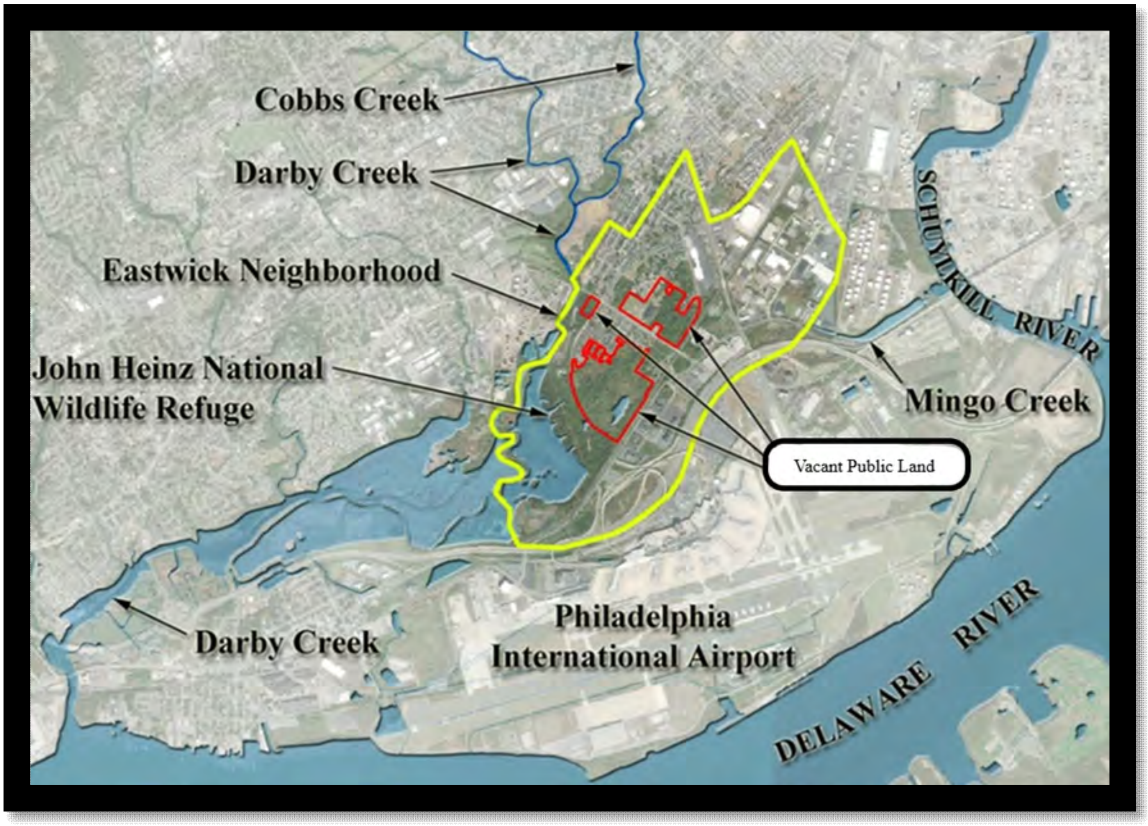
Eastwick
Hydrologic & Hydraulic Study Report



FEBRUARY 2022

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Executive Summary

This Hydrologic and Hydraulic (H&H) Study Report was prepared on behalf of the Philadelphia Redevelopment Authority (PRA) as an integral step to implementing the Lower Eastwick Public Land Strategy (LEPLS[1]). Specifically, the intent of the H&H study was to evaluate flooding in conjunction with consideration of beneficially reusing approximately 185 acres of vacant public land (See Figure 1) owned by the PRA and the School District of Philadelphia in the Eastwick neighborhood of Philadelphia, PA. This H&H Study Report was prepared under United States Environmental Protection Agency (USEPA) Hazardous Waste Grant No. BF-96368701.

Model Development

The study involved the development of an H&H model to discern the impact of possible land reuse scenarios outlined in the LEPLS with respect to flooding in Eastwick. Concurrently with H&H model development, a community engagement process was conducted (remotely via teleconference and videoconference due to the COVID-19 pandemic) to communicate the intent of the flood study, solicit input and answer questions from the community, and to share draft results. The H&H model developed for the study benefitted from collaborative discussion, and coordination with other ongoing initiatives with shared or overlapping goals as facilitated by PRA and the City of Philadelphia's floodplain manager. The formal details characterizing the assumptions, boundaries, construction, and calibration of the H&H model (Attachment A and Attachment B of this report) were completed in March 2021 and provided to industry experts conducting other flood-related evaluation work in Eastwick along with Steering Committee members for review.

AKRF's modeling approach for the study used a combination of one-dimensional (1D) and two-dimensional (2D) analytical models to generate projected water surface profiles using United States Army Corps of Engineers (USACE) Hydrologic Engineering Center's River Analysis System (HEC-RAS). The 1D model predicts the expected stream and river behavior within Darby Creek, Cobbs Creek, Schuylkill River, and the Delaware River in the vicinity of Eastwick, based on available mapping of existing conditions (e.g., topography, bathymetry), United States Geological Survey (USGS) streamflow data, National Oceanic and Atmospheric Administration (NOAA) tide data, and NOAA predicted data for climate and sea level change. The 2D portion of the model represents how surface flooding flows within and through the Eastwick community. Model development also incorporated a simplified approach to representing the stormwater drainage network within Eastwick, stormwater runoff generally within Eastwick, as well as the effects of the Mingo Creek Pumping Station.

Model Calibration

Both the 1D and 2D models were calibrated to high watermark and flow data for Tropical Storm Isaias which occurred in August 2020, after AKRF began the assignment. Calibration resulted in adjustments to the Manning's N roughness parameter in the model, which represents the surface roughness of the land surface. The higher Manning's N values used in the final calibrated model significantly improved model fit. Our analysis indicated that this value was more representative of the physical elements that flood water interacts with in Eastwick's landscape such as parked

[1] The Lower Eastwick Public Land Strategy (LEPLS) was prepared for PRA in March 2019 by Interface Studios following a two-year planning process in partnership with a Steering Committee of community residents and public-sector stakeholders. The LEPLS focused on planning for an inclusive and resilient future in Eastwick.

cars, walls, and fences. Based on the data generated during the final calibration, the model developed by AKRF, under ongoing coordination with agency and stakeholder review, is considered suitable for the purposes of evaluating reuse alternatives for the vacant public lands in Eastwick. Model limitations are discussed herein and include performance of the model outside of the limits of calibration (e.g., for storms larger than Tropical Storm Isaias), and the simplified assumptions used to model stormwater runoff and the Mingo Creek Pumping Station. The 2D model has not been validated against other flooding events in real time. During the next flooding event, the calibration of the model should be revisited so that it could be improved by incorporating future flooding event data, including additional high water marks or other official measurements.

Modeling Results for Reuse Scenarios

The calibrated model was used to model existing conditions and to evaluate the flooding implications of implementing possible reuse scenarios for the vacant public lands identified within the LEPLS. Specifically, the effects of reuse scenarios were evaluated for three publicly owned properties in Eastwick comprising the approximately 185-acre study area, referred to as Sites 1, 2, and 3 in the LEPLS and also in this report for consistency. For each site, digital terrain surfaces were developed by AKRF to represent the cut and fill required by the proposed reuse scenarios from the LEPLS. The updated digital terrain surfaces were used to evaluate flooding within the hydraulic model.

Hydraulic modeling of existing conditions and proposed reuse scenarios was performed for eight storm event cases. Each case corresponded to an extreme terrestrial, tidal, or combination tidal and terrestrial flood event, with some tidal events adjusted to reflect the influence of climate change on sea levels. Model results for existing conditions show that flooding severity varied by both site and the event modeled, with Site 3 showing consistently high or severe flooding across all storm event cases. Model results for existing conditions at Site 2 showed consistently low severity flooding across all storm event cases. Flooding severity for Site 1 ranged from low to high depending on the storm event case modeled. Existing conditions modeling also highlighted the importance in terms of flood protection of a manmade earthen berm along the southern and eastern boundary of Site 1 in limiting tidal flooding for some storm event cases.

Model results show that the proposed LEPLS reuse scenarios did not change flooding depths outside of the site boundaries (e.g., elsewhere within the Eastwick Community) for all storm event cases, except for storm event case 6. Storm event Case 6 modeled The Great Appalachian Storm of 1950, one of the largest storms on record in Eastwick, with adjustments to reflect sea level rise predictions for the year 2100. Under this projected storm event, the proposed LEPLS reuse scenarios produced an increase in flood depths of approximately 1 foot near 86th Street and 0.5 feet in the vicinity of Lindbergh Boulevard.

Modeling Results for Ecological Restoration

In addition to modeling the LEPLS scenarios, AKRF also modeled the effects of an ecological restoration scenario. This scenario attempted to maximize flood storage at lower elevations by excavating large, constructed wetlands within Sites 1 and 3, and connecting the two excavated basins via a culvert underneath 84th Street to facilitate flow between storage areas at Site 1 and Site 3. Such a scenario could provide storage for both tidal and terrestrial flood events and could be used as a starting point for future analysis, together with other potential community-wide flood mitigation alternatives.

Model results for the ecological restoration scenario showed that the constructed wetlands provided flood reduction benefits outside of the site boundaries for 6 of 8 storm event cases modeled. For example, for the 100-year (1 percent annual chance) terrestrial event (Storm event Case 2), a reduction of 1 to 2 feet of flooding depth (surface water elevation) were identified for the ecological restoration scenario modeled as part of this study.

Key Findings

Key findings of the study based on model results are summarized as:

- Redevelopment of the vacant public land as proposed by the LEPLS would not result in increases to flooding in Eastwick for seven of the eight modeled flood events in this study.
- Roadway modifications or other solutions are needed to provide for emergency access to all vacant public land sites during all modeled flood events.

Recommendations

Based on an analysis of model results and ongoing outreach and planning efforts, the following are provided as general recommendations for future consideration:

- The results of this study should be shared with the Eastwick community to facilitate planning and improve future flood preparation. Ongoing community engagement and outreach should be maintained and increased to determine and communicate what can be done by homeowners to help avoid negative impacts associated with flooding in Eastwick.
- Any proposed development of the vacant public lands should provide specific plans for emergency site access during flood events that consider the results of this study. Emergency site access plans should be prepared in accordance with federal, state, and local guidance and be acceptable to and understood by Eastwick community members and stakeholders.
- PRA, the Lower Eastwick Steering committee, and other organized committees including the Eastwick Flood Task Force are encouraged to continue collaborating with agencies representing the City of Philadelphia as well as other public and private stakeholders; however, to implement adaptive flood mitigation solutions in Eastwick it is critical to also coordinate efforts with neighboring jurisdictions. The model and results generated from this study should be shared with stakeholders evaluating flooding and flood mitigation strategies in Eastwick.
- The results of this study along with the results of technical work being completed by others in the area should be considered to determine if additional data collection and/or monitoring could improve flood planning and response efforts in Eastwick. Technical committee representatives should convene to determine if additional gages, sensors, or other data collection techniques measuring tidal elevations, stream flow, and/or rainfall are warranted to support public notification and emergency response.

- Based on the indication of potential flood reduction benefits of the modeled ecological restoration scenario for Site 1 and Site 3, further evaluation of adaptive hybrid reuse scenarios incorporating improved floodwater conveyance and storage should be considered. Coordination with the John Heinz National Wildlife Refuge may be warranted as part of further evaluation. Further analysis could incorporate viable roadway/access modifications to be confirmed with the Philadelphia Streets Department and/or PennDOT and potentially include culverts underneath 84th Street to convey floodwaters to storage areas as demonstrated in the ecological restoration scenario modeled in this study. Adaptive hybrid scenarios could also evaluate the potential benefit of raising the elevation of the existing earthen berm (bordering the southern and eastern portions of Site 1) from its existing elevation of approximately 8 feet to an elevation that will protect the community from future tidal flooding events, which are expected to occur more frequently during future climate conditions. Based on the model results for Storm event Case 6 (The Great Appalachian Storm of 1950 with adjustments to reflect sea level rise predictions for the year 2100), a berm elevation of approximately 13 feet should be considered as an initial test case for further evaluation.

1.0 Introduction

1.1 Study Purpose and Scope

The LEPLS identified the need to complete a detailed hydraulic and hydrologic (H&H) study to analyze floodwater conveyance and help inform the beneficial reuse potential of approximately 185 acres of vacant public land identified as Site 1, Site 2, and Site 3, as defined in the LEPLS. Understanding the complexities of the landscape and watersheds was essential before future considerations were made. The study included construction of a model, and analysis was performed to proactively plan for future flooding in the Lower Eastwick neighborhood (hereinafter referred to as Eastwick).

While hard structural solutions and watershed-scale solutions to mitigate flooding in the Lower Eastwick neighborhood are being evaluated by the United States Army Corps of Engineers (USACE) in coordination with the Philadelphia Water Department (PWD), it is our understanding that Sites 1, 2, and 3 have not been identified as part of the USACE study to support construction of hard structural solutions. It is noted that the design and analysis of such large-scale solutions to flooding require substantial time and effort and the tracking of ongoing studies has led to beneficial coordination, data sharing, and technical consultation with others; however, the evaluation or analysis of hard structural solutions or watershed-scale solutions of this scale was not the primary intent of this work.

On August 4, 2020, almost immediately after receiving a notice to proceed for this study, Tropical Storm Isaias occurred and affected the lives of many in Eastwick. By witnessing the flooding and utilizing data quickly made available through the coordination of many city, state, and federal agency partners, the decision to calibrate the model with this most recent storm and flood event aligned with the purpose: to be as accurate and yet as responsive and adaptive as possible. In addition to incorporating the most up-to-date data, the study comprehensively looked backward and forward to create projections of flood levels respecting all historic storms of record while also allocating appropriate adjustments to climate changes expected from increased precipitation and sea level rise.

1.2 Project Location

The study's primary focus included the vacant public lands identified in the LEPLS as Site 1, Site 2, and Site 3 in Eastwick, as shown on Figure 1. Eastwick is located in the southernmost portion of the City of Philadelphia and is mostly located on low-lying land surrounded by multiple surface water streams and rivers. Immediately to the west of Eastwick, the Darby Creek forms a confluence with Cobbs Creek, where it then forms a large marshland at the John Heinz National Wildlife refuge, and eventually discharges into the Delaware River. Immediately to the east and south of Eastwick are two major river systems, the Schuylkill River and the Delaware River, both of which are tidally influenced by the Delaware Bay and risk potential tidal surges and future sea level rise. Within Eastwick itself, stormwater runoff generated within the community is discharged through storm sewers where it is eventually conveyed to Mingo Creek. Due to these factors, Eastwick is a community often impacted and threatened by its multiple connections to water and resultant floodwaters. Therefore, it is necessary to understand how the flow of floodwaters may traverse within the community from each of these connections prior to proceeding with potential future beneficial reuse efforts.

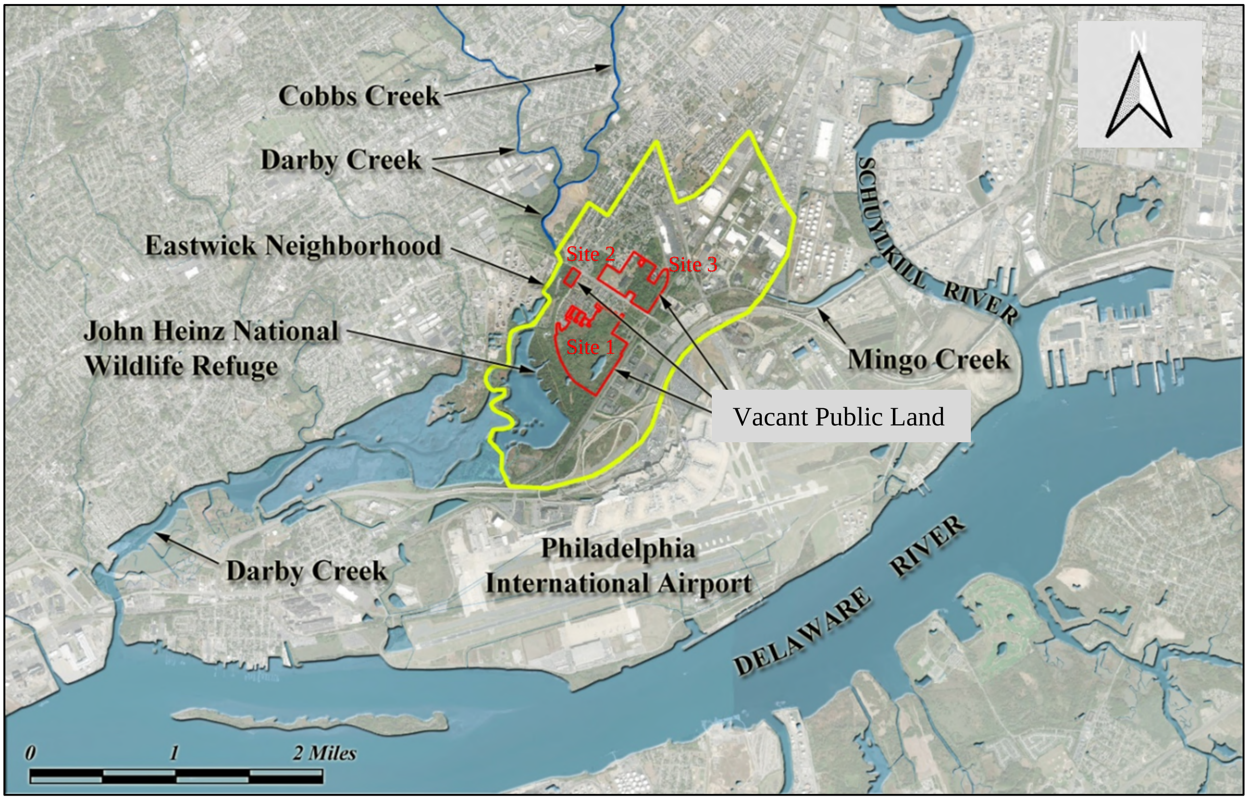


Figure 1: Vacant Public Land Evaluated for Beneficial Reuse

1.3 Conceptual Description of Eastwick Flooding

There are three primary sources of flooding in the Eastwick community: runoff from excess precipitation falling within Eastwick, overflow from Cobbs and Darby Creeks caused by terrestrial runoff, and tidal flooding. Flooding from these sources can also combine in some manner, resulting in compound flooding conditions which can affect community members differently. Presently, floodwaters are primarily removed from the community by storm sewers, along with some groundwater recharge. An illustration of these flooding pathways is shown in Figure 2.

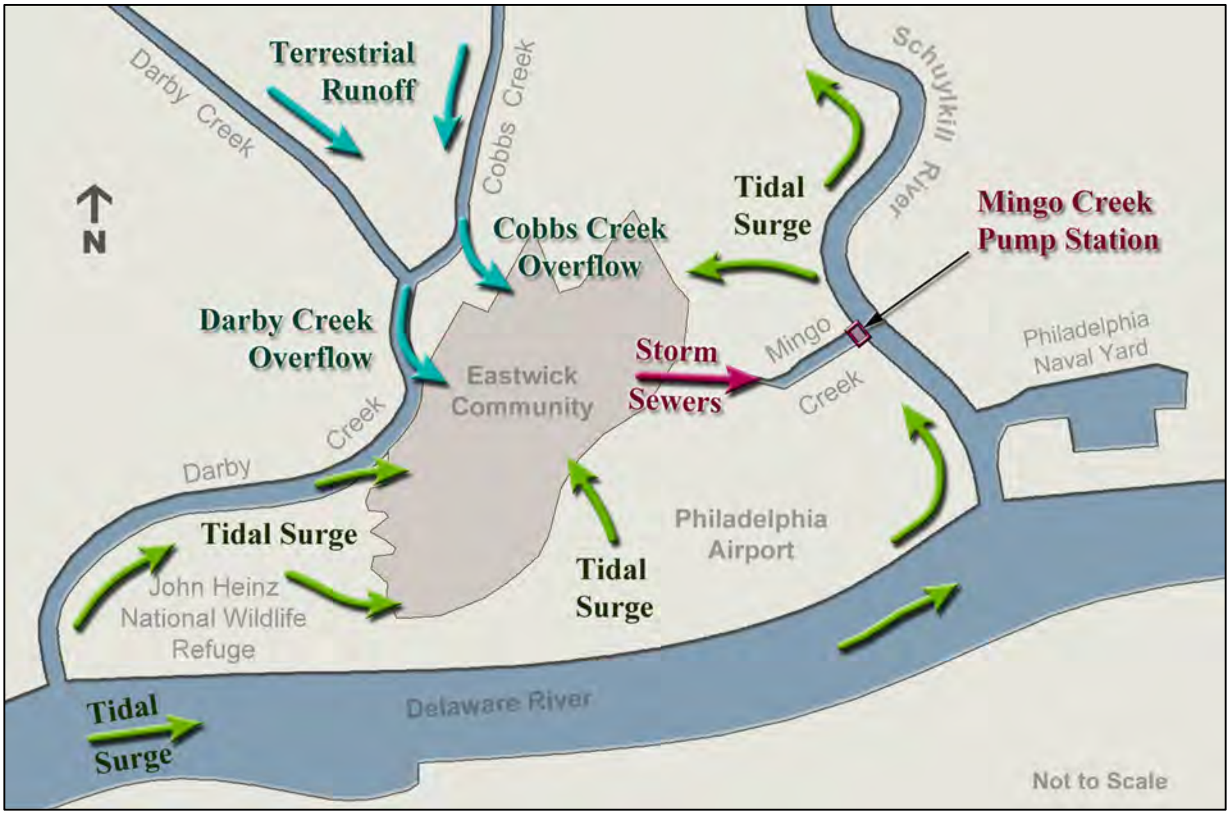


Figure 2: Concept Diagram of Eastwick Flooding Sources

2.0 Model Boundary Conditions

The flood model constructed for this study has two primary spatial components which generate water surface profiles including: 1) the external boundary conditions and 2) the internal model domain.

External boundary conditions

External boundary conditions are inputs that act on the model perimeter. External boundary inputs for the Eastwick model include upstream flows and downstream tidal stages.

Internal model domain

The internal model domain describes how flow moves within the interior of the model at critical hydraulic locations. Internal boundary condition inputs within the Eastwick model include runoff resulting from precipitation falling within Eastwick, and storm sewer discharges.

A full set of boundary conditions—both external and internal—must be specified for each flood condition evaluated.

As summarized in Section 1.3, flood conditions occur in Eastwick due to runoff from excess precipitation, terrestrial flooding, tidal surges emanating from the ocean, or a combination of the three. Due to projections of climate change, the degree of flooding from all sources is expected to increase in the future. Considering each of these conditions, eight individual boundary condition storm events were selected for evaluation as part of this study. These events are listed in Table 1.

Table 1: Boundary Condition Storm Events Analyzed

Storm Event Case	Storm Event Description
Case 1	Tropical Storm Isaias [approximate 10-year (10 percent annual chance) terrestrial event affecting Eastwick, August 2020]
Case 2	100-year (1 percent annual chance) terrestrial event
Case 3	Hurricane Sandy (the highest tidal surge recorded at Philadelphia, October 2012)
Case 4	Great Appalachian Storm of 1950 adjusted to 2020 (the highest tidal surge recorded at Philadelphia when adjusted for sea level rise)
Case 5	100-year (1 percent annual chance) terrestrial event estimated at 2100 (hypothetical event)
Case 6	Great Appalachian Storm of 1950 adjusted to 2100 (hypothetical event)
Case 7	100-year (1 percent annual chance) terrestrial event coincident with 10-year (10 percent annual chance) tidal event (hypothetical event)
Case 8	10-year (10 percent annual chance) terrestrial event coincident with Great Appalachian Storm of 1950 adjusted to 2020 (hypothetical event)

A statistical evaluation found that Case 1, Tropical Storm Isaias, is approximately the 10-year recurrence interval (10-percent chance of annual exceedance) storm event in Darby Creek and Cobbs Creek. Cases 2, 3, and 4 are extreme events in which either terrestrial flooding (Case 2) or tidal flooding (Cases 3 and 4) is considered as the individual sole source of flooding. Cases 5 and 6 are hypothetical but anticipated future events for terrestrial and tidal flooring, respectively, made more extreme by climate change. The last two cases (Cases 7 and 8) consider the hypothetical joint occurrence of terrestrial and tidal flooding.

The following subsections summarize the methods and sources used to develop boundary conditions for the above storm events. A detailed description of the analysis associated with the development of the boundary conditions is provided as Attachment A.

2.1 Terrestrial Flooding Analysis

Terrestrial flooding results from the accumulation of runoff that occurs when rainfall is unable to infiltrate or be stored on the land surface. Terrestrial flooding primarily occurs within Eastwick from flows originating from Darby Creek or Cobbs Creek. Terrestrial flooding can also be further exacerbated by runoff generated internally within Eastwick. Runoff generated within Eastwick is collected via internal storm sewers, where it is ultimately discharged to Mingo Creek and pumped into the Schuylkill River via the Mingo Creek pumping station. Please note that this section addresses flow in Darby Creek and Cobbs Creek. Runoff generated within Eastwick is addressed in Section 2.3.

Figure 3 shows upstream gaging stations (indicated as yellow dots) near Eastwick and the watersheds associated with the Darby Creek and Cobbs Creek gages. Streamflow at these gages was estimated from gaging station data obtained from the United States Geological Survey (USGS). For sub-watersheds downstream of the USGS gaging stations, the runoff generated in these sub-watersheds was estimated as proportional to gage flows by land area. Further information about this data and related modeling assumptions can be found in Section A.2.0 of Attachment A (Terrestrial Flooding Analysis).

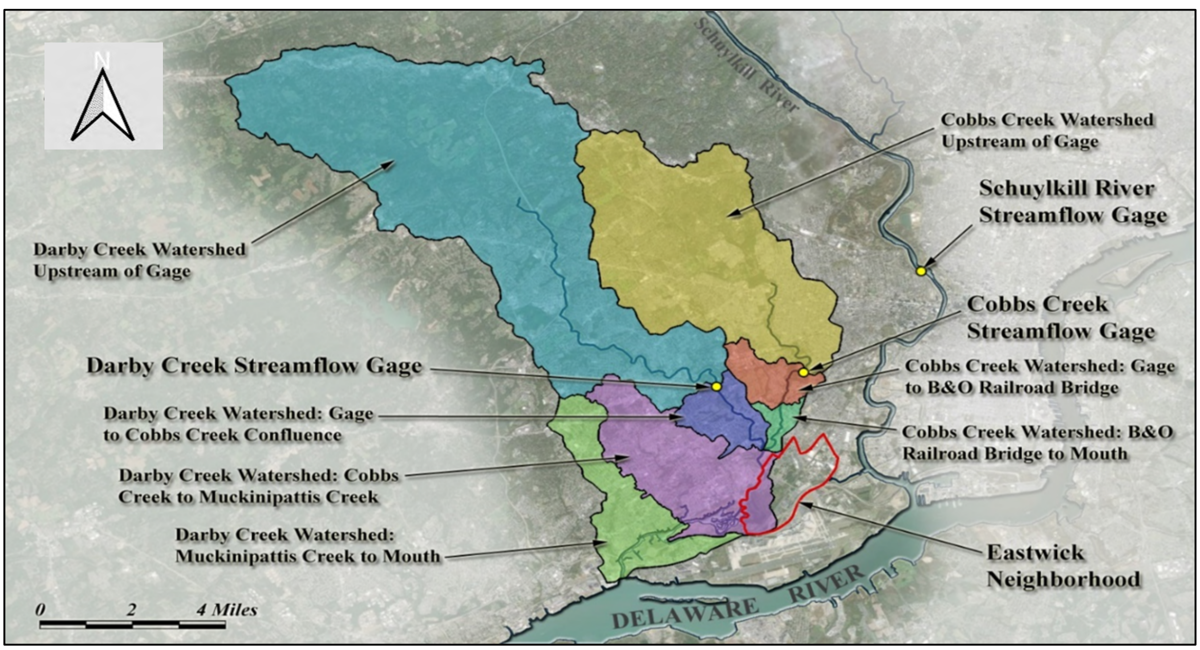


Figure 3: Watersheds and Upstream Gages near Eastwick

2.2 Tidal Surge Analysis

Except for a negligible tidal effect from the Chesapeake Bay through the Chesapeake and Delaware Canal, all tidal surge reaching the mouth of Darby Creek and the Schuylkill River is propagated from the Atlantic Ocean, through the Delaware Bay and Delaware River. Figure 4 shows Eastwick relative to the river, bay and ocean, and also shows several key tide gages maintained on the Delaware River by the National Oceanic and Atmospheric Administration (NOAA).

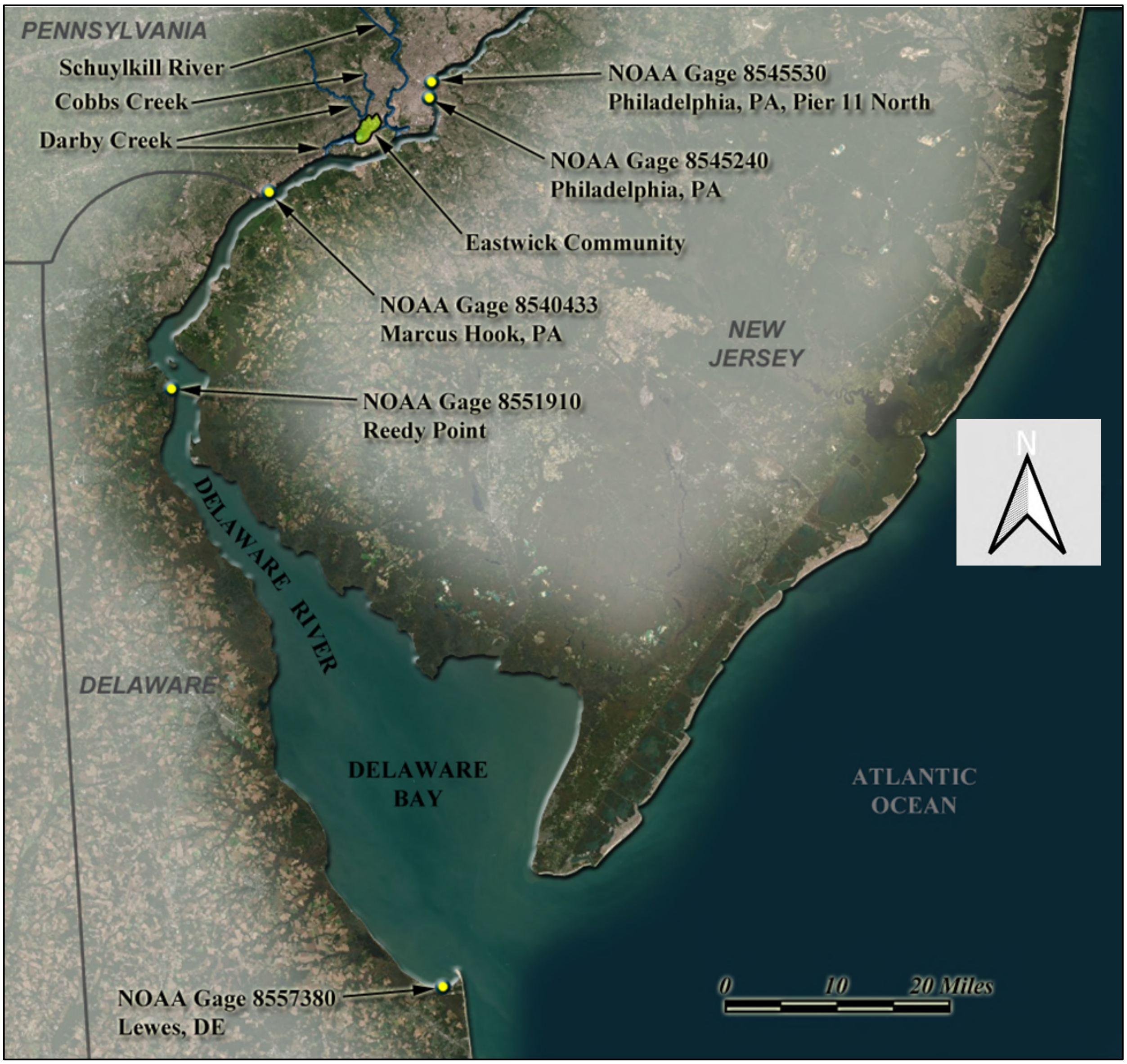


Figure 4: Selected Delaware River and Bay Tide Gages

Historical tidal surge events reaching Philadelphia have been performed and plotted by NOAA as shown in Figure 5. The results are based upon the combined tidal gage data recorded at Pier 11 North in Philadelphia (see Figure 4). A reiterating note that the extreme event analysis shown Figure 5 has been performed by NOAA and not by AKRF as part of this study. The red line (1 year per 100) depicts the 1-percent chance tidal flood event, which is equal to the 100-year event in terms of recurrence intervals. The yellow line (10 years per 100) depicts the 10-year event, the green line (50 years per 100) depicts the 2-year event, and the blue line (99 years per 100) depicts the 1-year event. Historical storms associated with high tidal surge events have also been noted in Figure 5. As shown, historical sea level rise at Philadelphia has been increasing at a linear rate of about one foot per century. This rate provides the basis for future sea level scenario adjustments (see Attachment A for further details).

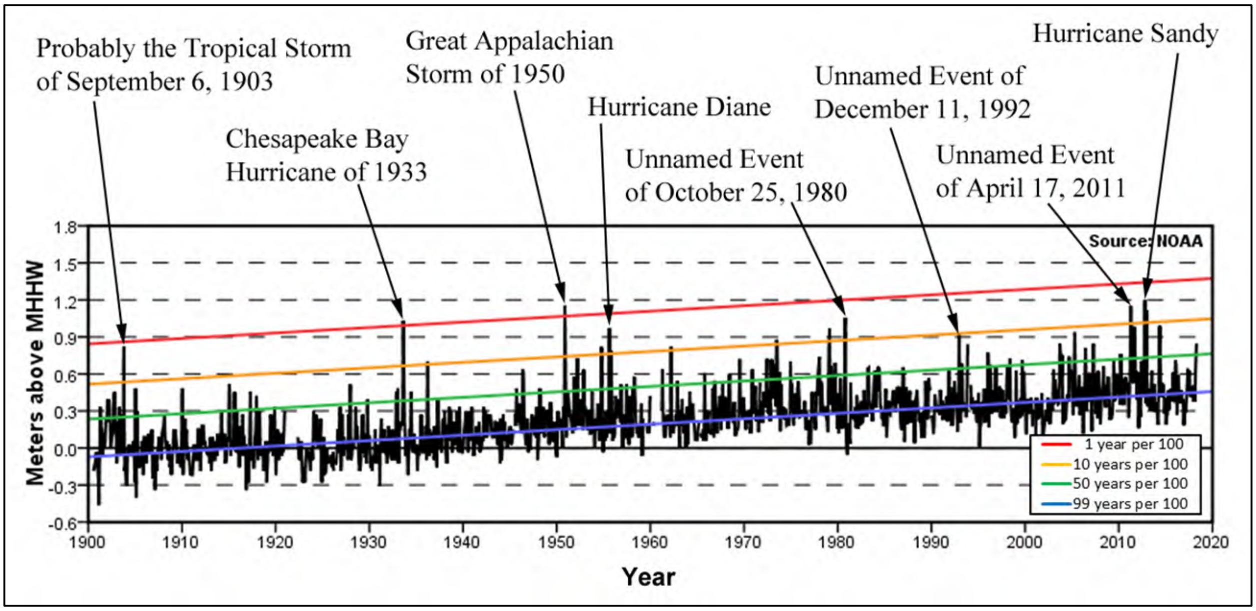


Figure 5: Extreme Water Levels at Philadelphia (Source: NOAA 2020, modified by AKRF)

The three worst tidal surge events relative to mean higher high water (MHHW) at the time of the storm[2] all occurred 69-117 years ago. The event that occurred in the first decade of 1900 was probably the so-called “Vagabond Hurricane,” a tropical storm that hit the New Jersey coast on September 6, 1903 (ACP 2019, CBS 2011). The next unusual tidal surge event was a result of the “Chesapeake Bay Hurricane” of August 23-24, 1933 (NWS 2012). According to NOAA (Figure A-8 in Attachment A), this storm produced the second highest recorded exceedance of tidal surge above MHHW at Philadelphia.

A large number of river stage gages recorded tide elevations in the vicinity of Eastwick during Tropical Storm Isaias. Of these, ten were used to provide model boundary condition data (rationale is provided in Attachment A). The location of each gage is shown in Figure 6, and their information is given in Table 2. Data from these gages was used or estimated, as needed, for each of the eight boundary condition storm events described in Table 1 (see Attachment A for further details).

[2] MHHW is the average of the higher of the two high tides that occur each day. As evident in Figure 5, MHHW has been increasing over the tidal period of record at Philadelphia.

Table 2: Tide Gage Information

Gage ID	Gage Operator	Station ID
Bridesburg	NOAA	8546252
Philadelphia	NOAA	8545240
Schuylkill River	USGS	01474501
Fort Mifflin	USGS	01474703
Darby Creek	USGS	01475553
Marcus Hook	NOAA	8540433
Delaware Memorial Bridge	USGS	01482100
New Castle	USGS	01482170
Delaware City	NOAA	8551762
Reedy Point	NOAA	8551910

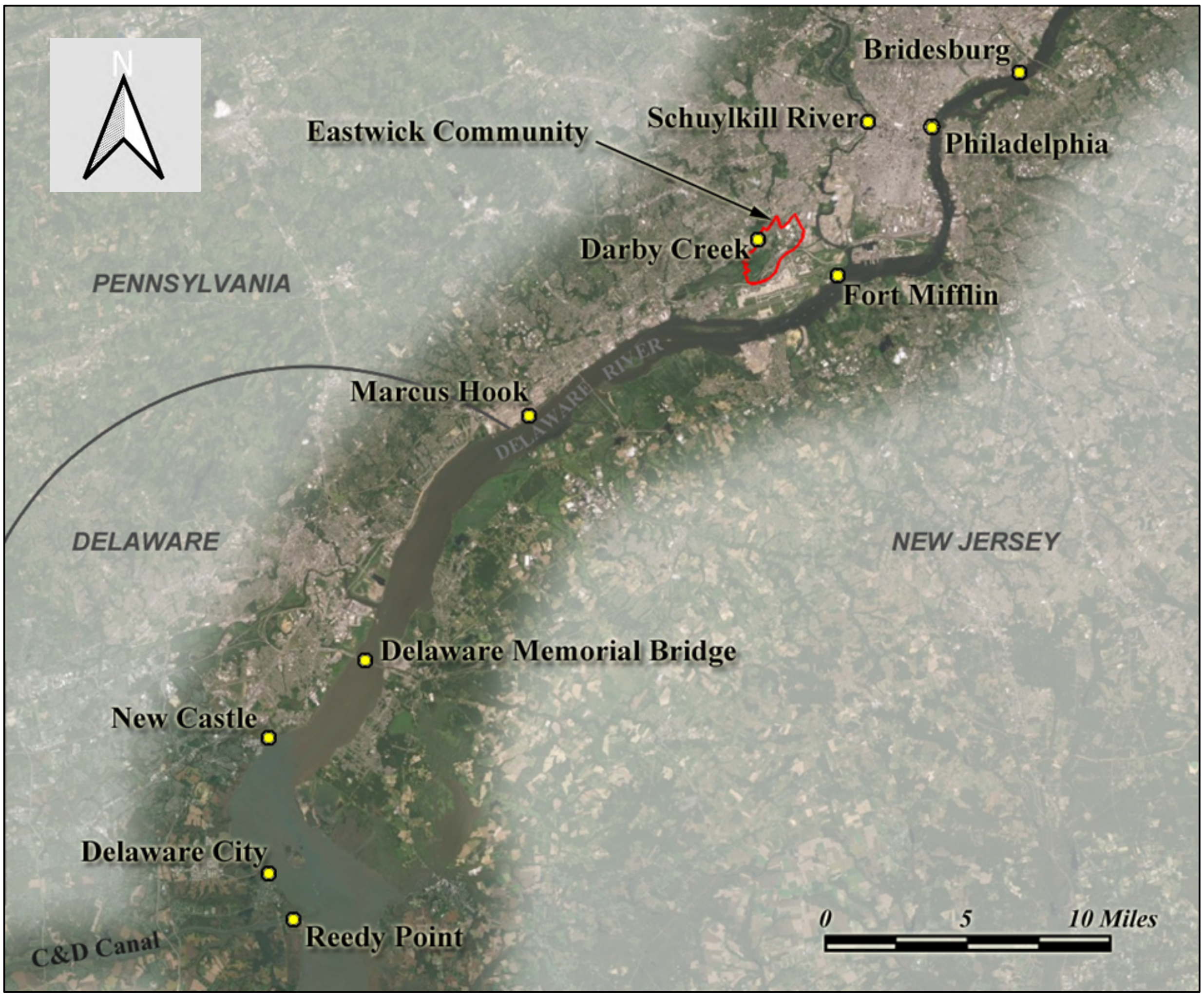


Figure 6: Tide Gages with Recorded Data During Tropical Storm Isaias

2.3 Internal Runoff

External terrestrial runoff is stormwater runoff that originates upstream within the Cobbs Creek and Darby Creek watershed basins and is transported downstream via creek channels. External terrestrial runoff generated in these watersheds eventually passes by the Eastwick community, where it then enters the Delaware River and eventually the Chesapeake Bay and Atlantic Ocean. In contrast, Internal terrestrial runoff is stormwater runoff that is generated within the boundaries of the Eastwick community itself. Internal runoff is generated when rainfall lands upon impervious surfaces or non-infiltrating pervious surfaces. To simulate the impacts of internal runoff, internal drainage areas within Eastwick were delineated using GIS mapping, as shown in Figure 7.

Within Eastwick's internal drainage areas, direct rainfall was converted to runoff using the Natural Resources Conservation Service (NRCS) methods described in National Engineering Handbook (NEH) Part 630 (USDA 2020). Details on the application of this method and derivation of land use, curve numbers, time of concentrations, and rainfall distribution for runoff generation are given in Section A4.2 of Attachment A.

In the development of the model for internal runoff boundary conditions, the effect of individual storm sewer inlets was not incorporated. Instead, the model takes the approach of applying drainage over a larger area, with its limits defined by surface topography (not storm sewer networks), which allows the two-dimensional model dynamic to drain to the topographic low points. Therefore, the effect of Eastwick's storm sewers is simulated in the model by removing flow from its topographic low points (see Attachment B for a detailed description). Figure 7 shows the Eastwick internal drainage areas (DAs) that drain to local topographic low points.

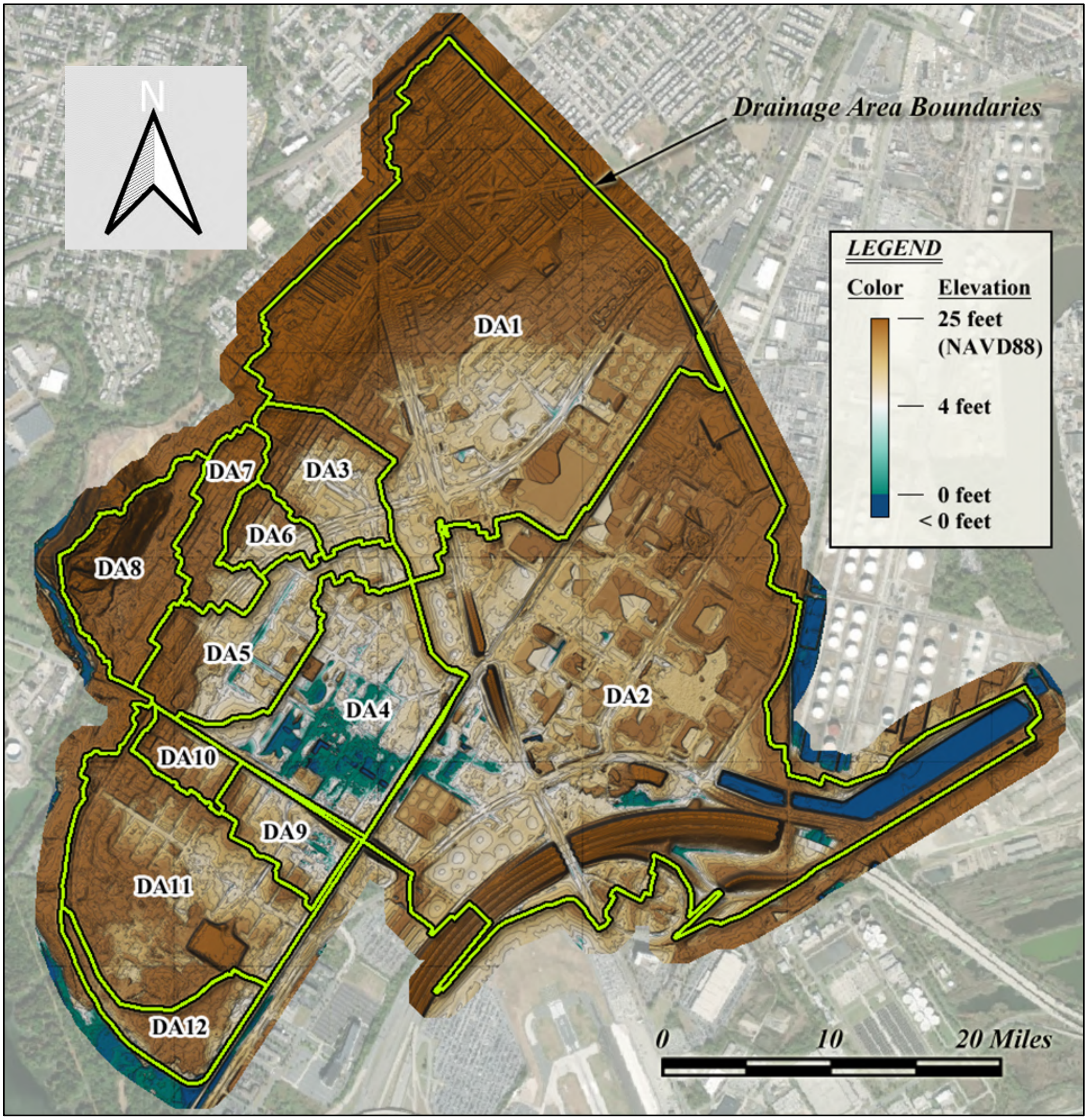


Figure 7: Eastwick Internal Drainage Areas

2.4 Joint Occurrence of Events

The likelihood of tidal surge and terrestrial runoff flood events (both internal and external) occurring simultaneously was evaluated using historical extreme event data of both types (tidal surge and terrestrial runoff) and a semi-quantitative analysis. Joint occurrence of high Delaware River tide elevations and Schuylkill River flows could result in floodwaters emanating from the Schuylkill River and flooding the Eastwick community from the east. However, the analysis indicated that there does not appear to be a strong correlation between extreme Delaware River peak tidal elevations and Schuylkill River peak flows (see Attachment A for more information on this analysis).

The correlation between peak runoff in Cobbs Creek and Delaware River peak tide elevations was evaluated using the Cobbs Creek flow gage data and Philadelphia tidal stage data. It should be noted that Cobbs Creek flow gage data only exists from 2005 to the present, so a full long-term correlation analysis using the historical Delaware River observations shown in Figure 5 was not possible. These data were statistically analyzed, converted to a return period, and then plotted, as shown in Figure 8. Based upon the analysis of the data, it appears that extreme events of tide at Philadelphia and flow at Cobbs Creek may be slightly negatively correlated; however, this trend is not sufficient to make definitive conclusions.

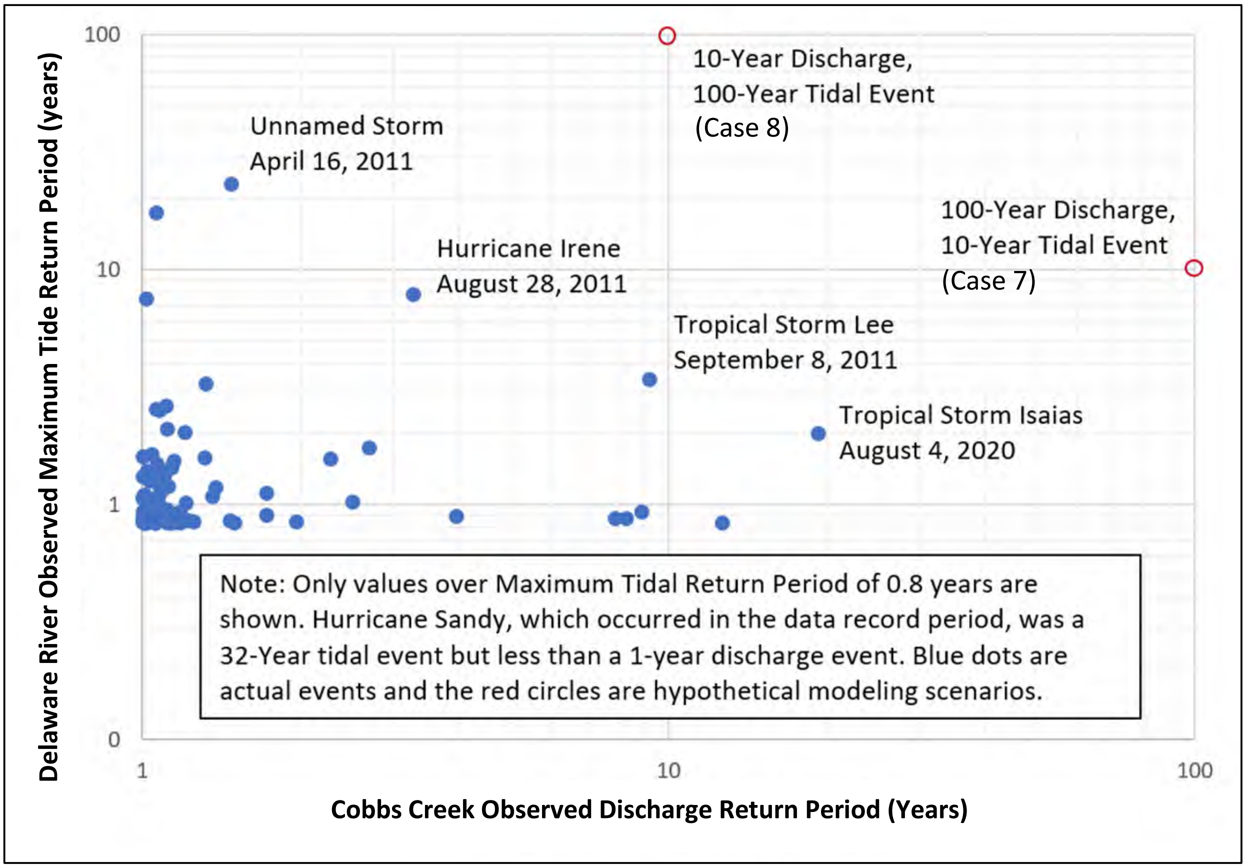


Figure 8: Return Period Correlation of Cobbs Creek Flow and Delaware River Tide

Based on the analysis summarized above and described in greater detail in Attachment A, our assessment is that the following storm events are conservatively sufficient in analyzing joint occurrence of tidal and runoff events at Eastwick:

- 10-year tidal surge event combined with the 100-year runoff event (Case 7); and
- 100-year tidal surge event combined with the 10-year runoff event (Case 8).

2.5 Sea Level Rise and Climate Change Conditions

Historical data indicates that the sea level has been rising in the Atlantic Ocean, resulting in a corresponding rise in the Delaware River estuary. In addition, rainfall patterns have been changing with increased rainfall amounts predicted by climate models. Both factors will increase the risk of future flooding in Eastwick. This section provides a basis for quantifying the increases to boundary conditions so that increased flooding within the Eastwick community can be assessed for future climate change impacts.

Figure 9 shows the historical period of monthly mean sea maximum tide levels at Philadelphia with projections for sea level rise (SLR) to the year 2100. The projections are from the Sea Level Trends, Regional Scenarios of the NOAA Philadelphia gage web page (NOAA 2020). The regional future climate change projection scenarios (indicated as solid lines) are based upon six representative global mean sea level rise scenarios, as documented in NOAA Technical Report NOS CO-OPS 083 (NOAA 2017).

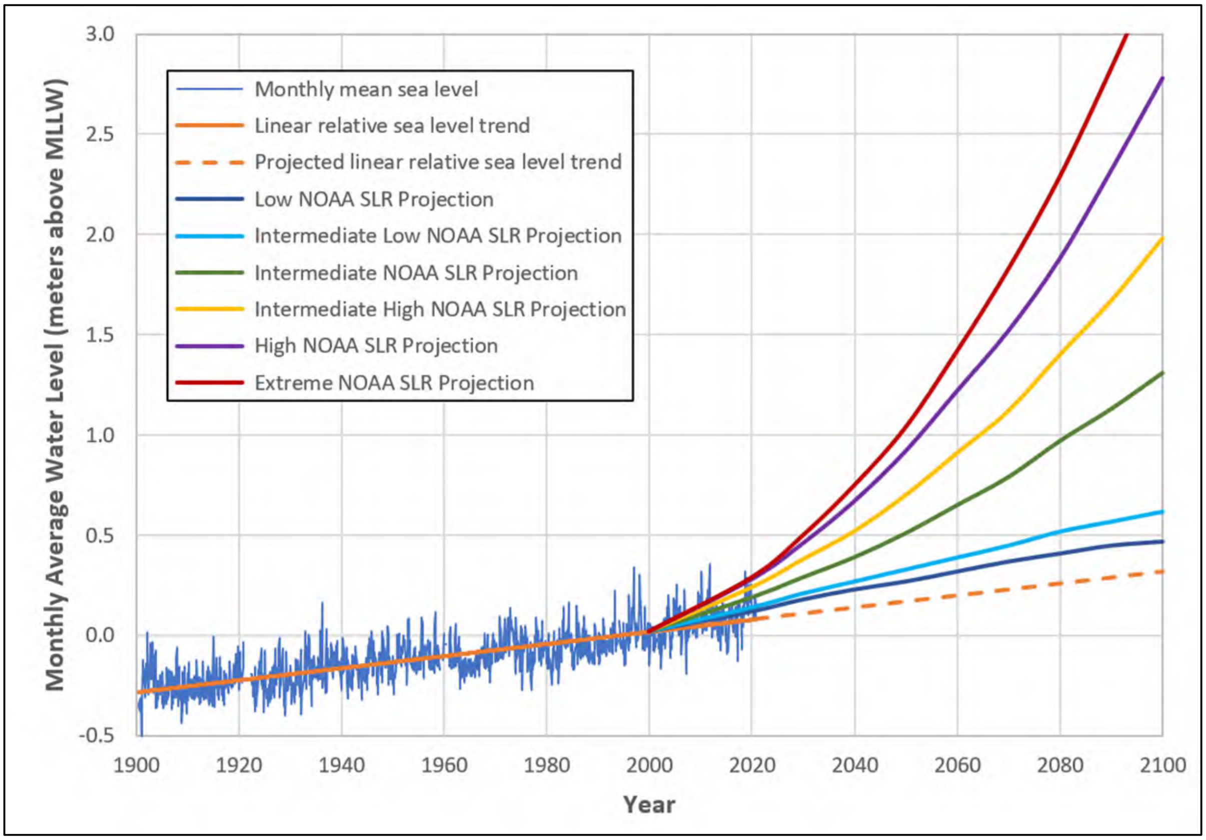


Figure 9: Philadelphia Sea Level Trend and Projected Sea Level Rise (Source: NOAA 2020)

As Figure 9 shows, the rise in sea levels over the past 120 years has been fairly linear with no clear recent indication of an increase in the rate of change. This trend, projected out to 2100 in Figure 9 (dashed line) indicates that there would be a 0.24-meter (0.79-foot) increase in sea level by the end of the century. NOAA SLR projections are all higher. The Intermediate NOAA SLR 2100 projection of a 1.28-meter increase above the 2020 mean sea level was chosen for this study's modeling analysis.

Future terrestrial runoff was estimated based upon the results presented in a recent paper in which the global climate model precipitation output was statistically downscaled for Philadelphia (Maimone et al. 2019). Future rainfall amounts and 100-year terrestrial flood hydrograph flows were increased by 10% to evaluate future flooding conditions.

3.0 Model Development

The following sections provide a high-level summary for the development of the Eastwick hydraulic model. See Attachment B for more information on the development of the model.

3.1 Model Domain and Boundary Conditions

The existing conditions model is composed of two interconnected models: a two-dimensional (2D) model within Eastwick, and a one-dimensional (1D) model of the rivers and streams surrounding Eastwick. 2D flow processes are required to describe the movement of floodwaters through the streets, homes, and other features of the Eastwick community. 1D flow processes describe the flow in the rivers. In general, 1D flow processes are more quickly computed and less computationally intensive, while 2D flow process provide more granular results but take longer to compute. Figure 10 shows the limits of the 1D and 2D model domains.

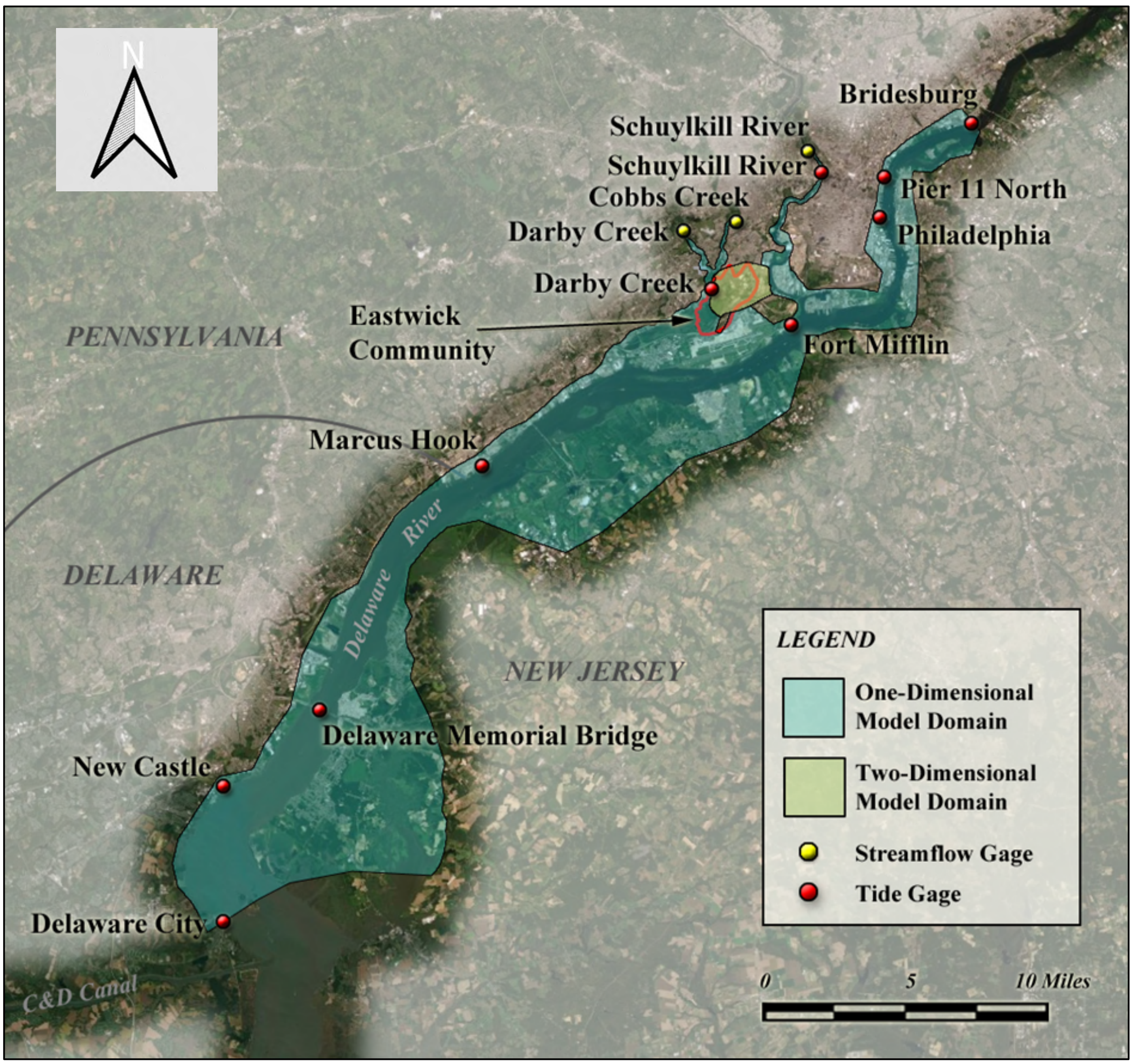


Figure 10: Model Domains

3.2 HEC-RAS Model and Geometry

The computer model used for both the 1D and 2D hydrodynamic analysis was the USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) program (USACE 2019). HEC-RAS's capabilities include computation of unsteady flow simulations using geometry described by reach lengths and bathymetric cross sections, and boundary conditions described by measured stage and flow data. Calibration parameters include channel and floodplain roughness, and expansion and contraction coefficients.

The 1D model was constructed using bathymetry data that were obtained from various sources, including the NOAA National Centers for Environmental Information's (NCEI) combined topographic and bathymetric digital elevation model (DEM) data (NCEI 2018) and NOAA Nautical Charts (NOAA 2018). Model cross sections were aligned and constructed in accordance with 1D modeling theory to describe representative geometry throughout the modeled domain. Cross sections were also defined at tide gage locations for direct entry of tide stage data at boundaries and direct comparison of model calibration results with internal tide gage data.

Schuylkill River is modeled from its mouth at the Delaware River to the head of tide at Philadelphia Water's Department Fairmount Dam, immediately downstream of USGS's Schuylkill River streamflow gage. Schuylkill River bathymetry was obtained from the combined source of the NOAA NCEI DEM and NOAA Nautical Charts, with adjustments to invert elevations based on the FEMA Flood Insurance Study (FIS) profile (FEMA 2019).

The USACE 2014 model (USACE 2014; Moore 2020) geometry was used for Darby Creek and Cobbs Creek. Model geometry was modified, as appropriate and particularly in Tinicum Marsh downstream of the Darby Creek tide gage, using 2018 Light Detection and Ranging (LiDAR) elevation data (PASDA 2020), bathymetric data (Moore 2020), and aerial photography (Nearmap 2020). Model geometry was extended from the upstream limit of the USACE 2014 model to the Darby Creek and Cobbs Creek USGS stream gages, which provide upstream boundary condition flows.

The HEC-RAS 2D model connects to the 1D model using HEC-RAS "lateral structures" between the ends of the 1D cross sections intersecting the 2D model boundary (see "1D/2D Connections" in Figure 11). These connections occur along Darby Creek and Cobbs Creek, on the south at the Philadelphia International Airport, and on the east along the Schuylkill River. Figure 11 also shows the Darby Creek tide gage (used for calibration of creek flows) and an outline of the three Vacant public land sites under consideration for this evaluation.

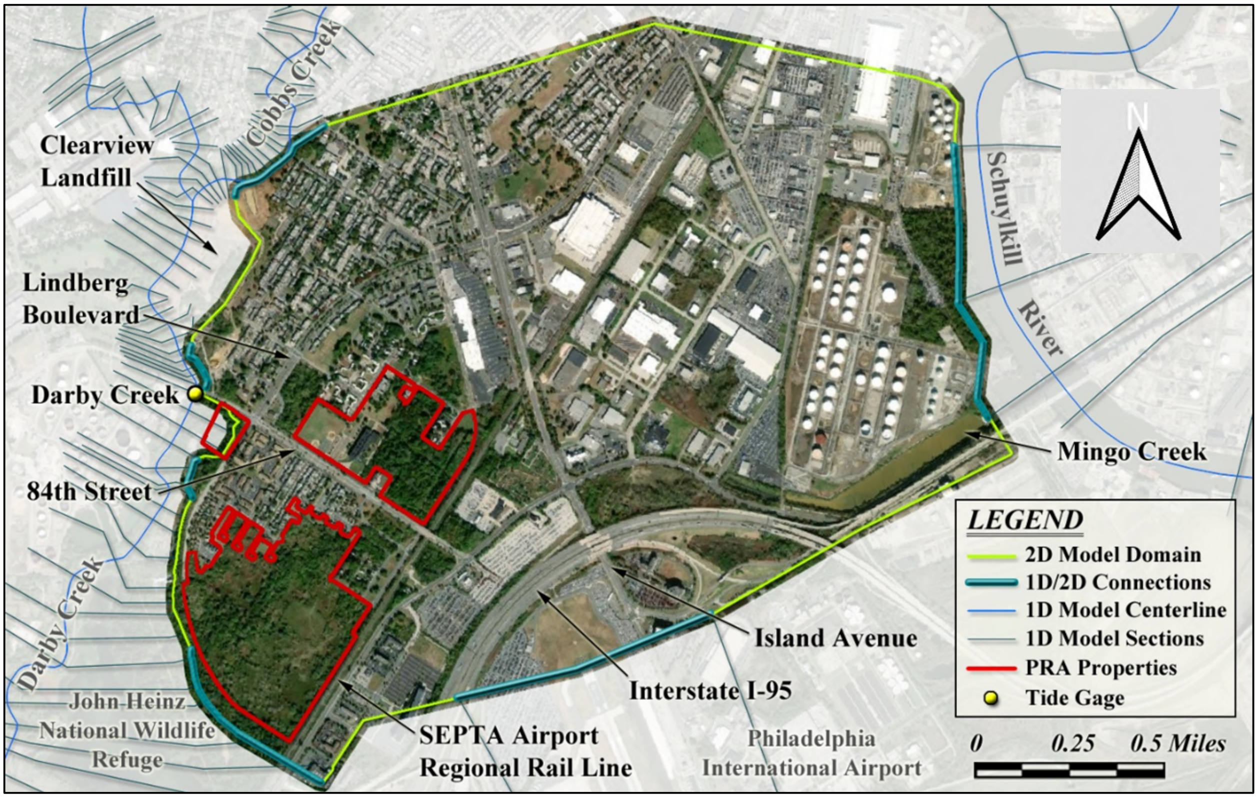


Figure 11: 2D Model Boundary and Connections to 1D Model

Surface terrain used in the 2D model is shown in Figure 12. The terrain used for the project in the 2D model area is a one-foot horizontal resolution DEM, which was derived by AKRF from 2018 LiDAR data (PASDA 2020). The vertical datum for the DEM is the National Vertical Geodetic Datum of 1988 (NAVD88).

The westerly 2D model domain boundary is primarily located on Darby Creek and Cobbs Creek banks. The boundary in this area is separated from the 1D model cross sections due to high ground at Clearview Landfill, which is located just south and east of the Darby Creek and Cobbs Creek confluence (see Figure 11). The easterly 2D model domain boundary is located on the Schuylkill Riverbank in the area of the tank farm to the northeast. The northern boundary is situated within Eastwick on land with elevations higher than known flooding occurs. It should be noted that the PRA property at 8401 Lindbergh Boulevard (Site 2) is only partially modeled in the 2D model domain boundary. This is due to this property being situated on high ground and therefore unimpacted by surface adjacent flooding transport. Furthermore, the 1D model domain cross sections accurately model this portion of Site 2.

The southern boundary of the 2D model domain is situated on higher ground, with the exception of the central portion that is located south of Interstate I-95. In this central portion, floodwaters from the Delaware River may inundate the Philadelphia International Airport and pass under Interstate I-95 at Island Avenue. The I-95 and Island Avenue interchange roadway ramps act as unintentional levees in this area and were incorporated into the 2D model to properly describe flow.

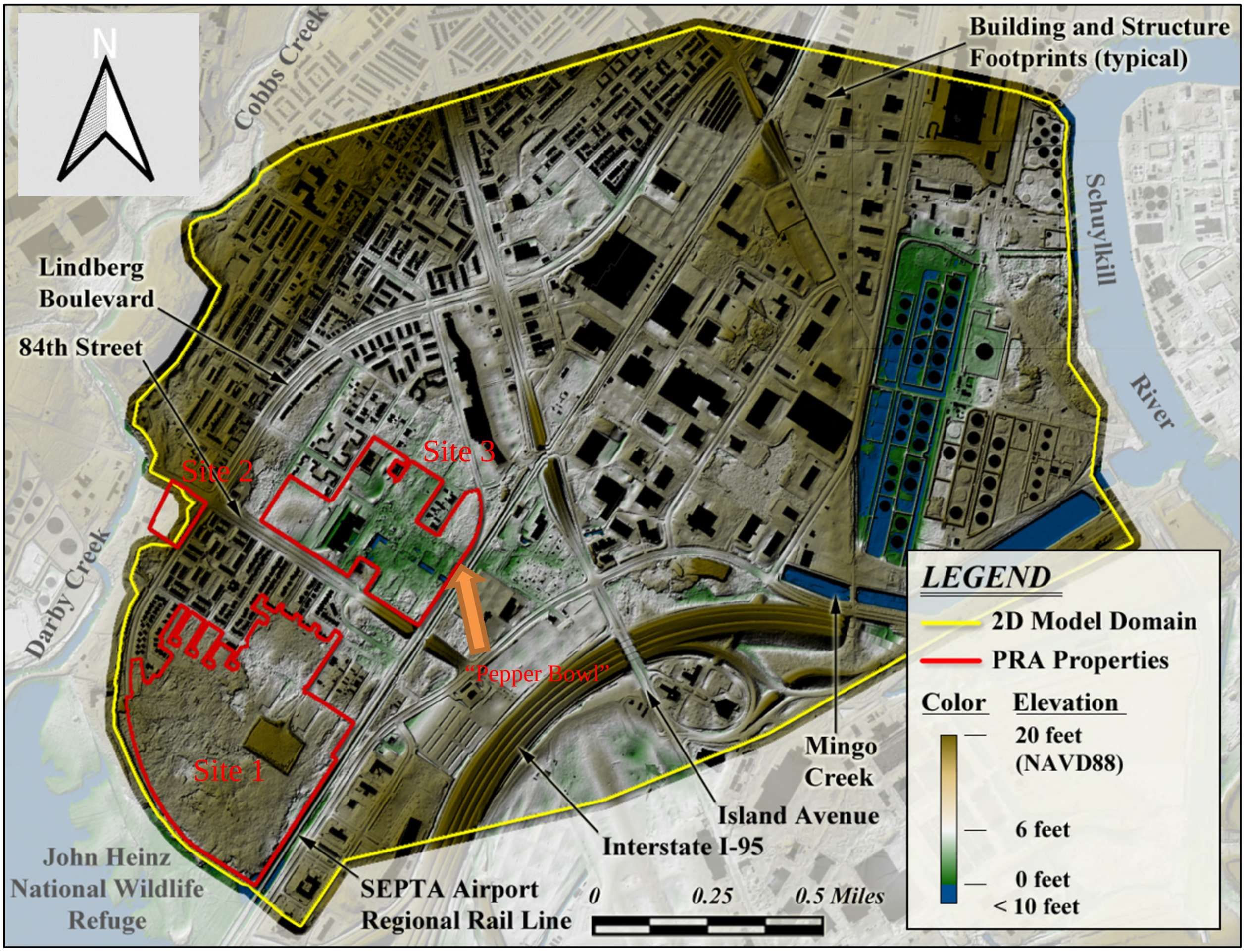


Figure 12: 2D Model – Existing Topography

Within the 2D model domain, the land elevation forms a bowl near the northeast PRA property (Site 3). This area is referred to as the "Pepper Bowl" in the LEPLS because the area contains some of the lowest elevations in all of Eastwick, including areas that are at or below sea level (IS 2019). Flow from Cobbs Creek overflows its bank just above Clearview Landfill and floods southeast through the community, passing over Lindberg Boulevard until it reaches the low area of the "Pepper Bowl." Floodwaters that accumulate within this low area are retained until they are drained by storm sewers or infiltration to groundwater occurs.

An earthen berm acting as a levee[3], having top elevations at approximately elevation 8 feet (NAVD88), is located in the southwestern portion of Eastwick and provides protection to a part of the community from tidal surge emanating from Darby Creek and the John Heinz National Wildlife Refuge. The 2D model boundary is situated on this berm from just south of 84th Street down to the south until it reaches the Southeastern Pennsylvania Transportation Authority (SEPTA) Airport Regional Rail Line. At this point, the berm curves to the northeast along the westerly side of the rail line and continues almost to Island Avenue. The berm in this area of the

[3] This levee-like structure is not certified by FEMA.

rail line presents a barrier to flow from flooding in the “Pepper Bowl” to low areas east in the direction of Mingo Creek. See Section 3.5 for a greater description of the earthen berm.

A HEC-RAS 2D model mesh for existing conditions analysis (see Attachment B) was developed with default rectangular cell spacing of 50 feet by 50 feet. Refinement areas were defined by break lines aligned along roadway centerlines and curb lines in areas where significant flow occurs. The mesh resolution and locations of break lines were determined by an iterative modeling process until mesh resolution cell refinement resulted with the flow conditions being stable and properly represented. A total of 86 break lines were defined having near spacing (immediately adjacent cells) of 15 feet and far spacing of 49 feet. The final model existing conditions 2D mesh contains 42,629 grid cells.

3.3 Existing Land Use and Model Parameters

Surface roughness, as defined by Manning’s n coefficients, is typically the principal calibration parameter for HEC-RAS models. However, initial values are selected based upon previously published n values corresponding to land use or river-bottom conditions. In 1D model areas, these values, and all subsequent calibration values, were selected to be within the ranges given in Table 3-1 of the HEC-RAS Hydraulic Reference Manual (USACE 2016).

There are large areas of the Eastwick 2D model domain for which no calibration data are available and flow predictions in these areas must rely upon best estimates based upon land use and published n values. Ponded areas were approximated with reference to other values as being mostly smooth but with some edge vegetation and irregularities. Buildings are set at a high n value of 100 to allow for water to be stored within, but not move quickly through the structures. Other land use values were selected based upon the information contained in the United States Department of Agriculture National Engineering Handbook, Hydrology (USDA 2010). Areas with mixed use of wooded, vegetated and grass were estimated as a weighted average according to the proportion of each use.

Expansion and contraction coefficients for the 1D model were set according to typical values of 0.3 and 0.1 respectively in river reaches, and 0.5 and 0.3 respectively at bridges. Bridge overflows were modeled as broad crested weirs with weir coefficients of 2.6. Ineffective flow areas were identified and modeled in accordance with HEC-RAS guidance. The junction of the Schuylkill River and the Delaware River and the junction of Darby Creek and the Delaware River were both modeled by forcing equal water surface elevations. The higher-energy environment of the Darby Creek and Cobbs Creek junction was modeled using the energy balance method option in HEC-RAS.

3.4 Storm Sewer and Mingo Creek Pump Station Flow

Most floodwaters and stormwater within the Eastwick model boundary area drain by storm sewer to Mingo Creek. The water is then pumped to the Schuylkill River, which has a higher elevation at normal pool river stage (PWD 2020). The Mingo Creek pump station houses six 500-horsepower pumps, each capable of pumping 124 cubic feet per second (cfs) (approximately a 5-year, 24-hour storm event) (IS 2019). As indicated by the PWD 2020 Eastwick / Mingo Creek basin stormwater model utilizing a Storm Water Management Model (SWMM) report (and subsequently confirmed by this study), these pumping rates are relatively small with respect to floodwater flows that enter within Eastwick. However, the pump stations do provide drainage after flood events and have some limited effect during flood events.

Storm sewer model flow rates were apportioned based on comparing the overall sewershed (PWD 2020) with modeled drainage areas. Storm sewer withdrawals were modeled as internal boundary conditions by assigning negative flow values. HEC-RAS applies negative flow by withdrawing up to that rate, if available from the cells connected to the internal boundary. Two withdrawals were modeled with 200 cfs withdrawn from the “Pepper Bowl” and 100 cfs withdrawn from the low area southwest of the intersection of 84th Street and the SEPTA Airport Regional Rail Line (see Attachment B for more discussion regarding these assumptions). It is recognized that this is a simplified approach to modeling the storm sewers within Eastwick and is somewhat of a limitation in context of system dynamics; however, we do not expect the limitation to be significant or to alter the ability of the model to meet the study objective. This model limitation, among others, is discussed further in Section 4.1.

3.5 <u>John Heinz National Wildlife Refuge and SEPTA Rail Line Earthen Berm</u>

During model development and examination of the surface terrain model, it was discovered that a pronounced and noticeable earthen berm exists in the southern most portion of Eastwick. The earthen berm is approximately two miles in length and extends along the John Heinz National Wildlife Refuge and the SEPTA rail line paralleling Mario Lanza Boulevard, where the berm eventually ends just prior to where the SEPTA rain line intersects with Island Avenue. The digital elevation model highlighting the earthen berm, along with a Google Street view photo of the berm along Mario Lanza Boulevard, is shown in Figure 13.

As seen in Figure 13, it is evident that the earthen berm is of manmade origin. However, the history of the construction of the berm and its purpose is unknown. Historical aerial photography was reviewed, and it is suspected that the berm was constructed sometime after the 1950s. Due to the amount of vegetation and tree growth along large stretches of the berm, it is suspected that the berm is no longer maintained or regularly inspected by whomever performed the original construction. The City of Philadelphia’s floodplain manager also confirmed that the earthen berm is not an official FEMA-certified levee.

Even though the berm is not an official FEMA-certified levee, there is likely still tangible benefit to Eastwick given the length and size of the berm. Therefore, additional model break lines along the berm within the HEC-RAS 2D surface model were inserted into the model to increase model resolution in this area. The addition of the break lines will provide additional modeling accuracy and the ability to understand possible flood protection realized due to the berm. This is especially important for possible tidal events originating from the John Heinz National Wildlife Refuge, including future climate projections from sea level rise.

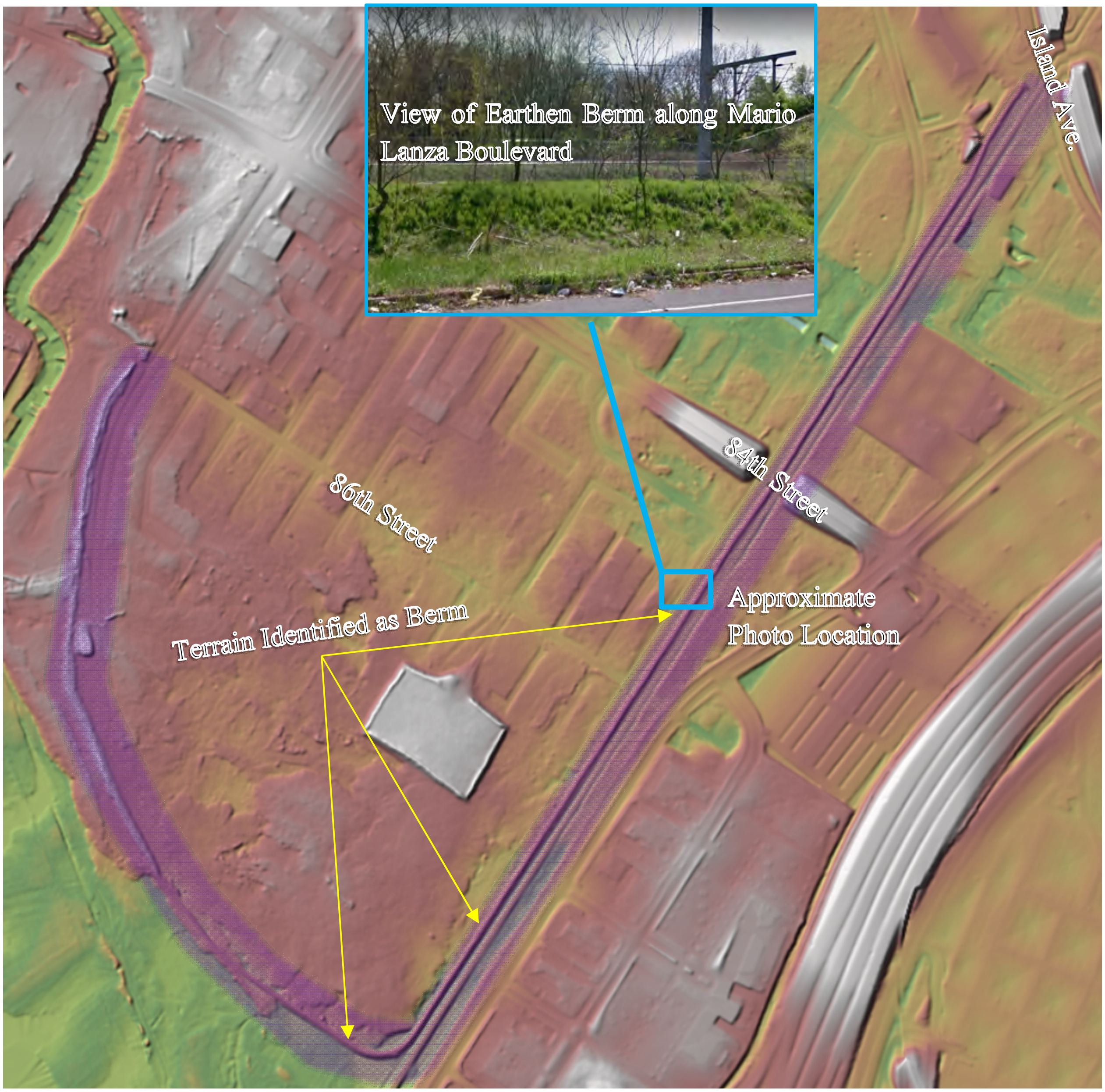


Figure 13: Surface Terrain Model Identifying Earthen Berm

4.0 Model Calibration

The following section provides a high-level summary of the Eastwick model calibration efforts as part of this study. For more details on the model calibration efforts, please refer to Attachment B.

In general, the existing conditions model developed (as described in Section 3.0) was calibrated in areas for which data is available. These areas include the Delaware River and Schuylkill River, Darby Creek up to its confluence with Cobbs Creek, Cobbs Creek up to the overflow, and the 2D model in portions of Eastwick where Tropical Storm Isaias high watermark data is available. Upper reaches of Darby Creek and Cobbs Creek were modeled solely for purposes of more properly representing the timing of flows arriving from upstream gages, and therefore more detailed calibration of these areas is not considered to be important (nor is it possible because of lack of data). Because the Delaware River is large in comparison to Darby and Cobbs Creeks, its flow is not measurably affected by the flow from the creeks. As a result, the Delaware River and Schuylkill River portions of the 1D model were calibrated independently of Darby Creek, Cobbs Creek, and the 2D model.

Two data sets were available for 2D model calibration of Tropical Storm Isaias flows: the Darby Creek gage (USGS 2020) and high watermark data collected by USACE (Dohm 2020). High watermark data were provided in the form of water depths, which were then converted by AKRF to high watermark elevations. This was accomplished by carefully reviewing the reported ground location to determine the nearby vertical object (fence post, tree, pole, etc.) on which the watermark was likely observed at each measurement location. The ground elevation, as determined from the project DEM (see Attachment B), at the point of measurement was estimated and added to the watermark depth to obtain an estimate of high watermark elevation at each reported high watermark location. It is possible that these transformed high watermark data elevations could have an error of a foot or more, given these assumptions.

Initial calibration runs resulted in poor matches with simulated peak water surface elevations two or more feet lower than the peak recorded at the Darby Creek gage. In addition, computed high watermark elevations in the immediate vicinity of Cobbs Creek in Eastwick were significantly lower than the observed watermark elevation data. Further to the southeast in Eastwick, computed elevations from the initial calibration runs were higher than the observed watermark elevation data. Furthermore, the model predicted well over a foot of flooding on 84th Street near the Pepper School. Review of aerial news footage taken during the event (ABC 2020) indicates that flooding of this area on 84th Street was minimal during Tropical Storm Isaias. Taken together, these results indicated that the model was over-predicting flood elevations through Eastwick and under-predicting peak flood elevations near Cobbs Creek.

Further evaluation of flow conditions in the Eastwick overflow area showed that flow impedance had not properly been accounted for where floodwaters had moved through the residential neighborhoods. Two primary factors were identified as the cause of significant impedance. The first factor was the extensive fencing and walls that exist throughout the community. Most of the dwelling units have fenced-in back yards and many also have fenced-in side and front yard areas. Eastwick Park has fencing around tennis and basketball courts as well as other fenced areas and walls. Construction fencing was placed along most of the boundary between the landfill and the residences, and silt fencing upgradient further added to flow impedance in many areas. Review of the aerial news footage indicated that a significant amount of debris may have accumulated in the fences, further increasing flow impedance. Areas with fences are shown in Figure 14 and a Manning's N roughness value of 1.0 was assigned in these areas rather than the mixed vegetation values initially assigned.

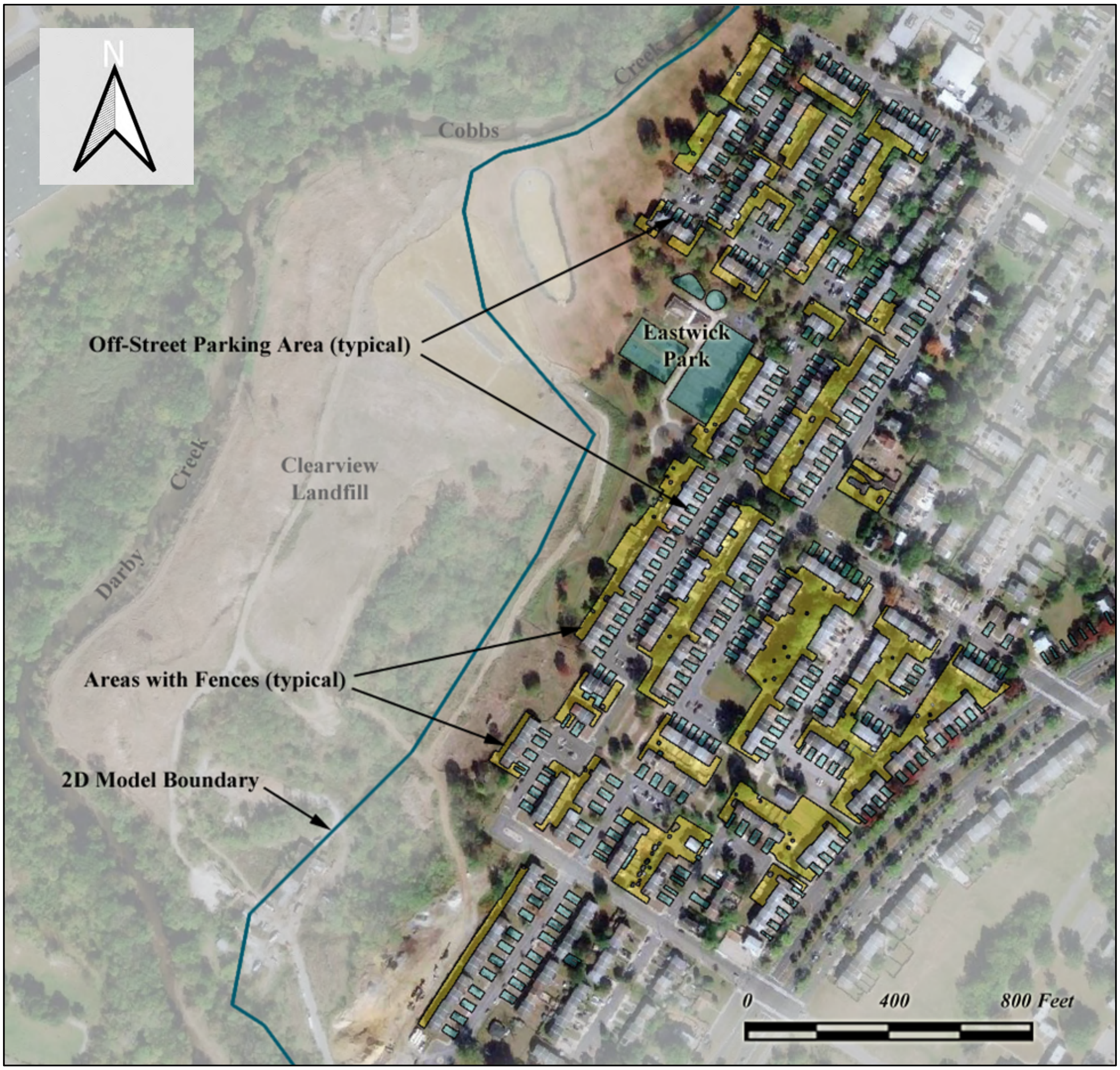


Figure 14: Manning's N Adjustments in Terrestrial Overflow Area

The second impedance factor identified was the large number of vehicles observed in the aerial news footage that were parked both on and off the roadways. An attempt was made to compensate for this by adjusting the off-street parking from the Manning's N value of 0.011 to a value of 0.05. Only off-street values were modified and roadway Manning's N values were maintained at 0.011.

The final calibration plot for results at the Darby Creek gage is shown as Figure 15, with the Philadelphia gage data also shown for reference purposes. A somewhat poor calibration was achieved for tidal stage data on August 3, 2020; however, a reasonably good match of the peak flood was achieved. Given the limited flow and calibration data, and the assumptions made for tributary inflows downstream of the flow gages (see Section 2.1 and Attachment A), it is our assessment that this calibration is reasonable for the purposes of this study.

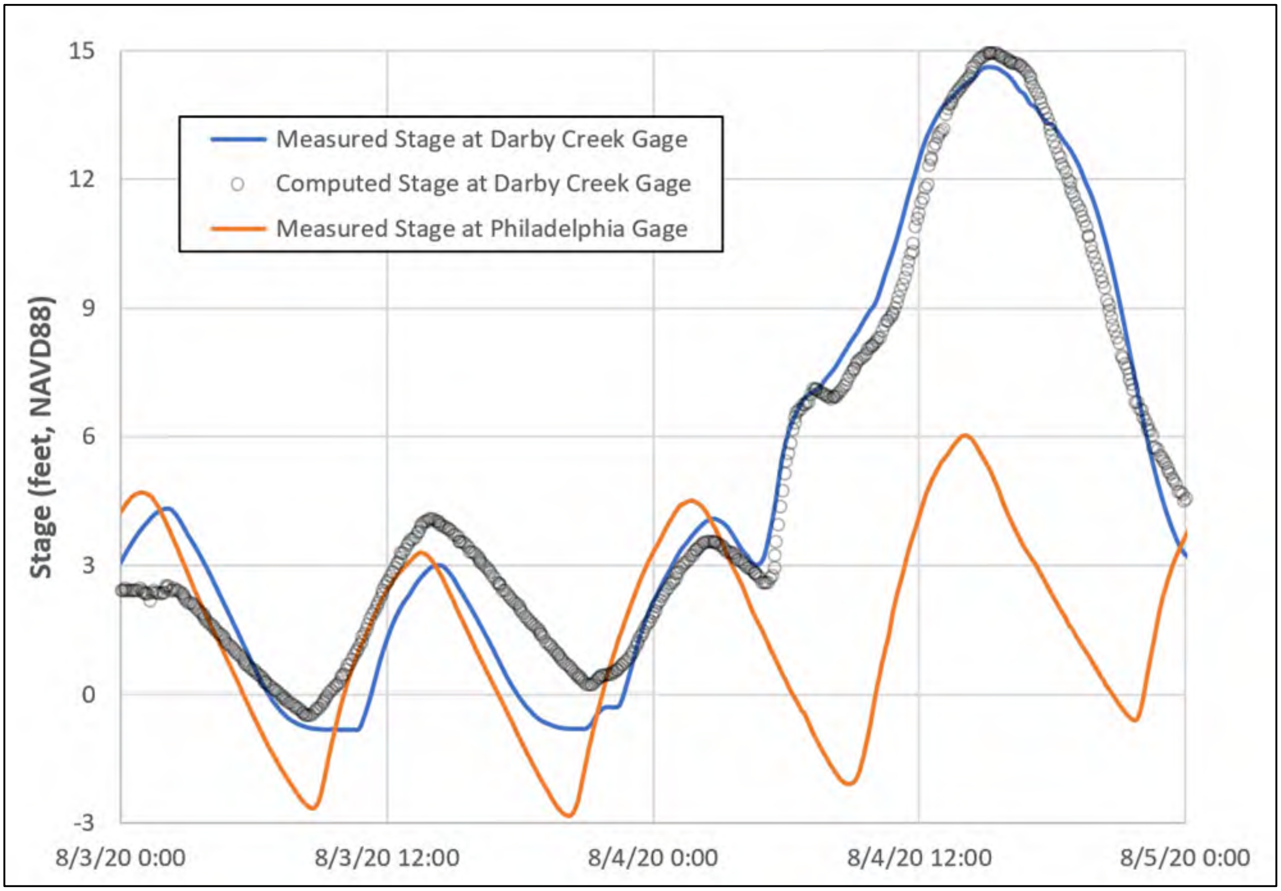


Figure 15: Plot of Final Calibration Results at Darby Creek Gage

Final calibration values and their corresponding high watermark elevations within Eastwick are shown in Figure 16. Figure 17 gives a paired watermark and simulated elevation data plot of the values shown in Figure 16. As Figure 17 shows, the value for the regression fit (R^2 value) is 0.89 and considered high, and, more importantly, the regression line closely matches the exact match line. The Root Mean Square Error[4] (RMSE) is 0.77 (feet), which would include the watermark estimation error (as discussed earlier in this section, there could be errors of a foot or more in these data) as well as model error.

[4] RMSE is a standard way to measure the error of a model in predicting quantitative data and is defined as the square root of the average of the squared differences between observed and predicted values.

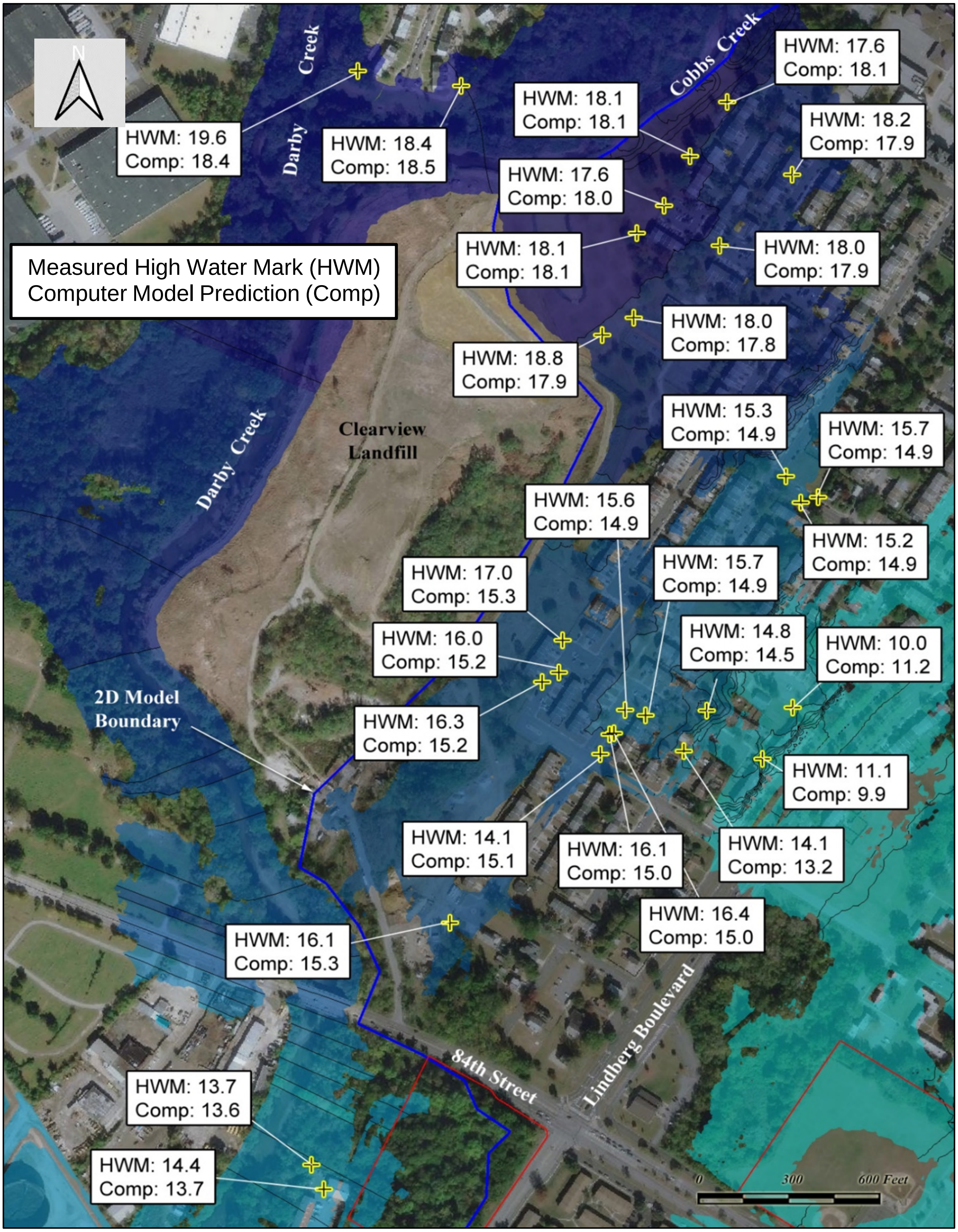


Figure 16: Final 2D Model Calibration vs. High Watermark Data for Tropical Storm Isaias

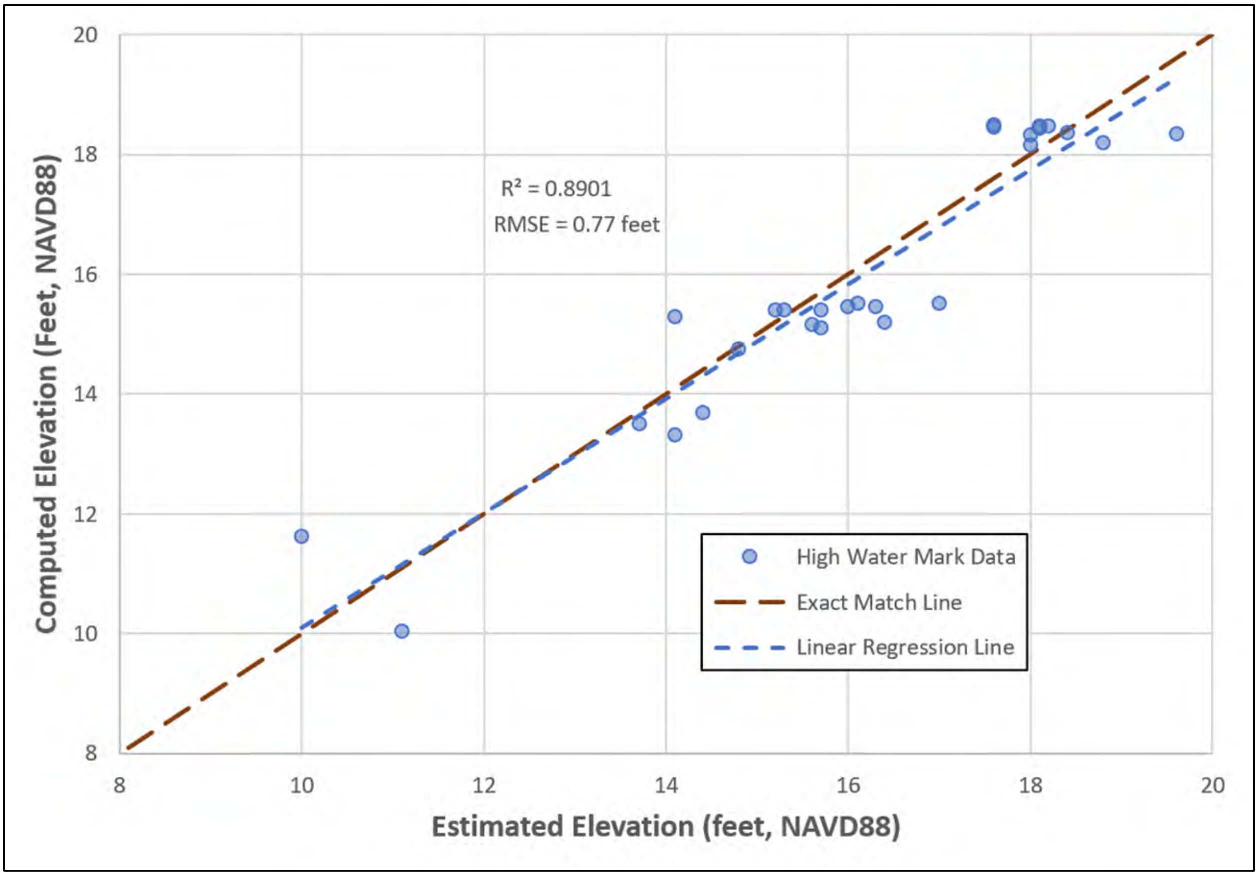


Figure 17: Plot of Computed vs. Observed Watermark Data

Based on the data generated during the final calibration, the constructed model is considered suitable for the purposes of evaluating reuse alternatives for the vacant public lands in Eastwick.

4.1 Model Limitations

This section summarizes the limitations associated with the calibrated model and its appropriate usage for scientific and engineering studies.

4.1.1 Lack of Model Validation by Independent Dataset

One of the more important limitations of this model is that it has not been validated by independent data sets at this time. The model has been calibrated and therefore it is our assessment that it can be utilized for its intended purpose. Future monitoring and data collection in Eastwick would allow for model validation of tidal surge and/or larger terrestrial runoff events. However, it should be mentioned that the model was shared with an independent and external modeling expert group for peer review and comment. These experts consisted of professors and students from Drexel University and Stevens Institute of Technology. During this limited external peer review, no major concerns with the AKRF model were brought forth by the reviewers.

4.1.2 Model Performance Outside Of Calibration Area Uncertainty

The model has been calibrated using observed high water mark data only where this data exists. Outside of this area, generated model results should be interpreted with some level of caution due to several factors, including hyper-localized effects of local storm sewers and street conveyance (see following sections).

4.1.3 Simplified Internal Stormwater Runoff Generation Assumptions

Simplified assumptions to the internal stormwater runoff generation were applied to the model. Given the relative magnitude of the water volume generated from external sources of flooding in comparison to the internal stormwater generated, this simplified approach to mimicking internal stormwater runoff generation likely has minimal effect on the results for the purposes of this study. However, it was still important to model internal stormwater runoff generation to account for all potential sources of water into Eastwick. In doing so, a simplified gross area stormwater loading approach was taken within the model at distributed internal boundary locations throughout Eastwick. Loading stormwater runoff onto the surface terrain model at these locations is a simplified approach to what really occurs in Eastwick. In reality, stormwater runoff is distributed over the entire area and is serviced by a complex network of local stormwater catch basins and underground storm sewer pipes. The model does not simulate localized flooding due to local storm sewer conditions such as limited pipe/inlet conveyance capacities. Given these assumptions, flooding results in the immediate vicinity of the internal boundary condition stormwater loading points should be interpreted with some level of caution.

4.1.4 Simplified Stormwater Removal Assumption

The model applies a simplified approach to mimic the effects of the Mingo Creek Pump Station by removing surface waters from the “Pepper Bowl” area using internal boundary condition lines and constant removal rates. The removal of water from the model only occurs to model grid cells immediately adjacent to these lines. In reality, the pump station would likely have effects beyond just this area and would remove stormwater throughout the storm sewer network. For this reason, the model is limited in its understanding of the removal of stormwater and the overall Eastwick community impacts of the Mingo Creek Pump Station. However, given the relative magnitude of water volume generated from flooding in comparison to the Mingo Creek Pump Station capacity, the effects of the pump station are likely minimal on the results generated for the purposes of this study.

4.1.5 Disclaimer

This model has been constructed to evaluate the potential for beneficial reuse of available public lands, as outlined in the LEPLS and approved by Eastwick Community Stakeholders with the support of city, state, and federal agencies. While it is our hope as scientists and engineers that this model may also be useful to other related studies in the area, it should not be used or considered for alternative purposes or objectives other than that for which it was intended. As with any similar flood model, this tool should not be used indiscriminately without first confirming all assumptions and inputs that would establish conditions or guide appropriate adjustments for alternative objectives.

5.0 Model Results

5.1 Existing Conditions

Using the calibrated model, the storm event boundary condition cases as previously discussed in Section 2.0 (and Attachment A) were simulated in the model. The selected storm event cases for modeling analysis included the following:

- Case 1: Tropical Storm Isaias (August 4, 2020)
- Case 2: The 100-year terrestrial event
- Case 3: Hurricane Sandy (October 30, 2012)
- Case 4: The Great Appalachian Storm of 1950 adjusted to 2020
- Case 5: The 100-year terrestrial event estimated at 2100
- Case 6: The Great Appalachian Storm of 1950 adjusted to 2100
- Case 7: The 100-year terrestrial event coincident with 10-year tidal event
- Case 8: The 10-year terrestrial event coincident with Great Appalachian Storm of 1950 adjusted to 2020

For each of the above cases, the plotted results for both computed maximum water depths and computed maximum water surface elevations are provided in Attachment B. The existing condition results are used for comparative purposes (i.e., baseline conditions) to potential reuse scenarios for Sites 1, 2, and 3 (see Figure 18 adapted from the LEPLS report).

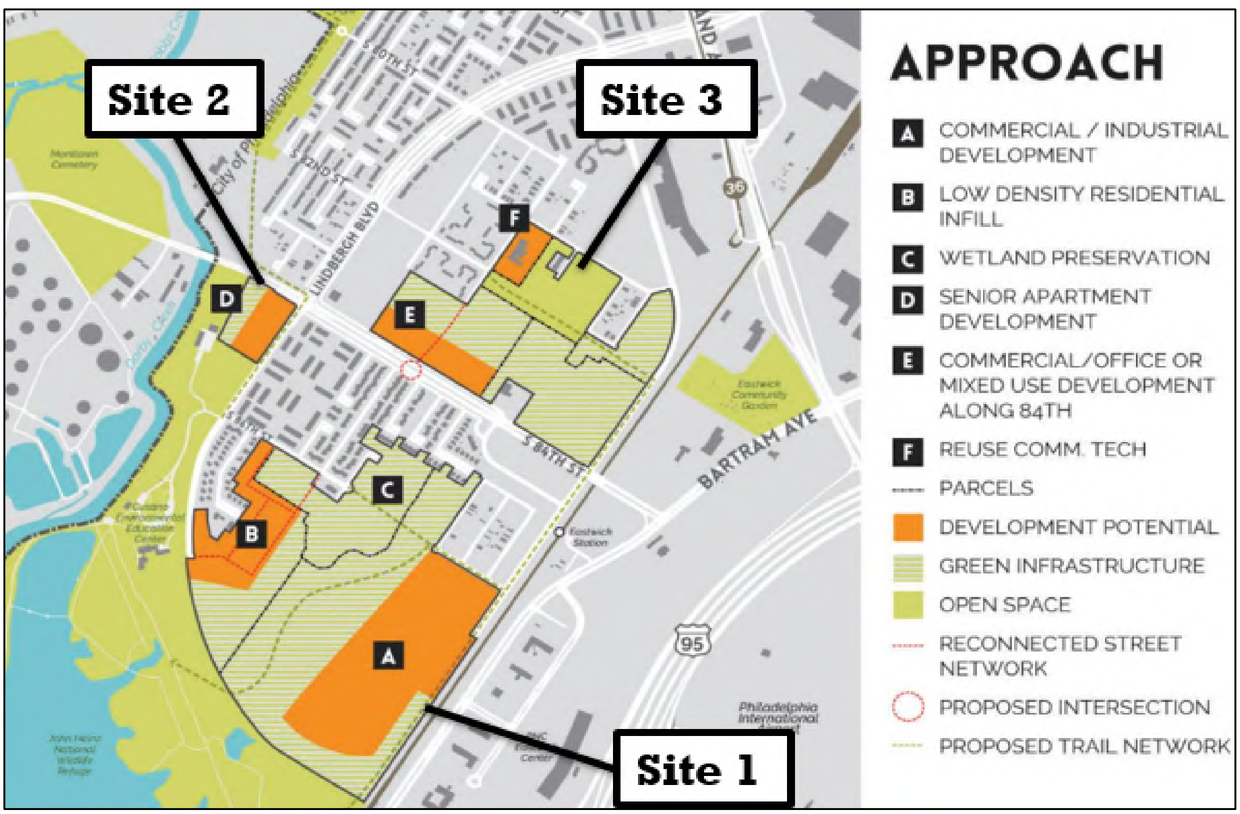


Figure 18: Proposed Beneficial Reuse Sites (Source: LEPLS)

The existing conditions model was used to evaluate where and how flooding (i.e., the sources of flooding) comes into Eastwick. Flooding into Eastwick can result from several sources, these include:

1) Cobbs Creek overtopping its banks just upstream of the landfill near 78th Street;
2) Tidal surges from the John Heinz National Wildlife Refuge;
3) Tidal surges from eastward in the vicinity of the Philadelphia International Airport from the opening at Island Avenue below I-95 interchange;
4) Overtopping of the Darby Creek in a gap just downstream of the landfill near 86th Street.

Table 3 provides a summary of how floodwaters enter the Eastwick community for each storm event for the existing conditions model simulations.

Table 3: Existing Conditions Model Simulation Sources of Flooding into Eastwick

Case	Storm Event	Storm Event Type	Eastwick Flooding Sources			
			Cobbs Creek upstream of landfill near 78th Street	**Tidal surge from John Heinz National Wildlife Refuge**	**Tidal surge from Airport/ I-95**	**Darby Creek at 86th Street gap**
1	Tropical Storm Isaias (August 4, 2020)	Terrestrial	☑			☑
2	The 100-year Terrestrial Event	Terrestrial	☑			
3	Hurricane Sandy (October 30, 2012)	Tidal	No flooding indicated in model other than internally generated stormwater runoff			
4	The Great Appalachian Storm of 1950 Adjusted to 2020	Tidal	☑			☑
5	The 100-year Terrestrial Event Estimated at 2100	Terrestrial Plus Climate Change Projections	☑			☑
6	The Great Appalachian Storm of 1950 Adjusted to 2100	Tidal Plus Climate Change Projections	☑	☑	☑	☑
7	The 100-year Terrestrial Event & 10-year Tidal Event	Terrestrial and Tidal	☑			☑
8	The 10-year Terrestrial Event & Great Appalachian Storm of 1950 adjusted to 2020	Terrestrial and Tidal	☑			☑

Table 4 provides a summary of the general level of severity of flood inundation experienced at the Vacant public land sites for each storm event under existing conditions. In this table, the level of severity is defined by the percentage of the property area that is by inundated by floodwater during the event. Detailed flood maps for each case scenario are provided in Attachment B.

Table 4: Existing Conditions Severity of Flood Inundation at Vacant Public Land Sites

Case	Storm Event	Site 1	Site 2	Site 3
1	Tropical Storm Isaias (August 4, 2020)	Low	Low	Severe
2	The 100-year Terrestrial Event	Medium	Low	Severe
3	Hurricane Sandy (October 30, 2012)	Low	Low	High
4	The Great Appalachian Storm of 1950 Adjusted to 2020	Low	Low	High
5	The 100-year Terrestrial Event Estimated at 2100	High	Low	Severe
6	The Great Appalachian Storm of 1950 Adjusted to 2100	High	Low	Severe
7	The 100-year Terrestrial Event & 10-year Tidal Event	Medium	Low	Severe
8	The 10-year Terrestrial Event & Great Appalachian Storm of 1950 adjusted to 2020	Low	Low	Severe

Low = 0-10% inundation
Medium = 10-50% inundation
High = 50-75% inundation
Severe = >75% inundation

The 100-year terrestrial event (Case 2) is an important event, as it is used for the National Flood Insurance Program (NFIP) and City of Philadelphia land development floodplain regulation purposes. The computed maximum water depth results for the existing conditions 100-year terrestrial event are shown in Figure 19. Maximum water depth results maps for all scenarios are provided within Attachment B.

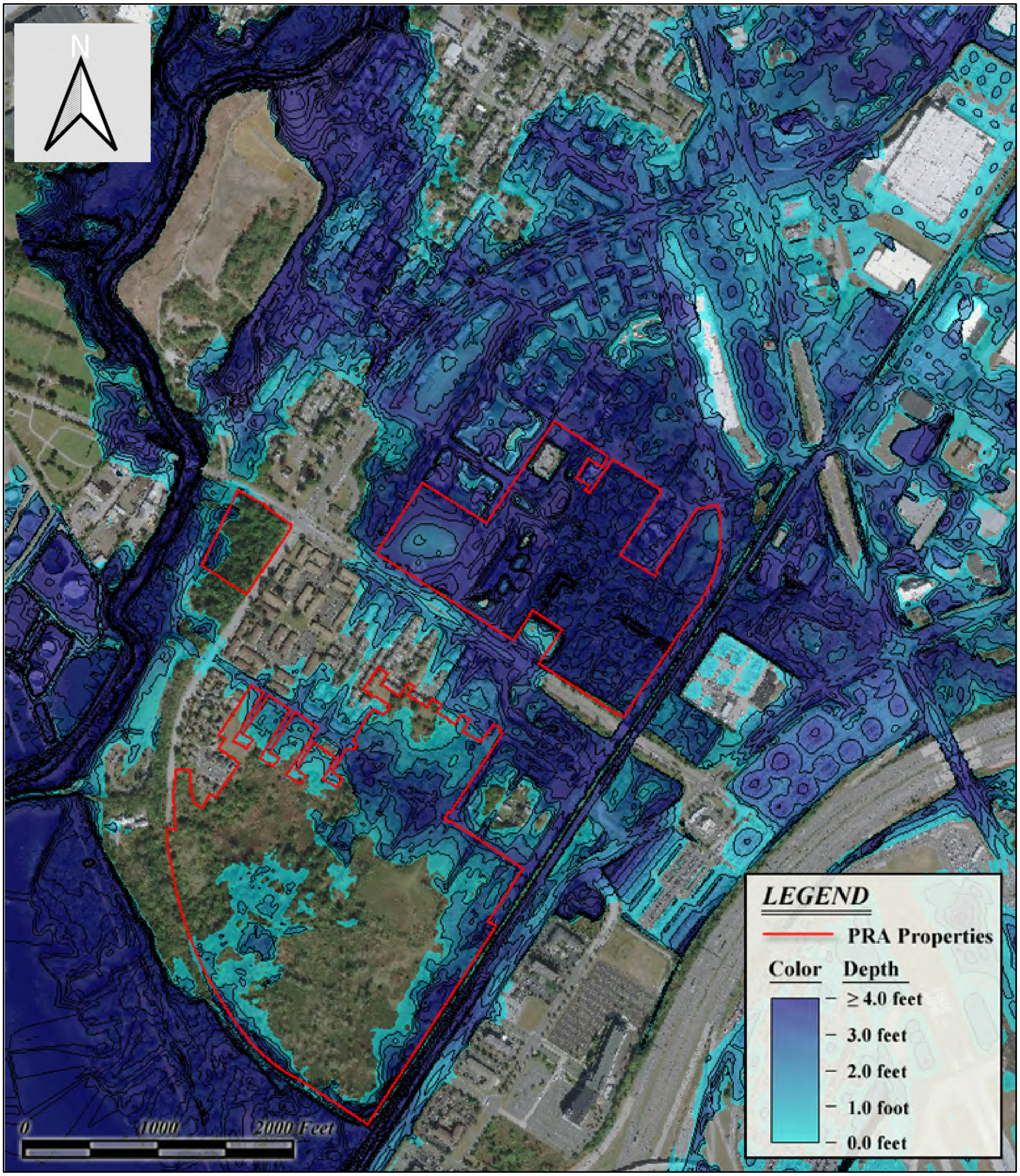


Figure 19: Maximum Depth for Existing Conditions 100-Year Terrestrial Flood Event

The existing conditions model results provide a baseline to compare potential future beneficial reuse scenarios at the Vacant public land sites. These scenarios and model results are provided in the following sections.

5.1.1 Existing Earthen Berm Flood Protection Results

A key finding from the existing conditions model results is the flood protection performance of the manmade earthen berm along the John Heinz National Wildlife Refuge and the SEPTA rail line. As previously shown in Table 3, model results indicate that flooding into Eastwick is protected from tidal surges for all flooding events analyzed except for the 2100 future climate change sea level rise projection (Case 6). For example, Figure 20 depicts the maximum water depths for Hurricane Sandy, which was primarily a tidal event in Philadelphia. Model results indicate that the berm held back significant possible tidal flood waters from entering Site 1 and the surrounding residential homes.

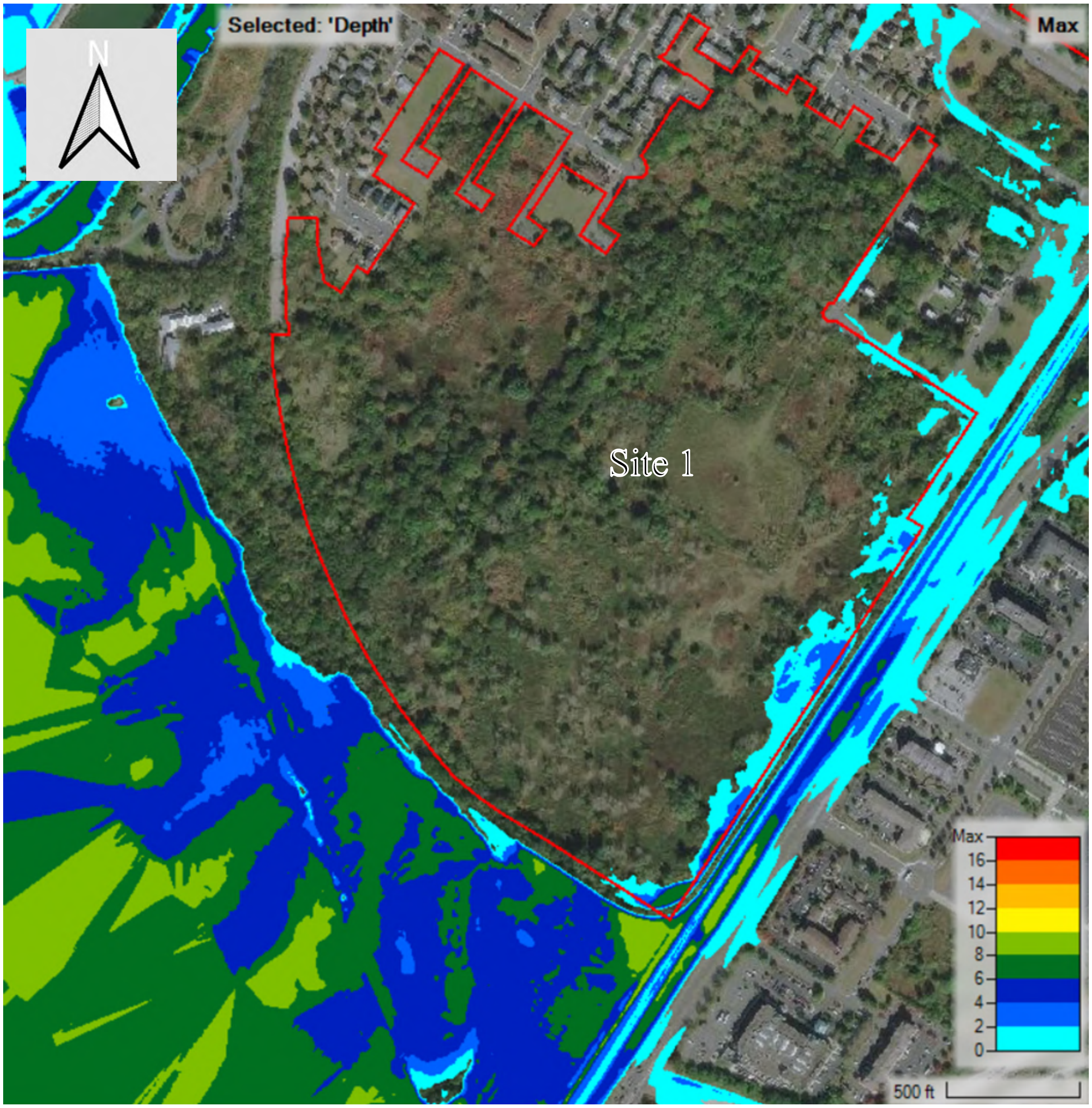


Figure 20: Maximum Floodwater Depth from Hurricane Sandy, Indicating the Tidal Floodwater Protection Effect of Earthen Berm

However, for the future climate projection flooding event, the Great Appalachian Storm of 1950 Adjusted to 2100 (Case 6), the model results indicate that the earthen berm becomes overtopped from tidal surges entering from the John Heinz National Wildlife Refuge and the gap at Island Avenue leading to Eastwick from the Philadelphia International Airport. The results of this simulation with flow particle tracing from HEC-RAS are shown in Figure 21.

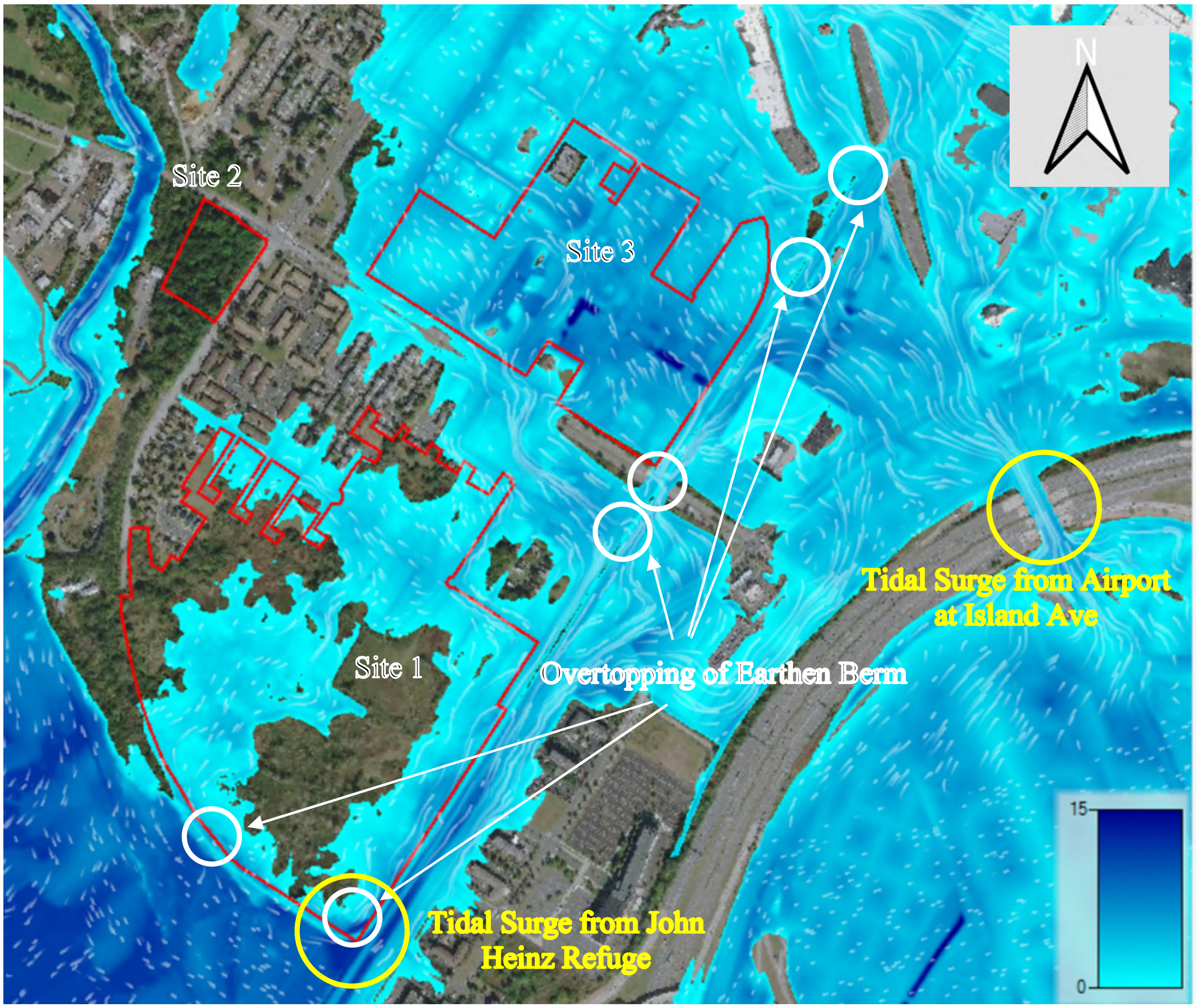


Figure 21: 2100 Future Sea Level Rise Model Projections with Flow Particle Tracing

5.2 <u>LEPLS Reuse Concepts</u>

The primary purpose of this study was to test the calibrated model using the conceptual site development plans included in the LEPLS. An overview of the conceptual site development plans for Sites 1, 2, and 3 from the LEPLS is shown in Figure 18. Analyzing the proposed concepts with a site-specific model improves the understanding of how changes to the vacant landscape may or may not impact flooding in Eastwick.

The LEPLS recommended regrading Site 1 to support building pads at the western and eastern bounds while reductions ("cuts") in topography in the central portion could serve as additional storage for floodwaters and potentially assist in flood mitigation. The proposed strategies are illustrated in Figure 22 and Figure 23 (both taken directly from the LEPLS).

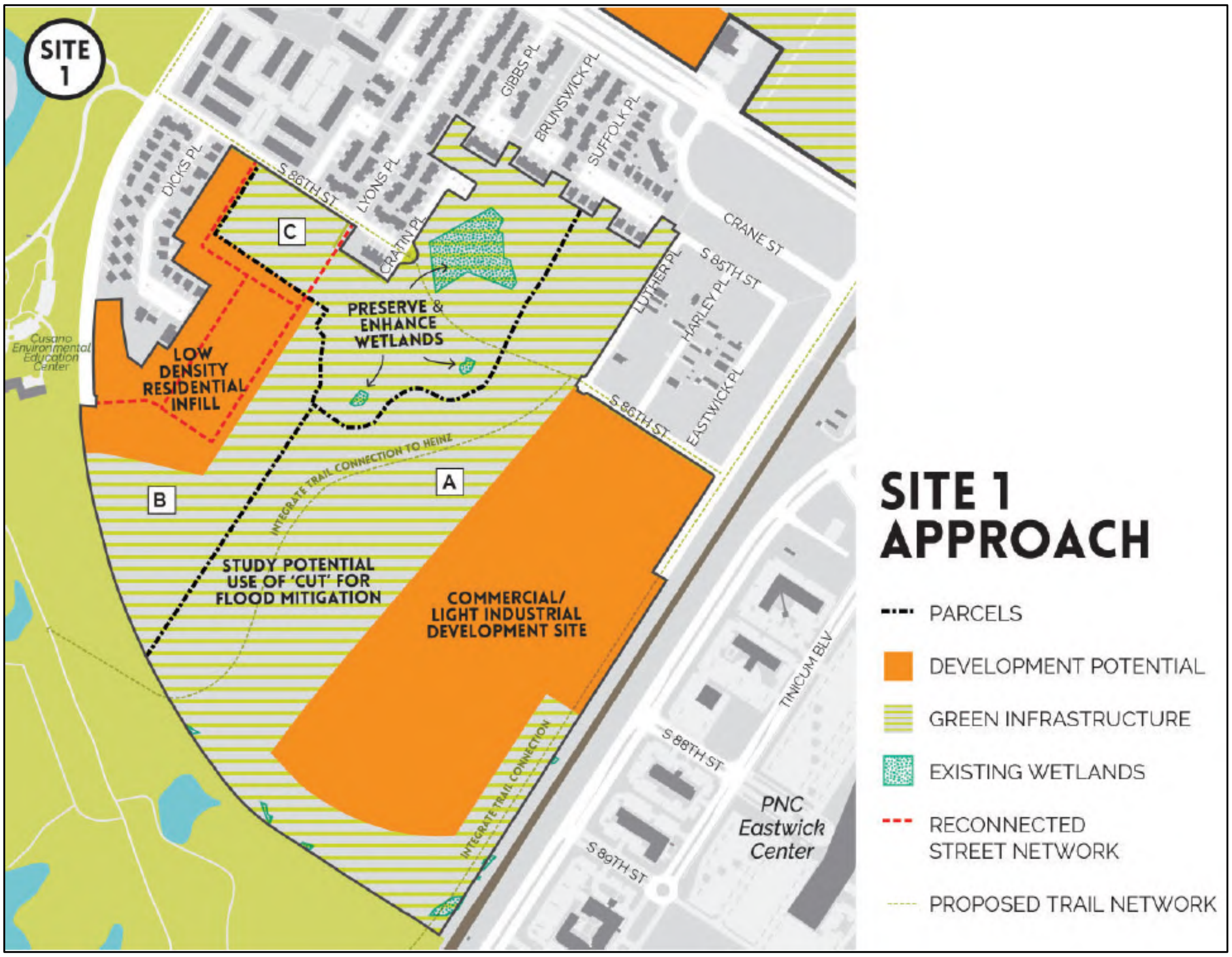


Figure 22: Flood Mitigation Strategy with Potential Redevelopment at Site 1 (LEPLS)

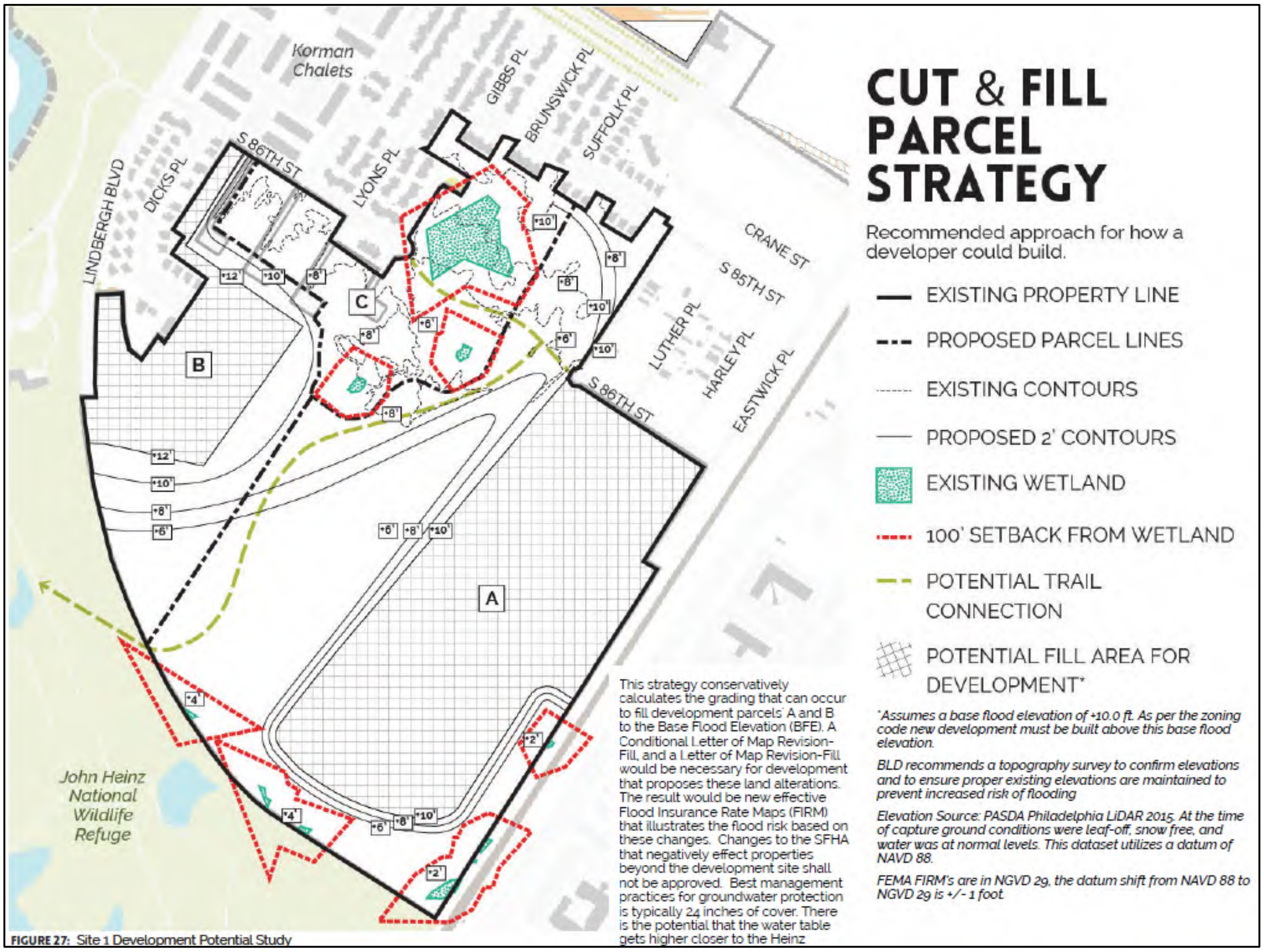


Figure 23: Proposed Regrading Strategy at Site 1 (LEPLS)

The regrading plan contour lines shown in Figure 23 were recreated in the HEC-RAS model to modify the existing conditions surface terrain. A comparison of the surface terrain models for existing conditions and the LEPLS reuse concepts is shown in Figure 24.

As shown in Figure 24, the surface terrain model was modified within Sites 1 and 3 to accommodate more flood storage in Site 1, and new elevated building pads on both Site 1 and Site 3. The terrain model was not modified at Site 2 due to its already high elevation, and since regrading plans for Site 2 were not included in the LEPLS concepts.

Using the modified surface terrain model, each boundary condition storm event was re-simulated in HEC-RAS to evaluate the resultant change to the maximum water depth flood elevations throughout Eastwick. A comparison of the maximum water depth between existing and the LEPLS reuse concepts for the 100-year terrestrial event are shown in Figure 25. The change in flooding depth reductions is shown in Figure 26. Additional results for the other analyzed flooding events are provided in Attachment C.

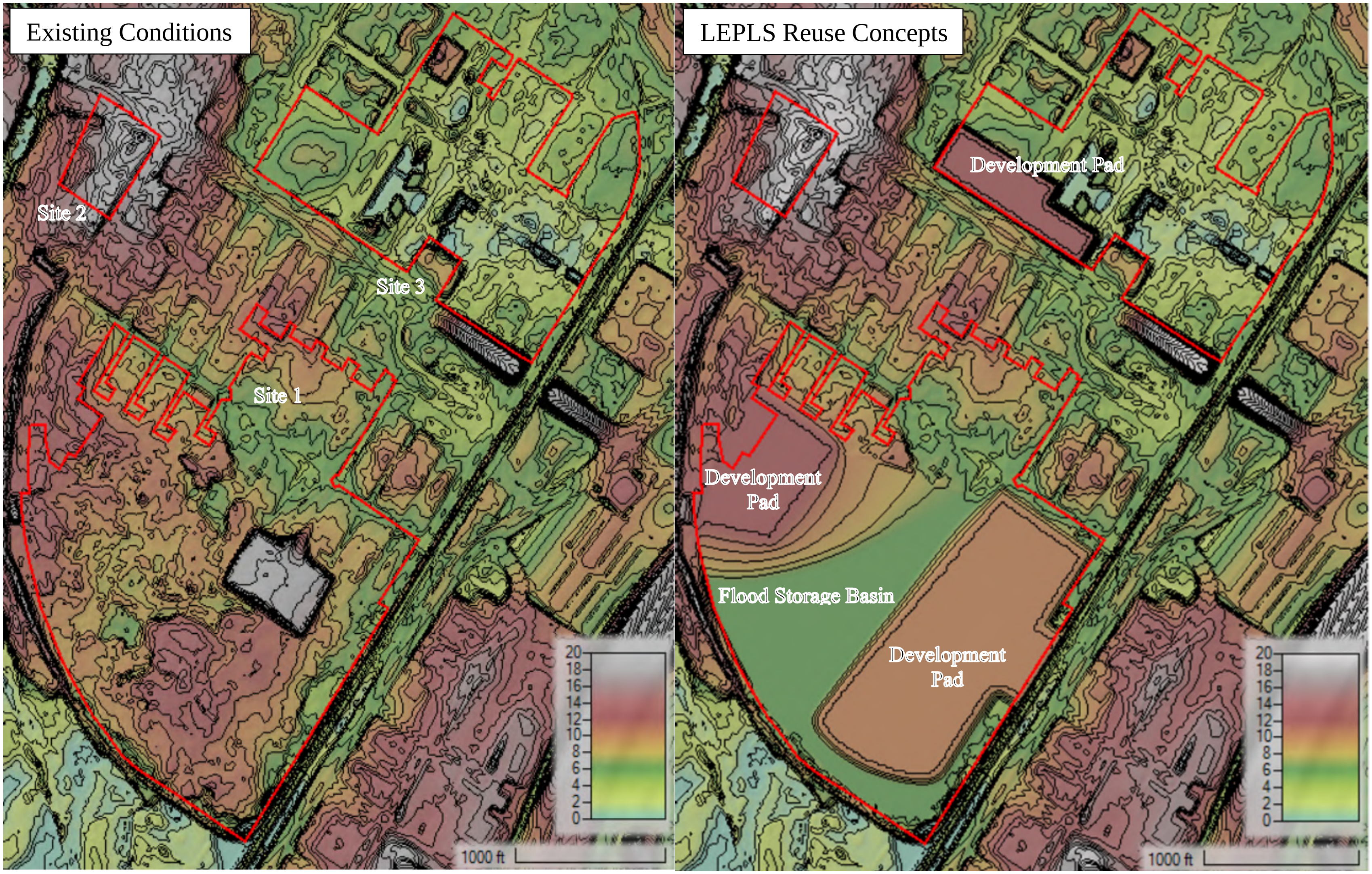
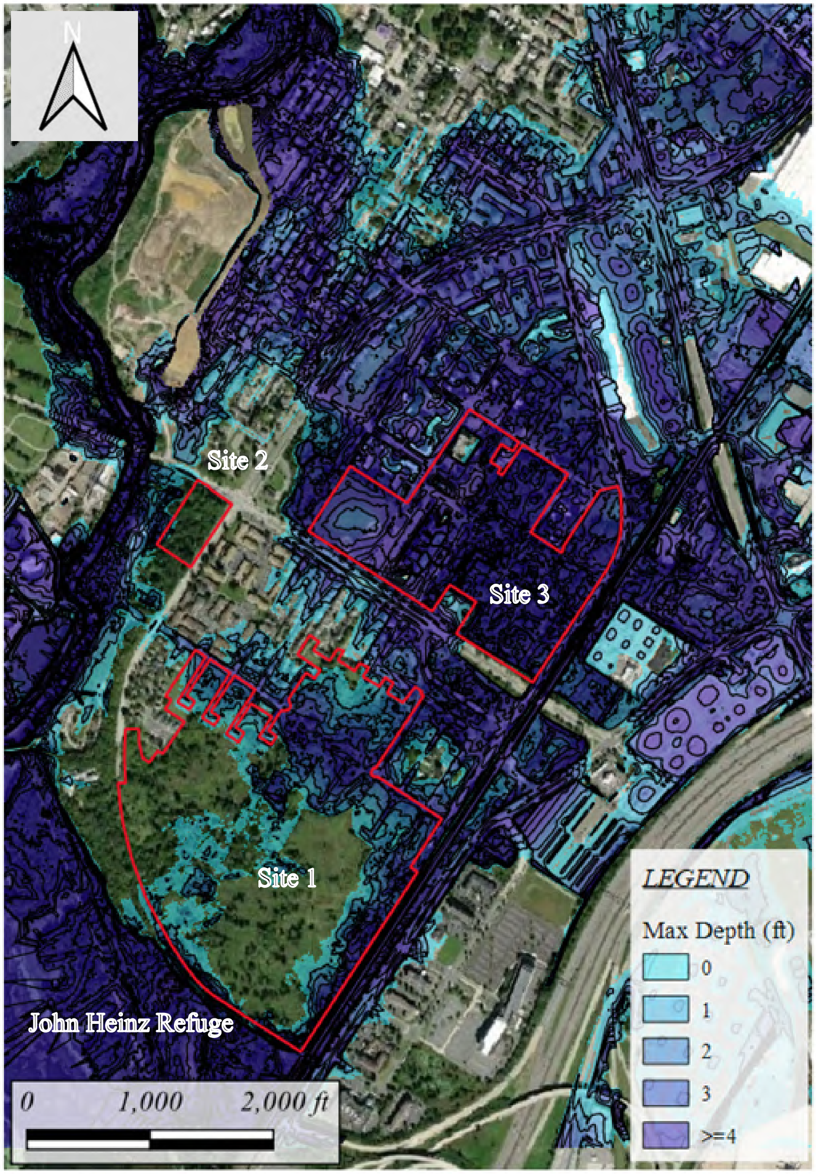


Figure 24: Comparison of Surface Terrain – Existing Conditions vs. LEPLS Reuse Concept



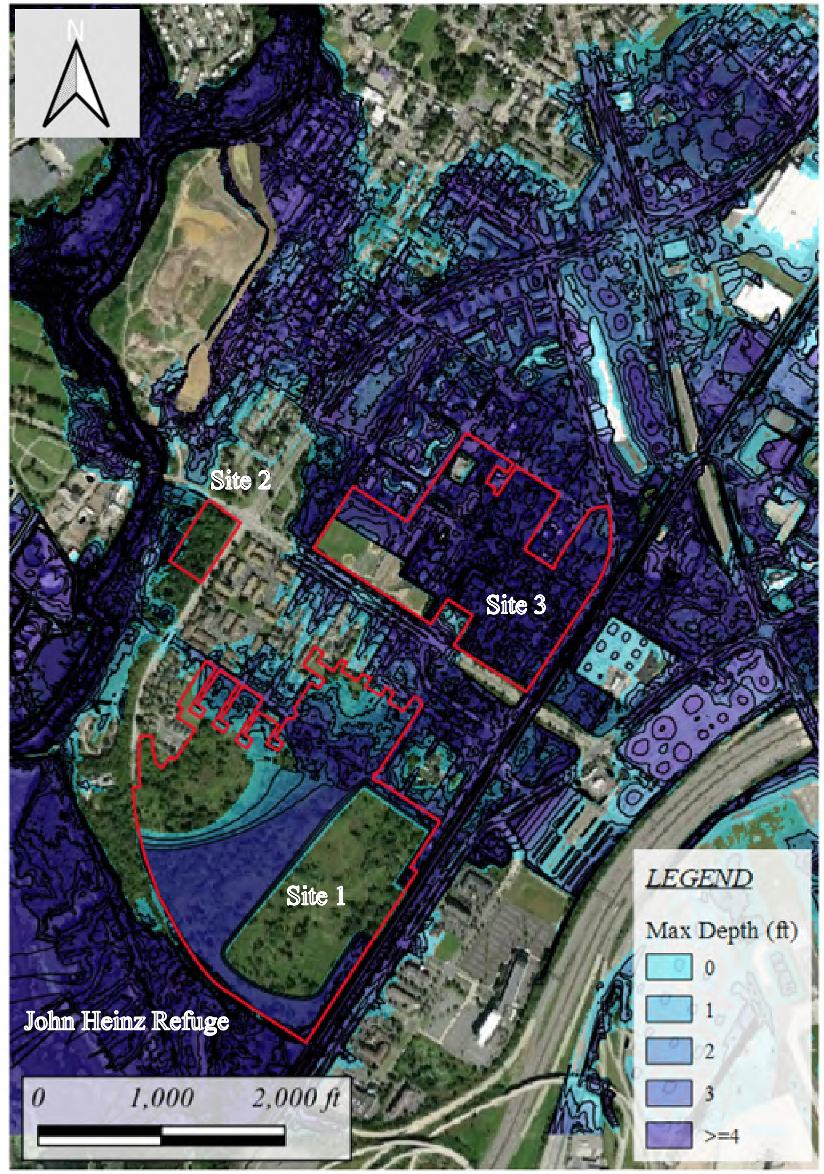


Figure 25: Existing Conditions (Left) and LEPLS Reuse (Right) 100-Year Terrestrial Event Flooding Depths

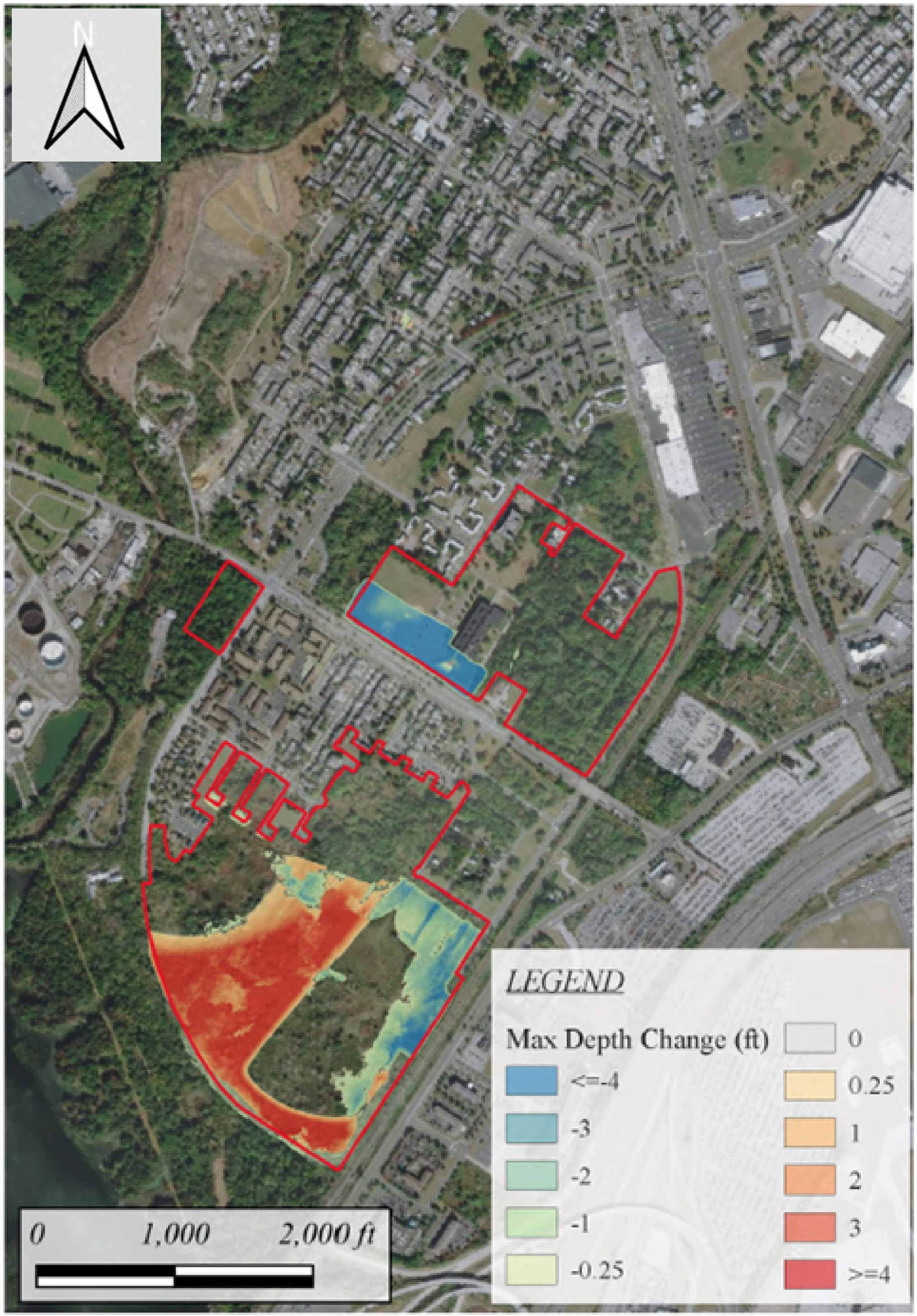


Figure 26. Flooding Depth Change Between Existing Conditions and LEPLS Reuse Concepts for the 100-Year Terrestrial Event

As shown from the results in Figure 25, under the 100-year terrestrial flood event, the proposed regrading as part of LEPLS will store more floodwater at Site 1 adjacent to the John Heinz National Wildlife Refuge area. However, this additional storage volume is not enough of an offset to reduce flooding in Eastwick by itself. Additional flood mitigation measures will be needed elsewhere, such as a structural levee along Cobbs Creek to prevent water from overtopping into Eastwick.

The model results indicate that the creation of elevated development pads on Sites 1 and 3 do not increase flooding depths in the immediate vicinity of the properties (with the exception of the intentionally designed flood retention on Site 1 area near John Heinz National Wildlife Refuge) for the 100-year terrestrial event. The results indicate the proposed elevations of the site development pads are high enough not to be inundated with floodwater. However, as shown in the maximum flood depth panel in Figure 25, similar to the existing conditions analysis, access to the Sites will be constrained due to flooding of major roadways, particularly along 84th Street and the bridge leading to Sharon Hill in Delaware County.

A summary table describing the model results of all the flooding events analyzed is shown in Table 5, below. The results are described for both the Vacant public land sites and the surrounding Eastwick Community. As seen from the table, the results vary depending on the type of flood event analyzed. The following are some key findings:

1) Reuse of Site 1, Site 2, and Site 3 per the LEPLS conceptual site development plans did not increase or decrease flood depths in the Eastwick community for the following modeled flood events:
    - Case 1: Tropical Storm Isaias (August 4, 2020)
    - Case 2: The 100-year terrestrial event
    - Case 3: Hurricane Sandy (October 30, 2012)
    - Case 4: The Great Appalachian Storm of 1950 adjusted to 2020
    - Case 5: The 100-year terrestrial event estimated at 2100
    - Case 7: The 100-year terrestrial event coincident with 10-year tidal event
    - Case 8: The 10-year terrestrial event coincident with Great Appalachian Storm of 1950 adjusted to 2020

For Case 6: The Great Appalachian Storm of 1950 adjusted to 2010 (for future sea level rise climate projections), the LEPLS concepts increase flooding in the surrounding Eastwick community by approximately 0.5 foot to 1.0 foot primarily in the vicinity of 86th street, 84th street, and Lindbergh Boulevard north of 84th street. This is most likely due to the addition of the elevated development pads on Sites 1 and 3. Even though the flood storage benefit is realized in the flood retention area on Site 1, a cut and fill soil quantity balance for Sites 1 and 3 was not performed for the LEPLS concepts, as this was not within the scope of the study. Additional grading studies for Site 1 could be undertaken to determine if alternative grading could mitigate the increases in flood depth associated with this flood event and still allow for elevated development pads. These additional grading studies are beyond the scope of this study. The results for this analysis are shown in Figure 27 and
Figure 28.

2) As observed in existing conditions, access to Site 1, Site 2, and Site 3 is impacted by flood water inundation of major roadways, including Lindbergh Boulevard, 84th Street, and the bridge leading to Sharon Hill in Delaware County, for all modeled flood events except Hurricane Sandy.
3) The intentional flood retention on Site 1 was not utilized for Cases 1, 3, and 8. This is because 84th Street acts as a barrier preventing flood waters from being transported from the “Pepper Bowl” at Site 3 to Site 1. To fully realize the capture potential of the flood retention area, a culvert or other conveyance infrastructure would be needed to connect these two areas.

Table 5: LEPLS Reuse Concepts Model Results Summary Table

Case	Storm Event	Observed Model Flood Depth Changes in Vacant Public Land	Observed Model Flood Depth Changes in Eastwick
1	Tropical Storm Isaias (August 4, 2020)	Small positive and negative changes near the periphery of the development pads for Sites 1 and 3. No changes on Site 2.	No changes in flooding depths to Eastwick Community.
2	The 100-year Terrestrial event	Increased flood storage in Site 1 due to intentional flood retention regrading concept. Moderate beneficial changes of 2 to 3 feet in flood depth reductions on the development pads for Sites 1 and 3. No changes on Site 2.	No changes in flooding depths to Eastwick Community.
3	Hurricane Sandy (October 30, 2012)	Small positive and negative changes near the periphery of the development pads for Sites 1 and 3. No changes on Site 2.	No changes in flooding depths to Eastwick Community.
4	The Great Appalachian Storm of 1950 Adjusted to 2020	Small positive and negative changes near the periphery of the development pads for Sites 1 and 3. No changes on Site 2.	No changes in flooding depths to Eastwick Community.
5	The 100-year terrestrial event estimated at 2100	Increased flood storage in Site 1 due to intentional flood retention regrading concept. Development pads at Site 1 inundated with increased flood depths of approximately 1 foot. Development pad at Site 3 elevated above flood water. No changes on Site 2.	No changes in flooding depths to Eastwick Community.
6	The Great Appalachian Storm of 1950 adjusted to 2100	Increased flood storage in Site 1 due to intentional flood retention regrading concept. The majority of Site 1, including development pads, inundated with increased flood depths. No changes on Site 2.	Increased flooding depths of approximately 1 foot near 86th Street. Increased flooding depths of ~0.5 foot in the vicinity of Lindberg Boulevard.
7	The 100-year terrestrial event & 10-year tidal event	Increased flood storage in Site 1 due to intentional flood retention regrading concept. Moderate beneficial changes of 2 to 3 feet in flood depth reductions on the development pads for Sites 1 and 3. No changes on Site 2.	No changes in flooding depths to Eastwick Community.
8	The 10-year terrestrial event & the Great Appalachian Storm of 1950 adjusted to 2020	Small positive and negative changes near the periphery of the development pads for Sites 1 and 3. No changes on Site 2.	No changes in flooding depths to Eastwick Community.

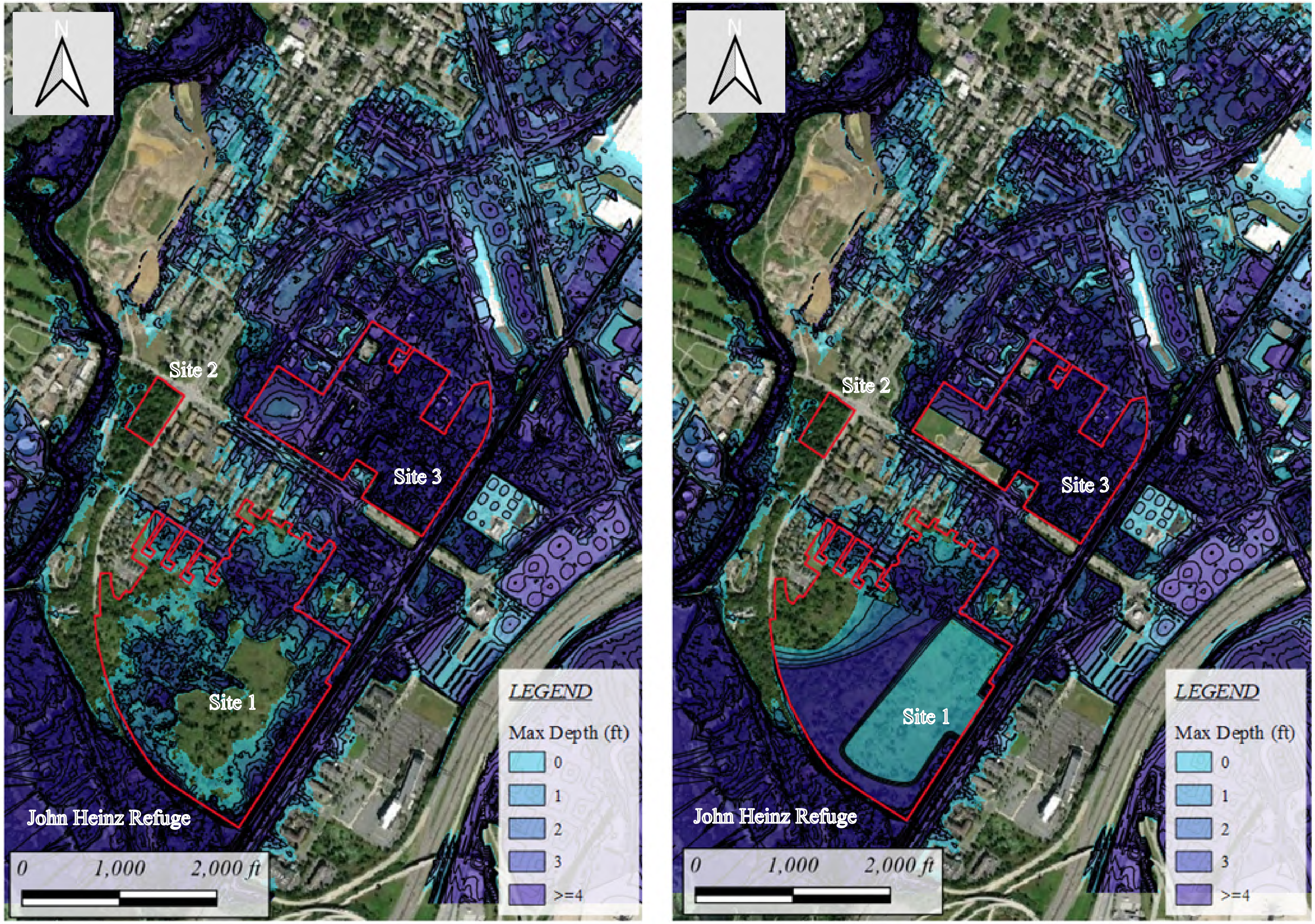


Figure 27. Existing Conditions (Left) and LEPLS Reuse (Right) 2100 Future Sea Level Rise Event (Case 6) Flooding Depths

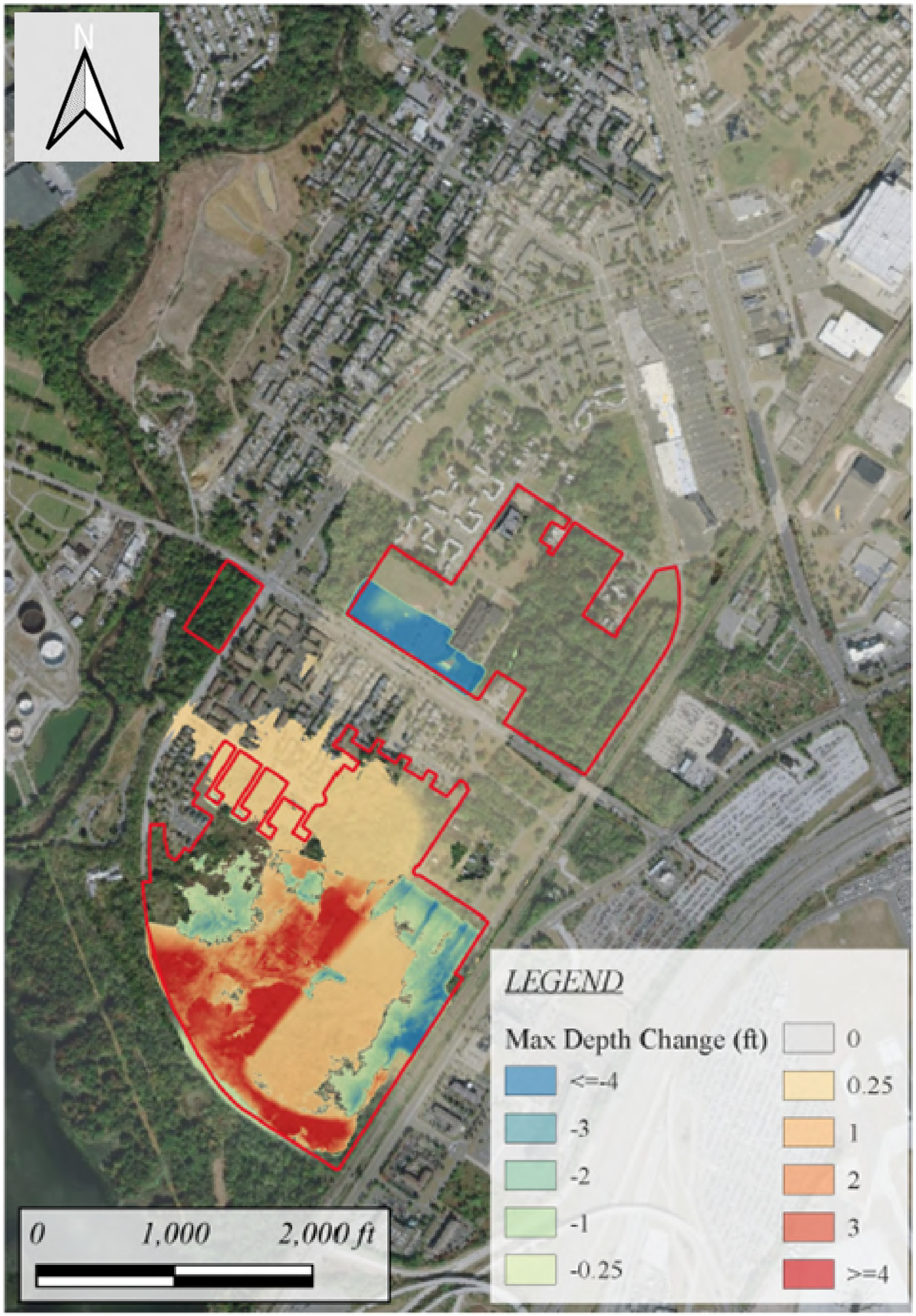


Figure 28. Flooding Depth Change Between Existing Conditions and LEPLS Reuse Concepts for the 2100 Future Sea Level Rise Event (Case 6)

5.3 Constructed Wetlands and Storage Basins Consideration

One unique and positive advantage of the vacant public land sites is the amount of available open green space and their proximity to the John Heinz National Wildlife Refuge. Future redevelopment efforts, particularly at Sites 1 and 3 due to their low elevations, could offer an opportunity for providing enhanced ecological restoration benefits to the surrounding Eastwick community. Enhanced ecological restoration at these Sites could be multifunctional: stormwater wetland systems that provide enhanced natural aesthetics, recreational benefits, wildlife habitats, stormwater treatment and storage during small intensity rain events, and flood mitigation storage during large flooding events. A representative example photo of an engineered stormwater wetland designed by AKRF elsewhere in Philadelphia is shown in Figure 29.

Figure 29: Example Stormwater Wetland Project in Philadelphia

Similar types of stormwater wetlands could be constructed in the existing open green spaces at Sites 1 and 3. Furthermore, the stormwater wetlands could be interconnected and linked together with culvert pipes under the roadway of 84th Street to transfer flooding and stormwater from the Site 3 to Site 1. Linking the two sites together could further maximize water storage and flood mitigation benefits, creating a "maximum ecological restoration" scenario. Evaluating a maximum ecological restoration scenario effectively sets an "upper bound" on what can be realistically accomplished in terms of flood mitigation on the vacant public land sites within Eastwick.

To evaluate the effects of this scenario, the existing HEC-RAS model was modified in a similar fashion as previously described in Section 5.2, LEPLS Reuse Concepts. A side-by-side comparison of the HEC-RAS surface terrain model for existing conditions and the maximum ecological restoration scenario can be seen in Figure 30. As shown, the surface terrain model was modified to create two large wetland storage systems on Sites 1 and 3. This involved establishing a setback from property boundaries and grading within the setback from existing ground surface down to approximated groundwater at 5:1 side slope. Both basins provide approximately 10-15 feet in effective water storage depth, assuming an empty basin prior to a flood event. For the purposes of this modeling exercise, the basins were assumed to be fully empty at the start of the simulations to understand full maximum potential benefits.

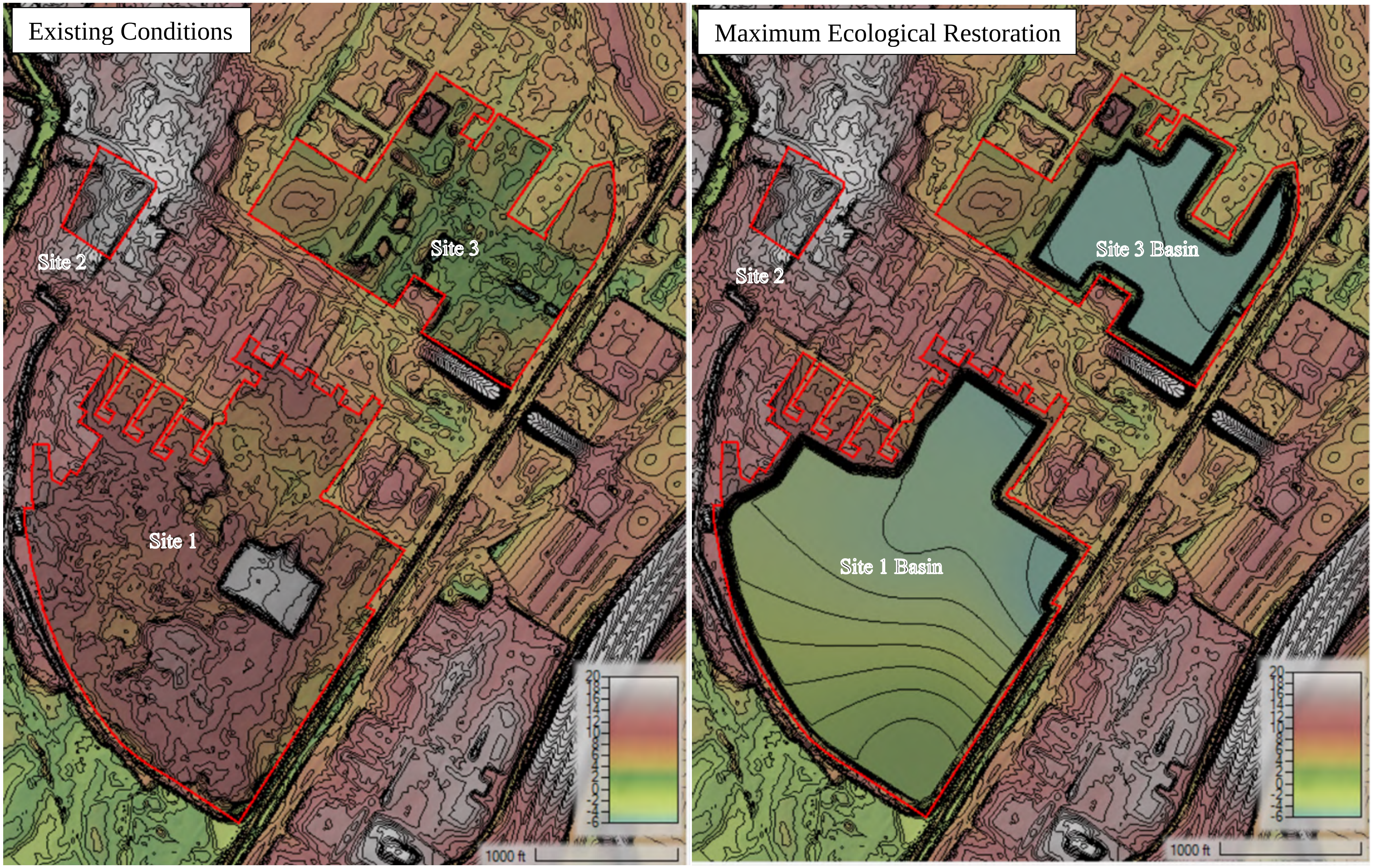


Figure 30: Comparison of Surface Terrain for Existing Conditions and Maximum Ecological Restoration Scenario

Once the surface terrain model was modified to include the basins, a 10-foot-high by 50-foot-wide underground box culvert was inserted into the HEC-RAS model to provide a hydraulic connection between the basins at Sites 1 and 3 and allow the transfer of flood waters between Sites. A screen capture of the culvert in HEC-RAS with flow particle tracing depicting water flowing through the culvert from Site 3 to Site 1 is shown in Figure 31.

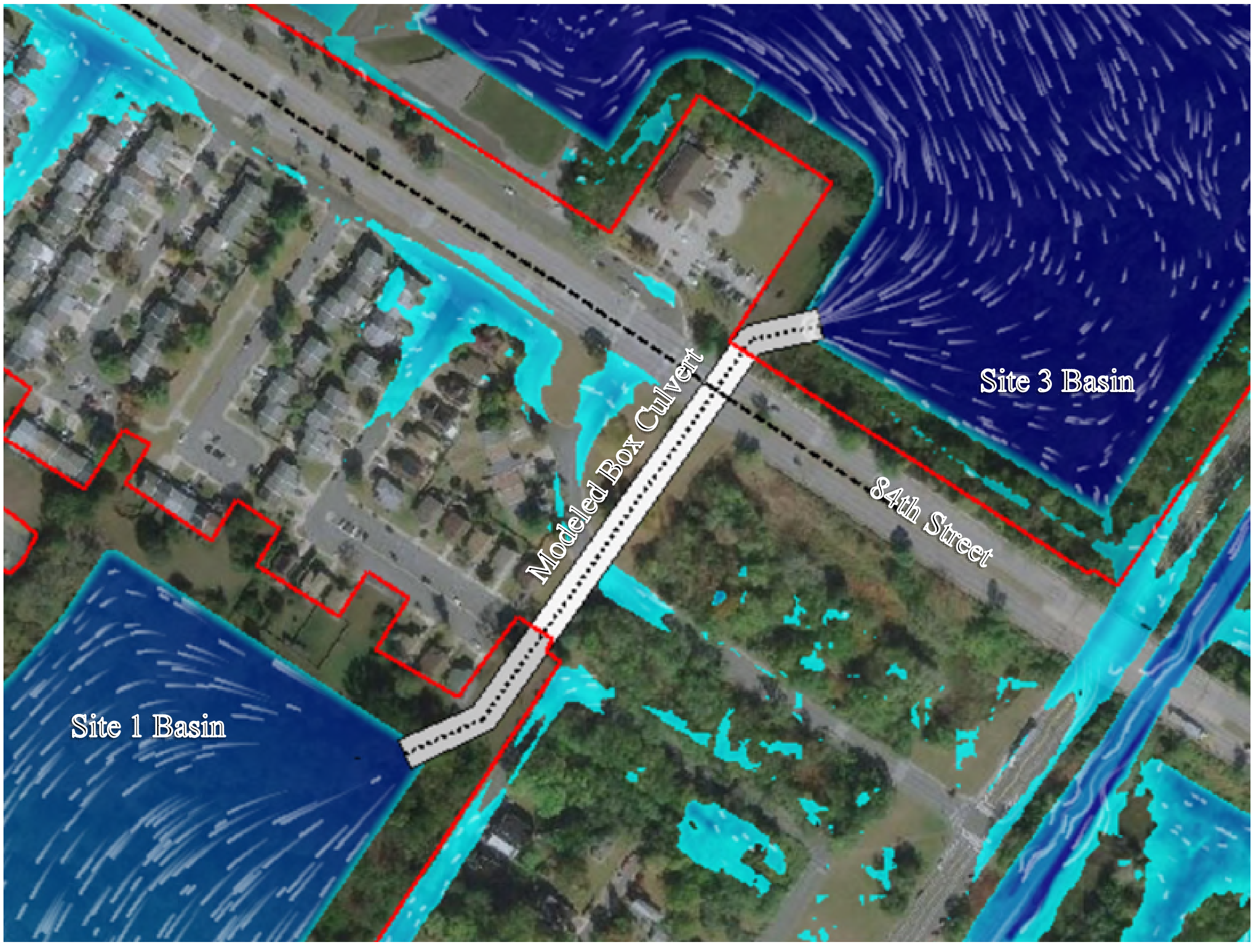


Figure 31: HEC-RAS Model Box Culvert with Flow Particle Tracing

The model was then simulated for each boundary condition storm event to evaluate the resultant change to the maximum water depth flood elevations throughout Eastwick. The maximum water depths for Existing Conditions and the maximum ecological restoration scenario for the 100-year terrestrial are shown in Figure 32. The comparative change in flood depths is shown in Figure 33. Additional results for the other analyzed boundary condition events are provided in Attachment D.

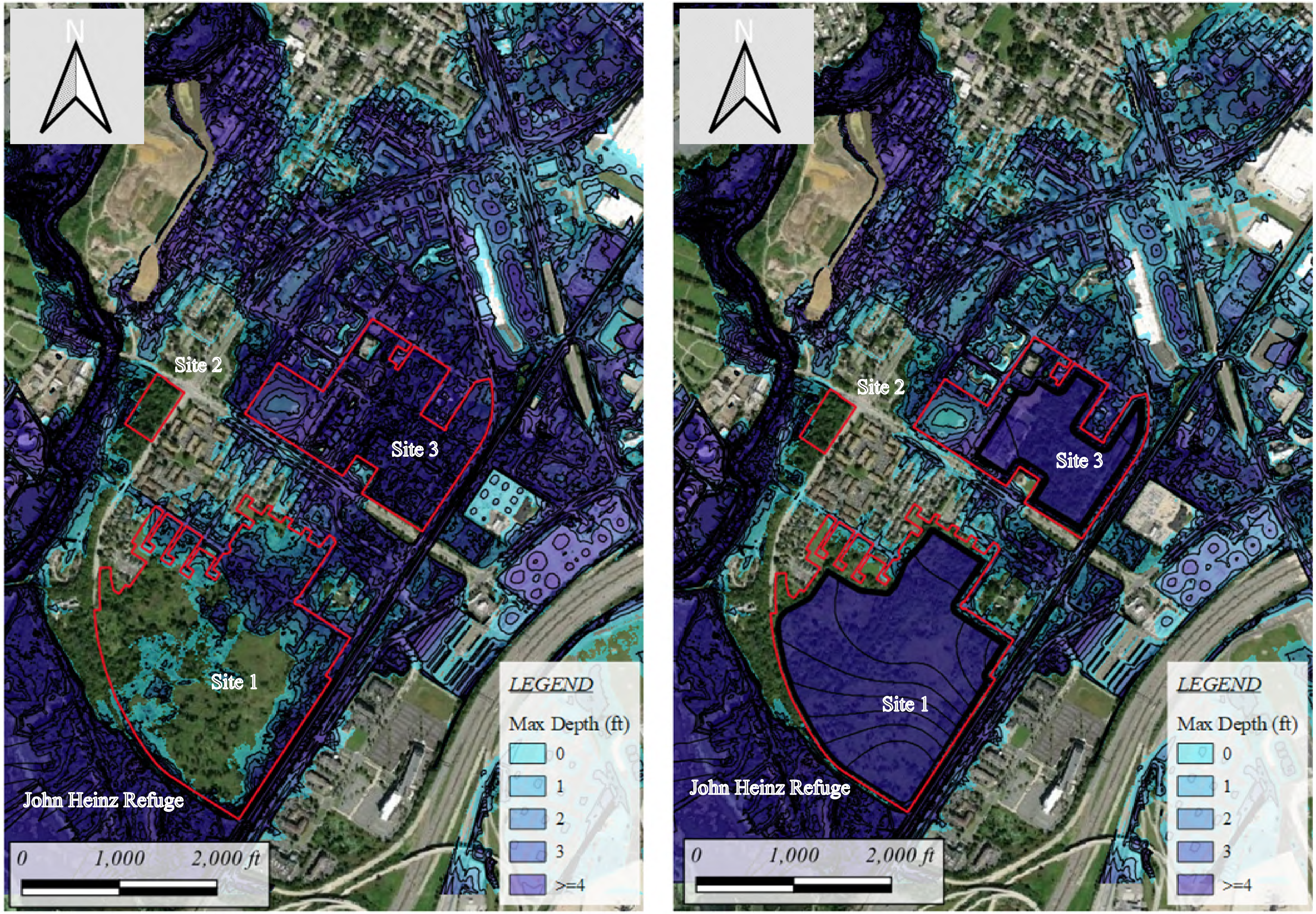


Figure 32: Existing Conditions (Left) and Maximum Ecological Restoration (Right) 100-Year Terrestrial Event Flooding Depths

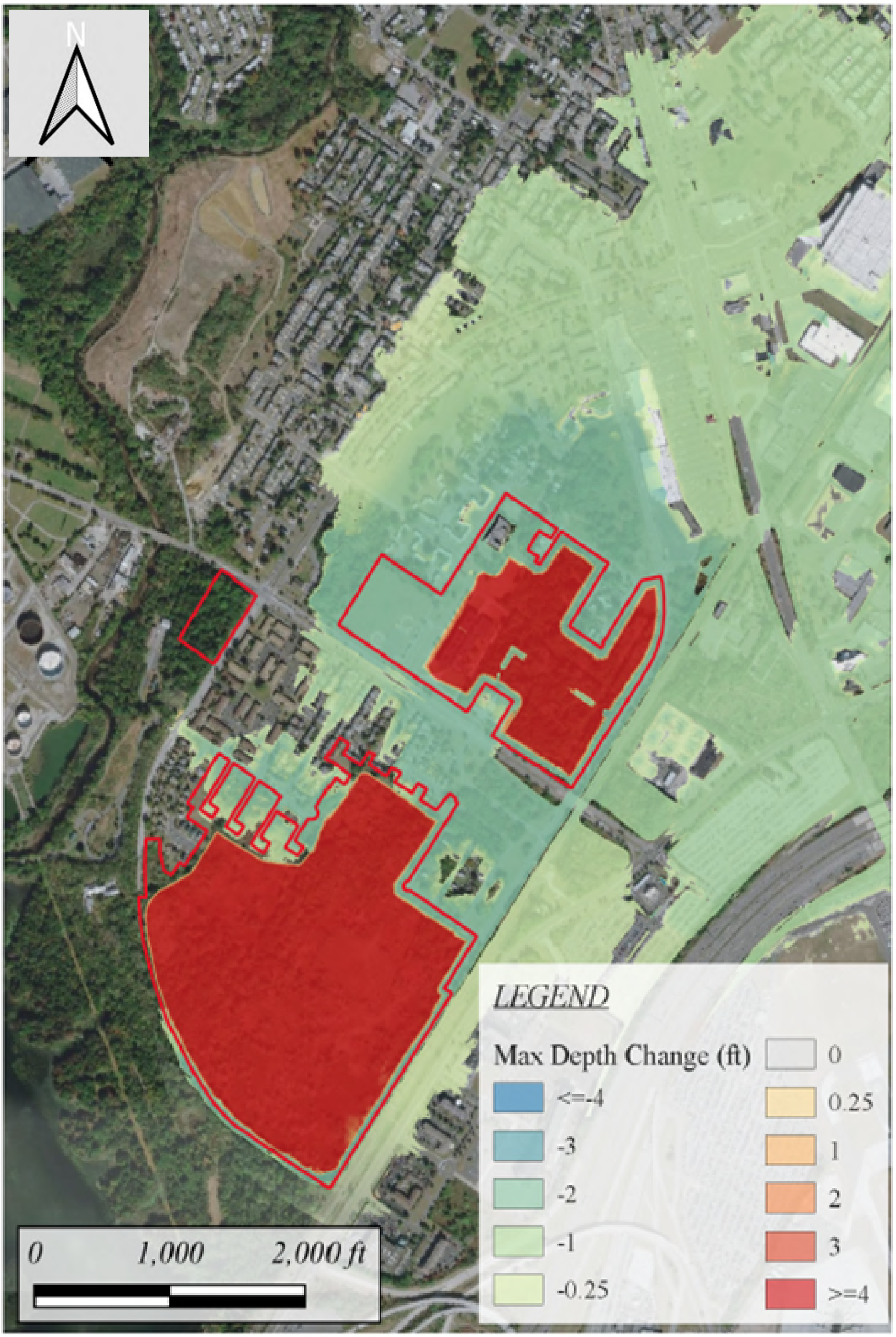


Figure 33: Flooding Depth Change Between Existing Conditions and Maximum Ecological Restoration Scenario for the 100-Year Terrestrial Event

As indicated by the model results shown in Figure 32, maximum water depths in the immediate vicinity of the basins drop on the range of 1-2 feet as compared to existing conditions water depths. However, the flood storage basins are not capable of preventing flooding in Eastwick. In general, the results indicate that the vacant public land sites, if strategically redeveloped to include interconnected large stormwater storage between Sites, could potentially serve as a positive benefit to the community when coupled with redevelopment efforts. Finding an optimum hybrid approach between the maximum ecological restoration scenario and the conceptual development plans for Sites 1 and 3 from the LEPLS is a possible next step.

It is also important to note that model results indicate that access to the Sites during flooding events still poses an issue with the maximum ecological restoration scenario. To ensure proper Site access during flooding events, modifications to existing roads for emergency access are likely needed, such as raising the road elevation of 84th Street, etc. However, when coupled with strategic storage basins as shown, model results indicate that the height necessary in the raising of the road is likely to be 1-2 feet lower for the 100-year event, as compared to existing conditions. This would thereby potentially lower the overall costs associated with these infrastructure modifications.

A summary table describing the model results of all the flooding events analyzed is shown in Table 6. The results are described for both the vacant public land sites and the surrounding Eastwick Community. As seen from the table, the results vary depending on the type of flood event analyzed. The following are some key findings:

1) The constructed wetlands and storage basins concepts do not increase flood depths in Eastwick, including for the 2100 future climate projection flood events.
2) The model results indicate tangible flood benefits for the Eastwick community primarily southeast of Lindbergh Boulevard in the vicinities of Site 1 and Site 3. The model results indicate that while there is some benefit, the scenario modeled cannot prevent flooding. The results indicate a reduction of flooding on 84th Street for Cases 1, 2, 5, 6, 7, and 8.
3) The addition of the culvert connecting Site 3 to Site 1 allows for transport of flood flows from the “Pepper Bowl” to the flood retention area in Site 1. In the LEPLS reuse concept, this was not possible due to the elevation of 84th Street. Even with the connecting culvert, the flood storage area in Site 1 is not fully utilized for Cases 3 and 4 due to the entry and modeled behavior of flood waters during tidal events.

Table 6: Constructed Wetlands and Storage Basins Concepts Model Results Summary Table

Case	Storm Event	Observed Model Flood Depth Changes in Vacant Public Land	Observed Model Flood Depth Changes in Eastwick
1	Tropical Storm Isaias (August 4, 2020)	Increased flood depths due to increased storage on Site 1. Increased flood depths on Site 3 in restoration area. Decreased flood depths of 1-4 feet outside of restoration area on Site 3. No changes on Site 2.	Flood reductions of 1-2 feet in the immediate vicinity of Site 3. Reduced flooding of 1 foot on 84th Street.
2	The 100-year terrestrial event	Full maximum flood storage in intentional flood retention areas in Sites 1 and 3. No changes on Site 2.	Substantial flood reductions of ~1 foot in Eastwick, primarily south of Lindbergh Boulevard. Reduction of flood depths of ~2 feet along 84th and 86th Streets.
3	Hurricane Sandy (October 30, 2012)	Small positive and negative changes for Sites 1 and 3. No changes on Site 2.	No changes in flooding depths to Eastwick Community.
4	The Great Appalachian Storm of 1950 adjusted to 2020	Small positive and negative changes for Sites 1 and 3. No changes on Site 2.	No changes in flooding depths to Eastwick Community.
5	The 100-year terrestrial event estimated at 2100	Full maximum flood storage in intentional flood retention areas in Sites 1 and 3. Flood depth reductions of ~2 feet outside of flood retention areas on Site 3. No changes on Site 2.	Substantial flood reductions of ~1 foot in Eastwick, primarily south of Lindbergh Boulevard. Reduction of flood depths of 1 foot along 84th and 86th Streets.
6	The Great Appalachian Storm of 1950 adjusted to 2100	Increased flood depths due to increased storage on Site 1. Increased flood depths on Site 3 in restoration area. Decreased flood depths of 1-4 feet outside of restoration area on Site 3. No changes on Site 2.	Flood reductions of 1-2 feet in the immediate vicinity of Site 3.
7	The 100-year terrestrial event & 10-year tidal event	Full maximum flood storage in intentional flood retention areas in Sites 1 and 3. Flood depth reductions of ~3 feet outside of restoration area on Site 3. No changes on Site 2.	Substantial flood reductions of ~1-2 feet in Eastwick primarily south of Lindbergh Boulevard. Reduction of flood depths of ~3 feet along 84th and 86th Streets.
8	The 10-year terrestrial event & the Great Appalachian Storm of 1950 adjusted to 2020	Increased flood depths due to increased storage on Site 1. Increased flood depths on Site 3 in restoration area. Decreased flood depths of 1-4 feet outside of restoration area on Site 3. No changes on Site 2.	Flood reductions of 1-2 feet in the immediate vicinity adjacent to Site 3.

5.4 Additional Modeling Scenarios

Based on the modeling results presented, it is recommended that additional modeling scenarios be considered for evaluation. These scenarios may include a hybrid approach between the LEPLS report and maximum ecological restoration scenario that also considers road emergency access improvements into and out of Eastwick. This would likely include roadway modifications to 84th Street, Lindbergh Boulevard, and the Sharon Hill side of the 84th Street Bridge and the low-lying area where it turns into Hook Road. However, discussions with the Pennsylvania Department of Transportation (PennDOT) and the Philadelphia Streets Department should occur prior to modeling this scenario to ensure that any proposed scenario is feasible and agreeable with the governing agency.

It should be noted that while these strategies may help support the feasibility of development at the Sites, they will not stop the flooding entering Eastwick without other flood mitigation efforts. Terrestrial flooding into Eastwick will continue to occur primarily at the opening along Cobbs Creek upstream of the landfill. Furthermore, future 2100 tidal projections affect Eastwick from the south from both the John Heinz National Wildlife Refuge and the Philadelphia International Airport.

6.0 Results and Key Findings

An existing conditions hydraulic model was created using advanced, integrated 1D and 2D modeling techniques in HEC-RAS. Both the 1D and 2D model domains were calibrated to best available data, including high water mark data within Eastwick after Tropical Storm Isaias. The calibrated model was then modified to evaluate possible reuse scenarios at the vacant public lands as called for within the LEPLS report. A maximum ecological restoration modeling scenario was also simulated to understand the "upper bounds" for maximum possible flood mitigation benefits of the vacant public land sites within Eastwick. A total of eight boundary condition flooding events were simulated to observe a range of possible flooding conditions within Eastwick at the vacant public lands (Sites 1, 2, and 3).

6.1 <u>Results</u>

6.1.1 <u>Existing Conditions</u>

Results from the eight boundary conditions flooding events indicate multiple sources of flooding into Eastwick (See Table 3). In general, the model results indicate that the sources of the flooding into Eastwick are external and independent from any potential internal improvements. The degree of flood inundation at the vacant public land sites (Sites 1-3) is variable depending on the flooding event and the PRA property in question (See Table 4).

The model indicates that Site 3 is the most flood prone given its location in the "Pepper Bowl," the lowest elevation within Eastwick. Site 1, near the John Heinz National Wildlife Refuge, has a varying degree of flooding depending on the flood event. Site 2 experiences low flood inundation due to its high elevation. On the basis of the existing condition results, Site 2 can be developed without any direct negative flood impact from any of the scenarios considered. While stormwater will be generated by an increase of impervious coverage from any proposed future development on Site 2, the volume of stormwater generated would be insignificant to the floodwater volumes projected from the storm case, but should be entirely mitigated by stormwater management measures required under the existing Philadelphia Water Department Regulations for Post-Construction Stormwater Management.

While the model shows that the proposed development scenario at Site 2 may not be impacted by flooding, there are significant access concerns at Site 2 during peak flooding because Lindbergh Boulevard and 84th Street become inaccessible. These roads are directly adjacent to Site 2 and are the main access points to Site 2. In addition, the existing conditions model results indicate access to all three Sites and to Eastwick in general would be limited for emergency responders during flooding events, especially along critical arterial entrance roads such as 84th Street and Lindbergh Boulevard. However, preliminary model results indicate that the flooding on 84th Street to the west of the Darby Creek bridge can possibly be eliminated by raising the roadway. This mitigation measure is not expected to increase upstream flooding in Darby Creek because floodwaters only appear to pond on the roadway and all floodwater is conveyed beneath the bridge. Further investigation should be conducted to verify this preliminary finding.

The existing conditions future sea level rise and tidal surge in 2100 indicates severe inundation from the south. Structural flood mitigation measures could be considered (in addition to the Cobbs Creek levee currently being evaluated by USACE), including raising and improving the existing earthen berm surrounding southern Eastwick and improving conveyance in Darby Creek. Modification of the existing earthen berm (See Section 3.5 and Figure 13), if feasible, is a potential improvement that can mitigate the future 2100 tidal surge scenario. Based upon the existing condition scenarios, this would require that the approximately 2-mile-long berm be raised from its present elevation of about 8 feet NAVD88 to approximately 13 feet NAVD88. It is important to note that this earthen berm is independent and separate from the levee that is under evaluation by USACE along Cobbs Creek.

6.1.2 LEPLS Reuse Concepts

Model results indicate that the results of LEPLS reuse concepts do not marginally increase nor decrease the modeled flood elevations in other parts of Eastwick. Although the creation of the elevated development pads on Sites 1, 2, and 3 will be at a high enough elevation to be above the modeled 100-year event, the model indicates that under future 2100 climate change flooding events, the elevated pads would potentially become inundated. Results of the model simulations incorporating proposed land reuse by the LEPLS indicated that additional flood storage only provides minimal benefit immediately surrounding the vacant public land sites. To achieve substantial flood reduction within the community, additional strategies are needed elsewhere.

The model results indicate that the ground elevation of the vacant public lands are above the modeled 100-year base flood elevation. However, as shown as part of the existing conditions, access to the Sites would still be limited for emergency responders. The existing 100-year terrestrial flood event, often used for regulation and design purposes, indicates potential flood inundation on major access routes into Eastwick. These access routes primarily include 84th Street and Lindbergh Boulevard, both of which have portions that are inundated by several feet of water during the 100-year event. Furthermore, flood inundation extents and depths only increase in severity with the addition of climate change impacts. 2100 future climate change model results indicate that smaller tertiary roads become inundated severely, limiting travel and access throughout all of Eastwick.

6.1.3 Constructed Wetlands and Storage Basins Consideration

In addition to modeling of LEPLS reuse concepts, modeling analysis of flood mitigation benefits that could be realized by maximizing flood storage on the vacant public land sites was also completed. The results of this preliminary evaluation indicate that tangible reduction in flood levels can be achieved, especially for the present day 100-year flood event where maximum flood depths can be reduced by 1-2 feet. However, it is important to note that even though flood reduction benefits can be realized with storage basins on the vacant public land sites, roadway and off-site flooding will not be entirely eliminated and access for emergency responders would still be limited. In addition, flood levels resulting from the future 2100 100-year tidal flooding scenario (Case 6, the Great Appalachian Storm of 1950 Adjusted to 2100) would not be measurably reduced.

6.2 Summary of Key Findings

Key findings of the study based on model results are summarized as:

- Redevelopment of the vacant public land as proposed by the LEPLS would not result in increases to flooding in Eastwick for seven of the eight modeled flood events in this study.
- Roadway modifications or other solutions are needed to provide for emergency access to all vacant public land sites during all modeled flood events.

7.0 Recommendations

Based on an analysis of model results and ongoing outreach and planning efforts, the following are provided as general recommendations for future consideration:

- The results of this study should be shared with the Eastwick community to facilitate planning and improve future flood preparation. Ongoing community engagement and outreach should be maintained and increased to determine and communicate what can be done by homeowners to help avoid negative impacts associated with flooding in Eastwick.

- Any proposed development of the vacant public lands should provide specific plans for emergency site access during flood events that consider the results of this study. Emergency site access plans should be prepared in accordance with federal, state, and local guidance and be acceptable to and understood by Eastwick community members and stakeholders.

- PRA, the Lower Eastwick Steering committee, and other organized committees including the Eastwick Flood Task Force are encouraged to continue collaborating with agencies representing the City of Philadelphia as well as other public and private stakeholders; however, to implement adaptive flood mitigation solutions in Eastwick it is critical to also coordinate efforts with neighboring upstream and downstream jurisdictions. The model and results generated from this study should be shared with stakeholders evaluating flooding and flood mitigation strategies in Eastwick.

- The results of this study along with the results of technical work being completed by others in the area should be considered to determine if additional data collection and/or monitoring could improve flood planning and response efforts in Eastwick. Technical committee representatives should convene to determine if additional gages, sensors, or other data collection techniques measuring tidal elevations, stream flow, and/or rainfall are warranted to support public notification and emergency response.

- Based on the indication of potential flood reduction benefits of the modeled ecological restoration scenario for Site 1 and Site 3, further evaluation of adaptive hybrid reuse scenarios incorporating improved floodwater conveyance and storage should be considered. Coordination with the John Heinz National Wildlife Refuge may be warranted as part of further evaluation. Further analysis could incorporate viable roadway/access modifications to be confirmed with the Philadelphia Streets Department and/or PennDOT and potentially include culverts underneath 84th Street to convey floodwaters to storage areas as demonstrated in the ecological restoration scenario modeled in this study. Adaptive hybrid scenarios could also evaluate the potential benefit of raising the elevation of the existing earthen berm (bordering the southern and eastern portions of Site 1) from its existing elevation of approximately 8 feet to an elevation that will protect the community from future tidal flooding events, which are expected to occur more frequently during future climate conditions. Based on the model results for Storm event Case 6 (The Great Appalachian Storm of 1950 with adjustments to reflect sea level rise predictions for the year 2100), a berm elevation of approximately 13 feet should be considered as an initial test case for further evaluation.

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