Raritan Bay and Sandy Hook Bay
Highlands, New Jersey
Coastal Storm Risk Management
Feasibility Study

Feasibility Report

May 2020

Appendix B4:

Hydrology and Hydraulics, Interior Drainage Analysis

Raritan Bay and Sandy Hook Bay, Borough of Highlands, New Jersey
Coastal Storm Risk Management Feasibility Study

Appendix B4: Hydrology and Hydraulics, Interior Drainage Analysis

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Chapter 1: Introduction

The Highlands Coastal Flood Risk Management study includes the recommendation of floodwalls to reduce the risk of coastal storm damage for the Borough of Highlands, New Jersey. The study requires an interior drainage hydrology and hydraulics analysis, because normal drainage of runoff from the drainage area intercepted by the proposed line of protection will be blocked with the proposed line of protection (floodwalls) in place.

The purpose of the Interior Drainage Analysis is to complete two key tasks for the project area. The first task is the Minimum Facility Analysis, which determines what interior drainage facilities need to be placed through the proposed line of protection, to maintain the existing conditions stage vs. frequency curve, for the protected area landward of the line of protection, with the proposed line of protection (floodwalls) in place. The second task is Alternatives Analysis, which will determine the effects of additional drainage features, including pump stations, detention ponds, and diversion structures, on the interior water levels. In order for the proposed interior drainage alternative measures to be added to the overall plan, the final selected features must be cost-justified on an individual basis.

This Appendix will document both the Minimum Facility Analysis and the Alternatives Analysis, and all of the data that was necessary to develop estimates of quantities, which were required for the economic analysis for this study. References and additional output data from the alternatives are presented at the end of this appendix.

Drainage Basins A, B, and C form the interior of the project area. These basin names are used throughout this appendix, and their extents can be seen in Figure B4-1 below. Basin A is the westernmost drainage area near the Harborside at Hudson's Ferry property. Basin B is centrally located in the Highlands project area and also includes the upland drainage to the south of Basin A. Basin C is the easternmost drainage area, which extends near the Rt. 36 Bridge.

Chapter 2: Background Information

2.1 Previous Studies

The New York District (NAN) performed an earlier investigation of minimum facility and preliminary investigation of interior drainage alternatives for the Highlands CSRM study, documented in a technical memorandum dated August, 2007. The basic layout of the hydrologic sub-basins from this earlier work was used as a starting point for the current update of the Interior Analysis, conducted by St. Louis District (MVS). The study team determined that there were no significant pumps or outlet structures added to the area since 2007. Therefore, the existing basin outlets were verified and kept as a part of the updated analysis.

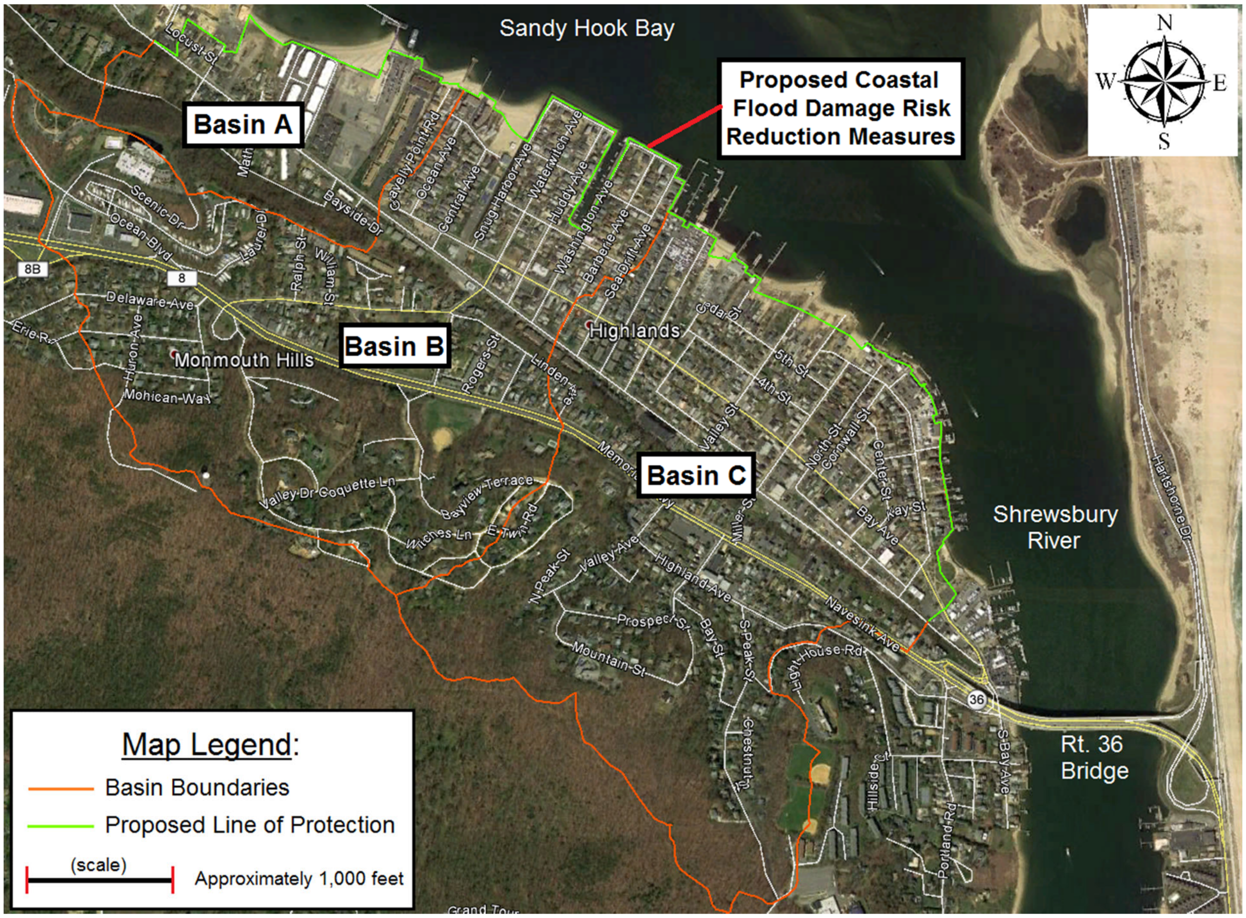

Figure B4-1: Overview of Highlands Interior Analysis, Line of Protection and Drainage Basins

The Minimum Facility report was referenced for the methodology of coastal engineering studies with an interior hydraulics component. Hydrologic parameters such as drainage areas, loss rates, and times of concentration were assumed to have not changed since 2007. Land cover and usage has not changed significantly in recent years. This was therefore a valid assumption for the updated analysis.

2.2 Prior Hydrologic Models

The 2007 analysis utilized legacy software from the USACE Hydrologic Engineering Center (HEC) called HEC-1 and Interior Flood Hydrology (HEC-IFH). The HEC-1 and HEC-IFH programs have since been superseded by HEC's Hydrologic Modeling System (HEC-HMS).

The basic framework and data parameters from the HEC-1 model were used to re-compute and verify the hydrologic analysis with HEC-HMS. Rainfall frequency data was verified using the National Oceanic and Atmospheric Administration (NOAA) Atlas 14, Precipitation Frequency Atlas of the U.S. The HEC-HMS program also contains the modeling features that were formerly accomplished with HEC-IFH, for computing stages behind flood damage risk reduction features, and incorporating pumps and outlet pipes for detention ponds. The results from the original HEC-1 and HEC-IFH model studies were not matched exactly by the new modeling methods in HEC-HMS, but any inconsistencies were discussed with the New York District Civil Resources Branch team members, and the team proceeded with the newly computed HEC-HMS results.

2.3 Other Data Sources

Another important required data source was a terrain coverage of the project area, which was available from multiple sources. The MVS Civil Design section mapping products were based on a Triangular Irregular Network (TIN) created from New York District Data, but two additional Light Detection and Ranging (LiDAR) sources were also investigated. One LiDAR source was that obtained from a State of New Jersey database, which was recorded in 2014. Another source was the USGS "LAS Point Cloud" data source for the project area, which was recorded in 2015. The New Jersey LiDAR data was a bare earth terrain model, with some large buildings indicated as "no data". The Point Cloud LiDAR data was a "first return" dataset, so buildings were included, but some erroneous data points were observed in areas that were heavily wooded. Fortunately, there are not large wooded areas in the lowest portion of the Highlands project area.

The original HEC-IFH model had storage vs. elevation curves for each of the 3 basins, but there were not enough points to define an accurate curve for the HEC-HMS analysis. Therefore, all three newer terrain data sources were used to compute a new storage vs. elevation curve for comparison to the original model data. Plots of these storage vs. elevation curves can be found in Chapter 8 at the end of this Appendix, in Figure B4-5, Figure B4-6, and Figure B4-7. Some HEC-HMS simulations did not appear to give realistic results using the USGS data, so the final decision was made to use the NJ State LiDAR data source. Because the newer data sources contained elevation data in NAVD 88, all information from previous studies had to be converted from NGVD 29 to NAVD 88, using the local conversion of -1.05 feet (NGVD 29 to NAVD 88).

In addition to terrain data, a Microstation file from the Borough of Highlands was used to reference utility data. This was useful for locating any underground utilities that could impact the project area. The utility layer was also used to verify the pipe sizes and locations for outlets to Sandy Hook Bay.

Lastly, the NOAA Atlas 14 was used as the source for precipitation data for the hydrologic analysis. These updated values are generally higher than the values from the earlier version of the NOAA Precipitation Atlas that was used in the prior interior drainage analysis.

2.4 Storm History

Hurricane of 14 September 1944. This hurricane caused losses estimated at over $2,500,000 (1944 dollars) in the bayshore area. Peak tide height reached 8.4 ft. NGVD in the area from Highlands to Keyport and 12.0 inches of rain were recorded in New Brunswick. At Highlands, the storm caused damage to streets, sewers, water lines and bulkheads. About 150 homes, 20 hotels, numerous stores and the sewage and water plants were inundated. Several pavilions were destroyed by waves.

Extratropical Storm of 25 November 1950. This storm, which produced tides of 9.1 feet at Keyport, caused over $2,000,000 (1950 dollars) of damage in the Bayshore area. According to newspaper accounts, there were two deaths, one in Union Beach and another in Keansburg. Rainfall totals were approximately 2.5 inches. The accompanying tides in the New York Harbor area were about one to two feet above the previous maximums recorded during the 1944 hurricane.

At Leonardo, Atlantic Highlands, and Highlands, boats and piers were damaged severely by tide and wave action in Sandy Hook Bay. The entire downtown section of Highlands was flooded resulting in the evacuation of the residents and heavy damage to many commercial establishments. Beach erosion was extensive, and many streets in the area were damaged.

Extratropical Storm of 6-7 November 1953. This storm caused damage estimated at $1,630,000 (1953 dollars) with peak tides of 8.9 feet. At Long Branch (Atlantic coast), the strongest wind was measured as 78 miles per hour from the east. Total rainfall was estimated at 1.25 inches. Flooded tracks near South Amboy and other places resulted in loss of railway service along the entire north shore.

As a result of severe damages caused by this storm, the State Legislature of New Jersey organized the "Legislative Commission to Study Sea Storm Damage." The Commission found that direct damage to public property in the Bayshore area was $374,000 (1953 dollars).

Hurricane of 12 September 1960 (Donna). Tides produced by Hurricane Donna reached 8.9 feet at Morgan with a reported rainfall of 4.5 inches. Tidal damages were estimated at about $6,000,000 (1960 dollars). At Long Branch the highest gust recorded was 79 mph from the northeast.

At Atlantic Highlands and Highlands, boats and piers were severely damaged by the storm. In Highlands, water was 4 to 5 feet deep on the main street and a great number of stores and homes were flooded. Newspapers carried reports of raw sewage floating in the borough streets. A bulkhead recently constructed by the State was flanked by the tide, and the street behind the bulkhead was washed out.

Northeaster of 6-8 March 1962. The storm of 6-8 March produced unusually high wind driven tides and very high waves that battered the shore for three successive days. Public and private damages consisted mainly of beach and dune erosion and damages to the bulkhead, seawalls, groins, boardwalks, buildings and roads along the New Jersey coast. Peak tides at Perth

Amboy were 8.1 feet. Damage estimates for the entire Raritan Bay and Sandy Hook area were estimated to be $6,400,000 (1962 dollars). At Highlands, the business area was completely flooded and 60 percent of the residential area was flooded by five successive tides.

Northeaster of 12 March 1984. The storm of 12 March produced a mixture of snow, sleet, hail and hurricane force winds. A peak stage of +7.0 ft. MSL was reported at Keansburg.

In Highlands, most of the low-lying streets were under water, and through the day estimates of water levels were from three to four feet above roadways. More than 300 residents were evacuated, and many by boat. The northern section of Highlands was most severely affected; the area bounded to the south by Bay Avenue, was almost completely inundated. More than 80 cars were submerged.

Northeaster Storm of 11-12 December 1992. The storm caused extensive flooding along the coastal communities of Raritan Bay and Sandy Hook Bay. Extensive wave and erosion damage was also reported. The high tide recorded in the bay was +9.8 ft. NGVD at Luppatatong Creek in Keyport.

As a result of this storm, the entire study area was included in a disaster area declaration. Residents, businesses and public organizations were therefore eligible for aid under a variety of Federal disaster assistance programs. Major Federal programs include:

- Individual Financial Assistance (IFA) to provide emergency aid for temporary housing. Data indicates that within the study area 249 applicants received $303,480 in assistance in comparison to the 469 total applicants and $659,220 for the Raritan Bay and Sandy Hook Bay Area.

- Individual Financial Grants (IFG) to provide assistance to eligible applicants in repairing uninsured damages. Data for the study area indicates 96 grants totaling $239,280 were issued out of the 165 total grants and $353,740 for the Raritan Bay and Sandy Hook Bay Area.

- Small Business Administration (SBA) low interest loans to provide individual residents or businesses assistance in restoring properties. Within the study area 283 SBA applications were provided out of the 648 total for the Raritan Bay and Sandy Hook Bay Area.

- Public Assistance provides Federal reimbursement of 75% for eligible public damage expenses. Public assistance for the study area was $253,990 out of the estimated $1.2 million total for the Raritan Bay and Sandy Hook Bay Area.

A section of bulkhead at the end of Snug Harbor at Highlands was destroyed, possibly contributing to the severe inundation damages suffered by the low-lying town. Other bulkheads suffered moderate damage. In a garage attached to the second house on Water Witch Avenue, landward of the bulkhead, the water level reached approximately 4-5 ft. above the ground elevation. This level of inundation appeared to be typical of all the homes in the town/within approximately five blocks of the waterfront. Widespread flooding resulted in vast amounts of furniture, debris and personal belongings stacked along the sidewalks awaiting removal. Flooding also prevented emergency response to a fire, which destroyed a five-unit residential building.

October 20-26, 2005. The Combination of a large high pressure system centered over eastern Canada, Hurricane Wilma, and the remnants of Tropical Storm Alpha offshore, and a cold front approaching from the Great Lakes resulted in the formation of a powerful hybrid coastal storm that quickly deepened just east of the Delmarva Peninsula. The resulting low brought with it strong onshore winds, moderate coastal flooding, and severe erosion on all Atlantic Ocean facing beaches statewide. Sustained northeast winds peaked around 40 knots early in the morning of October 24, resulting in large breakers exceeding 12 feet along the New Jersey shore.

Nor'easter of February 11-12, 2006. A strong northeaster affected the region, bringing with it copious amounts of snow, strong onshore winds, moderate coastal flooding, and moderate erosion on Atlantic facing beaches. Northeast winds peaked around 40 knots throughout the early morning hours of November 12, resulting in storm surges averaging 3 feet and recorded wave heights at an offshore buoy exceeding 19 feet.

Storm of August 27-28, 2011 (Irene). Irene made its second landfall United States landfall near Little Egg Inlet, NJ, 10 miles ESE of Atlantic City, at 5:35 a.m. Eastern Daylight Time (EDT), Sunday, August 28, 2011 as a hurricane, with maximum sustained winds of 75 mph. At 9:00 a.m. EDT, Irene was over New York City and had weakened to a tropical storm. Tropical Storm Irene dropped about three to thirteen inches of rain on the watersheds within the New York District's civil works boundaries in northern New Jersey and southern New York in about a 16 hour period between about 4 p.m. Saturday August 27 2011 and about 8 a.m. Sunday August 28th, 2011. A total rainfall of 7.75 inches was recorded at Holmdel, New Jersey, close to Port Monmouth. This represents a significant rainfall event at the Pews Creek project site.

Storm of October 22-29, 2012 (Sandy). Sandy was a classic late-season hurricane in the southwestern Caribbean Sea but weaken into a tropical storm north of the Bahamas Islands. The system re-strengthened into a hurricane while it moved northeastward, parallel to the coast of the southeastern United States, and reached a secondary peak intensity of 85 knots while it turned northwestward toward the Mid-Atlantic States. Sandy weakened somewhat and then made landfall as a post-tropical cyclone near Brigantine, New Jersey. Sandy was predominately a coastal storm, having devastating coastal impacts in the Sandy Hook Bay vicinity. However, the storm was not much of a rainfall producer in the project area and did not provide any impact from runoff. Only 1.84 inches of precipitation was recorded at Holmdel, New Jersey.

Chapter 3: Minimum Facility Analysis

3.1 Methods of Analysis

The procedure for completing a Minimum Facility Analysis included updates of the 2007 computations of interior water surface elevations at all three lower Drainage Basins (A, B, and C), for a series of combinations of exterior and interior storm events.

The exterior storm events were computed with the North Atlantic Coast Comprehensive Study (NACCS), and are discussed in Appendix B2 covering Coastal Hydraulics and exterior stage-frequencies. This analysis evaluated the normal tide conditions, and coastal storm frequencies ranging from the 50% Annual Exceedance Probability (AEP) to the 2% AEP (or the 2 to 50-year) flood events. These events were evaluated for the present conditions (based on construction completion date of 2021) and future conditions (end of 50-year period of analysis, in 2071).

The coastal storm surge values that were used in the Minimum Facility Analysis are presented in Table B4-1 below. The interior storm events ranged from 50% AEP to 0.2% AEP precipitation, as defined by the NOAA Atlas 14 document referenced in **Chapter 2.3** above. The precipitation values used for the interior rainfall-runoff analysis are shown below in Table B4-2**.**

The Minimum Facility Analysis considers the ability of the existing drainage basins to evacuate local runoff from the project area in a "without project" condition. As mentioned above, the present and future conditions are modeled for selection of coastal storm stages and frequencies. The HEC-HMS model was developed using the earlier HEC-1 and HEC-IFH models. The HEC-HMS model schematic is shown in Figure B4-2 below.

After creating the HEC-HMS basin model schematic, the sub-basin hydrologic parameter values were determined and input to the HEC-HMS model. ArcGIS was utilized to obtain a more accurately defined drainage area for each subbasin, but previous values of parameters from the 2007 analysis were spot-checked and used for the current analysis. Table B4-3 below shows all hydrologic parameters for the Highlands sub basins.

3.2 Initial Results and Adjustments

The initial simulations for the Minimum Facility Analysis were tabulated and reviewed by the New York District (NAN) Civil Resources Branch. A few key changes were made to the model before all model simulations were completed. First, the terrain data source was switched to the New Jersey State LiDAR, as mentioned in **Chapter 2.3** above. Next, a routing reach from the C-upper basin to the C outlet was removed. This resulted in a more conservative timing of the outflow hydrographs, which was requested by the New York District. The lag times of the A and C-Lower basins were also adjusted to complete the hydrologic analysis with more reasonable results.

Once the outflow hydrographs were agreed upon between MVS and NAN hydraulic engineers, the entire set of interior and exterior conditions was analyzed and reviewed by NAN and an external contractor, AECOM. During the review, the peak stages for the 2-year rainfall event with normal tide conditions for Basin A were found to be higher than the exterior tidal levels for the 2-year coastal event. This is an indication of a "Minimum Facility" condition that is not acceptable for normal, non-coastal storm drainage control. Therefore, additional outlet pipes (Two 4-foot square concrete box culverts) were added to the project, to become part of the new Minimum Facility.

Table B4-1: Highlands Coastal Storm Frequency from NACCS

Coastal Storm Frequency	Coastal Storm Return Period	Present or Future Condition	Peak Elevation (Feet, NAVD 88)
Normal Tide	N/A	Present (2021)	2.35
50% AEP*	2-year	Present	5.6
20% AEP	5-year	Present	6.7
10% AEP	10-year	Present	7.5
4% AEP	25-year	Present	8.8
2% AEP	50-year	Present	9.7
Normal Tide	N/A	Future (2071)	3.05
50% AEP	2-year	Future	6.3
20% AEP	5-year	Future	7.4
10% AEP	10-year	Future	8.2
4% AEP	25-year	Future	9.5
2% AEP	50-year	Future	10.4

**AEP = Annual Exceedance Probability (%)*

Table B4-2: Highlands Interior Precipitation Frequency from NOAA Atlas 14

Precipitation Probability	Precipitation Frequency	Precipitation (inches)								
		5 min	15 min	1 hour	2 hrs	3 hrs	6 hrs	12 hrs	1 day	2 days
50% AEP	2-year	0.41	0.82	1.42	1.76	1.94	2.47	3.00	3.33	3.98
20% AEP	5-year	0.48	0.98	1.77	2.22	2.46	3.11	3.80	4.28	5.10
10% AEP	10-year	0.54	1.09	2.05	2.58	2.87	3.62	4.46	5.10	6.06
4% AEP	25-year	0.61	1.23	2.41	3.08	3.43	4.36	5.43	6.34	7.48
2% AEP	50-year	0.66	1.33	2.69	3.48	3.90	4.97	6.26	7.41	8.71
1% AEP	100-year	0.71	1.43	2.99	3.90	4.38	5.63	7.16	8.61	10.07
0.5% AEP	200-year	0.76	1.51	3.28	4.34	4.89	6.32	8.14	9.95	11.57
0.2% AEP	500-year	0.82	1.63	3.69	4.96	5.61	7.32	9.57	11.9	13.83

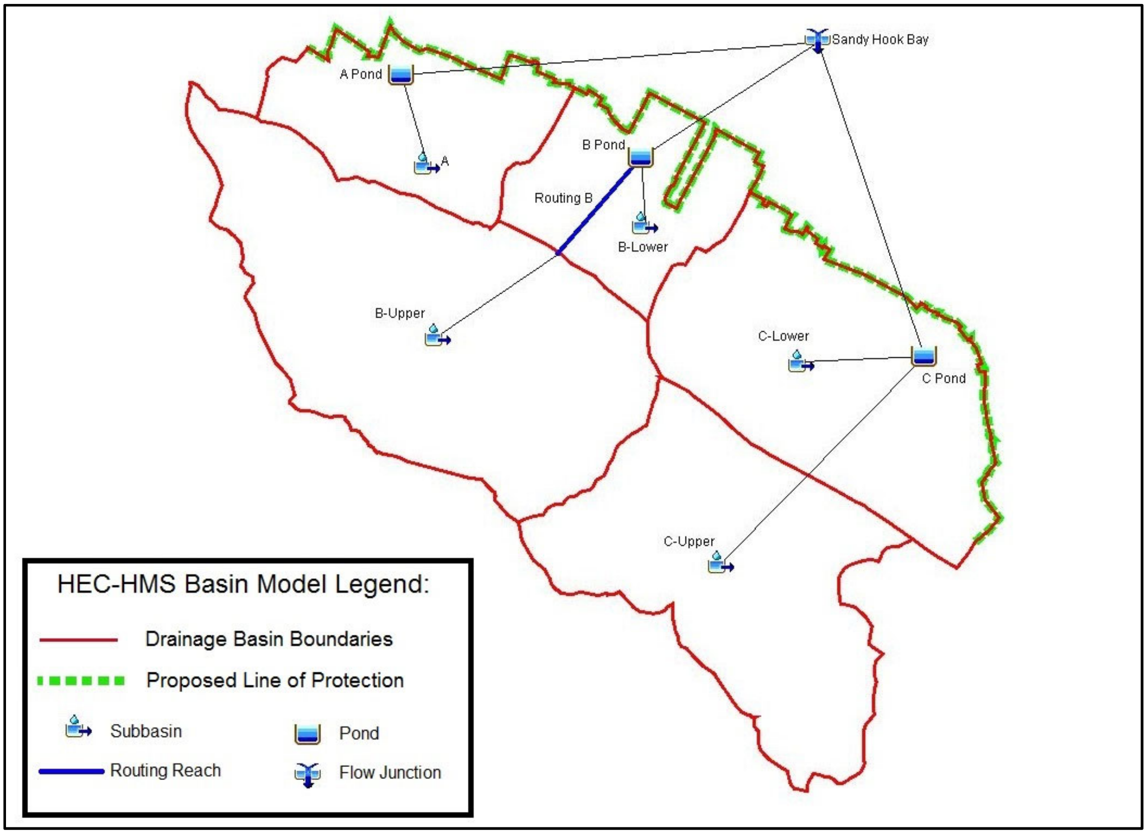

Figure B4-2: HEC-HMS Basin Model Schematic (Minimum Facility)

Table B4-3: Hydrologic Parameters for Highlands Subbasins

Subbasin Name	Drainage Area (square miles)	NRCS Curve # (CN)	NRCS Lag Time (min)
A	0.083	84	14.6*
B-Lower	0.077	85	6.3
B-Upper	0.238	74	5.6
C-Lower	0.164	84	36.2*
C-Upper	0.173	63	13.4

(*) Note: Lag Times were adjusted from original HEC-1 analysis based on preliminary results

3.3 Final Results for Minimum Facility Analysis

After all of the necessary adjustments were made to the HEC-HMS model, the final Minimum Facility Results were tabulated and reviewed by the NAN District and AECOM. The economic analysis determined residual damages for each drainage basin based on the combinations stated above, precipitation values ranging from 50% to 0.2% Annual Exceedance Probability (AEP), and coastal storm frequencies from normal tide to 2% AEP. The resulting

Minimum Facility for Drainage Area "A" was one existing outfall, and two proposed outfalls; for Drainage Area "B" was four existing outfalls; and for Drainage Area "C" was six existing outfalls. All Minimum Facility results can be found at the end of this Appendix, in Table B4-6, Table B4-7, and Table B4-8.

Chapter 4: Alternatives Analysis

4.1 Formulation of Alternatives

The initial alternatives were adapted from the 2007 analysis. The goal of each alternative was to reduce the residual damages enough to justify the cost of the measure. The following is a list of measures that were considered:

- Pump Stations
- Additional drainage outlet pipes
- Detention Storage ponds
- Pressurized diversion pipes
- Combinations of the above measures

Initially, the exact same alternatives from 2007 were analyzed with the new HEC-HMS model. Based on the effectiveness of the results, some alternatives were modified and some were discarded. The result of those revisions are described in the following sections.

4.2 Initial Analysis and Adjustments

After the initial alternatives were developed, the HEC-HMS hydrologic model was used to determine the peak interior ponding elevations for the revised conditions. The first significant damage elevation for each basin area (provided by Economics personnel) was used as a guide for how effective the alternative would be at reducing residual damages. Basin A has a first significant damage elevation of +5.45 feet (NAVD 88). Basins B and C have a first significant damage elevation of +3.95 feet (NAVD 88).

The sizes for pumps and detention ponds were adjusted until the results were more effective. The pump on and off elevations were also adjusted for optimum results. The revised interior drainage alternatives are listed below in Table B4-4.

4.3 Selected Interior Drainage Description

For the purpose of interior drainage, the study area was divided into three basins: A, B, and C, and up to two alternatives were identified per basin (Figure B4-3, Figure B4-4 and Table B4-4) a final selected interior drainage alternatives are described below.

Table B4-4: List and Descriptions for Final Interior Drainage Alternatives

Alt. #	Feature:	Description
1A	Pump Station	Single Pump, capacity of 160 cubic feet per second (cfs)
2A	Detention Pond	Detention pond with 8 acre-foot volume capacity; average area of 1.6 acres, average depth of 5 feet.
1B	Pump Station	600 cfs capacity Pump Station; one pump at 450 cfs capacity, and one pump at 150 cfs capacity
2B	Pressurized Diversion Pipe	Upper-B Basin diversion into pressurized pipe; Two 5'x5' concrete box culverts, 1,600 feet long.
1C	Pump Station	300 cfs capacity Pump Station; one pump at 250 cfs capacity, and one pump at 50 cfs capacity
2C	Pump Station with Additional Gravity Outlets	150 cfs capacity Pump Station; one pump at 100 cfs, one pump at 50 cfs, plus 4 extra outlets @ 36" RCP

1. Interior Drainage Basin A : Detention pond with 8 acre-foot volume capacity within an approximate area of 1.6 acres with a connecting outfall in the Bay Parking Lot, northeast of the corner of Shore Drive and Willow Street. The top of the ponding area is elevation +7 ft NAVD88 and the bottom is elevation 0 ft NAVD88, with an average depth of five feet.

2. Interior Drainage Basin B : Upper-B Basin diversion into pressurized pipe: From the intersection of Waterwich Avenue and South Linden Street, the new pressurized line will consist of two five feet by five feet box culverts spanning a distance of 1600 lf in place of the existing drainage ditch along Snug Harbor Avenue to the bay. The culverts will be covered and access will be provided through sealed manholes at selected locations. This configuration was chosen to leverage existing infrastructure and to divert drainage from Upper B Basin before it reaches lower B Basin.

3. Interior Drainage Basin C: Basin C has a drainage area of 0.34 square miles, and significant damages from interior flooding begins when surface water elevations reach +3.9 ft NAVD88. The Basin C selected alternative is 300 cfs capacity Pump Station; one pump at 250 cfs capacity, and one pump at 50 cfs capacity. The pump station is located on North Street next to the project alignment.

4.4 Final Results for Alternative Analysis

After all of the potential interior drainage alternatives were adjusted, the Alternative Results were tabulated and sent for review by the NAN District and AECOM. The economic analysis determined residual damages for each drainage basin for all alternatives, for the 50% to 0.2% AEP precipitation events, combined with coastal storm frequencies from normal tide to 2% AEP. All of the alternative analysis results can be found at the end of this Appendix, in Table B4-9, Table B4-10, and Table B4-11.

Chapter 5: Data Output for Economic Analysis

The final results of the Minimum Facility Analysis and the Alternatives Analysis were compiled for economic computation using the HEC-FDA (Flood Damage Analysis) program. The peak water surface levels (for each combination of interior and exterior stage frequencies) were computed for the present and future conditions, and the entire list of interior water levels for Basin A, B, and C were tabulated. Based on the pre-defined Damage-Elevation relationships, the residual damages were compared for each alternative versus the residual damages from the minimum facility analysis.

Chapter 6: Summary and Recommendations

Upon the completion of the economic analysis, the interior drainage features with the maximum net benefits were selected for each basin. Table B4-5 below shows the computed Annual Net Benefits for each Interior Drainage Feature, and indicates the final alternative that was selected for each basin.

After the optimization of the Highlands Coastal Storm Risk Management plan, additional details will be required for the Plans and Specifications stage of the project. For Basin A, the outlet for the Detention Pond will either be an extension of the existing drainage outlet for Basin A, or a new outlet specifically built for the Detention Pond. The cost estimate includes the new outlet, but site layout conditions will determine the best method for draining the pond. The final project alternative for Basin A should consider a tide gate structure for efficient operation of the project, and to prevent the detention basin from being flooded during coastal storm events.

For the Basin B Pressurized Diversion Pipe, a small section of above-ground ditching may be required to supplement the capacity of the pressurized pipe in case an extreme rainfall event causes a surcharge condition in the pipe. The analysis for the Basin B pressurized pipe made the assumption that all upland drainage can be diverted through the pressurized pipe. This was accomplished in the HEC-HMS model by connecting the Subbasin B-Upper outflow directly to the basin outlet downstream. The slope of the pipe was found to be sufficient to maintain gravity flow during the design coastal storm events. The size of the proposed box culverts was determined from the peak flow from Subbasin B-Upper.

The Pump Station alternative for Basin C will only need a minor investigation to ensure that a large enough "wet well" is placed into the final Plans for this project feature. The wet well is necessary to prevent the pump station from cycling on and off too frequently, which would lead to excess wear and tear on the equipment. It is also important to note that the final configuration of pumps could be modified for additional flexibility for operations. For example, instead of two pumps (at 250 cfs and 50 cfs), another suitable alternative would be three pumps equaling 300 cfs in capacity, so that 2/3 capacity would be maintained even if one pump was out of order. However, the current economic calculations were based on the two pumps indicated in Table B4-4. Any modification to final pump configuration would also have to be modeled to ensure that all design goals are still met.

Table B4-5: Final Selection of Interior Drainage Alternatives

Alternative #	Description:	Annual Net Benefits	Alternative Selected
1A	Pump Station	-$226,904	No
2A	Detention Pond	$58,160	Yes
1B	Pump Station	$260,022	No
2B	Pressurized Diversion Pipe	$769,382	Yes
1C	Pump Station	$2,721,735	Yes
2C	Pump Station with Additional Gravity Outlets	$2,487,347	No

A map of the final selected alternatives for interior drainage is shown below in Figure B4-3 and Figure B4-4.

Figure B4-3: Interior Drainage Measures Proposed Alternatives

Figure B4-4: Interior Drainage Measures Selected Alternatives

Chapter 7: References

- Engineering Manual 1110-2-1413, "Hydrologic Analysis of Interior Areas", USACE-HQ, January 1987.
- Engineering Manual 1110-2-1415, "Hydrologic Frequency Analysis", USACE-HQ, March 1993.
- Engineering Regulation 1105-2-101, "Risk Analysis for Flood Damage Reduction Studies", USACE-HQ, January 2006.
- HEC-HMS 4.1 User's Manual, USACE Hydrologic Engineering Center, July 2015.
- "Interior Flooding Minimum Facility Analysis, Borough of Highlands, Combined Erosion Control and Storm Damage Reduction Study", USACE New York District, August 2007.
- NOAA Atlas 14, Volume 2, Precipitation Frequency Atlas of the United States, National Oceanic and Atmospheric Administration, October 2006.
- "North Atlantic Coast Comprehensive Study Report", USACE North Atlantic Division, 2015.

Chapter 8: Additional Tables and Figures

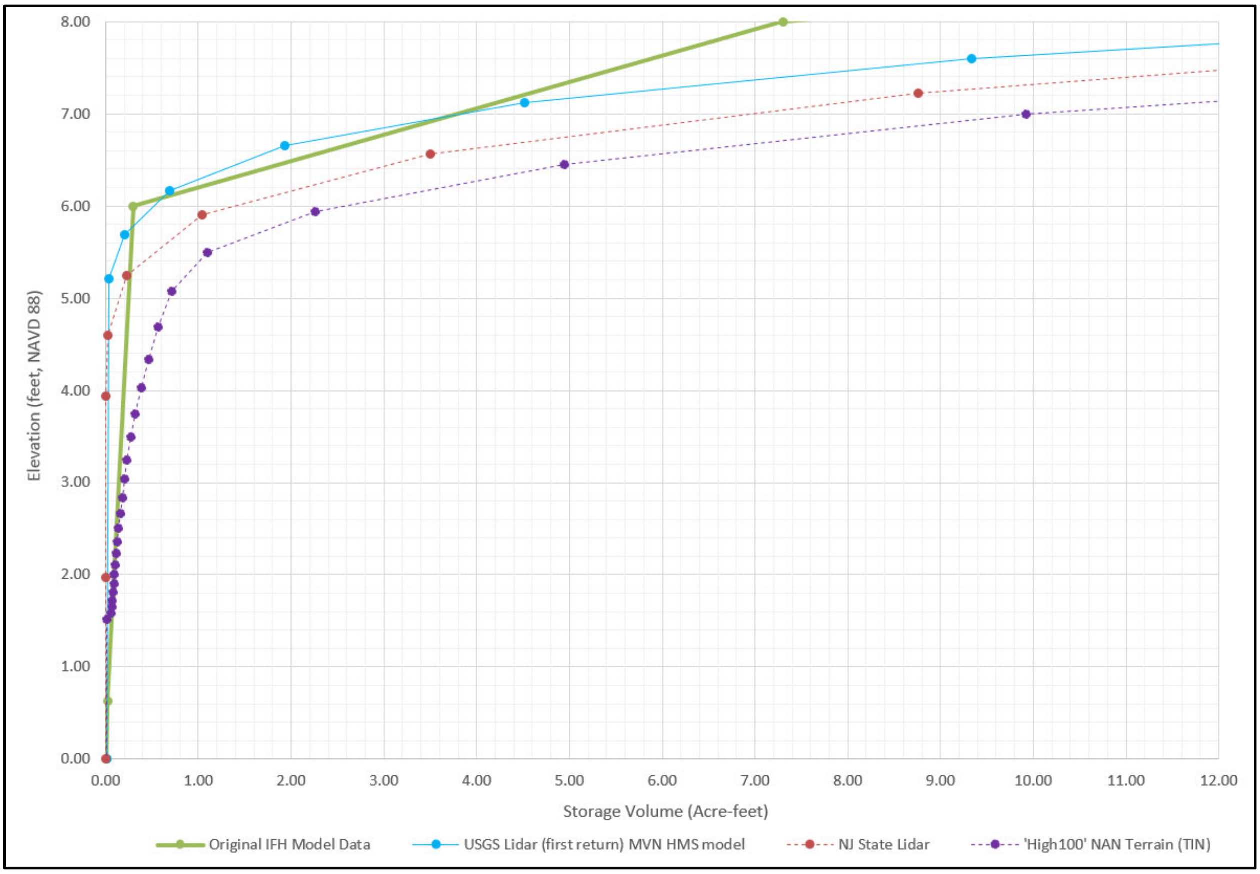

Figure B4-5: "Pond A" Elevation-Storage Curve Comparison

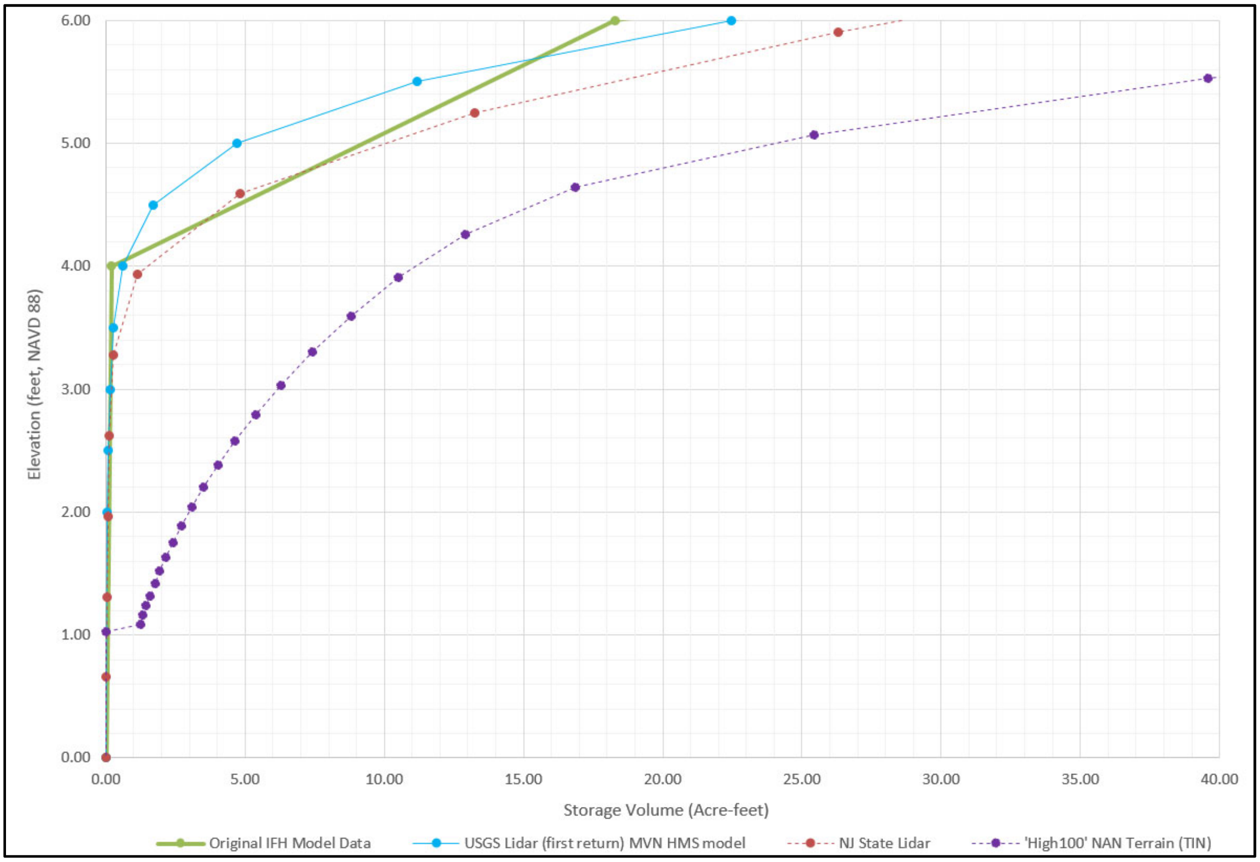

Figure B4-6: "Pond B" Elevation-Storage Curve Comparison

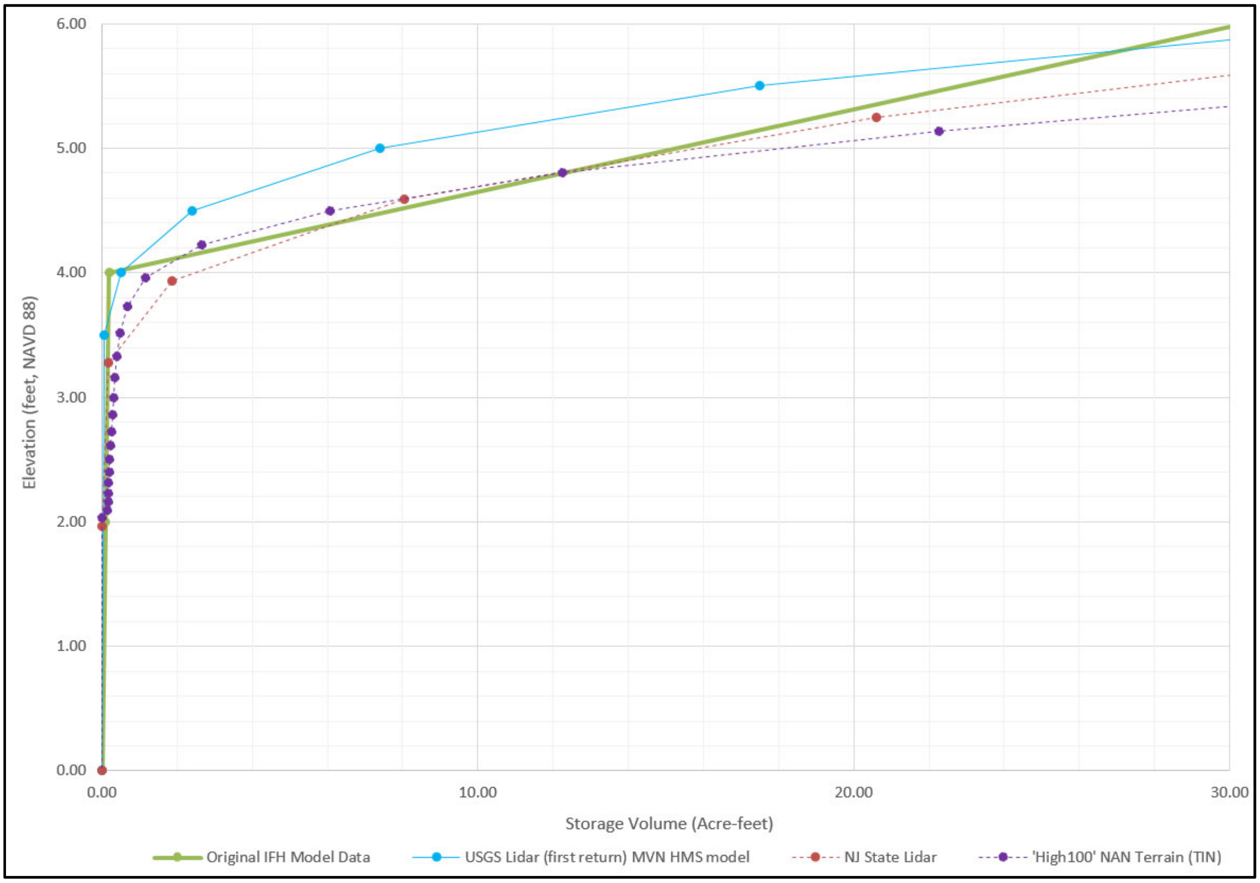

Figure B4-7: “Pond C” Elevation-Storage Curve Comparison

Table B4-6: Minimum Facility Analysis – Peak Water Surface for Pond A

Interior WSEL for Highlands "A" Storage Pond (in feet NAVD 88) - using NJ State LiDAR *(*See Note Below*)*											
Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Max Interior WSEL	Risk
2 yr	Normal	Present	2.6	2.35						2.6	Low
5 yr	Normal	Present	2.8	2.35						2.8	Low
10 yr	Normal	Present	3.0	2.35						3.0	Low
25 yr	Normal	Present	3.4	2.35						3.4	Low
50 yr	Normal	Present	3.8	2.35						3.8	Low
100 yr	Normal	Present	4.1	2.35						4.1	Low
200 yr	Normal	Present	4.4	2.35						4.4	Low
500 yr	Normal	Present	4.8	2.35						4.8	Low
2 yr	2 yr	Present	5.7	5.60	2 yr	2 yr	Present	5.7	5.60	5.7	Likely
5 yr	2 yr	Present	5.8	5.60	2 yr	5 yr	Present	6.7	6.70	6.7	Likely
10 yr	2 yr	Present	5.9	5.60	2 yr	10 yr	Present	6.9	7.50	6.9	Likely
25 yr	2 yr	Present	6.0	5.60	2 yr	25 yr	Present	7.0	8.80	7.0	Likely
50 yr	2 yr	Present	6.1	5.60	2 yr	50 yr	Present	7.1	9.70	7.1	Likely
100 yr	2 yr	Present	6.2	5.60						6.2	Likely
200 yr	2 yr	Present	6.3	5.60						6.3	Likely
500 yr	2 yr	Present	6.4	5.60						6.4	Likely
2 yr	10 yr	Present	6.9	7.50	2 yr	2 yr	Present	5.7	5.60	6.9	High
5 yr	10 yr	Present	7.2	7.50	10 yr	5 yr	Present	6.8	6.70	7.2	High
10 yr	10 yr	Present	7.3	7.50	10 yr	10 yr	Present	7.3	7.50	7.3	High
25 yr	10 yr	Present	7.5	7.50	10 yr	25 yr	Present	7.5	8.80	7.5	High
50 yr	10 yr	Present	7.5	7.50	10 yr	50 yr	Present	7.6	9.70	7.6	High
100 yr	10 yr	Present	7.6	7.50						7.6	High
200 yr	10 yr	Present	7.6	7.50						7.6	High
500 yr	10 yr	Present	7.7	7.50						7.7	High
2 yr	Normal	Future	3.2	3.05						3.2	Low
5 yr	Normal	Future	3.3	3.05						3.3	Low
10 yr	Normal	Future	3.5	3.05						3.5	Low
25 yr	Normal	Future	3.7	3.05						3.7	Low
50 yr	Normal	Future	3.9	3.05						3.9	Low
100 yr	Normal	Future	4.2	3.05						4.2	Low
200 yr	Normal	Future	4.5	3.05						4.5	Low
500 yr	Normal	Future	4.9	3.05						4.9	Low
2 yr	2 yr	Future	6.3	6.30	2 yr	2 yr	Future	6.3	6.30	6.3	Likely
5 yr	2 yr	Future	6.4	6.30	2 yr	5 yr	Future	6.9	7.40	6.9	Likely
10 yr	2 yr	Future	6.5	6.30	2 yr	10 yr	Future	7.0	8.20	7.0	Likely
25 yr	2 yr	Future	6.6	6.30	2 yr	25 yr	Future	7.1	9.50	7.1	Likely
50 yr	2 yr	Future	6.6	6.30	2 yr	50 yr	Future	7.1	10.40	7.1	Likely
100 yr	2 yr	Future	6.7	6.30						6.7	Likely
200 yr	2 yr	Future	6.8	6.30						6.8	Likely
500 yr	2 yr	Future	6.9	6.30						6.9	Likely
2 yr	10 yr	Future	7.0	8.20	2 yr	2 yr	Future	6.3	6.30	7.0	High
5 yr	10 yr	Future	7.3	8.20	10 yr	5 yr	Future	7.3	7.40	7.3	High
10 yr	10 yr	Future	7.5	8.20	10 yr	10 yr	Future	7.5	8.20	7.5	High
25 yr	10 yr	Future	7.7	8.20	10 yr	25 yr	Future	7.5	9.50	7.7	High
50 yr	10 yr	Future	7.9	8.20	10 yr	50 yr	Future	7.6	10.40	7.9	High
100 yr	10 yr	Future	8.0	8.20						8.0	High
200 yr	10 yr	Future	8.1	8.20						8.1	High
500 yr	10 yr	Future	8.2	8.20						8.2	High

Note*: Minimum Facility for Basin A includes 2 additional concrete box culvert outlets, 4'x4';

These are required to reduce 2-yr interior stage to equal exterior level.

Table B4-7: Minimum Facility Analysis – Peak Water Surface for Pond B

Interior WSEL for Highlands "B" Storage Pond (in feet NAVD 88) - using NJ State LiDAR											
Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Max Interior WSEL	Risk
2 yr	Normal	Present	4.1	2.35						4.1	Low
5 yr	Normal	Present	4.6	2.35						4.6	Low
10 yr	Normal	Present	4.8	2.35						4.8	Low
25 yr	Normal	Present	5.2	2.35						5.2	Low
50 yr	Normal	Present	5.4	2.35						5.4	Low
100 yr	Normal	Present	5.6	2.35						5.6	Low
200 yr	Normal	Present	5.9	2.35						5.9	Low
500 yr	Normal	Present	6.2	2.35						6.2	Low
2 yr	2 yr	Present	5.4	5.60	2 yr	2 yr	Present	5.4	5.60	5.4	Likely
5 yr	2 yr	Present	5.7	5.60	2 yr	5 yr	Present	5.6	6.70	5.7	Likely
10 yr	2 yr	Present	5.9	5.60	2 yr	10 yr	Present	5.6	7.50	5.9	Likely
25 yr	2 yr	Present	6.1	5.60	2 yr	25 yr	Present	5.7	8.80	6.1	Likely
50 yr	2 yr	Present	6.4	5.60	2 yr	50 yr	Present	5.7	9.70	6.4	Likely
100 yr	2 yr	Present	6.6	5.60						6.6	Likely
200 yr	2 yr	Present	6.9	5.60						6.9	Likely
500 yr	2 yr	Present	7.2	5.60						7.2	Likely
2 yr	10 yr	Present	5.6	7.50	2 yr	2 yr	Present	5.4	5.60	5.6	High
5 yr	10 yr	Present	6.1	7.50	10 yr	5 yr	Present	6.3	6.70	6.3	High
10 yr	10 yr	Present	6.4	7.50	10 yr	10 yr	Present	6.4	7.50	6.4	High
25 yr	10 yr	Present	6.9	7.50	10 yr	25 yr	Present	6.6	8.80	6.9	High
50 yr	10 yr	Present	7.2	7.50	10 yr	50 yr	Present	6.6	9.70	7.2	High
100 yr	10 yr	Present	7.5	7.50						7.5	High
200 yr	10 yr	Present	7.7	7.50						7.7	High
500 yr	10 yr	Present	8.1	7.50						8.1	High
2 yr	Normal	Future	4.3	3.05						4.3	Low
5 yr	Normal	Future	4.7	3.05						4.7	Low
10 yr	Normal	Future	4.9	3.05						4.9	Low
25 yr	Normal	Future	5.3	3.05						5.3	Low
50 yr	Normal	Future	5.5	3.05						5.5	Low
100 yr	Normal	Future	5.7	3.05						5.7	Low
200 yr	Normal	Future	5.9	3.05						5.9	Low
500 yr	Normal	Future	6.3	3.05						6.3	Low
2 yr	2 yr	Future	5.5	6.30	2 yr	2 yr	Future	5.5	6.30	5.5	Likely
5 yr	2 yr	Future	5.9	6.30	2 yr	5 yr	Future	5.6	7.40	5.9	Likely
10 yr	2 yr	Future	6.2	6.30	2 yr	10 yr	Future	5.7	8.20	6.2	Likely
25 yr	2 yr	Future	6.5	6.30	2 yr	25 yr	Future	5.7	9.50	6.5	Likely
50 yr	2 yr	Future	6.7	6.30	2 yr	50 yr	Future	5.7	10.40	6.7	Likely
100 yr	2 yr	Future	6.9	6.30						6.9	Likely
200 yr	2 yr	Future	7.2	6.30						7.2	Likely
500 yr	2 yr	Future	7.6	6.30						7.6	Likely
2 yr	10 yr	Future	5.7	8.20	2 yr	2 yr	Future	5.5	6.30	5.7	High
5 yr	10 yr	Future	6.1	8.20	10 yr	5 yr	Future	6.4	7.40	6.4	High
10 yr	10 yr	Future	6.5	8.20	10 yr	10 yr	Future	6.5	8.20	6.5	High
25 yr	10 yr	Future	7.0	8.20	10 yr	25 yr	Future	6.6	9.50	7.0	High
50 yr	10 yr	Future	7.3	8.20	10 yr	50 yr	Future	6.6	10.40	7.3	High
100 yr	10 yr	Future	7.7	8.20						7.7	High
200 yr	10 yr	Future	8.0	8.20						8.0	High
500 yr	10 yr	Future	8.4	8.20						8.4	High

Table B4-8: Minimum Facility Analysis – Peak Water Surface for Pond C

Interior WSEL for Highlands "C" Storage Pond (in feet NAVD 88) - using NJ State LiDAR											
Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Max Interior WSEL	Risk
2 yr	Normal	Present	4.2	2.35						4.2	Low
5 yr	Normal	Present	4.7	2.35						4.7	Low
10 yr	Normal	Present	4.9	2.35						4.9	Low
25 yr	Normal	Present	5.3	2.35						5.3	Low
50 yr	Normal	Present	5.6	2.35						5.6	Low
100 yr	Normal	Present	5.8	2.35						5.8	Low
200 yr	Normal	Present	6.1	2.35						6.1	Low
500 yr	Normal	Present	6.5	2.35						6.5	Low
2 yr	2 yr	Present	5.0	5.60	2 yr	2 yr	Present	5.0	5.60	5.0	Likely
5 yr	2 yr	Present	5.4	5.60	2 yr	5 yr	Present	5.1	6.70	5.4	Likely
10 yr	2 yr	Present	5.6	5.60	2 yr	10 yr	Present	5.2	7.50	5.6	Likely
25 yr	2 yr	Present	6.0	5.60	2 yr	25 yr	Present	5.3	8.80	6.0	Likely
50 yr	2 yr	Present	6.3	5.60	2 yr	50 yr	Present	5.3	9.70	6.3	Likely
100 yr	2 yr	Present	6.6	5.60						6.6	Likely
200 yr	2 yr	Present	6.8	5.60						6.8	Likely
500 yr	2 yr	Present	7.3	5.60						7.3	Likely
2 yr	10 yr	Present	5.2	7.50	2 yr	2 yr	Present	5.0	5.60	5.2	High
5 yr	10 yr	Present	5.6	7.50	10 yr	5 yr	Present	5.8	6.70	5.8	High
10 yr	10 yr	Present	5.9	7.50	10 yr	10 yr	Present	5.9	7.50	5.9	High
25 yr	10 yr	Present	6.3	7.50	10 yr	25 yr	Present	5.9	8.80	6.3	High
50 yr	10 yr	Present	6.6	7.50	10 yr	50 yr	Present	6.0	9.70	6.6	High
100 yr	10 yr	Present	6.9	7.50						6.9	High
200 yr	10 yr	Present	7.2	7.50						7.2	High
500 yr	10 yr	Present	7.6	7.50						7.6	High
2 yr	Normal	Future	4.4	3.05						4.4	Low
5 yr	Normal	Future	4.8	3.05						4.8	Low
10 yr	Normal	Future	5.0	3.05						5.0	Low
25 yr	Normal	Future	5.4	3.05						5.4	Low
50 yr	Normal	Future	5.6	3.05						5.6	Low
100 yr	Normal	Future	5.9	3.05						5.9	Low
200 yr	Normal	Future	6.2	3.05						6.2	Low
500 yr	Normal	Future	6.6	3.05						6.6	Low
2 yr	2 yr	Future	5.1	6.30	2 yr	2 yr	Future	5.1	6.30	5.1	Likely
5 yr	2 yr	Future	5.5	6.30	2 yr	5 yr	Future	5.2	7.40	5.5	Likely
10 yr	2 yr	Future	5.8	6.30	2 yr	10 yr	Future	5.2	8.20	5.8	Likely
25 yr	2 yr	Future	6.1	6.30	2 yr	25 yr	Future	5.3	9.50	6.1	Likely
50 yr	2 yr	Future	6.4	6.30	2 yr	50 yr	Future	5.3	10.40	6.4	Likely
100 yr	2 yr	Future	6.7	6.30						6.7	Likely
200 yr	2 yr	Future	7.0	6.30						7.0	Likely
500 yr	2 yr	Future	7.4	6.30						7.4	Likely
2 yr	10 yr	Future	5.2	8.20	2 yr	2 yr	Future	5.1	6.30	5.2	High
5 yr	10 yr	Future	5.6	8.20	10 yr	5 yr	Future	5.9	7.40	5.9	High
10 yr	10 yr	Future	5.9	8.20	10 yr	10 yr	Future	5.9	8.20	5.9	High
25 yr	10 yr	Future	6.3	8.20	10 yr	25 yr	Future	6.0	9.50	6.3	High
50 yr	10 yr	Future	6.7	8.20	10 yr	50 yr	Future	6.0	10.40	6.7	High
100 yr	10 yr	Future	7.0	8.20						7.0	High
200 yr	10 yr	Future	7.3	8.20						7.3	High
500 yr	10 yr	Future	7.8	8.20						7.8	High

Table B4-9: Alternatives Analysis – Peak Water Surface for Pond A (with Detention Pond)

Interior WSEL for Highlands "A" Basin (all elevations are in feet NAVD 88)												
Alternative #2 for Basin A -- "Ponding Area" -- 8 Acre-foot ponding area (no pumping or additional outlets)												
Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Max Interior WSEL	First Damage Elevation	Risk
2 yr	Normal	Present	2.4	2.35						2.4	5.45	Low
5 yr	Normal	Present	2.5	2.35						2.5	5.45	Low
10 yr	Normal	Present	2.7	2.35						2.7	5.45	Low
25 yr	Normal	Present	3.0	2.35						3.0	5.45	Low
50 yr	Normal	Present	3.1	2.35						3.1	5.45	Low
100 yr	Normal	Present	3.4	2.35						3.4	5.45	Low
200 yr	Normal	Present	3.6	2.35						3.6	5.45	Low
500 yr	Normal	Present	3.9	2.35						3.9	5.45	Low
2 yr	2 yr	Present	3.6	5.60	2 yr	2 yr	Present	3.6	5.60	3.6	5.45	Likely
5 yr	2 yr	Present	5.6	5.60	2 yr	5 yr	Present	3.8	6.70	5.6	5.45	Likely
10 yr	2 yr	Present	5.7	5.60	2 yr	10 yr	Present	3.9	7.50	5.7	5.45	Likely
25 yr	2 yr	Present	5.9	5.60	2 yr	25 yr	Present	4.7	8.80	5.9	5.45	Likely
50 yr	2 yr	Present	6.0	5.60	2 yr	50 yr	Present	5.0	9.70	6.0	5.45	Likely
100 yr	2 yr	Present	6.1	5.60						6.1	5.45	Likely
200 yr	2 yr	Present	6.2	5.60						6.2	5.45	Likely
500 yr	2 yr	Present	6.4	5.60						6.4	5.45	Likely
2 yr	10 yr	Present	3.9	7.50	2 yr	2 yr	Present	3.6	5.60	3.9	5.45	High
5 yr	10 yr	Present	6.3	7.50	10 yr	5 yr	Present	6.6	6.70	6.6	5.45	High
10 yr	10 yr	Present	6.7	7.50	10 yr	10 yr	Present	6.7	7.50	6.7	5.45	High
25 yr	10 yr	Present	7.1	7.50	10 yr	25 yr	Present	6.8	8.80	7.1	5.45	High
50 yr	10 yr	Present	7.4	7.50	10 yr	50 yr	Present	6.9	9.70	7.4	5.45	High
100 yr	10 yr	Present	7.5	7.50						7.5	5.45	High
200 yr	10 yr	Present	7.6	7.50						7.6	5.45	High
500 yr	10 yr	Present	7.7	7.50						7.7	5.45	High
2 yr	Normal	Future	2.9	3.05						2.9	5.45	Low
5 yr	Normal	Future	3.1	3.05						3.1	5.45	Low
10 yr	Normal	Future	3.3	3.05						3.3	5.45	Low
25 yr	Normal	Future	3.5	3.05						3.5	5.45	Low
50 yr	Normal	Future	3.7	3.05						3.7	5.45	Low
100 yr	Normal	Future	3.8	3.05						3.8	5.45	Low
200 yr	Normal	Future	4.3	3.05						4.3	5.45	Low
500 yr	Normal	Future	4.8	3.05						4.8	5.45	Low
2 yr	2 yr	Future	3.8	6.30	2 yr	2 yr	Future	3.8	6.30	3.8	5.45	Likely
5 yr	2 yr	Future	6.0	6.30	2 yr	5 yr	Future	3.9	7.40	6.0	5.45	Likely
10 yr	2 yr	Future	6.3	6.30	2 yr	10 yr	Future	4.4	8.20	6.3	5.45	Likely
25 yr	2 yr	Future	6.4	6.30	2 yr	25 yr	Future	5.0	9.50	6.4	5.45	Likely
50 yr	2 yr	Future	6.6	6.30	2 yr	50 yr	Future	5.3	10.40	6.6	5.45	Likely
100 yr	2 yr	Future	6.7	6.30						6.7	5.45	Likely
200 yr	2 yr	Future	6.8	6.30						6.8	5.45	Likely
500 yr	2 yr	Future	6.9	6.30						6.9	5.45	Likely
2 yr	10 yr	Future	4.4	8.20	2 yr	2 yr	Future	3.8	6.30	4.4	5.45	High
5 yr	10 yr	Future	6.4	8.20	10 yr	5 yr	Future	6.7	7.40	6.7	5.45	High
10 yr	10 yr	Future	6.8	8.20	10 yr	10 yr	Future	6.8	8.20	6.8	5.45	High
25 yr	10 yr	Future	7.3	8.20	10 yr	25 yr	Future	6.9	9.50	7.3	5.45	High
50 yr	10 yr	Future	7.5	8.20	10 yr	50 yr	Future	6.9	10.40	7.5	5.45	High
100 yr	10 yr	Future	7.8	8.20						7.8	5.45	High
200 yr	10 yr	Future	8.0	8.20						8.0	5.45	High
500 yr	10 yr	Future	8.2	8.20						8.2	5.45	High

Table B4-10: Alternatives Analysis – Peak Water Surface for Pond B (with Diversion Pipe)

Interior WSEL for Highlands "B" Basin (all elevations are in feet NAVD 88)												
Alternative #2 for Basin B -- "Upper Diversion" -- Diversion of entire Upper Basin into pressurized pipe												
Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Max Interior WSEL	First Damage Elevation	Risk
2 yr	Normal	Present	2.8	2.35						2.8	3.95	Low
5 yr	Normal	Present	3.2	2.35						3.2	3.95	Low
10 yr	Normal	Present	3.4	2.35						3.4	3.95	Low
25 yr	Normal	Present	3.6	2.35						3.6	3.95	Low
50 yr	Normal	Present	3.8	2.35						3.8	3.95	Low
100 yr	Normal	Present	4.0	2.35						4.0	3.95	Low
200 yr	Normal	Present	4.0	2.35						4.0	3.95	Low
500 yr	Normal	Present	4.1	2.35						4.1	3.95	Low
2 yr	2 yr	Present	4.7	5.60	2 yr	2 yr	Present	4.7	5.60	4.7	3.95	Likely
5 yr	2 yr	Present	4.9	5.60	2 yr	5 yr	Present	4.8	6.70	4.9	3.95	Likely
10 yr	2 yr	Present	5.1	5.60	2 yr	10 yr	Present	4.8	7.50	5.1	3.95	Likely
25 yr	2 yr	Present	5.3	5.60	2 yr	25 yr	Present	4.8	8.80	5.3	3.95	Likely
50 yr	2 yr	Present	5.4	5.60	2 yr	50 yr	Present	4.8	9.70	5.4	3.95	Likely
100 yr	2 yr	Present	5.5	5.60						5.5	3.95	Likely
200 yr	2 yr	Present	5.6	5.60						5.6	3.95	Likely
500 yr	2 yr	Present	5.6	5.60						5.6	3.95	Likely
2 yr	10 yr	Present	4.8	7.50	2 yr	2 yr	Present	4.7	5.60	4.8	3.95	High
5 yr	10 yr	Present	5.0	7.50	10 yr	5 yr	Present	5.2	6.70	5.2	3.95	High
10 yr	10 yr	Present	5.2	7.50	10 yr	10 yr	Present	5.2	7.50	5.2	3.95	High
25 yr	10 yr	Present	5.4	7.50	10 yr	25 yr	Present	5.3	8.80	5.4	3.95	High
50 yr	10 yr	Present	5.5	7.50	10 yr	50 yr	Present	5.3	9.70	5.5	3.95	High
100 yr	10 yr	Present	5.7	7.50						5.7	3.95	High
200 yr	10 yr	Present	5.8	7.50						5.8	3.95	High
500 yr	10 yr	Present	6.0	7.50						6.0	3.95	High
2 yr	Normal	Future	3.4	3.05						3.4	3.95	Low
5 yr	Normal	Future	3.6	3.05						3.6	3.95	Low
10 yr	Normal	Future	3.8	3.05						3.8	3.95	Low
25 yr	Normal	Future	4.0	3.05						4.0	3.95	Low
50 yr	Normal	Future	4.0	3.05						4.0	3.95	Low
100 yr	Normal	Future	4.1	3.05						4.1	3.95	Low
200 yr	Normal	Future	4.2	3.05						4.2	3.95	Low
500 yr	Normal	Future	4.3	3.05						4.3	3.95	Low
2 yr	2 yr	Future	4.8	6.30	2 yr	2 yr	Future	4.8	6.30	4.8	3.95	Likely
5 yr	2 yr	Future	5.0	6.30	2 yr	5 yr	Future	4.8	7.40	5.0	3.95	Likely
10 yr	2 yr	Future	5.1	6.30	2 yr	10 yr	Future	4.8	8.20	5.1	3.95	Likely
25 yr	2 yr	Future	5.3	6.30	2 yr	25 yr	Future	4.8	9.50	5.3	3.95	Likely
50 yr	2 yr	Future	5.5	6.30	2 yr	50 yr	Future	4.9	10.40	5.5	3.95	Likely
100 yr	2 yr	Future	5.6	6.30						5.6	3.95	Likely
200 yr	2 yr	Future	5.7	6.30						5.7	3.95	Likely
500 yr	2 yr	Future	5.9	6.30						5.9	3.95	Likely
2 yr	10 yr	Future	4.8	8.20	2 yr	2 yr	Future	4.8	6.30	4.8	3.95	High
5 yr	10 yr	Future	5.1	8.20	10 yr	5 yr	Future	5.2	7.40	5.2	3.95	High
10 yr	10 yr	Future	5.2	8.20	10 yr	10 yr	Future	5.2	8.20	5.2	3.95	High
25 yr	10 yr	Future	5.4	8.20	10 yr	25 yr	Future	5.3	9.50	5.4	3.95	High
50 yr	10 yr	Future	5.6	8.20	10 yr	50 yr	Future	5.3	10.40	5.6	3.95	High
100 yr	10 yr	Future	5.7	8.20						5.7	3.95	High
200 yr	10 yr	Future	5.9	8.20						5.9	3.95	High
500 yr	10 yr	Future	6.1	8.20						6.1	3.95	High

Table B4-11: Alternatives Analysis – Peak Water Surface for Pond C (with Pump Station)

Interior WSEL for Highlands "C" Basin (all elevations are in feet NAVD 88)												
Alternative #1 for Basin C -- "Pump Station Only" -- 300 cfs pump station (pump sizes 250 cfs and 50 cfs)												
Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Interior Flow	Exterior Stage	Time Condition	Peak Interior WSEL	Peak Exterior Stage	Max Interior WSEL	First Damage Elevation	Risk
2 yr	Normal	Present	3.7	2.35						3.7	3.95	Low
5 yr	Normal	Present	3.7	2.35						3.7	3.95	Low
10 yr	Normal	Present	3.7	2.35						3.7	3.95	Low
25 yr	Normal	Present	3.9	2.35						3.9	3.95	Low
50 yr	Normal	Present	4.0	2.35						4.0	3.95	Low
100 yr	Normal	Present	4.4	2.35						4.4	3.95	Low
200 yr	Normal	Present	4.7	2.35						4.7	3.95	Low
500 yr	Normal	Present	5.0	2.35						5.0	3.95	Low
2 yr	2 yr	Present	3.7	5.60	2 yr	2 yr	Present	3.7	5.60	3.7	3.95	Likely
5 yr	2 yr	Present	3.7	5.60	2 yr	5 yr	Present	3.7	6.70	3.7	3.95	Likely
10 yr	2 yr	Present	3.9	5.60	2 yr	10 yr	Present	3.7	7.50	3.9	3.95	Likely
25 yr	2 yr	Present	4.1	5.60	2 yr	25 yr	Present	3.7	8.80	4.1	3.95	Likely
50 yr	2 yr	Present	4.4	5.60	2 yr	50 yr	Present	3.7	9.70	4.4	3.95	Likely
100 yr	2 yr	Present	4.7	5.60						4.7	3.95	Likely
200 yr	2 yr	Present	5.0	5.60						5.0	3.95	Likely
500 yr	2 yr	Present	5.4	5.60						5.4	3.95	Likely
2 yr	10 yr	Present	3.7	7.50	2 yr	2 yr	Present	3.7	5.60	3.7	3.95	High
5 yr	10 yr	Present	3.7	7.50	10 yr	5 yr	Present	3.9	6.70	3.9	3.95	High
10 yr	10 yr	Present	3.9	7.50	10 yr	10 yr	Present	3.9	7.50	3.9	3.95	High
25 yr	10 yr	Present	4.1	7.50	10 yr	25 yr	Present	3.7	8.80	4.1	3.95	High
50 yr	10 yr	Present	4.4	7.50	10 yr	50 yr	Present	3.9	9.70	4.4	3.95	High
100 yr	10 yr	Present	4.7	7.50						4.7	3.95	High
200 yr	10 yr	Present	5.0	7.50						5.0	3.95	High
500 yr	10 yr	Present	5.4	7.50						5.4	3.95	High
2 yr	Normal	Future	3.7	3.05						3.7	3.95	Low
5 yr	Normal	Future	3.7	3.05						3.7	3.95	Low
10 yr	Normal	Future	3.7	3.05						3.7	3.95	Low
25 yr	Normal	Future	3.9	3.05						3.9	3.95	Low
50 yr	Normal	Future	4.1	3.05						4.1	3.95	Low
100 yr	Normal	Future	4.4	3.05						4.4	3.95	Low
200 yr	Normal	Future	4.7	3.05						4.7	3.95	Low
500 yr	Normal	Future	5.1	3.05						5.1	3.95	Low
2 yr	2 yr	Future	3.7	6.30	2 yr	2 yr	Future	3.7	6.30	3.7	3.95	Likely
5 yr	2 yr	Future	3.7	6.30	2 yr	5 yr	Future	3.7	7.40	3.7	3.95	Likely
10 yr	2 yr	Future	3.9	6.30	2 yr	10 yr	Future	3.7	8.20	3.9	3.95	Likely
25 yr	2 yr	Future	4.1	6.30	2 yr	25 yr	Future	3.7	9.50	4.1	3.95	Likely
50 yr	2 yr	Future	4.4	6.30	2 yr	50 yr	Future	3.7	10.40	4.4	3.95	Likely
100 yr	2 yr	Future	4.7	6.30						4.7	3.95	Likely
200 yr	2 yr	Future	5.0	6.30						5.0	3.95	Likely
500 yr	2 yr	Future	5.4	6.30						5.4	3.95	Likely
2 yr	10 yr	Future	3.7	8.20	2 yr	2 yr	Future	3.7	6.30	3.7	3.95	High
5 yr	10 yr	Future	3.7	8.20	10 yr	5 yr	Future	3.8	7.40	3.8	3.95	High
10 yr	10 yr	Future	3.9	8.20	10 yr	10 yr	Future	3.7	8.20	3.9	3.95	High
25 yr	10 yr	Future	4.1	8.20	10 yr	25 yr	Future	3.9	9.50	4.1	3.95	High
50 yr	10 yr	Future	4.4	8.20	10 yr	50 yr	Future	3.9	10.40	4.4	3.95	High
100 yr	10 yr	Future	4.7	8.20						4.7	3.95	High
200 yr	10 yr	Future	5.0	8.20						5.0	3.95	High
500 yr	10 yr	Future	5.4	8.20						5.4	3.95	High