NEW YORK STATE CANAL CORPORATION

Earthen Embankment Integrity Program

SEQR Draft Generic Environmental Impact Statement

APPENDIX B

RISK EXPOSURE PRESENTED BY CANAL EMBANKMENTS

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Table of Contents

Table of Tables

Table of Figures

Appendix B Risk Exposure Presented by Canal Embankments

This Appendix has two components:

- Part 1 - Discussion of risk factors for embankment dam failures, including industry standards for tolerable risk, and event and failure mode probability for Canal embankments compared to dam embankments and levees. Also included is a summary of the potential adverse effects of allowing vegetation to grow on dam embankments.
- Part 2 - Summary of Canal embankment breach analyses conducted in 2019 at several locations on the Erie Canal.

PART 1: FAILURE RISK CONCEPTS FOR EMBANKMENT DAMS AND CANAL EMBANKMENTS

1.1 Overview of Tolerable Risk for Embankment Dams and Canal Embankments

A widely accepted value of tolerable risk for existing dams is on the order of 1×10^{-5}, which is approximately the lifetime risk of death in a commercial plane crash. An important principle to achieve tolerable risk for all types of dams is to "reduce risks to as low as reasonably practicable" or ALARP. This principle is founded on the legal obligation of dam owners to reduce risks to a point of diminishing returns where additional risk reduction would "cost" "disproportionally" more than the risk reduction benefit achieved. A prerequisite for estimating and evaluating whether or not ALARP has been met is the identification of any "physically possible" structural or non-structural options for further risk reduction. The Australian National Committee on Large Dams (ANCOLD) has developed guidelines on dam safety management that have been adopted by USACE and other dam owners (2). These guidelines have been based on the annual estimated probability (AEP) of a dam failure and the potential number of lives lost due to a dam failure. These are plotted on a log-log plot with AEP plotted on the vertical (Y) axis and number of fatalities on the horizontal (X) axis. An example plot is shown in Figure 1.1-1.

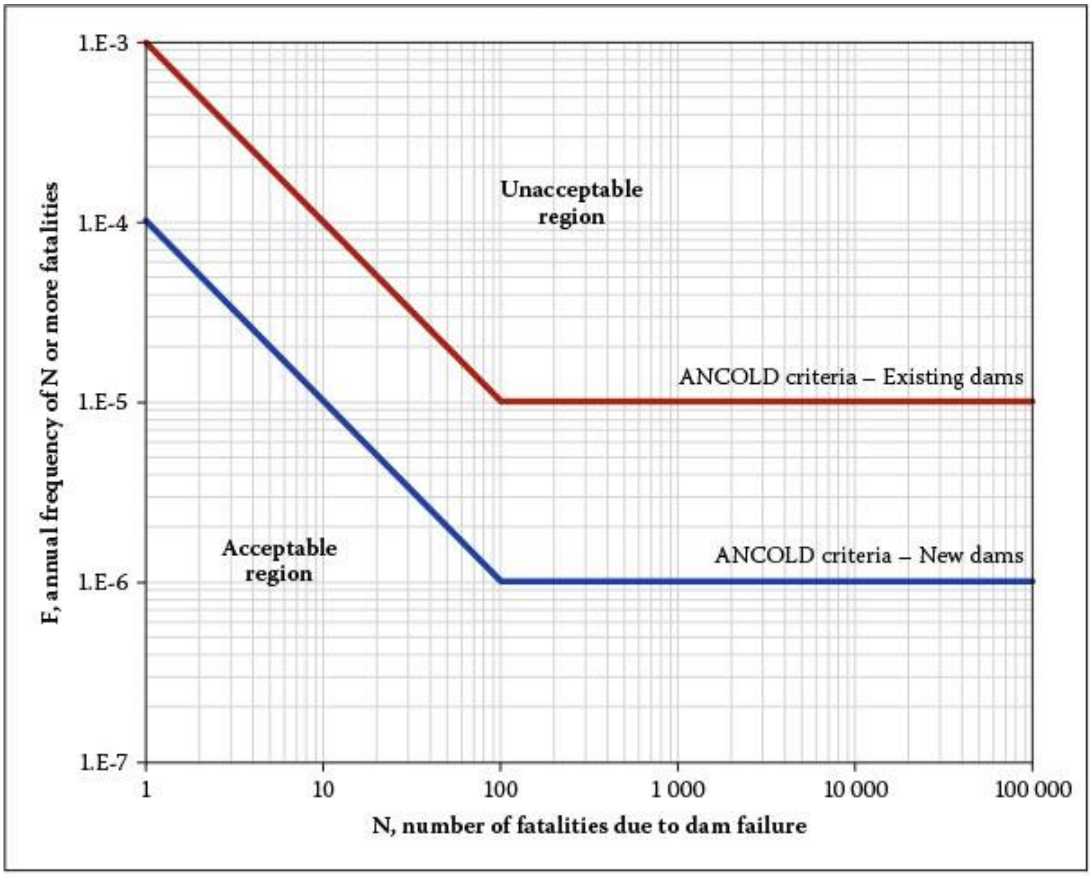

Figure 1.1-1: ANCOLD FN Criteria for New and Existing Dams

A risk assessment considers the results from a quantitative or qualitative estimated risk analysis of an existing dam, along with other factors related to a safety decision. These factors include social/economic impacts, environmental impacts, constructability and the potential to increase risks. The risk analysis provides quantitative measures including:

- Likelihood of failure occurrence in terms of annual probability;
- Estimated loss of life given a failure presented as the total estimated loss for a given the annual probability of failure; and
- Economic damages given the annual probability of failure.

Probability of failure is typically associated with the risk of life loss similar to Figure 1.1-1.

Other factors to be considered in decision making include:

- Design and construction of the dam
- Past and future monitoring of the dam
- Public perceptions, expectations and input
- Ease, difficulty and practicality of remediation work
- Potential to do harm as a result of remediation

- Uncertainty about the results and success of the remediation.

A risk-informed approach to dam safety decisions allows for consideration of both quantitative and qualitative factors.

When a judgement is made that risks are as low as reasonably practicable (ALARP), this is determined by comparing the effectiveness of reducing risk further (evaluated by considering the cost to further reduce risk and the amount of risk reduction achieved, and comparing it to other risk reduction actions). If the costs to achieve an additional level of risk reduction are disproportionate, the current risk may be as low as reasonably practicable. The risk remaining after specific dam safety decisions have been implemented, is considered a tolerable, or residual risk.

1.2 Failure Modes for Dam Embankments

Data on dam embankment failures through 1986 was analyzed by Foster, Fell and Spannagle in *The Statistics of Embankment Dam Failures and Accidents,* Canadian Geotechnical Journal, 2002 (5). They examined three categories: overtopping and failures at spillways, piping (seepage), and sliding (slope failure). For the canal embankments, overtopping is a highly unlikely failure mode, as the canal gates, and waste weirs, present along the embankment, control the volume of water contained in an embankment section. Sliding failure had a very low percentage of occurrence in the surveyed data. Therefore, Table 1.2-1 summarizes only data for piping, which is the principal failure risk for dam embankments. The number and frequency of failures is compared to a total of 11,192 dams considered in the study:

Table 1.2-1: Number and Frequency of Dam Failures By Failure Mode

Mode of Failure	Number of Cases	Average Frequency of Failures ($x10^{-3}$)
Piping Through Embankment	39	3.5
Piping Through Foundation	19	1.7
Piping from Embankment into Foundation	2	0.2

The data indicate that piping through the embankment is the most likely cause of embankment dam failure, by a factor of 2 compared to piping through the foundation. It is this failure mode that concerns dam and canal embankment owners and dam safety officials with respect to ensuring that the integrity of embankments is preserved through active and ongoing maintenance.

1.3 Effects of Vegetation on Dam Embankments

FEMA 534 *Technical Manual for Dam Owners – Impact of Plants on Earthen Dams*, September 2005 (3) is an accepted guidance document for dam owners and state dam safety agencies. State and Federal agency dam safety officials, and dam engineers are in agreement that trees and woody vegetation have no place on embankment dams, for three reasons:

- Trees and dense vegetation hinder effective dam inspections
- Tree roots can cause serious structural instability or hydraulic problems, which could lead to dam failure and possible loss of life
- Trees and woody plants attract burrowing animals which can in turn cause serious structural or hydraulic problems.

Dams need to be inspected for seepage, cracking, sinkholes, slumping, settlement, deflection and other signs of stress in periodic safety inspections. Vegetation is a major hindrance for dam inspections. In a 1999 survey of state dam safety officials, it was reported that trees and woody vegetation on an estimated 30,000 dams (nearly one-third of all state-regulated dams) obstruct effective dam safety inspections.

It is a common misconception that tree roots stabilize the soil mass. On the contrary, tree roots actually loosen the soil mass. Tree root penetration of an earthen dam loosens the compacted soil of an embankment slope and crates conditions conducive to surface water penetration and slope failure. In fact, an effective remedial measure for controlling vegetation growth on embankments is soil compaction. It reduces the air void content and limits the infiltration of surface water into the embankment slope.

The US Bureau of Reclamation manages some 8,000 miles of canals in the Western states, along with numerous dams. *Canal Operation and Maintenance: Embankments*, USBR November 2017 (14) discuss canal embankment problems and mitigation measures. Some of the primary causes of seepage and internal erosion include flaws created by burrowing animals or decaying root systems.

Shields' 2016 publication *Synthesis of Levee Vegetation Research Results (2007–2014*) (12) was prepared for the California Levee Vegetation Research Program. He noted that incorporating risk factors related to the presence or absence of woody vegetation on and adjacent to levees into risk analyses is at a very primitive state. Current findings indicate that the effects of vegetation on total failure probability of central California levee systems is small in comparison to factors such as seismic events and underseepage. Nonetheless, the report endorses many of the same practices advocated by the dam safety community: detailed hands-on inspections for signs of seepage or embankment distress; and well-enforced vegetation management practices.

A key distinction between levees and earth embankment dams operated by the NYSCC is that levees are normally dry. They are located generally parallel to rivers and protect residential and commercial lands from riverine flooding. In contrast, the canal embankments are normally full for half the year, and then drained for the winter. This means that the canal embankments have time to become fully saturated, similar to a dam with a permanent water pool.

Engineering principles shared by various agencies' studies being applied to embankments
Embankments need to generally be kept clear of trees, brush and woody vegetation for the following reasons:

- Dense vegetation hinders access to and visibility of slopes, with the consequence that serious problems can go undetected;
- Extensive root systems provide seepage paths for canal water to escape and lead to internal erosion, piping and potential embankment failure;
- Dense vegetation provides a good habitat for burrowing animals, which may lead to water loss through their tunnels, and eventually embankment failure due to erosion;
- Large trees could be uprooted by high wind or erosion and leave large holes or pull portions of the bank loose;
- Trees overhanging the canal could also fall into the canal, obstruct navigation and create debris removal problems at structures;
- The presence of trees and woody vegetation can delay access to critical failure locations by Contactor forces, materials and heavy equipment needed to correct the deficiency;

1.4 Event and Failure Mode Probability for Canal Embankments

Table 1.4-1 illustrates the point that the probability of exposure to a seepage induced failure is much higher for canal embankments than for levees. The probability of failure for a seepage-induced breach used in this example is 3.5×10^{-5} from Foster, et al. (5) and is assumed to be equal for levees, canal embankments and embankment dams. The values in the "Combined Event and Failure Mode Probability" column in Table 1.4-1 are the product of the values in the "Event Probability" and "Probability of Failure" columns, and the inverse of that is the "Mean Time to Failure", or MTTF.

Table 1.4-1: Comparison of Failure Probabilities and Mean Time To Failure for Levees, Canals and Dams

Event	Failure Mode	Event Probability (per year)	Probability of Failure	Combined Event and Failure Mode Probability	Mean Time to Failure - MTTF (years)
Levee Reservoir Full (100-year flood)	Seepage Induced Breach	0.01	$3.5x10^{-3}$	$3.5x10^{-5}$	28,500
Canal Embankment Reservoir Full	Seepage Induced Breach	0.5	$3.5x10^{-3}$	$1.7x10^{-3}$	588
Dam Reservoir Full	Seepage Induced Breach	1.0	$3.5x10^{-3}$	$3.5x10^{-3}$	285

The failure probability is for illustrative purposes. The key point is that the dam and canal embankments are at much higher risk for a seepage induced breach than a levee because the exposure (event probability) is two orders of magnitude greater.

In order to reduce canal embankment failure risk to tolerable levels for (as low as reasonably practicable) it is necessary to manage these embankments similar to any embankment dam with a permanent upstream pool. Tree and woody vegetation removal is a key component of managing risk by facilitating safety inspections and eliminating tree roots as seepage hazards.

In the example above, the failure probability of $3.5x10^{-3}$ is for well-maintained embankment dams with no woody vegetation. Canal embankments, many of which are covered with trees and difficult to inspect, likely have a higher failure probability than grass-covered embankment dams. It can be assumed that the probability of failure due to seepage or a poorly maintained earthen canal embankment is at least double that for a well-maintained embankment dam. The presence of tree roots in the embankment, and the hindrance to full inspection caused by the presence of vegetation, both increase the seepage failure probability in the canal embankment.

Therefore, the combined probability of failure for a well-maintained embankment dam that is full all the time would be the same as for a poorly maintained canal embankment that is full for half the year:

Canal Embankment	$0.5 \times 7.0 \times 10^{-3} = 3.5 \times 10^{-3}$
Embankment Dam	$1.0 \times 3.5 \times 10^{-3} = 3.5 \times 10^{-3}$

Since failure probabilities are comparable, it is important to manage vegetation with the same degree of care for a canal embankment as for an earthen dam. Without evaluation and removal of woody vegetation from the canal embankments, it will not be possible to achieve risk levels that are as low as reasonably practicable (ALARP).

PART 2: EMBANKMENT BREACH ANALYSIS AT SELECTED CANAL LOCATIONS

2.1 Overview

HEC-RAS modeling was conducted to assess potential impacts of embankment (levee) breaches along the Erie Canal at five locations: near Hulberton, NY; Spencerport, NY; East and West Greece, NY; and Brockport, NY (see **Figure *2.1-1***). The Brockport simulation is for an embankment failure that can be used to contrast a structure failure at that location. Each potential breach location was modeled using 1,200 cfs flow in the Canal, and three downstream boundary conditions: 12 ft, 5 ft, and 8 ft of channel depth. The downstream boundary of the Canal reach is near the West (Rochester) Guard Lock. Two breach scenarios were modeled; a 2-hr sinusoidal breach progression and a "fast collapse" that represents a piping-soil bridge collapse-downcutting progression occurring in 1.5 hours.

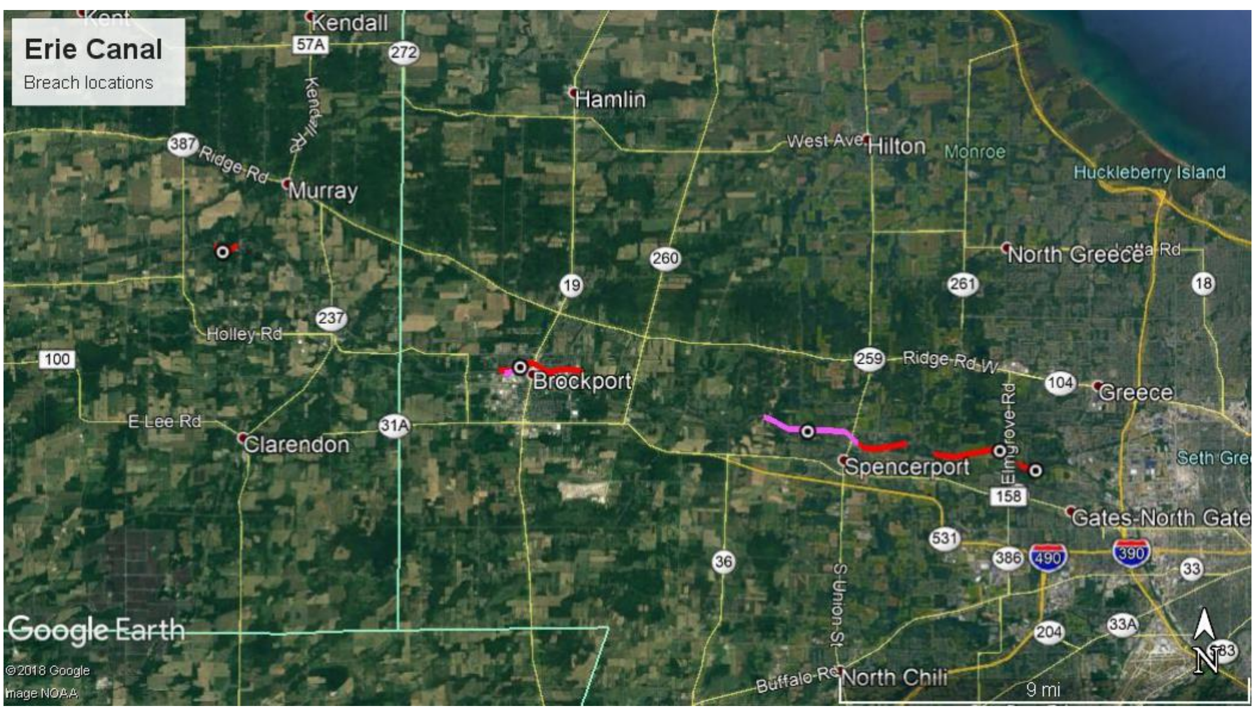

Figure 2.1-1: Map of Breach Locations

2.2 Hydraulic Model Assumptions

The modeling used to generate inundation area and maximum depth maps was accomplished using a HEC-RAS model and lidar coverage of adjacent overflow areas. Lateral structures were created at four breach location. The main canal section and lateral structure locations for breaching were represented with a one-dimensional HEC RAS model. The breach flow was routed into two-dimensional flow areas created from the lidar. The two-dimensional flow areas were sufficiently large to capture and route the flow from the breaches. A grid cell size of 200 ft by 200 ft was used to represent overflow areas and a constant Mannings N-value of 0.06 was used. The channel N-value was 0.02 and the overbank N-value was 0.032.

Separate model runs were made in unsteady mode for each breach location using a constant inflow of 1,200 cfs and downstream boundary condition of 12 ft, 8 ft, and 5 ft of depth (to reflect alternative management scenarios). Model simulations were run for five days using a computational time step of 30 seconds based on sensitivity analyses during preliminary modeling. The output hydrograph was recorded at a 15-minute interval.

2.3 Embankment Breach Assumptions

Canal embankment breach modeling is employed to assess various failure scenarios, typically as part of a risk assessment. Since limited geotechnical or erodibility data was available for this study, model parameters were based on written and anecdotal information provided by Bergmann supplemented with published data on levee failures and personal experience of the modelers, particularly as derived from assessing and modeling numerous failures on the Missouri and Mississippi Rivers that occurred in 2011 and 2019.

The canal embankment material is assumed to be a relatively homogenous soil with moderate compaction and vegetated slopes. Likely failure mode at all locations is piping that advances to the stage where bridging material collapses and is followed by rapid downcutting and widening. The piping coefficient was set at 0.5. Previous studies and observations from aforementioned modeling suggest the maximum bottom width of the breach is generally between 5 and 10 times the embankment height. The modeled embankment is about 16 ft tall and preliminary modeling confirmed that 150-ft bottom width for the breach yielded reasonable results.

The final breach elevation is conventionally set at the higher of the channel bed or ground level in the outflow area near the breach unless vegetation, soils, or structural measures dictate an alternative elevation. The initial piping elevation was set at 502 ft., and the starting water surface elevation for failure was set at 505 ft. Side slopes of the breach were assumed to be 0.5H:1V given the assumed failure mechanism. The breach formation time was set at 2 hours using a sinusoidal breach progression for the most probable outcome. A faster breach time (1.5 hrs) and more severe progression rate was simulated as well and could be substituted for a worstcase condition. The resultant maximum inundation areas and depths do not differ significantly between the two sets of assumptions.

2.4 Results

Model results in the form of output files, inundation shapefiles and maps of maximum depth were generated, along with project, plan, geometry, and other HEC-RAS file sets for the two breach progression scenarios. The figures on the following pages show inundation extent immediately downstream of the breach locations. Results in the furnished files reflect the model conditions for the 2-hr breach progression. However, results for the other scenario are not distinguishable at the plotted scale. Additional model runs for other simulation conditions can be generated readily from these files.

The model assumptions for the breaches represent a reasonable, if conservative choice for this levee based on the furnished information. The differences in inundation area and depth in overflow areas for the three canal depth scenarios (12 ft, 8 ft, and 5 ft) were small. Simulations indicate that the breach flood wave is attenuated quickly in the overbank, but model assumptions for the 2-D flow areas may obscure some differences. A finer cell resolution and/or refined roughness estimates might demonstrate more significant differences. The following figures depict inundation depth at the assumed 12 ft. canal depth scenario.

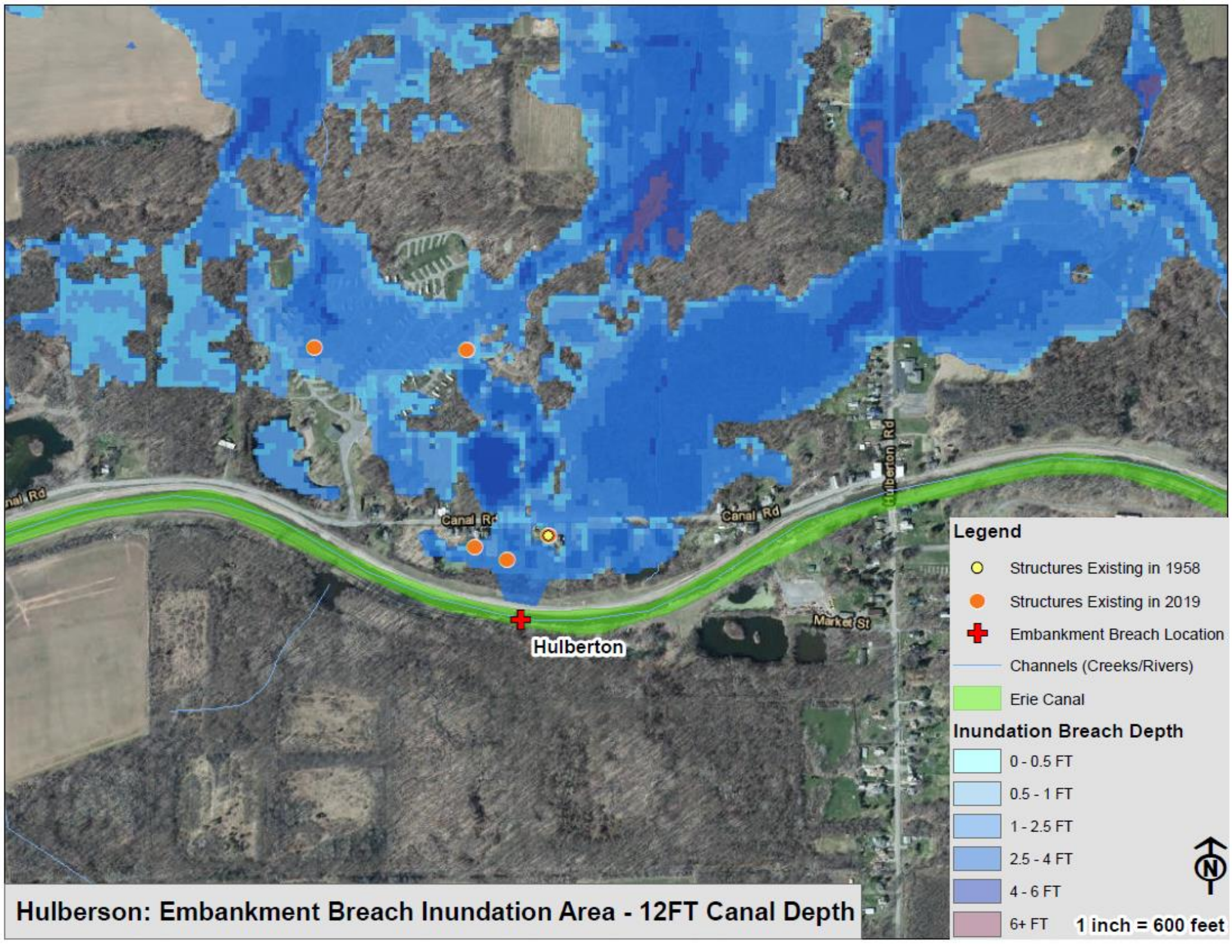

Figure 2.4-1: Hulberton Breach 1,200 cfs @ 12 ft. Depth

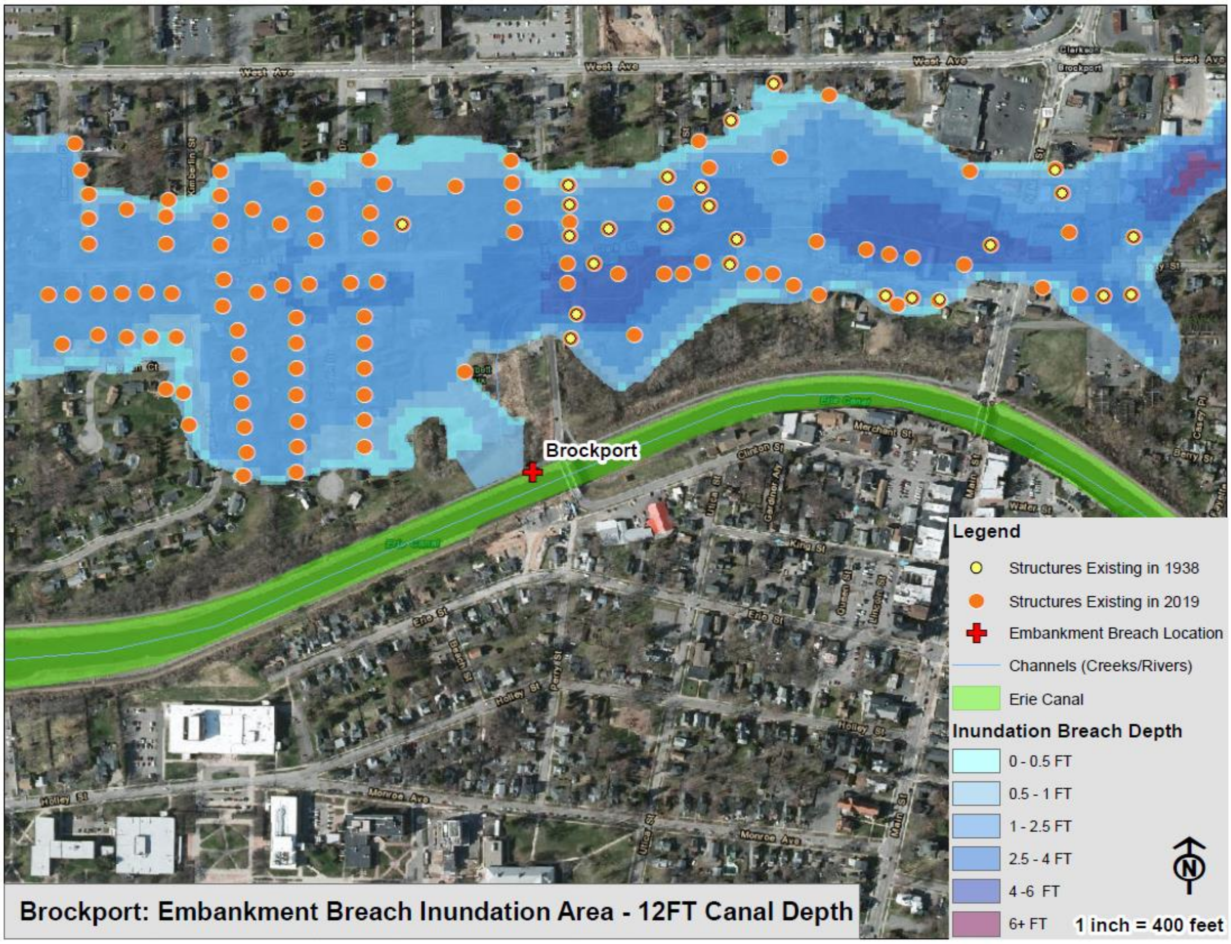

Figure 2.4-2: Brockport Breach 1,200 cfs @ 12 ft. Depth

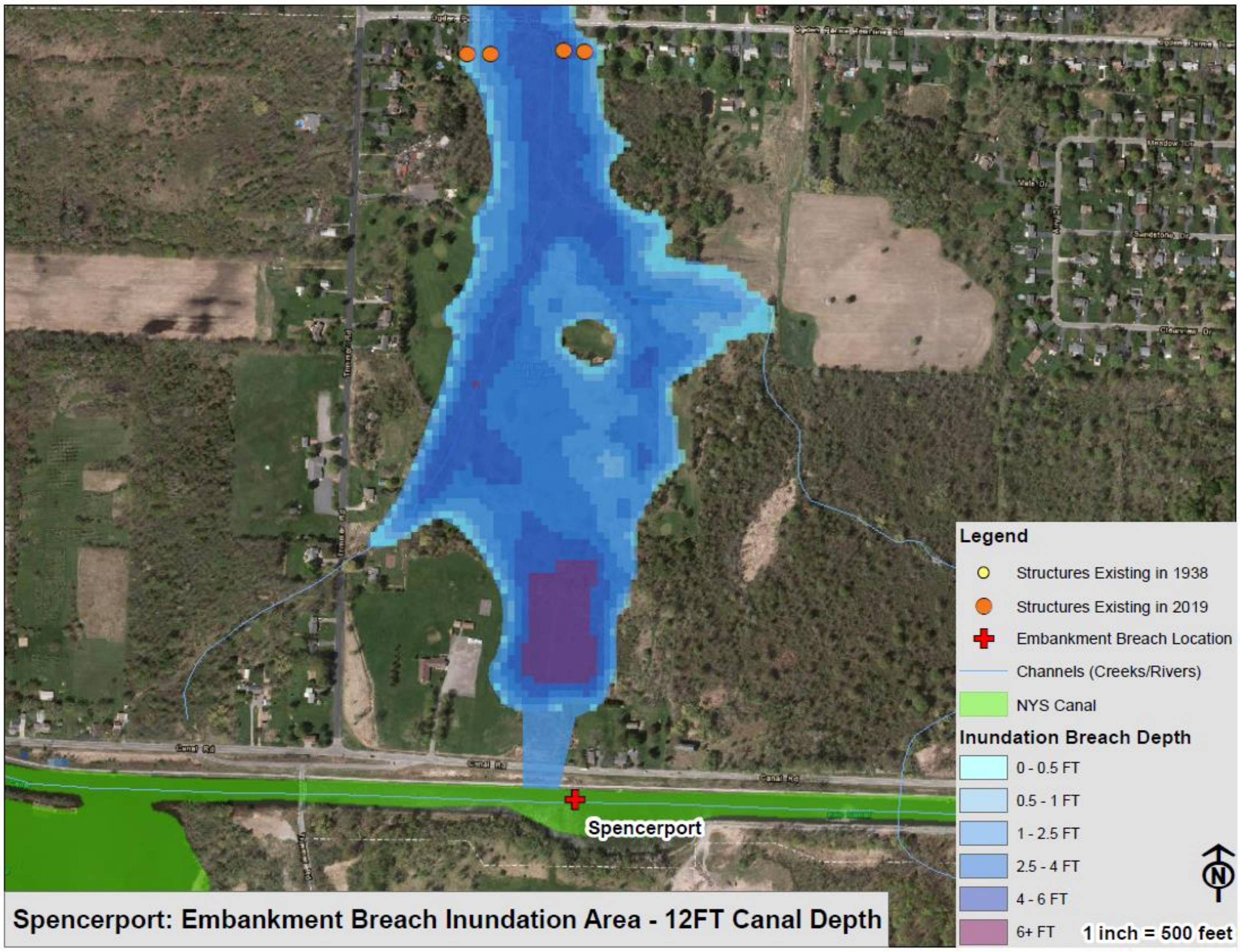

Figure 2.4-3: Spencerport Breach 1,200 cfs @ 12 ft. Depth

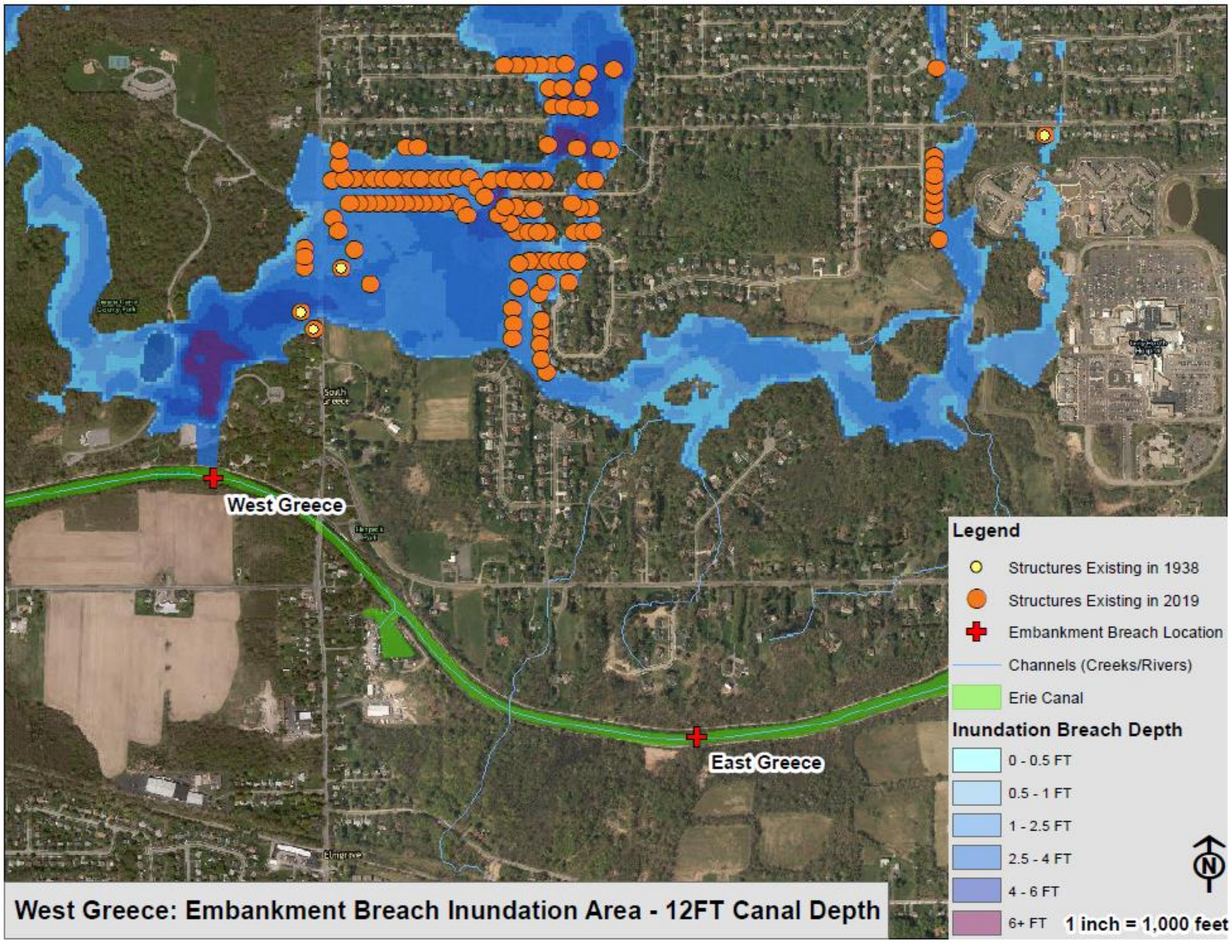

Figure 2.4-4: West Greece Breach 1,200 cfs @ 12 ft. Depth

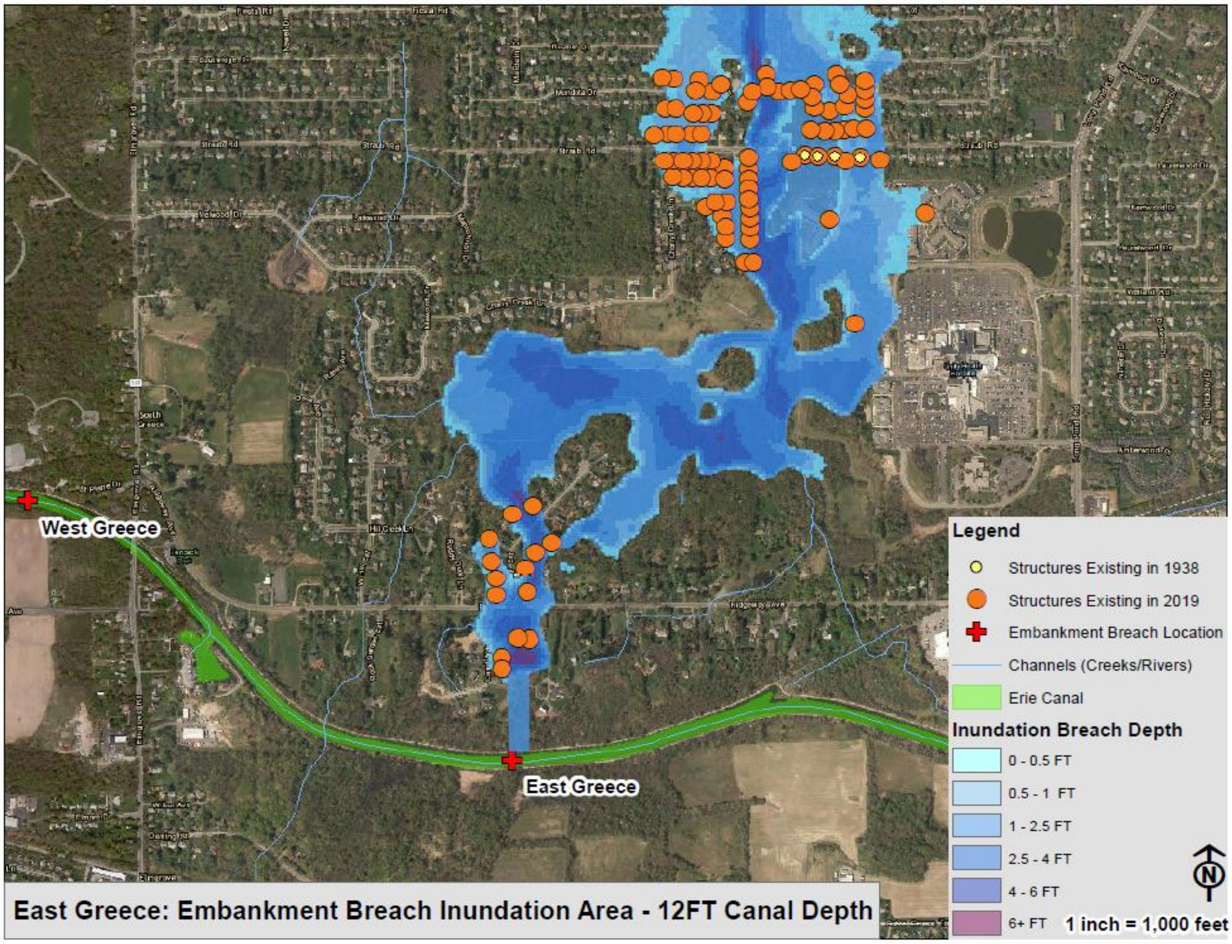

Figure 2.4-5: East Greece Breach 1,200 cfs @ 12 ft. Depth

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