
-8.00
Water Level (ft, NGVD29)
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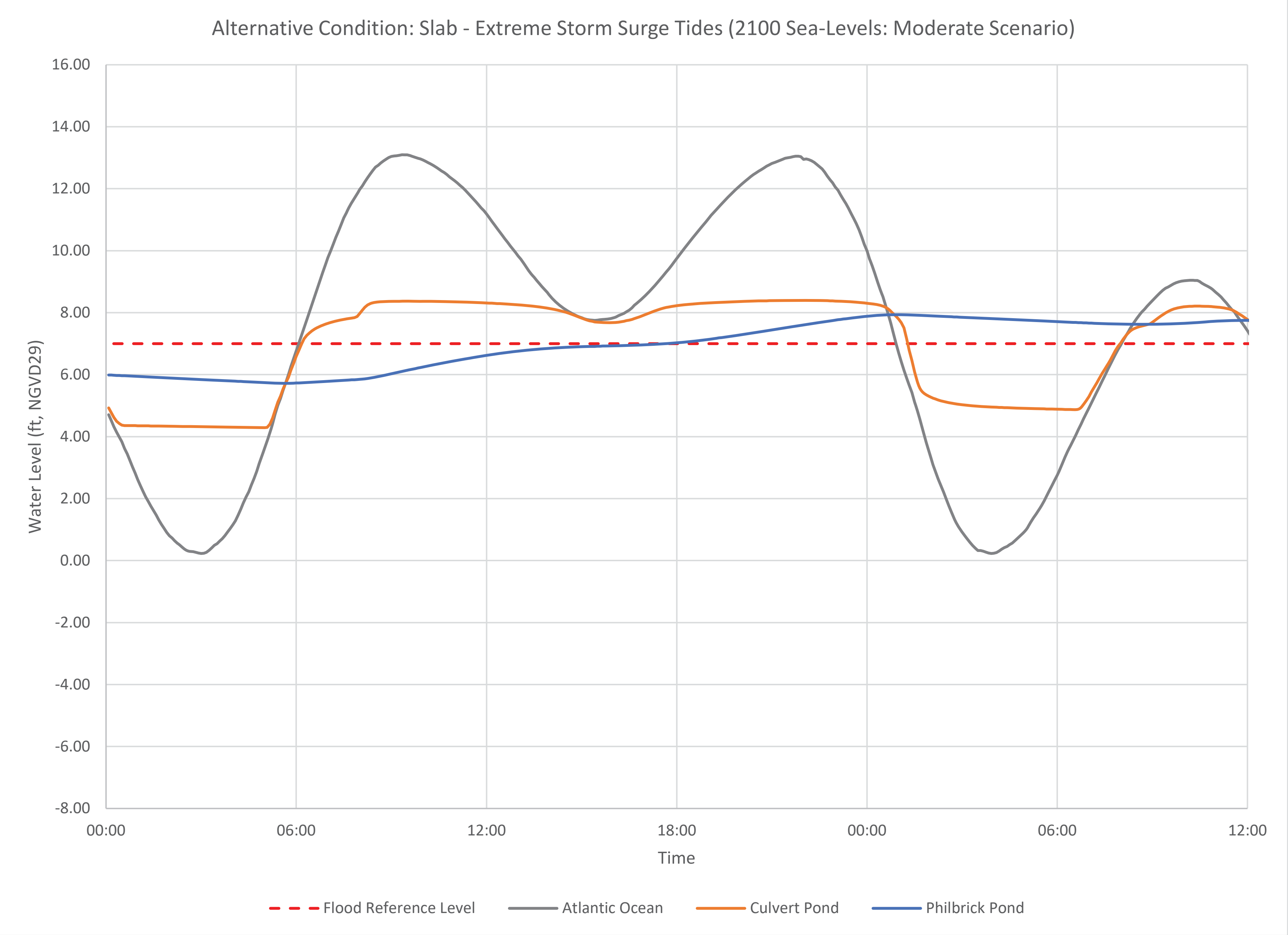
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Extreme Storm Surge Tides (2100 Sea-Levels: Moderate Scenario)
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-6.00
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Water Level (ft, NGVD29)
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06:00
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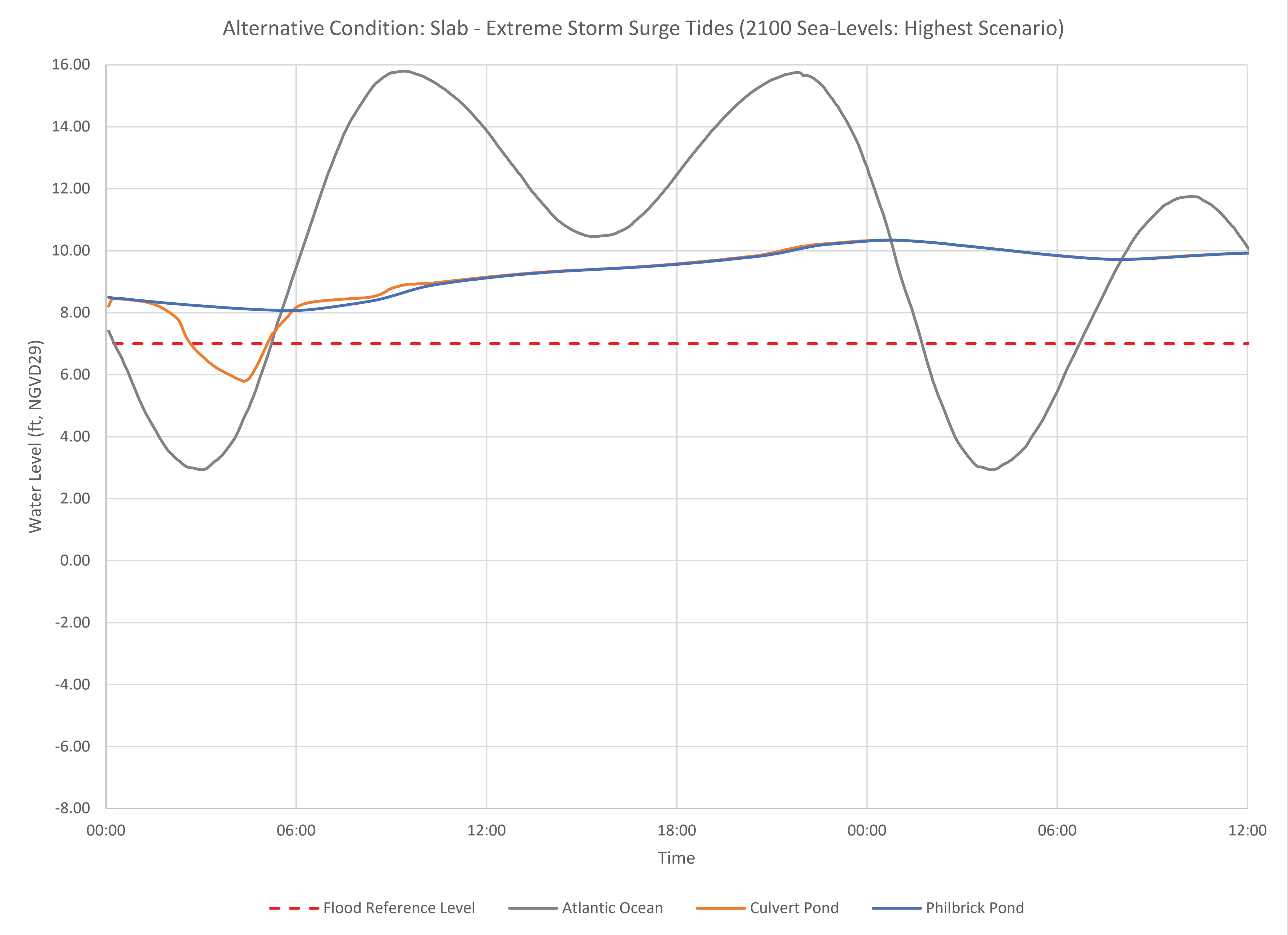
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Slab - Extreme Storm Surge Tides (2100 Sea-Levels: Highest Scenario)
Water Level (ft, NGVD29)
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12.00
10.00
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6.00
4.00
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-4.00
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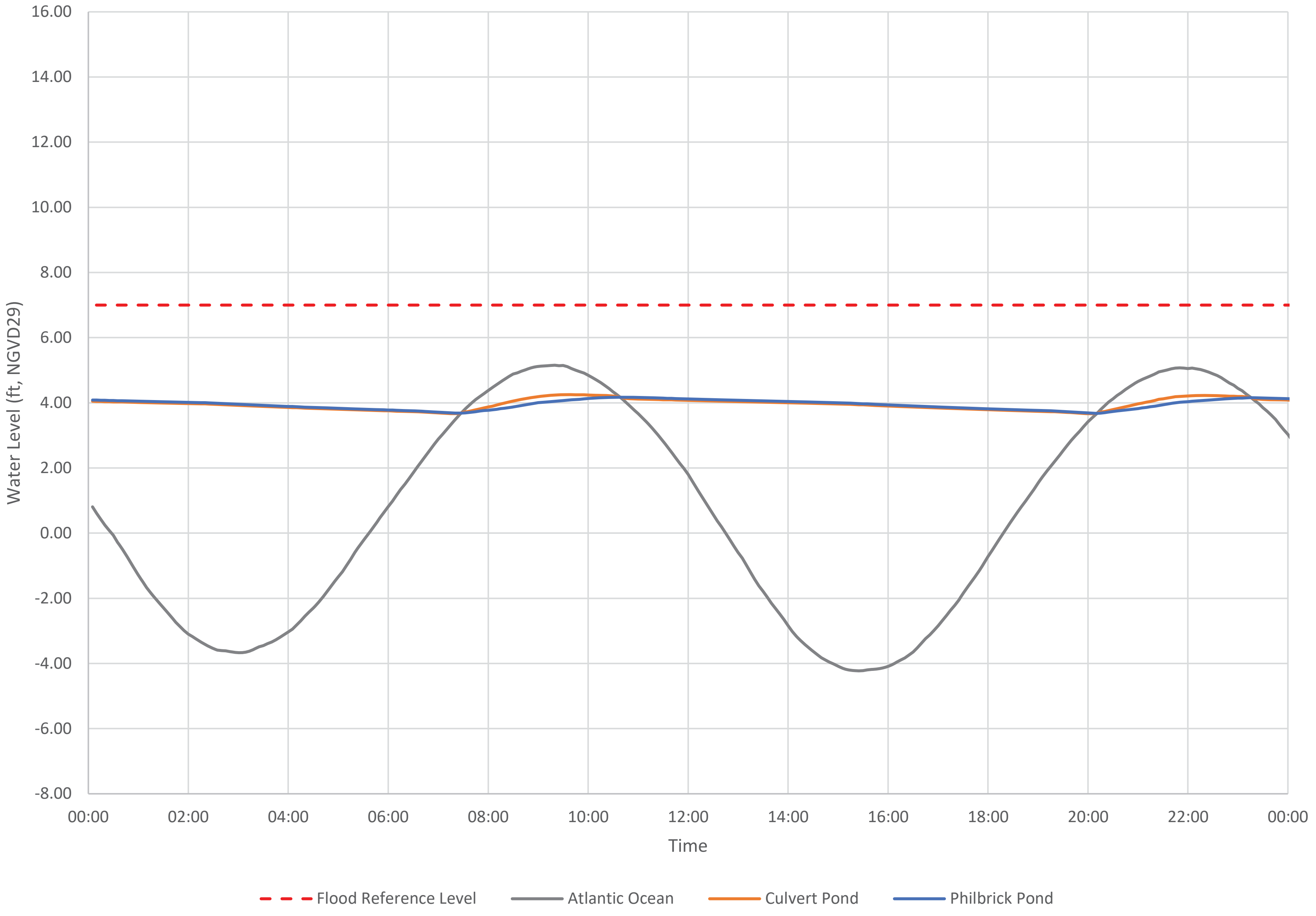
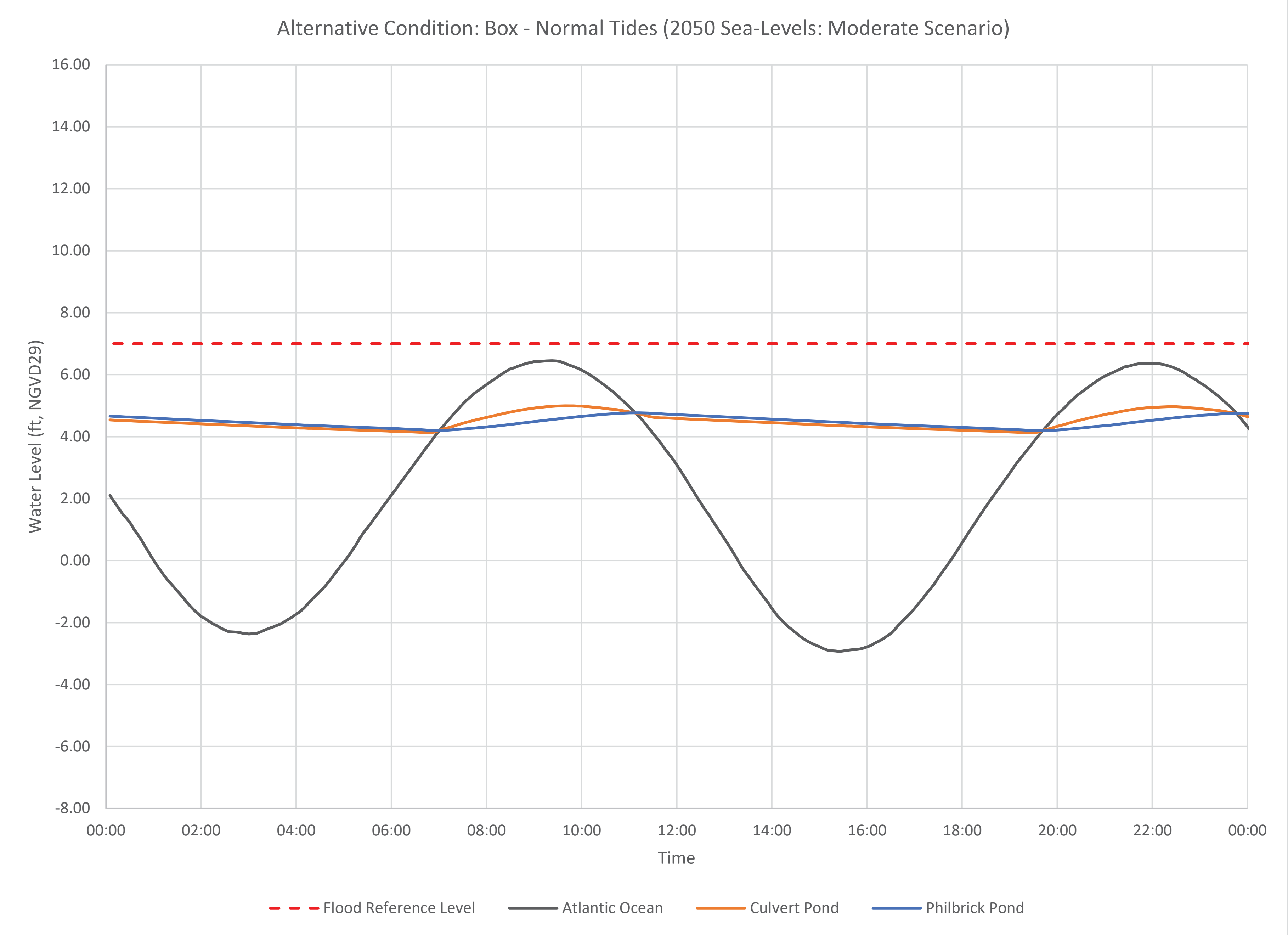
12:00
18:00
00:00
06:00
12:00
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond

Alternative Condition: Box - Normal Tides (Current Sea-Levels)





Alternative Condition: Box - Normal Tides (2050 Sea-Levels: Moderate Scenario)
Water Level (ft, NGVD29)
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12.00
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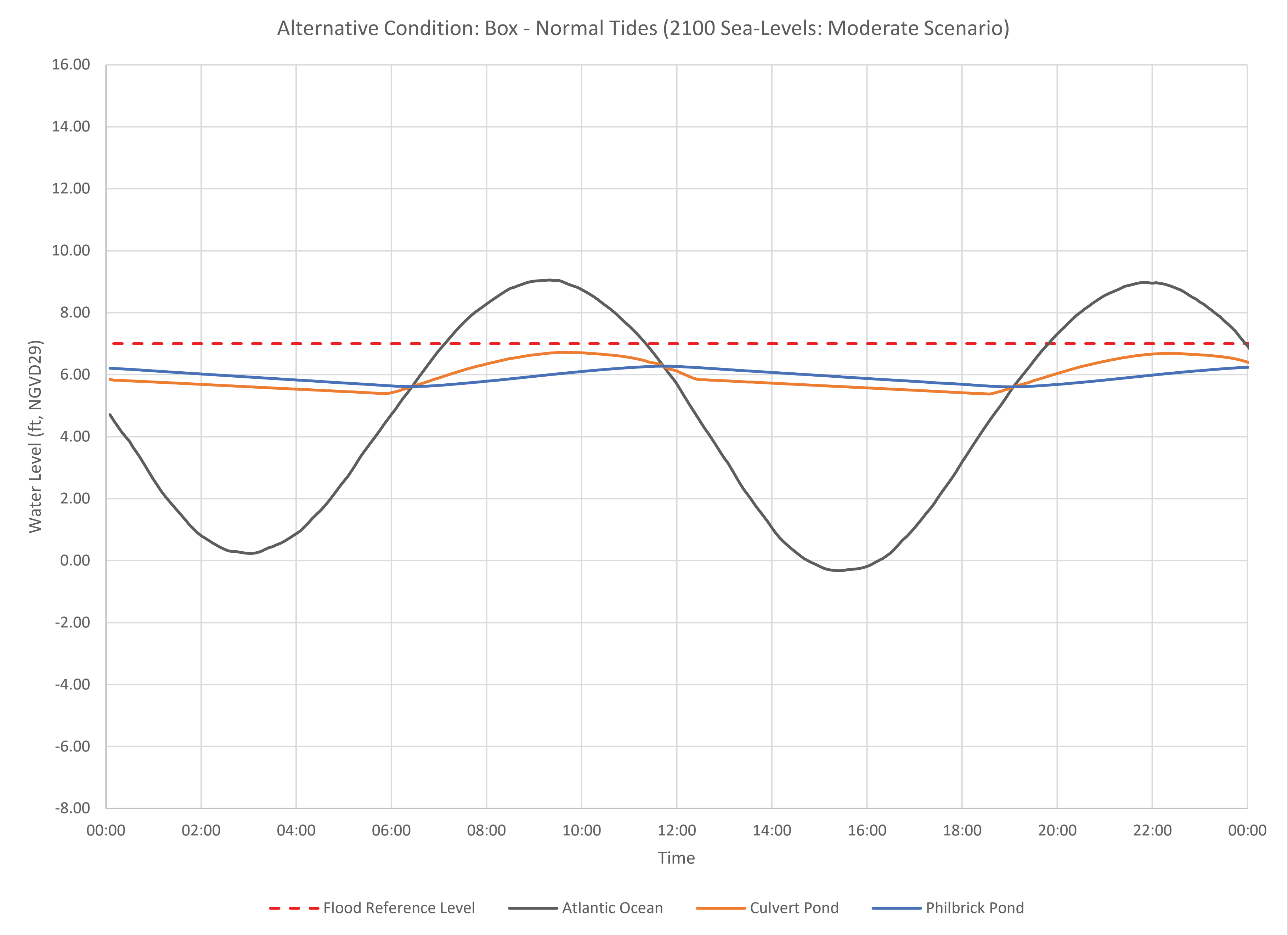
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box - Normal Tides (2100 Sea-Levels: Moderate Scenario)
Water Level (ft, NGVD29)
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12.00
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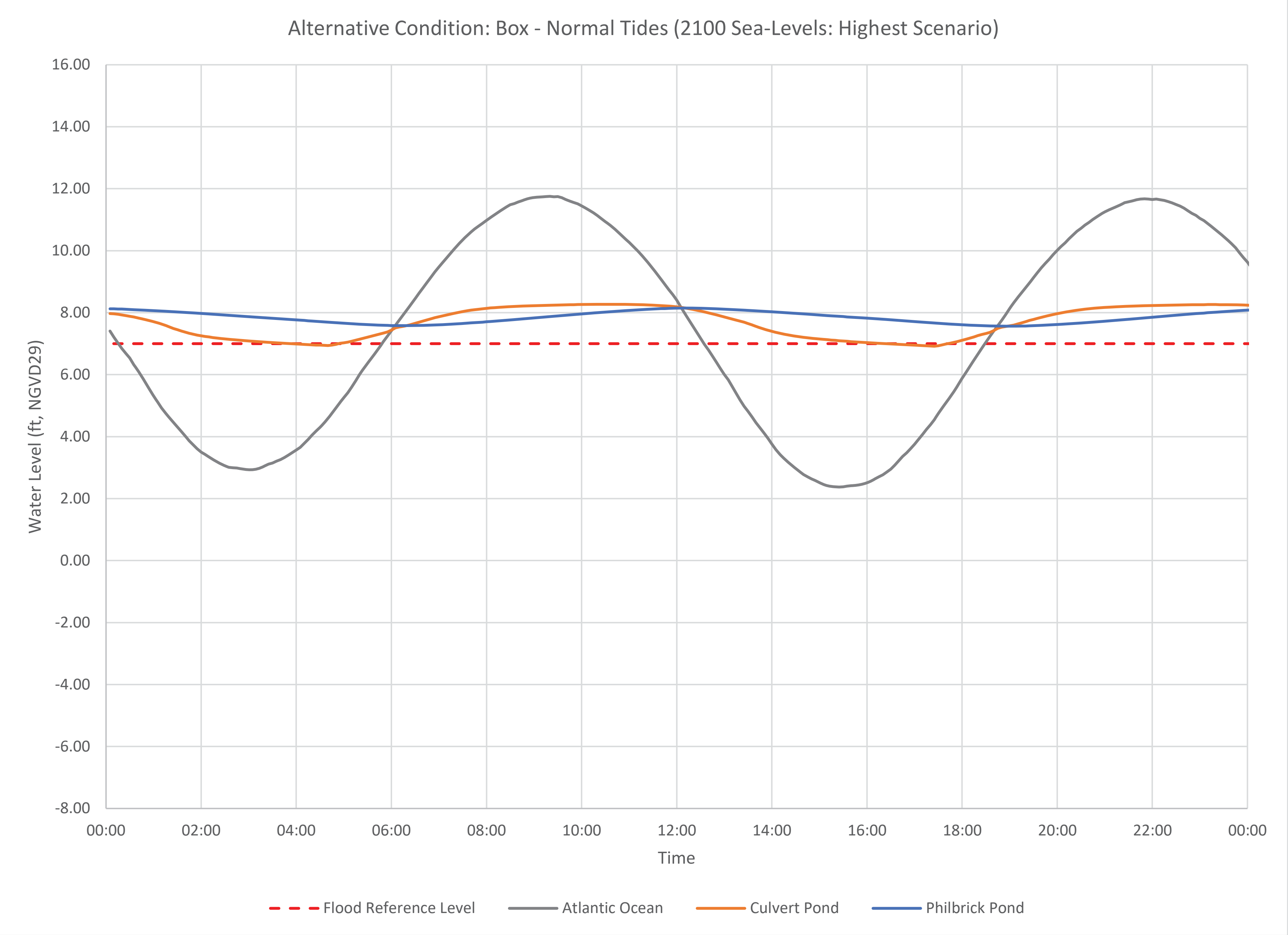
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box - Normal Tides (2100 Sea-Levels: Highest Scenario)
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Water Level (ft, NGVD29)
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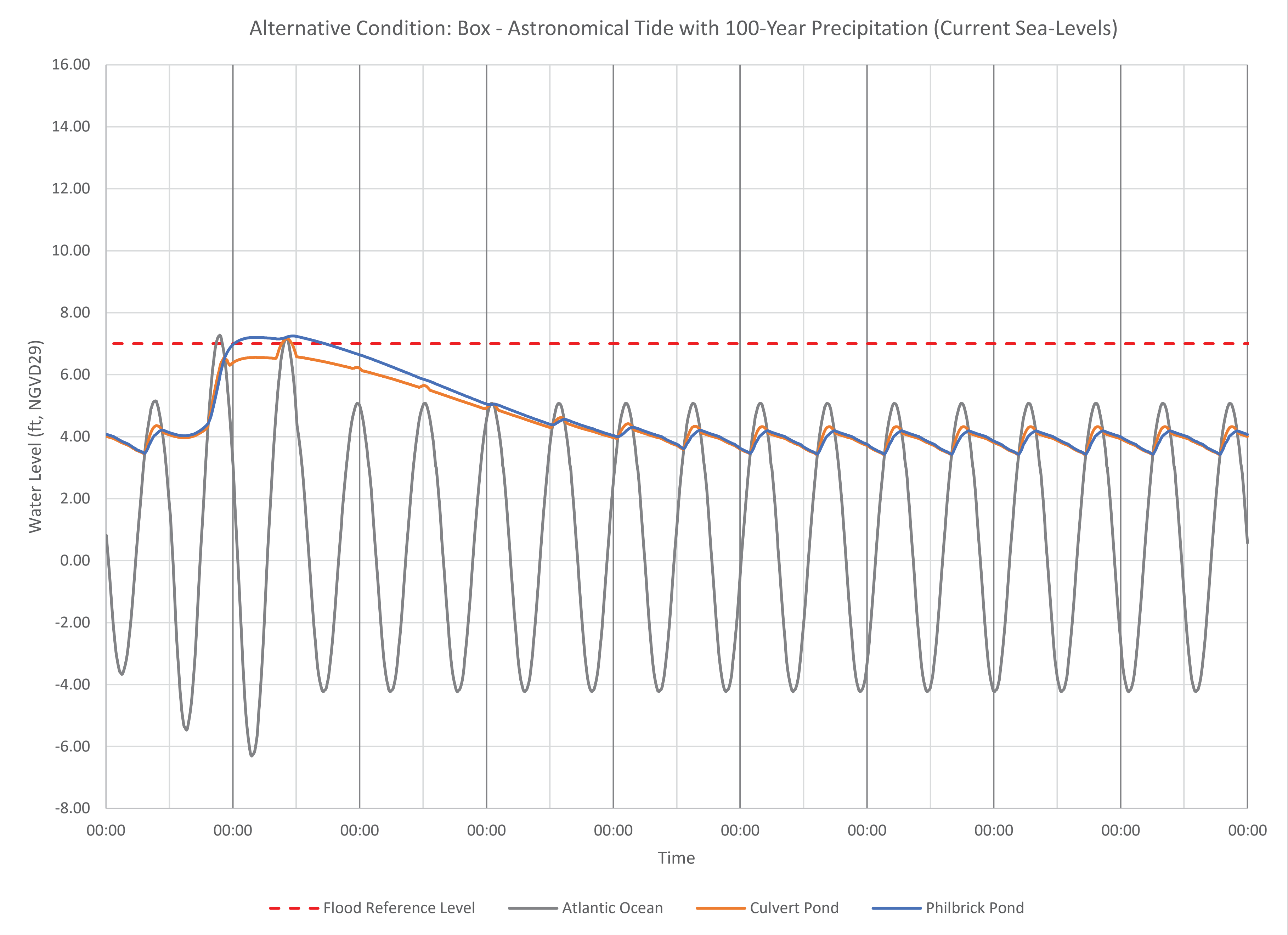
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box - Astronomical Tide with 100-Year Precipitation (Current Sea-Levels)
Water Level (ft, NGVD29)
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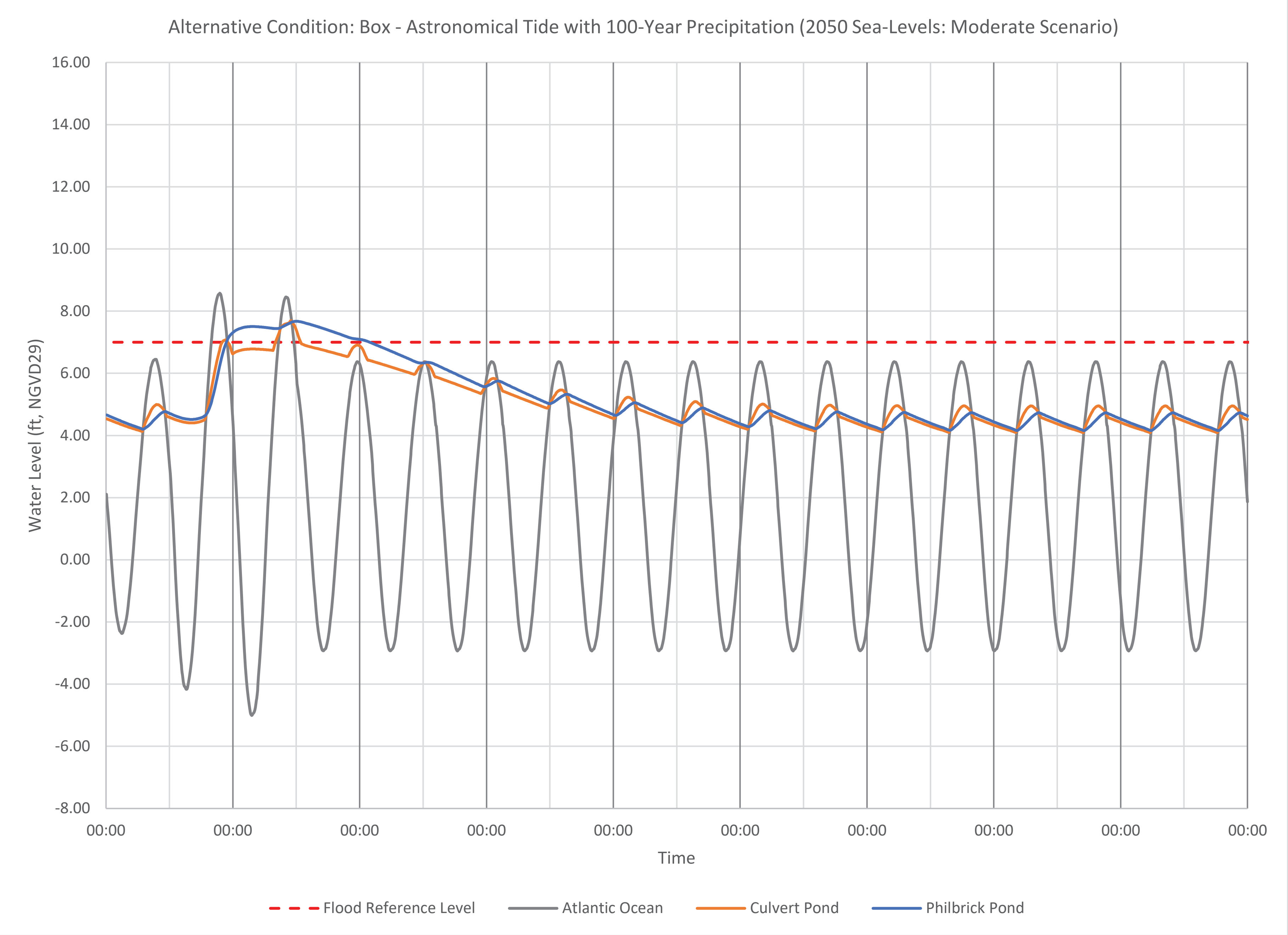
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box - Astronomical Tide with 100-Year Precipitation (2050 Sea-Levels: Moderate Scenario)
Water Level (ft, NGVD29)
16.00
14.00
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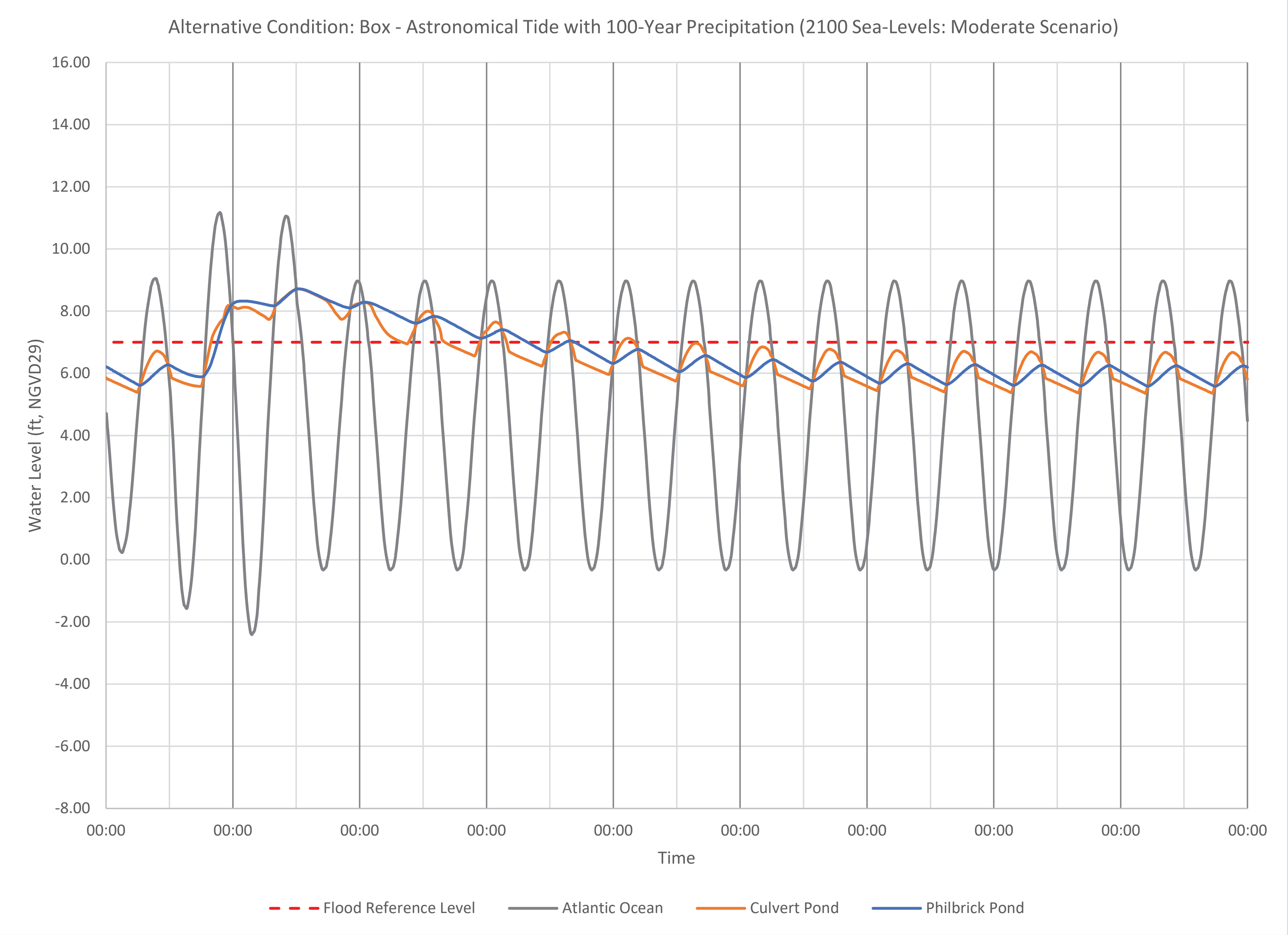
Time
Flood Reference Level
Atlantic Ocean
Culvert Pond
Philbrick Pond


Alternative Condition: Box - Astronomical Tide with 100-Year Precipitation (2100 Sea-Levels: Moderate Scenario)
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Water Level (ft, NGVD29)
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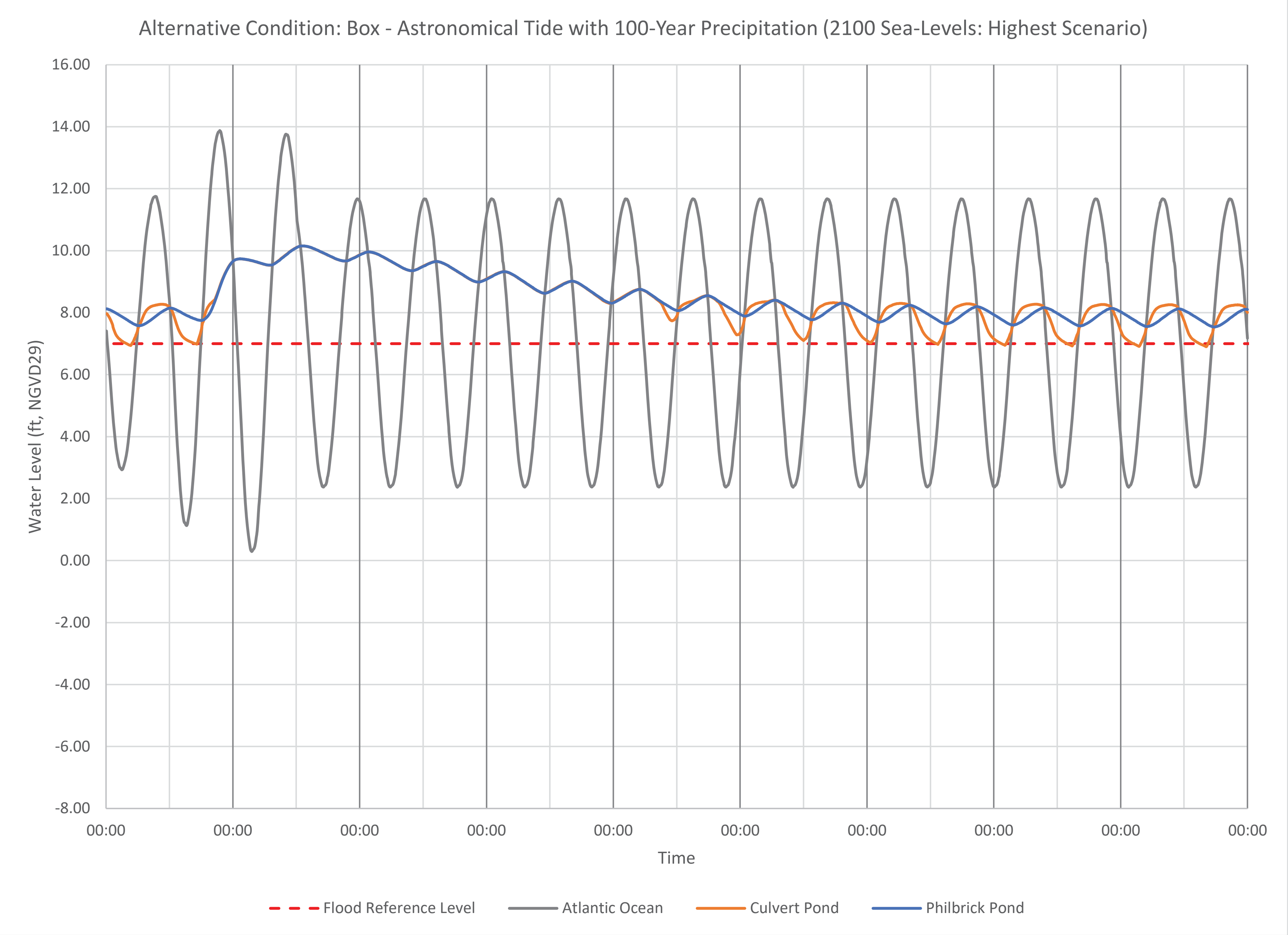
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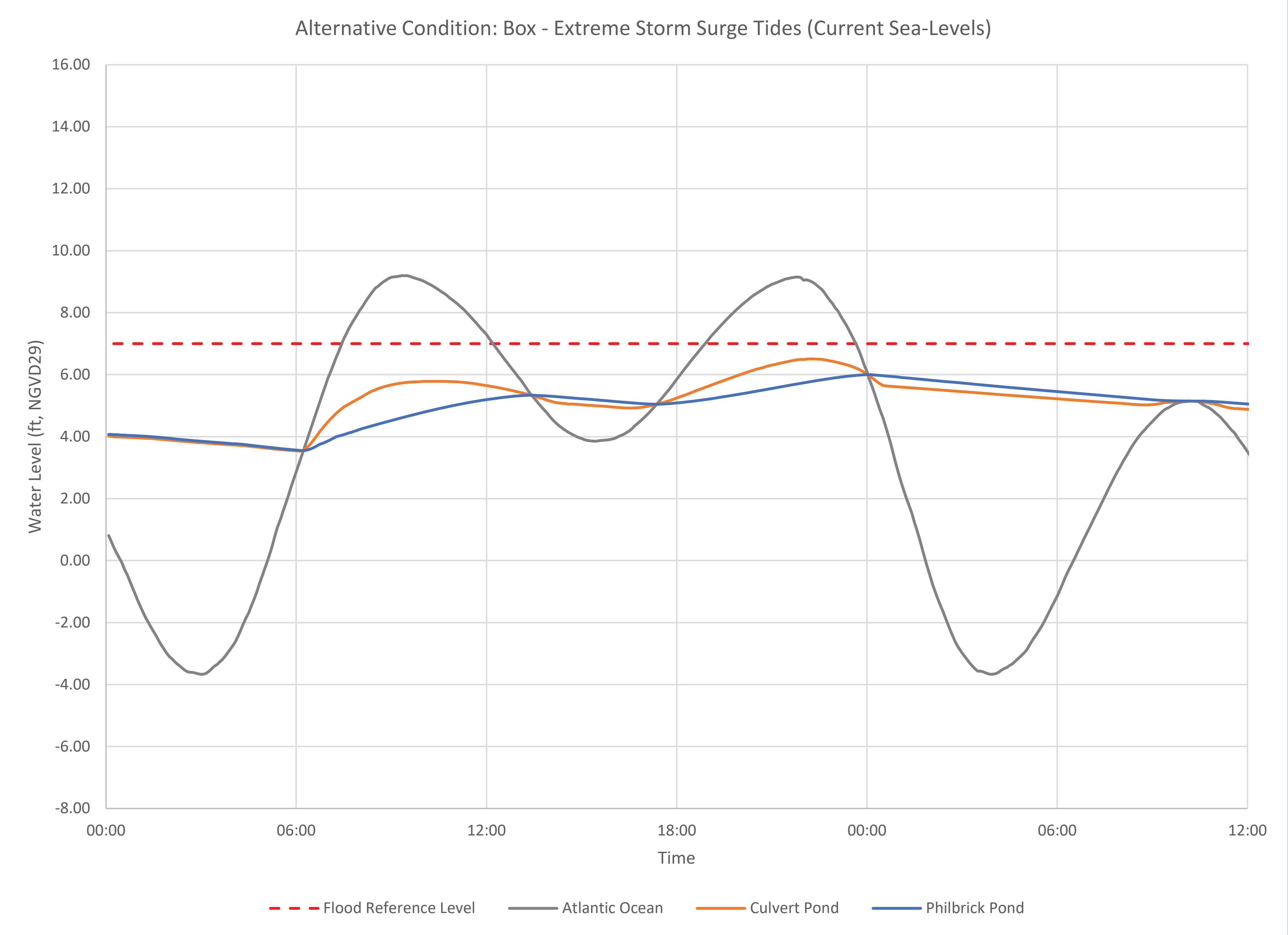
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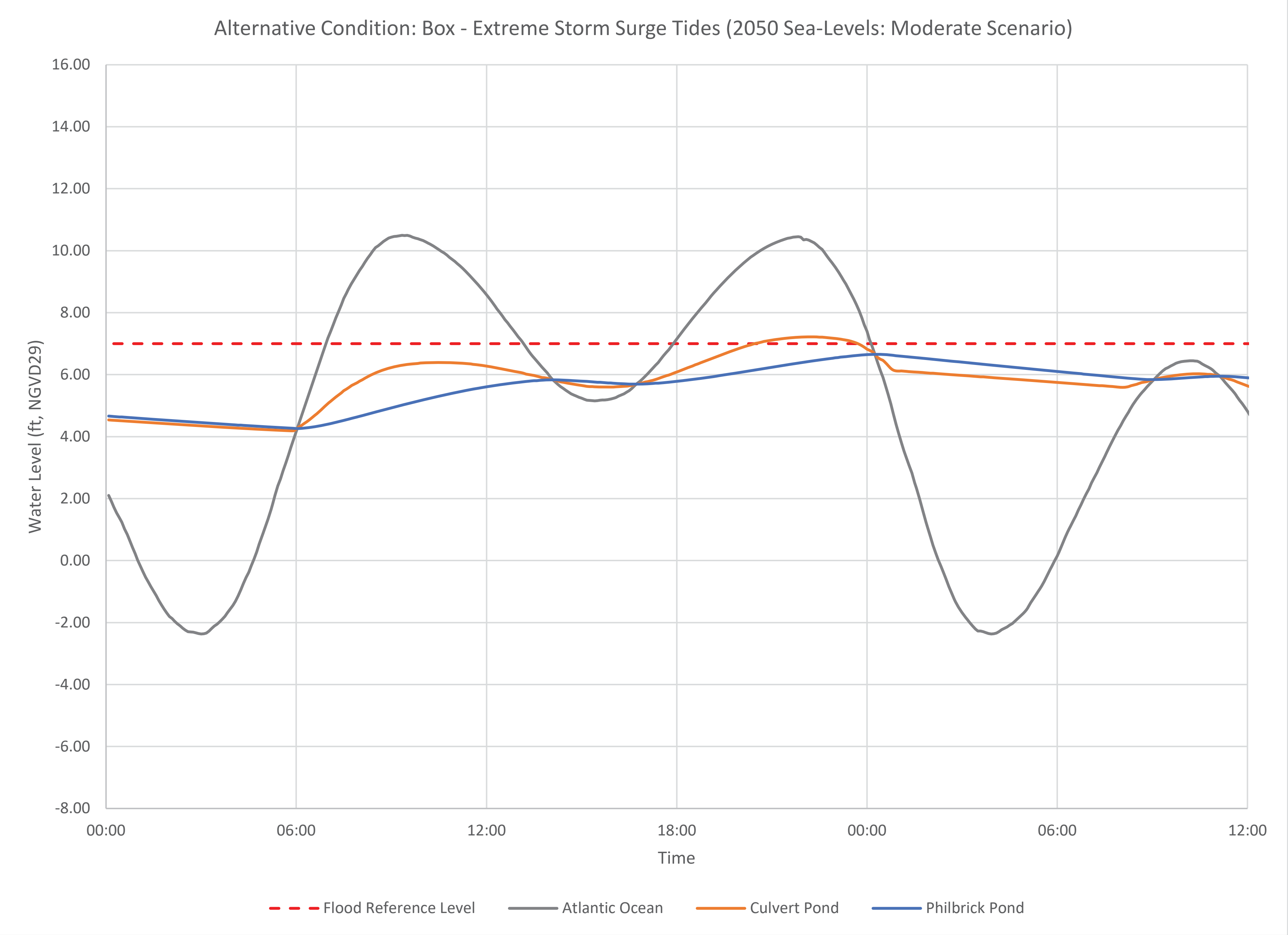
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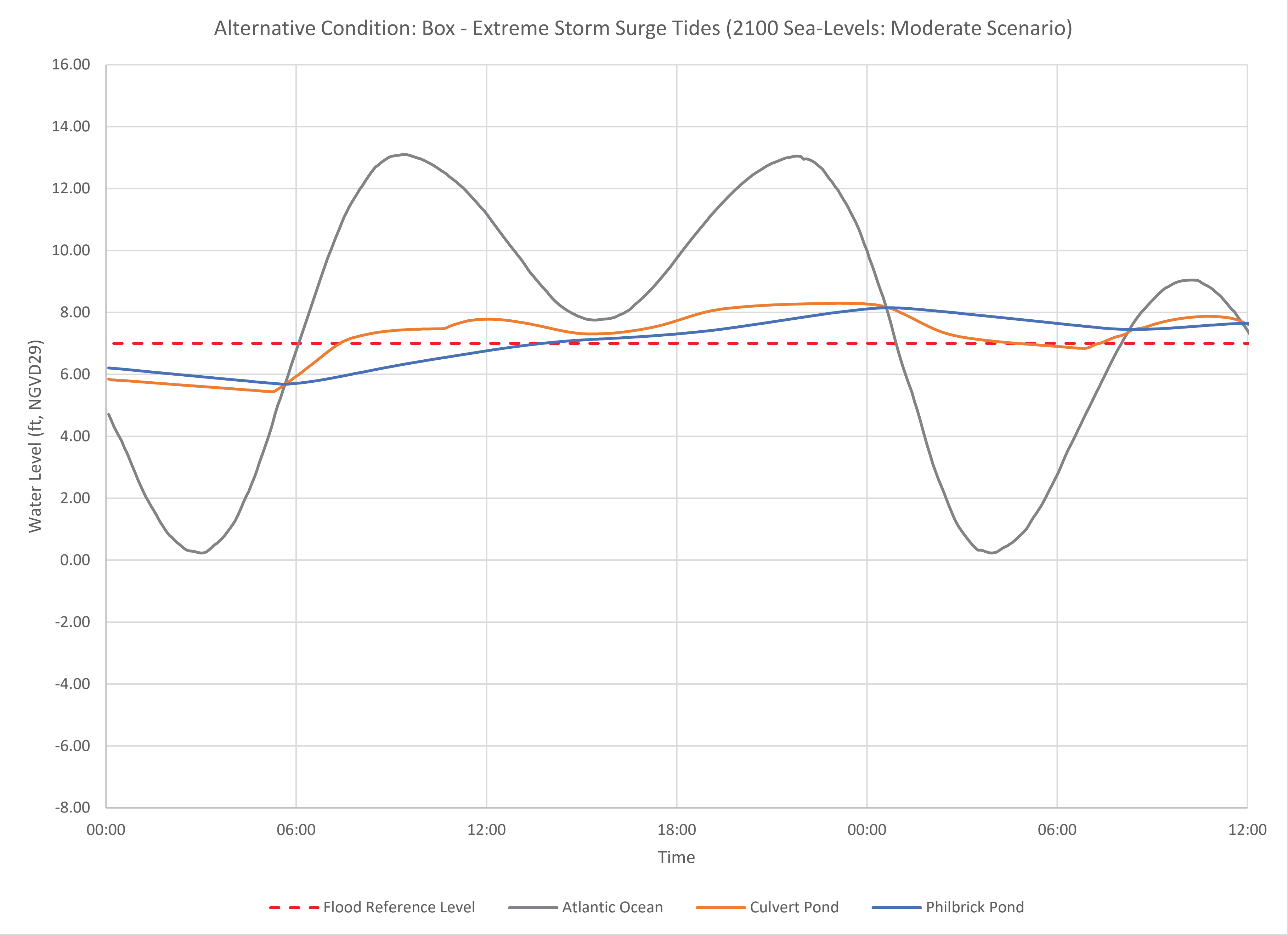
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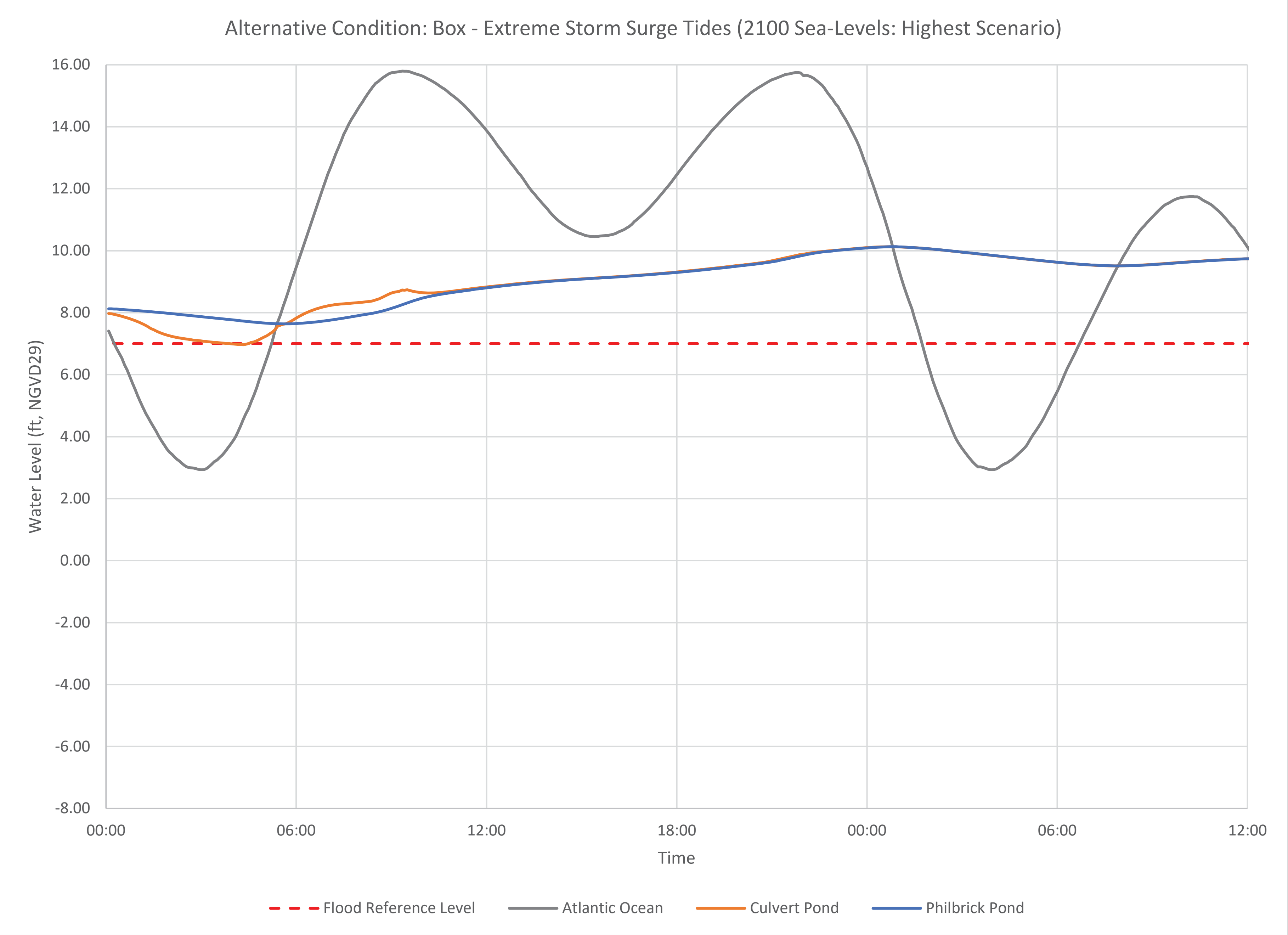
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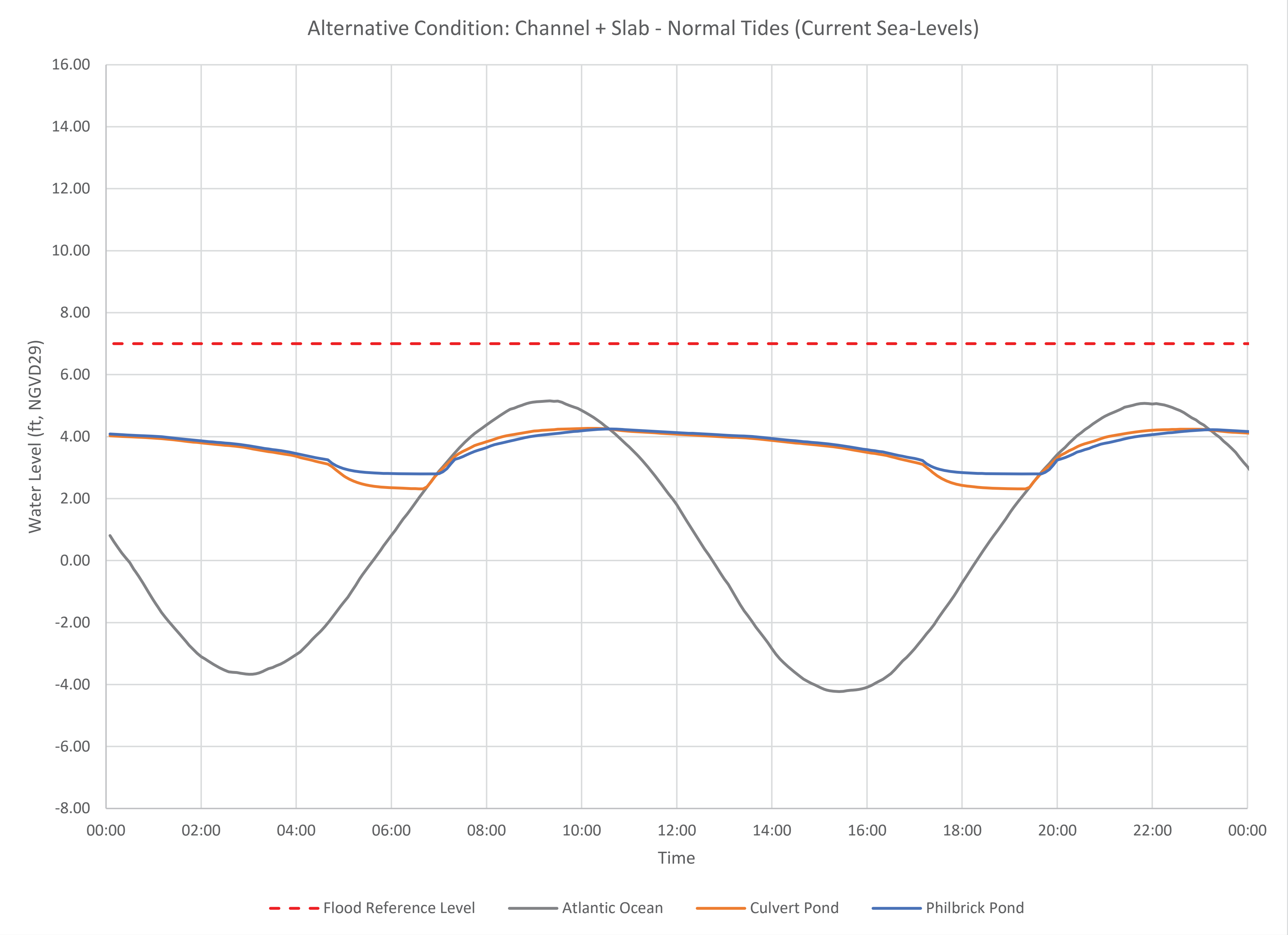
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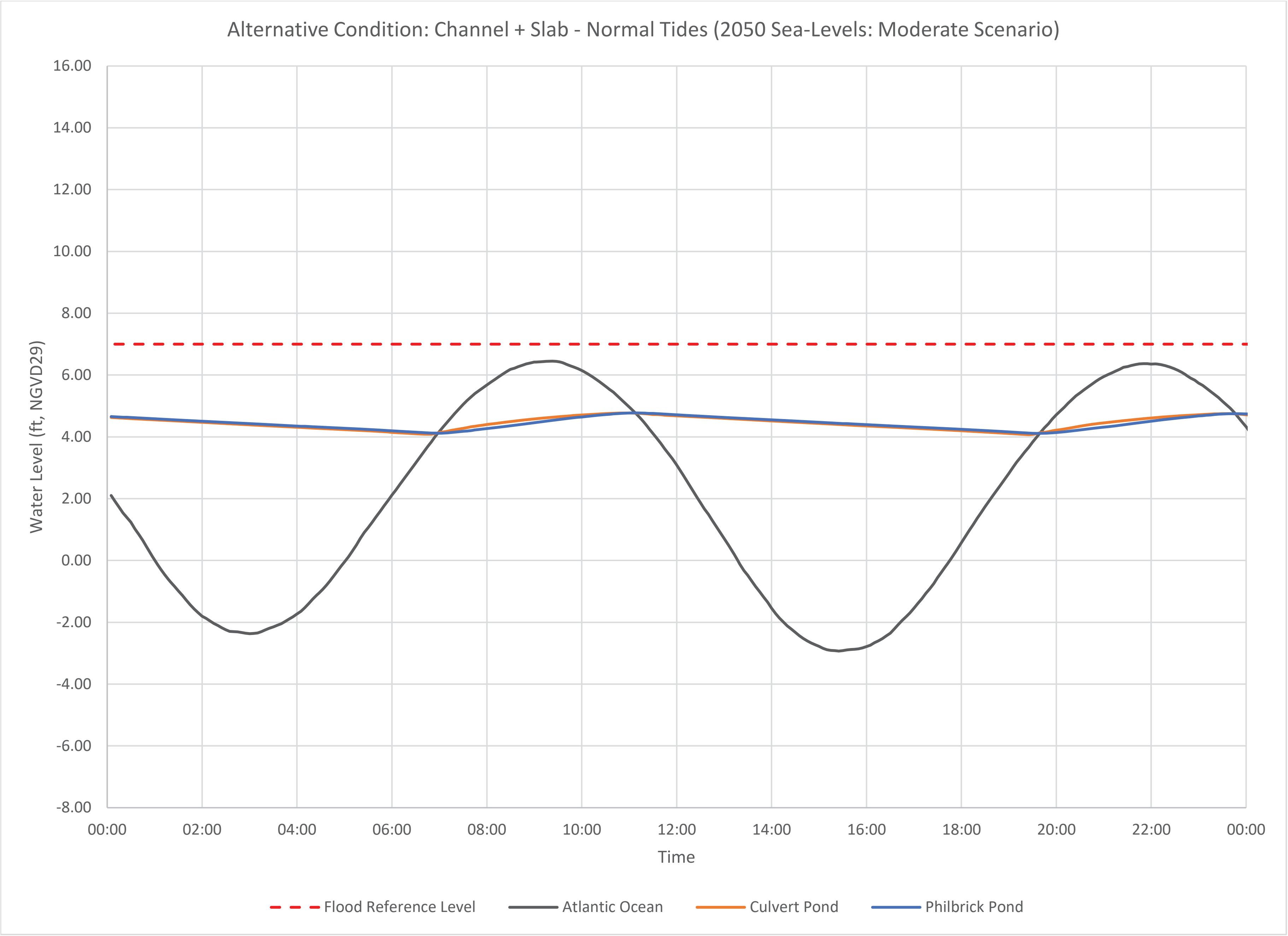
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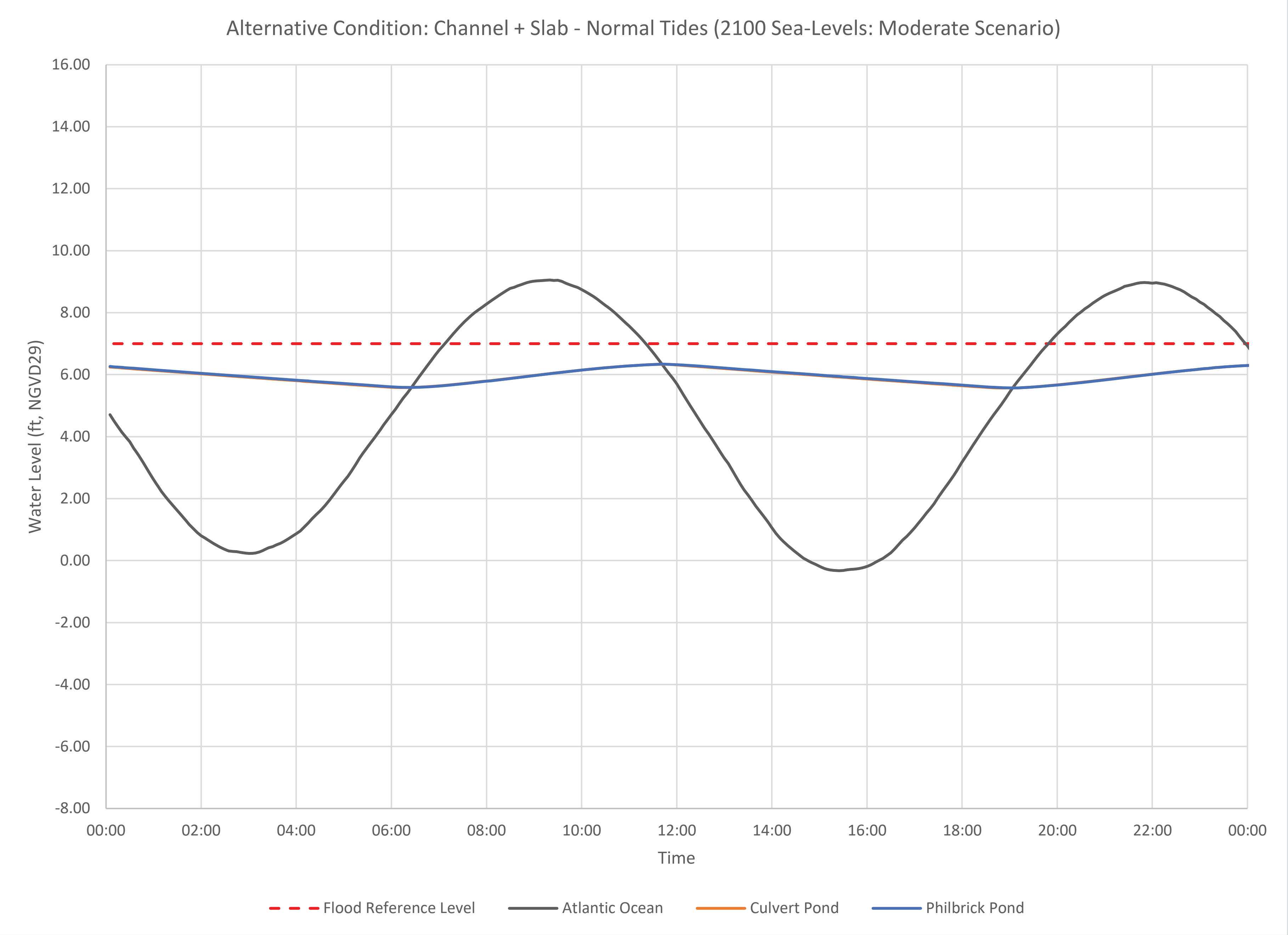
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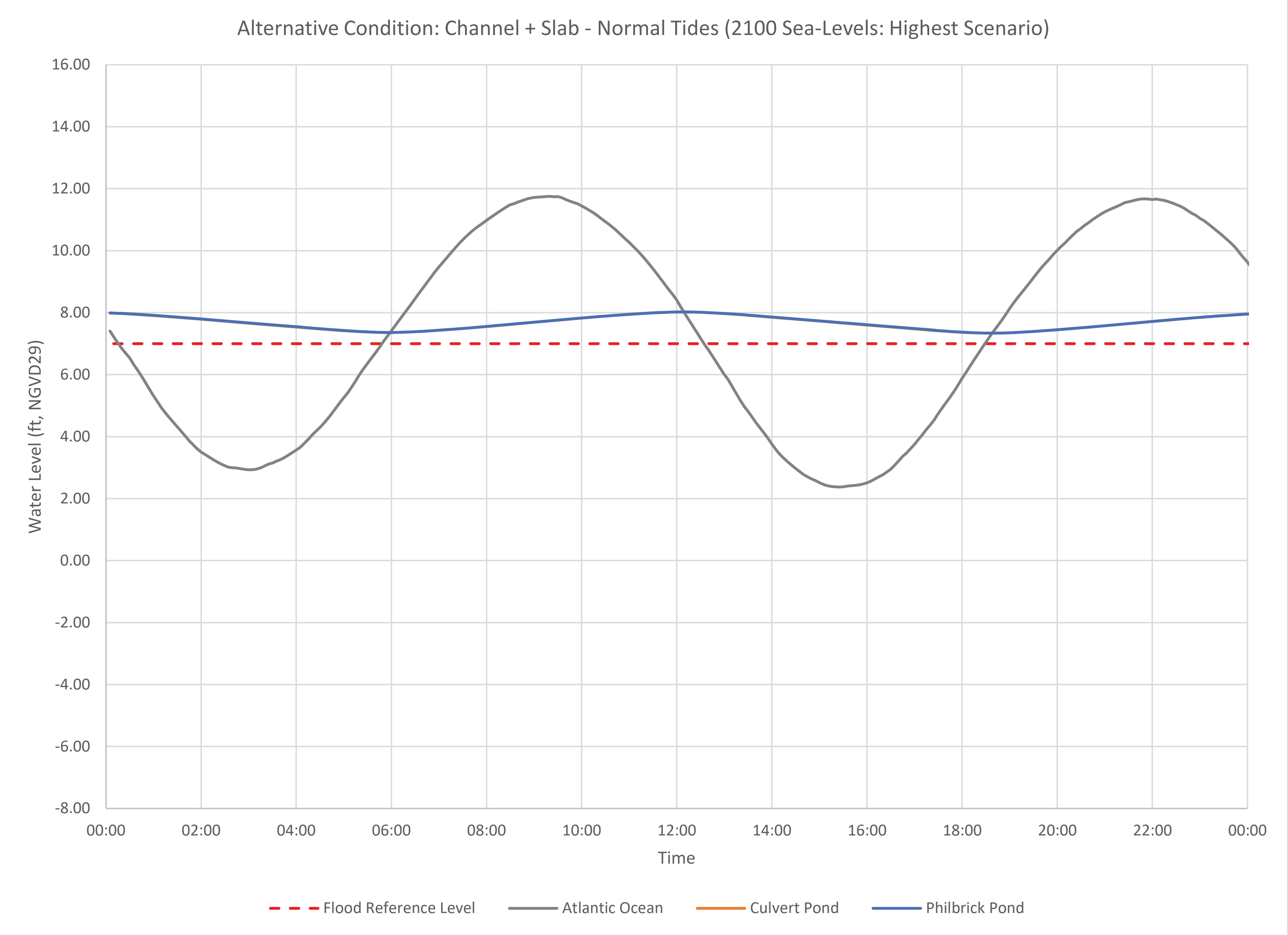
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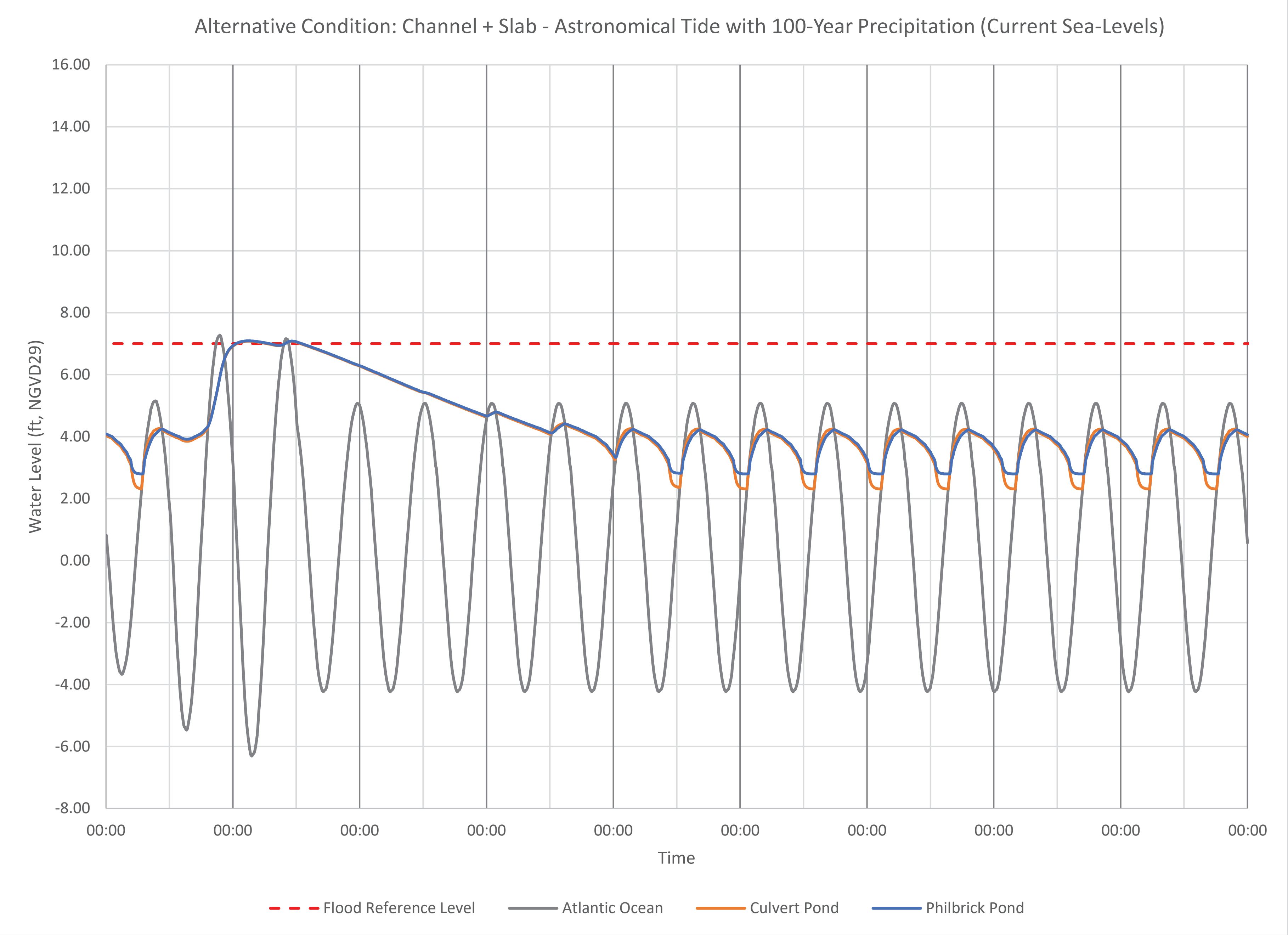
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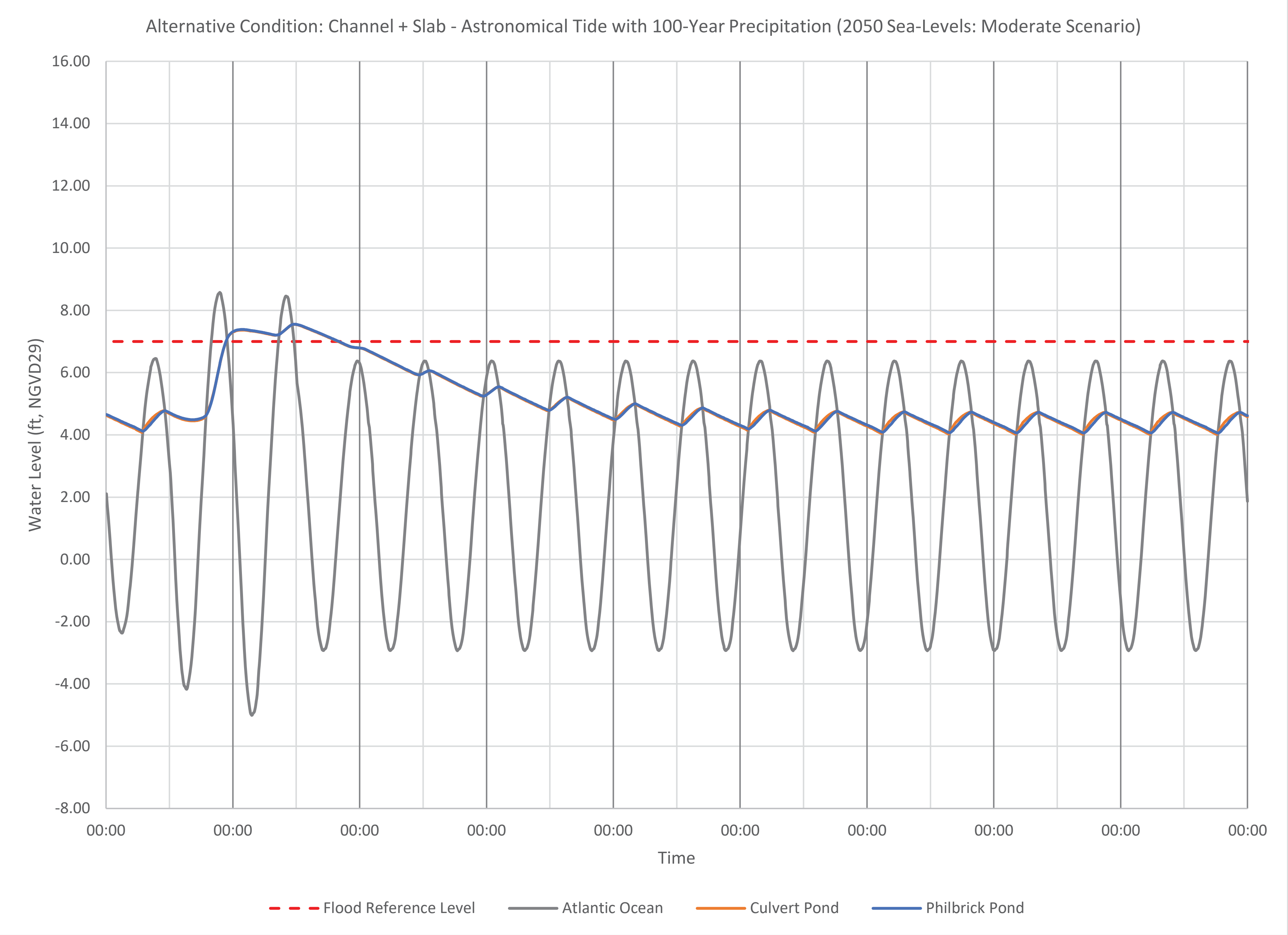
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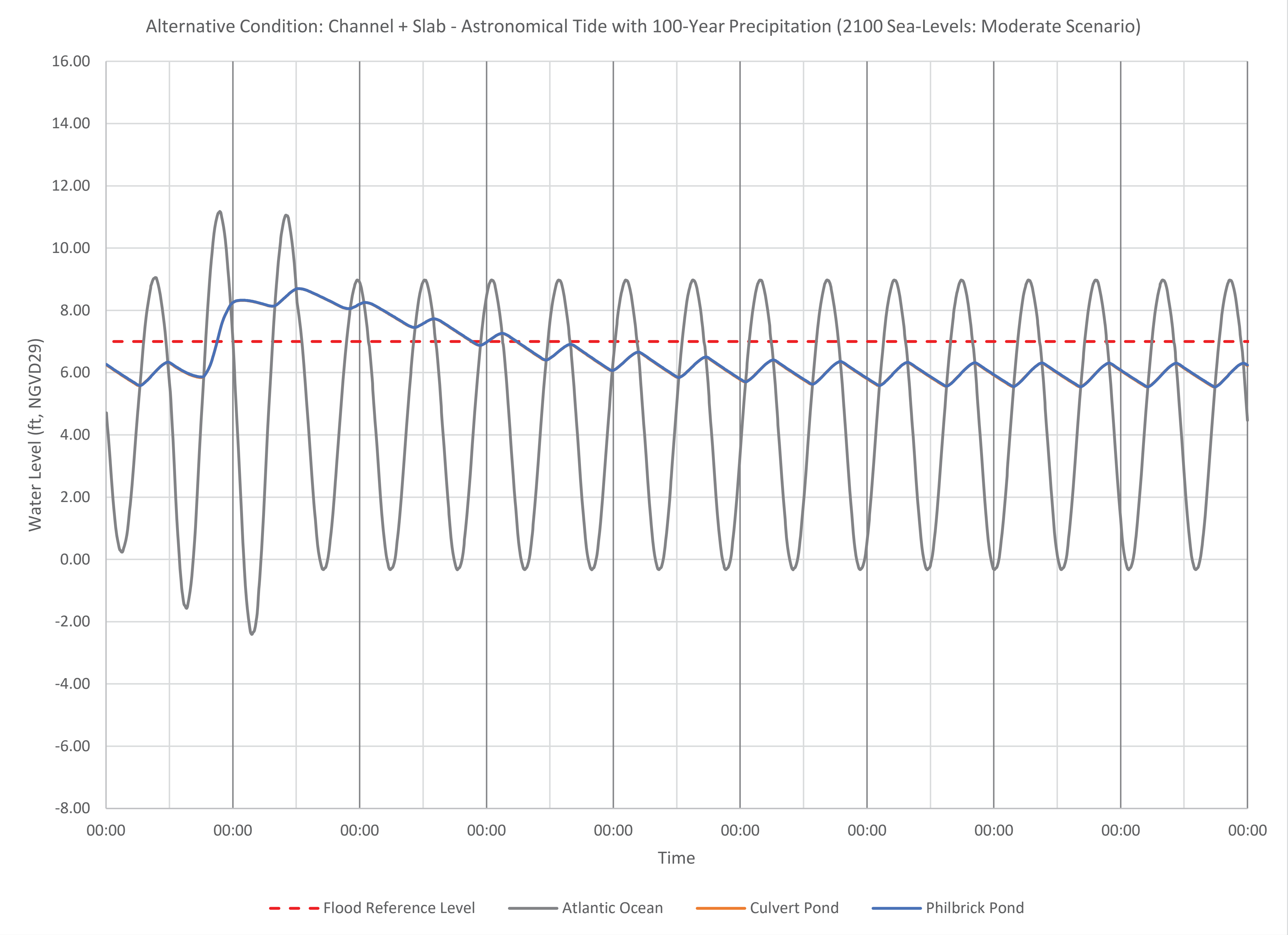

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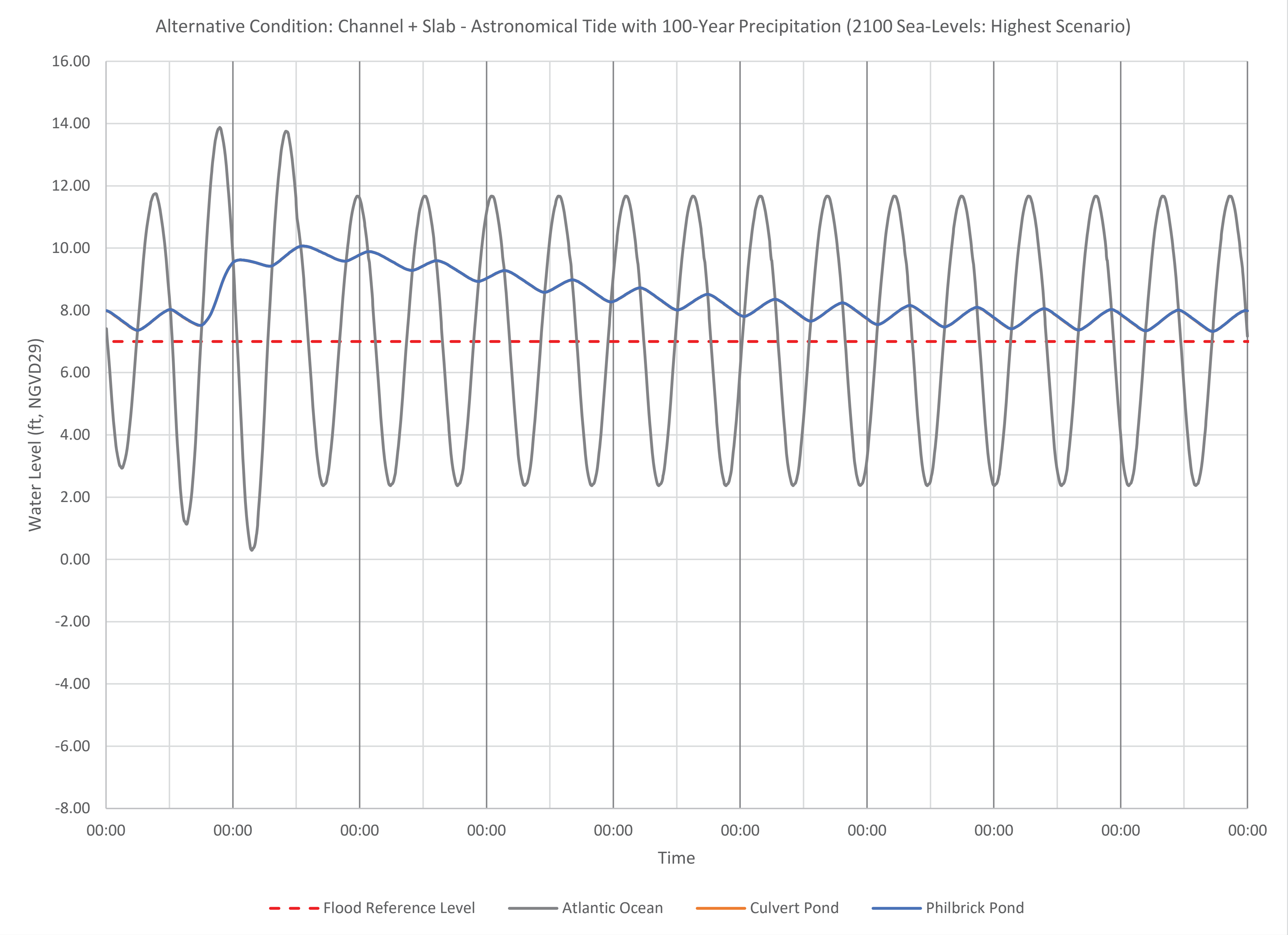

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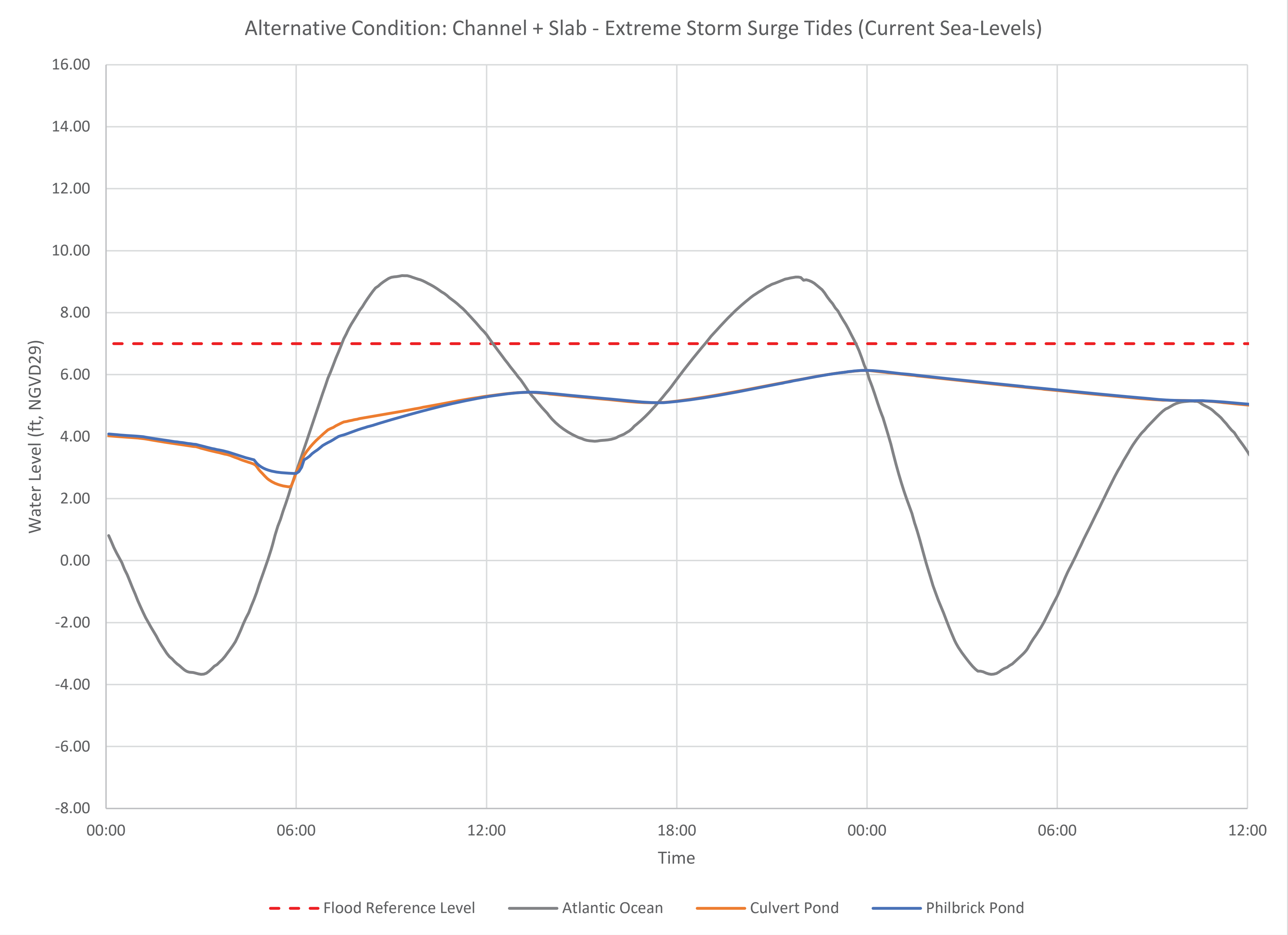
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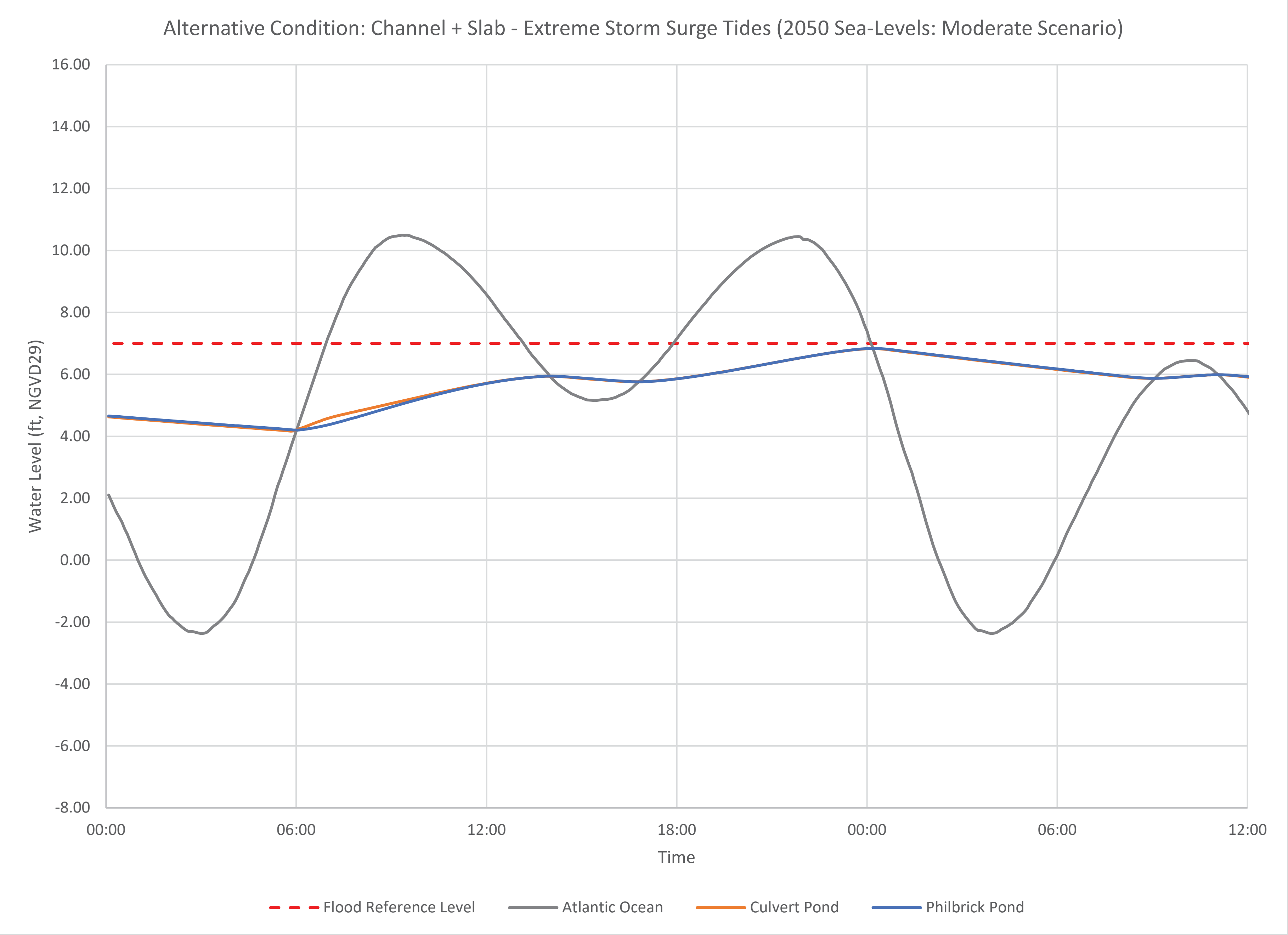
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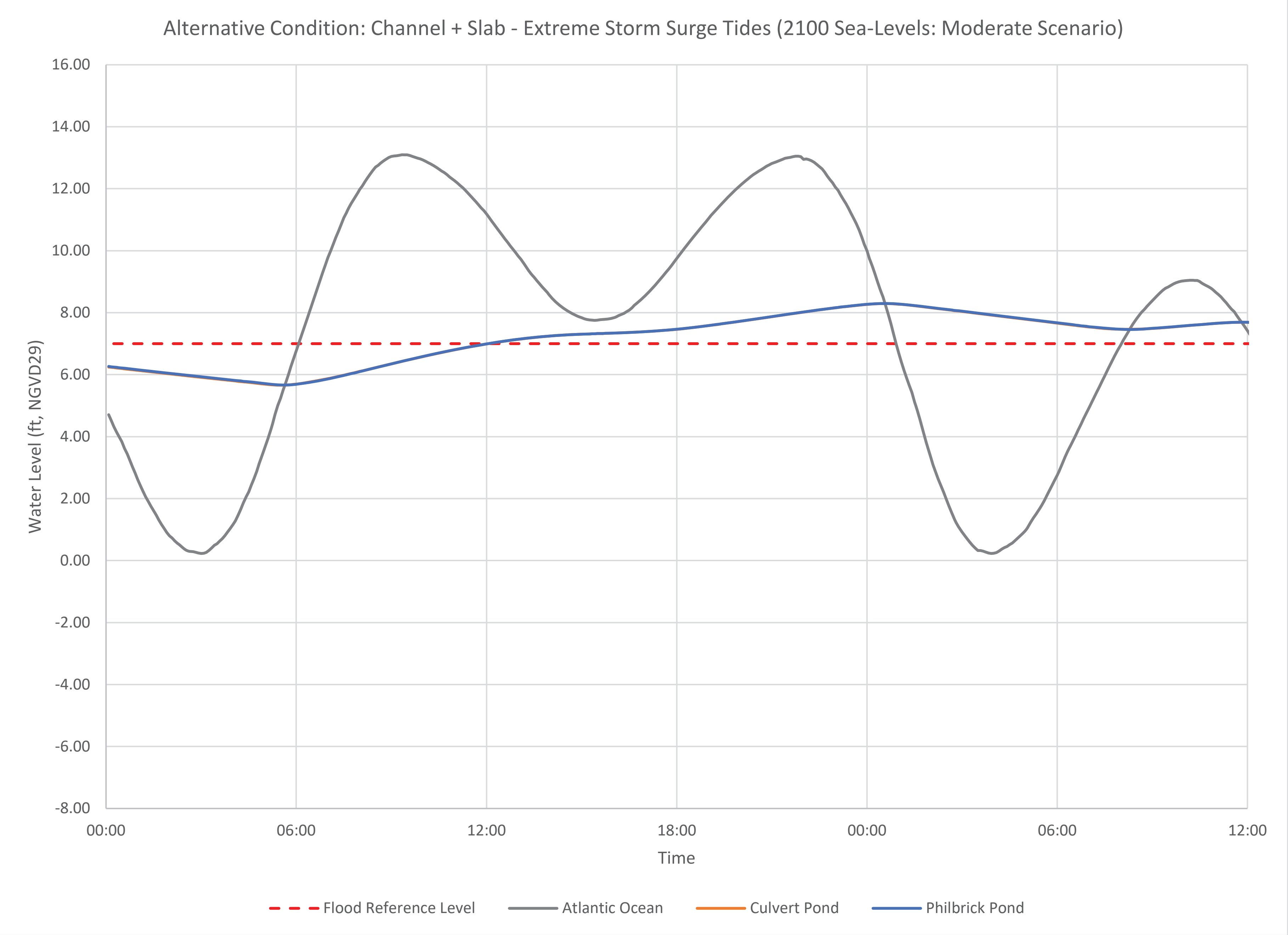
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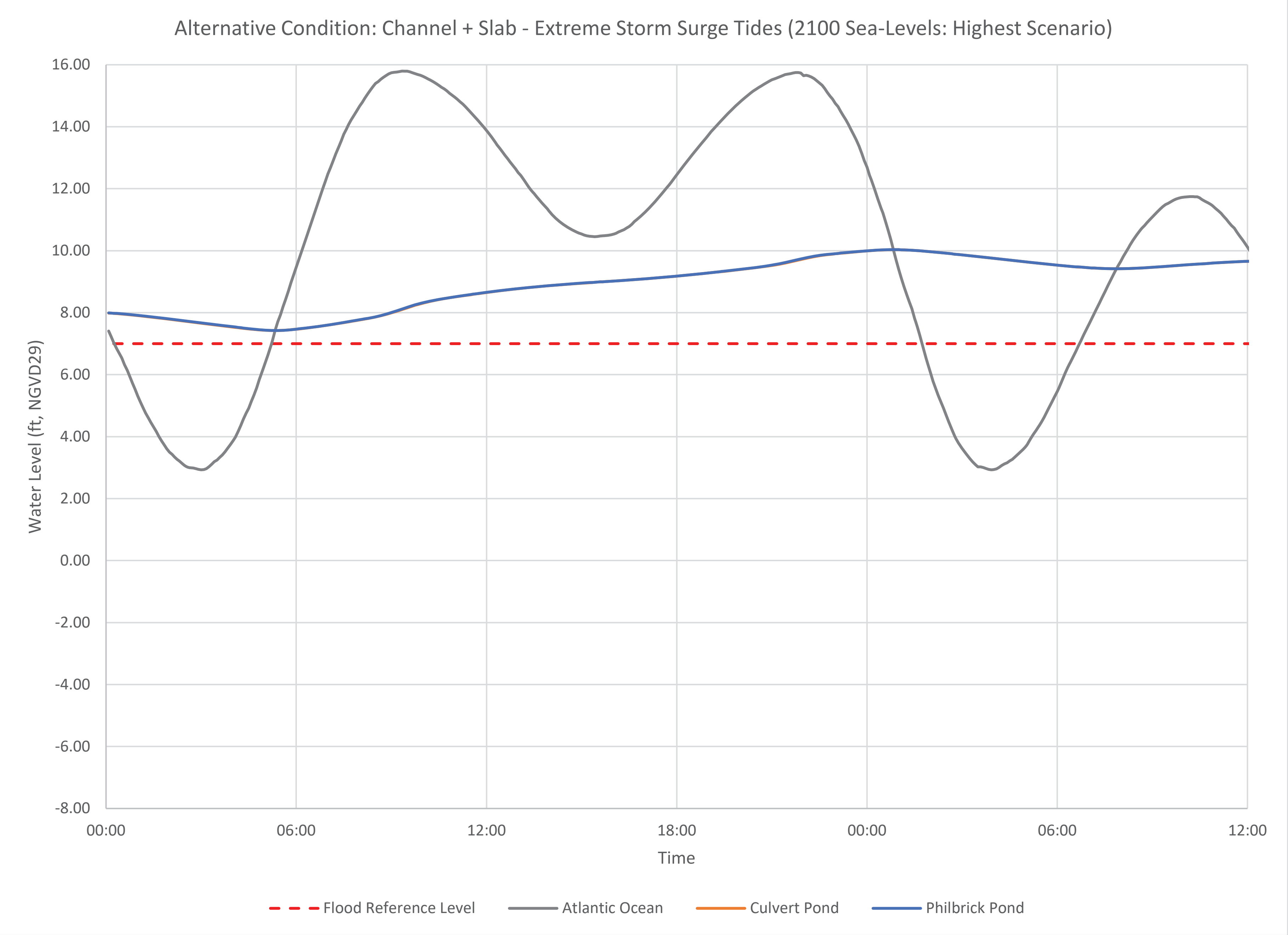
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Appendix D

Wetlands Evaluation for
Philbrick Pond Marsh
Drainage Evaluation, North Hampton, NH

Wetlands Evaluation for Philbrick's Pond Marsh Drainage Evaluation, North Hampton, NH

Prepared for:
CMA Engineers
35 Bow Street
Portsmouth, NH 03801

Prepared by:
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May 1, 2018

Philbrick's Pond Marsh Drainage Evaluation, North Hampton, NH

Wetlands Evaluation

Philbrick's Pond is a lagoon type estuary that formed landward of barrier beach spits in North Hampton, NH. Its inlet was stabilized and restricted by the road that is now Route 1A or Ocean Boulevard. Water flow from the Gulf of Maine passes through a culvert running under Route 1A and into a small waterway and is further restricted as it runs through a clay pipe under an old trolley berm. The lagoon is characterized as a 29 acre tidal marsh. The overall drainage basin surrounding Philbrick's Pond is small, comprising about 680 acres, or a little more than one square mile.

The goal of the project is to evaluate the condition and hydrology of the two restrictions recognizing the conflicting needs for improved drainage from upstream flooding and limiting tidal flooding associated with extreme (i.e., storm surge) and normal flooding events due to sea level rise. The tidal marsh itself is a resource held in the public trust and therefore should be protected from any negative impacts associated with current conditions or predicted impacts due to future alternatives that may be chosen by the Town and its residents. Ditching of the marsh in the mid twentieth century rerouted drainage paths (e.g., Chapel Brook) and has resulted in large areas of vegetation loss between ditches in the past 60 years, as first reported by Short in 1984.

Philbrick's Pond was identified as having inadequate tidal exchange to support healthy marsh by the Soil Conservation Service in 1994 and this agency suggested both culverts needed to be replaced (SCS 1994). Current observations and modeling shows the large culvert under Route 1A does not impede water flow as much as the existing 30-inch culvert under the trolley berm. This round clay culvert constrains flow into the marsh during normal tidal fluctuations, and the restricted hydrology likely has negative impacts on salt marsh health (Burdick and Roman 2012). During the extreme "Mother's Day" storm in 2006, flow limitations due to the culvert exacerbated flood impacts to homes surrounding the marsh due to flow limitations on outgoing tides. The existing clay pipe also limits flow and flood levels into the marsh during storm surge conditions. If it is to be replaced, this trolley berm culvert needs an appropriately configured opening that optimally minimizes flood damage from both extreme precipitation events and storm surges, and that also improves marsh health through improved daily tidal inundation and draining.

The objectives of this report on the tidal marsh are threefold: 1) to evaluate the health of the tidal marsh by comparing existing and new data in Philbrick's Pond with conditions found in the Little River tidal marsh just to the south; 2) characterize the relative benefits to the tidal marsh for the hydraulic alternatives evaluated by the hydrologic modeling; and 3) recommend management actions to restore marsh health using small scale drainage improvements (also known as runneling).

Methods

Philbrick's Pond ("PP") Marsh and Little River ("LR") Marsh were both assessed as part of the NH Coastal Program's salt marsh monitoring program at the turn of the century, which involved collections of species composition and abundance of salt marsh plants along transects running from major tidal creeks to the upland edge at randomized locations. Using positions documented in the original database, we re-occupied four transects in each of the two marshes (Figure 1), and collected data in August from 0.5 m^2 plots at 1, 10, 50 feet and every 50 feet thereafter up to 200 feet. After 200 feet, 50 or 100 foot intervals were used to obtain seven plots per transect. This resulted in 29 plots at PP Marsh (Figure 2) and 28 at LR Marsh (Figure 3).

In addition to the vegetation, plot elevations were determined by real time kinematic geographic positioning system (Leica Viva GS14 GNSS RTK) and soil pore water was collected using stainless steel sippers with an inner diameter of 1 mm. Pore water salinity (temperature corrected refractive index) and chemical redox potential (ORP probe and millivolt reader) were measured in the field, whereas pH and sulfides (Cline 1969) were measured at the laboratory.

Data were entered into Excel spreadsheets and imported to JMP Statistical Software for analysis (JMP version 13). To examine soil differences between marshes, analysis of variance and covariance were used, with Tukey's post hoc test for significant effects ($P<0.05$).

Results of Wetland Surveys

Both marshes had severe tidal restrictions. Little River Marsh was restored to 75% of its potential tidal range in 2000 (Chmura et al. 2012), but the tidal restriction at PP Marsh remains to date. The average elevation of the marsh surface was found to be higher at LR Marsh (4.7 feet above NGVD) compared to PP Marsh (3.9 feet) – a difference of about 10 inches (Table 1). Even when unvegetated pools were removed from the data, PP Marsh remained 8 inches lower in elevation and the difference was highly significant.

Pore water salinity averaged 30 ppt in Philbrick's Pond Marsh, almost the strength of seawater (Table 1). In comparison, LR Marsh was about 32 ppt, the typical value for seawater in the Gulf of Maine. The difference in salinity between the two marshes was not statistically significant. Both marsh soils showed fairly neutral pH values, about 6.6 pH.

Redox potential, or Eh, is a measure of the ability of the soil constituents to accept electrons produced during chemical reactions. Eh ranges from fully oxidized (+700 millivolts) to severely reduced (-400 mV), with oxygen disappearing at about +400 mV. The chemical reduction of the soils was much more severe at PP Marsh (-305 mV) than LR Marsh (-119 mV), indicating more stressful conditions for life. Similarly, the plant toxin H_2S was 4-fold greater at PP marsh and these levels have been shown to stress marsh grasses as they interfere with nitrogen uptake, energy balance and salinity adaptation (Mendelssohn and Morris 2000). Both the Eh and sulfide concentration showed significant differences between the two sites, with PP Marsh having soil conditions indicative of greater flooding and impaired drainage.

Lower elevations, impeded drainage and more stressful conditions were reflected in the vegetation of Philbrick's Pond Marsh. In 2017, we found typical salt marsh plants (halophytes: *Spartina alterniflora*, *S. patens*, and others) covering about 55% of the plots and 40% bare sediment or dead grasses (Figure 4). Plant cover was similar to the original survey in 2002, with slightly less *S. alterniflora* (cordgrass) but more *S. patens* (salt hay). The most dramatic changes appear to have occurred sometime after the mid-twentieth century, but before 1984 when Dr. Short interpreted the large unvegetated areas still seen today as: "an area of dead saltwater hay (*Spartina patens*) covered by a thick mat of blue green algae."

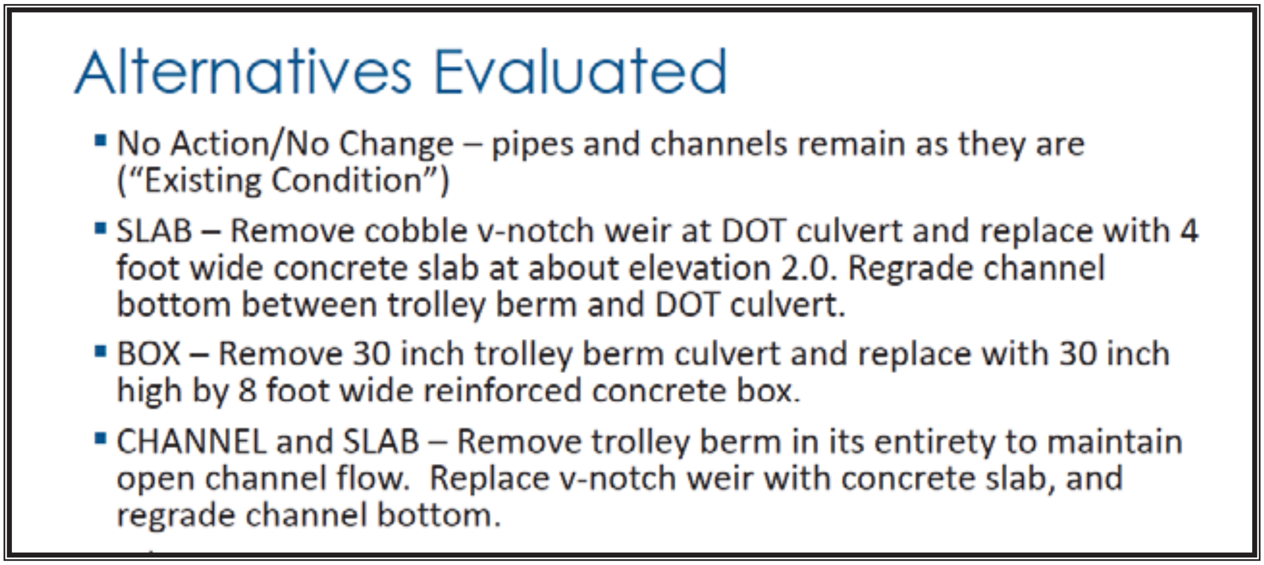
In comparison, Little River Marsh showed a dramatic recovery from the large tidal restoration completed in 2000, based on data from 2003 and 2005 in addition to 2017 (Figure 5). Dead plants and bare ground were dominant at 60% cover in 2003, but decreased to 20% cover in 2017 while *S. patens* and *S. alterniflora* both increased, contributing to a total of 76% halophyte cover in 2017. With LR Marsh now largely restored (Chmura et al. 2012) it can serve as a reference marsh to compare conditions in Philbrick's Pond Marsh.

In 2017, our reference site at Little River Marsh was dominated by salt hay (38%) but also had a variety of other high marsh plants (halophytes) summing to 21% cover (Figure 6). In wetter areas (areas with greater flooding and/or less drainage), tall cordgrass was found to dominate the vegetation, contributing 17% cover. We found only 20% cover of dead and bare and 2% cover of invasive species, notably *Phragmites australis* (common reed). In sharp contrast, Philbrick's Pond Marsh showed 40% dead and bare (including the plots that fell within the large pools), likely due to stressful conditions. When compared to Little River Marsh, we found half as much salt hay, the high marsh dominant, and almost twice as much *S. alterniflora*, which is better adapted to the more stressful inundated conditions at Philbrick's Pond Marsh.

In summary, the lower elevations of Philbrick's Pond Marsh and impeded drainage has led to lower Eh and greater sulfides, all of which stress the vegetation and favor cordgrass over salt hay and other marsh plants typical of New Hampshire salt marshes. Many areas between ditches are too stressful for vegetation since extensive ditching took place 60 years ago. As a result, pools have replaced vegetation between ditches across large portions of the marsh.

Evaluation of Alternatives with respect to potential impacts to salt marsh

Several management alternatives were examined using hydrologic modeling for present day conditions and several sea level rise scenarios (see inset). They were chosen to capture the range of options for hydrologic management of the system to reduce flooding for residents and preserve the functions and values of the natural resources of the system.



Alternatives Evaluated

- No Action/No Change – pipes and channels remain as they are ("Existing Condition")
- SLAB – Remove cobble v-notch weir at DOT culvert and replace with 4 foot wide concrete slab at about elevation 2.0. Regrade channel bottom between trolley berm and DOT culvert.
- BOX – Remove 30 inch trolley berm culvert and replace with 30 inch high by 8 foot wide reinforced concrete box.
- CHANNEL and SLAB – Remove trolley berm in its entirety to maintain open channel flow. Replace v-notch weir with concrete slab, and regrade channel bottom.

Under the NO ACTION alternative, the Philbrick's Pond Marsh will continue on its path to complete degradation. The very small tides allow only a few inches of drainage every tide, leaving stagnant waters and stressful soil conditions that plants have difficulty surviving. With only intermittent flooding and no sediment sources, the marsh cannot perform its function of building through accretion and peat formation and so becomes lower relative to sea level as sea level rises.

Under the second alternative, SLAB, improved drainage is expected, leading to better growing conditions and a healthier marsh. Removal of the V-notch weir and channel re-grading will allow waters that are currently trapped behind the weir to drain, increasing the typical tidal range from less than 6 inches to 16 inches. Plant productivity and cover is likely to increase following implementation of this alternative. However, the flooding and sediment marshes need to build will still not be carried into the marsh under this alternative and the marsh will likely continue on its path to degradation once sea levels rise substantially (1-2 feet). This alternative will likely have no impact on flooding of homes and roads due to significant rainfall or storm surge events.

BOX is the third alternative, which is limited to replacing the trolley berm pipe with a box culvert alone (no replacement of V-notch weir with slab). Modeling indicates this alternative would not change the tidal flooding or drainage significantly compared to current conditions. The cross-sectional area of tidal exchange would increase from 5 to 20 square feet at the trolley berm, but the V-notch weir and shallow area in the channel would limit normal tides to existing conditions. The BOX alternative therefore, would be unlikely to increase the functions and values of the salt marsh unless it was combined with the removal of the V-notch weir (SLAB alternative).

The fourth alternative, CHANNEL AND SLAB would result in unrestricted tides from the landward side of Route 1A throughout the marsh. The culvert under Route 1A would still partially restrict the full range of tides. This solution would increase the normal tidal range to 1.4 feet (17 inches). Removing the trolley berm in its entirety and removing the v-notch weir at the Route 1A culvert would lower typical low tides by 0.9 feet from current levels and increase typical high tides by 0.1 feet. The current daily tidal fluctuation of 0.4 feet would increase to 1.4 feet. Flooding associated with significant rainfall events would be substantially reduced but not eliminated, and storm surges under assumed ranges of sea level rise would result in flooding conditions for homes and roads after 2050. Under current sea level conditions Philbrick Pond water levels during astronomical high tides would increase by about one foot. The greater flooding and flushing would likely bring substantial improvements to the health of the marsh.

Recommendations for marsh restoration activities beyond culvert replacement

Important changes in the hydrology of Philbrick's Pond Marsh occurred when natural drainages were replaced by ditches (sometime in the late 1950s according to USGS topographic maps). Hydrologic changes have led to impaired drainage and ponding, with loss of vegetation in areas surrounded by ditches. Since the turn of the last century, rising sea levels combined with altered hydrology, specifically old ditch systems, has led to patterns of vegetation loss in Rhode Island and Massachusetts salt marshes similar to those found at Philbrick's Pond (Raposa et al. 2015). The loss of vegetation from the large impounded areas was reported by Dr. Short in 1984 and has slowly continued to the present, as indicated by our quantitative vegetation survey.

Vegetation loss could be reversed, but only if tidal drainage is increased for the system. Once culvert or channel improvements are implemented for Philbrick's Pond, additional steps could be taken to hasten pant regrowth and reverse the pattern of marsh loss caused by impoundments associated with the old ditches. The increased drainage predicted from the hydraulic models would justify establishing a strategy to partially drain the impounded (ponded) areas between ditches using shallow drainage paths called runnels. Runnels are shallow drainages cut through unnatural impediments to drainage that allow the top six inches of sediment to drain. Runnels do not drain the peat deeply, unlike ditching which has led to loss of marsh elevation elsewhere (Burdick et al. 2017). Runnels have been used in Rhode Island, where low tidal ranges and rising sea levels have alarmed managers and the public (Ardito 2014; http://seagrant.gso.uri.edu/elevating-drowning-salt-marshes/). Runnels have also been tried in the Great Marsh of Massachusetts with documented success in reversing the expansion of the impoundments (Burdick et al. 2017).

Currently, there are over 20 impounded ponds in the southern portion of the marsh, 10 in the center and another 20 ponds in the northern section representing a significant opportunity to enhance restoration benefits. Several of these impounded areas could be partially drained by runneling and monitored to document plant response to the increased drainage above and beyond the increased drainage from the hydrologic improvements to the system. The addition of runneling to a restoration program for Philbrick's Pond Marsh represents a relatively low-cost strategy to enhance the benefits of restored hydrology. Furthermore, such a strategy is aligned with several current funding opportunities for developing innovative approaches to increasing coastal resilience in the State (e.g., NHDES Coastal Resiliency Grant).

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Tables and Figures

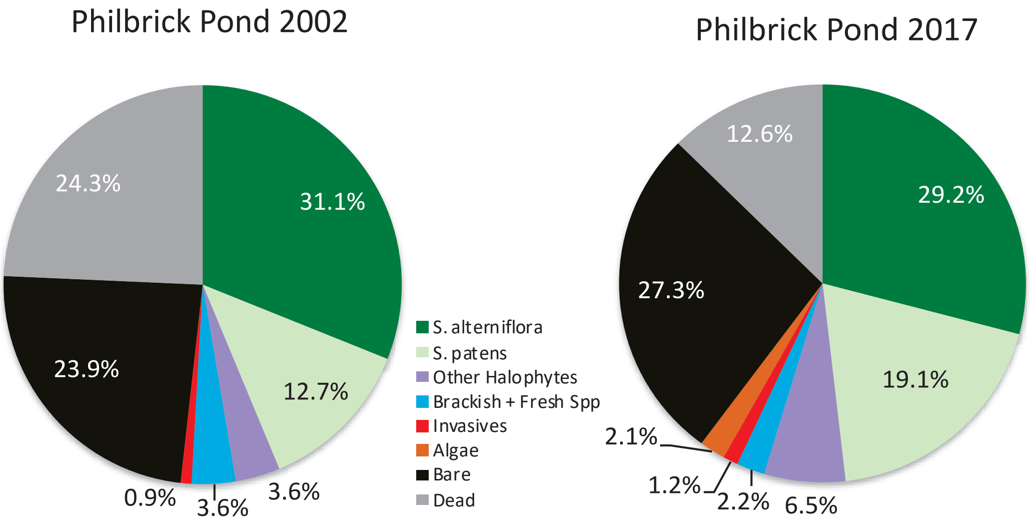
Table 1. Soil elevation and chemical characteristics in Philbrick's Pond Marsh and Little River Marsh. Values are Means (averages) and Standard Errors from 28 (PP) and 29 (LR) independent samples. P value is the probability that the difference between the two marshes is not real. Elevations were not normally distributed so Kruskal-Wallis test used.

	Little River		Philbrick Pond		
	Mean	SE	Mean	SE	p value
Elevation (ft NGVD29)					
All Plots	4.71	0.05	3.87	0.08	<0.01
High Marsh	4.73	0.03	4.02	0.05	<0.01
Pore water					
Salinity (ppt)	32.8	0.6	30.4	1.2	0.08
Redox (mV)	-119	26	-305	6	<0.01
pH	6.67	0.04	6.61	0.05	0.32
Sulfides (mM)	0.60	0.22	2.50	0.22	<0.01

Figure 1. Overview of Philbrick's Pond (upper right) and Little River (lower left); two back-barrier marshes along the Atlantic coast of New Hampshire.

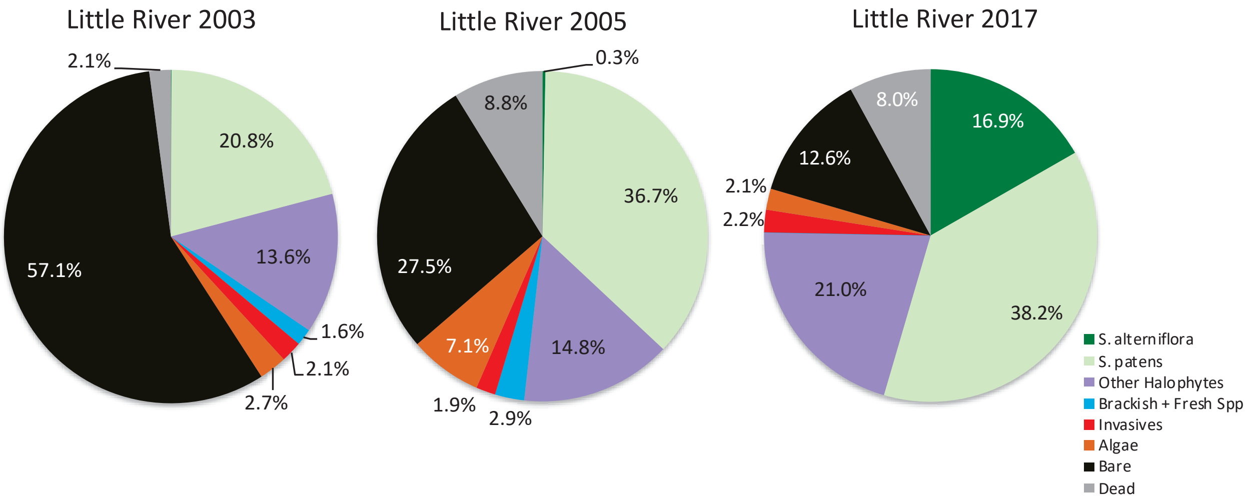
Figure 2. Stations along four transects in Philbrick's Pond sampled in 2017.

Figure 3. Stations along four transects in Little River Marsh Pond sampled in 2017.



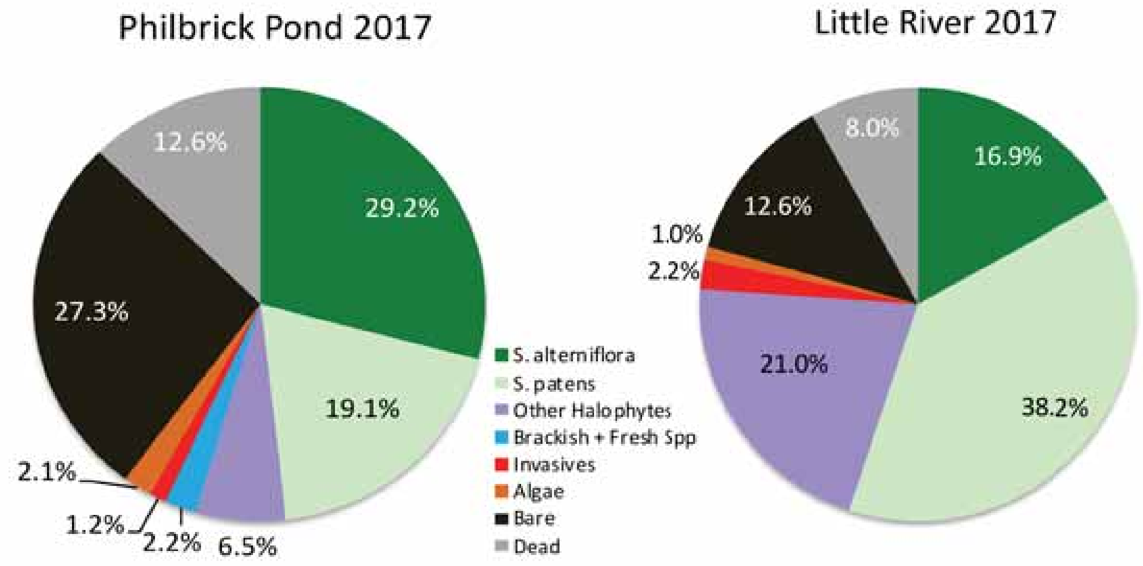
Notes: Other Halophytes = all halophytes except SA and SP. In 2002, monitoring done by NHCP, which measured open water as a category factored into 100% cover; assumed bare. 2002 n=52, 2017 n=29 due to different sampling intensity.

Figure 4. Vegetation cover averaged across four transects at Philbrick's Pond Marsh in 2002 and 2017.



Notes: Other Halophytes = all halophytes except SA and SP. In 2003 and 2005, monitoring done by NHCP, which measured open water as a category factored into 100% cover; assumed bare. 2003 n=131, 2005 n=140, 2017 n=28 due to to different sampling intensity and more transects in 2003 and 2005.

Figure 5. Vegetation cover averaged across four transects at Little River Marsh in 2017 compared with earlier results that combined more transects and closer plot spacing in 2003 and 2005. A large tidal restoration project was completed in 2000, resulting in loss of fresher plant species.



Note: Other Halophytes = all halophytes except SA and SP.

Figure 6. Vegetation cover averaged across four transects at Philbrick's Pond Marsh and Little River Marsh in 2017.

Appendix E

Conceptual Designs
and Construction Cost Estimates

CMA ENGINEERS, Inc.

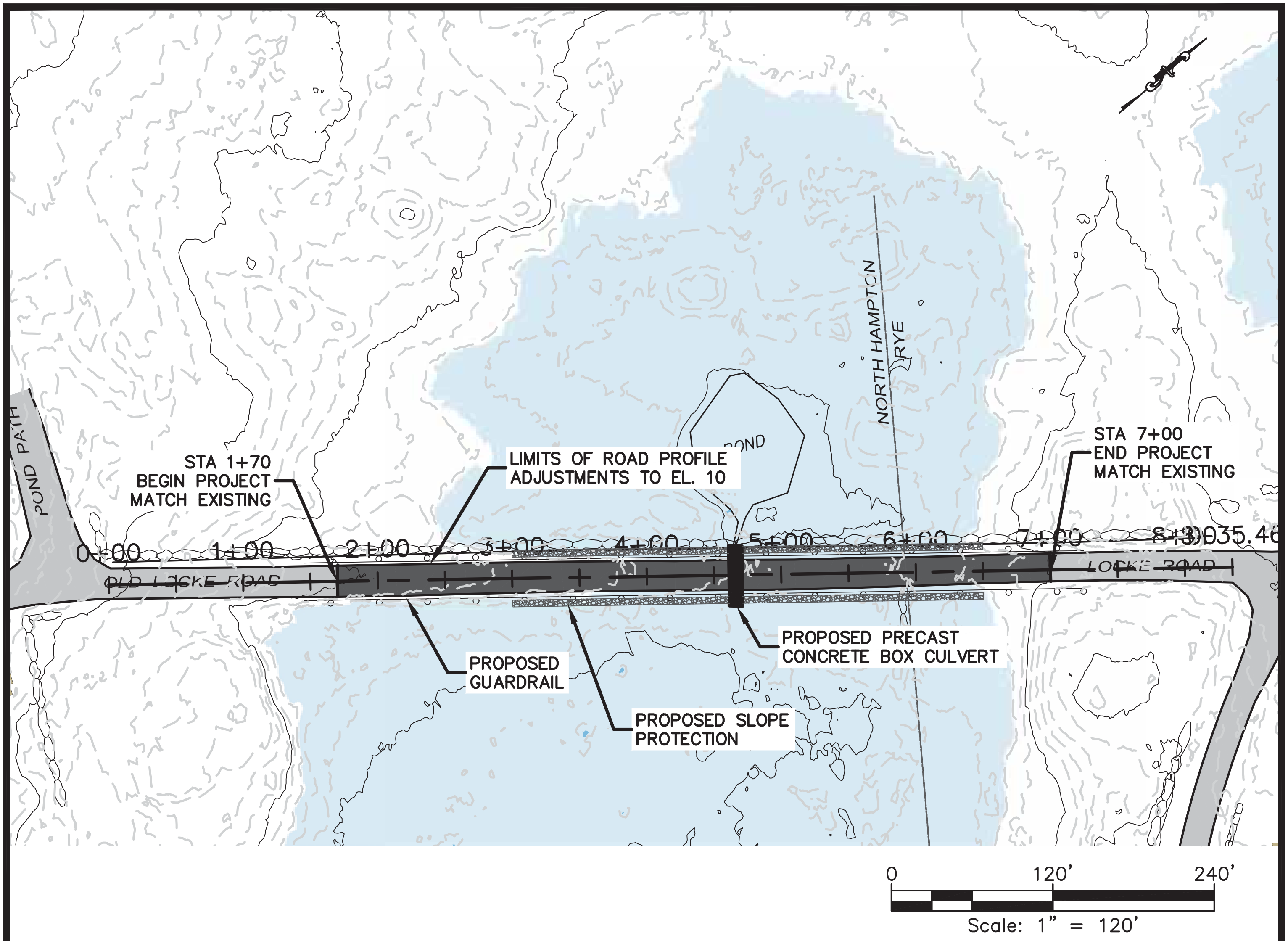
Civil/Environmental Engineers
35 Bow Street
Portsmouth, NH 03801

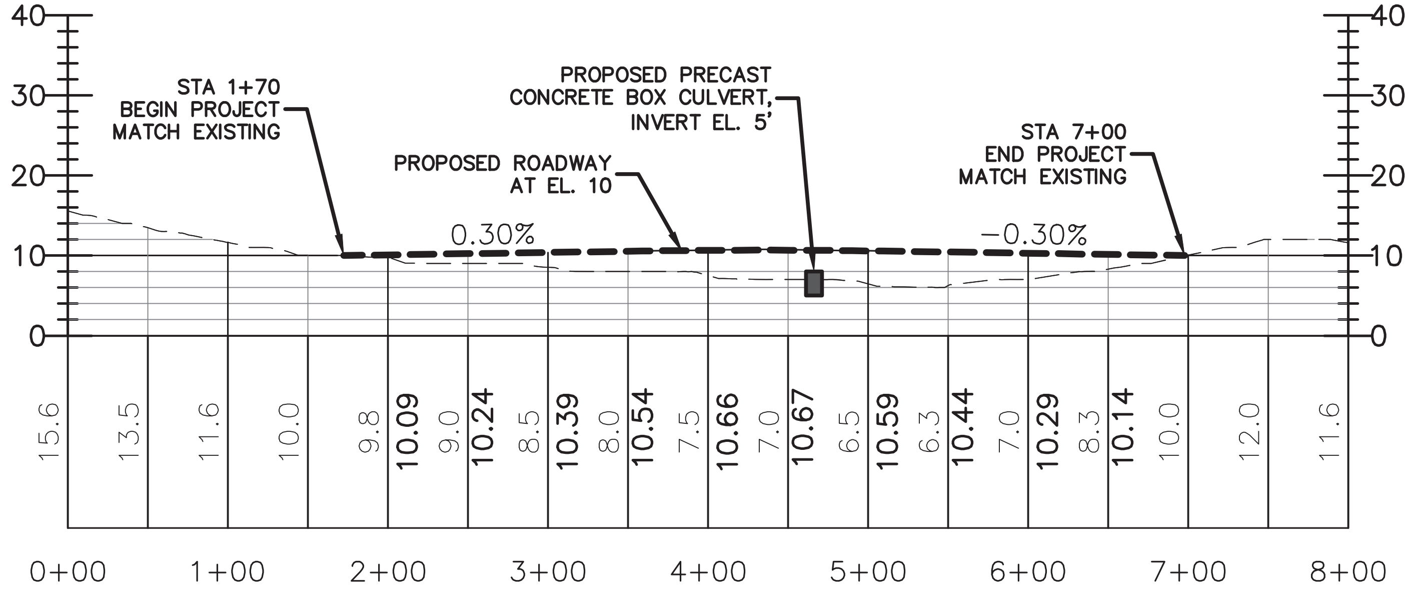
PROJECT NAME:	**Philbrick Pond**		
PROJECT NO.:	1028		
SHEET NO.:	1	OF	1
CALCULATED BY:	SJE	DATE:	4/26/2018
CHECKED BY:	JWB	DATE:	4/27/2018

Option #1: Raising Old Locke Road to Elevation 10
Budget Estimate

Item #	Item Description	U	Quantity	Cost	Item Cost ($)
1	Site Preparation	LS	1	$10,000.00	$ 10,000.00
2	Clearing & Grubbing	A	0.25	$30,000.00	$ 7,500.00
3	Common Excavation	CY	800	$12.00	$ 9,600.00
4	General Site Work	LS	1	$10,000.00	$ 10,000.00
5	Project Cleanup & Site Restoration	LS	1	$10,000.00	$ 10,000.00
6	Guardrail	LF	1160	$35.00	$ 40,600.00
7	Culvert	LS	1	$100,000.00	$ 100,000.00
8	Gravel (shim)	CY	1500	$25.00	$ 37,500.00
9	4" Hot Bituminous Pavement	TON	320	$80.00	$ 25,600.00
10	Slope Protection (Riprap)	CY	400	$50.00	$ 20,000.00
11	Striping	LF	2104	$0.50	$ 1,052.00
12	Project Cleanup and Site Restoration	LS	1	$20,000.00	$ 20,000.00
13	Mobilization	LS	1	$20,000.00	$ 20,000.00

Construction Subtotal	**$311,900**
Construction Contingency (20%)	$62,400
Engineering Design & Permitting (15%)	$46,800
Construction Administration/Resident Project Representative (10%)	$31,200
Legal Reserve	$20,000
Subtotal	**$160,400**
Budget Estimate Total	**$472,300**





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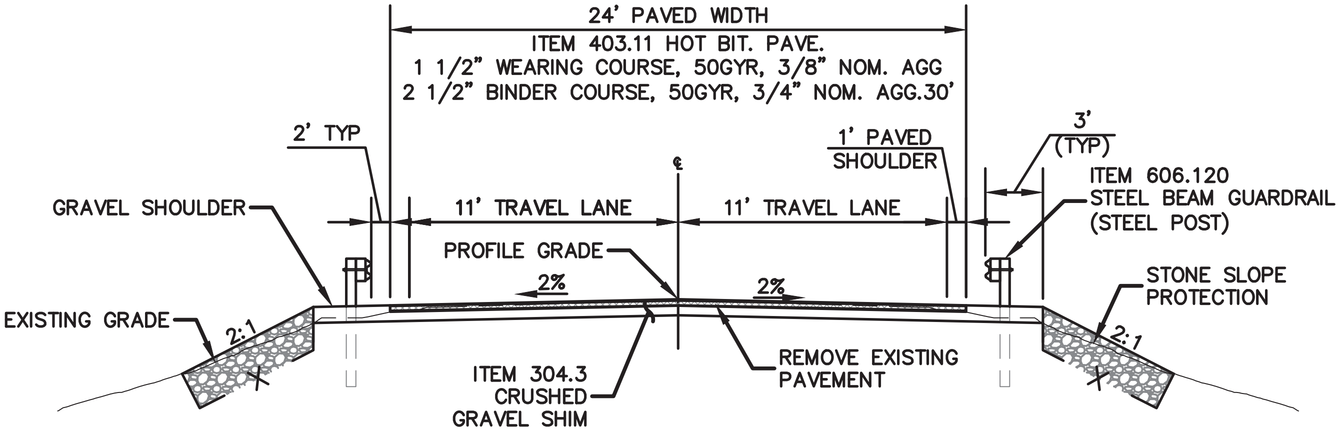
Salt Marsh
Drainage Evaluation
Town of North Hampton, NH

Project #1: Raising Old Locke Road to Elevation 10'

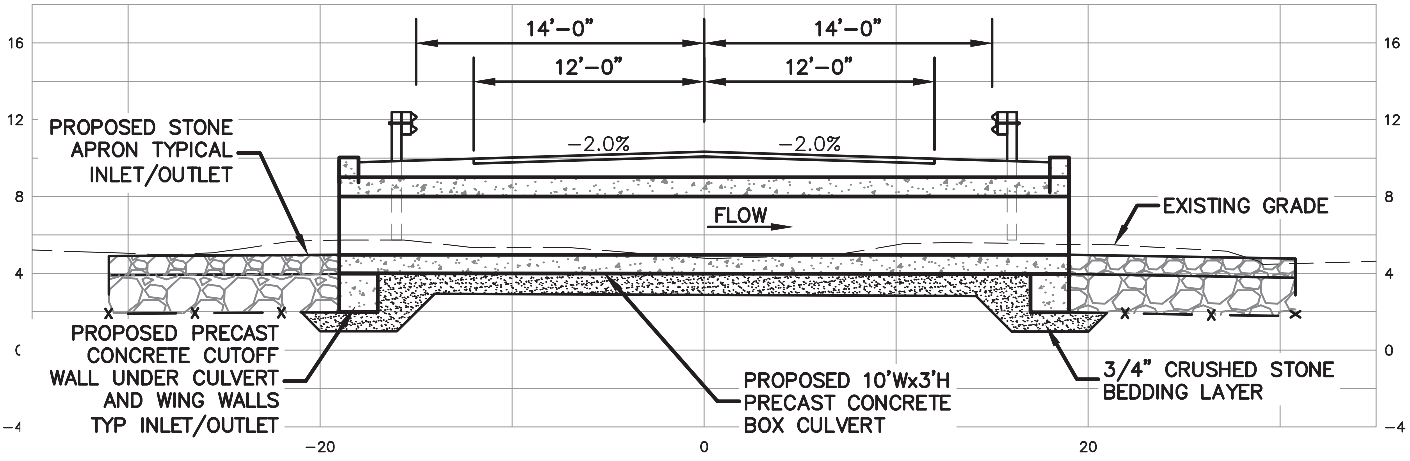
Scale 1"=120' *April 2018*

F:\CADD\PROJECTS\1028 N Hampton Philbrick Pond\Engineering\Figure 1-Raising the Road.dwg Date Plotted: Apr 27, 2018 - 4:08pm



Old Locke Road Section

Not to Scale



Precast Concrete Box Culvert

Not to Scale

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Project #1: Raising Old Locke Road: Typical Roadway Sections

Not to Scale *April 2018*

F:\CADD\PROJECTS\1028 N Hampton Philbrick Pond\Engineering\Figure 1-Raising the Road.dwg Date Plotted: Apr 27, 2018 - 2:35pm

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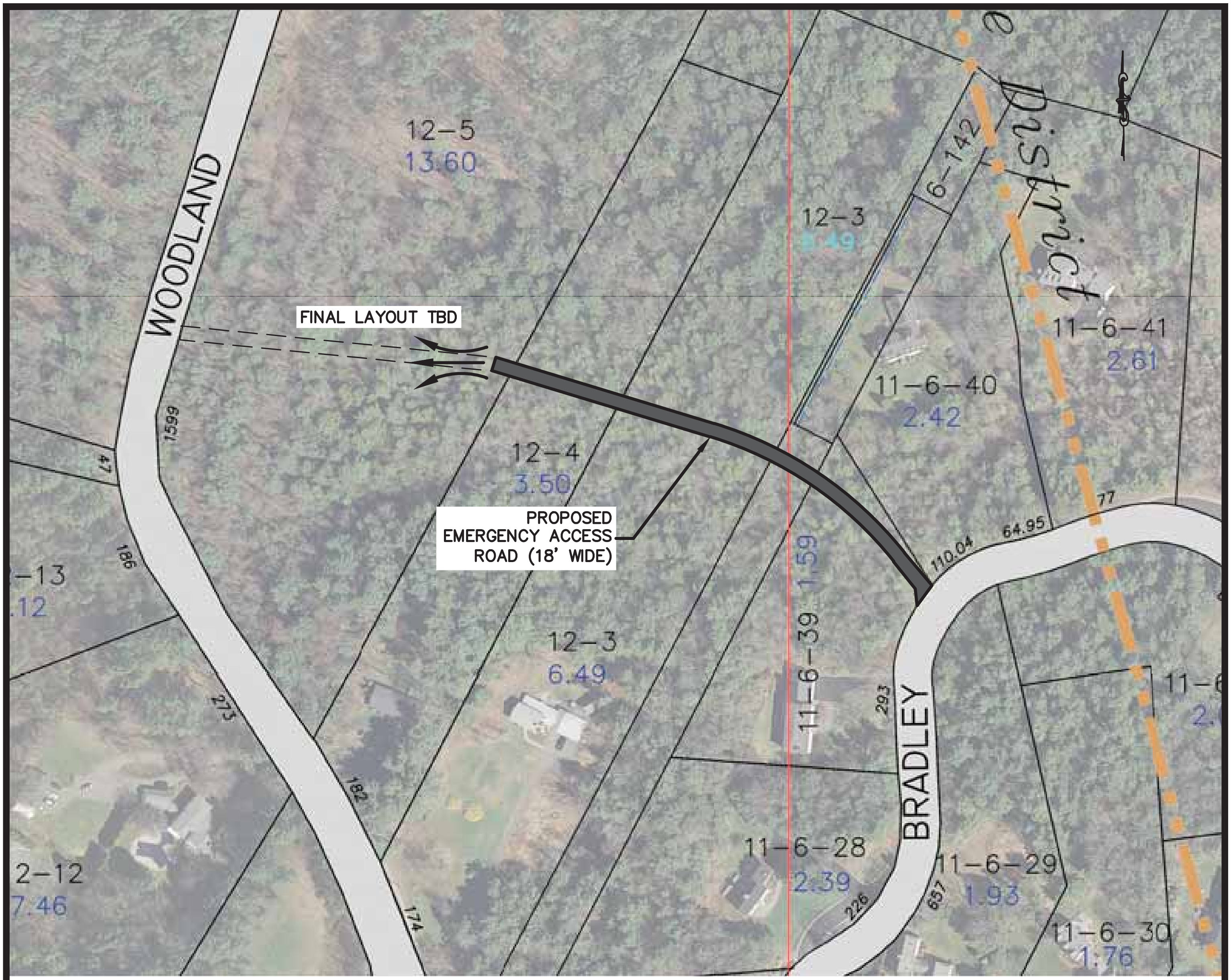
Civil/Environmental Engineers
35 Bow Street
Portsmouth, NH 03801

PROJECT NAME:	**Philbrick Pond**		
PROJECT NO.:	1028		
SHEET NO.:	1	OF	1
CALCULATED BY:	SJE	DATE:	4/26/2018
CHECKED BY:	JWB	DATE:	4/27/2018

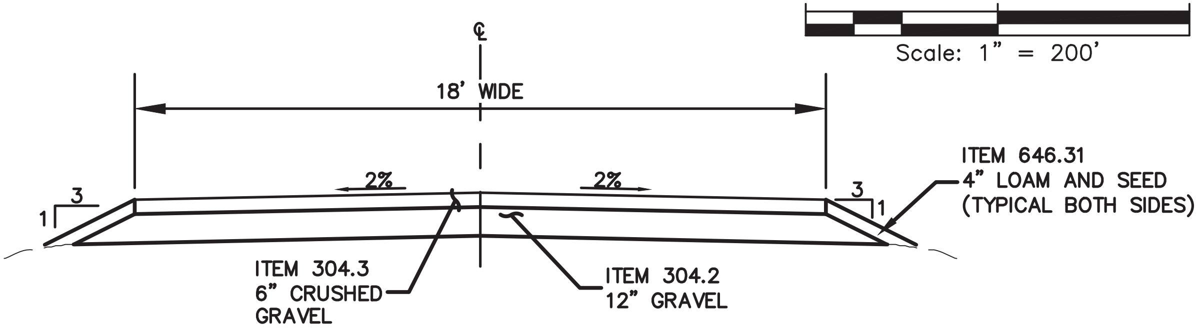
Option #2: Bradley Lane to Woodland Road Emergency Access Road
Budget Estimate

Item #	Item Description	U	Quantity	Cost	Item Cost ($)
1	Site Preparation	LS	1	$10,000.00	$ 10,000.00
2	Clearing & Grubbing	A	0.74	$30,000.00	$ 22,200.00
3	Common Excavation	CY	1200	$12.00	$ 14,400.00
4	Crushed Gravel	CY	360	$30.00	$ 10,800.00
5	Gravel	CY	710	$30.00	$ 21,300.00
6	Gate	EA	2	$3,000.00	$ 6,000.00
7	General Site Work	LS	1	$20,000.00	$ 20,000.00
8	Project Cleanup & Site Restoration	LS	1	$10,000.00	$ 10,000.00
9	Mobilization	LS	1	$10,000.00	$ 10,000.00

Construction Subtotal	**$124,700**
Construction Contingency (20%)	$24,900
Engineering Design & Permitting (15%)	$18,700
Construction Administration/Resident Project Representative (10%)	$12,500
Legal and Property Acquisition	$60,000
Subtotal	**$116,100**
Budget Estimate Total	**$240,800**



0 200' 400'
Scale: 1" = 200'



Emergency Access Road

Not to Scale

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Project #2:Bradley Lane to Woodland Road Emergency

Scale 1"=200' *Access Road* *April 2018*

F:\CADD\PROJECTS\1028 N Hampton Philbrick Pond\Engineering\Figure 2–Bradley Lane Acess.dwg Date Plotted: Apr 27, 2018 – 12:20pm

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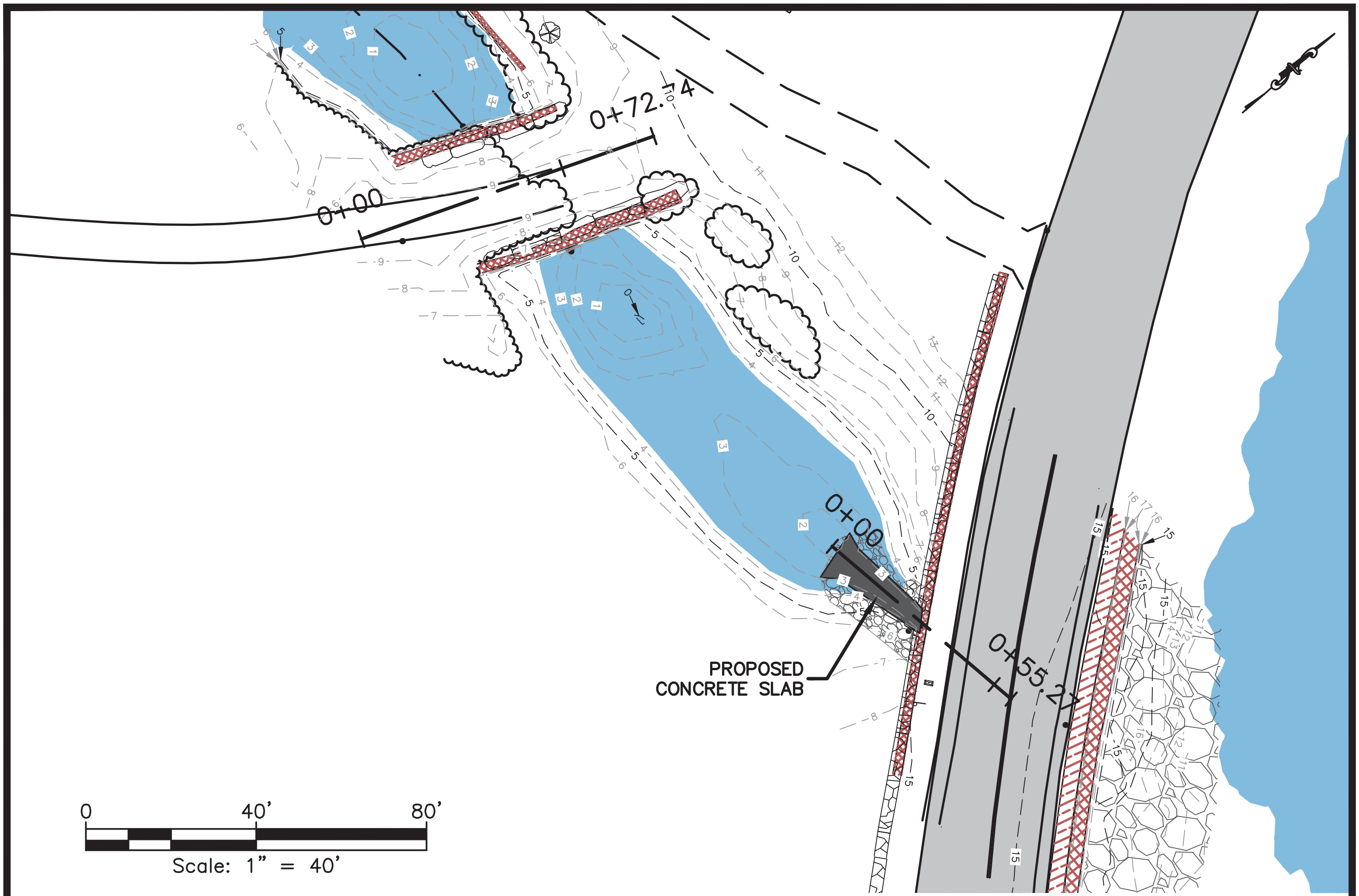
Civil/Environmental Engineers
35 Bow Street
Portsmouth, NH 03801

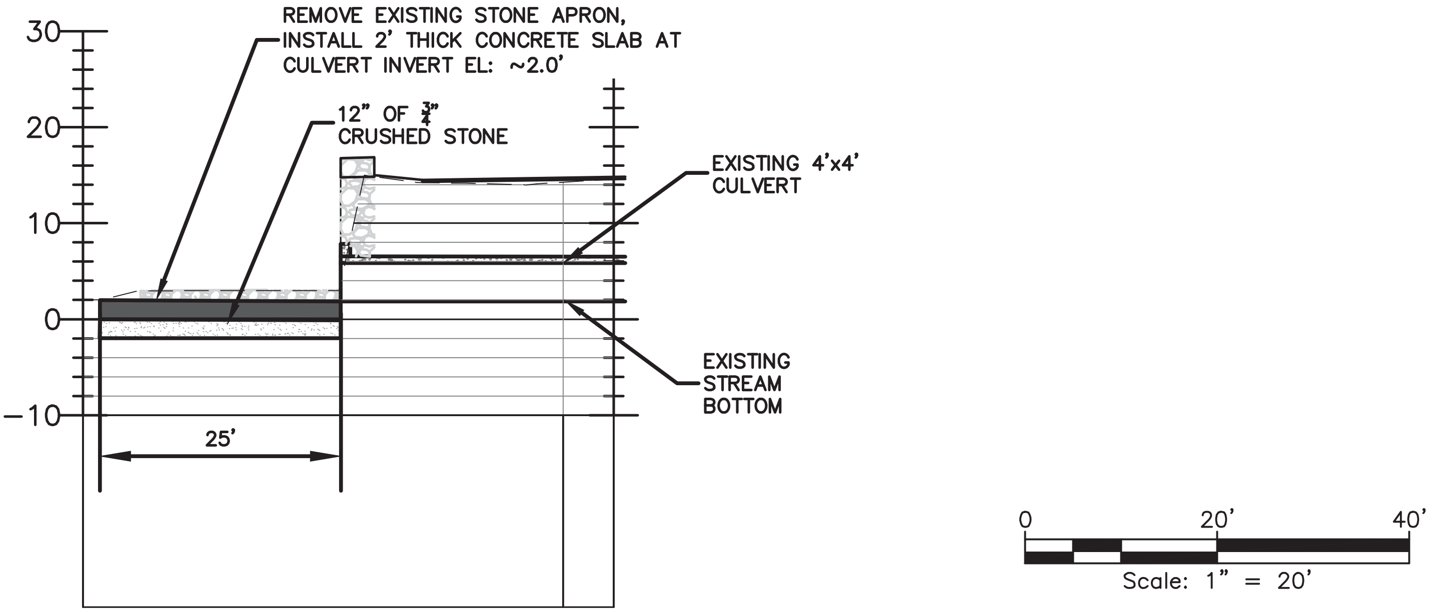
PROJECT NAME:	**Philbrick Pond**		
PROJECT NO.:	1028		
SHEET NO.:	1	OF	1
CALCULATED BY:	SJE	DATE:	4/26/2018
CHECKED BY:	JWB	DATE:	4/27/2018

Option #3: Slab at Route 1A Culvert
Budget Estimate

Item #	Item Description	U	Quantity	Cost	Item Cost ($)
1	Site Preparation	LS	1	$4,000.00	$ 4,000.00
2	3/4" Crushed Stone	CY	7	$30.00	$ 210.00
3	Common Excavation	CY	16	$12.00	$ 192.00
4	Rock Excavation	CY	5	$200.00	$ 1,000.00
5	Concrete Slab	CY	16	$600.00	$ 9,600.00
6	Cofferdam/Dewatering	EA	1	$10,000.00	$ 10,000.00
7	Project Cleanup and Site Restoration	LS	1	$5,000.00	$ 5,000.00
8	Mobilization	LS	1	$5,000.00	$ 5,000.00

Construction Subtotal	**$35,000**
Construction Contingency (20%)	$7,000
Engineering Design & Permitting	$15,000
Construction Administration/Resident Project Representative (10%)	$3,500
Subtotal	**$25,500**
Budget Estimate Total	**$60,500**





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Salt Marsh
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Town of North Hampton, NH

Project #3: Slab at Route 1A Culvert

Scale 1"=40' *April 2018*

F:\CADD\PROJECTS\1028 N Hampton Philbrick Pond\Engineering\Figure 1-Raising the Road.dwg Date Plotted: Apr 27, 2018 - 3:38pm

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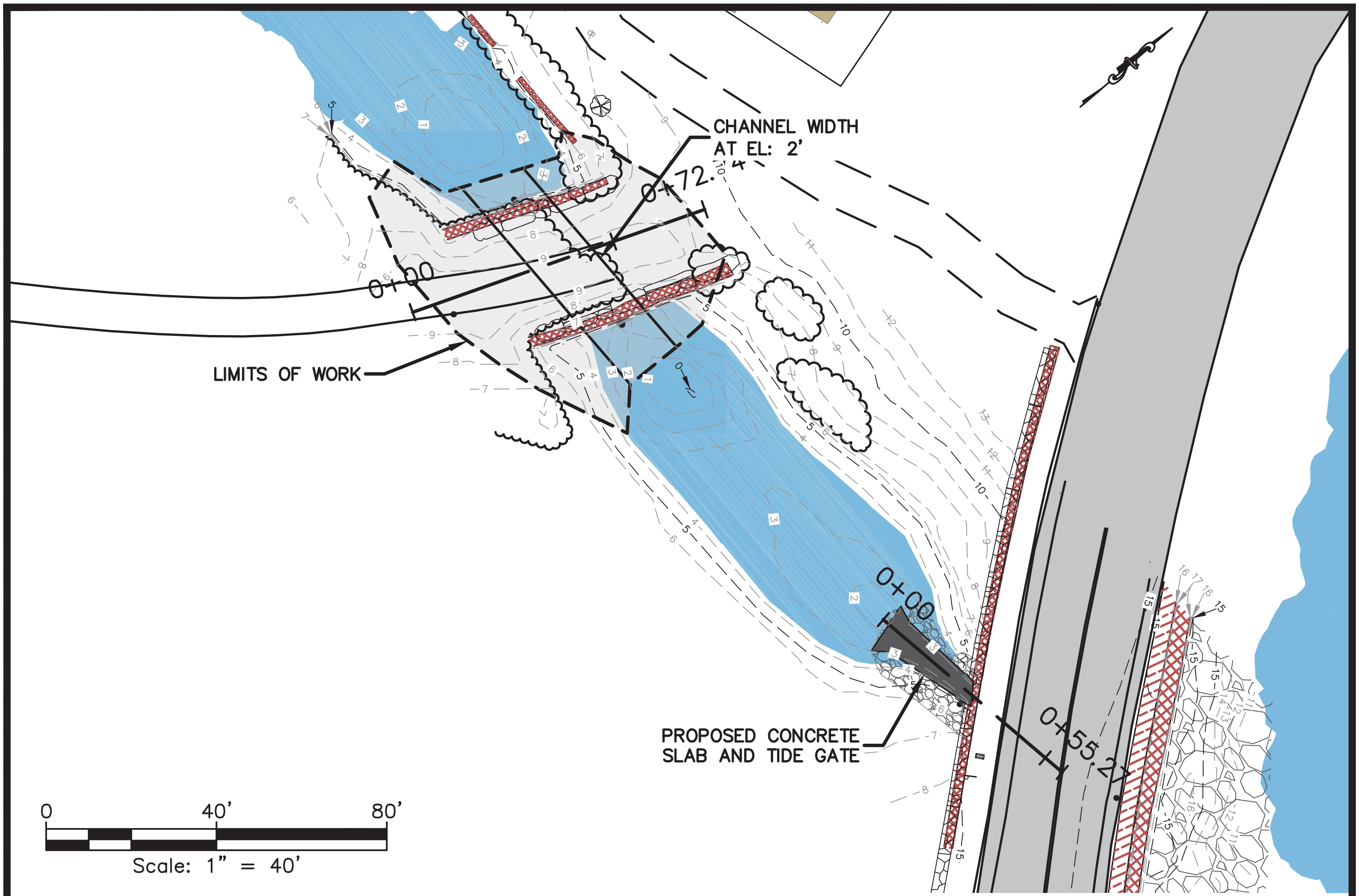
Civil/Environmental Engineers
35 Bow Street
Portsmouth, NH 03801

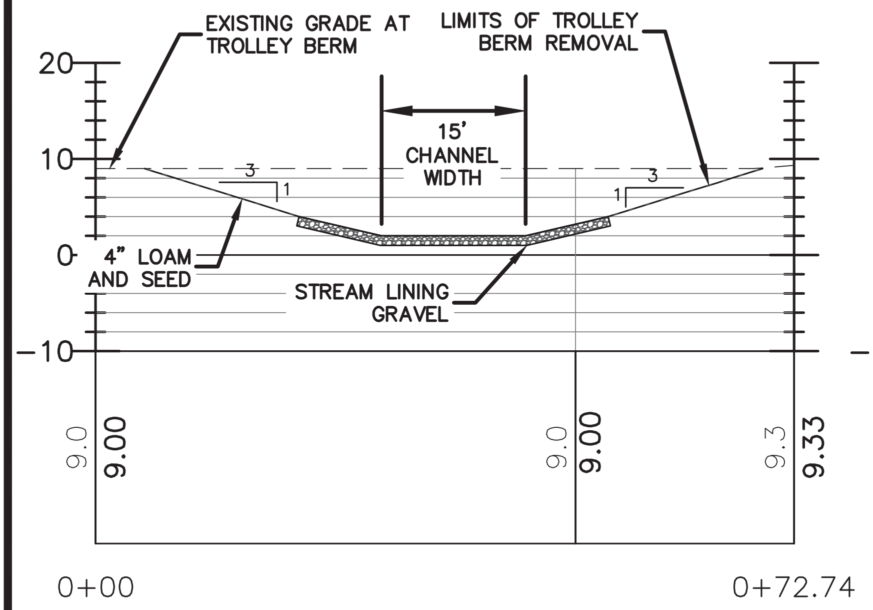
PROJECT NAME:	**Philbrick Pond**		
PROJECT NO.:	1028		
SHEET NO.:	1	OF	1
CALCULATED BY:	SJE	DATE:	4/26/2018
CHECKED BY:	JWB	DATE:	4/27/2018

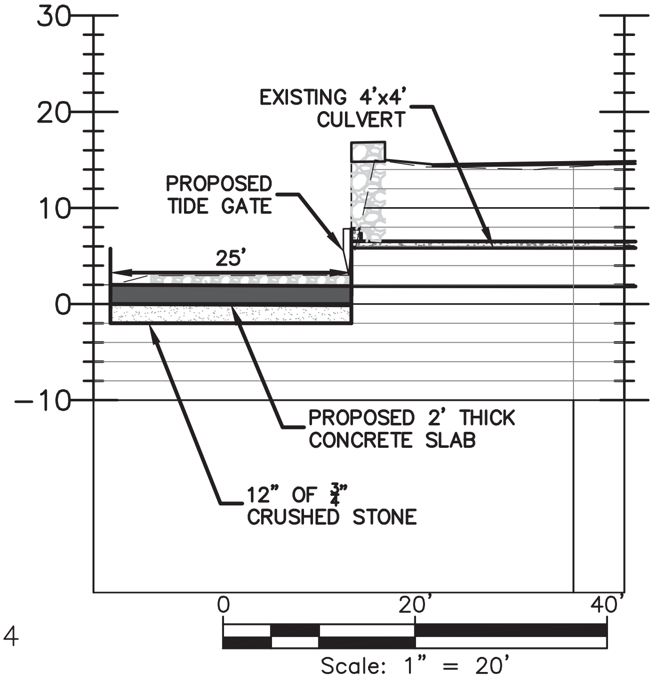
Option #4: Trolley Berm Removal and Tide Gate Installation
Budget Estimate

Item #	Item Description	U	Quantity	Cost	Item Cost ($)
1	Site Preparation	LS	1	$8,000.00	$ 8,000.00
2	Clearing & Grubbing	A	0.08	$30,000.00	$ 2,400.00
3	Cofferdam/Dewatering	EA	1	$30,000.00	$ 30,000.00
4	3/4" Crushed Stone	CY	7	$30.00	$ 210.00
5	Common Excavation	CY	800	$12.00	$ 9,600.00
6	Rock Excavation	CY	5	$200.00	$ 1,000.00
7	Concrete Slab	CY	16	$300.00	$ 4,800.00
8	Tide Gate with Structure	EA	1	$75,000.00	$ 75,000.00
9	Stream Lining Gravel	CY	26	$50.00	$ 1,300.00
10	General Site Work	LS	1	$15,000.00	$ 15,000.00
11	Project Cleanup and Site Restoration	LS	1	$5,000.00	$ 5,000.00
12	Mobilization	LS	1	$10,000.00	$ 10,000.00

Construction Subtotal	**$162,300**
Construction Contingency (20%)	$32,500
Engineering Design & Permitting (20%)	$32,500
Construction Administration/Resident Project Representative (10%)	$16,200
Subtotal	**$81,200**
Budget Estimate Total	**$243,500**







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Philbricks Pond
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Project #4: Trolley Berm Removal & Tide Gate Installation

Scale 1"=40'
April 2018

F:\CADD\PROJECTS\1028 N Hampton Philbrick Pond\Engineering\Figure 1—Raising the Road.dwg Date Plotted: Apr 27, 2018 — 4:10pm

Appendix F

Public Participation

November 30, 2017 from 7-9 PM

Philbrick Pond Public Meeting Summary

Questions from Attendees, with summarized answers:

- Capacity of the 1A culvert and trolley causeway if functioning properly
    - Not the issue, head loss is. 30 in in diameter trolley is the issue, hydraulic capacity of DOT culvert is greater and less of a constraint on the elevations
- Egress from Bradley lane, fisherman's right from way from woodland road to ocean, North Hampton maintains it through road to Woodland road and could be used. → informal, grandfathered in
    - Not owned by the town
    - 10 or 12 Bradley lane are access point, north west part of Bradley lane
    - Goes right through to woodland→ used too, not sure from Old Locke to Woodland
- Raising Old Locke road, whole length or starting from where –gets water on her property as it is, would it affect that
    - Elevation 9 or 10 by causeway over towards the golf course, with improved drainage.
    - New culvert centered on the pond on the golf course
    - Might be able to get a FEMA grant for increasing access during storm events
- If they raise the road, still flood on the north side of causeway, if ocean storm then shale on the road and can't get out anyway from Ocean Boulevard → need to look at sea wall
    - 3-4 foot berm and there would be a slope down on each side to the properties, within right of way, guardrails
- Could the southern part of Old Locke Road be raised?
    - Raise road and then their driveways and grading issues into the lots for 3 houses
    - Could add addressing that too, more money than other section and changes to private properties
    - Nothing can solve the flooding problem
- DOT engineer: 1a culvert at the inlet, appreciate the slab and engineering judgement and read UNH thesis and hydraulic analysis, was this a 1d study? Ocean blvd construction at different times and different riprap, costal structures decisions made in the field→ trying to control scour at the inlet, increase in velocity if we take that out? Is anyone aware of the rationale for why this was done? Hard to find old hydraulic calculations→ only have blue print plans
    - High bottom between 1a culvert and trolley, bedrock? Doubt it. Needs to be regraded and be stable. Don't know what the bottom of the culvert is, granite? Natural?
    - Look into the calculations of the model and make sure what it is finding for head loss and not make flooding worse, lets more water in as tide goes up.
- Historically, what was this engineering intended to protect and do? Who was responsible for executing this?
    - Trolley berm and 1A berm probably same time period→ not sure what they were thinking
    - Probably not thinking of marsh health and didn't have computers
- Wasn't any flow into the marsh initially, flapper valve on the end of the pipe

- If you raise Old Locke road, contain more water in the pond and get blocked up on the other properties? Fixing funnel from the top not the bottom.
    - No fix from the bottom
    - Can be configured to have no negative impact on people. Not affect water level in the pond
    - Other side of Old Locke road, complicated with conduits and harder to do
        - Concentrate more water into the pond?
    - What happens downstream? Does it get loaded up in the pond if it isn't going upstream? →not going to change
- Would a gate work to hold back the water? Works on Eel pond
    - Rye has discussed taking that out and make into a salt marsh
    - Eel pond outlet was further north and was constructed to move it from a house.
- Could dam and make it a pond
    - but it would increase the flooding
- North Hampton ran a pipe under the road and water can't get out because of the groves, if there was a channel from upstream down the marsh to the trolley berm, would drain out and no flooding. Owner is only allowing the replacement of the pipe and possibly add a tide gate. Would a channel from golf course to the trolley berm make a difference in the storm? Would road be accessible? 30" pipe and culvert holding it up?
- There is an Aquarion Water right of way from Fairway Drive in Rye to Pond Path. Water from the public water service→ can make an emergency road, 12' wide less than to Woodland road and be good for fire access and cars to get out
- Mosquito trenching after road was constructed through the marsh and impacts on the oxygen levels
    - In the 40s ponded water, threw mud up behind the trenches
- Maximum capacity of the structures, make the trolley causeway equal to the 1A and a gate to prevent inflow to existing, benefit to marsh health and increased flood capacity.
    - 8' wide 30" high box was to mimic the 1A culvert
    - Box didn't resolve the flooding issue
- Doesn't maximize the flow and resolve the flooding?
    - No
    - Minimizes it to 1 day and drops the elevation a bit → still floods, cuts flood time down in half
- How high of water on the road before you can't drive on the road?
    - Not more than a foot, mother's day flood was up 3-4 feet and had to walk through the water
    - Gate doesn't help water going out, tide gate not needed until future sea level rise.
    - Next 20-30 years problem is to get water out from freshwater storms
- Freshwater flooding, first constraint is the trolley berm and then the 1A culvert, not looking at taking out both.
- Would be different if the channel in the 1A culvert had a lower bottom.
- Who pays for fixing the problem? Town, state, neighborhood?
    - Grant, local funding, FEMA applications, inlet structure might even meet NOAA requirements as well

- Logistics, to a vote?
    - Finish report, have a meeting with selectman, talk about recommendations, if proceed→ peruse two different grant opportunities
    - Takes more time that you think, first need to look at different opportunities and costs and selectmen decide where to move forward
- How did this list get generated (handout)? People who are around the pond→ who floods directly
- Owners will not let the berm get taken out→ owners of that property are present.
    - The current trolley berm owners did not speak at the meeting.

PHILBRICK POND SALT MARSH
DRAINAGE EVALUATION
TOWN OF NORTH HAMPTON, NH
November 30, 2017

- Craig N. Musselman, P.E., BCEE
- CMA Engineers, Inc.
- PORTSMOUTH, NH | MANCHESTER, NH | PORTLAND, ME

Project Funding

- Town of North Hampton (1/3)
- Federal Grant, Coastal Zone Management (2/3)
  - New Hampshire Coastal Program (NHCP)
  - New Hampshire Department of Environmental Services (NH DES)
  - National Oceanic and Atmospheric Administration (NOAA)

Project Team

- CMA Engineers, Portsmouth, NH – project management, engineering
- Gomez and Sullivan, Henniker, NH – hydrology and hydraulic modeling
- James Verra Associates, Newington, NH – surveying
- David Burdick, PhD, University of NH – wetlands scientist
- Edward S. Kelly, P.E., New Castle, NH – engineering review
- Ted Berry Company, Livermore, ME – DOT culvert inspection

Tasks and Schedule

- Survey (2005 and 2017)
- Pipe and Channel Inspections
- Hydrological and Hydraulic Evaluations
- Wetlands Evaluation
  - Above tasks nearly completed, June, 2017 through November, 2017
- Formulation and Evaluation of Alternatives – in process
- Report – June, 2018
- Two Public Meetings – June, 2017 and November, 2017

*Note – seawall assessment not included in scope

Problem Statement

- Flooding of Homes in 100 Year Storm (i.e. 2006 Mother's Day Storm)
- Isolation of Neighborhood in 100 Year Storm (45 homes +/-)
- Concern Re: High Tide Flooding in the Future
- Concern Re: Storm Surge Flooding in the Future
- Flooding of Golf Course in annual and extreme storms

Philbrick Pond - North Hampton NH

Philbrick Pond Salt Marsh Drainage Evaluation				Property Elevations, Datum 1929 NGVD			
Map	Lot	Street Address	2017 Owner	Basement	Garage	First Floor	Septic Field
2	78	44 Causeway Rd	Sophinos	9.9	13.9	14.5	11.6
2	79	60 Causeway Rd	Brunce	8.7		17.7	10.2
2	82	70 Causeway Rd	McDowell	7.8		11.4	6
2	83	2677 Ocean Boulevard	Costa	7.7	14.7	16.4	6
2	85	2680 Ocean Boulevard	Germain			15.31	
5	8	24 Willow Ave	Gelston			12.5	
5	9	34 Willow Ave	Falzone	8.6	16.9	17.3	7
5	10	88 Ocean Blvd	Earthrowl	7.11		15.97	
5	10-1	90 Ocean Blvd	Latham	7.1		16.8	12.5
5	11	92 Ocean Blvd	Berardini	10.5		18.7	17
5	15	31 Old Locke Rd	McClure	Access Denied			
5	16	29 Old Locke Rd	Gassner	14.9	21.2	23.8	19.9
5	17	27 Old Locke Rd	Veale	8.8	14.8	17.4	14
5	18	23 Old Locke Rd	Emory	8	11.3	16.3	12.7
5	19	19 Old Locke Rd	Moore	7.8	8.7	15.6	13.1
5	21	9 Old Locke Rd	Bolyea		8.6	9.4	8.5
5	23	7 Old Locke Rd	Fontana	6.6		14.7	11
5	24	21 Chapel Rd	Stone	9.9	9.5	18.1	11
5	25	19 Chapel Rd	Stevens	6.9	10.6	15.1	12
5	26	15 Chapel Rd	Whittier	7.6		16	12.6
5	78	8 Old Locke Rd	Gallant	7.5		15.6	12.5
5	80	16 Old Locke Rd	Schneider	9.55		13.3	12.9
5	81	18 Old Locke Rd	O'Heir	7.1		12.4	9.7
5	82	20 Old Locke Rd	Schreck				10.5
5	9-1	34 Willow Ave	Falzone			13.2	

Status of Existing Culverts

- **Trolley Berm Culvert** – 30 inch diameter Vitrified Clay, ca. 1900
  - 40 feet in length
  - Pipe is intact
  - Berm is eroding above pipe – significant voids on upstream (west) side

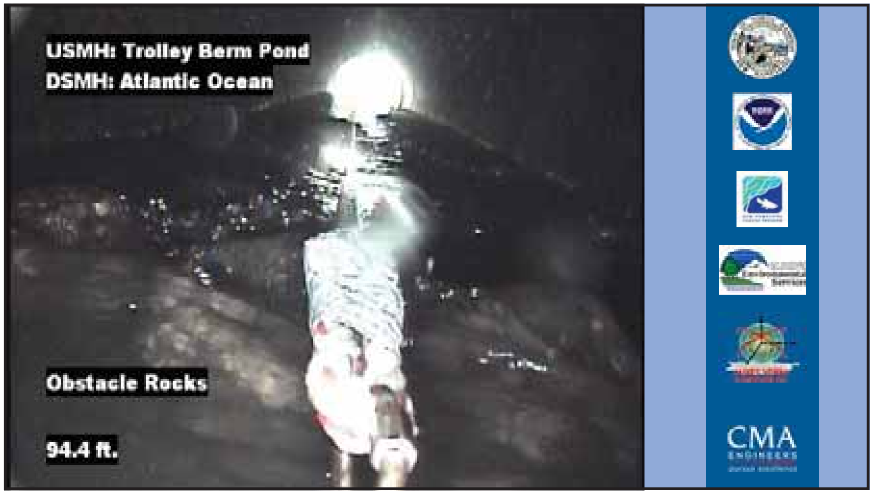
- **NHDOT Ocean Boulevard Culvert** – 4' x 4' box (boulder sides, concrete roof) transitioning to 48 inch diameter reinforced concrete pipe. Box - 45 feet in length, Pipe – 140 feet in length to ocean outfall

Condition – Good. Boulders protruding up from invert, and in pipe.

Cobble "V-notch Weir" at west inlet

USMH: Trolley Berm Pond
DSMH: Atlantic Ocean

General Observation
Field Stone Side & Concrete Top
13.9 ft.



USMH: Trolley Berm Pond
DSMH: Atlantic Ocean

Obstacle Rocks

94.4 ft.

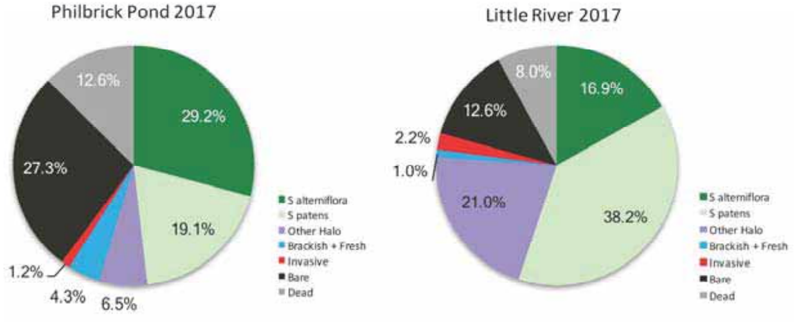
Status of Philbrick Pond Salt March

David Burdick, Ph.D.

University of New Hampshire

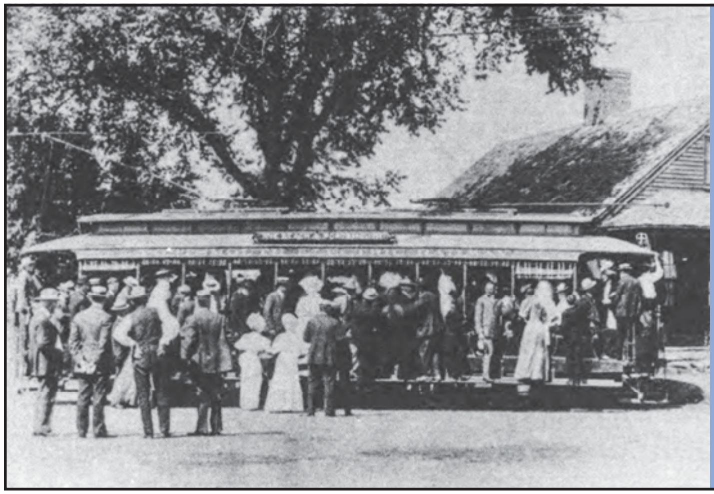
Jackson Estuarine Laboratory

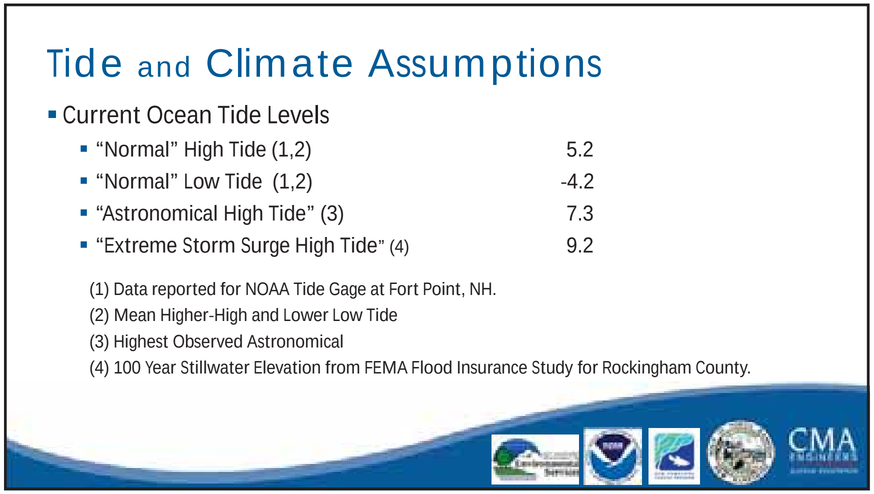
Pore water 2017				
	Little River	SE	Philbrick	SE
Salinity (ppt)	32.9	0.6	30.4	1.2
Redox (mV)	-122	26	-295	12
pH	6.66	0.04	6.63	0.05
Sulfides (mM)	0.62	0.23	2.40	0.23



History

- Rye Harbor at Philbrick Pond? 1757 Lottery authorized by New Hampshire legislature. Never completed. Some construction initiated by Joses Philbrick.
- Trolley – Portsmouth Electric Railway, service through North Hampton began July 28, 1900.
- House Relocations – 1940's.



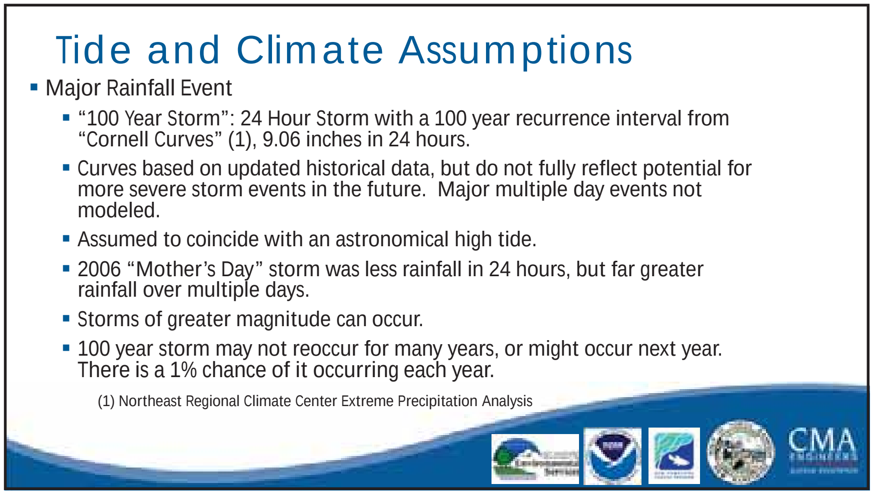


Tide and Climate Assumptions

- Current Ocean Tide Levels

"Normal" High Tide (1,2)	5.2
"Normal" Low Tide (1,2)	-4.2
"Astronomical High Tide" (3)	7.3
"Extreme Storm Surge High Tide" (4)	9.2

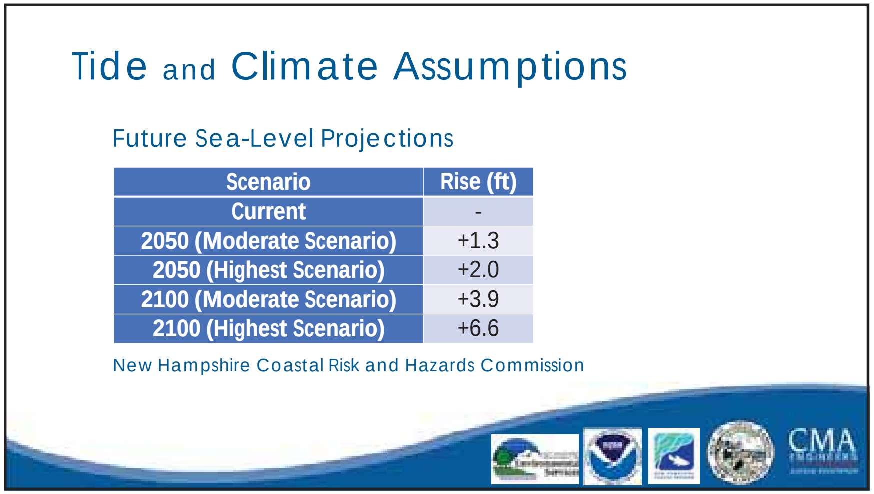
(1) Data reported for NOAA Tide Gage at Fort Point, NH.
(2) Mean Higher-High and Lower Low Tide
(3) Highest Observed Astronomical
(4) 100 Year Stillwater Elevation from FEMA Flood Insurance Study for Rockingham County.



Tide and Climate Assumptions

- Major Rainfall Event
  - "100 Year Storm": 24 Hour Storm with a 100 year recurrence interval from "Cornell Curves" (1), 9.06 inches in 24 hours.
  - Curves based on updated historical data, but do not fully reflect potential for more severe storm events in the future. Major multiple day events not modeled.
  - Assumed to coincide with an astronomical high tide.
  - 2006 "Mother's Day" storm was less rainfall in 24 hours, but far greater rainfall over multiple days.
  - Storms of greater magnitude can occur.
  - 100 year storm may not reoccur for many years, or might occur next year. There is a 1% chance of it occurring each year.

(1) Northeast Regional Climate Center Extreme Precipitation Analysis



Tide and Climate Assumptions

Future Sea-Level Projections

Scenario	Rise (ft)
Current	-
2050 (Moderate Scenario)	+1.3
2050 (Highest Scenario)	+2.0
2100 (Moderate Scenario)	+3.9
2100 (Highest Scenario)	+6.6

New Hampshire Coastal Risk and Hazards Commission

Hydrologic and Hydraulic Modeling

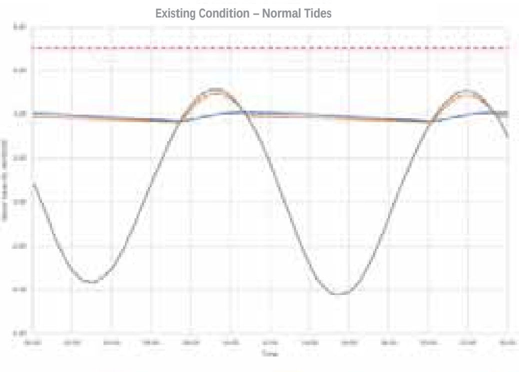
- Calibration – level sensors on both sides of trolley berm monitored through June and July, 2017.
- Hydraulics of Trolley Berm culvert confirmed through calibration.
- Hydraulics of Route 1A culvert estimated through internal inspection and engineering judgment.
- Modeling – HEC-RAS, Hydrologic Engineering Center's River Assessment System.
  - US Army Corps of Engineers

Alternatives Evaluated

- No Action/No Change – pipes and channels remain as they are ("Existing Condition")
- SLAB – Remove cobble v-notch weir at DOT culvert and replace with 4 foot wide concrete slab at about elevation 2.0. Regrade channel bottom between trolley berm and DOT culvert.
- BOX – Remove 30 inch trolley berm culvert and replace with 30 inch high by 8 foot wide reinforced concrete box.
- CHANNEL and SLAB – Remove trolley berm in its entirety to maintain open channel flow. Replace v-notch weir with concrete slab, and regrade channel bottom.

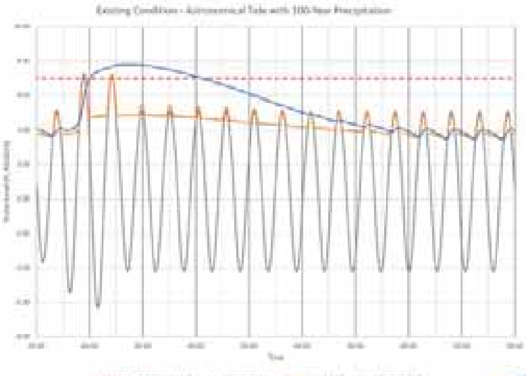
*No change to NH DOT culvert pipes assumed, other than SLAB.

Current Sea Level

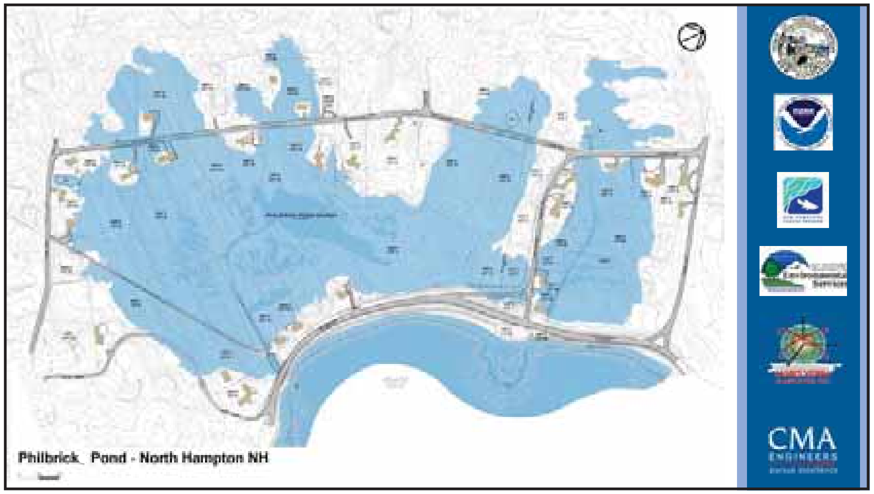


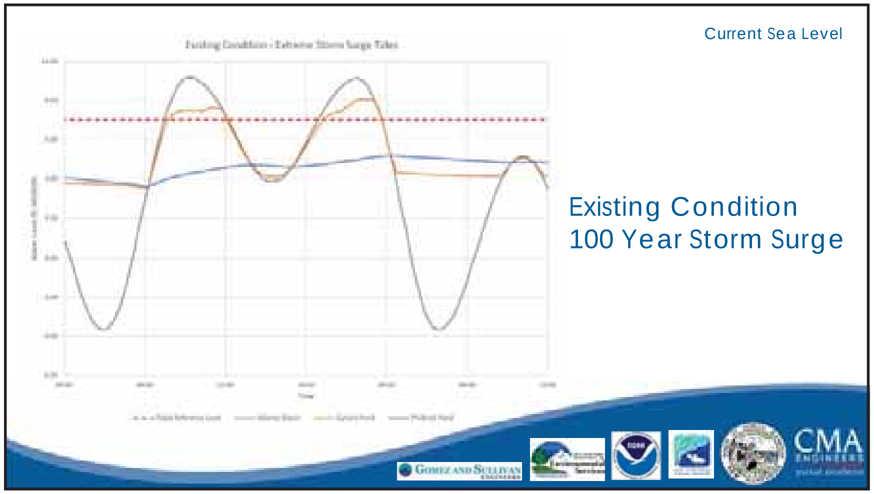
Existing Condition – Normal Tides

Current Sea Level

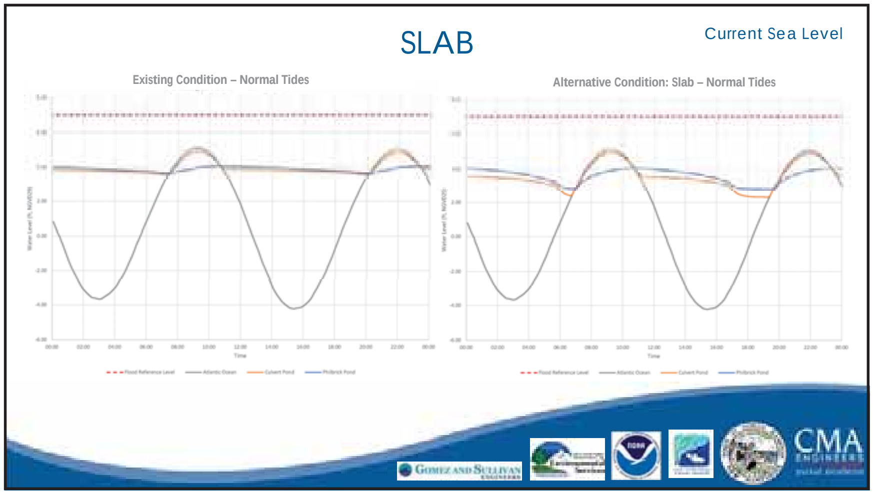


Existing Condition 100 Year Precipitation

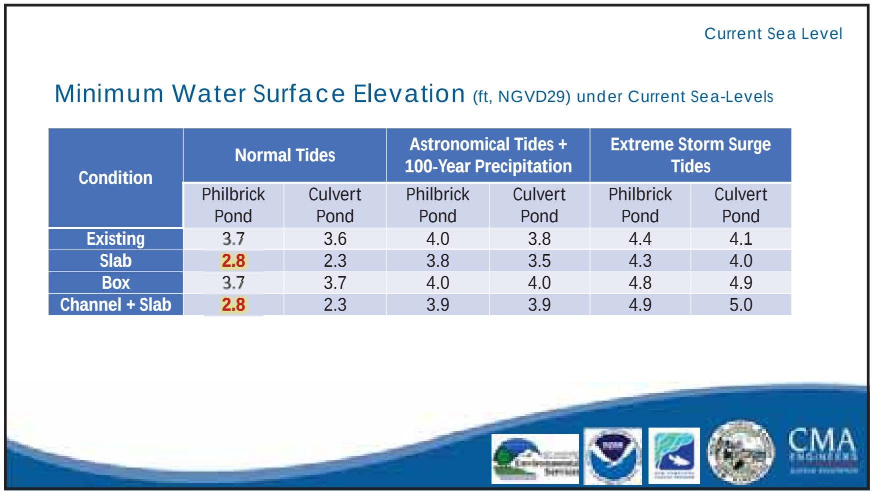



Current Sea Level

Existing Condition
100 Year Storm Surge

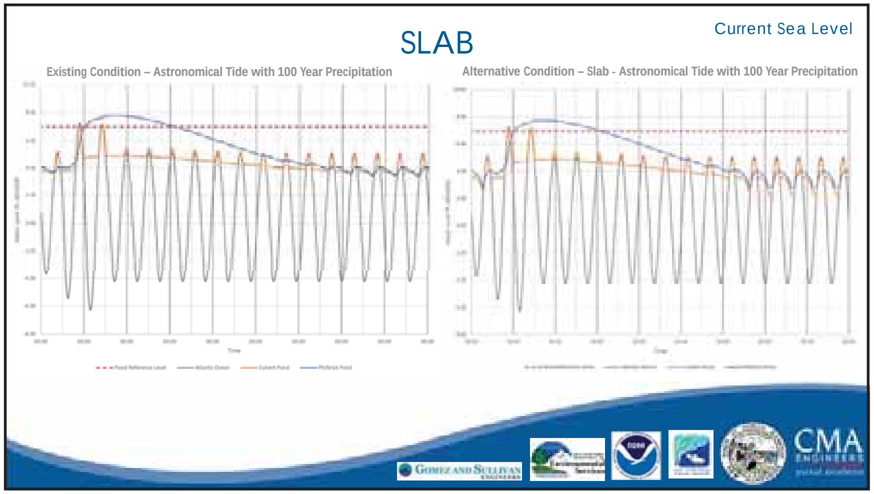

SLAB

Current Sea Level


Current Sea Level

Minimum Water Surface Elevation (ft, NGVD29) under Current Sea-Levels

Condition	Normal Tides		Astronomical Tides + 100-Year Precipitation		Extreme Storm Surge Tides	
	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond	Philbrick Pond	Culvert Pond
Existing	3.7	3.6	4.0	3.8	4.4	4.1
Slab	2.8	2.3	3.8	3.5	4.3	4.0
Box	3.7	3.7	4.0	4.0	4.8	4.9
Channel + Slab	2.8	2.3	3.9	3.9	4.9	5.0

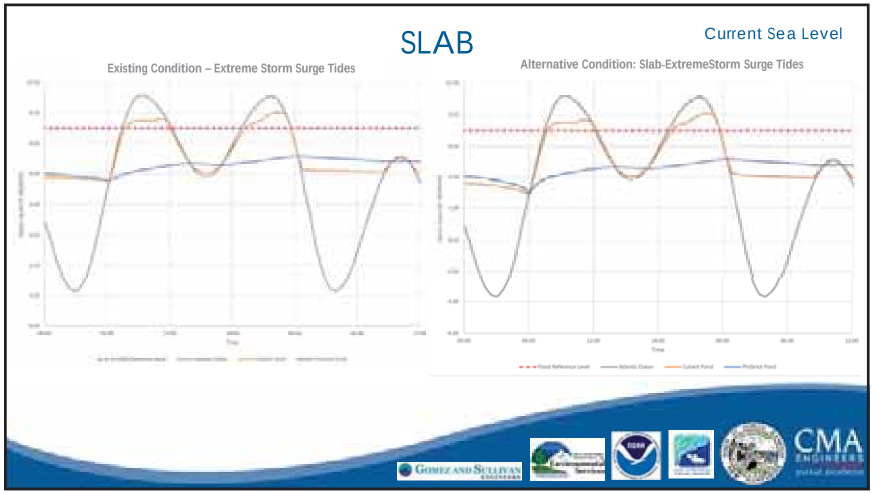


SLAB

Current Sea Level

Existing Condition – Astronomical Tide with 100 Year Precipitation

Alternative Condition – Slab - Astronomical Tide with 100 Year Precipitation

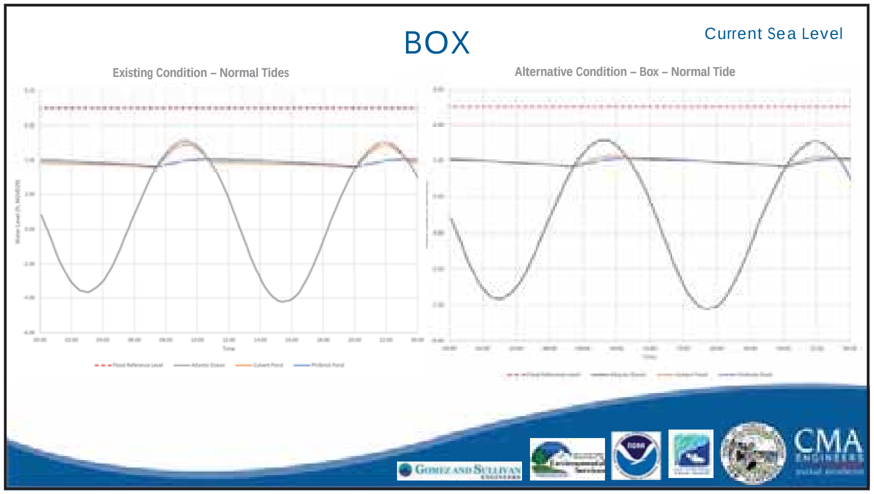


SLAB

Current Sea Level

Existing Condition – Extreme Storm Surge Tides

Alternative Condition: Slab-ExtremeStorm Surge Tides

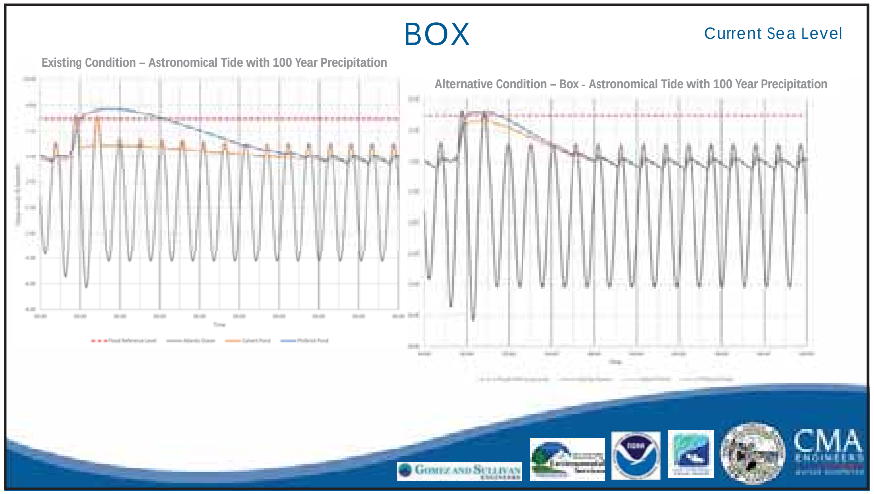


BOX

Current Sea Level

Existing Condition – Normal Tides

Alternative Condition – Box – Normal Tide

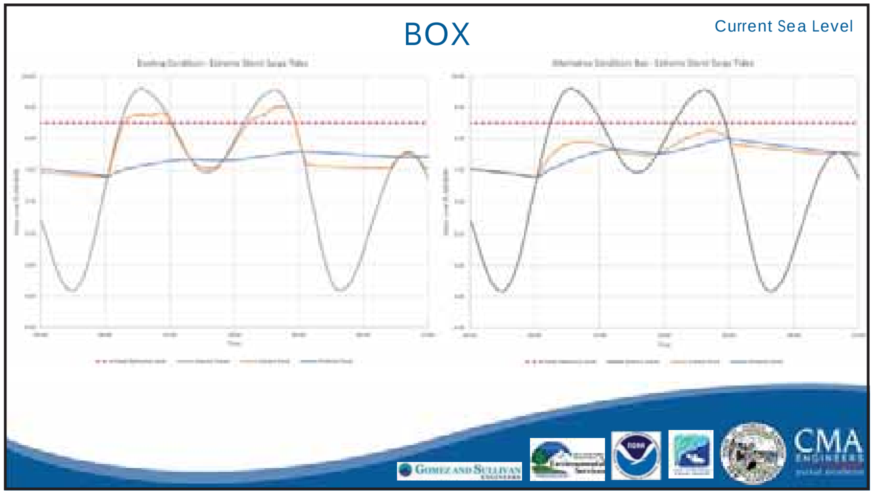


BOX

Current Sea Level

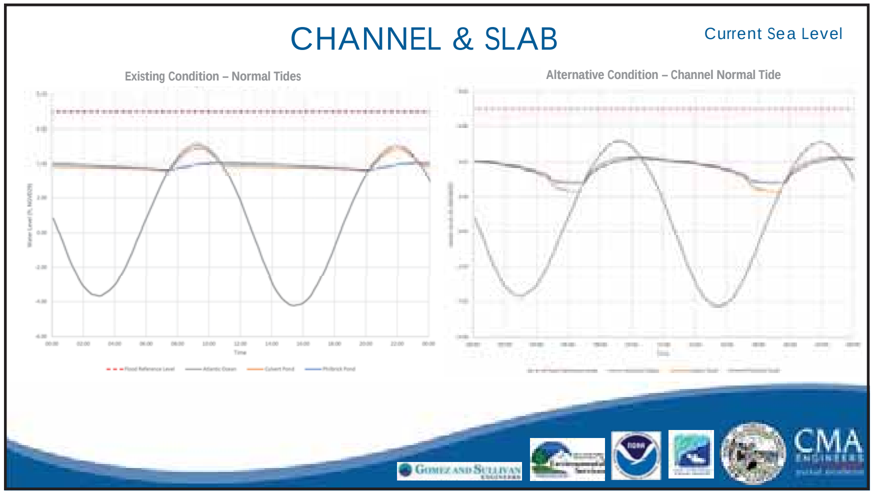
Existing Condition – Astronomical Tide with 100 Year Precipitation

Alternative Condition – Box - Astronomical Tide with 100 Year Precipitation



BOX

Current Sea Level

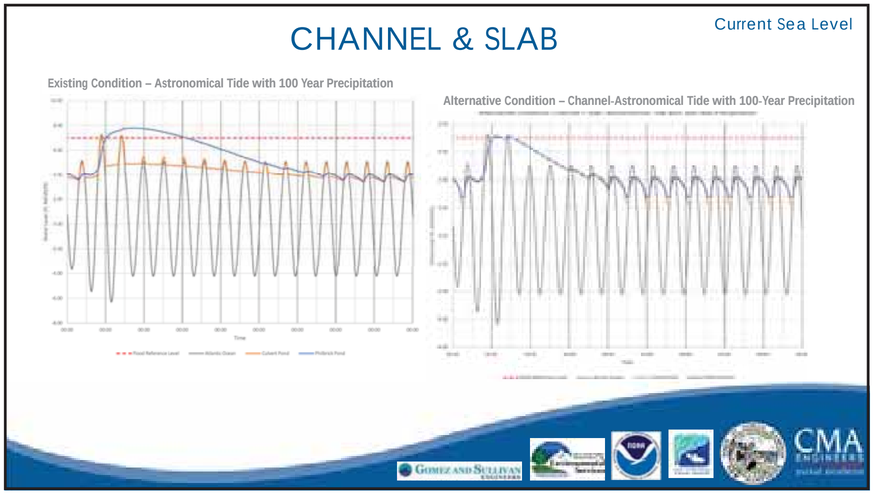


CHANNEL & SLAB

Current Sea Level

Existing Condition – Normal Tides

Alternative Condition – Channel Normal Tide

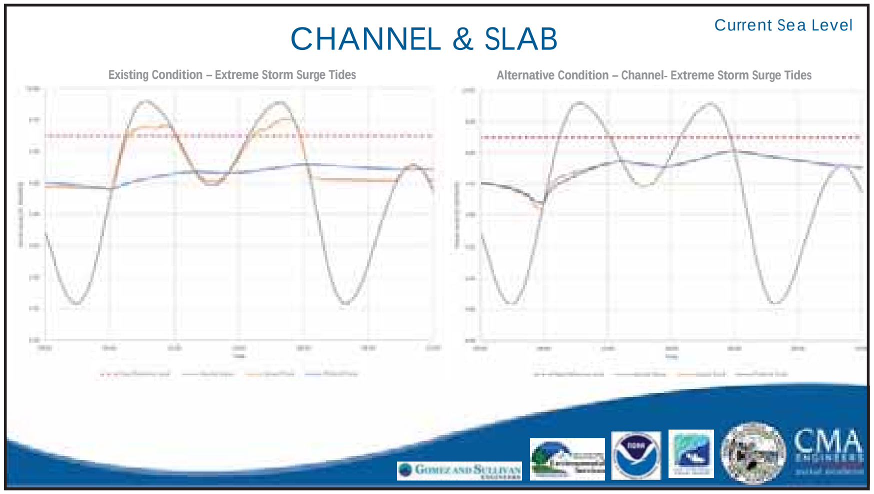


CHANNEL & SLAB

Current Sea Level

Existing Condition – Astronomical Tide with 100 Year Precipitation

Alternative Condition – Channel-Astronomical Tide with 100-Year Precipitation



CHANNEL & SLAB

Current Sea Level

Existing Condition – Extreme Storm Surge Tides

Alternative Condition – Channel- Extreme Storm Surge Tides

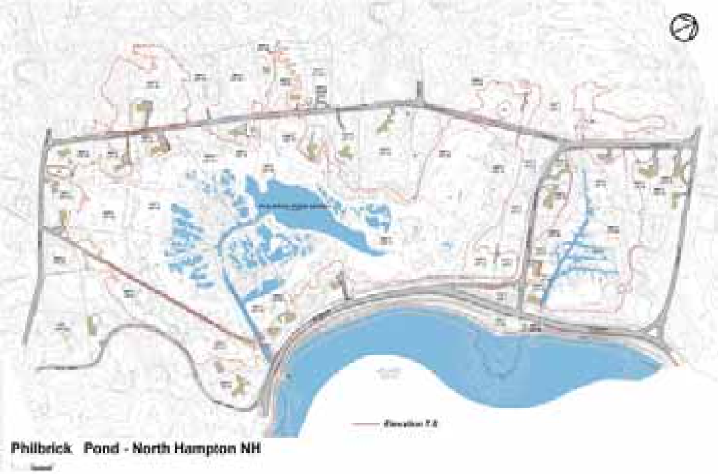
High Tide with Sea Level Rise

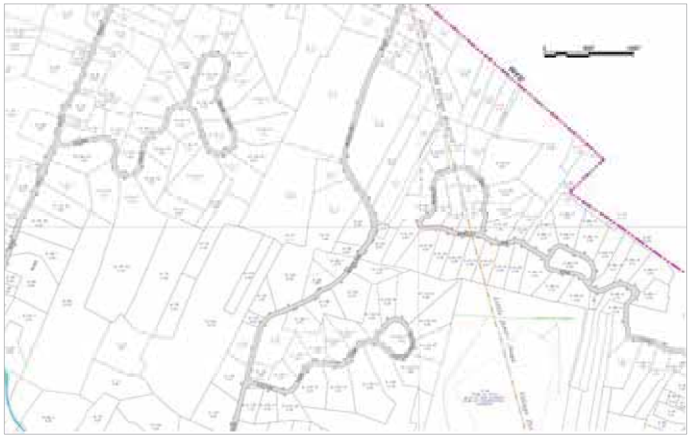
Sea Level	Normal High Tide			Astronomical Tide & 100 year Precipitation			Extreme Storm Surge Tides		
	Existing Condition	Box	Channel	Existing Condition	Box	Channel	Existing Condition	Box	Channel
Current	4.1	4.2	4.2	**7.8**	**7.2**	**7.1**	5.2	6.0	6.1
2050 Moderate	4.5	4.8	4.8	**8**	**7.7**	**7.6**	6.0	6.7	6.8
2100 Moderate	6	6.3	6.3	**8.8**	**8.7**	**8.7**	**7.9**	**8.2**	**8.3**
2100 Highest	**8.5**	**8.2**	**8.0**	**10.3**	**10.2**	**10.1**	**10.3**	**10.1**	**10**

Alternatives Proposed to be Considered

- **Concrete Slab** to replace v-notch cobble weir at NHDOT culvert
  - Improves marsh health
  - Doesn't exacerbate flooding issues
- **Improve Neighborhood Roadway Access**
  - Raise Old Locke Road at Abenaqui Golf Course by 3-4 feet (about 500 feet + in length), with box culvert.

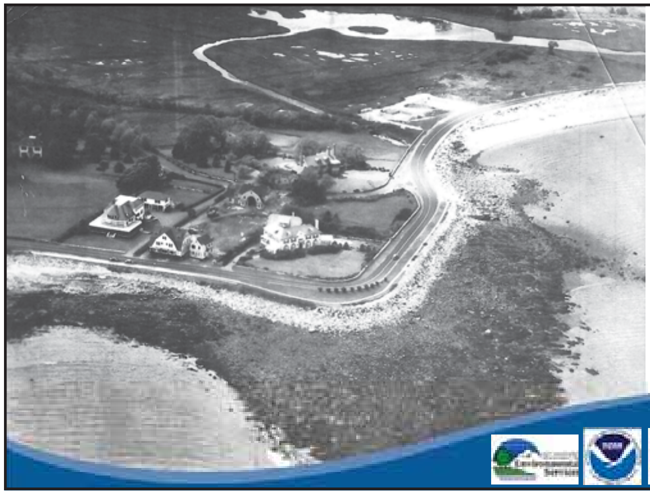
  Or
  - Construct new road from Bradley Lane to Woodland Road (about 1,000 feet in length across multiple properties).





Alternatives Proposed NOT to be Considered Further

- **Replacing Trolley Berm Pipe with larger conduit or open channel.**
  - Doesn't solve the current set of flooding problems
  - Hastens the day and compounds the problem somewhat if and when sea level rises and storm surge creates additional flooding problems from the other direction.
  - However, marsh health would be significantly improved if higher high tides regularly covered the marsh surface.



Questions, Discussion?

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