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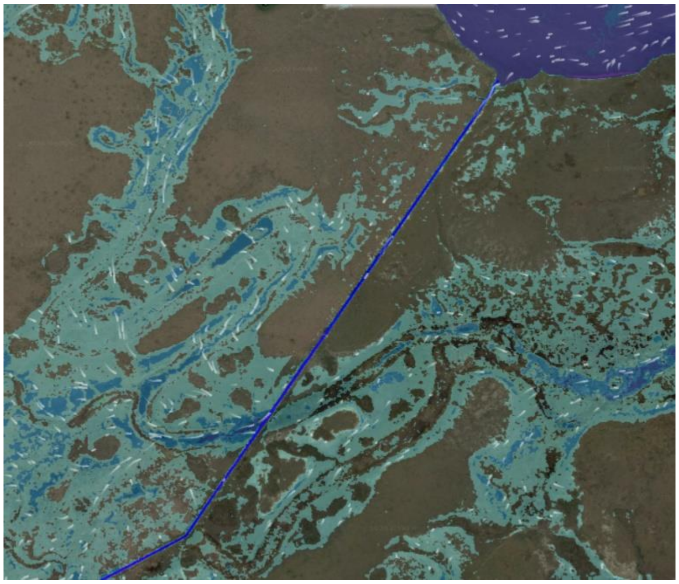

# HYDROLOGICAL RESTORATION OF THE BRAZORIA NATIONAL WILDLIFE REFUGE WETLANDS

Prepared for:

## Ducks Unlimited, Inc.

December 17, 2020

Prepared by:

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FREESE AND NICHOLS

Innovative approaches
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Outstanding service

# HYDROLOGICAL RESTORATION OF THE BRAZORIA NATIONAL WILDLIFE REFUGE WETLANDS

Prepared for:

## Ducks Unlimited, Inc.

STATE OF TEXAS
J. GARRETT JOHNSTON
115779
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12/16/2020

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DKS18637

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# EXECUTIVE SUMMARY

The U.S. Fish and Wildlife Service (USFWS) has partnered with DU to design and oversee construction of features to improve the ecological structure and function of wetlands in the Chocolate Bay Prairie Unit. In October 2018, Ducks Unlimited, Inc. (DU) authorized Freese and Nichols, Inc. (FNI) to provide professional engineering services in relation to Phase I of the Hydrologic Restoration of the Chocolate Bay Prairie Unit wetlands in the Brazoria National Wildlife Refuge within Brazoria County, Texas.

Under existing conditions, several manmade ditches intercept the natural runoff patterns throughout the Unit and convey it to Chocolate Bay. The purpose of this study is to develop conceptual alternative designs for the Unit that achieve USFWS's desired wetlands restoration goal of improving the site's natural hydro-period, that is, the duration of inundation that remains on the landscape during a typical storm event. To accomplish this, FNI developed a hydrologic model and multiple two-dimensional hydraulic models using HEC-HMS and HEC-RAS software.

FNI developed existing conditions hydrologic and hydraulic models to simulate the 2- and 100-year design storms using NOAA Atlas 14 rainfall depths. Both simulations assume a boundary condition equal to the mean higher high water (MHHW) mark as measured by the NOAA station at San Luis Pass, TX, just south of the site. A smaller historical rainfall event was also simulated using historical rain gauge and tidal data from a 3-inch rainfall that occurred on May 11, 2015. A second 100-year storm was also simulated to incorporate the peak storm surge that occurred during Hurricane Harvey in August 2017. Because storm surge elevations are highly variable, the two 100-year storm simulations bracket low (MHHW) and high (Harvey) boundary conditions that may occur. These 100-year scenarios were modeled to confirm that the modeled alternatives will not cause adverse impacts to adjacent properties during the 100-year event.

FNI prepared three alternative models with various combinations of weirs, culverts, and other features throughout the site to achieve the DU/USFWS goals of restoring the natural hydro-period on the landscape. The efficacy of each alternative was assessed, primarily based upon the historical 3-inch storm, and the results were documented within this report as well as the attached materials. Each modeled alternative improves the natural hydro-period of the site to varying degrees. Alternative 3 achieves a good balance between improving natural drainage south of the manmade ditch system while being easily maintainable by USFWS into the future. In the 3-inch rainfall scenario, Alternative 3 would increase the inundation duration between 2 and 12 hours for 289 acres, between 12 and 24 hours for 240 acres, and greater than 24 hours for 160 acres.

# 1.0 INTRODUCTION

## 1.1 OVERVIEW AND BACKGROUND

The U.S. Fish and Wildlife Service has partnered with DU to design and oversee construction of features to improve the ecological structure and function of wetlands in the Chocolate Bay Prairie Unit. In October 2018, Ducks Unlimited (DU) authorized Freese and Nichols, Inc. (FNI) to provide professional engineering services in relation to Phase I of the Hydrologic Restoration of the Chocolate Bay Prairie Unit (Unit) wetlands in Brazoria National Wildlife Refuge within Brazoria County, Texas. The authorized services include developing a two-dimensional (2D) hydraulic model to evaluate existing conditions of the project site, create up to three alternative 2D models of the Unit to achieve DU goals, and preparing an existing conditions and alternative conditions engineering report.

## 1.2 PURPOSE OF STUDY

The purpose of this study is to develop multiple alternative conditions for the Unit that will achieve USFWS's desired wetlands restoration goal of returning the site to its natural hydro-period without adverse impacts to adjacent properties or roadways. For the purposes of this study, an adverse impact is considered any increase in the modeled 100-year water surface on an adjacent property, measured to the hundredth of a foot. To complete this analysis, FNI developed a hydrologic model and a 2D hydraulic model to assess existing conditions along with separate 2D hydraulic models for each design alternative. This report presents the existing and alternatives conditions analysis as well as the process that FNI used to arrive at the results.

The following sections of the report include discussions regarding:

- Field reconnaissance and data collection
- Hydrologic and hydraulic methodology
- Existing conditions hydrologic and hydraulic analysis
- Alternatives conditions hydrologic and hydraulic analysis
- Hydrologic and hydraulic results and recommendations

## 1.3 PROJECT AREA

**Figure 1** shows an overview of the project area and identifies several key areas on the site. The project area is generally bounded by Chocolate Bayou on the east, Farm-to-Market Road (FM) 2004 on the north, Hoskins Mound Road on the west, and West Bay to the south. The extents of the Brazoria National Wildlife Refuge continue west of Hoskins Mound Road, but it was found during this analysis that rainfall west of the road does not contribute to the area of concern for this study.

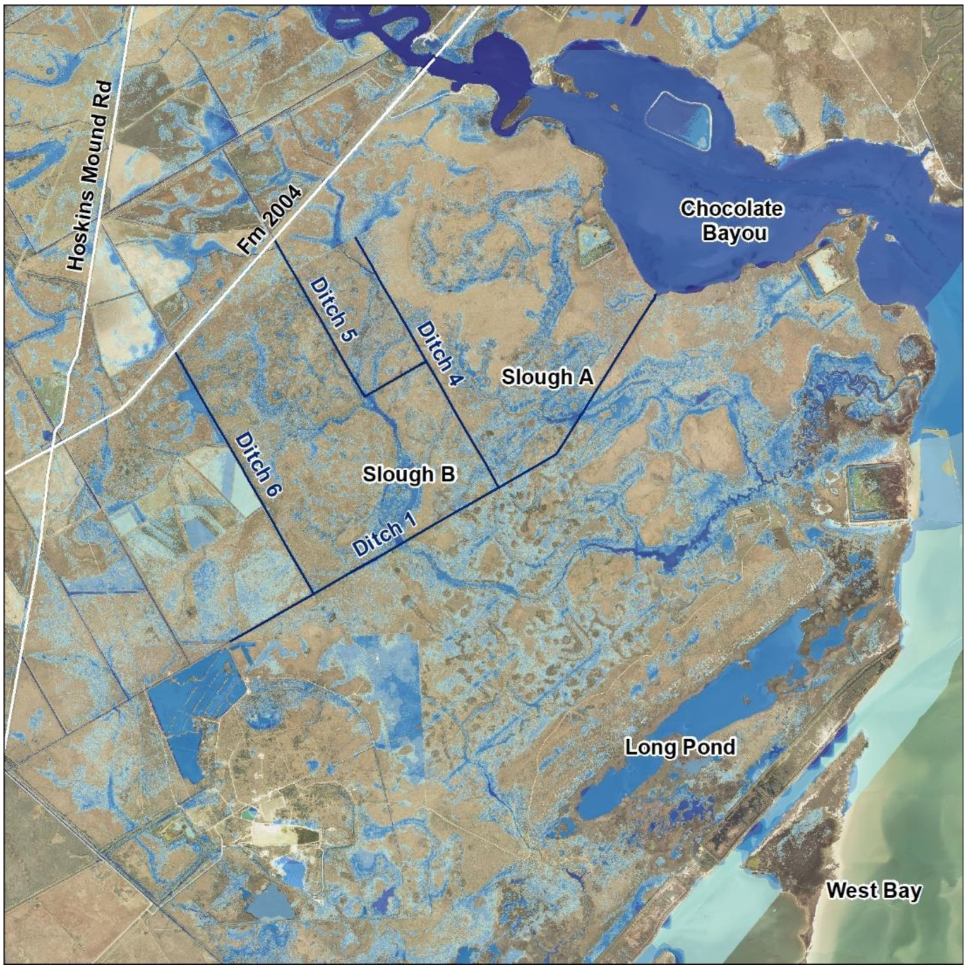
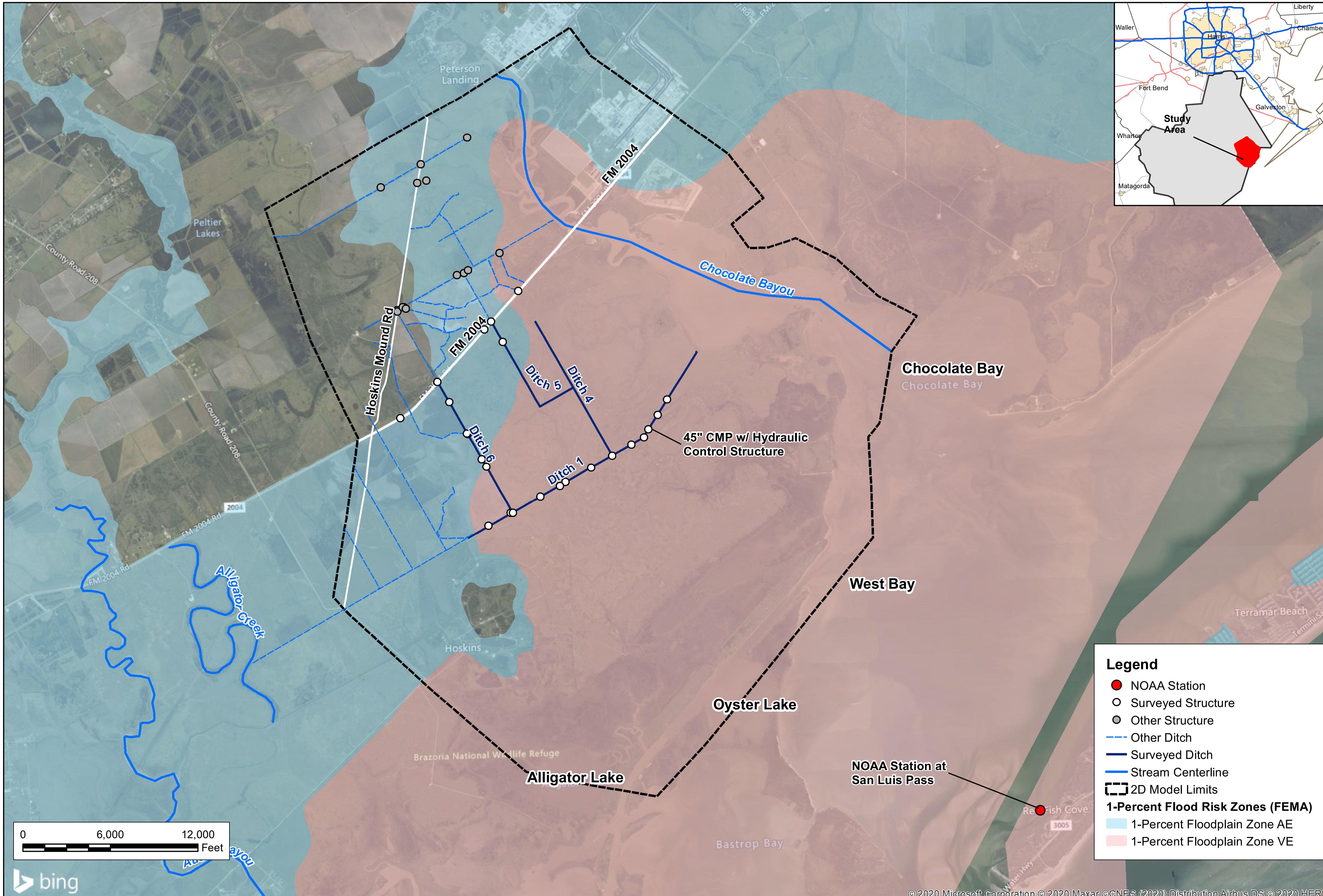



**Figure 1: Site Overview**

**Figure 2** on the next page shows that most of the Unit lies within FEMA's current effective 100-year floodplain. According to FEMA's maps, the Unit falls under two different floodplain zones: Zone AE – Base Flood Elevations determined and Zone VE – Coastal flood zone with velocity hazard (wave action) with Base Flood Elevations determined. **Figure 2** also notes the location of the NOAA tidal station from which tailwater data was obtained.




BRAZORIA NWR WETLANDS RESTORATION

SITE OVERVIEW

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FIGURE

2

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# 2.0 DATA COLLECTION

The following sections describe the field reconnaissance and data collection completed for the project.

## 2.1 SITE VISITS

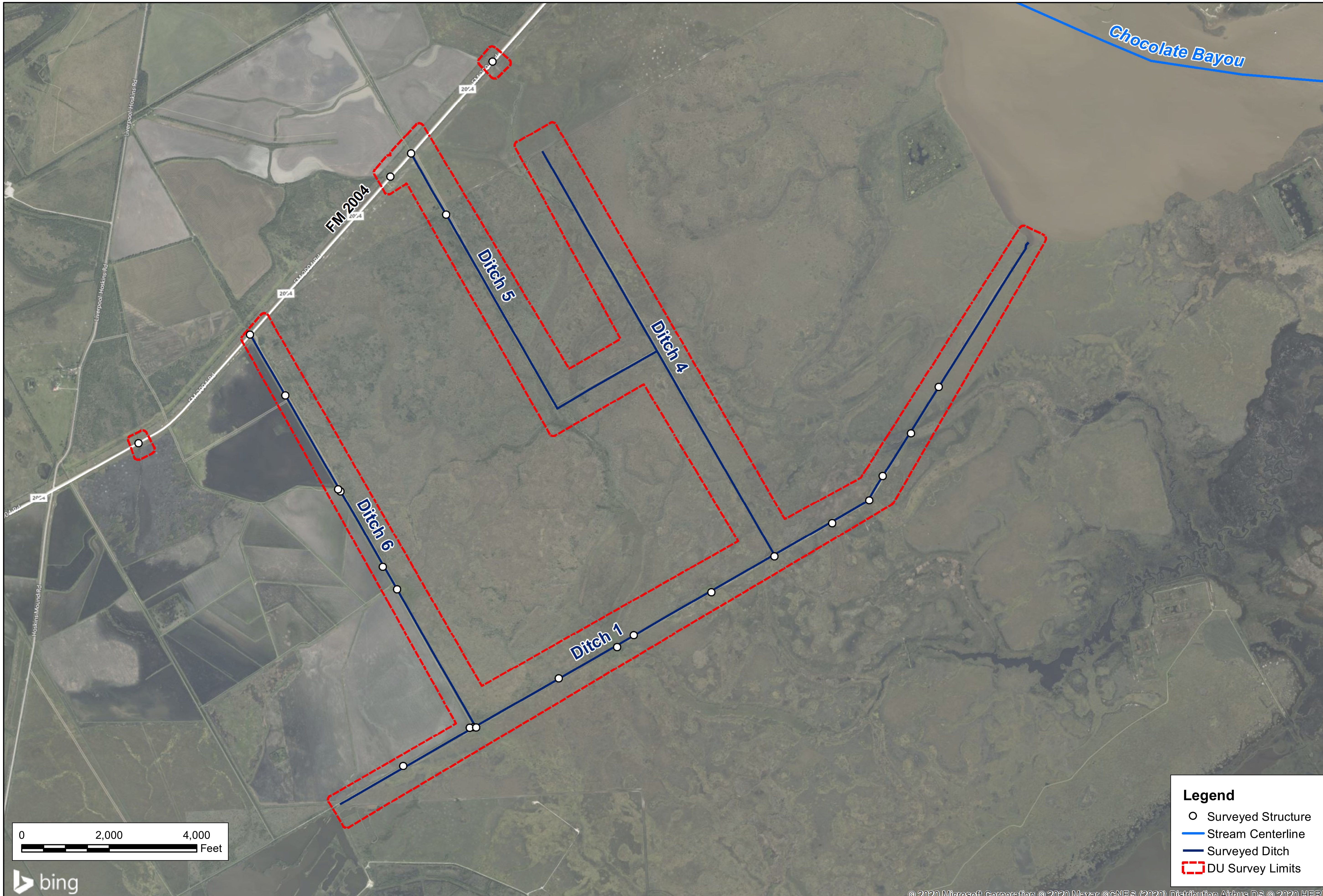
A site visit was conducted on December 19, 2018, to observe and verify existing conditions for the project area and included project team members Garrett Johnston and David Buzan. The site visit included driving along Ditch 6 to Ditch 1, then east along Ditch 1 to the hydraulic control structure near the steel tank.

Information obtained during the site visits includes existing drainage patterns, land use conditions, and stormwater infrastructure location and conditions.

## 2.2 DATA OBTAINED FROM DU

FNI received survey data from DU that included elevation data for the drainage ditches within the project site as well as culvert sizes and invert elevations. A high-resolution LiDAR dataset that encompassed the site was also obtained from DU. The survey and lidar datasets, along with all elevations used in this study, are based on the NAVD 88 datum.

The survey was limited to key data necessary for evaluating existing drainage patterns and existing ditch capacity, with the understanding that detailed survey will be required for the design of future alternatives. The collected survey data include select roadway and surface topography, ditches, and reinforced concrete pipe (RCP) and corrugated metal pipe (CMP) culverts. **Figure 3** shows the areas included in the provided survey. The survey data were incorporated into the 2D HEC-RAS terrain.




FN PROJECT NO. DKS18637
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DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central
FILE NAME Name: Figure 2 - Survey Limits Map
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# BRAZORIA NWR WETLANDS RESTORATION

## SURVEY LIMITS MAP

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FIGURE
3

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# 3.0 METHODOLOGY

FNI developed existing conditions hydrologic and hydraulic models using the HEC-HMS and HEC-RAS software packages, respectively. HEC-HMS utilizes rainfall inputs and infiltration data provided by the user to produce hydrologic outputs such as excess rainfall and flow. HEC-RAS incorporates topographic data and hydrologic outputs from HEC-HMS to model flow patterns. The site is a large overland area without specific flow paths, so the 2D component of HEC-RAS was used to model hydraulic conditions on the site.

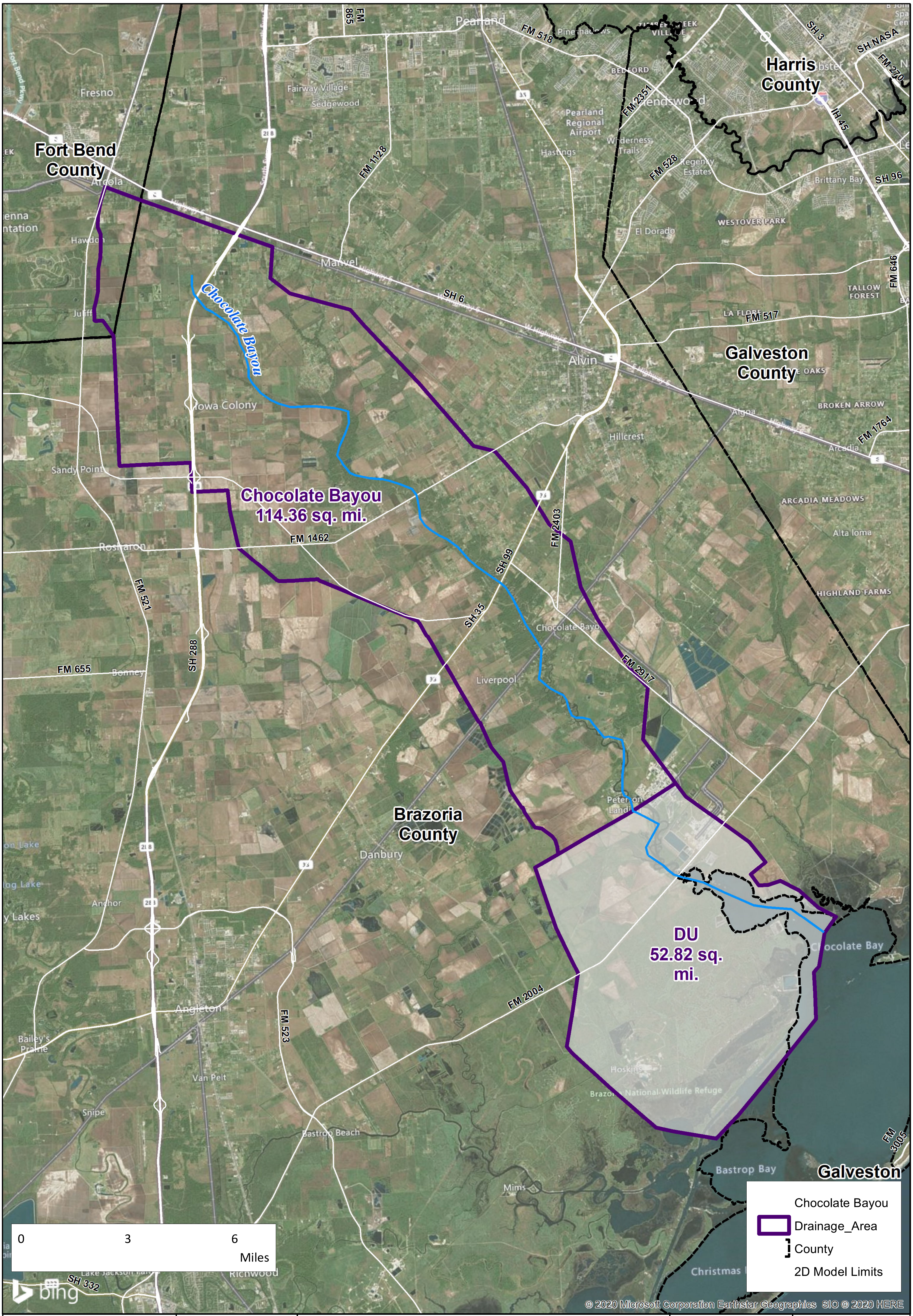
## 3.1 HYDROLOGIC METHODOLOGY

The existing conditions analysis evaluated the Unit for the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 2- and 100-year frequency storm events. One smaller historical storm on May 11, 2015 was also evaluated using precipitation gauge data from the cooperative weather observation project MesoWest. The historical storm will herein be referred to as the “3-inch rainfall”. Because hydrologic conditions on the site are not changing as part of the evaluated alternatives, output from the existing conditions HEC-HMS model was used for both existing and alternatives conditions hydraulic models. Hydrologic parameters were defined according to the Clark unit hydrograph method as outlined in the Brazoria County Drainage Criteria Manual.

### 3.1.1 Drainage Areas

The FEMA effective hydrologic model for Chocolate Bayou was last updated in 2003 and does not likely reflect conditions that have occurred in the watershed since its development. Therefore, FNI prepared a new hydrologic model of the Chocolate Bayou watershed, analyzing it as a single drainage area based on existing land use as documented in the 2011 National Land Cover Dataset. A review of recent aerial imagery shows that the area is largely undeveloped and minimal development has occurred since the creation of the land cover dataset.

To obtain the excess rainfall over the entire project site, a representative drainage area was set up with its boundaries equivalent to the 2D grid boundary. **Figure 4** shows the two drainage areas delineated for the project. The hydrologic parameters for the two drainage areas are shown in **Table 1.** These required inputs to the Clark unit hydrograph method are outlined in the *Brazoria County Drainage Criteria Manual* and were calculated using ArcGIS measurements based on LiDAR, NLCD Land Cover, and aerial imagery.

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| FN PROJECT NO. DKS18637<br>DATE CREATED Date: 10/26/2020<br>DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central<br>FILE NAME Name: Figure 4 - Drainage Area Map<br>PREPARED BY AAS | FREESE AND NICHOLS, INC.<br>10431 MORADO CIRCLE<br>SUITE 300<br>AUSTIN, TEXAS 78759<br>PHONE: 512.617.3100 | BRAZORIA NWR WETLANDS RESTORATION<br><br>DRAINAGE AREA MAP | N W E S | FIGURE<br>4 |

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**Table 1. Hydrologic Parameters**

| Parameter | Chocolate Bayou | Brazoria NWR |
|---|---|---|
| Area (square miles) | 114.36 | 52.82 |
| Length (miles) | 40.58 | 8.07 |
| Length to Centroid (miles) | 27.85 | 4.51 |
| Channel Slope (feet/mile) | 1.48 | 1.64 |
| Watershed Slope (feet/mile) | 5.26 | 5.00 |
| Percent Urban Development (%) | 28.70 | 12.40 |
| Percent Channel Improvement (%) | 100.00 | 50.00 |
| Percent Channel Conveyance (%) | 85.00 | 20.00 |
| Percent Impervious (%) | 27.31 | 12.40 |
| Watershed Slope Factor (D, unitless) | 2.46 | 2.46 |
| Time of Concentration (TC) (hour) | 28.55 | 6.49 |
| Storage Coefficient (R) (hour) | 42.95 | 20.11 |
| TC+R (hour) | 71.50 | 26.60 |

### 3.1.2 Excess Rainfall

Precipitation-on-grid was the primary method used to apply rainfall to the 2D HEC-RAS model. This is a standard boundary condition method for 2D HEC-RAS models as described in Chapter 3 of the *HEC-RAS River Analysis System 2D Modeling User's Manual, Version 5.0*. This method was utilized because the project site does not contain distinct flow patterns, and stormwater runoff is collected into various ditches by overland sheet flow and shallow flow. HEC-HMS was used to generate a proper rainfall time series for each storm. HEC-RAS does not incorporate hydrologic losses in its computations, so HEC-HMS was used to calculate losses. The term excess rainfall is used to describe precipitation that accounts for losses. Losses represent rainfall that does not contribute to stormwater runoff because it is lost to infiltration, depression storage, canopy storage, and evaporation. The relationship between precipitation, losses, and excess rainfall is shown below.

*Precipitation – Losses = Excess Rainfall*

Losses were calculated in HEC-HMS according to the methodology outlined in Section 2 of the Brazoria County Drainage Criteria Manual. The loss parameters are shown below in **Table 2**.

**Table 2. HEC-HMS Initial and Constant Loss Parameters**

| Parameter | Value |
|---|---|
| Initial Range (in) | 0.0 |
| Initial Coefficient | 0.5 |
| Coefficient Ratio | 3.0 |
| Exponent | 0.6 |

### 3.1.3 Rainfall Data

FNI utilized the NOAA Precipitation Frequency Data Server to obtain Atlas 14 rainfall data for the site. The rainfall frequencies for each storm analyzed were measured at the centroid of the 2D area. For this analysis, the 2- and the 100-year storms were analyzed. As noted previously, a smaller 3-inch rainfall event was also evaluated based on May 11, 2015 gauge data. The 1-hour precipitation data were recorded by gauge BZRT2, a Remote Automatic Weather Stations (RAWS) gauge at the Brazoria National Wildlife Refuge (29.146306° N, 95.303083° W). The inclusion of this storm is intended to model a more common rainfall event the site may encounter outside of the 2- and 100-year design storms. The depths associated with each storm are shown in **Table 3** below.

**Table 3. Rainfall Data**

| Storm | Rainfall Depth by Duration (inches) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5-min | 15-min | 1-hr | 2-hr | 3-hr | 6-hr | 12-hr | 24-hr |
| 2-year | 0.59 | 1.20 | 2.29 | 2.88 | 3.24 | 3.87 | 4.55 | 5.26 |
| 100-year | 1.34 | 2.65 | 5.15 | 7.40 | 9.05 | 11.90 | 14.50 | 17.10 |
| 3” rainfall | - | - | 1.14 | 2.07 | 2.30 | 2.76 | 2.89 | 2.98 |

For the 2-year and 100-year design storms, FNI created a frequency storm in HEC-HMS. For the 3-inch rainfall event, precipitation gauge data was entered directly as time series data. HEC-HMS produced a 24-hour excess rainfall time series for each storm. The excess rainfall time series were then entered in the 2D HEC-RAS model to create a plan file for each event. **Figure 5** shows the incremental rainfall distribution for the 3-inch rainfall event.

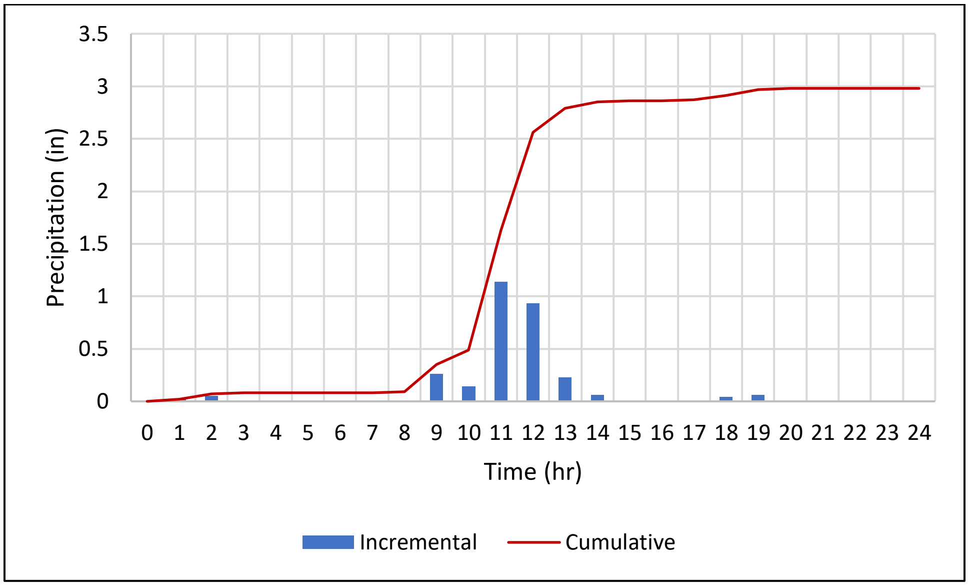
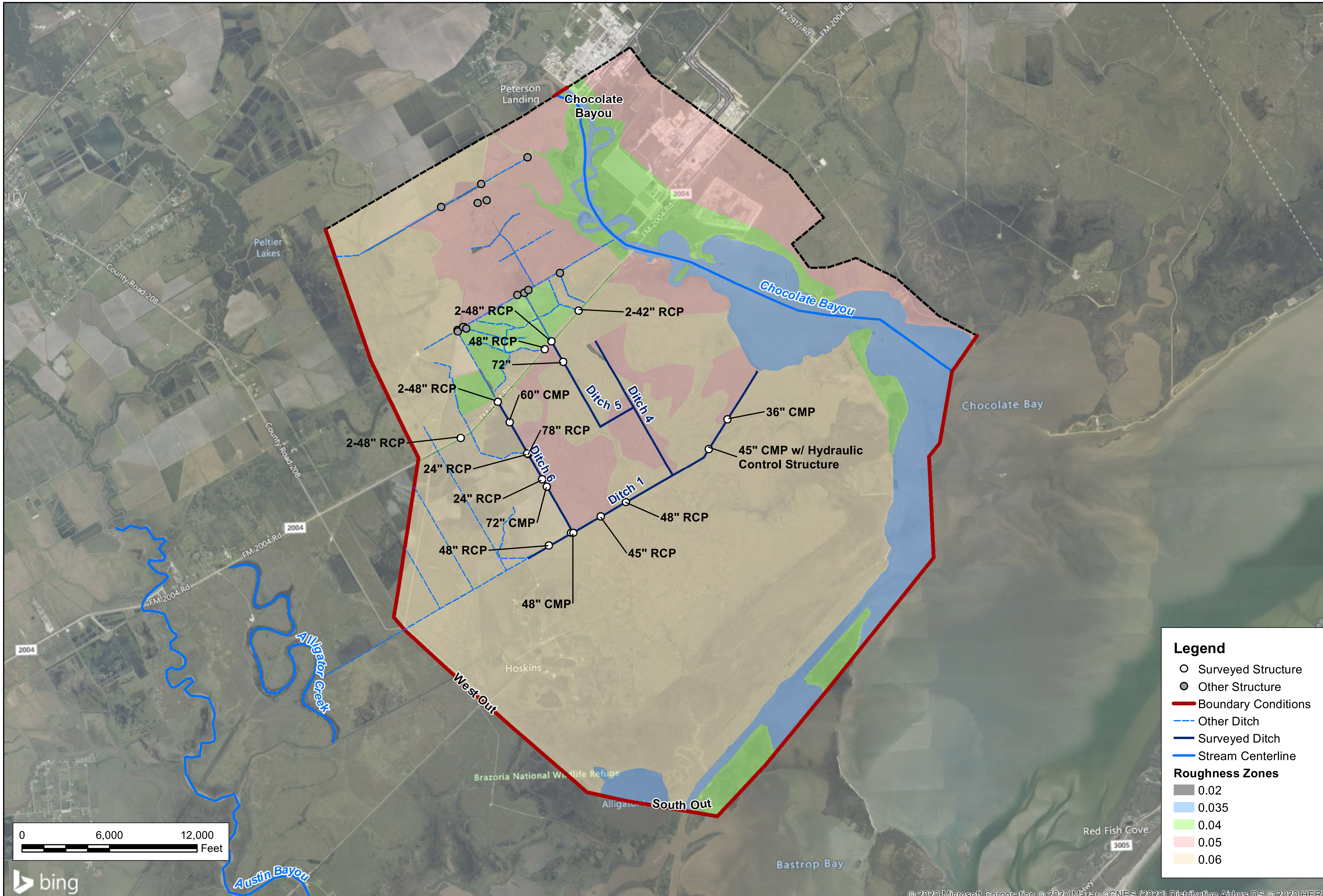



**Figure 5. 3-inch Rainfall Incremental Precipitation**

## 3.2 HYDRAULIC METHODOLOGY

The 2D platform of HEC-RAS was used for the hydraulic analysis in order to simulate two-dimensional flow patterns within the project site. In a traditional hydraulic model (e.g., 1D HEC-RAS), a water surface is calculated using gradually varied flow equations, which assume that flow travels in a single downstream direction perpendicular to predefined cross sections. In contrast, 2D HEC-RAS calculates a water surface using the St. Venant shallow-water equations, which assume that flow can travel in two horizontal directions across a predefined 2D grid. The 2D grid boundary, which is shown in **Figure 6**, extends far enough outside the area of interest to determine exactly where overland flow stops contributing to the stormwater runoff of the project site.

In the project area, water flows in many directions before it is collected into various drainage ditches and reinforced concrete pipe (RCP) and corrugated metal pipe (CMP) culverts. These ditches and culverts are also shown on **Figure 6**. Stormwater runoff that is not collected in the drainage ditches either leaves the project area to the west, flows into Chocolate Bayou to the east, or flows into one of multiple bays to the south. The use of 2D modeling allows FNI to evaluate the complex overland flow patterns in more detail than traditional 1D modeling would allow.

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FILE NAME: Name: Figure 6 - Hydraulic Model Layout

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# BRAZORIA NWR WETLANDS RESTORATION

# EXISTING HYDRAULIC MODEL LAYOUT

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FIGURE 6

### 3.2.1 Terrain and Hydraulic Structures

The existing conditions 2D terrain was developed using 2018 LIDAR provided by DU on December 19, 2018 and supplemented with survey of the drainage ditches also provided by DU. In some instances, the terrain was modified manually at the culvert inlets and outlets to apply invert elevations from the survey. The existing conditions terrain served as a baseline for the alternative analyses, where minor additions were made for proposed features such as a berm or access road. Changes were localized to proposed features and the baseline terrain remained unchanged.

During the existing conditions analysis, DU raised concerns regarding the accuracy of the bare earth LiDAR data. While LiDAR data is generally acceptable, it struggles to record accurate elevation data in areas where there is standing water or heavy vegetation. This site contains large areas of flat undeveloped land with wetland areas that frequently retain some shallow depth of standing water and vegetation that may obscure the bare earth LiDAR returns. FNI compared the survey points provided by DU to the provided LiDAR data. Over 4,000 survey points were recorded. The differences between the LiDAR data and surveyed elevations were sorted and summarized in **Figure 7** below. Positive values represent areas where the LiDAR elevation is higher than the survey data. Based on this elevation comparison, the baseline LiDAR terrain was uniformly lowered by 1.0 foot before merging it with the provided survey. This uniform lowering did not impact the overall drainage patterns of the site, but did allow for more accurate hydraulic interaction between the surveyed ditches and the immediate surrounding landscape area.

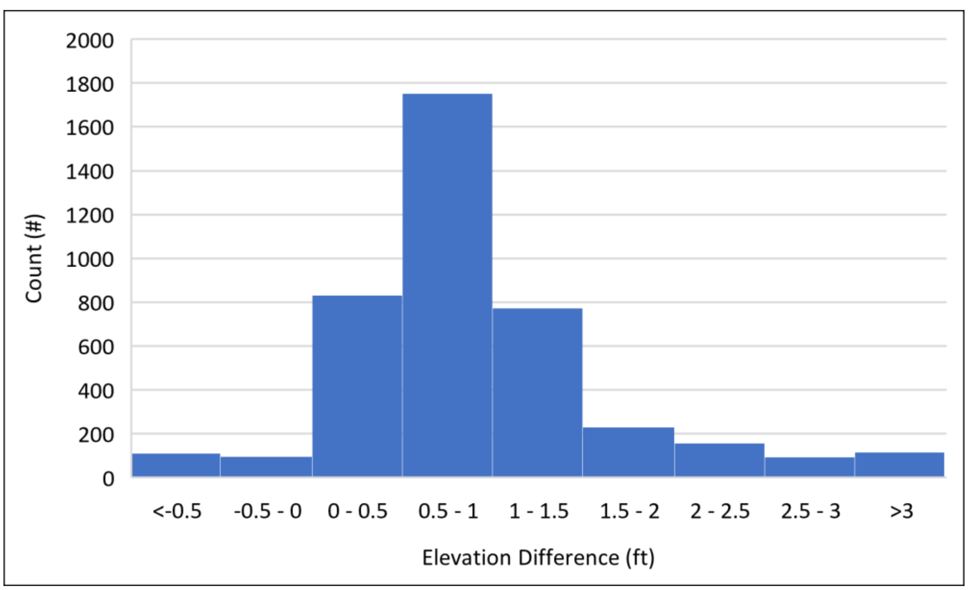



**Figure 7: LiDAR vs. Survey Elevation Comparison Summary**

The 2D model includes culverts that allow flow to cross FM 2004 as well as several crossings of the surveyed ditches. The culvert sizes, locations, and invert elevations were taken from the survey provided by DU. The culvert locations and sizes are shown on **Figure 6** above.

**Figure 6** also shows a hydraulic control structure at the downstream end of Ditch 1 that retains water on the upstream side of the ditch and acts as a saltwater barrier to keep Chocolate Bay from backing up through the ditch system. Survey data provided by DU indicates that this structure has a 4.0' weir length with boards set at elevation 3.40.

### 3.2.2 Roughness Zones

The 2D grid includes spatially varying roughness elements to capture the increased resistance associated with various types of land use, which affect the ability of water to flow across the surface. Typical roughness values were assigned using aerial photography and data gathered during the field visit. Standard values for 2D RAS modeling are provided in the detailed study *Australian Rainfall and Runoff Revision Projects – Project 15: Two Dimensional Modelling in Urban and Rural Floodplains* (2012). **Figure 6** above shows the roughness zones used in the model, and **Table 4** lists the land use per roughness zone.

**Table 4. Manning's Roughness Zone Values**

| General Land Use | Manning's Roughness Value |
|---|---|
| Paved Area | 0.02 |
| Open Water, High Flow Area | 0.035 |
| Open Space, Ditch | 0.04–0.05 |
| Open Space, Light Brush | 0.05 |
| Medium Brush, Wetland | 0.06 |

### 3.2.3 Tailwater Conditions and Storm Surge

Two types of tailwater conditions were incorporated into the 2D model: variable stage and fixed stage. Both were based on NOAA Gauge 8771972 in San Luis Pass, TX. A variable stage tailwater changes over time, while a fixed stage tailwater condition remains at a constant elevation throughout the simulation.

**A. Variable Stage**

A variable stage tailwater condition was used in the analysis of the historic 3-inch rainfall that occurred on May 11, 2015. The tailwater data for this event was pulled directly from the NOAA gauge at San Luis Pass, TX and applied to the 2D model. This stage hydrograph is shown below in **Figure 8**.

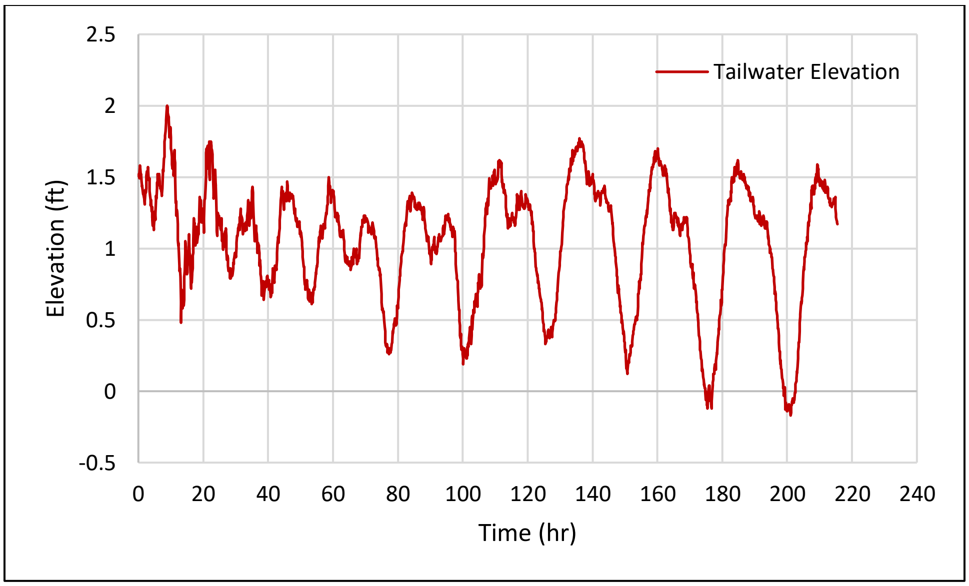



**Figure 8: 3-inch Rainfall Tailwater Elevations**

**B. Fixed Stage**

Two fixed stage tailwater conditions were used in the hydraulic analysis, the Mean Higher High Water (MHHW) and the Hurricane Harvey 2017 storm surge. The MHHW elevation was based on the NOAA gauge at San Luis Pass, TX which gives a mean higher-high water elevation of 0.85 feet (NAVD88). The tailwater elevation of 0.85 feet was used in the analysis of the Atlas 14 2-year and 100-year events and represents a conservative average tailwater elevation for the site. The MHHW tailwater elevation does not significantly impact the project area, and it allows for a precise analysis of flow patterns on the site absent the influence of a significant storm surge. **Figure 9** below shows tidal data obtained from the NOAA website regarding the gauge located at San Luis Pass, TX.

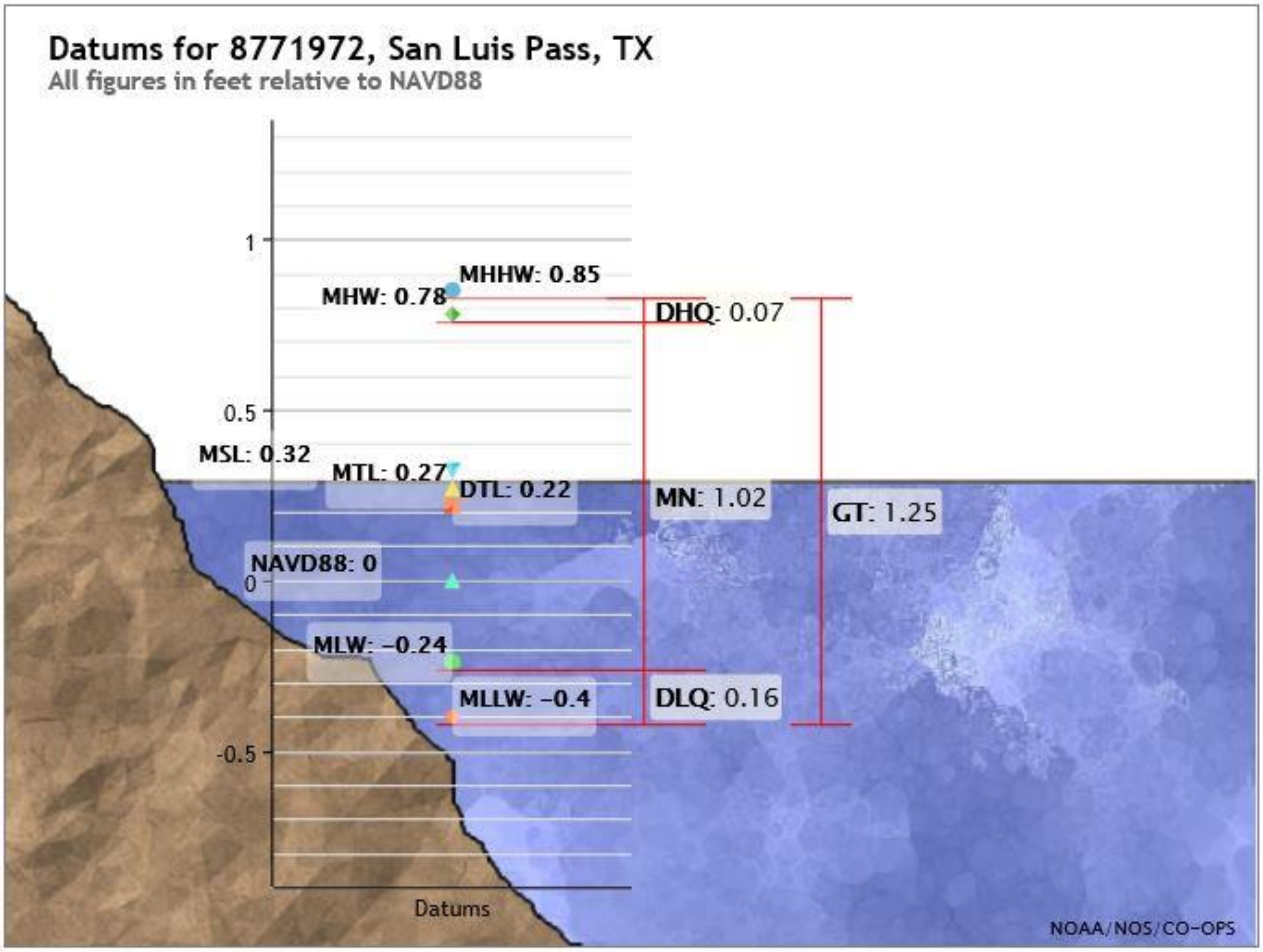



**Figure 9: NOAA Tidal Data for San Luis Pass, TX**

Other parameters shown on **Figure 9** document additional tidal data recorded by each NOAA station. MTL and MSL refer to mean tide and sea levels, respectively. MLW and MHW each represent the mean of all recorded low and high water elevations, respectively. This differs from MLLW and MHHW, which include only the lower or higher of each diurnal tidal elevation in the average, respectively. DLQ and DHQ calculate one-half the average difference between two low or high waters of each tidal day, respectively. GT represents the difference between MHHW and MLLW. For more information on these parameters, refer to the *NOAA Tidal Datums* website listed in Section 7.0.

An additional 100-year model run was created that uses a tailwater condition which corresponds to a substantial storm surge instead of the MHHW elevation. Because storm surge elevations are highly variable and the modeled 100-year event is a theoretical storm, the storm surge that occurred during

Hurricane Harvey in 2017 was used as a conservative estimate of a high storm surge on the site. **Figure 10** shows the stage hydrograph from the NOAA gauge at San Luis Pass, TX during Hurricane Harvey.

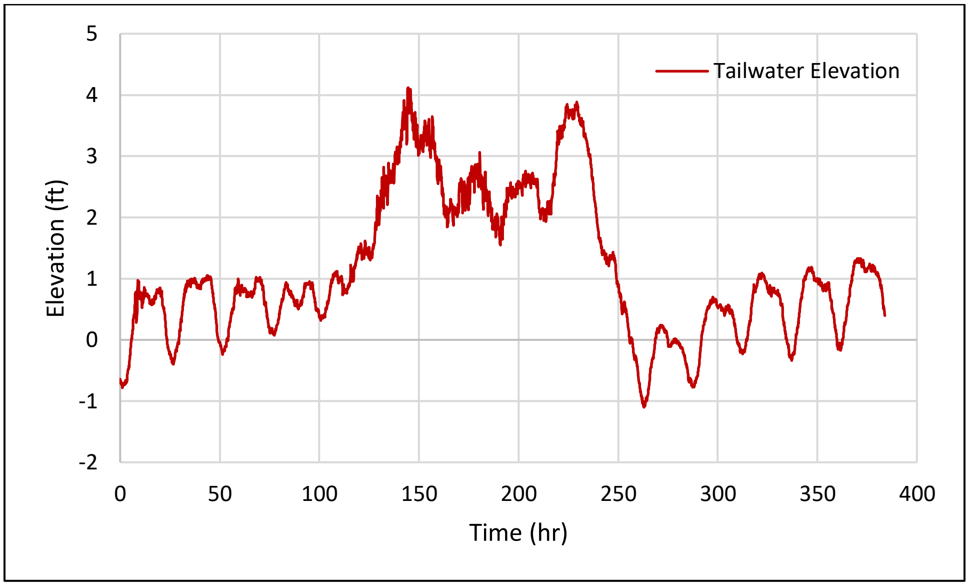



**Figure 10: Hurricane Harvey Tailwater Elevations**

Based on the Hurricane Harvey data, a fixed stage tailwater elevation of 4.0 feet was used for the additional 100-year model runs. The tailwater elevation of 4.0 feet inundates much of the site south of Ditch 1. By modeling a 100-year event with both a MHHW tailwater and a high storm surge tailwater, the two 100-year simulations will effectively bracket what the results of a 100-year event on the project site could be. The two 100-year runs will also allow for more detailed comparison between existing and proposed conditions when evaluating potential adverse impacts to adjacent property.

### 3.2.4 Event Summary

The following table summarizes the combination of rainfall events and tailwater conditions modeled as part of this analysis. These combinations were applied to existing conditions and all alternative conditions hydraulic models.

**Table 5: Modeled Event Summary**

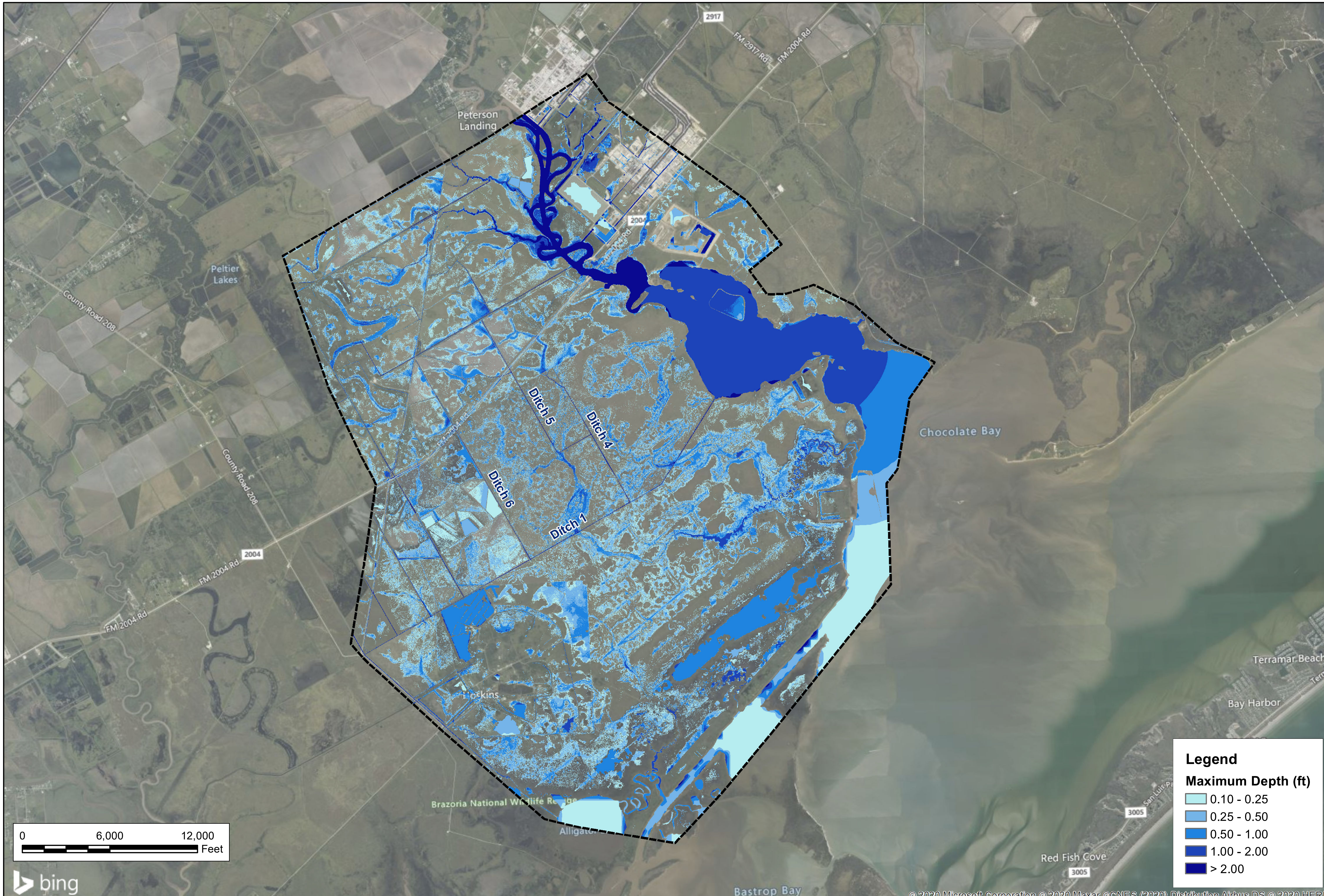
| Rainfall Event | Tailwater Type | Tailwater Elevation |
|---|---|---|
| 2-year | Fixed | MHHW |
| 100-year | Fixed | MHHW |
| 100-year | Fixed | Harvey Peak Surge |
| Historic 3-inch | Variable | Historic (5/11/2015) |

## 4.0 EXISTING CONDITIONS

FNI used the existing conditions hydraulic model to simulate the 2- and 100-year design storms using Atlas 14 rainfall depths. A 24-hour 3-inch total rainfall storm pulled from historical rain gauge data was also simulated in the existing conditions model. Maximum water surface elevations and depths on the 2D mesh were mapped for each storm. Maximum depth rasters for the 24-hour 3-inch, 2-year, and 100-year (MHHW) events are shown on **Figure 11 – Figure 13,** respectively.

## 4.1 FLOW PATTERNS

**Figure 14** shows flow arrows that represent the general flow patterns throughout the site. Flow that collects into the various ditches throughout the site discharges east into Chocolate Bayou. The ditches within the project site have capacity for small storms and do not show overtopping in the 2-year and 3-inch existing condition runs. In the 100-year run, Ditch 1, which runs west to east across the project site, overtops in multiple locations allowing flow to move across the ditch to the south. Stormwater runoff located south of Ditch 1 moves through wetland features and discharges into the coastal water features that line the project site to the south.

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DATE CREATED: Date: 10/26/2020

DATUM & COORDINATE SYSTEM: NAD83 State Plane Texas South Central (feet)

FILE NAME: Name: Figure 11 - Existing Conditions Small Storm Results

PREPARED BY: AAS

N W E S

# BRAZORIA NWR WETLANDS RESTORATION

## EXISTING CONDITIONS
## 3-INCH RAINFALL RESULTS (2015-05-11)


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**FIGURE**

**11**

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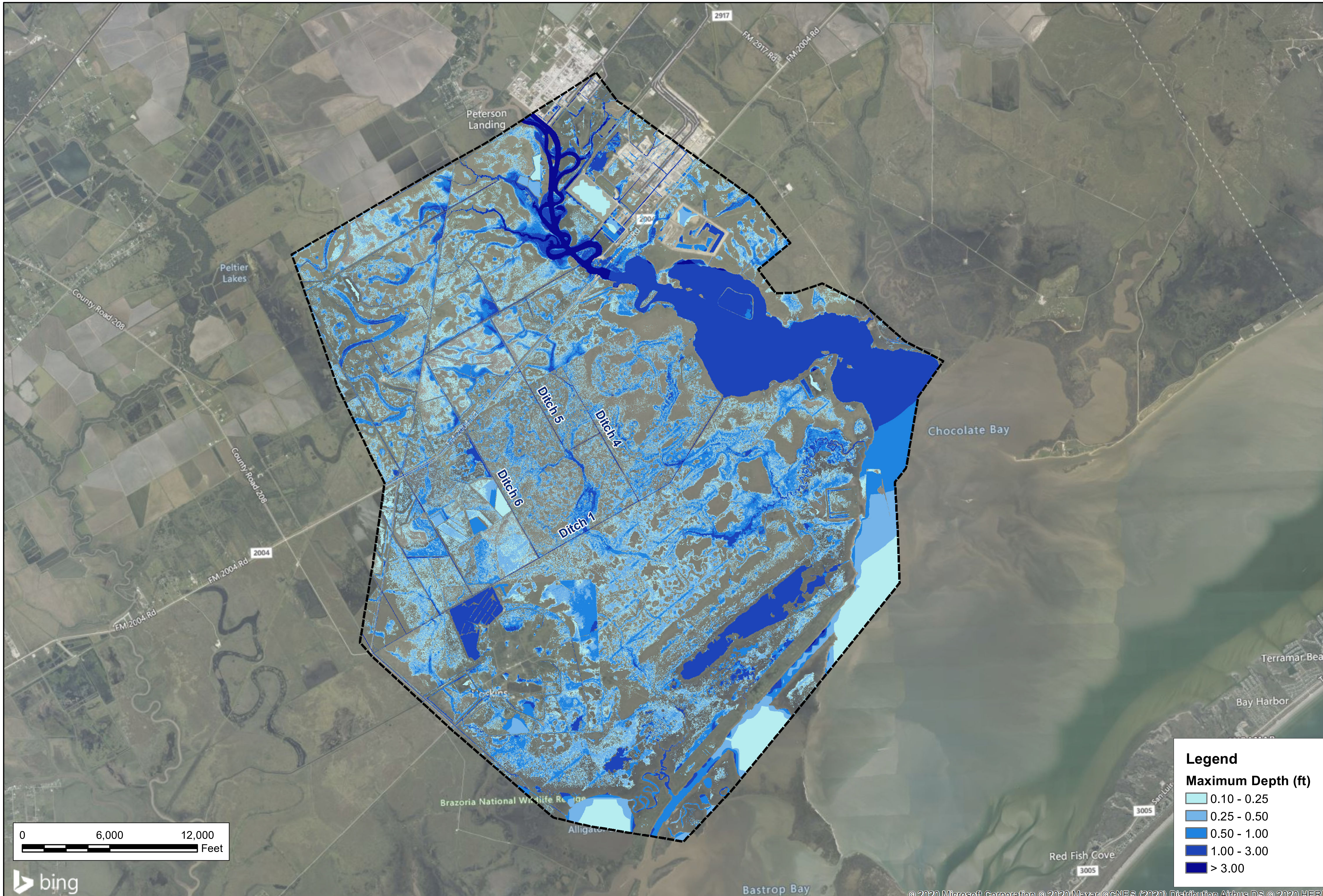
Path: H:\STORMWATER\Exhibits\2020-10\Exhibits\MXD\Figure 11 - Existing Conditions Small Storm Results.mxd

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DATE CREATED: Date: 10/26/2020

DATUM & COORDINATE SYSTEM: NAD83 State Plane Texas South Central (feet)

FILE NAME: Name: Figure 12 - Existing Conditions Atlas 14 2-YR Results

PREPARED BY: AAS

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# BRAZORIA NWR WETLANDS RESTORATION

## EXISTING CONDITIONS ATLAS 14 2-YEAR RESULTS

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FIGURE 12

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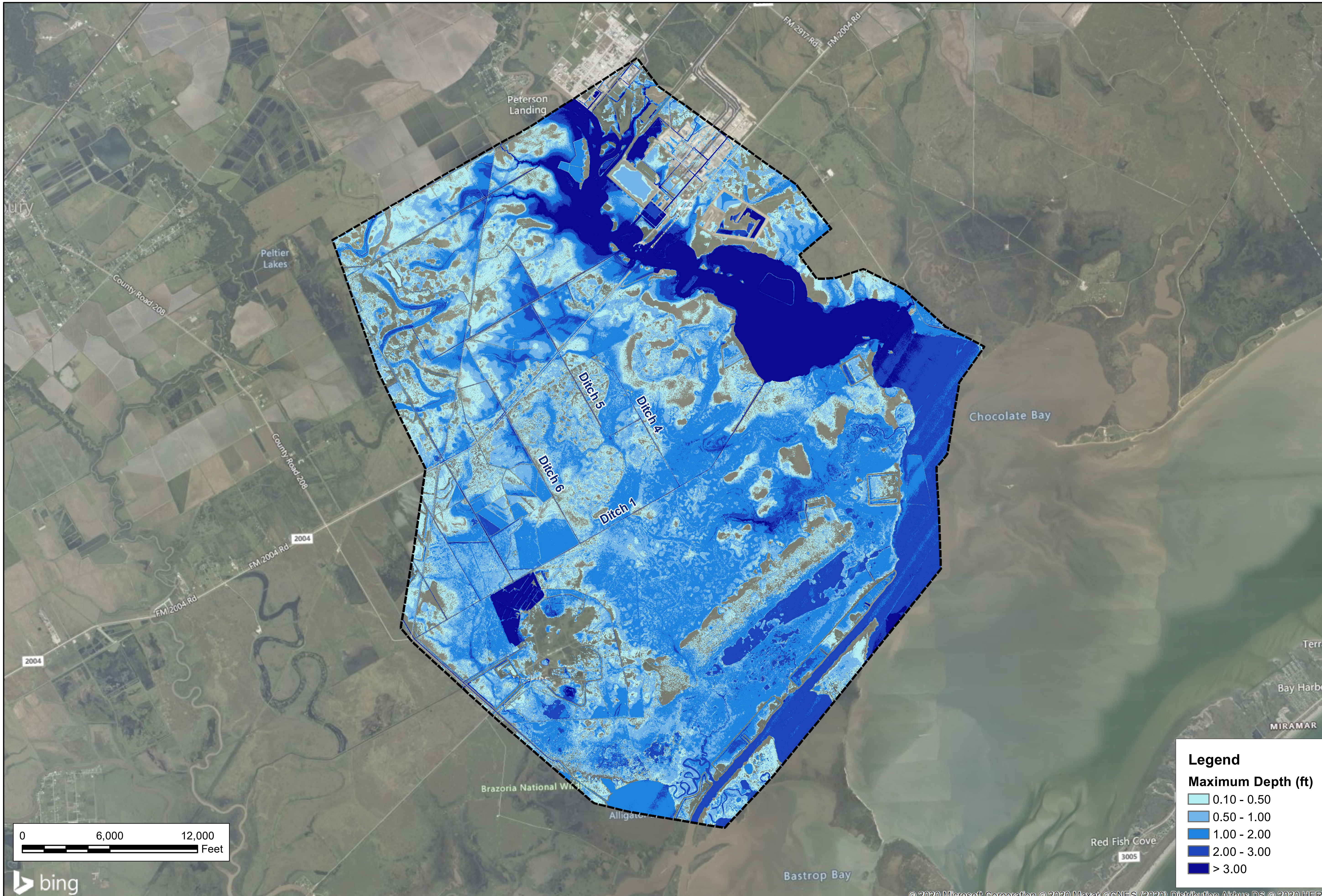
Path: H:\STORMWATER\Exhibits\2020-10\Exhibits\MXD\Figure 12 - Existing Conditions Atlas 14 2-YR Results.mxd




FN PROJECT NO. BRS19637

DATE CREATED Date: 10/26/2020

DATUM & COORDINATE SYSTEM NAD83 State Plane Texas South Central (Feet)

FILE NAME Name: Figure 13 - Existing Conditions Atlas 14 100-YR MHHW Results

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# BRAZORIA NWR WETLANDS RESTORATION

## EXISTING CONDITIONS ATLAS 14 100-YEAR MHHW RESULTS


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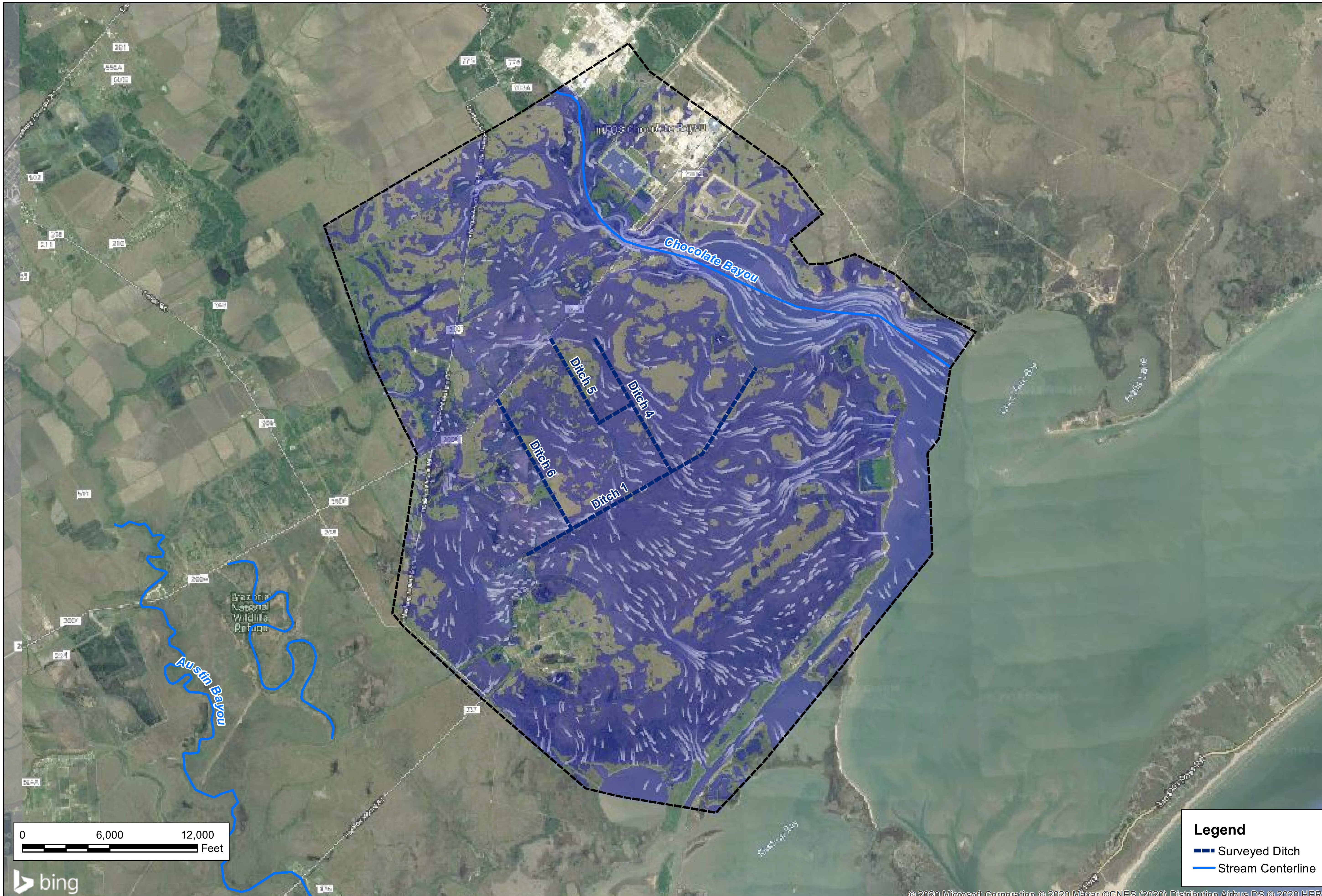
FIGURE 13




FN PROJECT NO.

DATE CREATED: Date: 10/26/2020

DATUM & COORDINATE SYSTEM: NAD83 StatePlane Texas South Central (Feet)

FILE NAME: Name: Figure 14 - Overland Flow Patterns

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# BRAZORIA NWR WETLANDS RESTORATION

# OVERLAND FLOW PATTERNS


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FIGURE 14

A review of the existing conditions hydraulic model results identified two disconnected existing sloughs that function as major flow paths through the site. These sloughs will be referred to as Sloughs A and B, which are described below. Alternatives near either of these locations will have the potential to restore natural drainage patterns to the site and move additional stormwater runoff into the wetland area south of Ditch 1.

### 4.1.1 Slough A

Slough A is located approximately 1,000 feet downstream of the existing riser that separates freshwater in Ditch 1 from saltwater in Chocolate Bay. Overland flow from approximately 1,100 acres contributes to runoff through this slough. **Figure 15** shows the location of the existing slough along with general flow patterns. **Figure 16** compares existing conditions volume accumulation through Slough A upstream of Ditch 1 and downstream of Ditch 1 for the historic small storm, which shows that only 65% of the volume upstream of Ditch 1 moves across Ditch 1 into the wetland areas. Based on this data, Ditch 1 presents a major disruption to the natural flow pattern in this area, intercepting a significant portion of Slough A runoff and conveying it directly into Chocolate Bay.

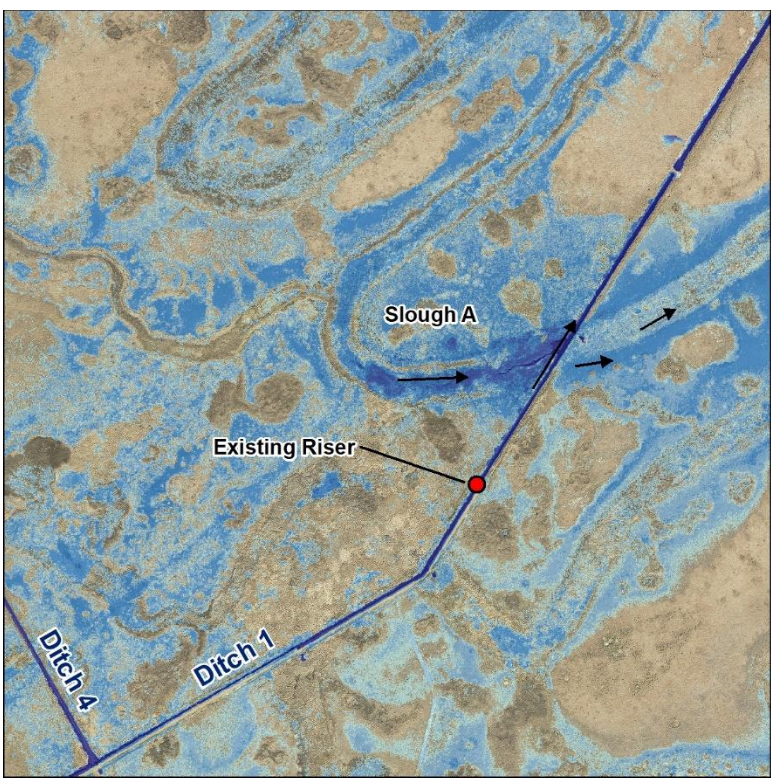



**Figure 15: Existing Conditions – Slough A**

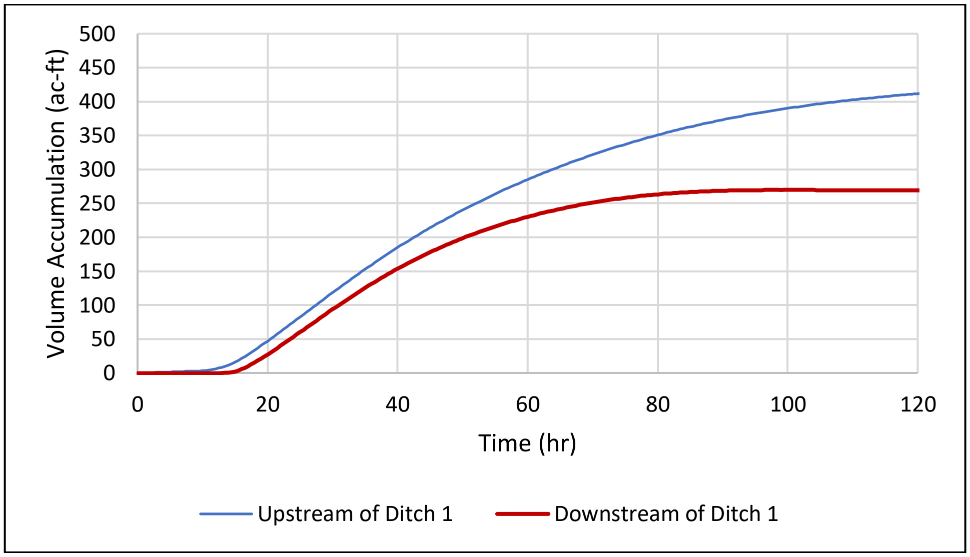



**Figure 16: Existing Conditions Slough A Volume Comparison – 3-inch Rainfall**

### 4.1.2 Slough B

Slough B is located midway between Ditch 1's confluences with Ditch 4 and Ditch 6. Approximately 1,500 acres contribute stormwater runoff to this slough. **Figure 17** shows the location of Slough B and its general flow patterns. **Figure 18** compares volume accumulation through Slough B upstream and downstream of Ditch 1, and it demonstrates that none of the volume upstream of Ditch 1 can cross into the wetland area downstream during the 3-inch rainfall event.

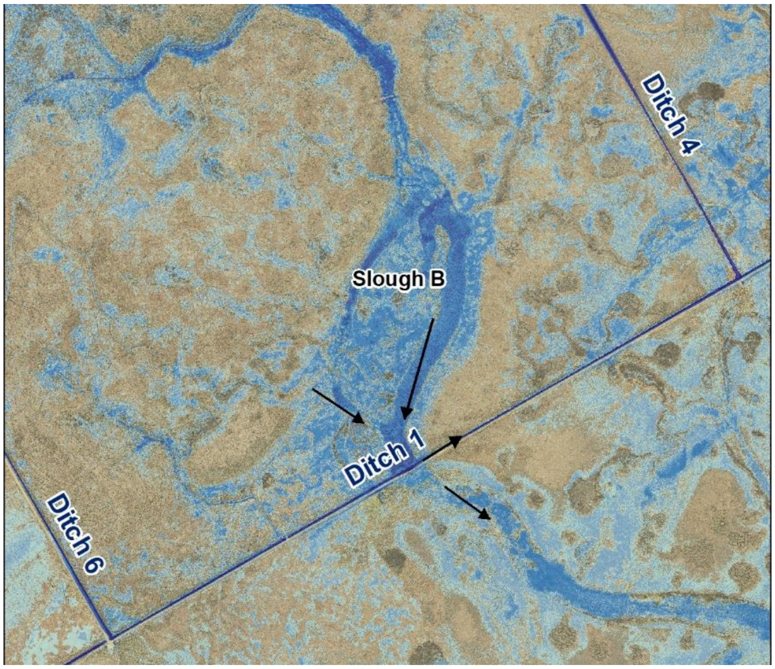



**Figure 17: Existing Conditions – Slough B**

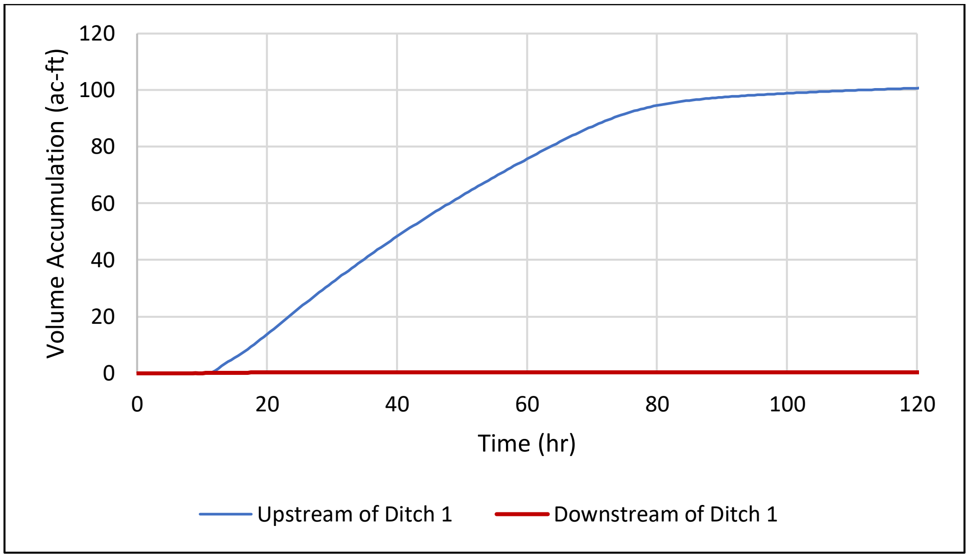



**Figure 18: Existing Conditions Slough B Volume Comparison – 3-inch Rainfall**

## 4.2 FM 2004

FM 2004 represents a major drainage divide within the project site. The area north of FM 2004 contains drainage swales with approximately one- to two-foot-tall berms on either side. These berms cause stormwater runoff to pond in open spaces. Runoff gradually flows south where it is collected into ditches that move stormwater runoff under FM 2004 via culverts. FM 2004 overtops in multiple locations in the 100-year storm.

## 4.3 CHOCOLATE BAYOU

Local stormwater runoff collects into ditches and enters Chocolate Bay long before upstream flows from Chocolate Bayou arrive and significantly impact the project site. The Chocolate Bayou watershed begins approximately 27 miles upstream of the project area just south of Highway 6 near Manvel, Texas. Due to the length of the Chocolate Bayou watershed, the timing of peak flows from Chocolate Bayou compared to local flows from the project site differ significantly. A comparison of the Chocolate Bayou Atlas 14 100-year hydrograph with the Ditch 1 outflow hydrograph from the same storm is shown in **Figure 19**.

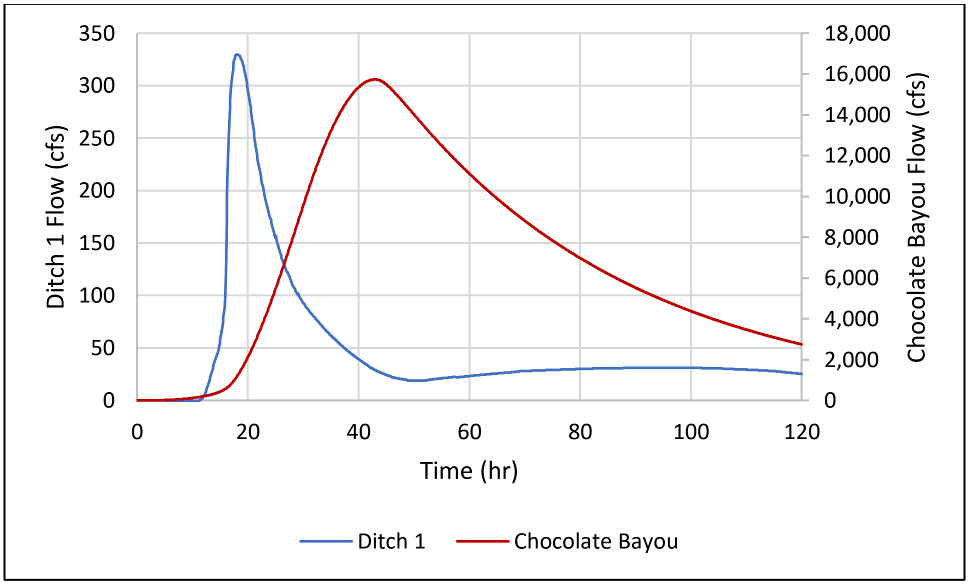



**Figure 19: 100-year Hydrograph Timing Comparison**

During high flow conditions on Chocolate Bayou, the main channel overtops and flows into the wetland areas south of Ditch 1. The alternatives analyzed for this study do not affect the overflow from Chocolate Bayou through the area south of Ditch 1.

## 5.0 ALTERNATIVES ANALYSIS

The primary goal of the alternatives is to restore the hydro-period on the site to a condition like one before the construction of Ditches 1, 4, 5, and 6. While these ditches do convey stormwater runoff, they also cut off natural drainage patterns that would have previously fed the wetland area south of Ditch 1.

Multiple key locations were identified for potential alternatives through a review of existing conditions model results, terrain data, and aerial imagery. Each alternative was designed to aid in restoring the natural hydro-period of the site. For the purposes of alternatives evaluation, the hydro-period for a given storm at a given location is defined as the number of hours that location remains at a flood depth of more than 3 inches, or 0.25 feet. For the sloughs on this site, a longer hydro-period with a gradual rise and fall indicates a more natural flow condition. A shorter or flashier hydro-period indicates that flow is being diverted or drained by manmade ditches. The three alternatives include several different components, but there are common elements in each. The elements common to each alternative are described below.

### 5.1.1 Proposed Riser

For each alternative, the existing Ditch 1 riser will be moved approximately 2,500 feet downstream. Moving the riser downstream will allow for more of Ditch 1 to retain water and help facilitate the movement of water across Ditch 1 through the previously disconnected Slough A. The road on the south side of Ditch 1 will also be extended to the new location in order to provide access to the proposed riser.

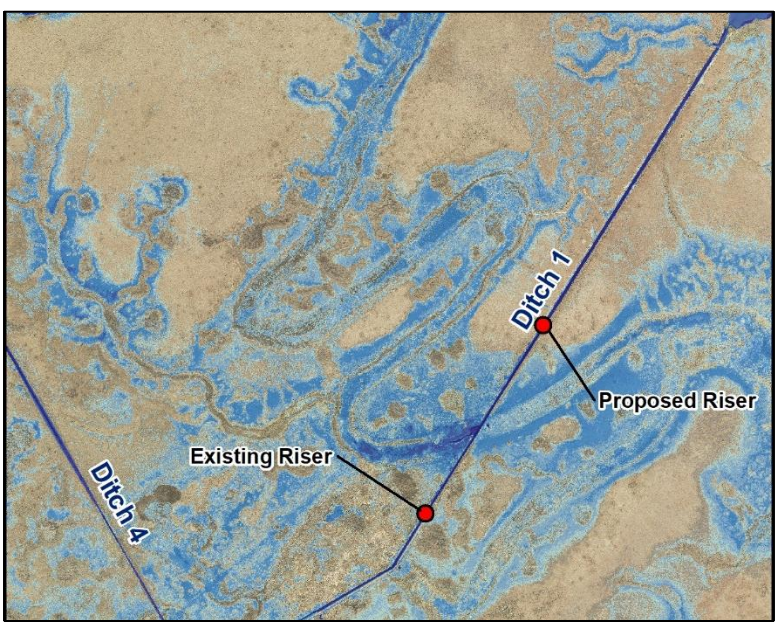



**Figure 20: Proposed Riser Location**

### 5.1.2 Ditch 5 Berms

Near the 90-degree bend on Ditch 5, berms on the north and south side of the ditch will be removed along the alignments shown in **Figure 21** below. The existing berms disrupt the natural movement of stormwater runoff between Ditch 4 and Ditch 5 by retaining runoff or diverting it into the ditches. The removal of both berms will allow runoff to move more freely downstream into Slough B. The removal of these berms will be a "cut only" scenario at elevation 5.70, the approximate elevation of natural ground near the berms. Berms with elevations above this value will be cut, while locations below elevation 5.70 will be left at existing elevations. The removal of these berms represents approximately 2,300 CY of cut volume. **Figure 22** demonstrates the "cut only" condition that will be applied to the Ditch 5 berms.

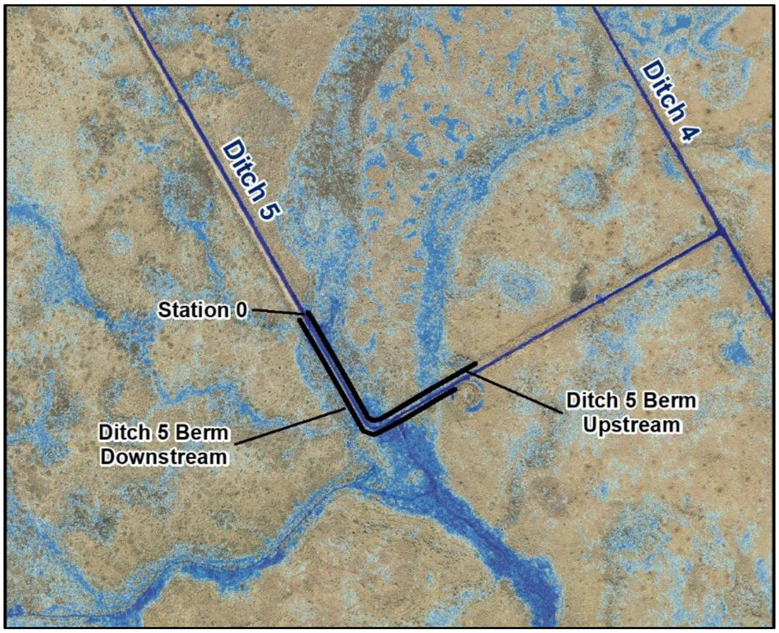



**Figure 21: Ditch 5 Berm Removal**

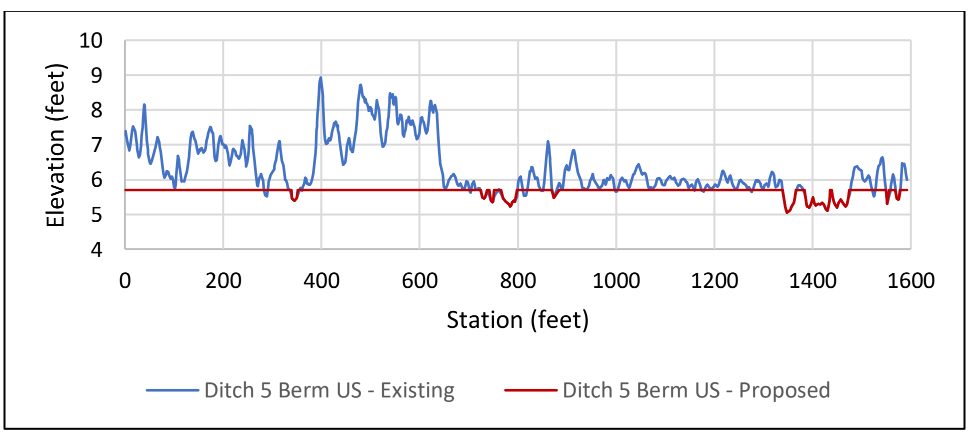



**Figure 22: Ditch 5 Berm Removal Profile**

### 5.1.3 Overland Berm Removal

There are several historic berms distributed throughout the overland area that will be removed in all proposed alternatives. The removal of these berms is a simple and cost-effective option that will aid in restoring the natural flow patterns on the site. Cutting the three existing berms to natural elevations represents a total cut volume of approximately 1,300 CY. The location of the berms that will be removed in each alternative is shown in **Figure 23**.

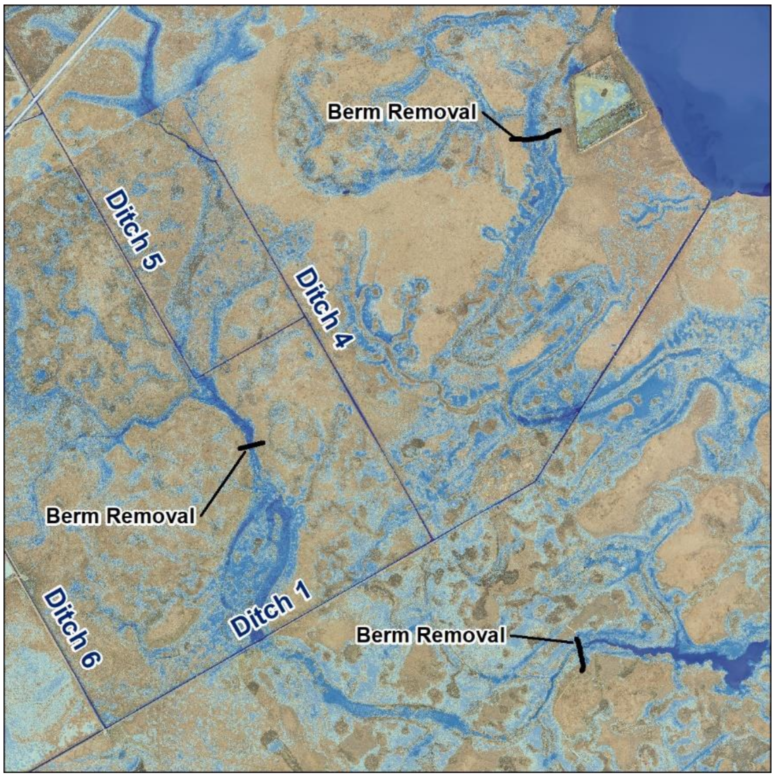



**Figure 23: Overland Berm Removal**

## 5.2 ALTERNATIVE 1

In addition to the common elements described above, Alternative 1 will include side weirs that will be constructed along the right bank of Ditch 1, through its south berm near existing Sloughs A and B. The weir elevation and size of the weir was determined through an analysis of existing conditions results and topography. By constructing weirs through the berm along Ditch 1, stormwater runoff will be able to spill out of the ditch and runoff north of the ditch will be able to cross into the wetland area to the south.

Alternative 1 includes Weir 1, a 430’ long weir at Slough A cut down to elevation 2.75, and Weir 2, a 245’ weir at Slough B cut down to elevation 3.75. The weir notch depths at Weir 1 and Weir 2 are approximately four and two feet, respectively. Each weir will tie in with natural ground via 8:1 side slopes. The weirs will also need to be sufficiently armored to prevent erosion from vehicle access or flooding events. The construction of Weir 2 represents approximately 200 CY of cut volume. The construction of Weir 1 represents approximately 300 CY of cut volume. **Figure 24** and **Figure 25** show the location of each proposed weir. An overview of the complete Alternative 1 layout is shown on **Figure 26**.

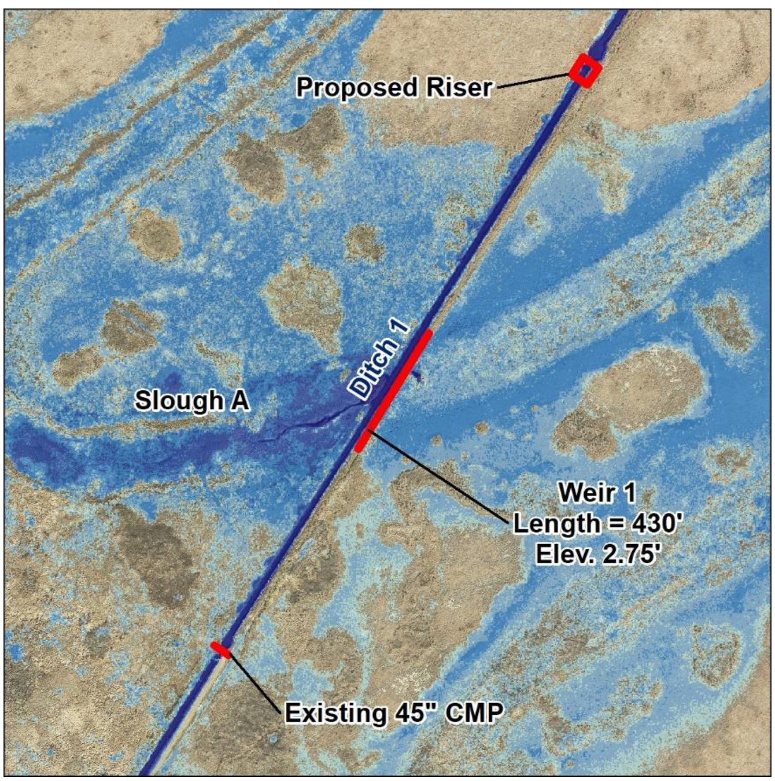



**Figure 24: Alternative 1 – Weir 1**

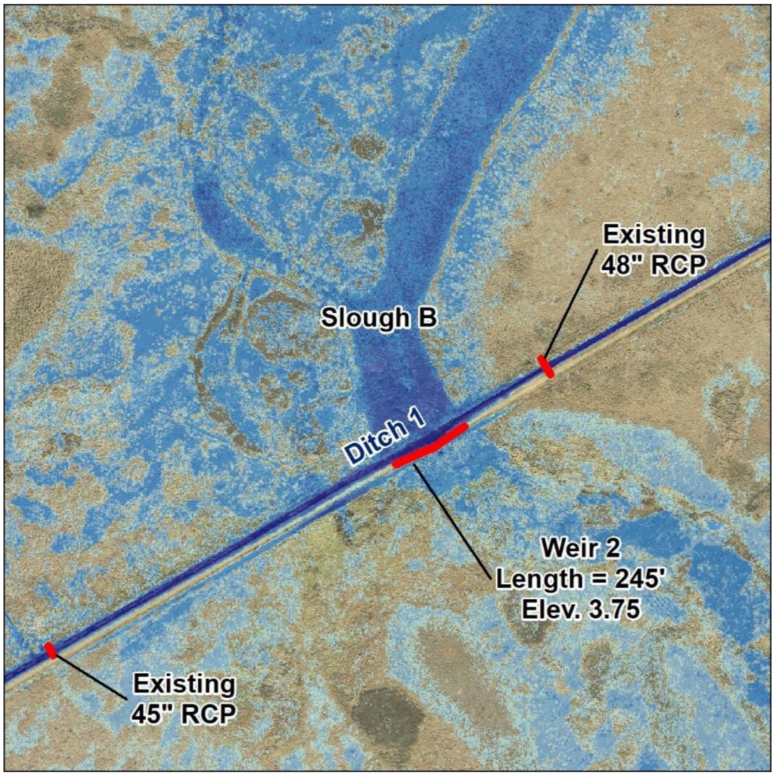
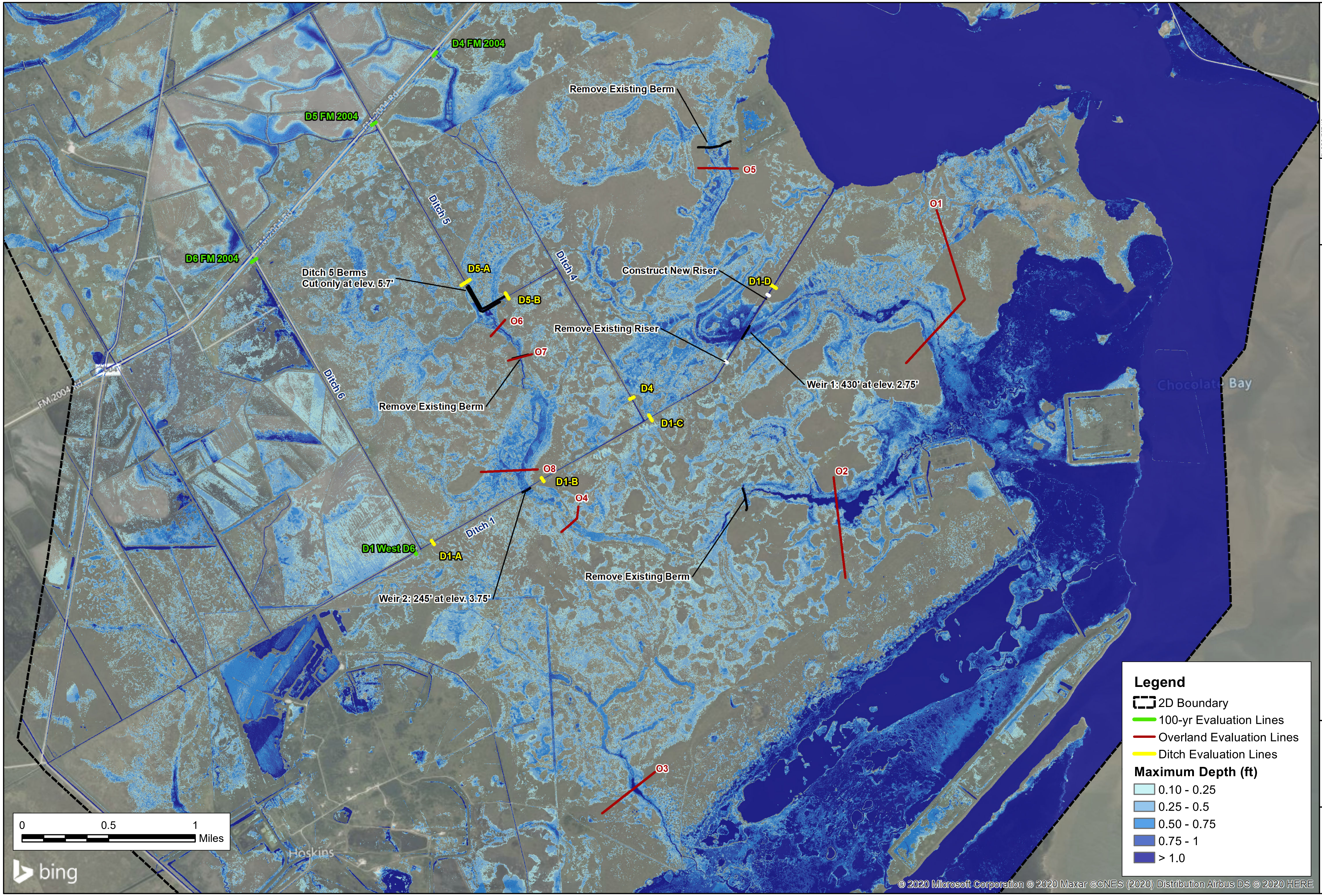



**Figure 25: Alternative 1 – Weir 2**

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FILE NAME: Name: Figure 26 - Alternative 1 Overview - 3-in Results

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# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 1 OVERVIEW
## 3-INCH RAINFALL RESULTS (2015-05-11)

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**FIGURE**

26

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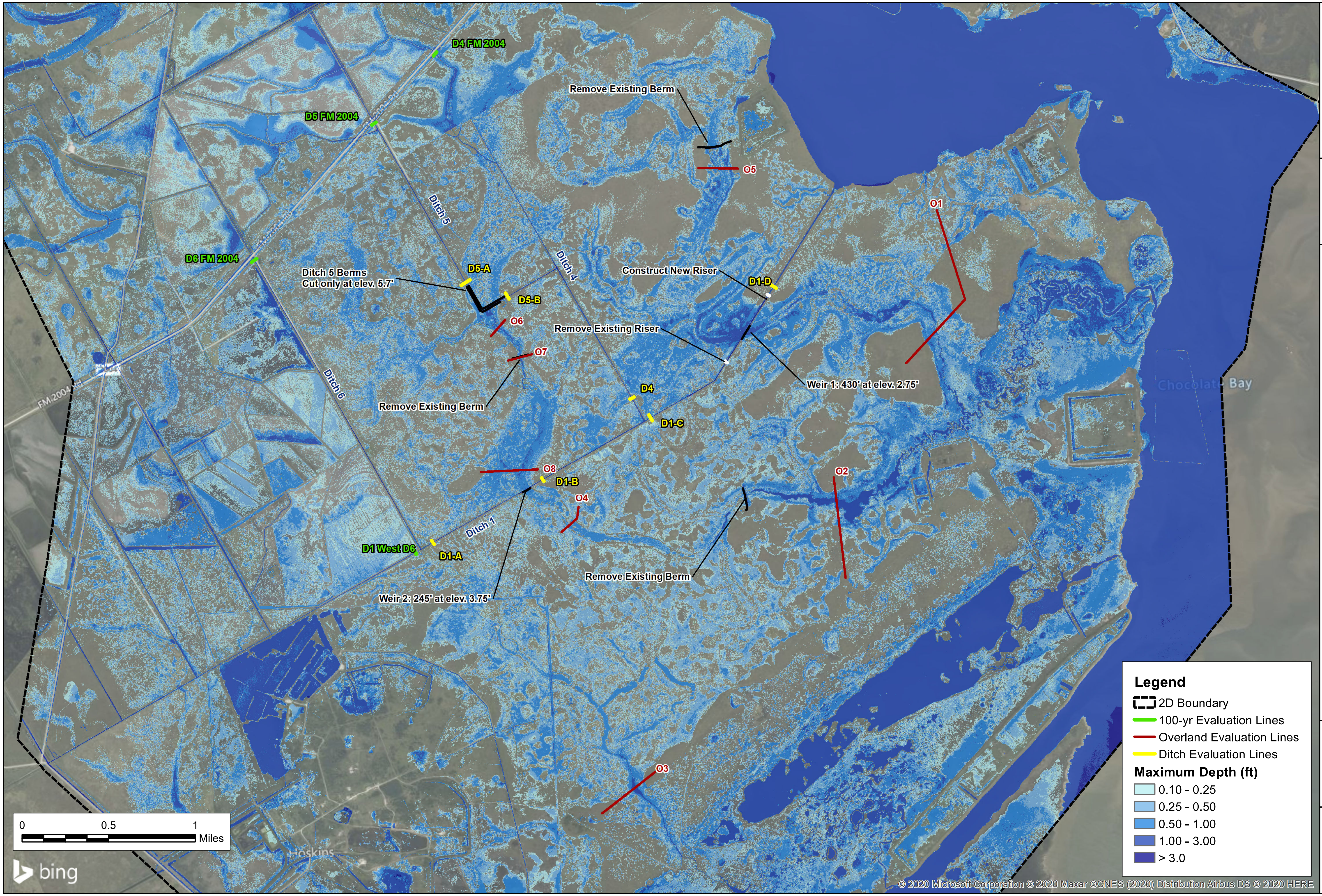


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FILE NAME Name: Figure 27 - Alternative 1 Overview - 2-YR Results

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# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 1 OVERVIEW
## ATLAS 14 2-YEAR RESULTS

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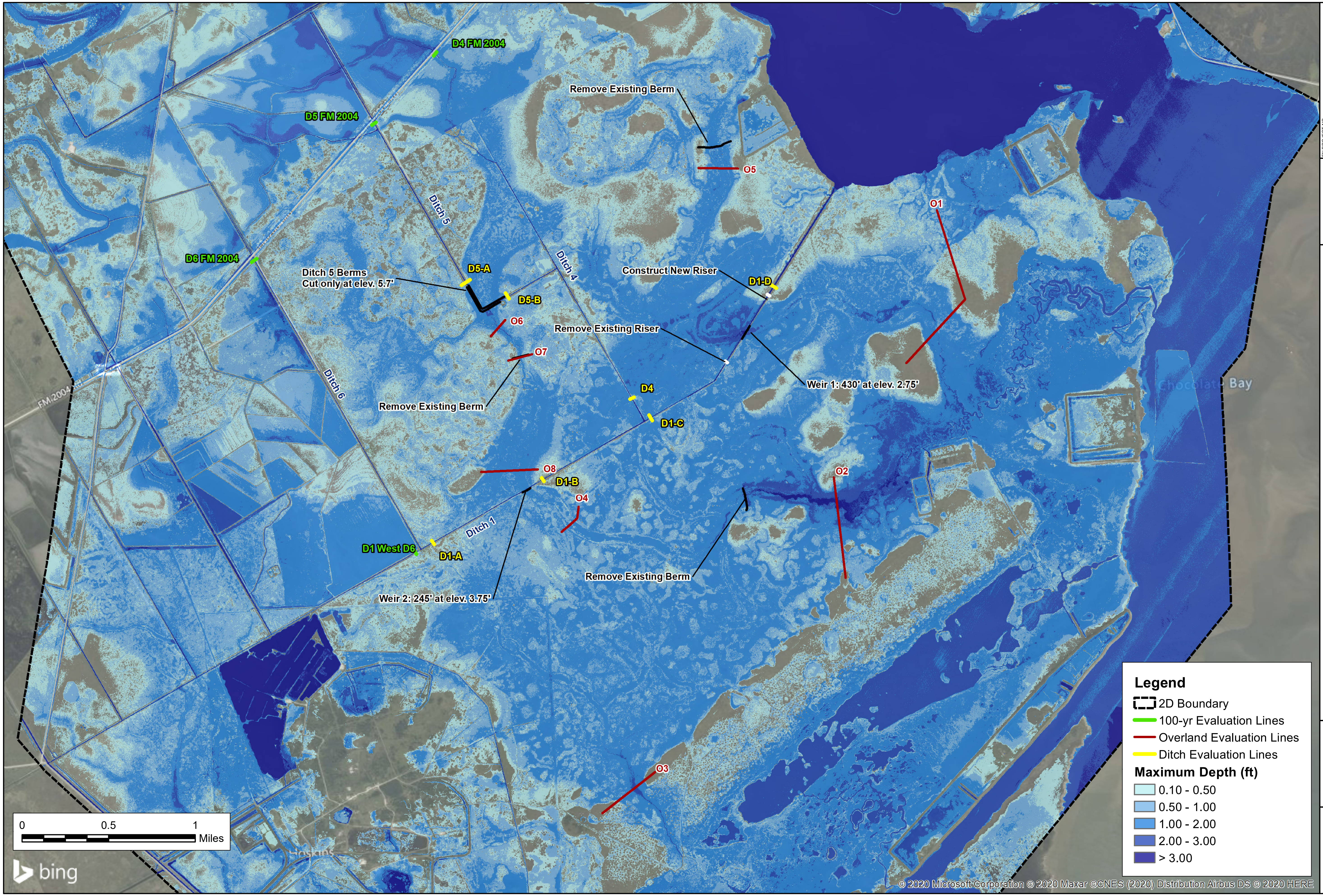
**FIGURE**

**27**

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DATUM & COORDINATE SYSTEM: NAD83 StatePlane Texas South Central (Feet)

FILE NAME: Name: Figure 28 - Alternative 1 Overview - 100-YR MHHW Results

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# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 1 OVERVIEW
## ATLAS 14 100-YEAR MHHW RESULTS


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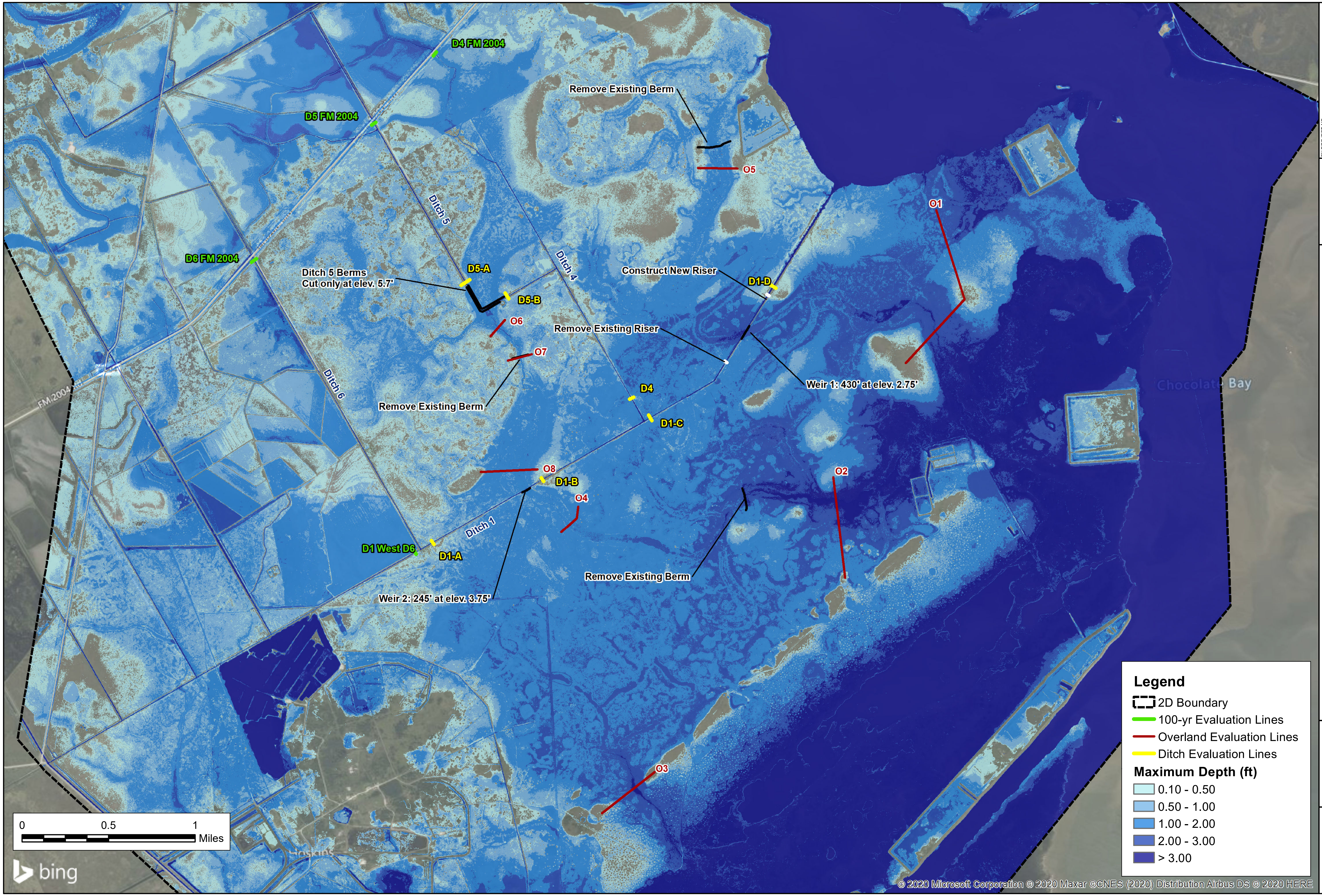
FIGURE
28

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DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central
FILE NAME Name: Figure 29 - Alternative 1 Overview - 100-YR Surge Results
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# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 1 OVERVIEW
## ATLAS 14 100-YEAR SURGE RESULTS

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FIGURE
29

## 5.3 ALTERNATIVE 2

Alternative 2 proposes structures at the same locations as Alternative 1, but it replaces the two proposed weirs with a series of culverts. This includes Culvert 1, constituting ten parallel 18" RCPs at Slough A with an upstream invert elevation of 0.0', and Culvert 2, constituting 4-6'x2' RCB's at Slough B with an upstream invert elevation of 2.0'. Both locations will require localized, limited grading at the downstream end of each culvert to allow for positive drainage. Because of the potential for sediment to accumulate within the proposed culverts, an additional scenario was modeled that assumes the culverts are clogged by a factor of 50%. The clogged scenario presents a more realistic long-term expectation of each culvert's capacity. The location of the two proposed culvert structures is shown below in **Figure 30** and **Figure 31**. An overview of the complete Alternative 2 is shown on **Figure 32**.

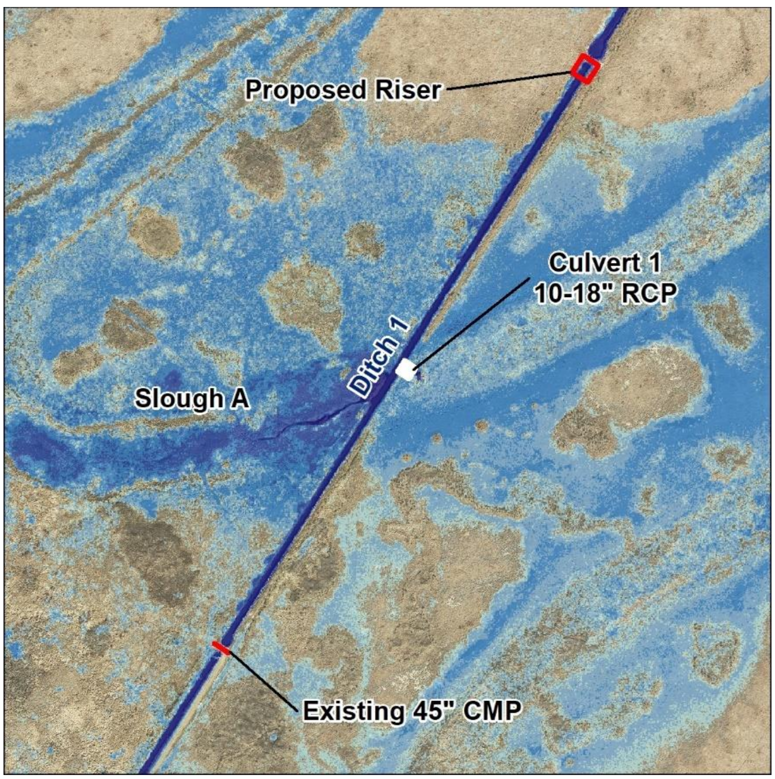



**Figure 30: Alternative 2 – Culvert 1**

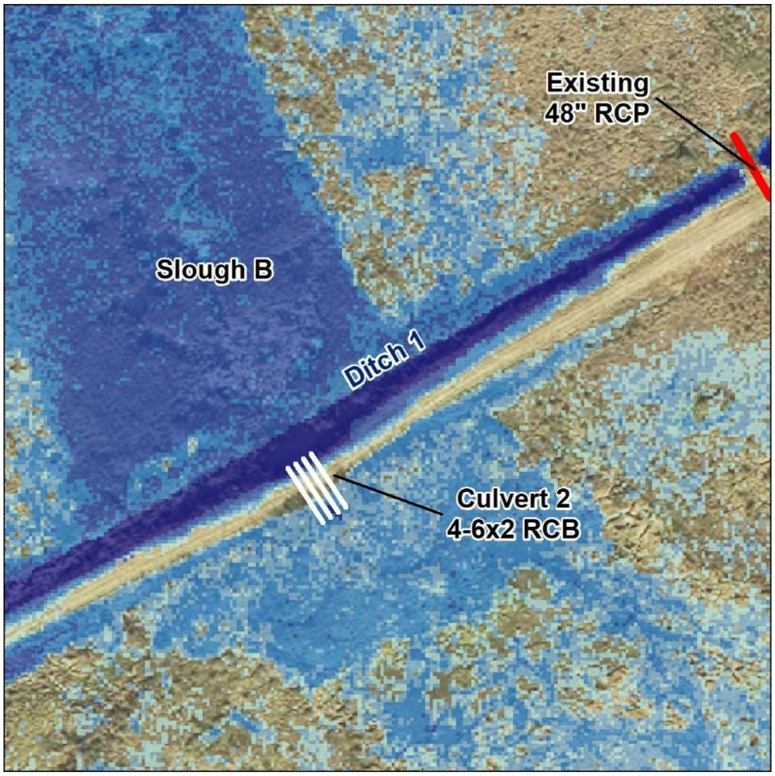
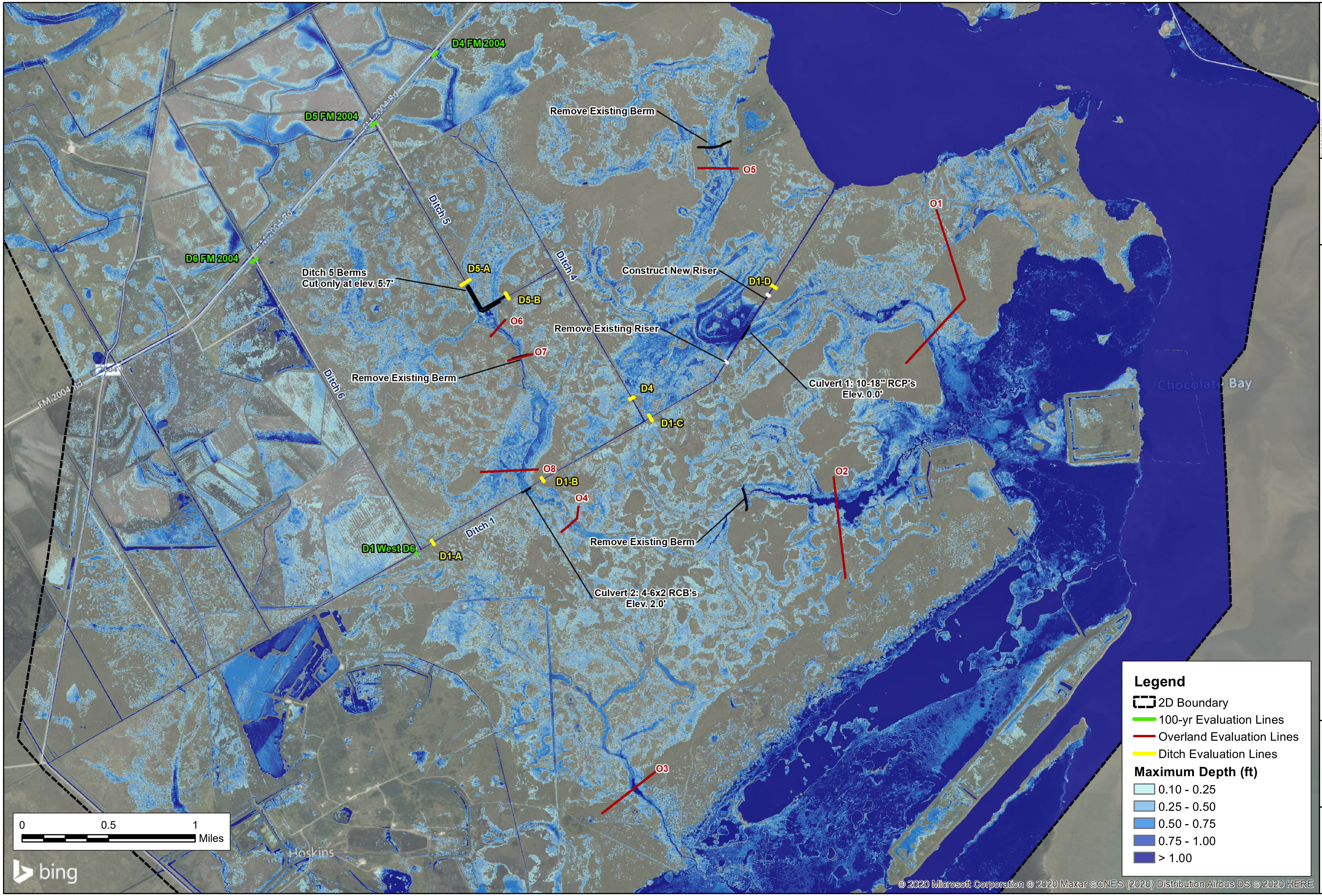



**Figure 31: Alternative 2 – Culvert 2**

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FILE NAME Name: Figure 32 - Alternative 2 Overview - 3-in Results
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# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 2 OVERVIEW
## 3-INCH RAINFALL RESULTS (2015-05-11)

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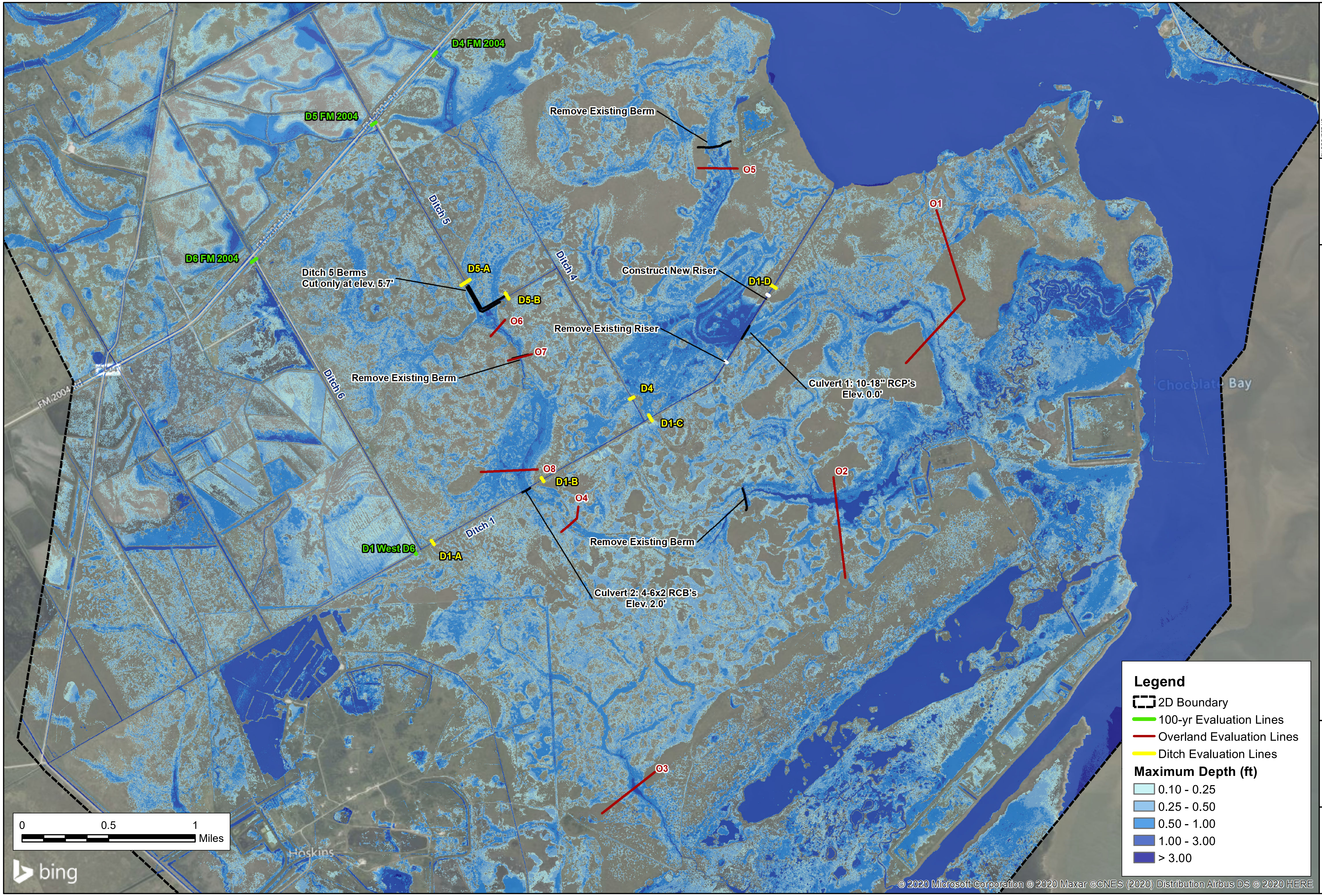
FIGURE 32

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| DATUM & COORDINATE SYSTEM | NAD83 State Plane Texas South Central |
| FILE NAME | Name: Figure 33 - Alternative 2 Overview - 2-YR Results |
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# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 2 OVERVIEW
## ATLAS 14 2-YEAR RESULTS


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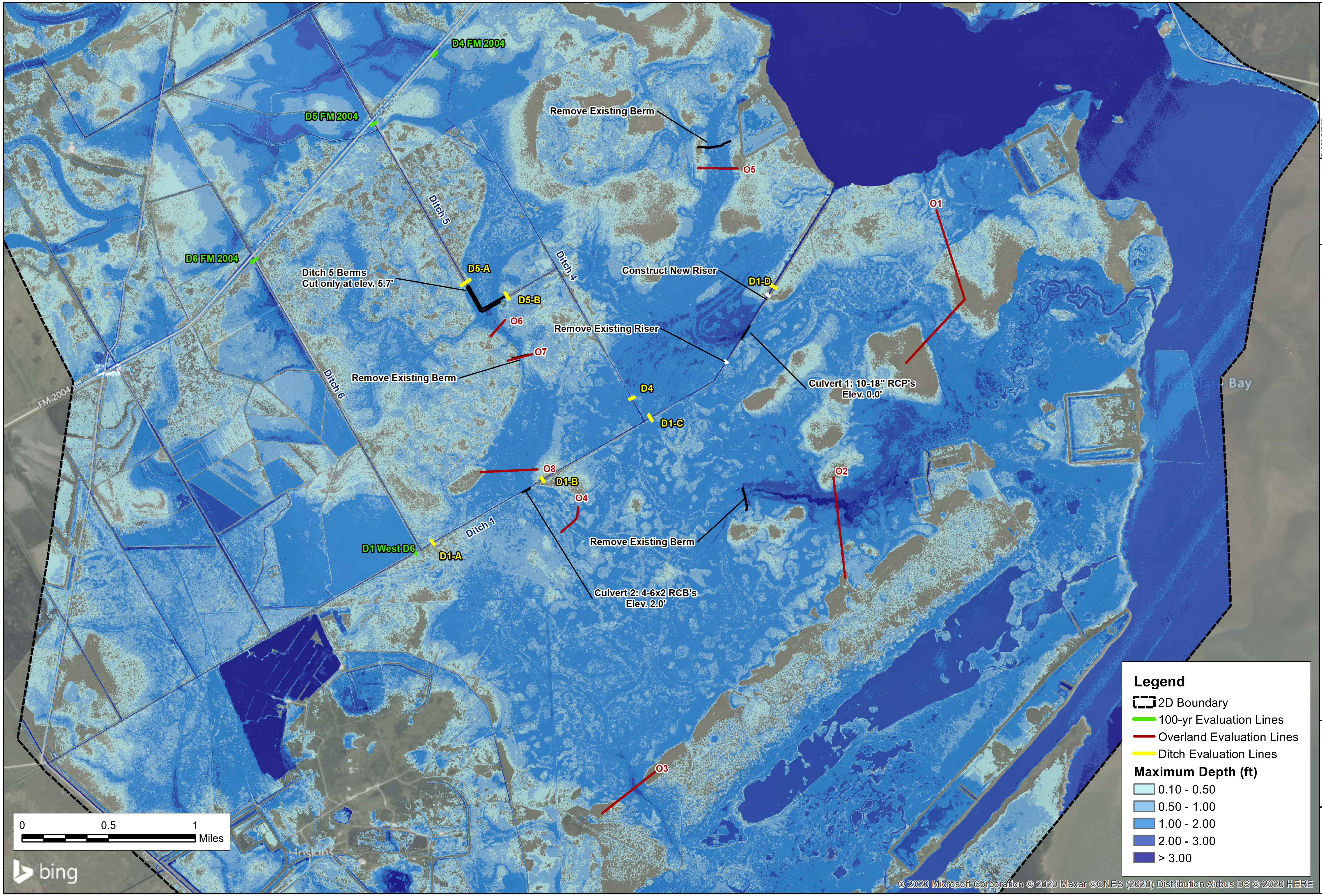
FIGURE
33




# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 2 OVERVIEW
## ATLAS 14 100-YEAR MHHW RESULTS

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DATUM & COORDINATE SYSTEM: NAD83 State Plane Texas South Central (Feet)

FILE NAME: Name: Figure 34 - Alternative 2 Overview - 100-YR MHHW Results

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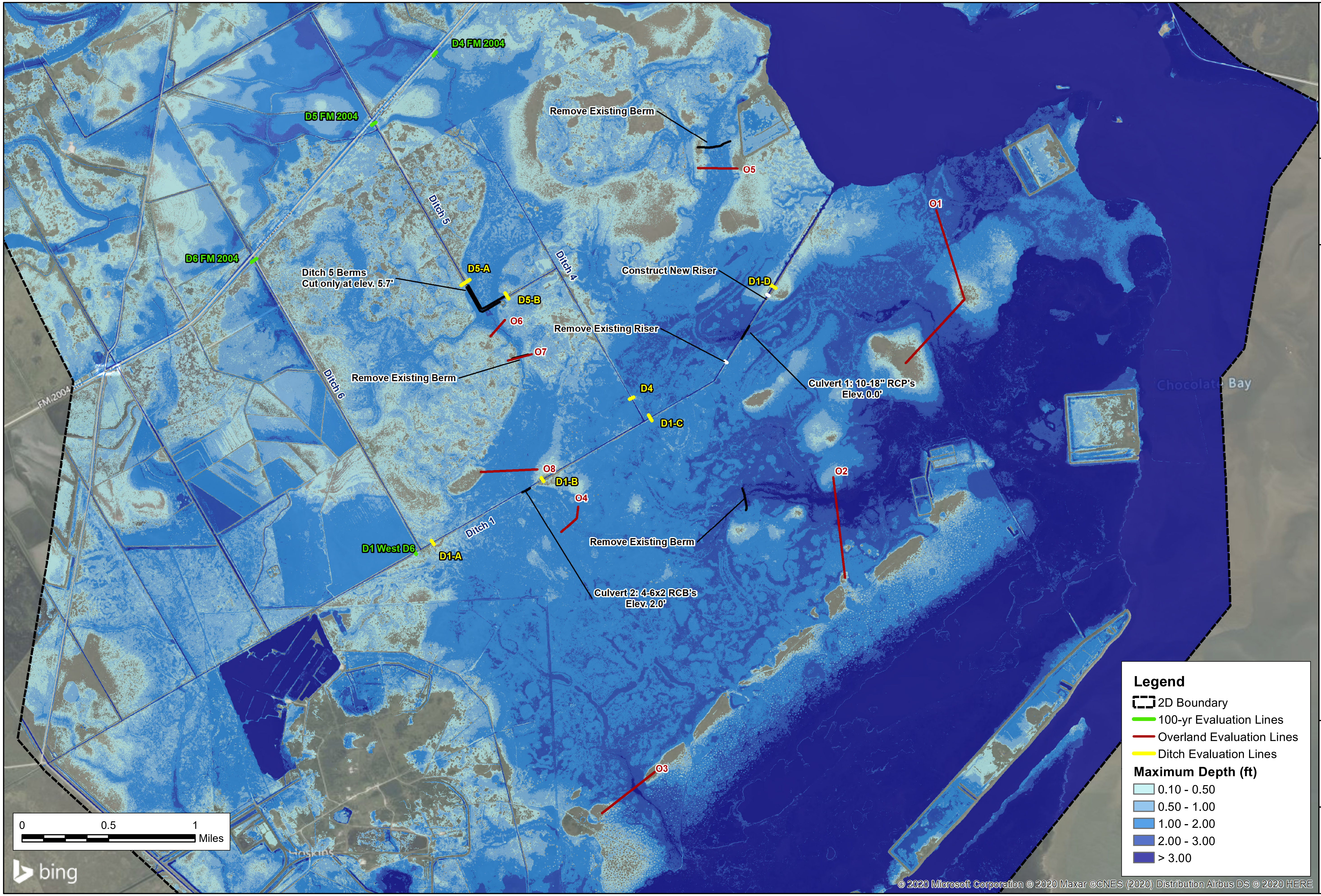
FIGURE 34

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DATUM & COORDINATE SYSTEM

FILE NAME Name: Figure 35 - Alternative 2 Overview - 100-YR Surge Results

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# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 2 OVERVIEW
## ATLAS 14 100-YEAR SURGE RESULTS

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**FIGURE 35**

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## 5.4 ALTERNATIVE 3

FNI evaluated the results of Alternatives 1 and 2 with input from DU and USFWS and created Alternative 3 as a hybrid of the most effective pieces of Alternatives 1 and 2. New elements not included in Alternatives 1 or 2 were also considered in Alternative 3 as described below.

Alternative 3 consists of a weir configuration similar to Alternative 1. Weir 1 near Slough A will be identical to the weir proposed in Alternative 1. Weir 2 near Slough B will be constructed with the same crest elevation as Alternative 1, but the weir will be lengthened to the west by an additional 500 feet. This results in a total weir length of 750 feet. The construction of this weir represents approximately 540 CY of cut volume. A summary of Weir 2 is shown below in **Figure 36.**

Multiple other features are also included in Alternative 3 and are described below.

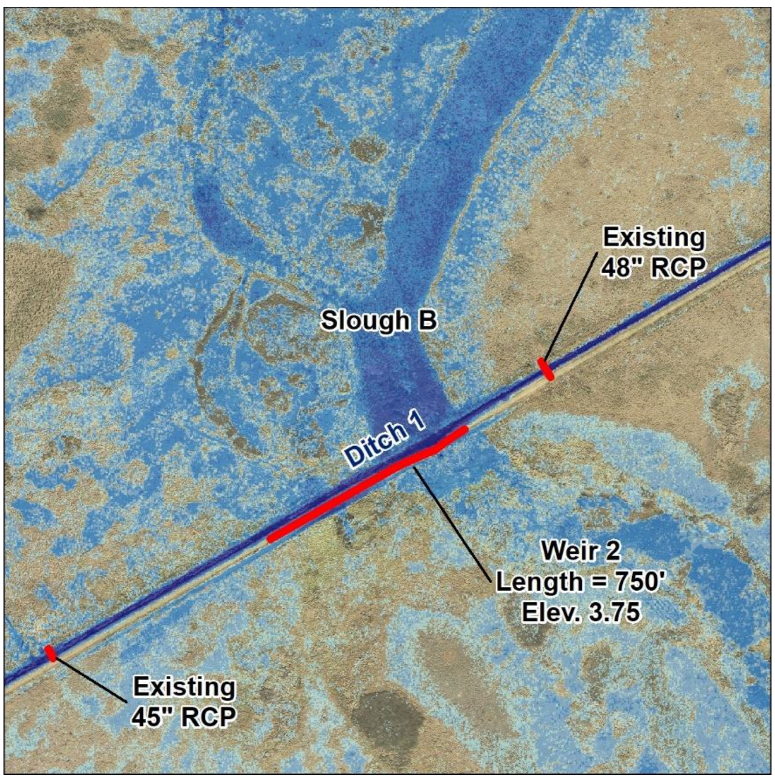



**Figure 36: Alternative 3 – Weir 2**

### 5.4.1 Ditch 5 Fill

Alternative 3 will fill the section of Ditch 5 east of the 90-degree bend and west of Ditch 4. This fill will cause additional runoff to flow out of the ditch near the berms along Ditch 5 to be removed. It is assumed that the berms adjacent to the fill location will also be cut. The removal of the berms on either side of Ditch 5 represents approximately 3,500 CY of cut volume. It will require approximately 5,000 CY of fill to fill the portion of Ditch 5 shown below. There are also multiple small breaks along the western berm of Ditch as it nears FM 2004. These will be repaired as part of Alternative 3.

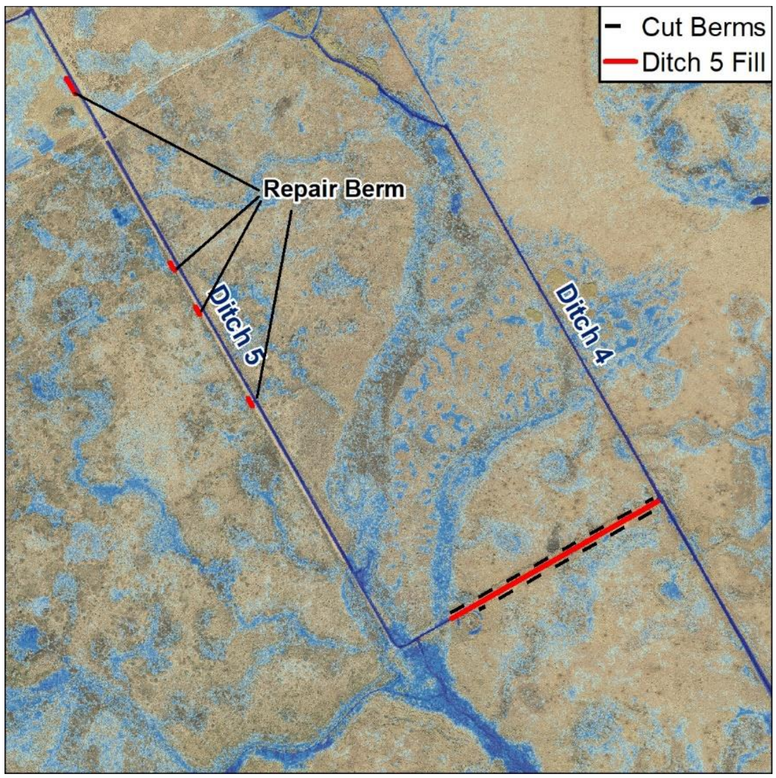



**Figure 37: Ditch 5 Fill**

### 5.4.2 Chocolate Bayou Berm

In the northeast portion of the site near Chocolate Bayou, an approximately one- to three-foot-tall berm at elevation 5.5' will be constructed to prevent stormwater runoff from escaping the site into Chocolate Bayou. In existing conditions, approximately 50 ac-ft of volume leaves the site through the drainage feature during the 3-inch event. The design of this berm will be subject to a more detailed preliminary design, but its construction will require approximately 210 CY of compacted fill if constructed with 3:1 side slopes. A small historic berm just south of the proposed location will also be removed as described in **Section 5.1.3**. The removal of the historic berm and construction of the proposed berm will prevent stormwater runoff from leaving the site and increase flow through Slough A.


**Figure 38: Alternative 3 – Chocolate Bayou Berm**

### 5.4.3 Long Pond Diversion

Just to the west of Long Pond, an approximately 40’ wide, 1’ deep trapezoidal cut will be made to connect the existing slough with the area that naturally drains to Long Pond. The goal of this diversion is to increase freshwater flow into Long Pond, reducing salinity from tidal exchanges. This cut volume of this diversion is approximately 390 CY. The location of this cut is shown on **Figure 39** .

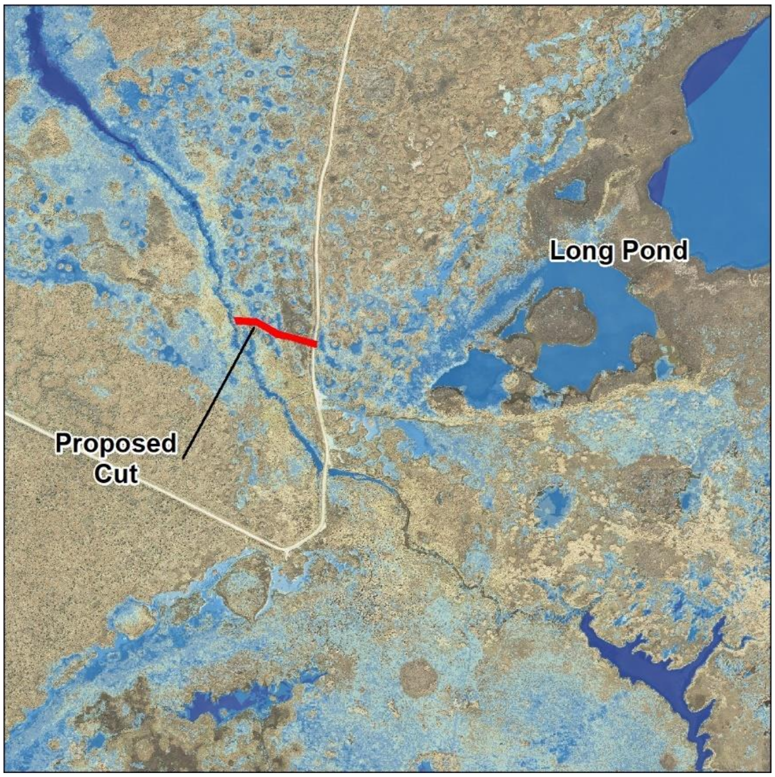
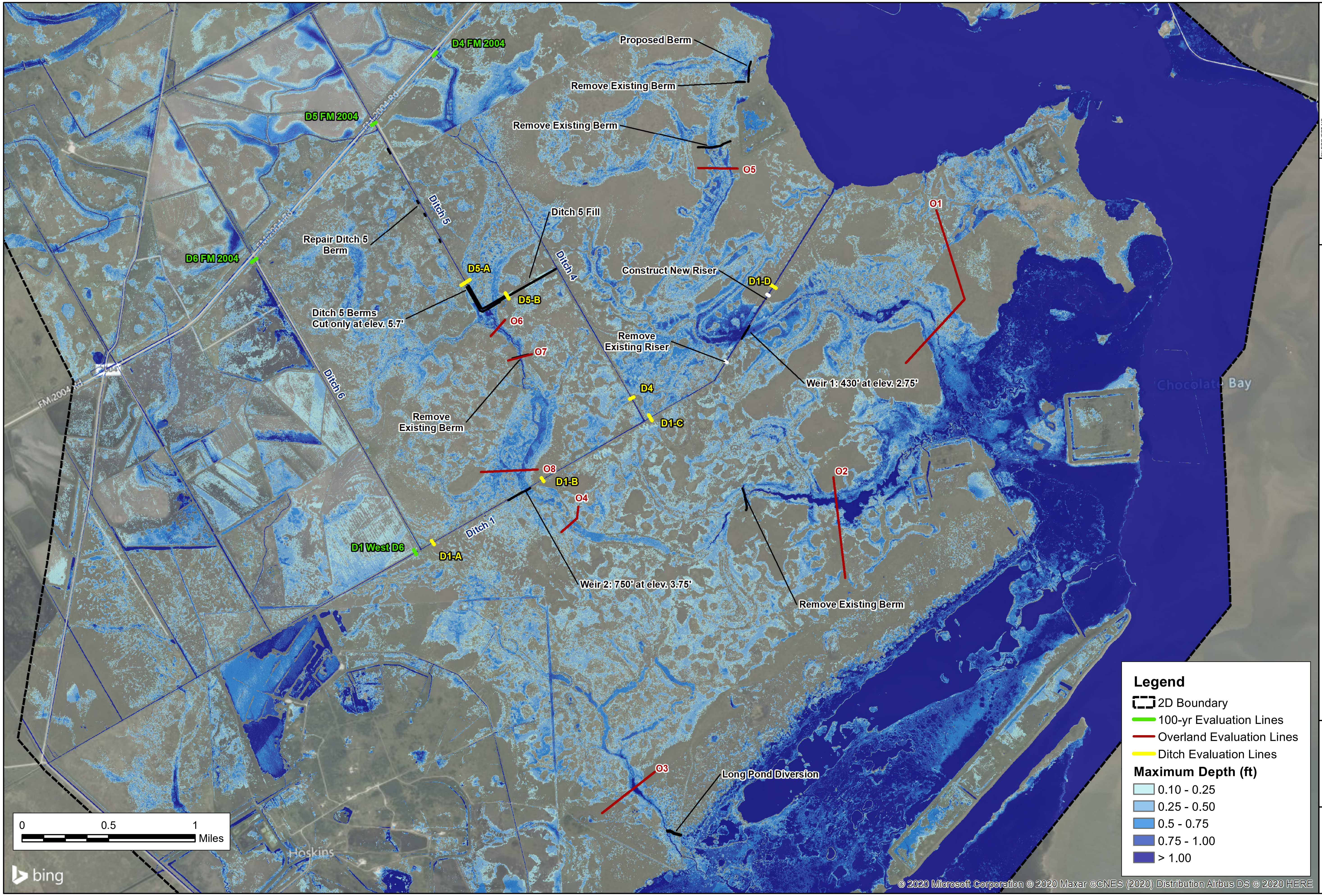



**Figure 39: Long Pond Diversion**

A complete overview of Alternative 3 is shown on **Figure 40**.




# BRAZORIA NWR WETLANDS RESTORATION

ALTERNATIVE 3 OVERVIEW

3-INCH RAINFALL RESULTS (2015-05-11)

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FILE NAME Name: Figure 40 - Alternative 3 Overview - 3-in Results

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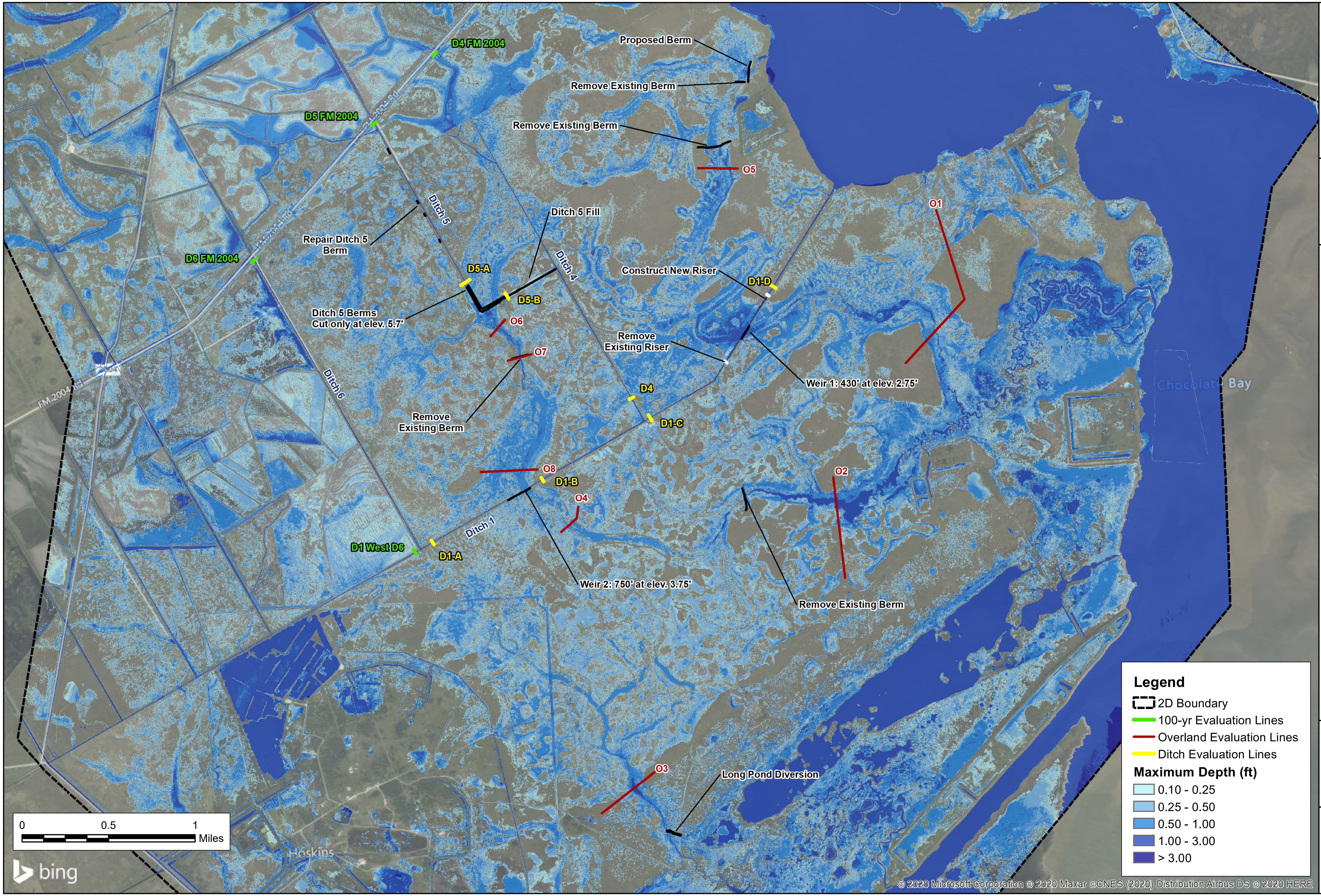
FIGURE

40




BRAZORIA NWR WETLANDS RESTORATION

ALTERNATIVE 3 OVERVIEW
ATLAS 14 2-YEAR RESULTS

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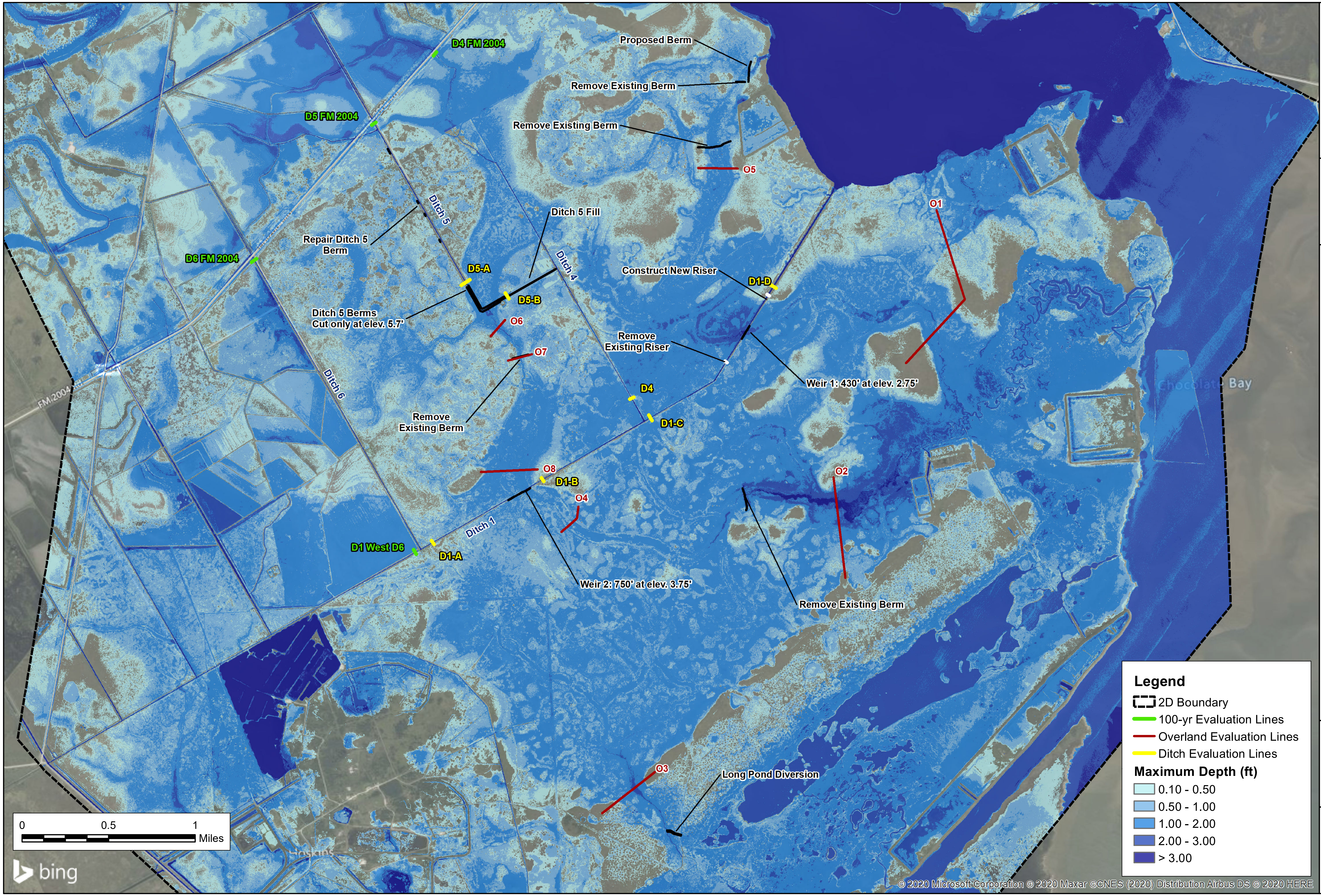
FIGURE

41

Date Saved: 12/9/2020 12:37:23 PM

Path: H:\STORMWATER\Exhibits\2020-12\Figure 41 - Alternative 3 Overview - 2-YR Results.mxd




# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 3 OVERVIEW
## ATLAS 14 100-YEAR MHHW RESULTS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10431 MORADO CIRCLE
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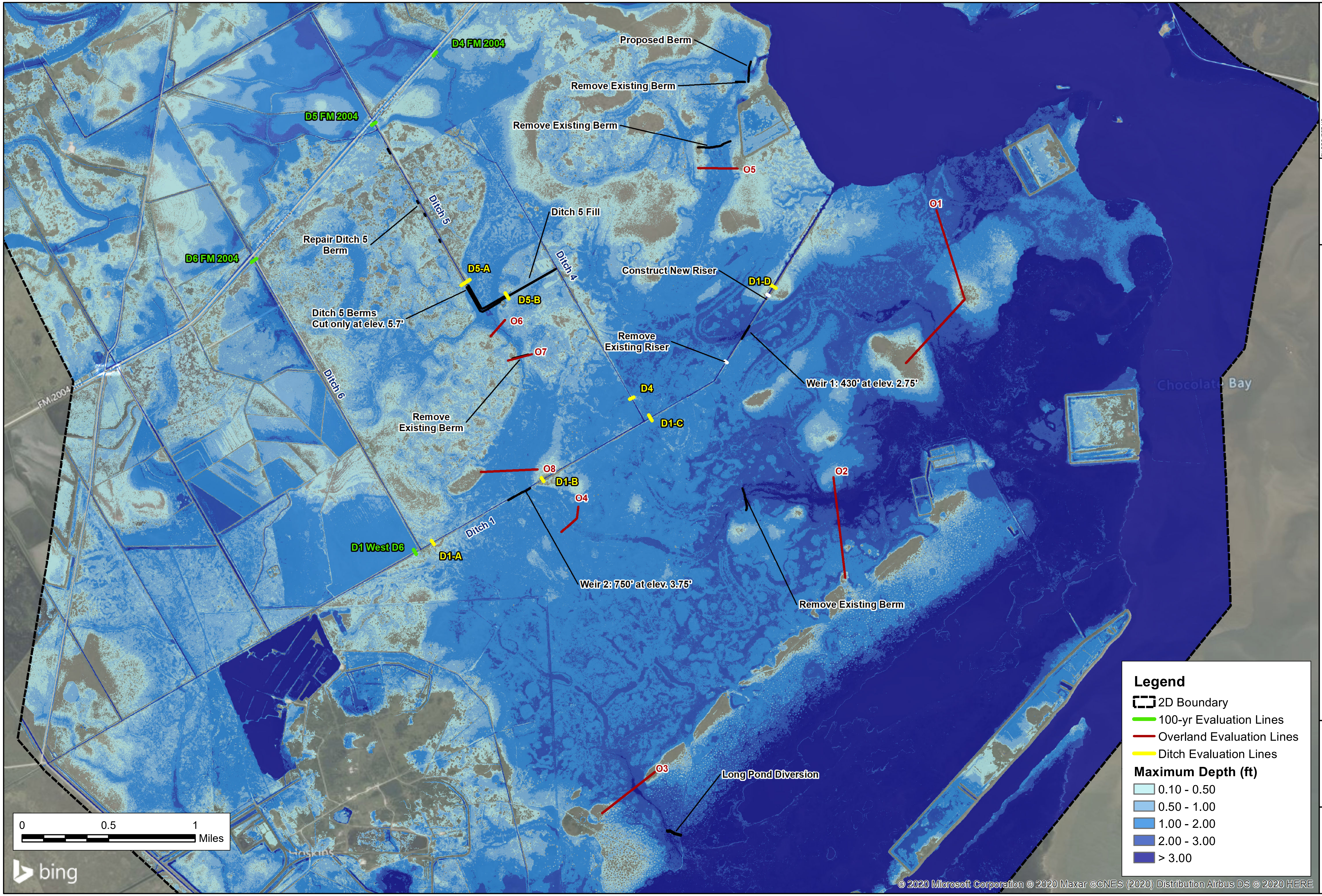
FIGURE 42




# BRAZORIA NWR WETLANDS RESTORATION

## ALTERNATIVE 3 OVERVIEW
## ATLAS 14 100-YEAR SURGE RESULTS

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**FIGURE**
**43**

FN PROJECT NO.
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FILE NAME Name: Figure 43 - Alternative 3 Overview - 100-YR Surge Results
PREPARED BY AAS

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# 6.0 RESULTS

To evaluate the efficacy of each design alternative, FNI compared multiple types of hydraulic results. A subset of each comparison and an explanation of the results is described in this section. The complete results comparison hydrographs are provided in Appendix A.

## 6.1 RESULTS HYDROGRAPHS

Three categories of hydrographs were used to compare hydraulic results: ditch, overland, and 100-year. Results for each type were obtained using profile lines in HEC-RAS, which were then used to measure flow and volume accumulation. The location of each profile line is shown on each Alternative Overview map.

Ditch profile lines were drawn across Ditches 1, 4, and 5 to compare flow and volume accumulation. Overland profile lines were drawn across the landscape in locations where alternatives are expected to improve restoration of the natural hydro-period, and were also used to compare flow and volume accumulation and to assess the efficacy of each alternative. Maximum depth along each overland line was also measured from the results. To demonstrate that the proposed alternatives do not cause an adverse impact to adjacent property during the 100-year event, evaluation lines were used to compare flow and peak water surface elevations at Ditches 4, 5, and 6 near FM 2004 and at Ditch 1 just west of Ditch 6, where Ditch 1 flows to the west. A summary of the results hydrographs for each rainfall event is included in the following sections. The full results hydrograph comparisons are included in Appendix A.

## 6.2 DURATION/HYDRO-PERIOD

To evaluate the cumulative impact of each alternative on the site, FNI utilized the duration feature built into HEC-RAS 2D. This is a raster output that quantifies the total time each terrain cell is inundated at or above a certain depth. For this analysis, a threshold of 0.25 feet was used because it represents meaningful conveyance and because, at lower threshold values, a precipitation-on-grid model shows minimal duration differences between scenarios.

The existing duration raster was subtracted from each alternatives duration raster to produce a difference raster that represents the change in flooding duration for each alternative. The results for the 3-inch rainfall and the 2-year storm event are summarized in the sections below. In general, each alternative that results in increased durations south of Ditch 1 can be considered as working toward achieving DU's wetland restoration goals.

## 6.3 3-INCH RAINFALL

### 6.3.1 Ditches

As shown in **Figure A2 – A4** in Appendix A, evaluation lines D1-B, D1-C, and D1-D show that each alternative successfully diverts flow out of Ditch 1 and onto the landscape during the 3-inch rainfall event. This is indicated by decreases in volume accumulation and lower peak flow rates for each alternative. The D1-D hydrographs show that almost no runoff crosses the proposed riser for each alternative, instead moving onto the landscape via Weir 1 or Culvert 1. The other ditch profile lines show small changes compared to existing conditions.

### 6.3.2 Overland

The incremental impact of the design elements in each alternative can be evaluated using hydrographs through evaluation lines 5–8. For the 3-inch rainfall event, evaluation line 5 shows slightly increased peak flow and volume for each alternative. Evaluation lines 6–8 show flow hydrographs with higher peak flow values and a more gradual shape for each alternative. This indicates that the various proposed options along Ditch 5 successfully move stormwater runoff into Slough B. The fill placed in Ditch 5 as part of Alternative 3 results in an average total volume increase through lines 6–8 of approximately 200%. Alternatives 1 and 2 increase the total volume through lines 6–8 by around 50%. Maximum depths in Slough A and B north of Ditch 1 are slightly decreased by each proposed alternative due to the proposed weirs and culverts. Instead of being backed up by Ditch 1, runoff in these sloughs can pass into the wetland area in a manner similar to the slough’s natural condition. An example of this decrease in depth is shown on **Figure 44.**

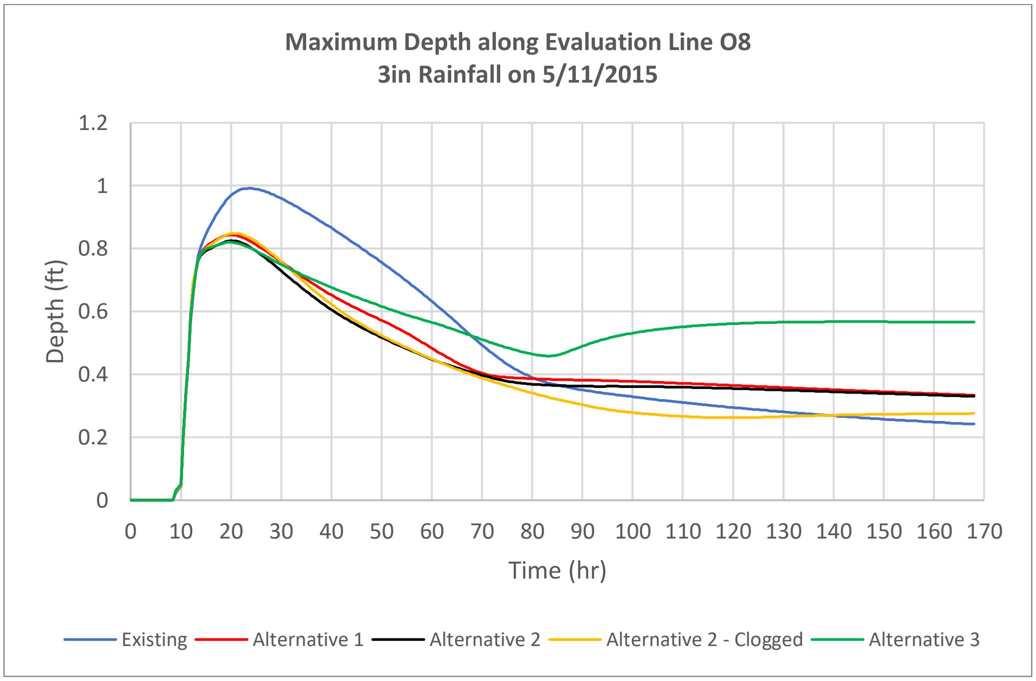



**Figure 44: Evaluation Line O8 – 3-inch Rainfall Maximum Depth**

The increases in runoff volume through Sloughs A and B is carried into the wetland area south of Ditch 1 in each proposed alternative to varying degrees. **Figure A8** shows evaluation line O1, south of Weir/Culvert 1, shows the differences in performance between weirs and culverts. Because the weirs are more efficient than the culverts, they result in large increases in peak flow and total volume much faster than the culverts. They also produce a more gradually shaped hydrograph compared to existing conditions.

Through line O1, the culverts proposed in Alternative 2 result in lower peak flows than existing conditions, but the hydrographs are much longer than those produced by even the weir alternatives. Through line O1, Alternatives 1 and 3 result in slightly higher total volumes than Alternative 2. In **Figure A11,** evaluation line O4 just downstream of Weir/Culvert 2 shows a similar pattern, with Alternative 2 resulting in slightly longer and more gradual hydrographs that move slightly more volume than Alternative 1 and 3. In **Figure A10,** which shows evaluation line O3 near Long Pond, there are slight increases in total volume for each alternative. Alternative 3 produces the largest increase due to the westward extension of Weir 2.

### 6.3.3 Duration/Hydro-Period

**Figure 45–Figure 48** show the changes in inundation duration for each alternative during the 3-inch rainfall event. In general, each alternative results in more gradually shaped overland hydrographs downstream of the ditch modifications, increasing the hydro-period on the site.

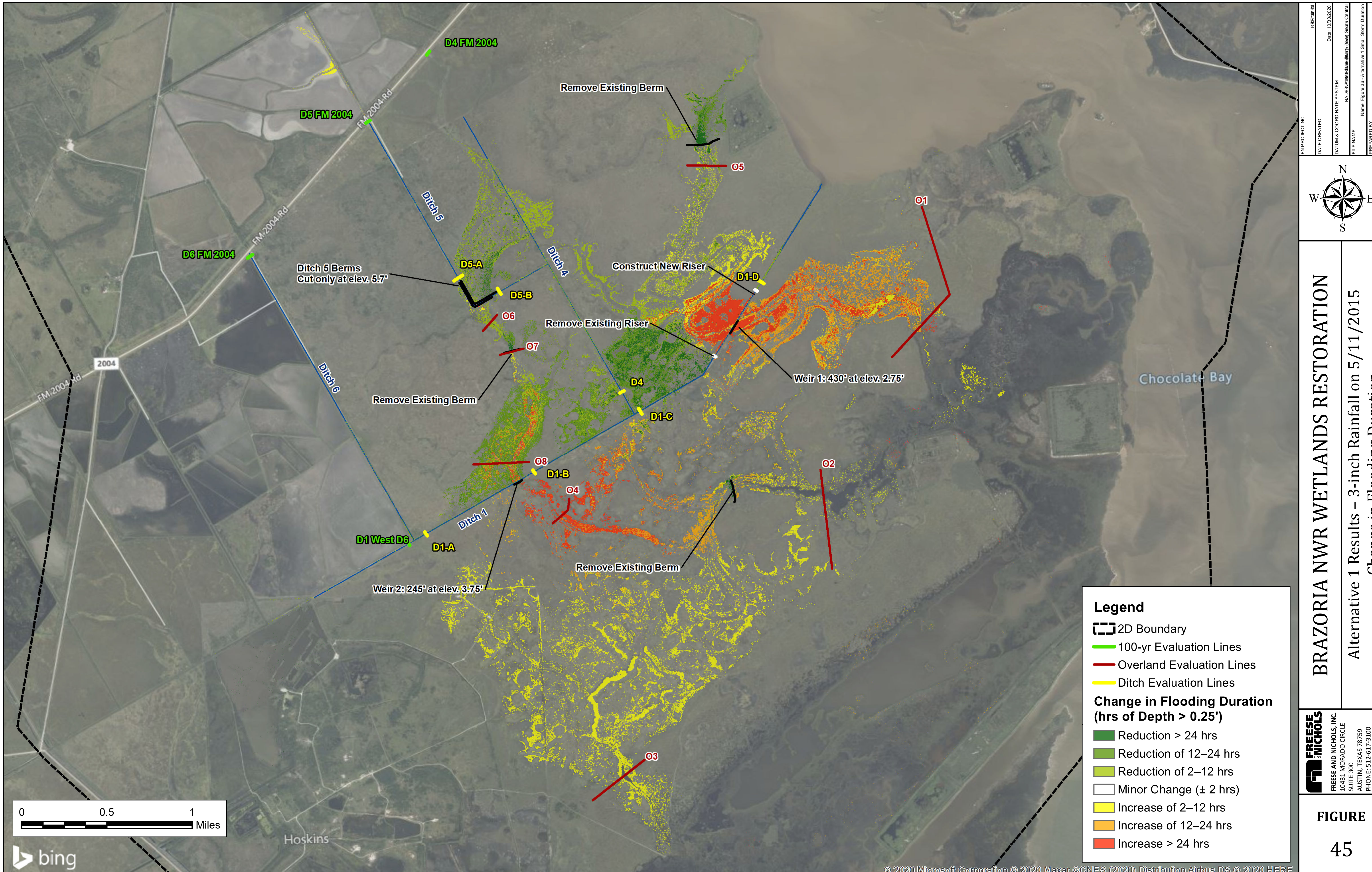
Additional stormwater runoff can move across Ditch 1, resulting in longer periods of inundation because the previously disconnected Sloughs A and B can now feed the wetland area. Durations are increased in much of the area south of Ditch 1. North of Ditch 1, durations generally decrease except just upstream of Weir/Culvert 1. Durations here are increased due to the relocation of the riser.

Each alternative also demonstrates that the removal of berms along Ditch 5 allows runoff to flow more freely through Ditch 5. The differences in function between the weir and culvert alternatives is also demonstrated by the slightly larger increases in flooding duration for Alternative 2. Because the culverts are at a lower elevation than the proposed weirs, they convey stormwater runoff for a longer period than the weirs.

**Table 6** below summarizes the total area that falls within each duration classification shown on **Figure 45–Figure 48**.

**Table 6: Area Summary of Changes in Flooding Duration – 3-inch Rainfall**

| Change in Flooding Duration (hrs of Depth > 0.25') | Area with Change in Flooding Duration (acres) | | | |
|---|---|---|---|---|
| | Alt. 1 | Alt. 2 | Alt. 2 Clogged | Alt. 3 |
| Reduction > 24 hrs | 45 | 49 | 41 | 60 |
| Reduction of 12–24 hrs | 164 | 127 | 124 | 131 |
| Reduction of 2–12 hrs | 136 | 141 | 119 | 128 |
| Minor Change (±2 hrs) | 1,266 | 1,263 | 1,263 | 1,259 |
| Increase of 2–12 hrs | 309 | 287 | 252 | 289 |
| Increase of 12–24 hrs | 163 | 134 | 118 | 240 |
| Increase > 24 hrs | 120 | 227 | 298 | 160 |

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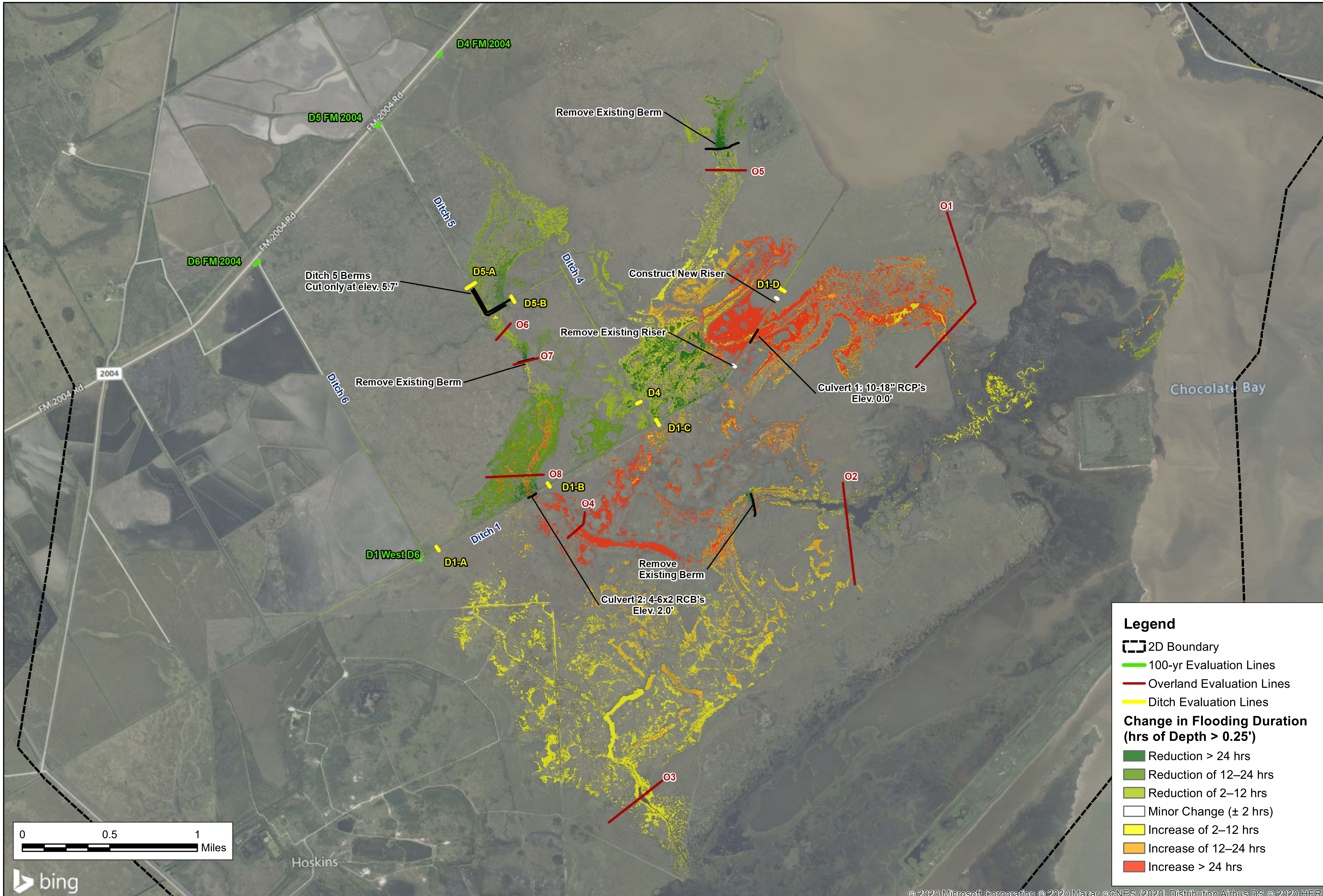
Path: H:\STORMWATER\Exhibits\2020-10\Exhibits\MXD\Figure 36 - Alternative 1 Small Storm Duration.mxd

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DATUM & COORDINATE SYSTEM NAD83 State Plane Texas South Central
FILE NAME Name: Figure 37 - Alternative 2 Small Storm Duration
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# BRAZORIA NWR WETLANDS RESTORATION

## Alternative 2 Results – 3-inch Rainfall on 5/11/2015 Change in Flooding Duration

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FIGURE 46

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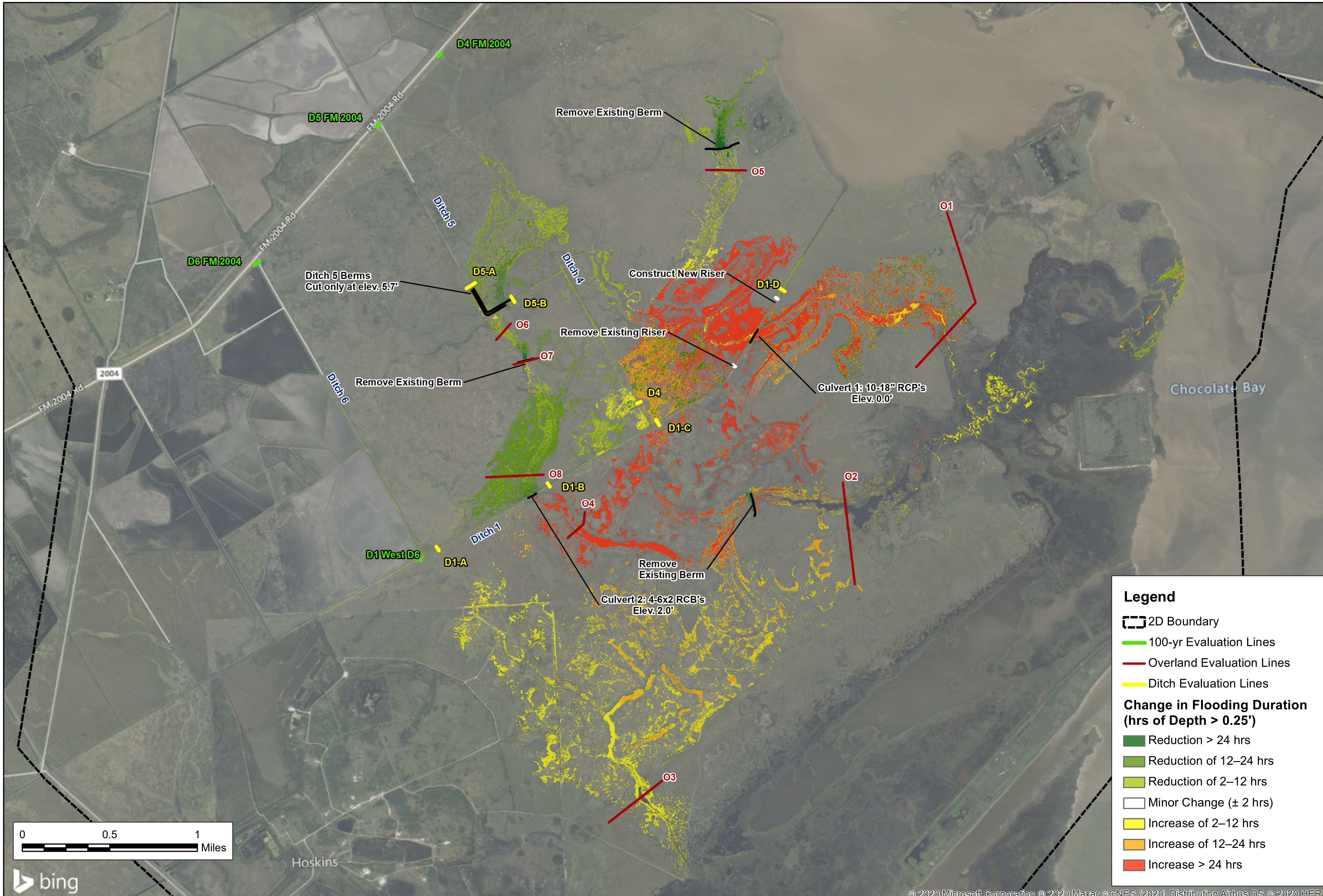


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DATE CREATED Date: 10/30/2020

DATUM & COORDINATE SYSTEM NAD83 State Plane Texas South Central (feet)

FILE NAME Name: Figure 38 - Alternative 2 Clogged Small Storm Duration

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# BRAZORIA NWR WETLANDS RESTORATION

## Alternative 2 Clogged Results – 3-inch Rainfall on 5/11/2015
## Change in Flooding Duration


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FIGURE

47

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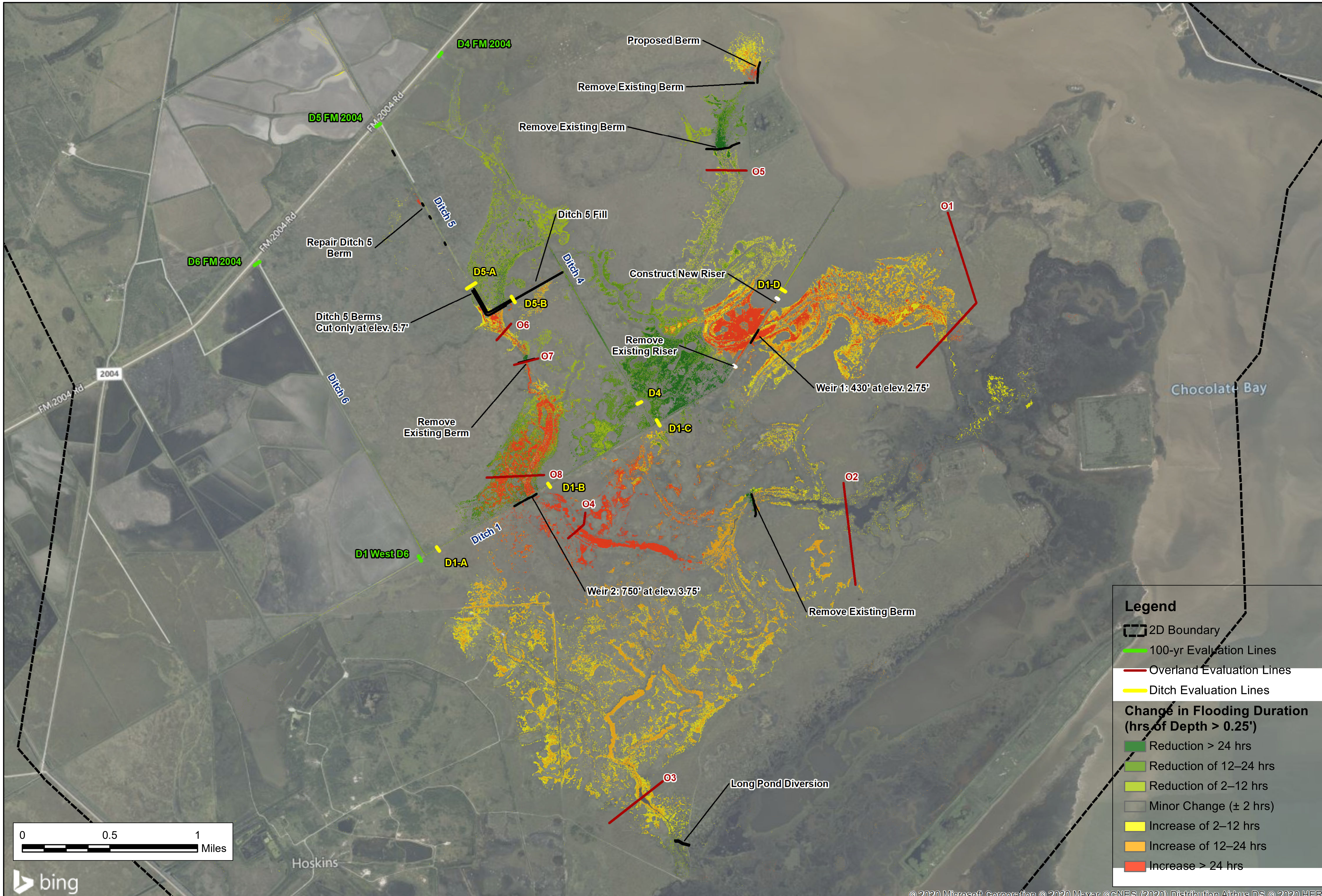


# BRAZORIA NWR WETLANDS RESTORATION

## Alternative 3 Results – 3-inch Rainfall on 5/11/2015
## Change in Flooding Duration


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FIGURE
48

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### 6.3.4 Summary

**Table 7–Table 9** summarize peak flow, volume, and duration through each overland evaluation line.

**Table 7: 3-inch Rainfall Peak Flow Summary**

| Evaluation Line | Peak Flow (cfs) | | | | |
|---|---|---|---|---|---|
| | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
| O1 | 76 | 102 | 68 | 62 | 95 |
| O2 | 86 | 87 | 88 | 88 | 87 |
| O3 | 59 | 59 | 59 | 59 | 59 |
| O4 | 17 | 37 | 39 | 35 | 39 |
| O5 | 20 | 41 | 41 | 41 | 41 |
| O6 | 35 | 40 | 40 | 40 | 52 |
| O7 | 25 | 55 | 55 | 55 | 66 |
| O8 | 20 | 56 | 57 | 54 | 67 |

**Table 8: 3-inch Rainfall Volume Summary**

| Evaluation Line | Volume (ac-ft) | | | | |
|---|---|---|---|---|---|
| | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
| O1 | 337 | 526 | 491 | 446 | 481 |
| O2 | 176 | 232 | 261 | 291 | 243 |
| O3 | 178 | 198 | 203 | 202 | 218 |
| O4 | 11 | 75 | 93 | 94 | 87 |
| O5 | 27 | 37 | 37 | 37 | 37 |
| O6 | 70 | 80 | 80 | 80 | 180 |
| O7 | 60 | 117 | 117 | 117 | 269 |
| O8 | 91 | 137 | 139 | 139 | 218 |

**Table 9: 3-inch Rainfall Duration Summary**

| Evaluation Line | Duration (hrs) | | | | |
|---|---|---|---|---|---|
| | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
| O1 | 141.5 | 161.5 | 165.5 | 165.5 | 162.0 |
| O2 | 157.5 | 157.5 | 158.0 | 158.0 | 157.5 |
| O3 | 158.5 | 158.5 | 158.5 | 158.5 | 158.5 |
| O4 | 67.5 | 86.0 | 105.5 | 125.0 | 95.0 |
| O5 | 129.5 | 90.5 | 90.5 | 90.5 | 90.5 |
| O6 | 160.0 | 160.0 | 160.0 | 160.0 | 160.0 |
| O7 | 69.0 | 80.0 | 80.0 | 80.0 | 158.0 |
| O8 | 147.0 | 157.5 | 157.5 | 157.5 | 157.5 |

## 6.4 2-YEAR STORM

The 2-year rainfall event is a small design storm, with a cumulative rainfall of 5.26 inches. The magnitude of this event is large enough to analyze impacts on the site from a larger storm but not so large as to inundate the entire area like a 100-year event. The complete set of results hydrographs is found in **Figure A16–A30** within Appendix A.

### 6.4.1 Ditches

Similarly to the 3-inch rainfall event results, the Ditch 1 hydrographs for the 2-year storm show that the proposed alternatives successfully move runoff out of the ditches and into overland areas. Hydrographs D1-B, D1-C, and D1-D on **Figure A17–A19** show decreases in peak flow and volume for each alternative. Even with the slightly larger rainfall total, very little flow passes through D1-D, meaning most of the runoff gets diverted by the weirs and culverts into the wetlands.

### 6.4.2 Overland

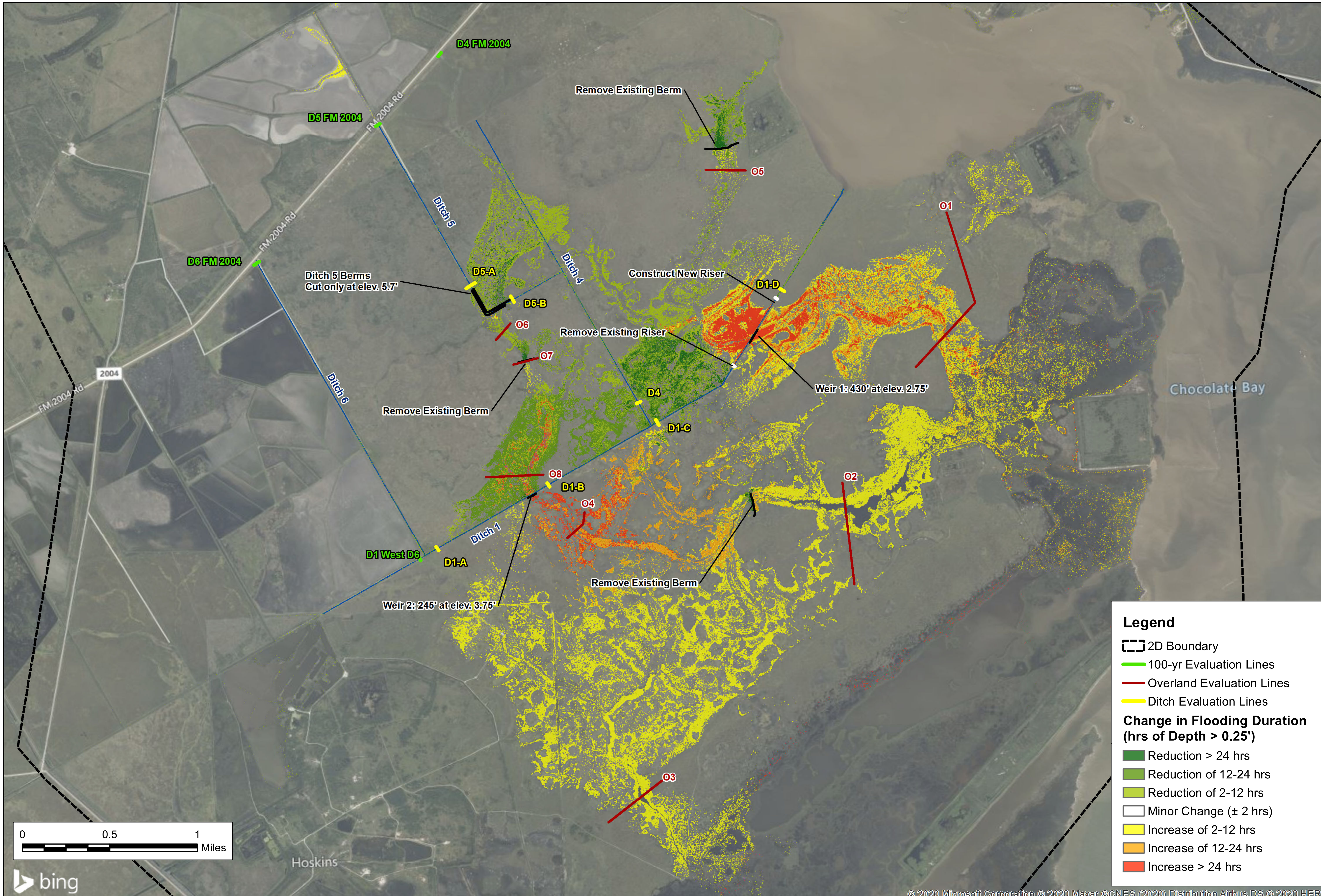
**Figure A27–A30** show benefits in the 2-year storm similar to those presented in the 3-inch rainfall event. North of Ditch 1, the various proposed alternatives divert additional runoff out of the ditches and into Sloughs A and B. These comparison hydrographs are provided in Appendix A. **Figure A23–A26** for evaluation lines O1–O4 show significant increases in flow and volume for each alternative. The flow hydrographs through line O1, O2, and O4 are dual-peaked, which is another indication that the proposed weirs and culverts allow runoff north of Ditch 1 to cross into the wetlands. The initial peak represents runoff from the local drainage area near the evaluation line, and the second peak represents runoff from north of Ditch 1 reaching the evaluation line. There is a slight increase in total volume through evaluation line O3 in each alternative, with approximate increases of 15–25%. For Alternative 3, the additional runoff volume has the potential to cross into Long Pond through the proposed diversion described in **Section 5.4.3**.

### 6.4.3 Duration/Hydro-Period

**Figure 49–Figure 52** show the differences in inundation duration for the 2-year storm under each alternative. Like the 3-inch rainfall event results, durations during the 2-year storm tend to decrease north of Ditch 1 and increase south of Ditch 1. Due to the higher rainfall associated with the 2-year storm, the improved areas south of Ditch 1 are larger and extend further south when compared to the 3-inch results. The efficiency of the weir alternatives is highlighted in these exhibits. Alternative 2 shows that runoff backs up in Sloughs A and B because the culverts do not have capacity to successfully handle the runoff. The weirs proposed in Alternatives 1 and 3 do not result in runoff backing up near the weirs. **Table 10** summarizes the total area that falls within each duration classification shown on **Figure 49–Figure 52**.

**Table 10: Area Summary of Changes in Flooding Duration – 2-year Storm**

| Change in Flooding Duration (hrs of Depth > 0.25') | Area with Change in Flooding Duration (acres) | | | |
|---|---|---|---|---|
| | Alternative 1 | Alternative 2 | Alternative 2 Clogged | Alternative 3 |
| Reduction > 24 hrs | 41 | 49 | 37 | 51 |
| Reduction of 12–24 hrs | 192 | 153 | 149 | 177 |
| Reduction of 2–12 hrs | 251 | 259 | 272 | 235 |
| Minor Change (±2 hrs) | 1258 | 1250 | 1254 | 1252 |
| Increase of 2–12 hrs | 922 | 590 | 513 | 768 |
| Increase of 12–24 hrs | 210 | 413 | 301 | 380 |
| Increase > 24 hrs | 118 | 291 | 444 | 168 |

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DATUM & COORDINATE SYSTEM

FILE NAME: Name: Figure 40 - Alternative 1 2YR Duration

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# BRAZORIA NWR WETLANDS RESTORATION

## Alternative 1 Results – Atlas 14 2-YR Change in Flooding Duration

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FIGURE 49

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DATE CREATED
Date: 10/30/2020

DATUM & COORDINATE SYSTEM
NAD83 State Plane Texas South Central (feet)

FILE NAME
Name: Figure 41 - Alternative 2 2-YR Duration

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AAS

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# BRAZORIA NWR WETLANDS RESTORATION

## Alternative 2 Results – Atlas 14 2-YR
## Change in Flooding Duration

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FIGURE
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| DATUM & COORDINATE SYSTEM | NAD83 State Plane Texas South Central (feet) |
| FILE NAME | Name: Figure 42 - Alternative 2 Clogged 2-YR Duration |
| PREPARED BY | AAS |

N W E S

# BRAZORIA NWR WETLANDS RESTORATION

## Alternative 2 Clogged Results – Atlas 14 2-YR Change in Flooding Duration

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10431 MORADO CIRCLE
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AUSTIN, TEXAS 78759
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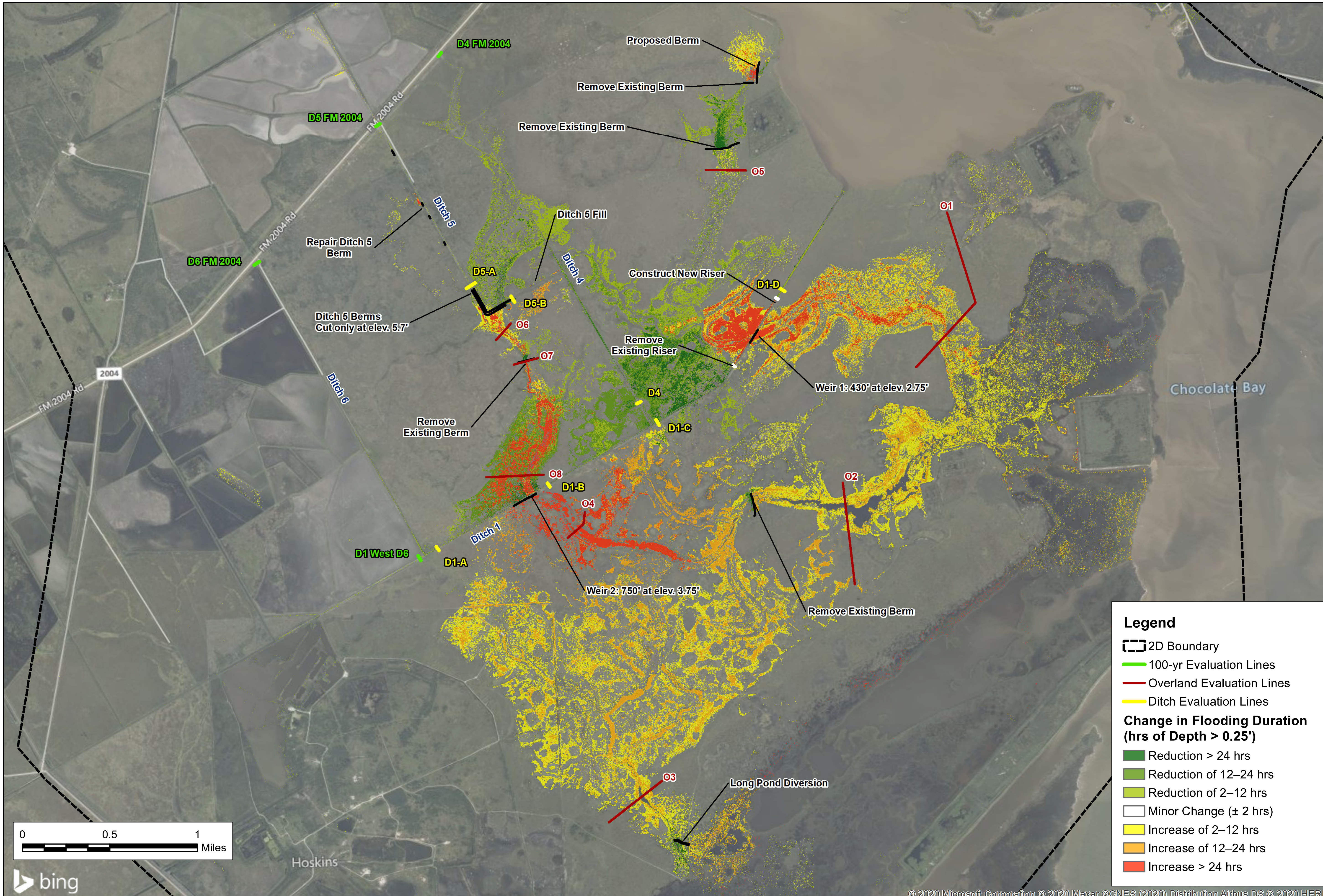
FAX: 512-617-3101

FIGURE
51




# BRAZORIA NWR WETLANDS RESTORATION

## Alternative 3 Results – Atlas 14 2-YR Change in Flooding Duration

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AUSTIN, TEXAS 78759
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FIGURE

52

### 6.4.4 Summary

**Table 11–Table 13** summarize peak flow, volume, and duration through each overland evaluation line.

**Table 11: 2-year Storm Peak Flow Summary**

| Evaluation Line | Peak Flow (cfs) | | | | |
|---|---|---|---|---|---|
| | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
| O1 | 145 | 162 | 100 | 96 | 152 |
| O2 | 147 | 151 | 151 | 151 | 151 |
| O3 | 104 | 104 | 104 | 104 | 104 |
| O4 | 31 | 66 | 60 | 50 | 70 |
| O5 | 40 | 65 | 65 | 65 | 65 |
| O6 | 60 | 64 | 64 | 64 | 74 |
| O7 | 37 | 77 | 77 | 77 | 87 |
| O8 | 28 | 85 | 78 | 66 | 103 |

**Table 12: 2-year Storm Volume Summary**

| Evaluation Line | Volume (ac-ft) | | | | |
|---|---|---|---|---|---|
| | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
| O1 | 567 | 733 | 659 | 586 | 679 |
| O2 | 318 | 410 | 478 | 528 | 424 |
| O3 | 276 | 318 | 322 | 316 | 348 |
| O4 | 25 | 132 | 150 | 143 | 147 |
| O5 | 40 | 55 | 55 | 55 | 55 |
| O6 | 121 | 134 | 134 | 134 | 238 |
| O7 | 93 | 187 | 188 | 188 | 336 |
| O8 | 102 | 205 | 203 | 193 | 295 |

**Table 13: 2-year Storm Duration Summary**

| Evaluation Line | Duration (hrs) | | | | |
|---|---|---|---|---|---|
| | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
| O1 | 120.0 | 160.0 | 167.0 | 167.0 | 160.5 |
| O2 | 154.0 | 154.0 | 154.5 | 154.5 | 154.0 |
| O3 | 158.5 | 158.5 | 158.5 | 158.5 | 158.5 |
| O4 | 25.0 | 49.0 | 60.5 | 64.0 | 56.5 |
| O5 | 162.0 | 162.0 | 162.0 | 162.0 | 162.0 |
| O6 | 158.0 | 158.5 | 158.5 | 158.5 | 158.5 |
| O7 | 39.5 | 19.5 | 19.5 | 19.5 | 30.5 |
| O8 | 120.5 | 152.5 | 152.5 | 93.0 | 152.5 |

## 6.5 100-YEAR ADVERSE IMPACT CHECK

To demonstrate that the proposed alternatives do not result in an adverse impact to adjacent property, evaluation lines were used to compare flow and peak water surface elevation. The locations of interest include Ditches 4, 5, and 6 near FM 2004 and Ditch 1 just west of Ditch 6 where Ditch 1 flows to the west.

Because a 100-year event on the site inundates most of the area modeled, only profile lines in ditches were evaluated. The primary purpose of the 100-year scenarios is to check if any proposed alternative is adversely impacting adjacent property. The 100-year MHHW scenario hydrographs mirror the 100-year surge scenario hydrographs closely. Both sets of hydrographs are included and are shown in **Figure A61–A68** of Appendix A. Comparisons of the 100-year MHHW and 100-year surge scenarios show that none of the evaluated alternatives result in adverse impacts relative to existing conditions.

### 6.5.1 Summary

**Table 14–Table 17** summarize peak flows and maximum water surface elevations for both 100-year scenarios. Peak flows and water surface elevations in both 100-year events are generally unchanged for each alternative because the locations of interest are far removed from each design element of the evaluated alternatives. The addition of weirs or culverts along Ditch 1 also slightly increases the capacity of the ditches, allowing for stormwater runoff to spill into the wetlands instead of filling up the ditches.

**Table 14: 100-year MHHW Summary – Peak Flow (cfs)**

| Evaluation Line | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
|---|---|---|---|---|---|
| D1 West D6 | 27 | 27 | 27 | 27 | 27 |
| D4 FM 2004 | 56 | 56 | 56 | 56 | 56 |
| D5 FM 2004 | 74 | 74 | 74 | 74 | 74 |
| D6 FM 2004 | 118 | 118 | 118 | 118 | 118 |

**Table 15: 100-year MHHW Summary – Peak WSE (feet)**

| Evaluation Line | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
|---|---|---|---|---|---|
| D1 West D6 | 5.23 | 5.23 | 5.23 | 5.23 | 5.23 |
| D4 FM 2004 | 7.41 | 7.41 | 7.41 | 7.41 | 7.41 |
| D5 FM 2004 | 9.36 | 9.36 | 9.36 | 9.36 | 9.36 |
| D6 FM 2004 | 11.02 | 11.02 | 11.02 | 11.02 | 11.02 |

**Table 16: 100-year Surge Summary – Peak Flow (cfs)**

| Evaluation Line | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
|---|---|---|---|---|---|
| D1 West D6 | 28 | 27 | 27 | 27 | 27 |
| D4 FM 2004 | 56 | 56 | 56 | 56 | 56 |
| D5 FM 2004 | 74 | 74 | 74 | 74 | 74 |
| D6 FM 2004 | 118 | 118 | 118 | 118 | 118 |

**Table 17: 100-year Surge Summary – Peak WSE (feet)**

| Evaluation Line | Existing | Alt. 1 | Alt. 2 | Alt 2. Clogged | Alt. 3 |
|---|---|---|---|---|---|
| D1 West D6 | 5.23 | 5.23 | 5.23 | 5.23 | 5.23 |
| D4 FM 2004 | 7.41 | 7.41 | 7.41 | 7.41 | 7.41 |
| D5 FM 2004 | 9.39 | 9.39 | 9.39 | 9.39 | 9.39 |
| D6 FM 2004 | 11.02 | 11.02 | 11.02 | 11.02 | 11.01 |

## 6.6 CONCLUSIONS

Using a detailed 2D model, FNI evaluated existing conditions and modeled three alternatives targeted toward restoring the natural hydro-period on the site. The efficacy of each alternative was assessed, and the results have been documented within this report as well as the attached materials. Each alternative evaluated achieves these goals to varying degrees. In general, Alternative 3 provides a substantial increase to periods of inundation in the area south of Ditch 1. The weirs included in Alternative 3 are expected to be less susceptible to clogging compared to the culverts included in Alternative 2 and thus more easily maintainable by DU and USFWS staff into the future.

Two 100-year scenarios were evaluated for each alternative to demonstrate that each shows no adverse impact on adjacent properties relative to existing conditions.

The analysis and alternatives presented in this report are conceptual in nature. The next steps toward implementing any alternative should include additional preliminary engineering design and development of a cost estimate. Additional survey and investigation of relevant environmental permitting requirements may also be required as part of the preliminary engineering effort. If the preliminary design elements (including the riser relocation, weirs, culverts, or grading) deviates significantly from the assumptions described in this report, the models may need to be re-run to verify that the adjusted design provides the hydraulic benefits desired.

# 7.0 REFERENCES


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- *Brazoria County Drainage Criteria Manual, Chapter 2 – Hydrology (November 2003)*. https://www.brazoriacountytx.gov/home/showpublisheddocument?id=1380

- *HEC-RAS River Analysis System, 2D Modeling User's Manual, Version 5.0* (2016). https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%202D%20Modeling%20Users%20Manual.pdf

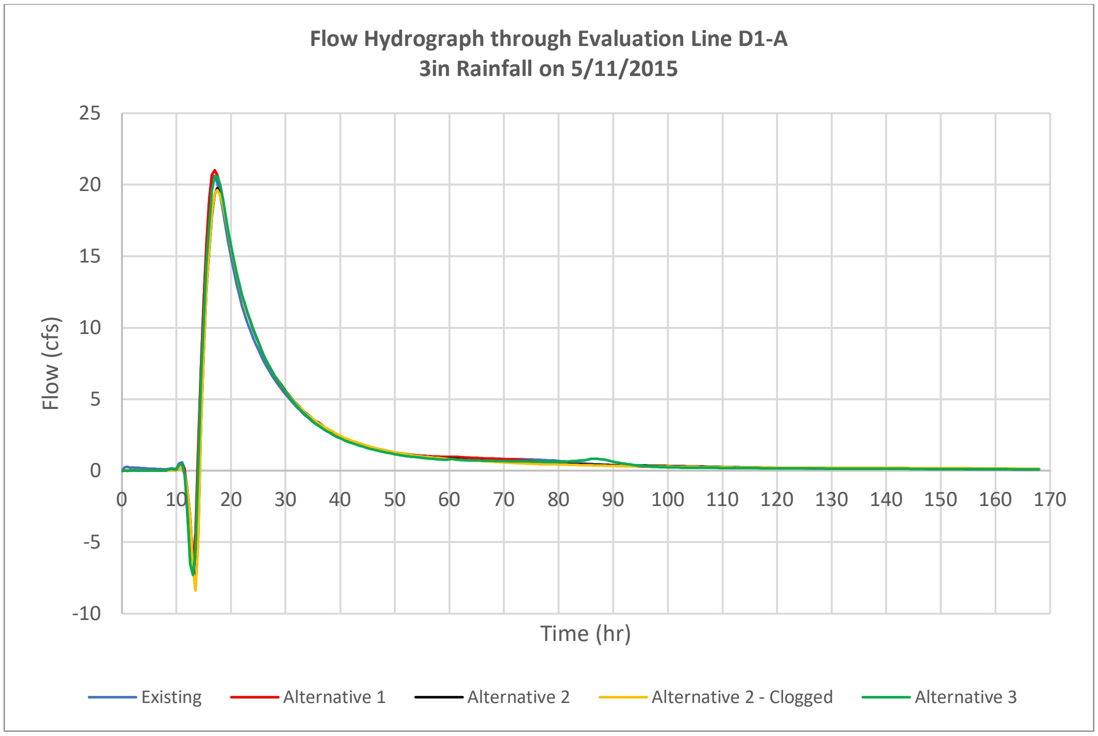
- *MesoWest RAWS Station Data for BZRT2*. https://mesowest.utah.edu/cgi-bin/droman/meso_base_dyn.cgi?stn=BZRT2&unit=0&timetype=LOCAL

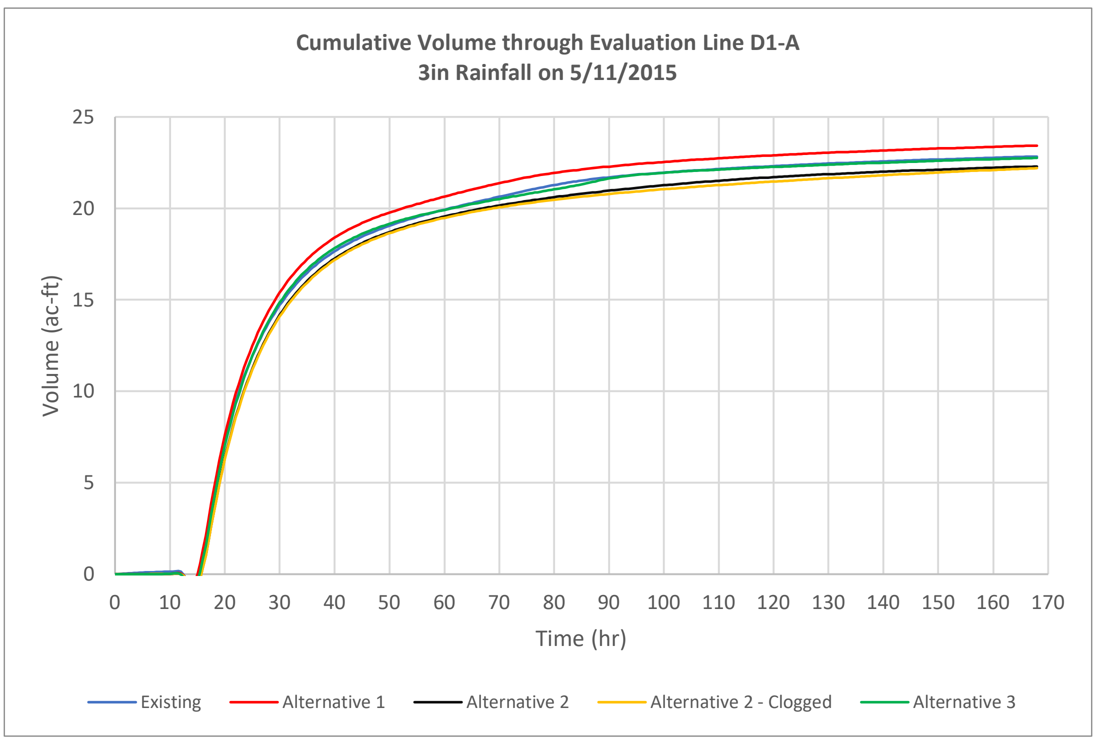
- *NOAA Atlas 14 – Precipitation-Frequency Atlas of the United States, Volume 11 Version 2.0: Texas (2018)*. https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=tx https://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume11.pdf

- *NOAA Tidal Datums.* https://tidesandcurrents.noaa.gov/datum_options.html

# APPENDIX A
# Results Hydrographs

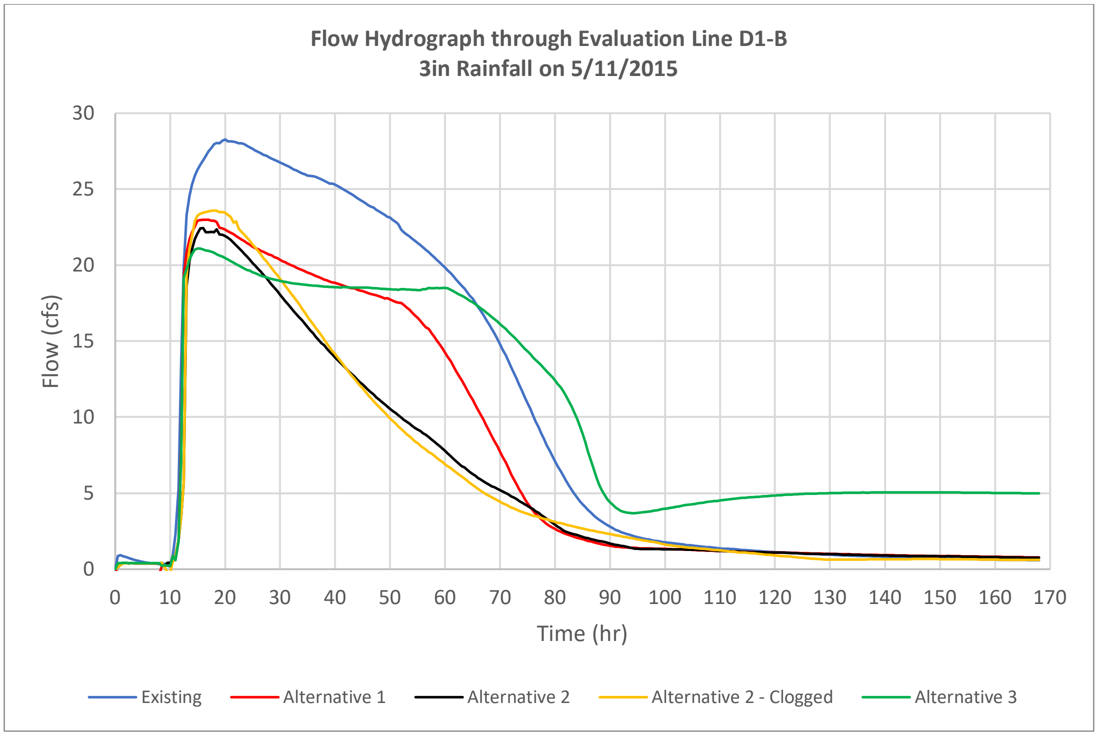
**Figure A1**

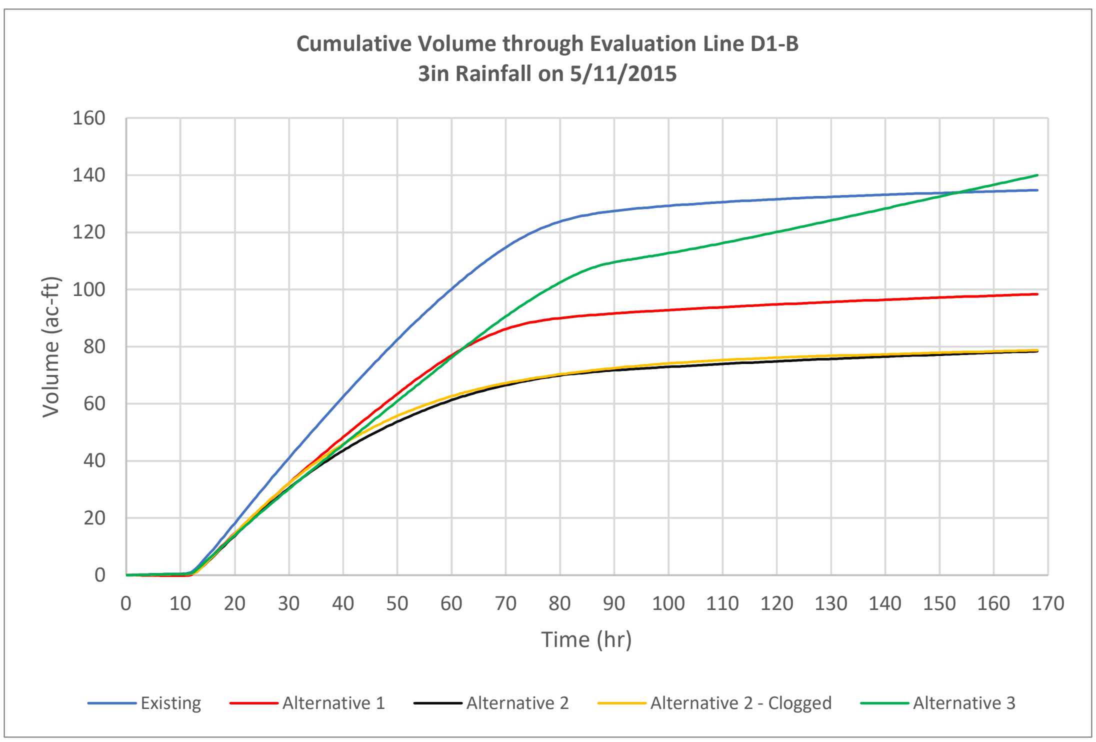



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

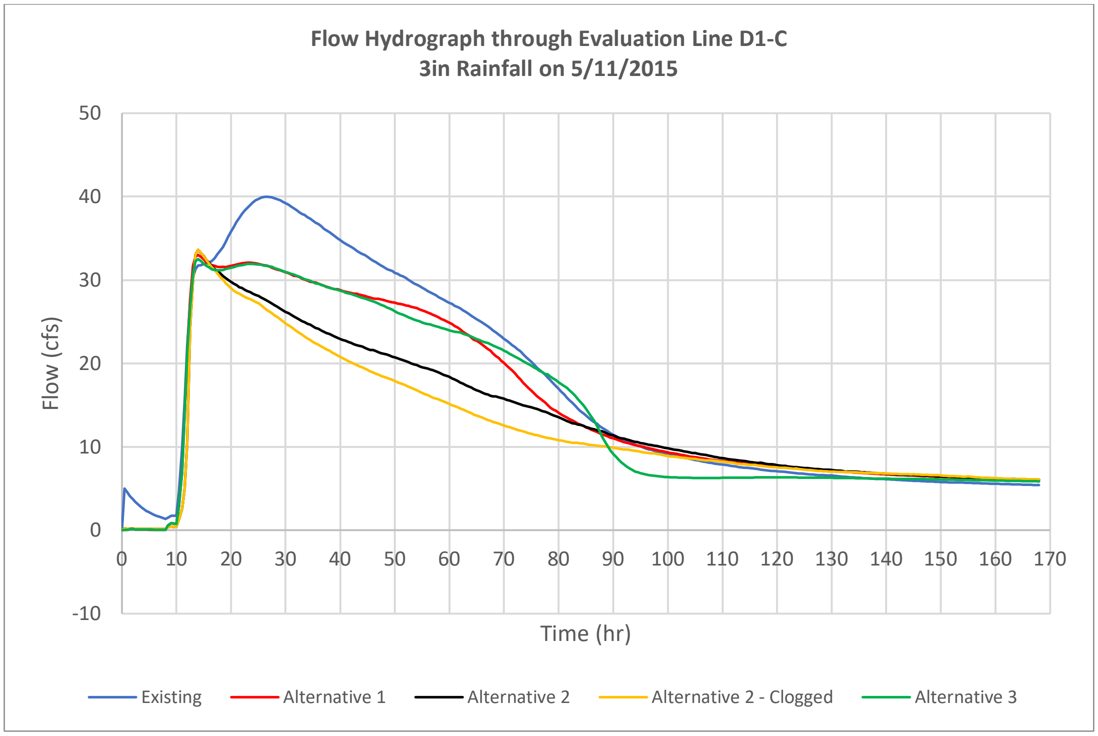
**Figure A2**

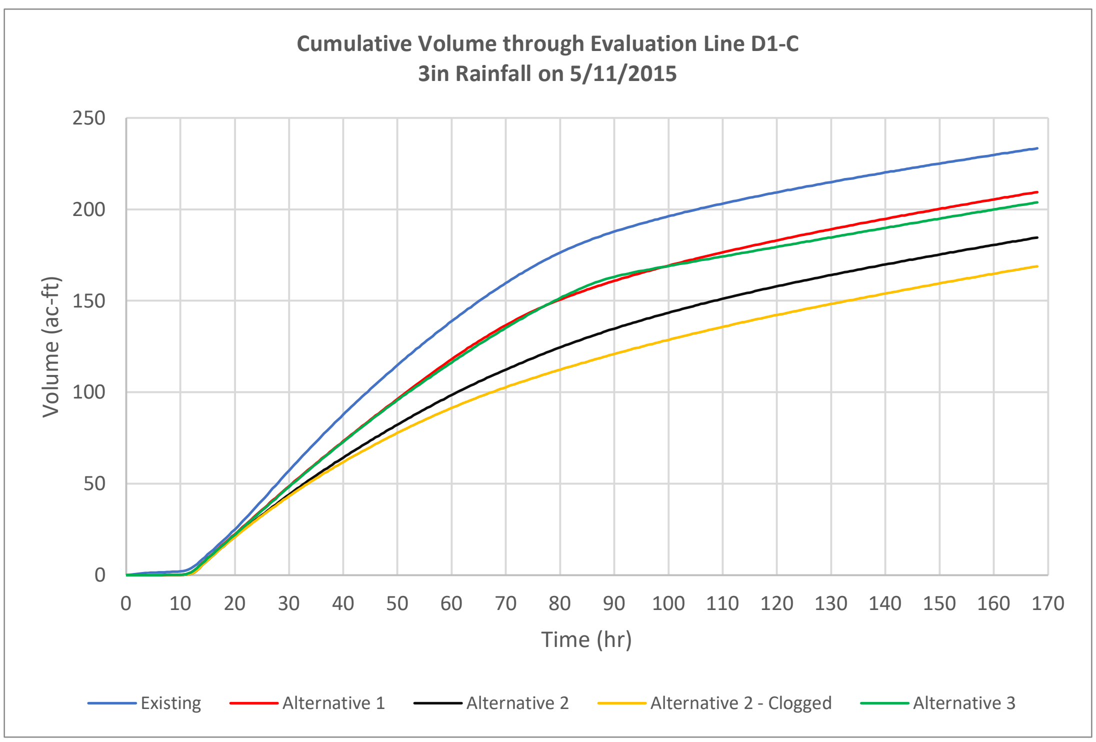



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

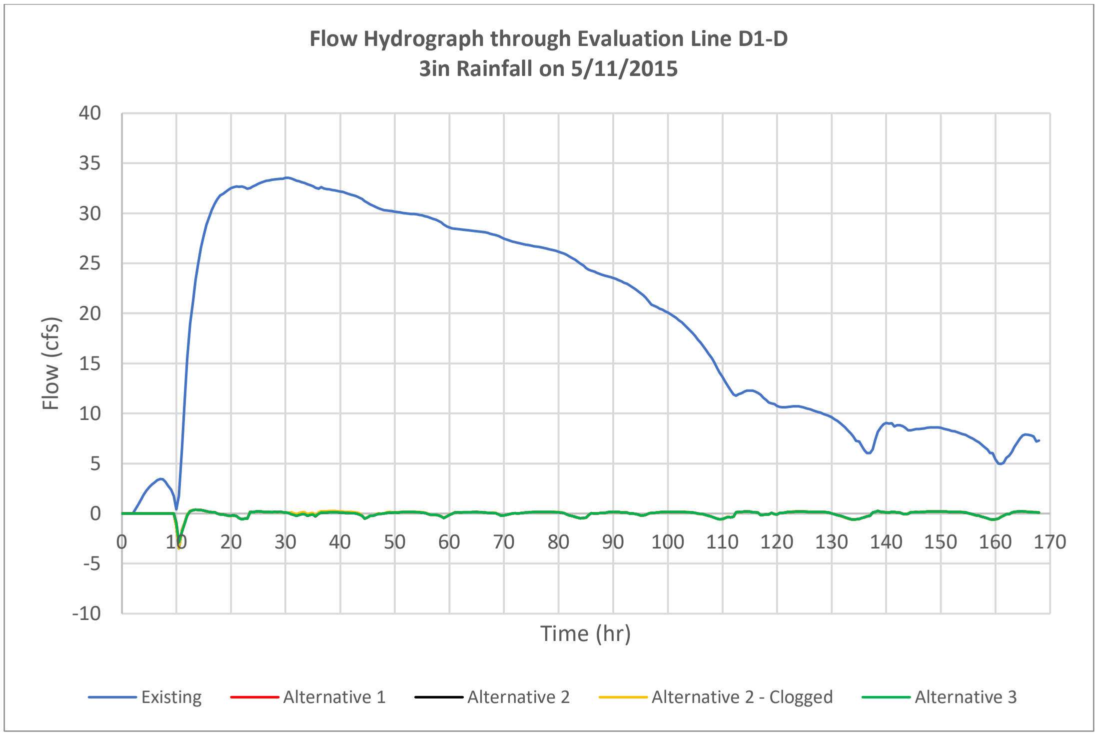
**Figure A3**

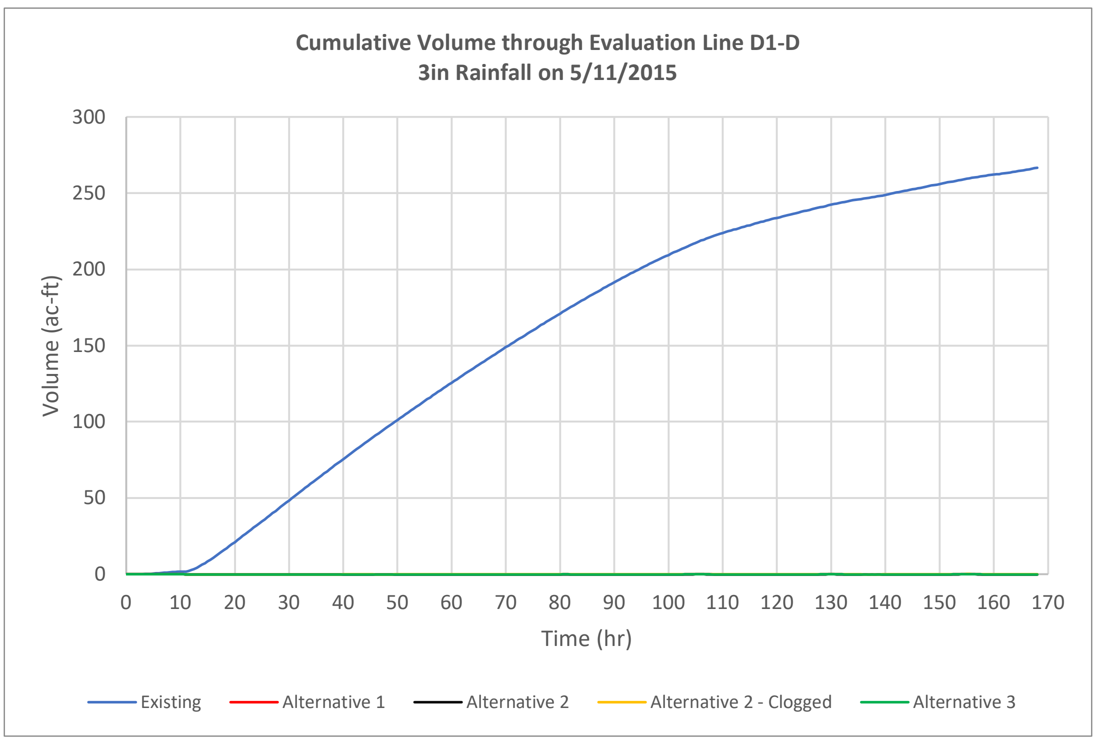



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

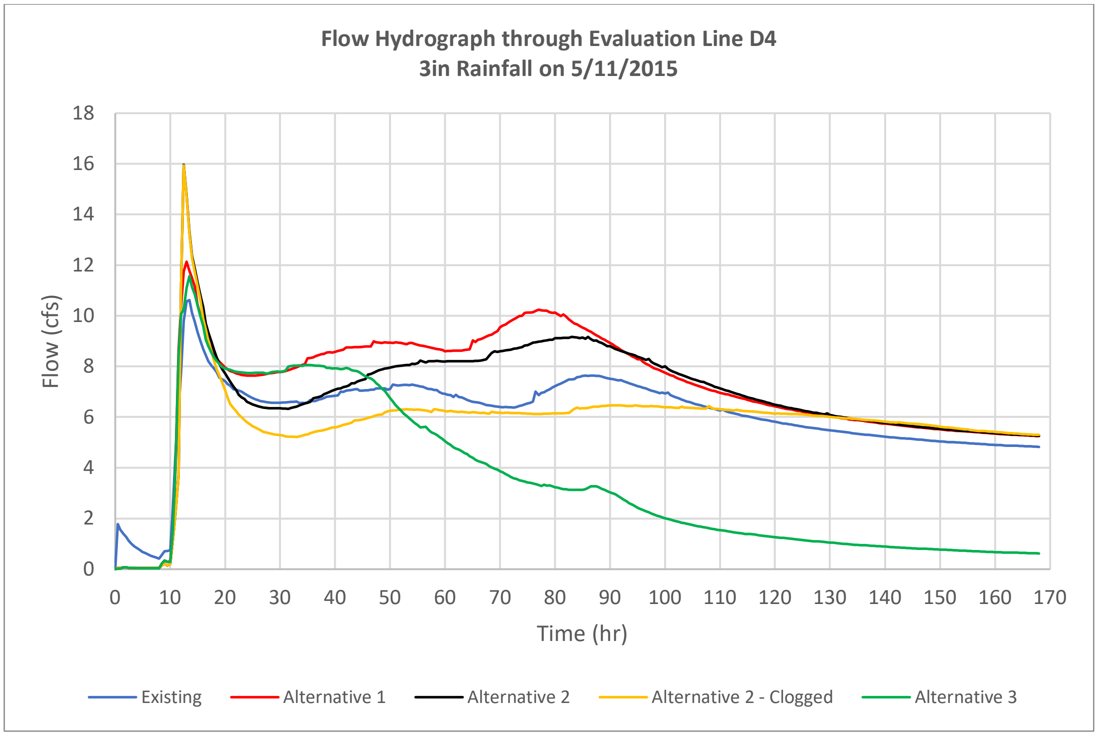
**Figure A4**

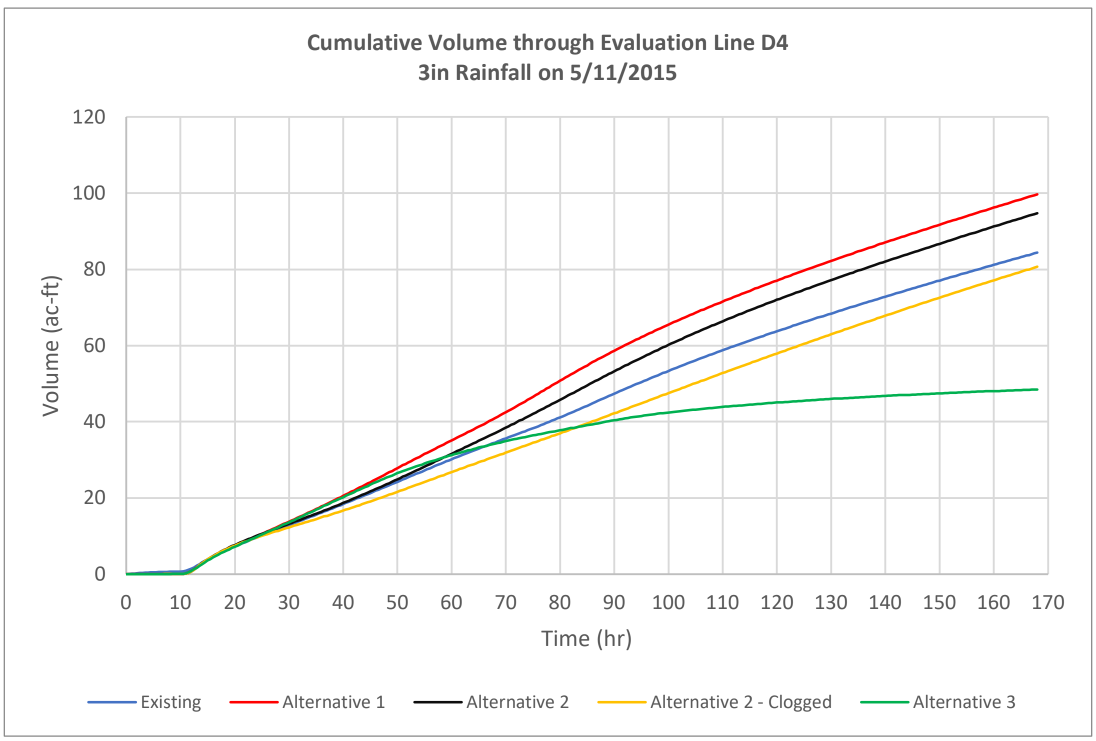



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

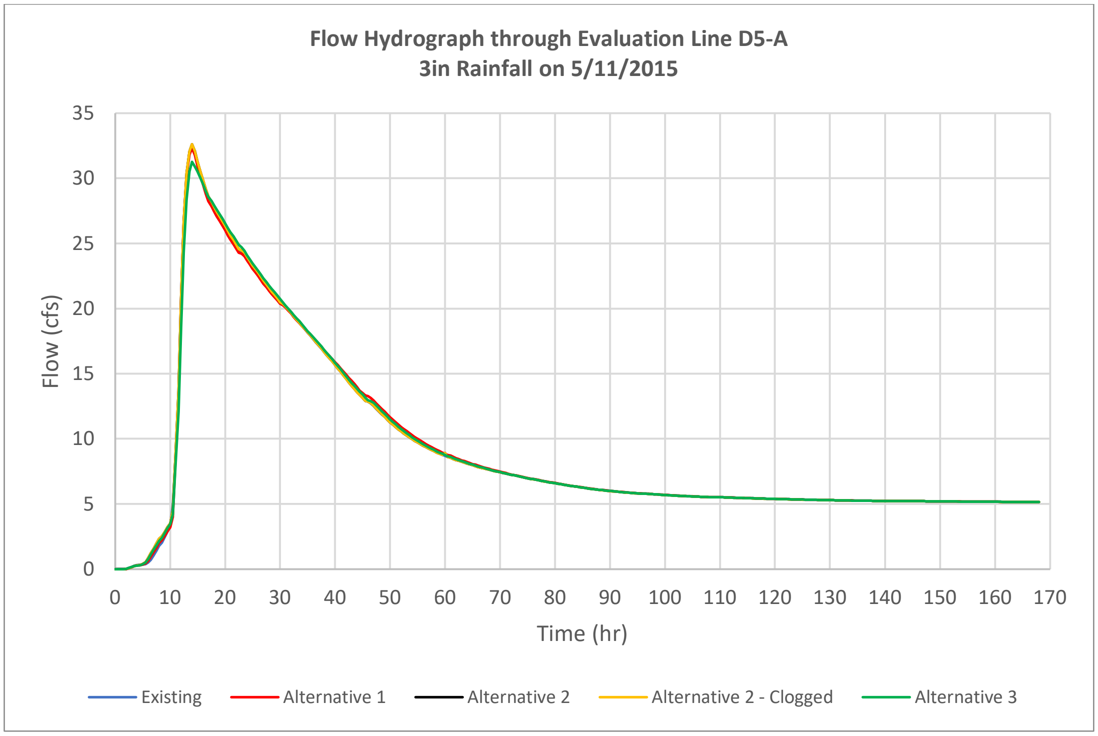
**Figure A5**

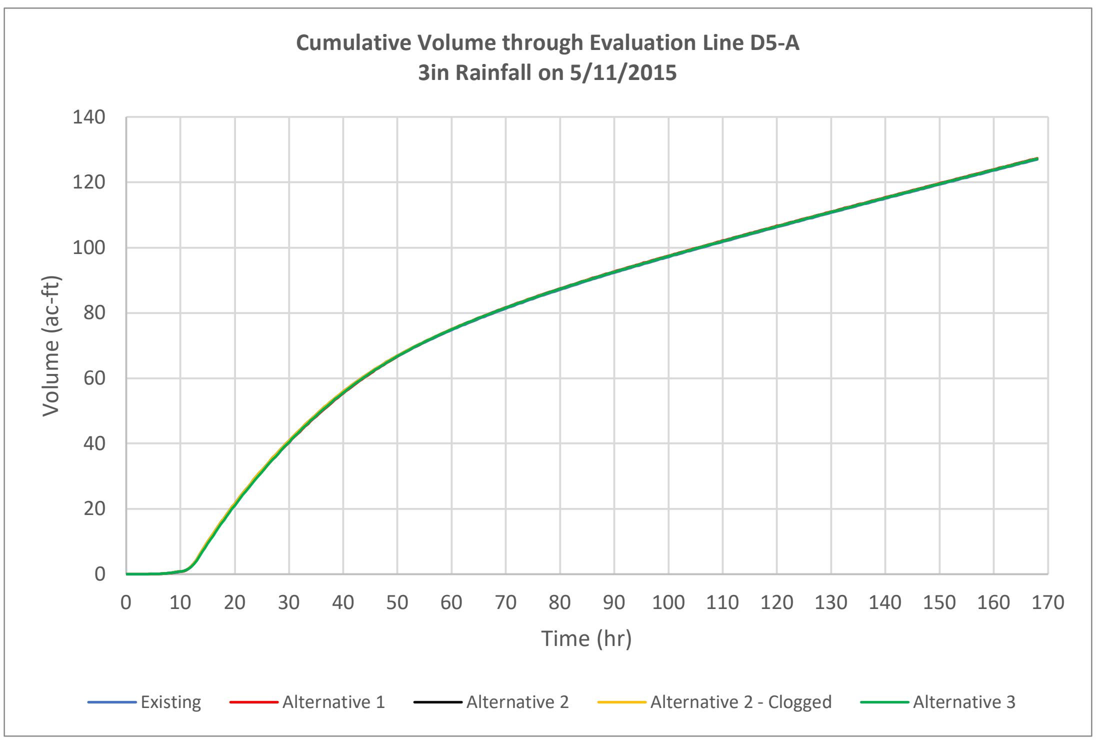



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

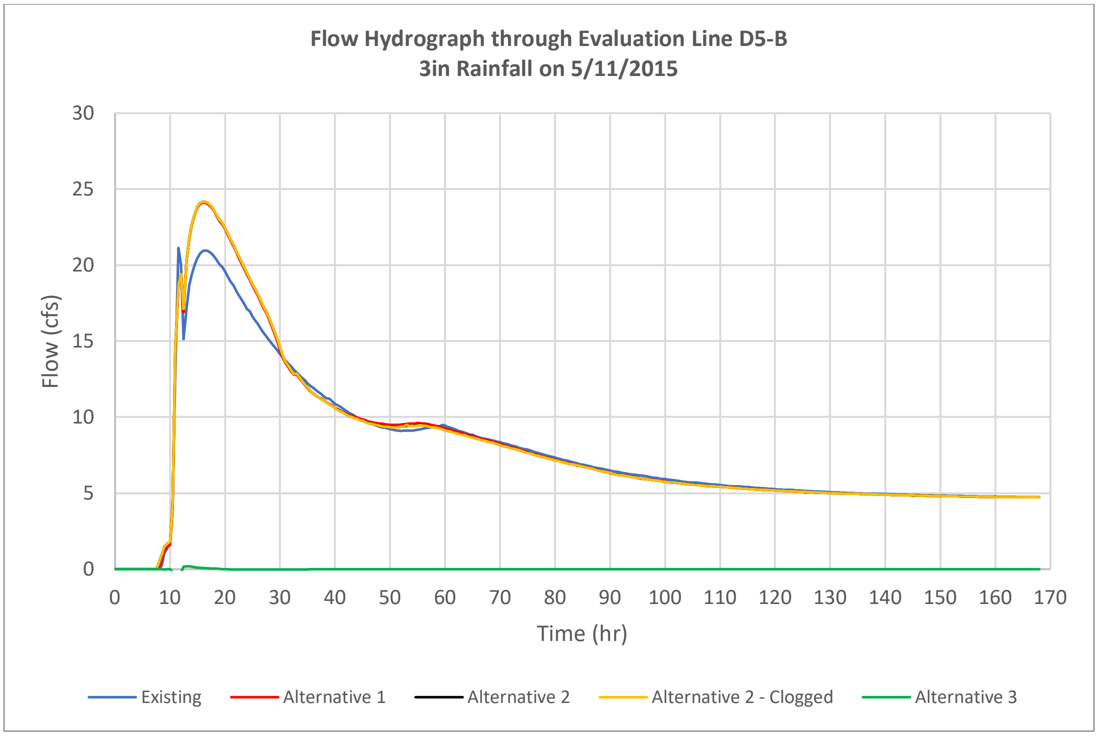
**Figure A6**

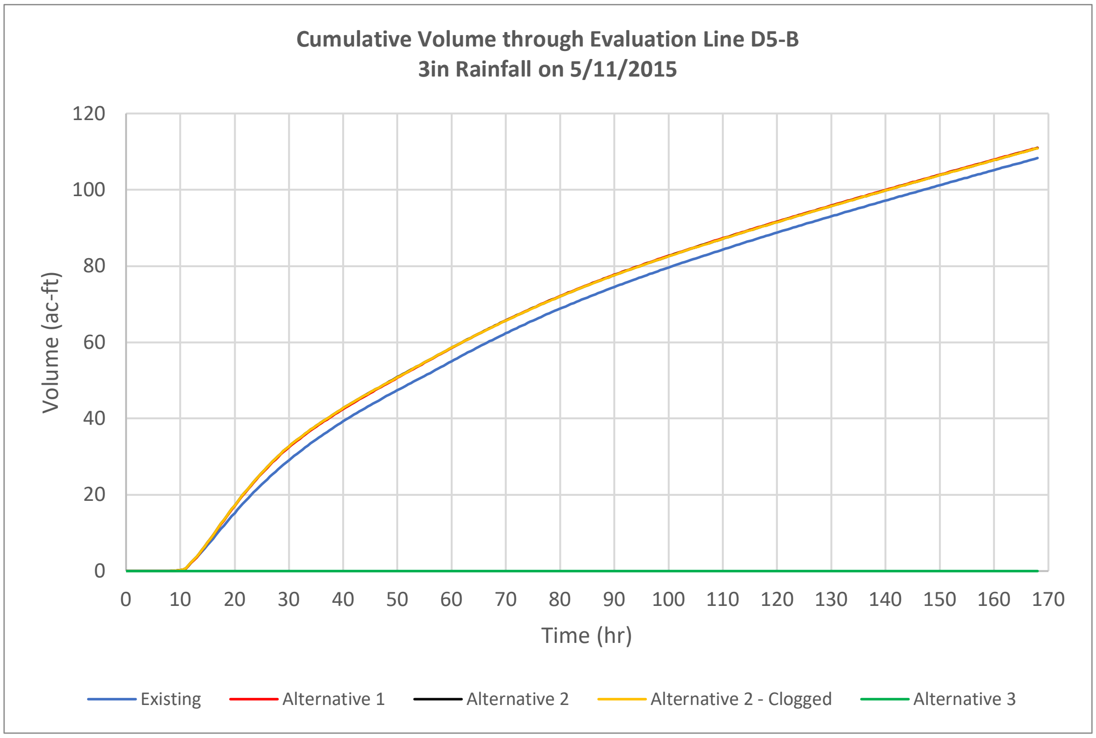



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

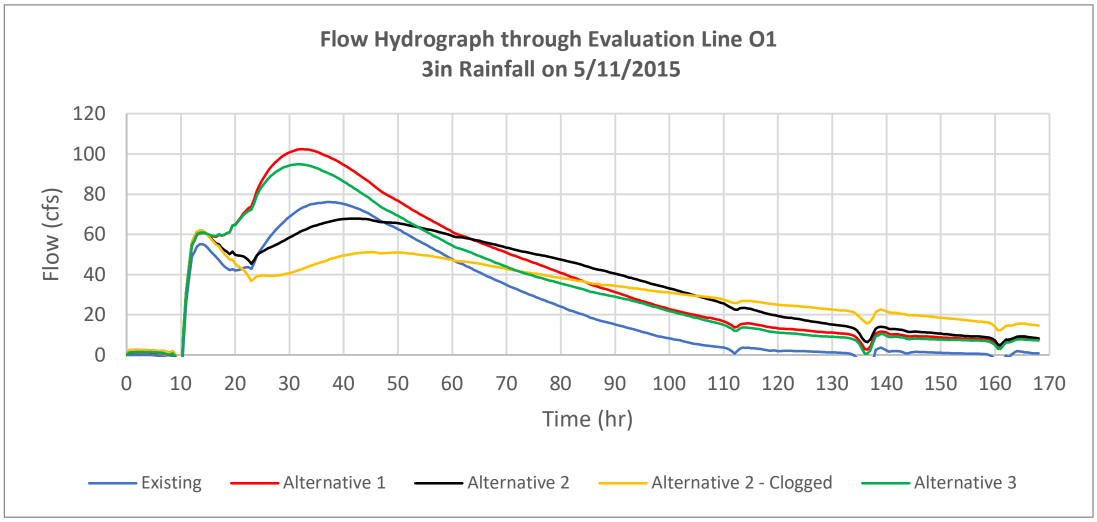
## Figure A7

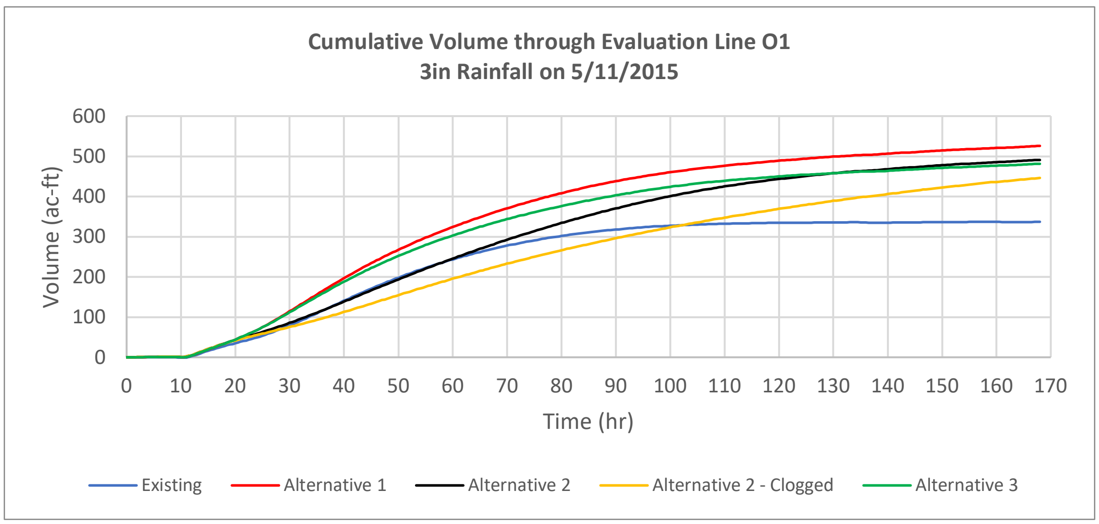


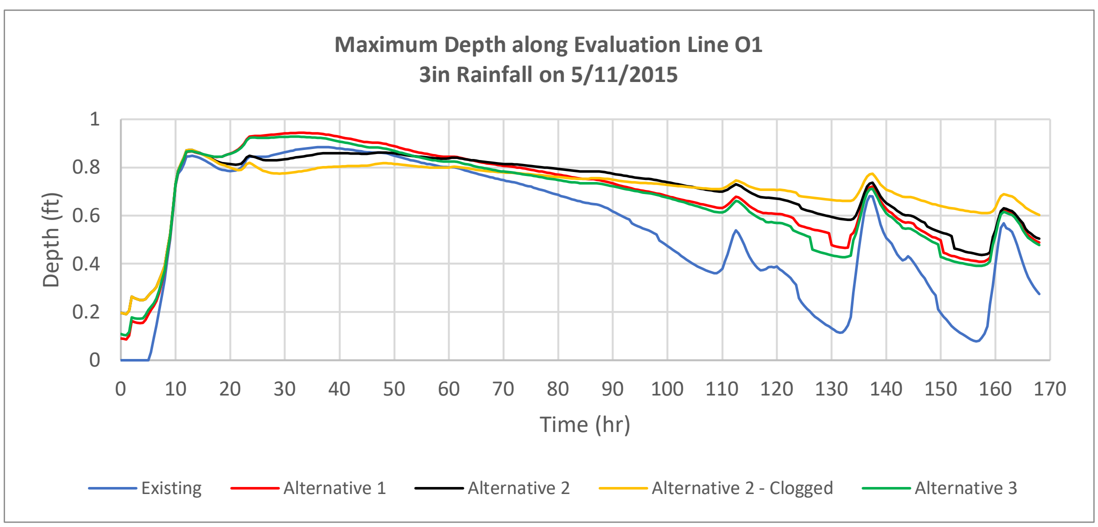




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

## Figure A8

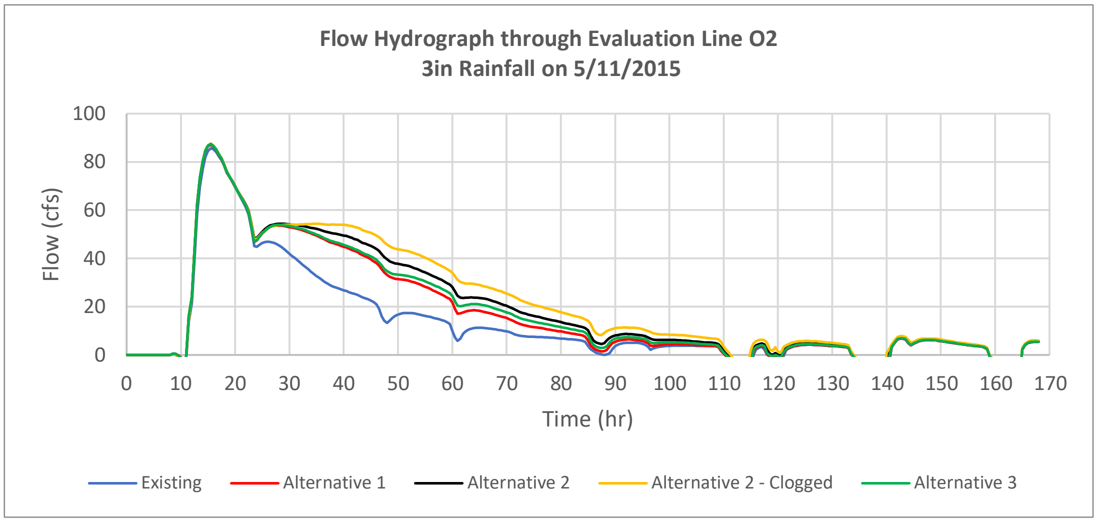


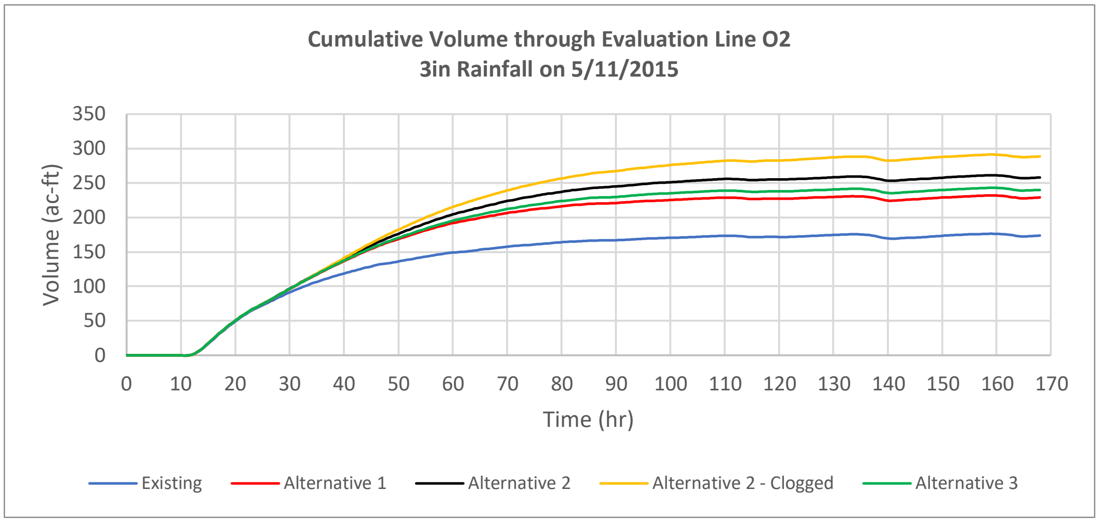



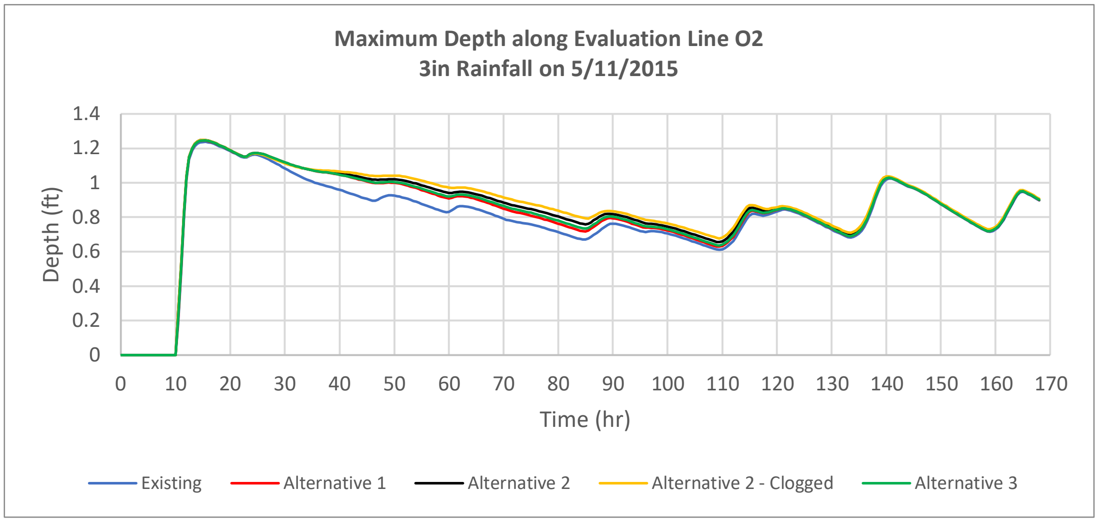




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

## Figure A9

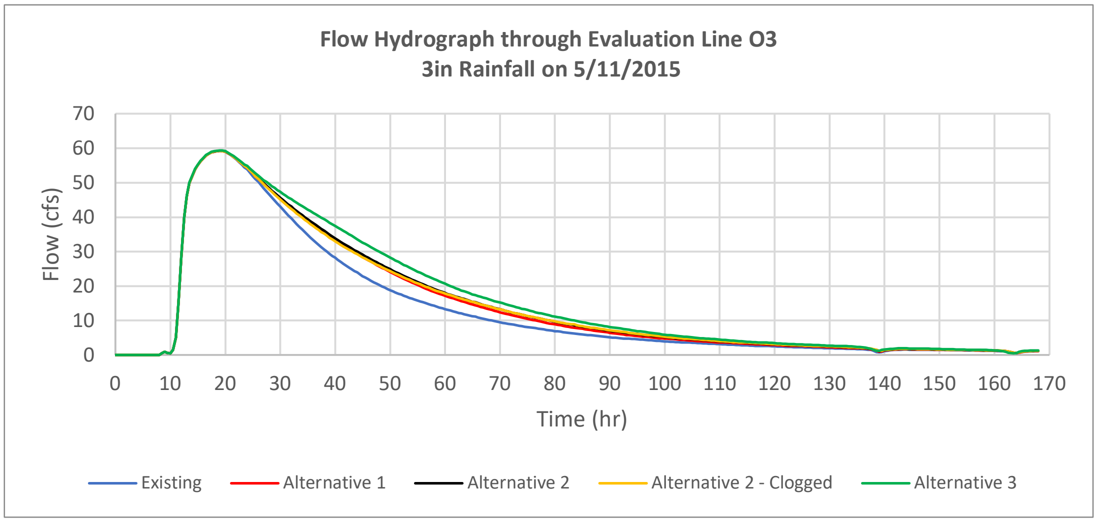


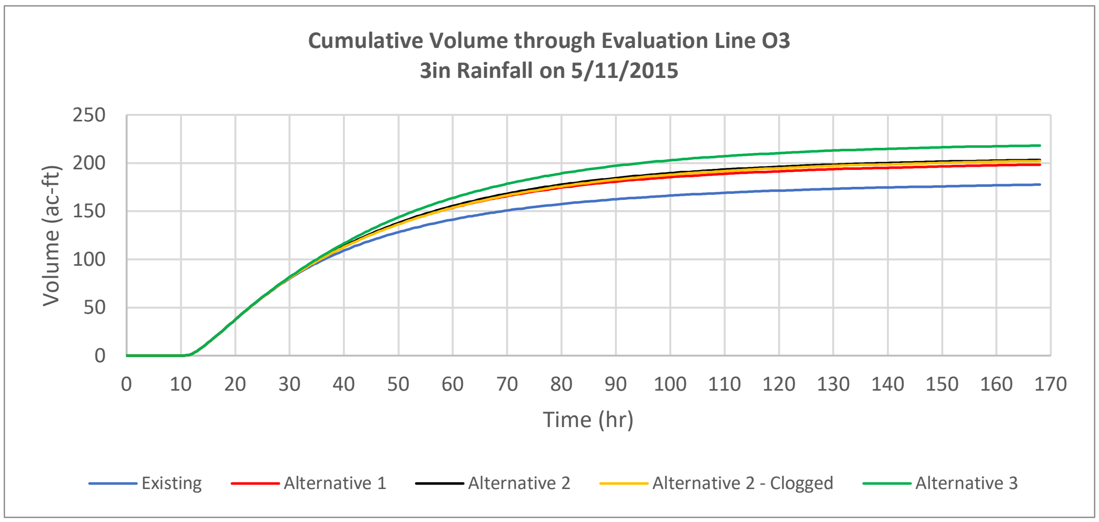



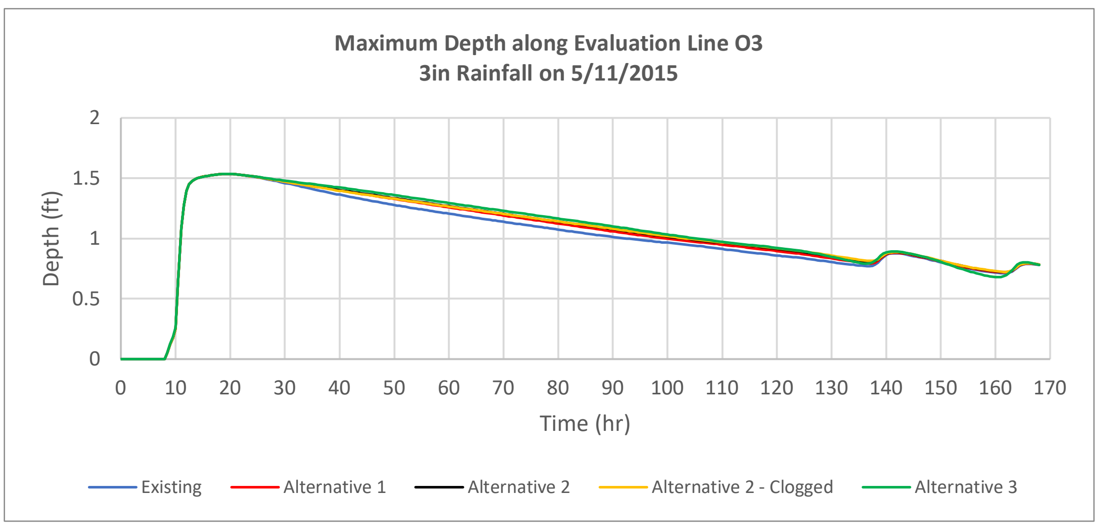




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A10**

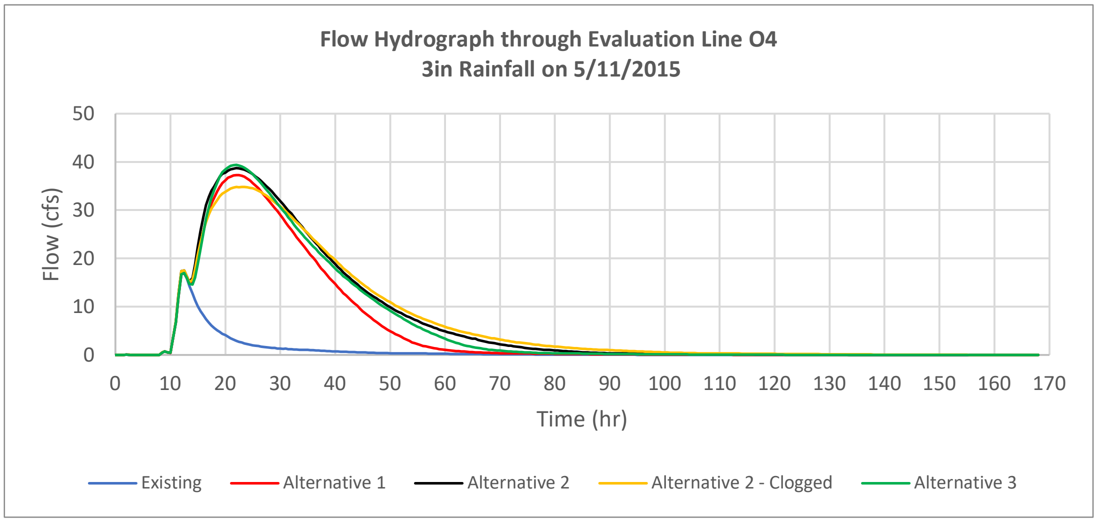


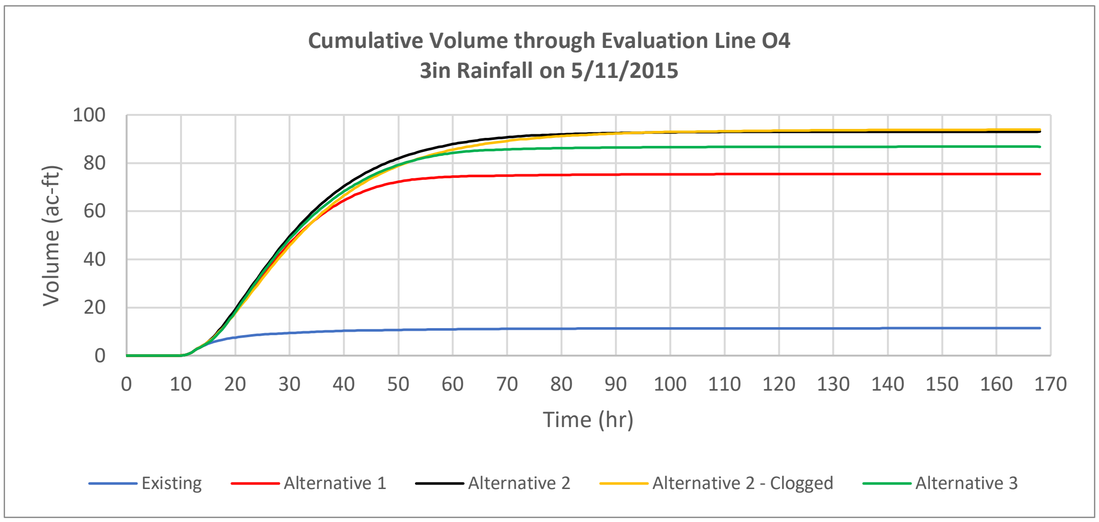



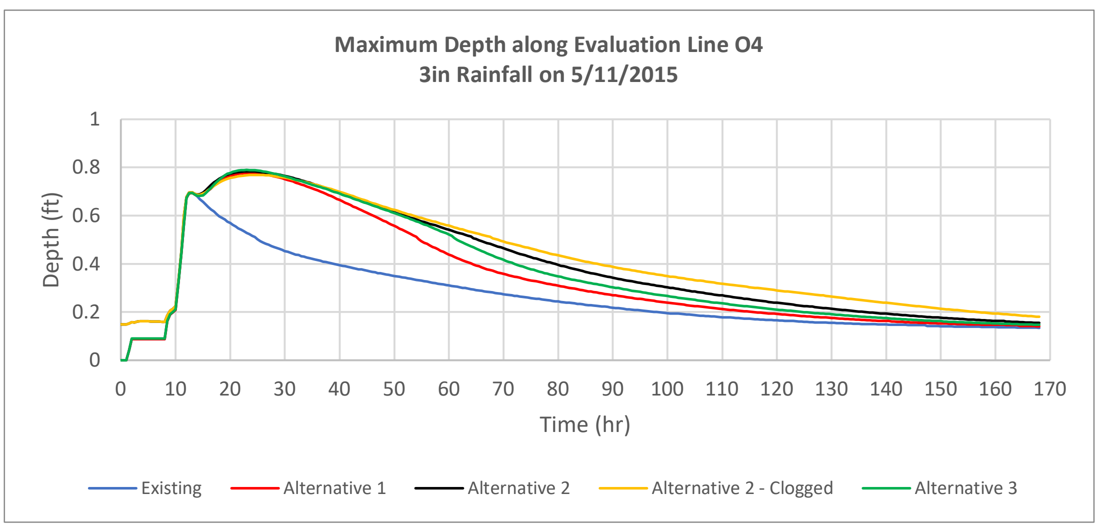




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

## Figure A11

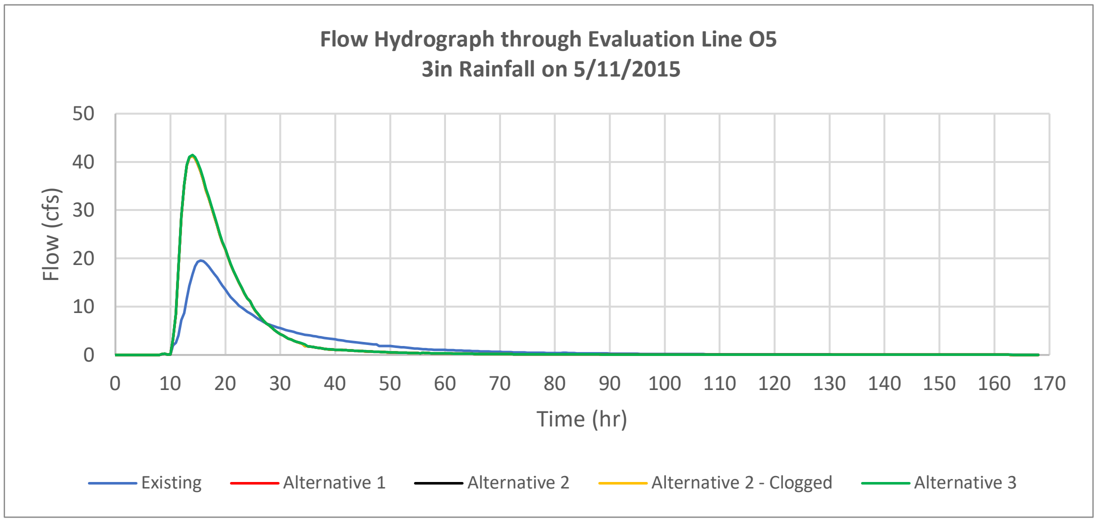


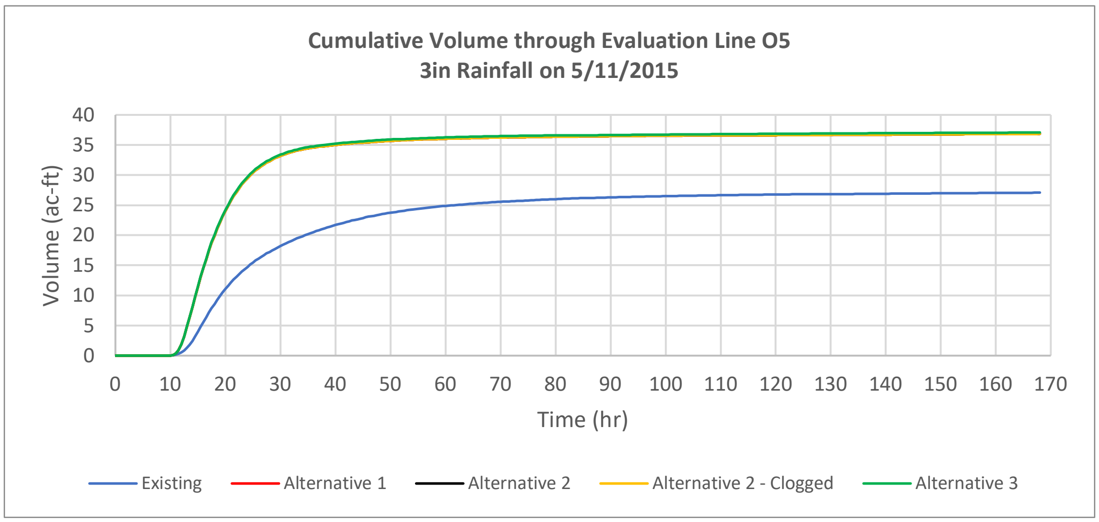



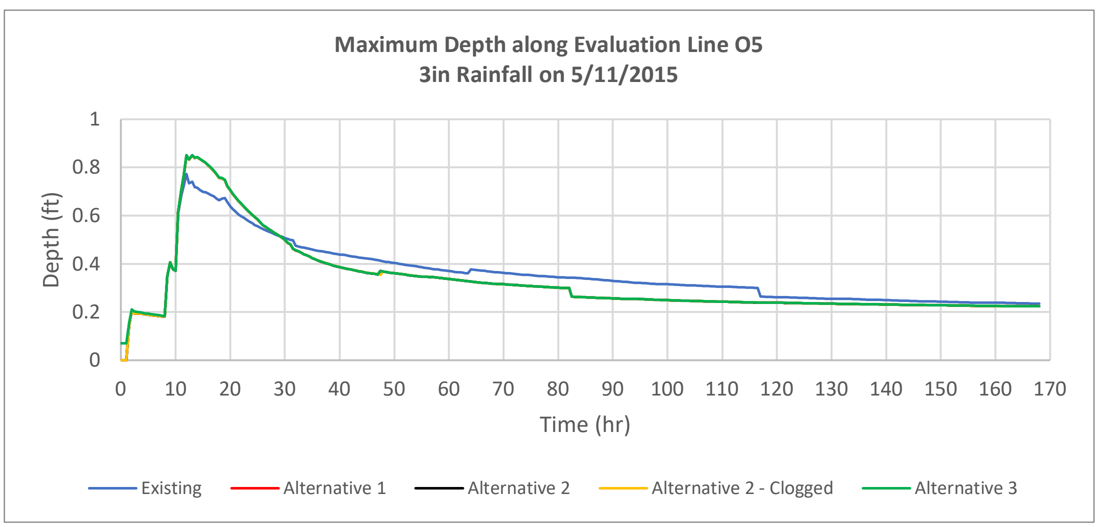




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A12**

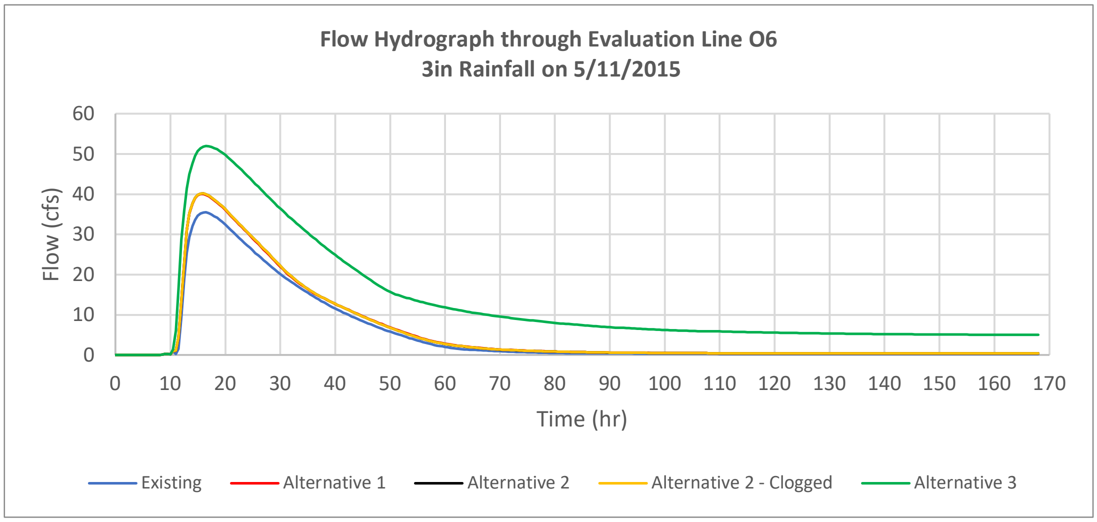


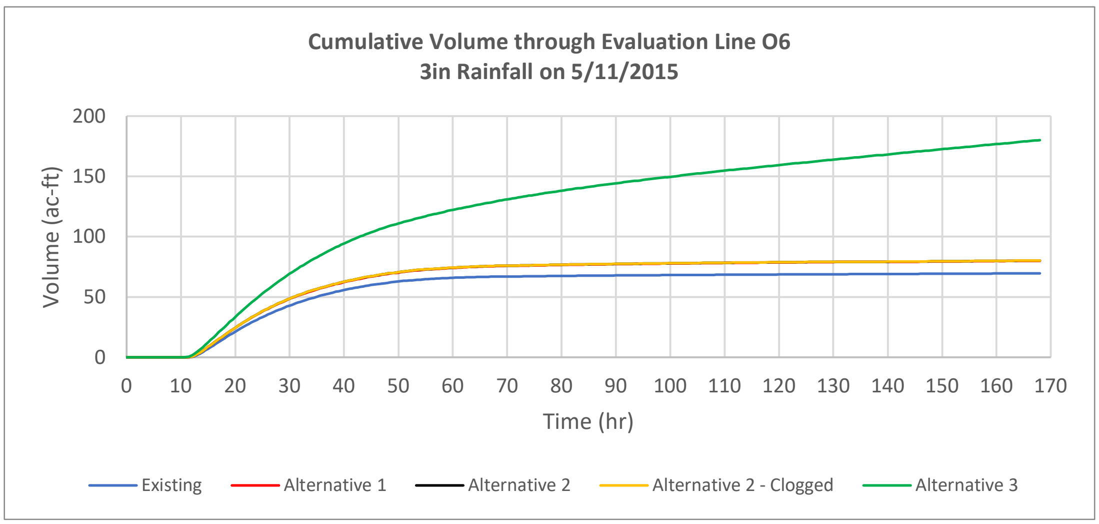



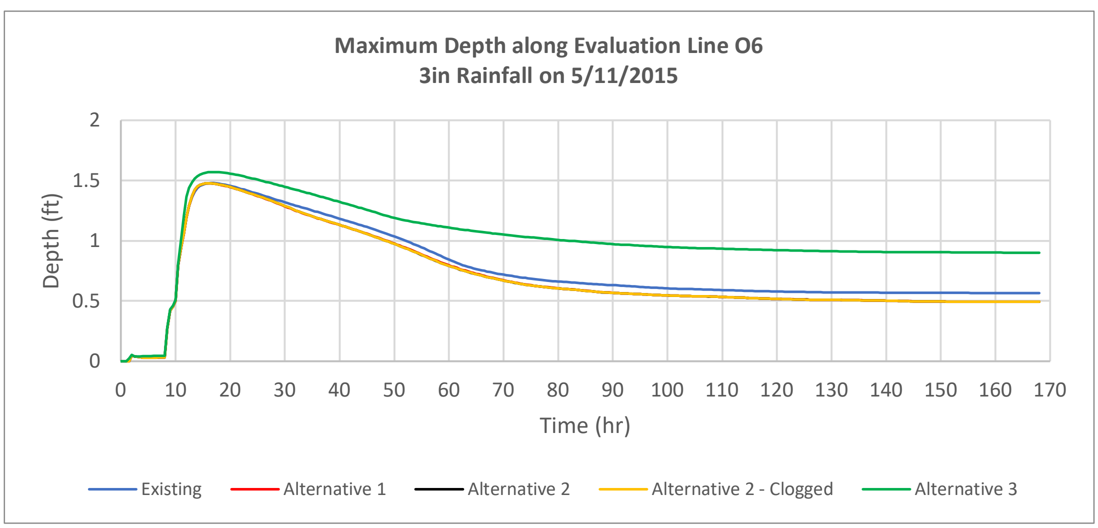




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A13**

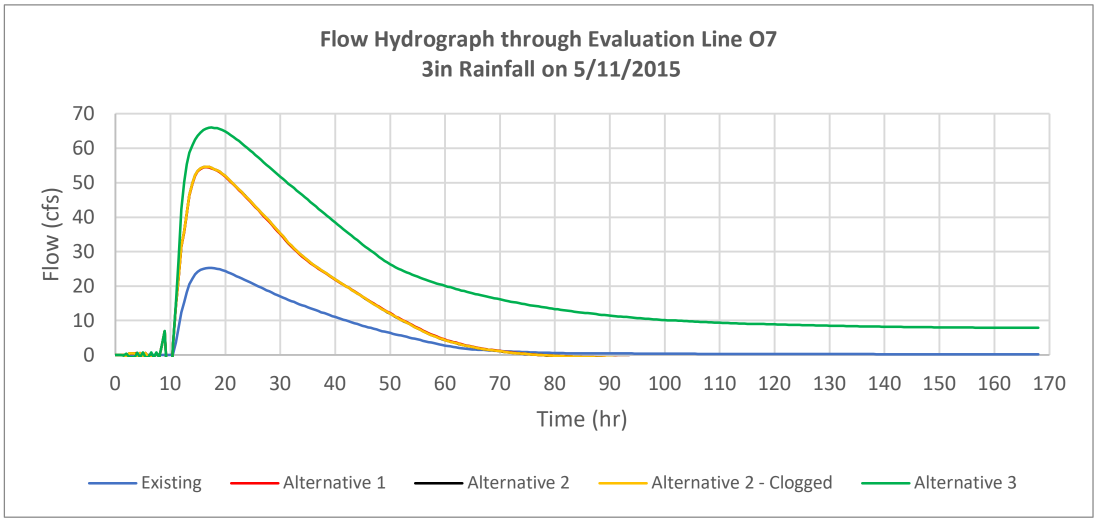


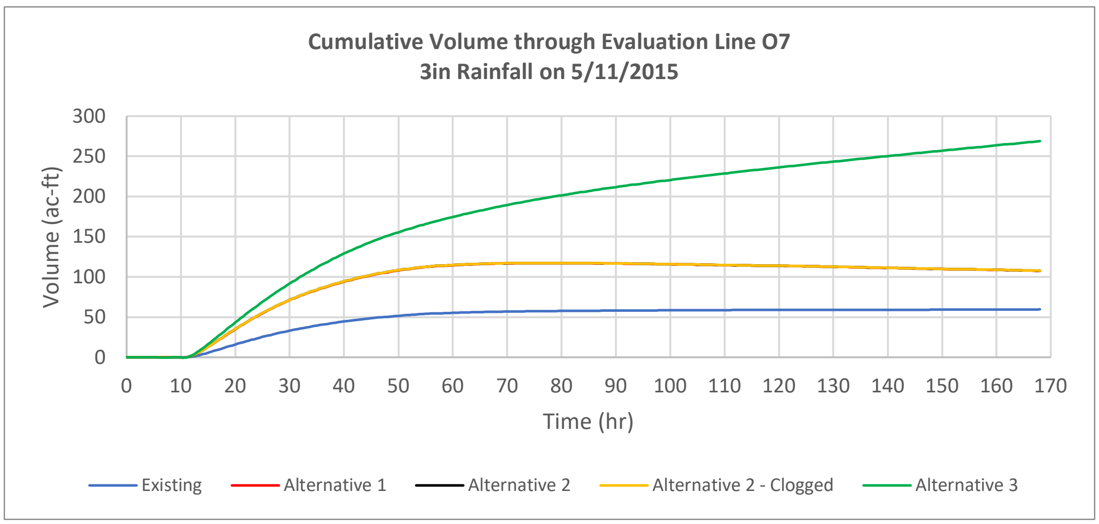



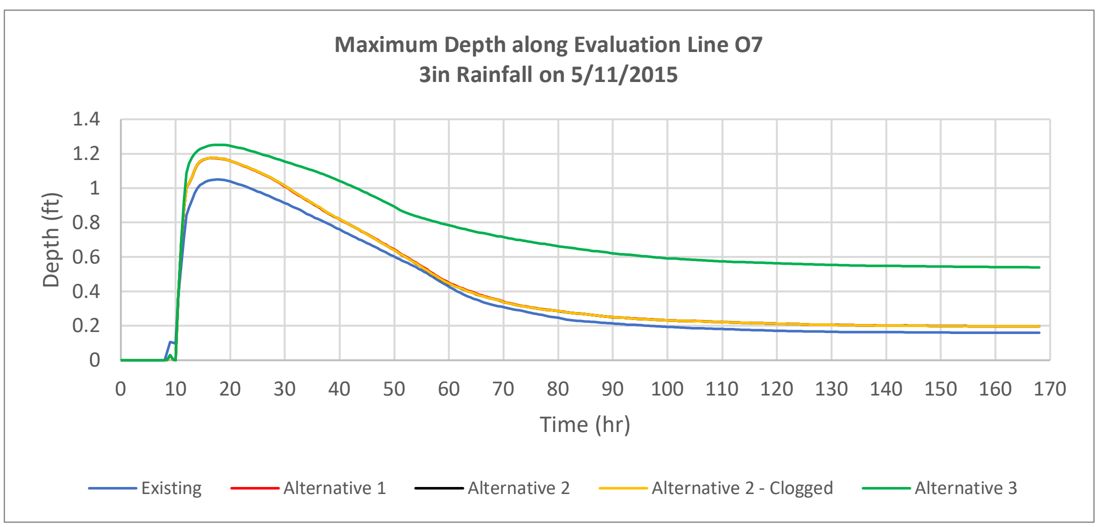




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A14**

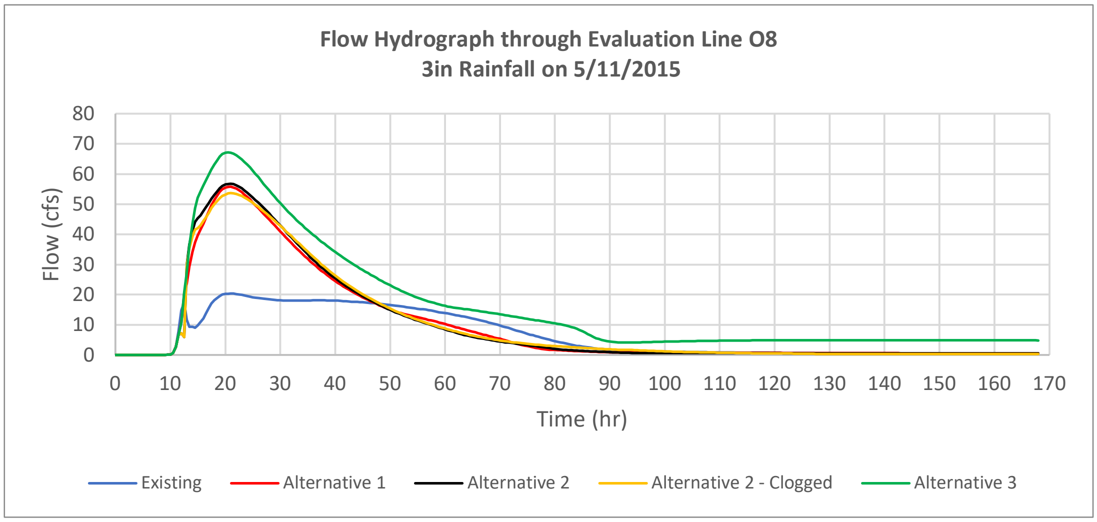


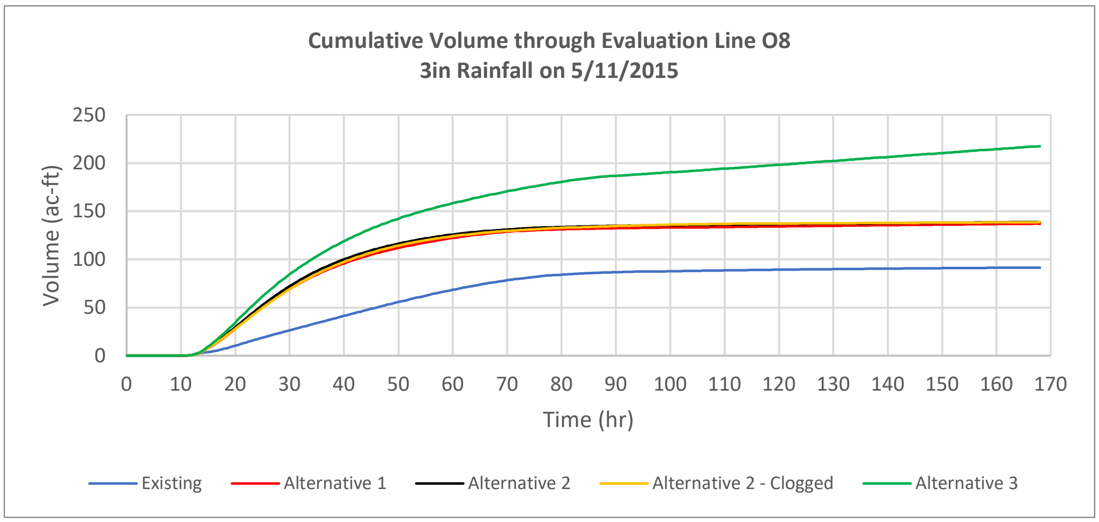



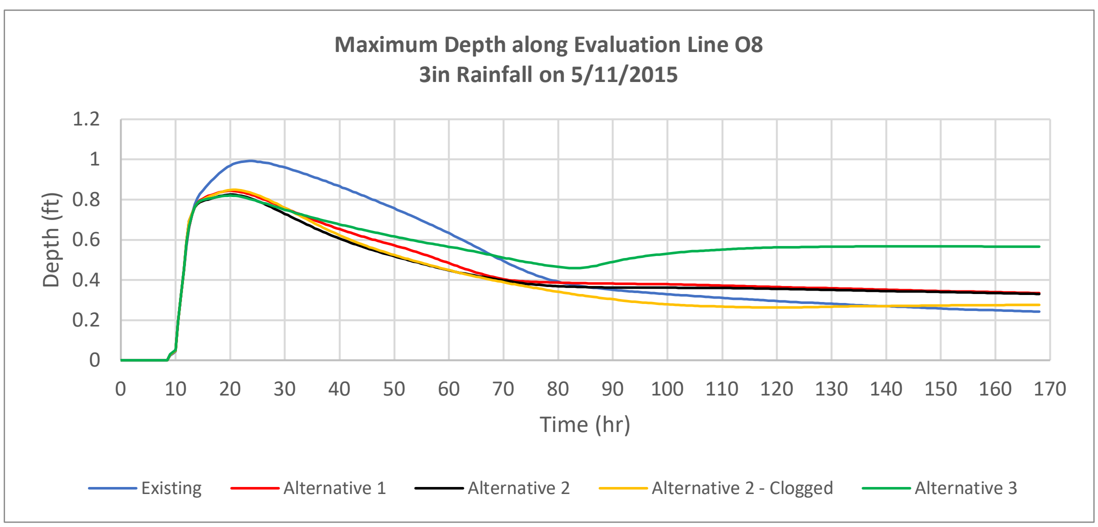




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A15**

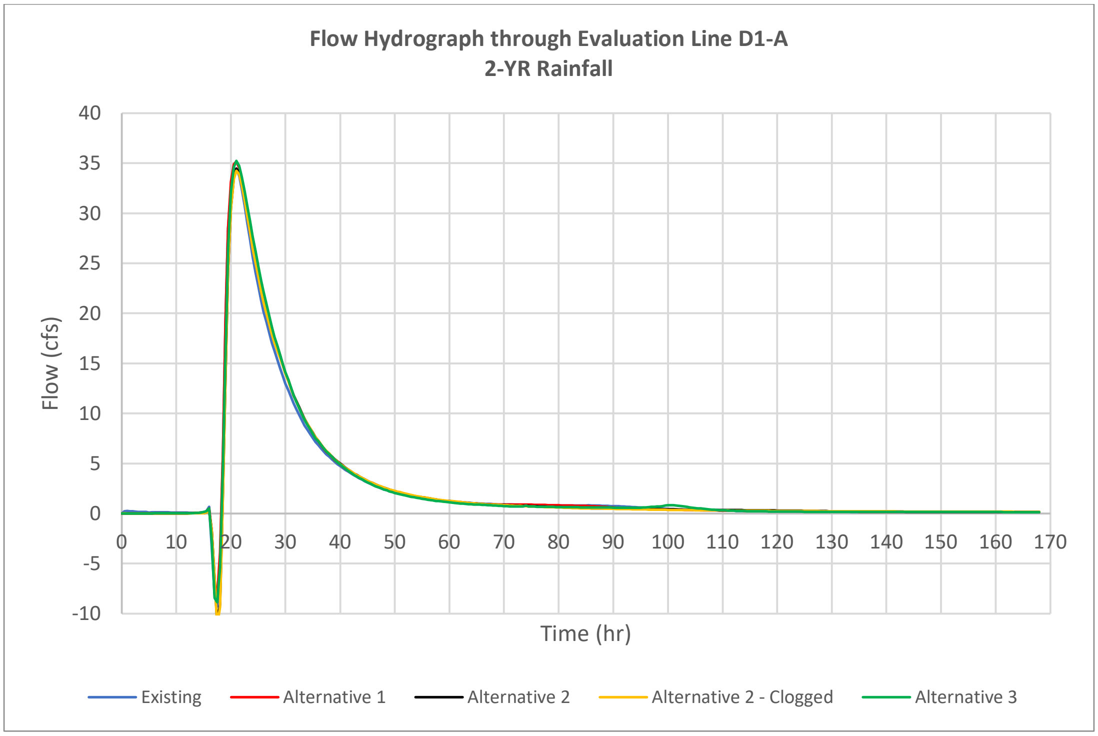


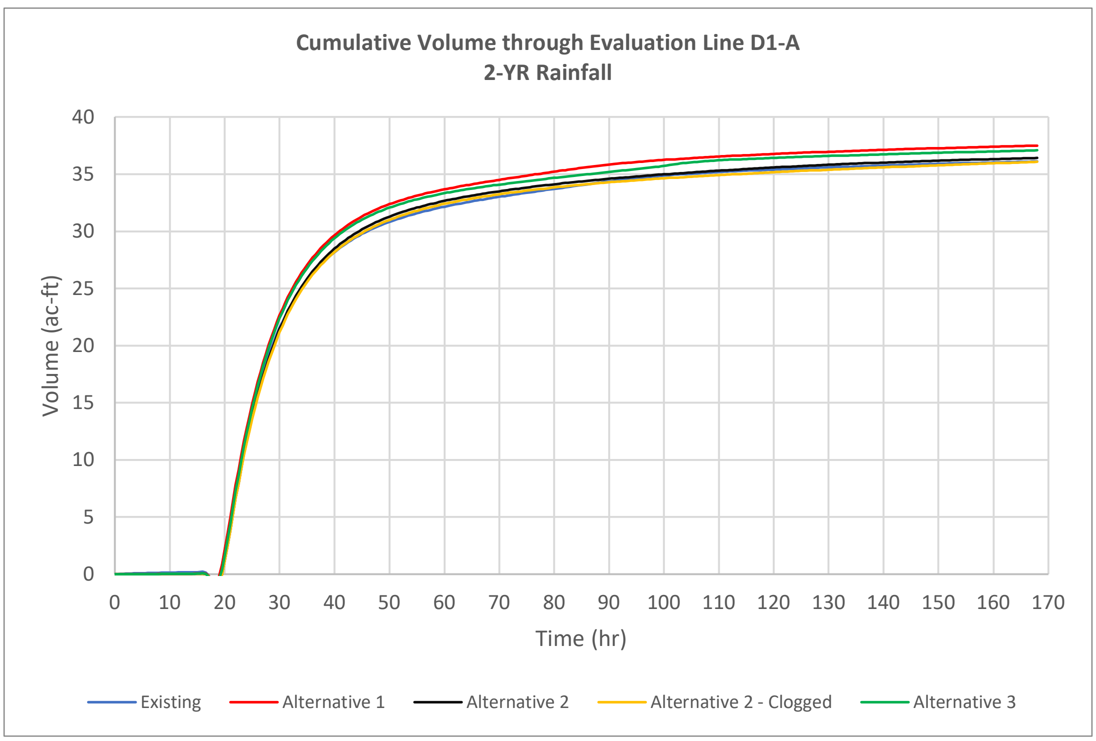




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

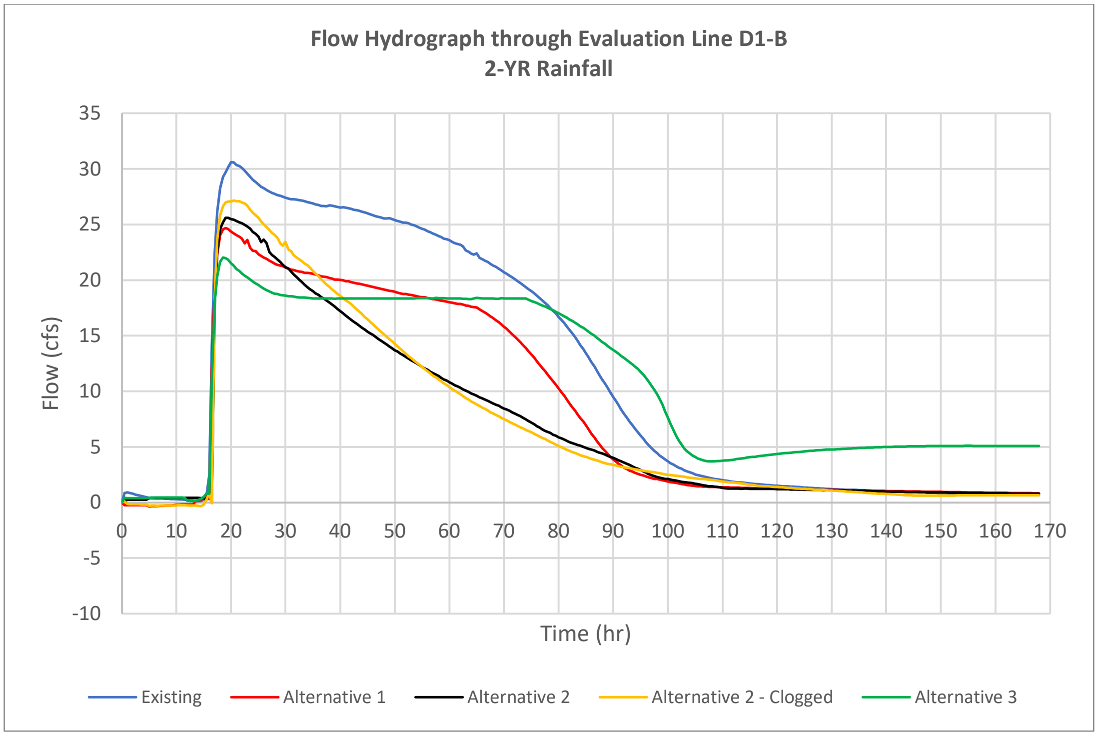
**Figure A16**

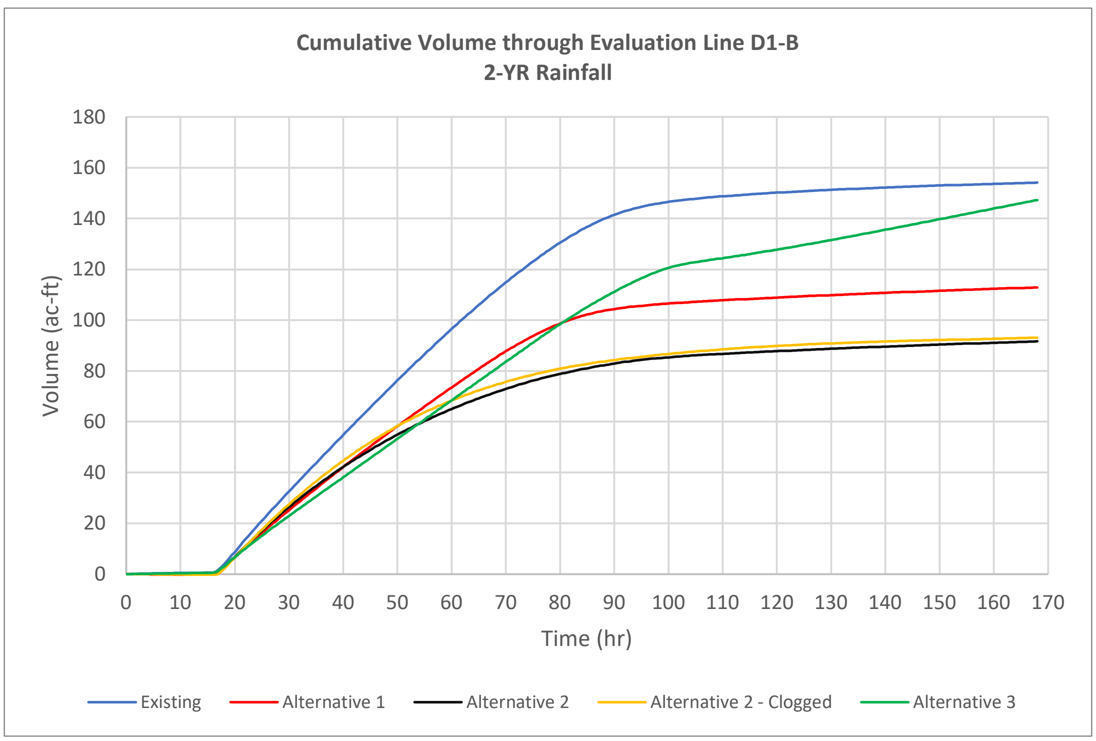



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

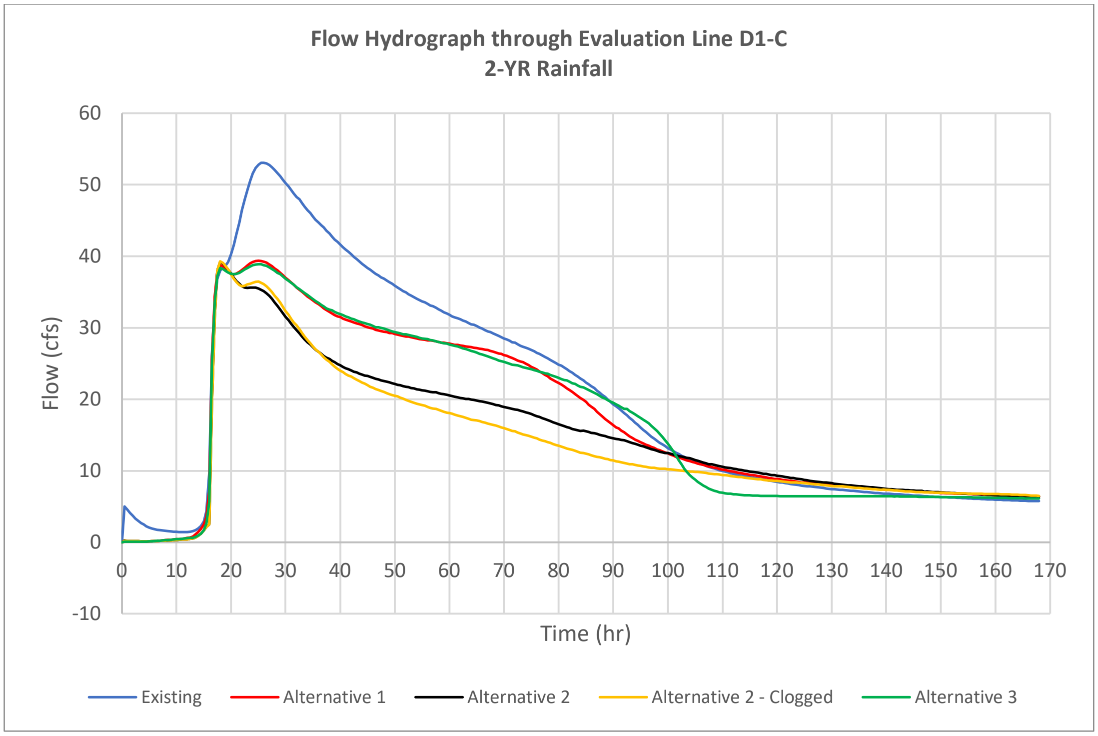
**Figure A17**

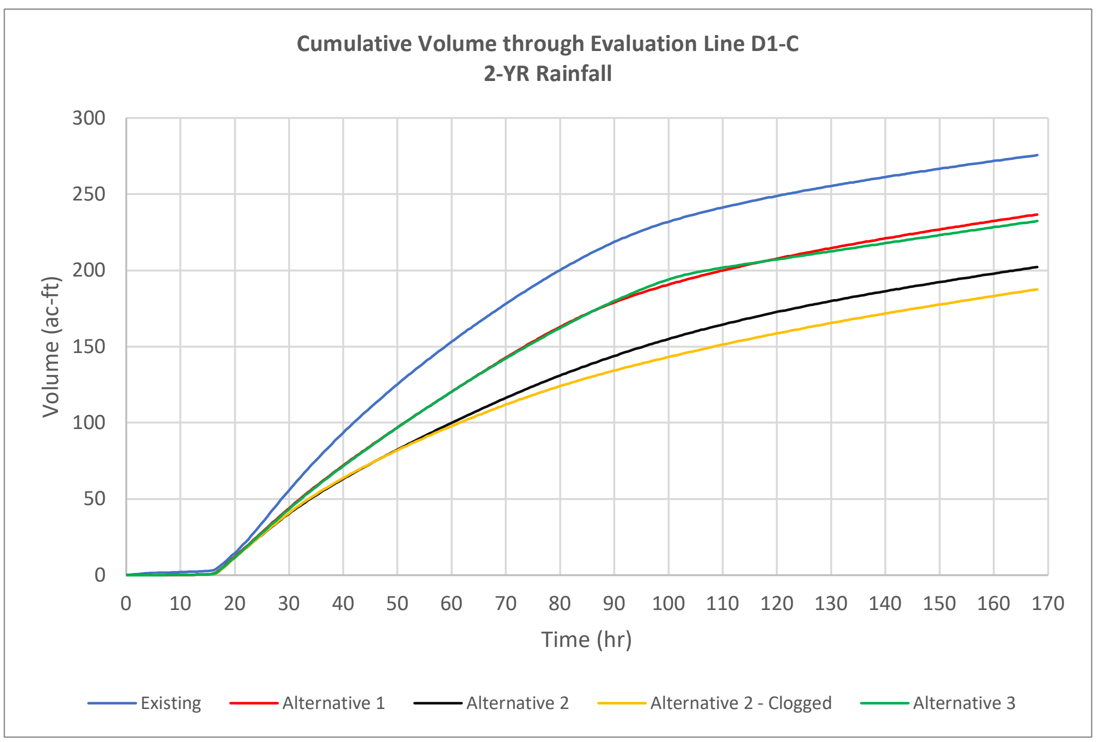



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

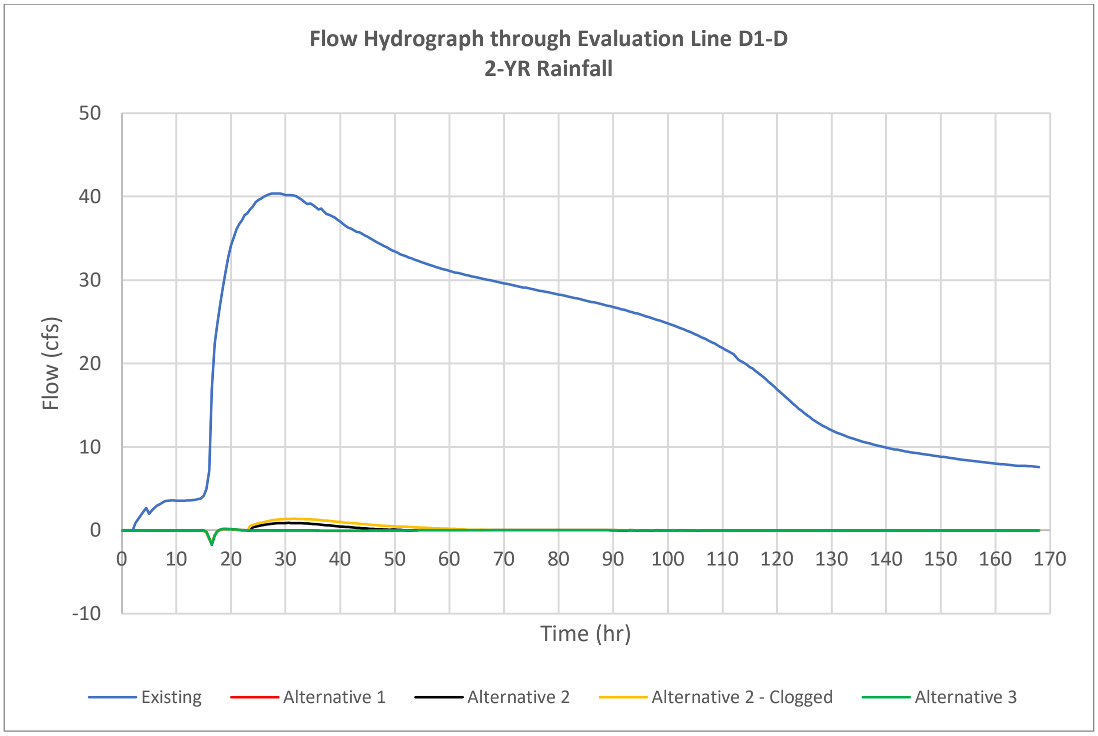
**Figure A18**

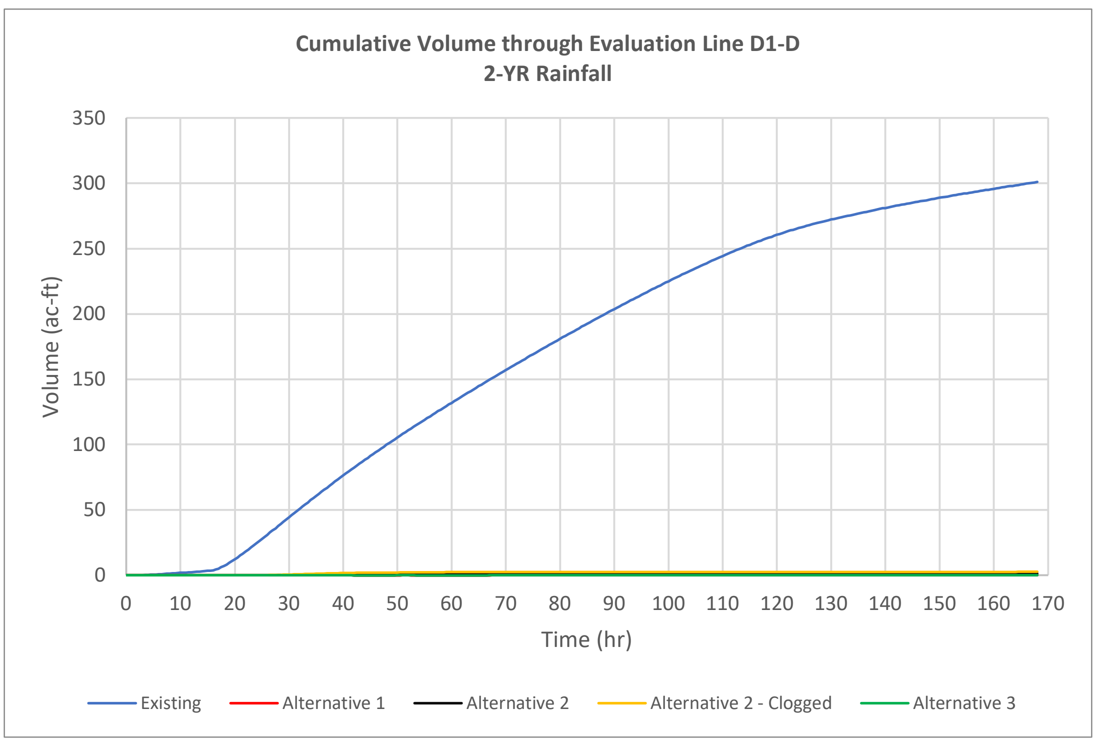



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

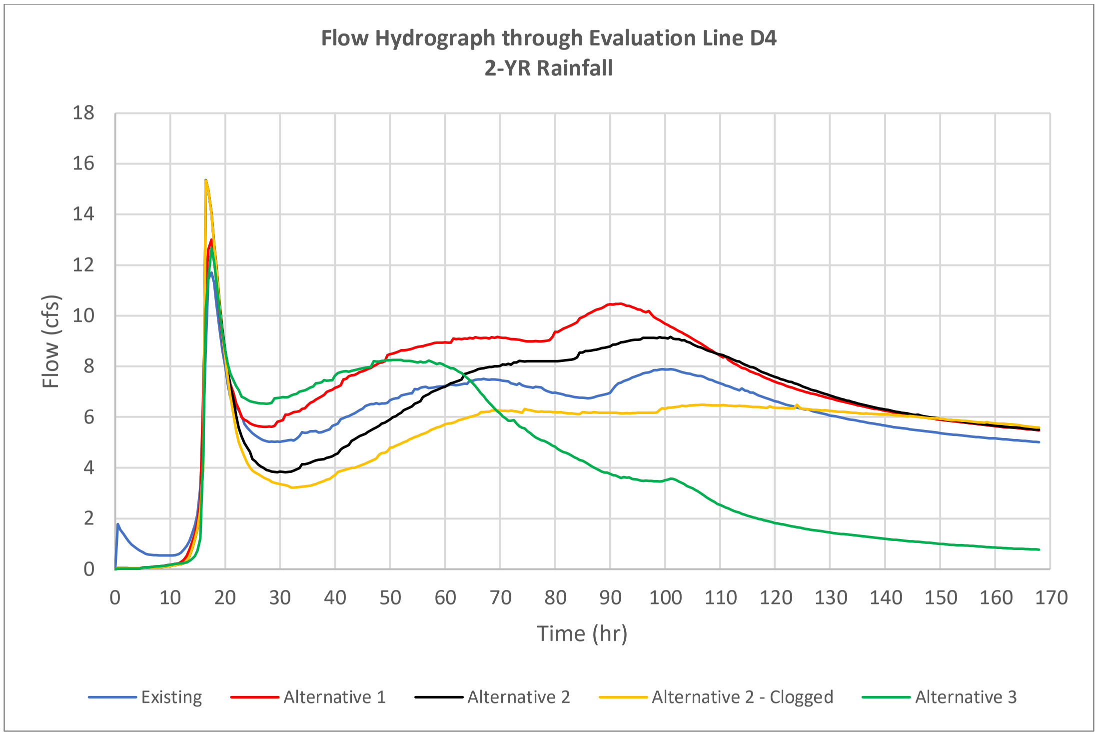
**Figure A19**

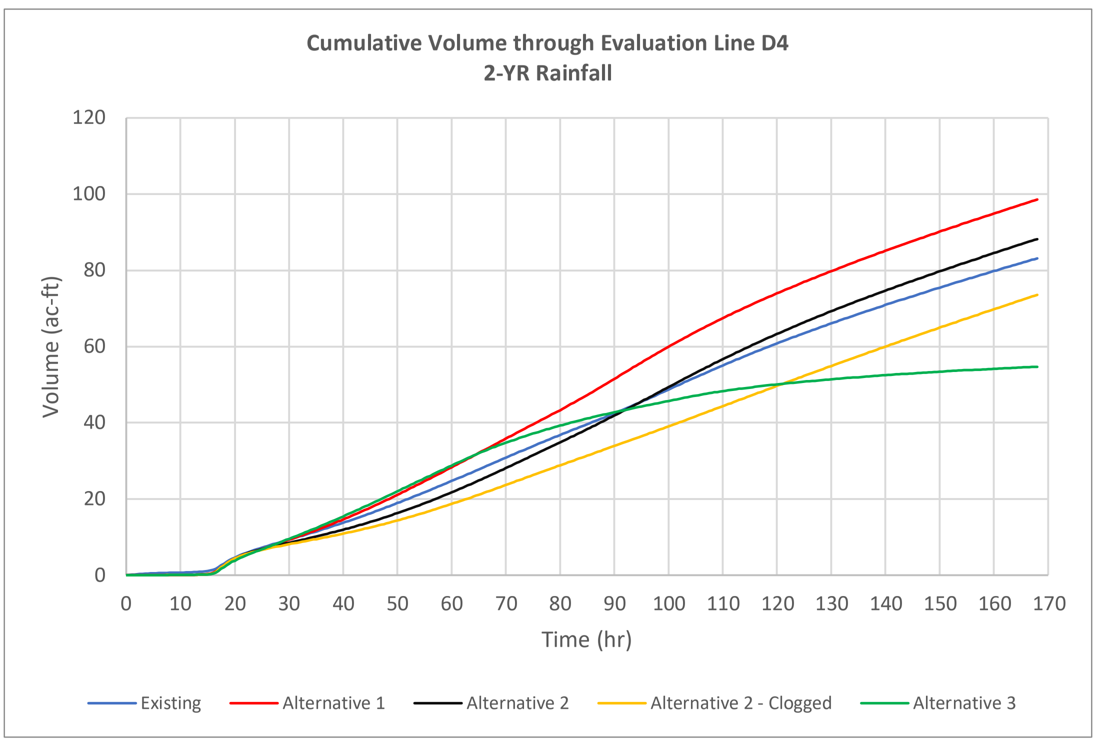



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

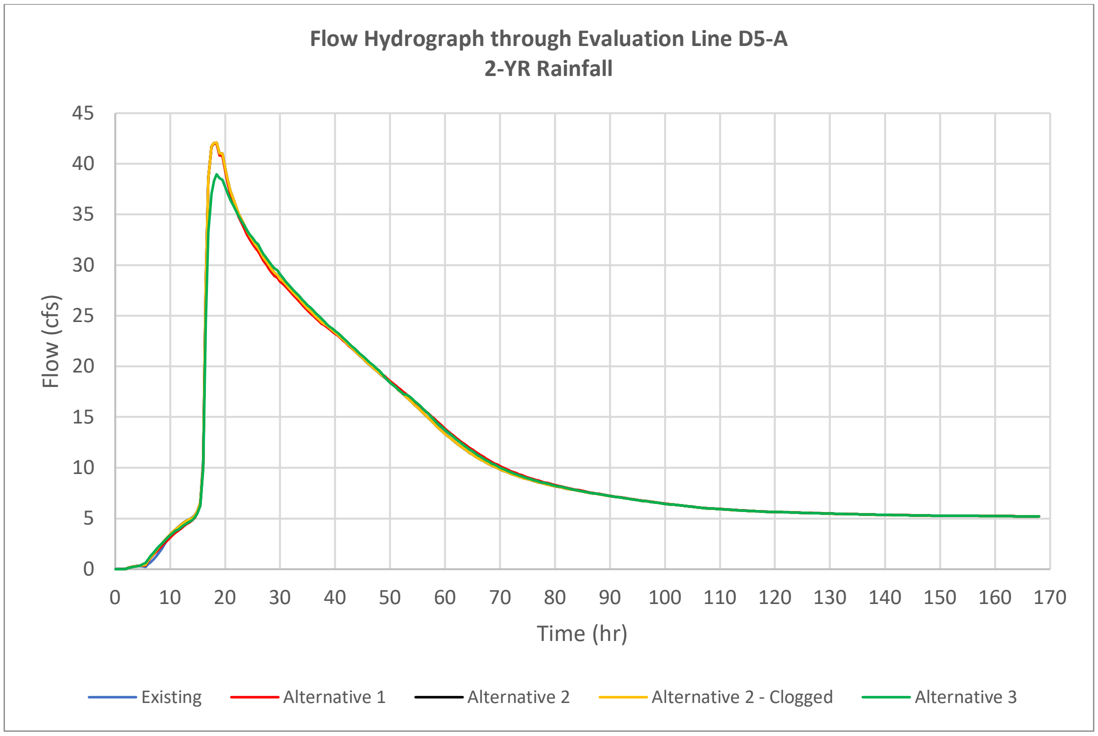
**Figure A20**

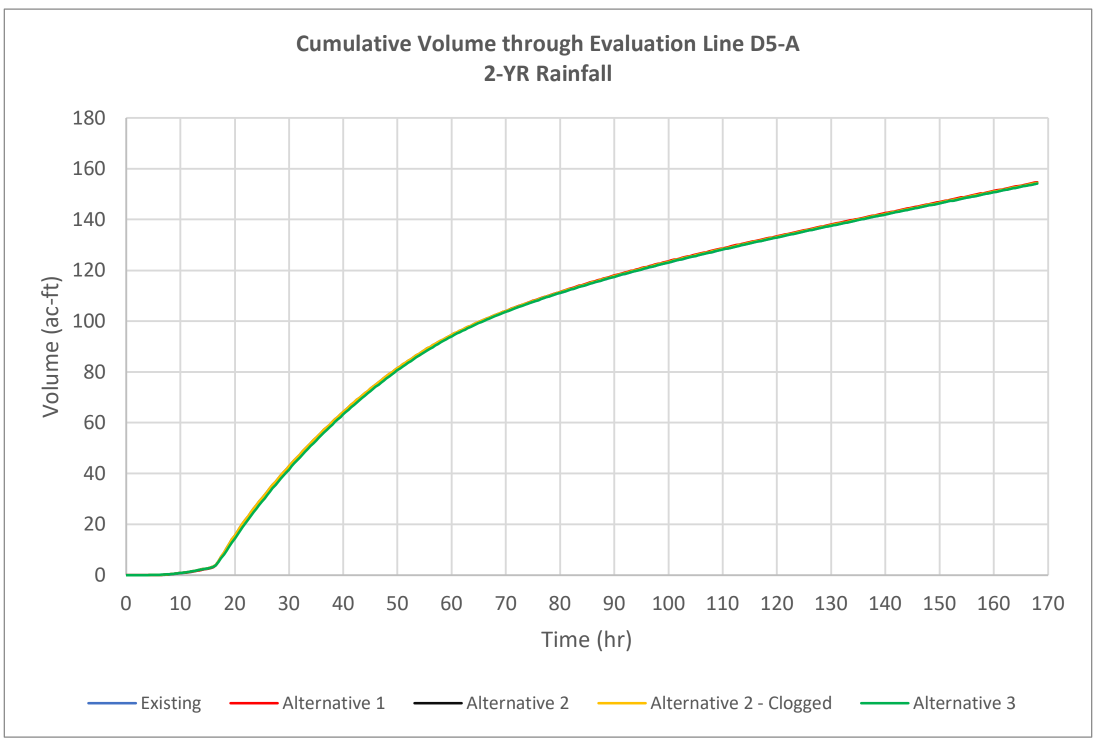



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

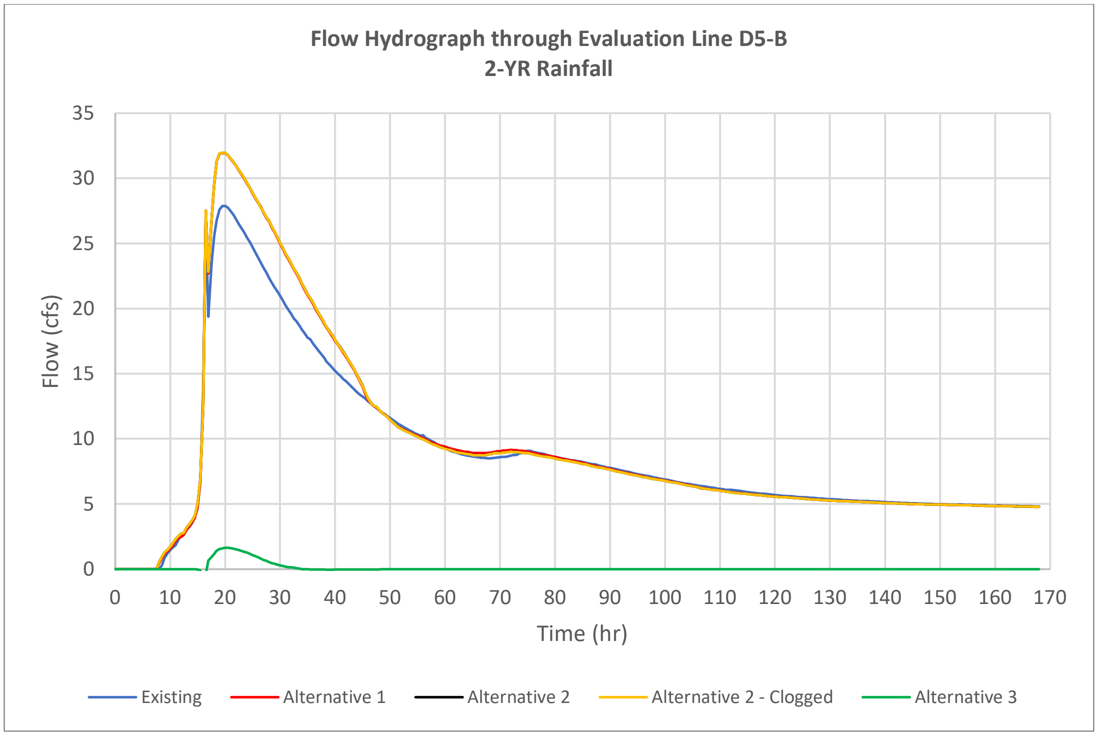
**Figure A21**

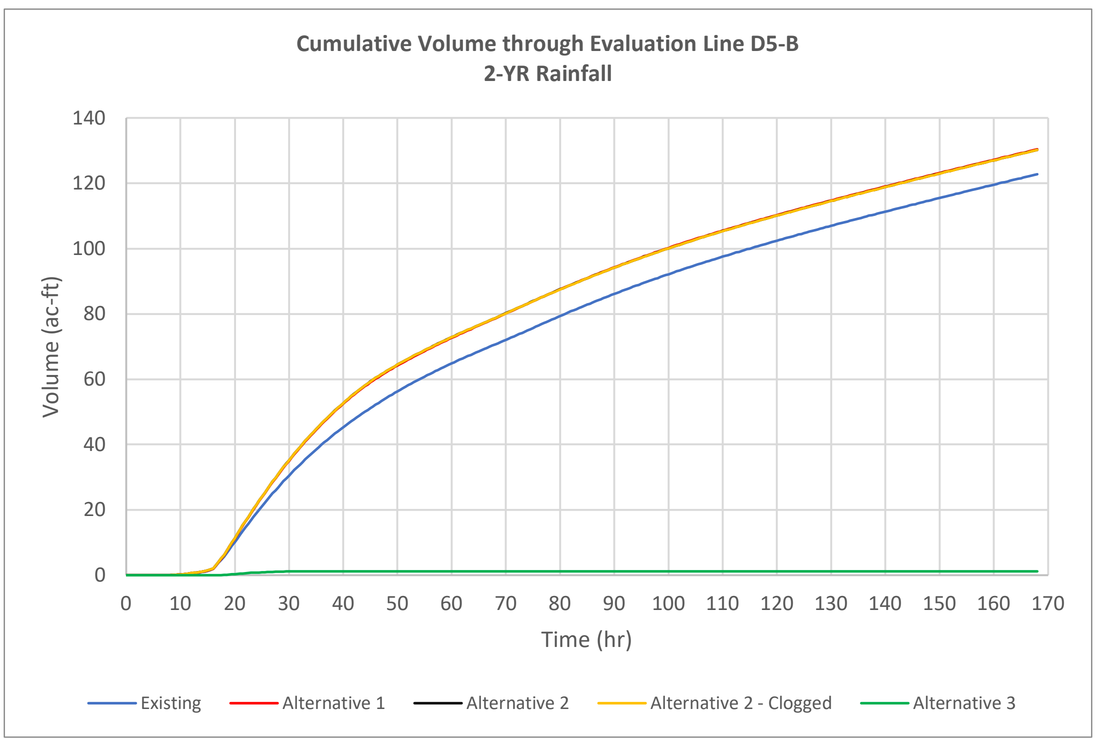



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

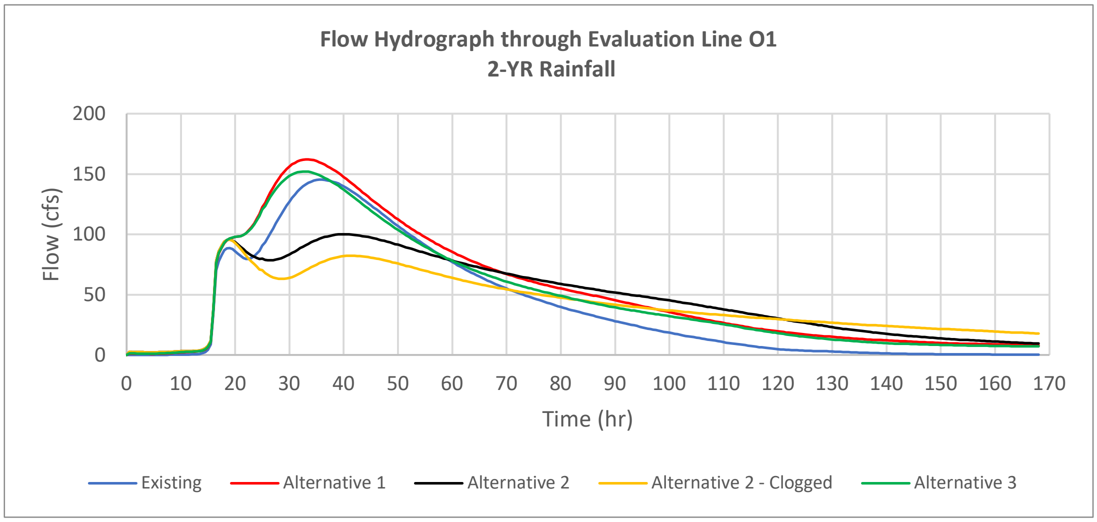
**Figure A22**

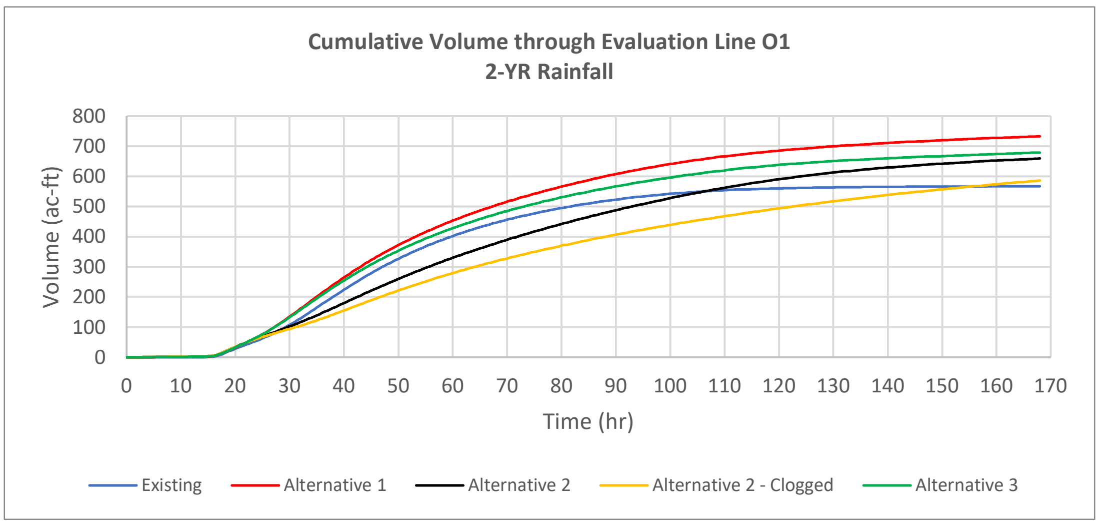


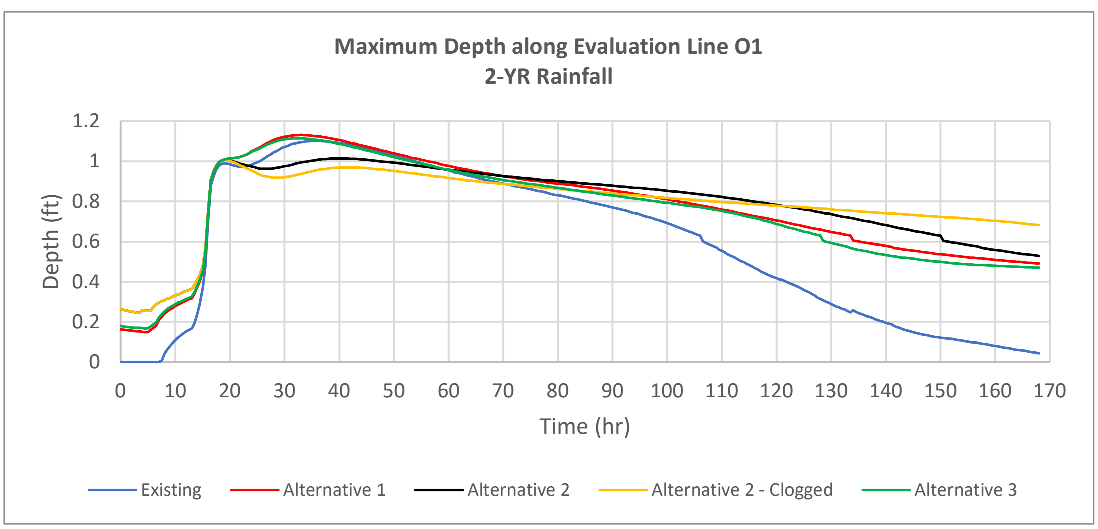




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A23**

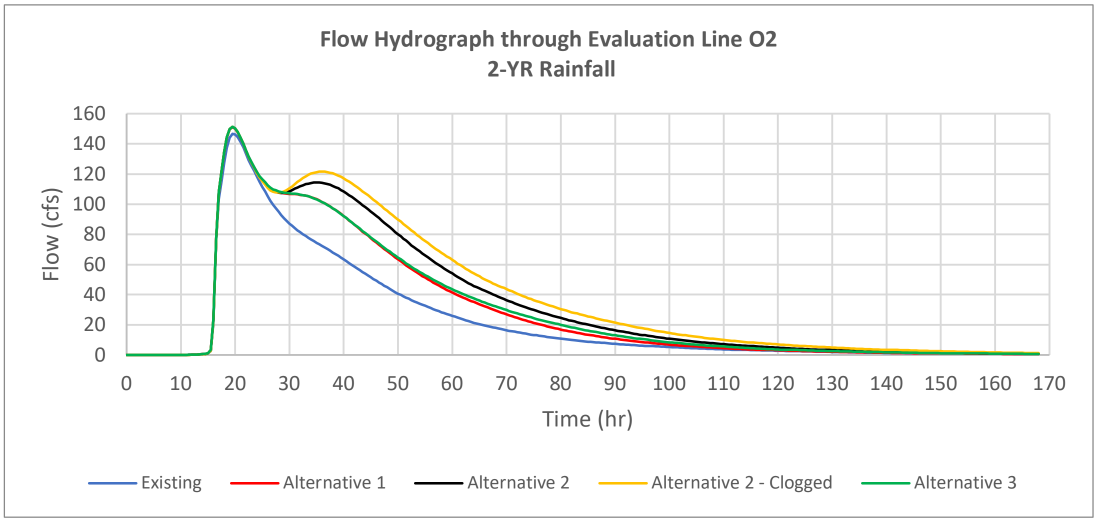


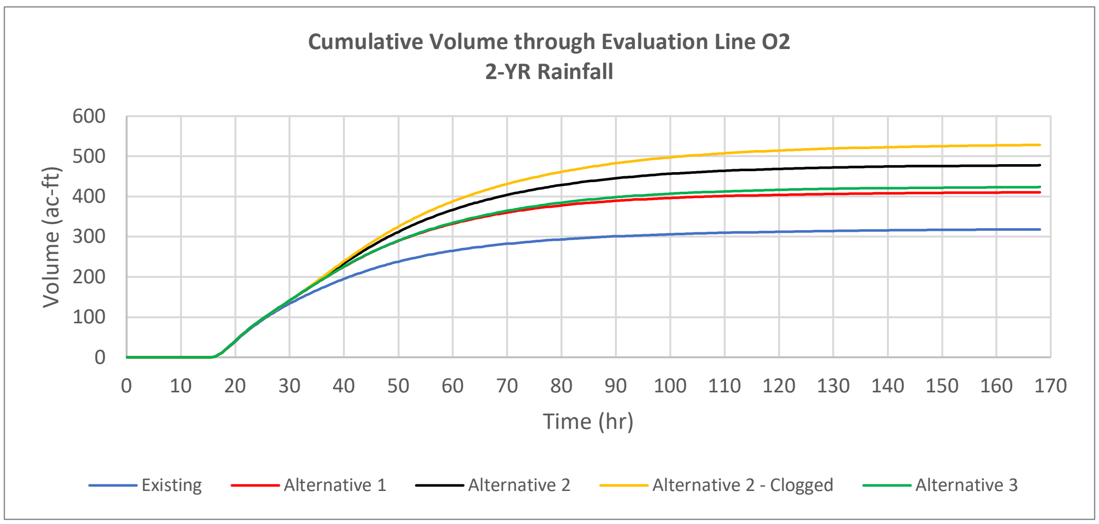



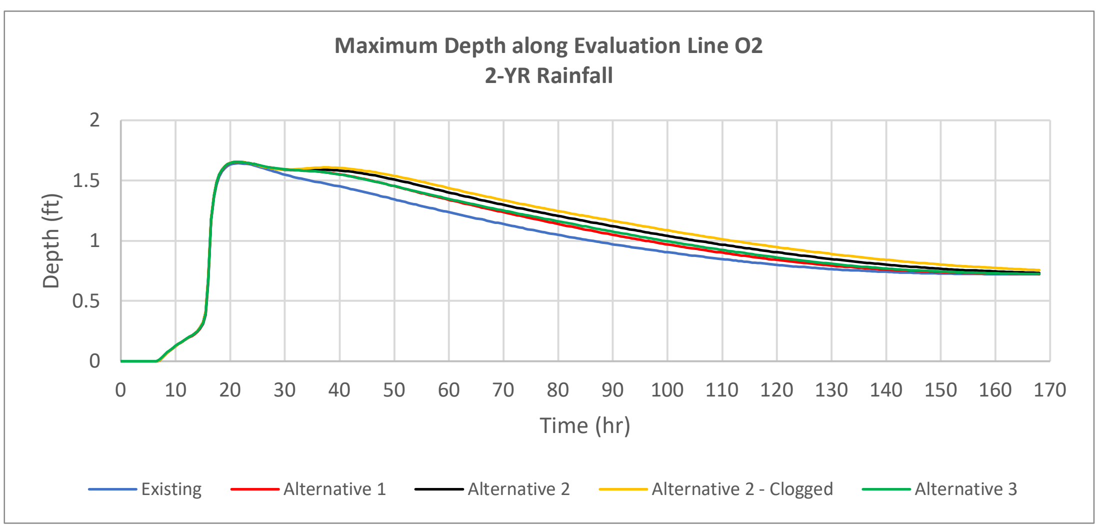




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A24**

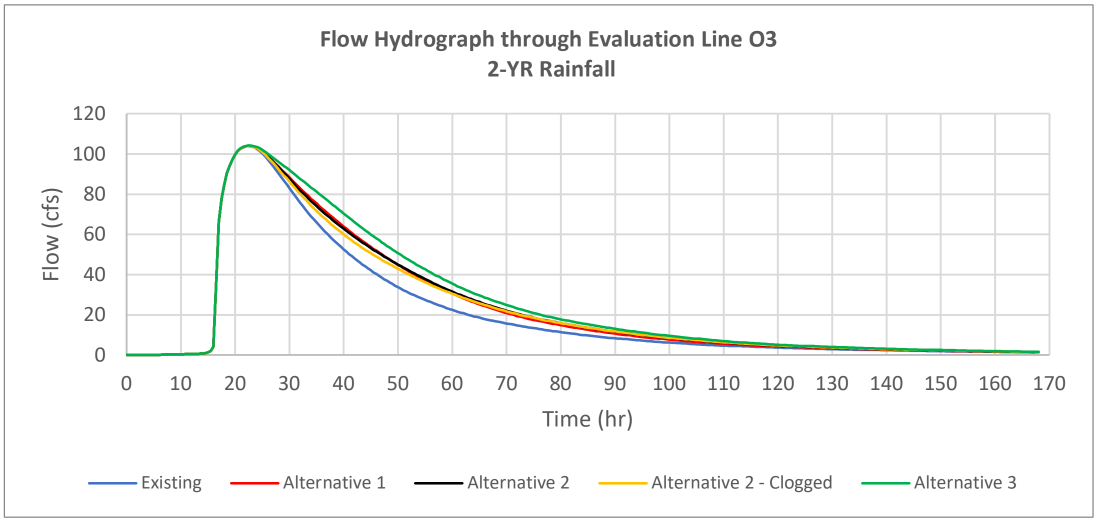


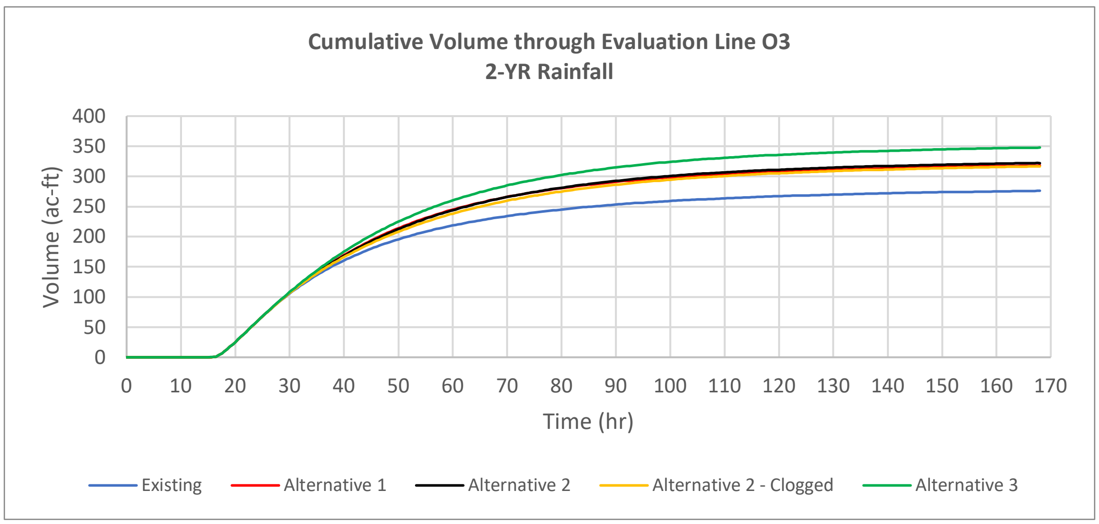



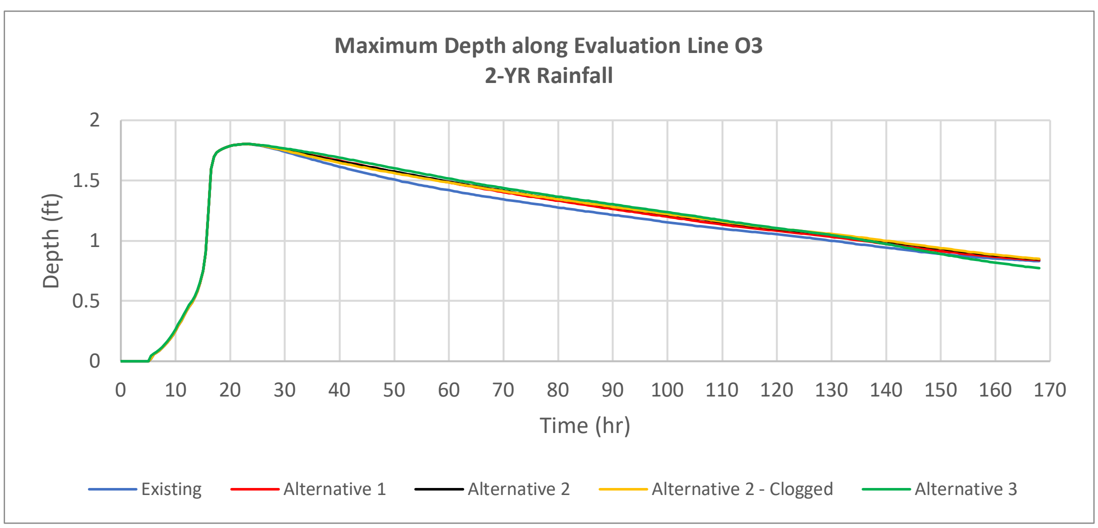




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A25**

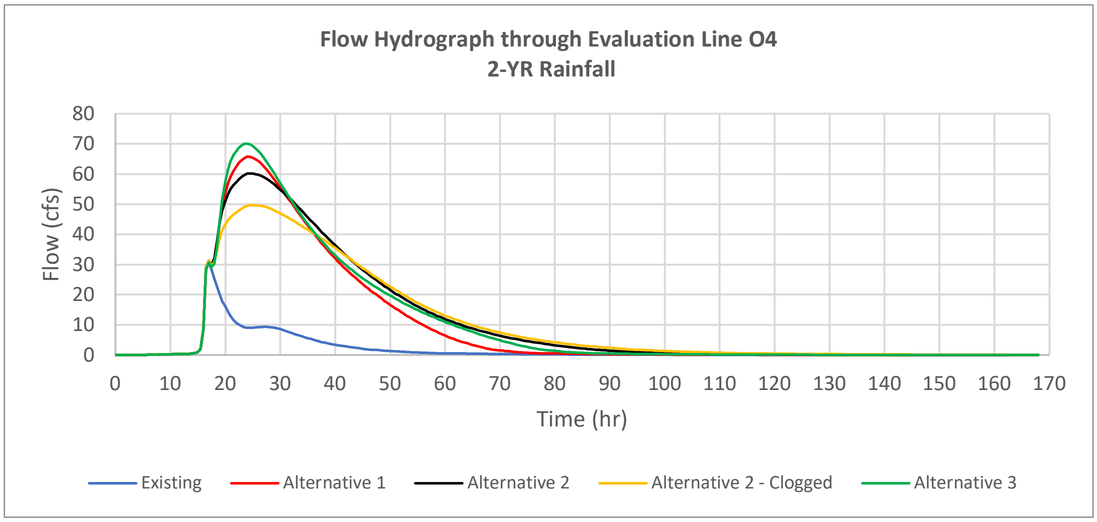


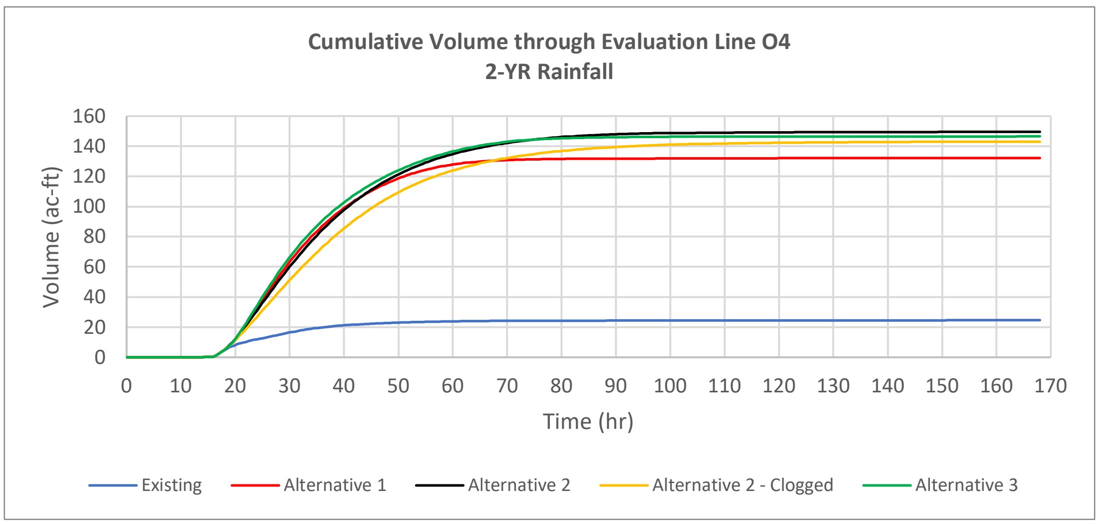



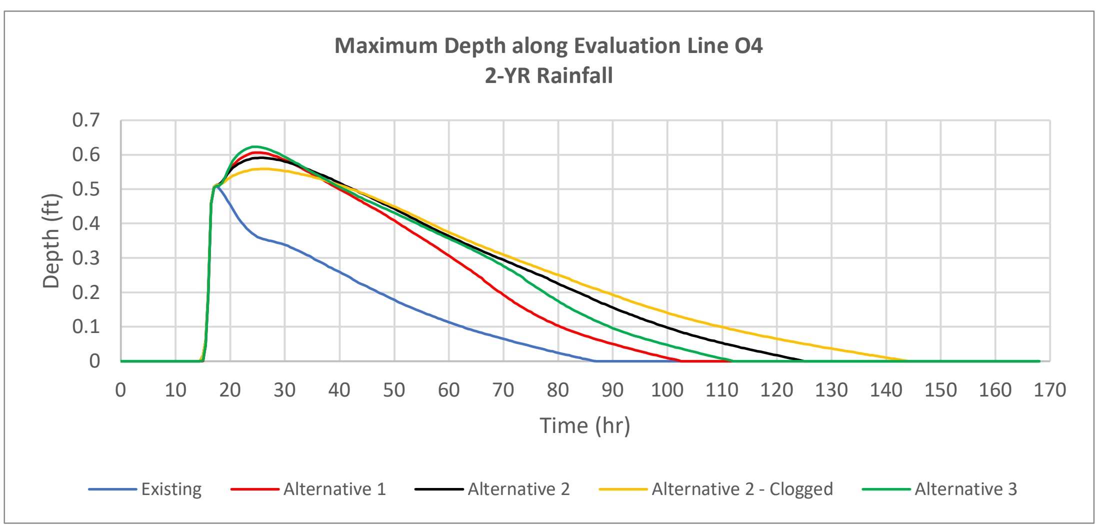




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A26**

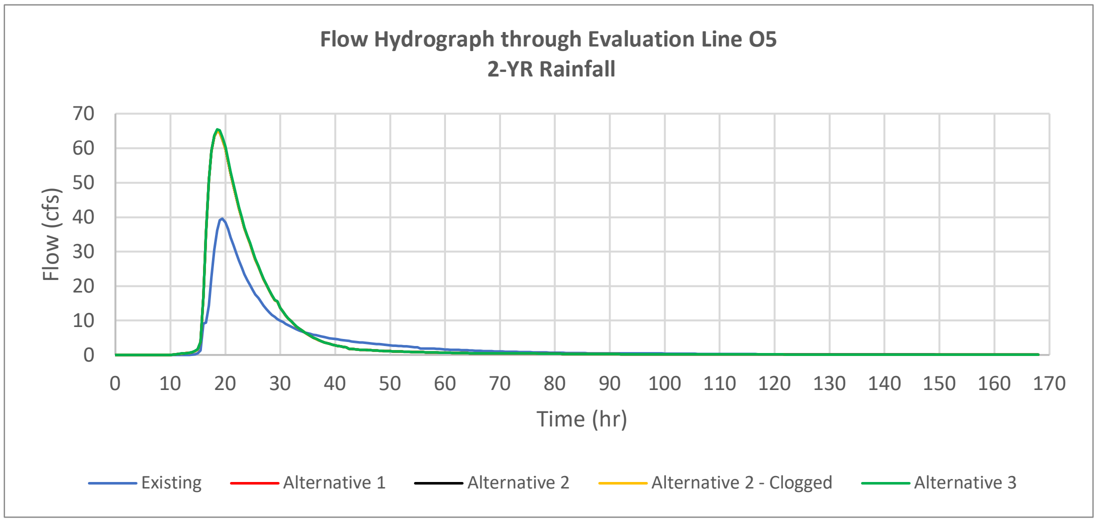


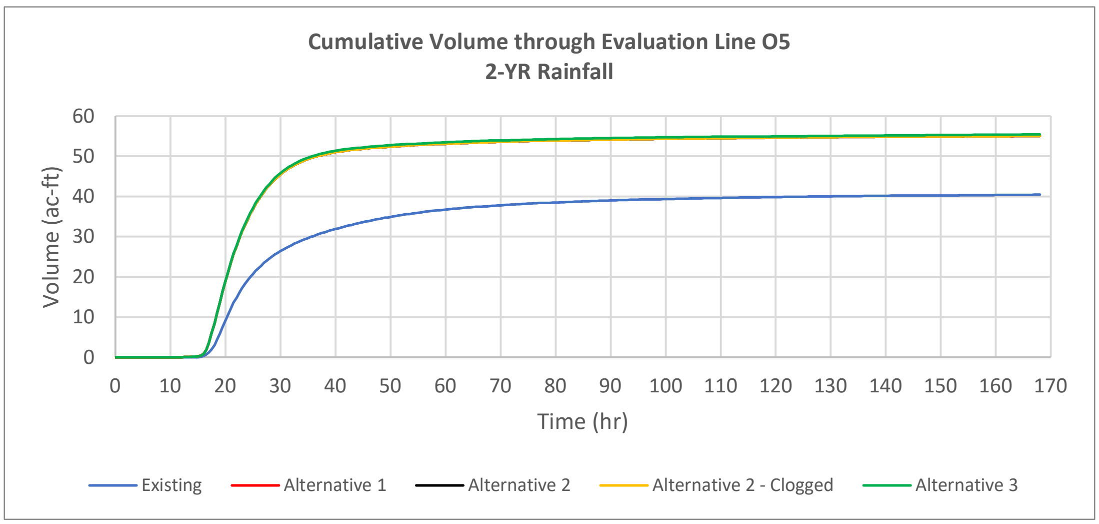



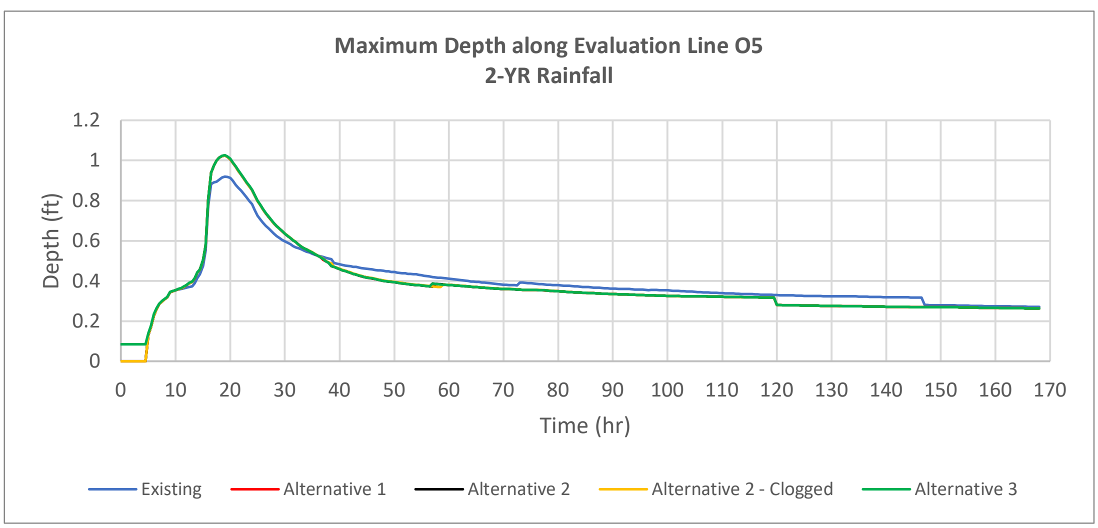




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A27**

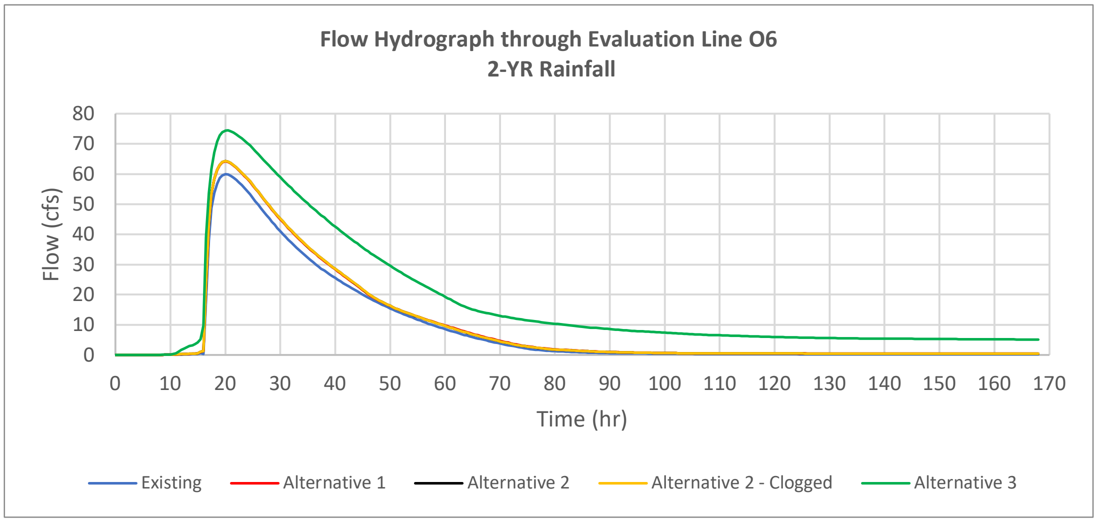


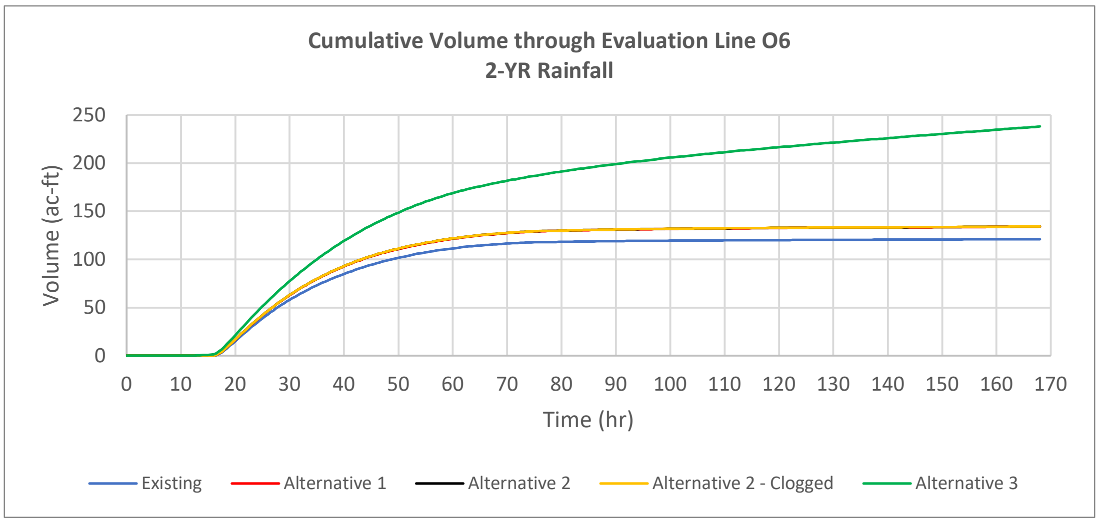



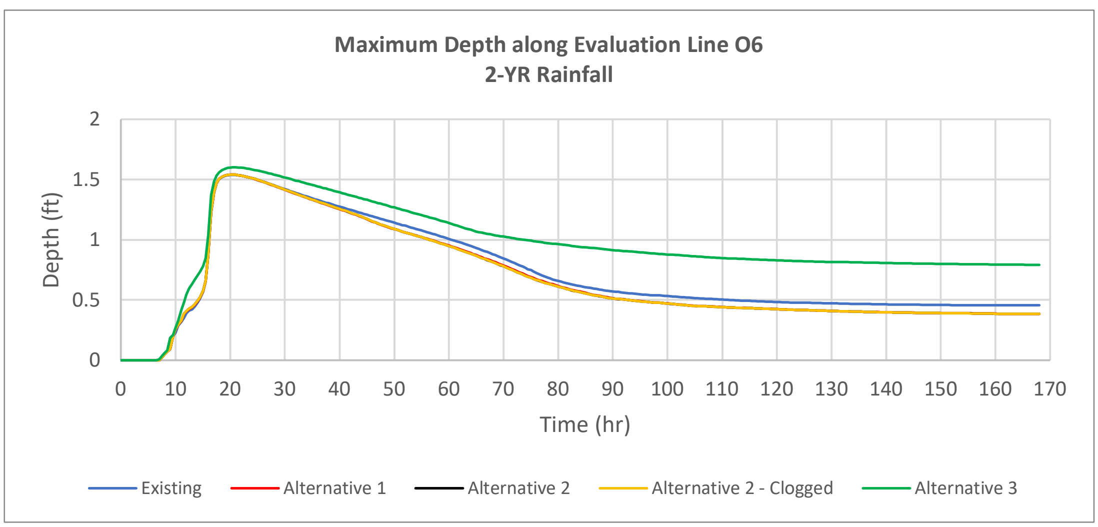




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A28**

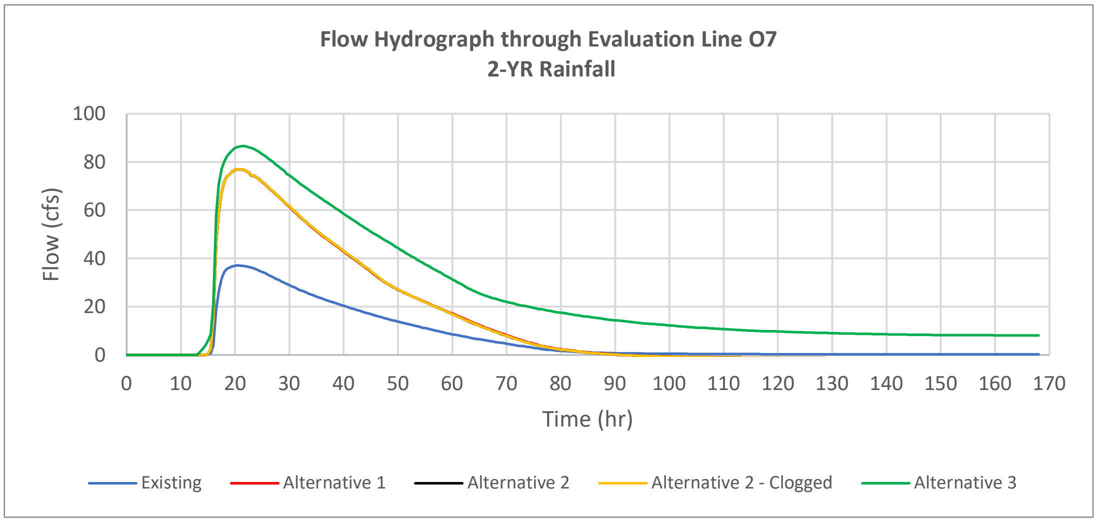


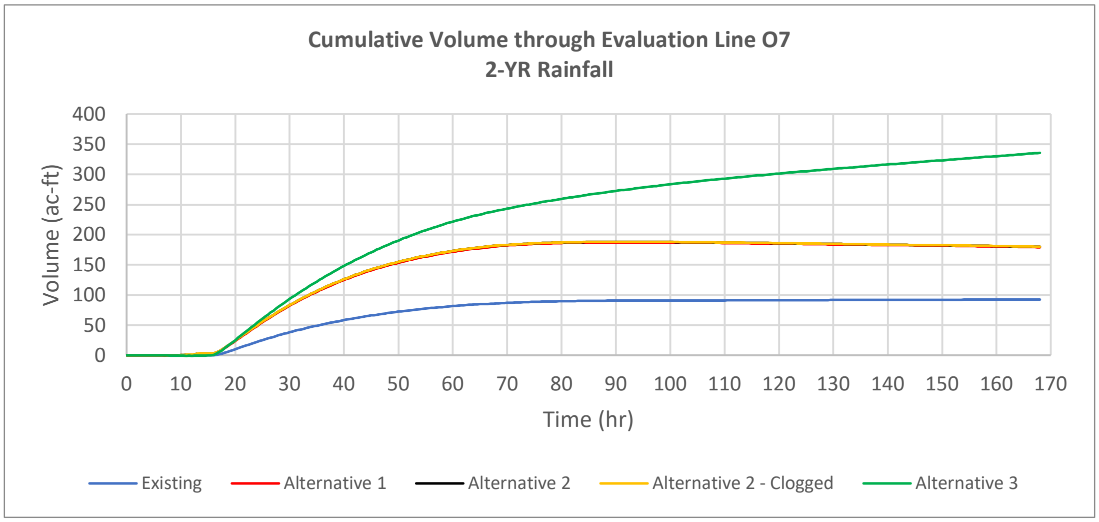



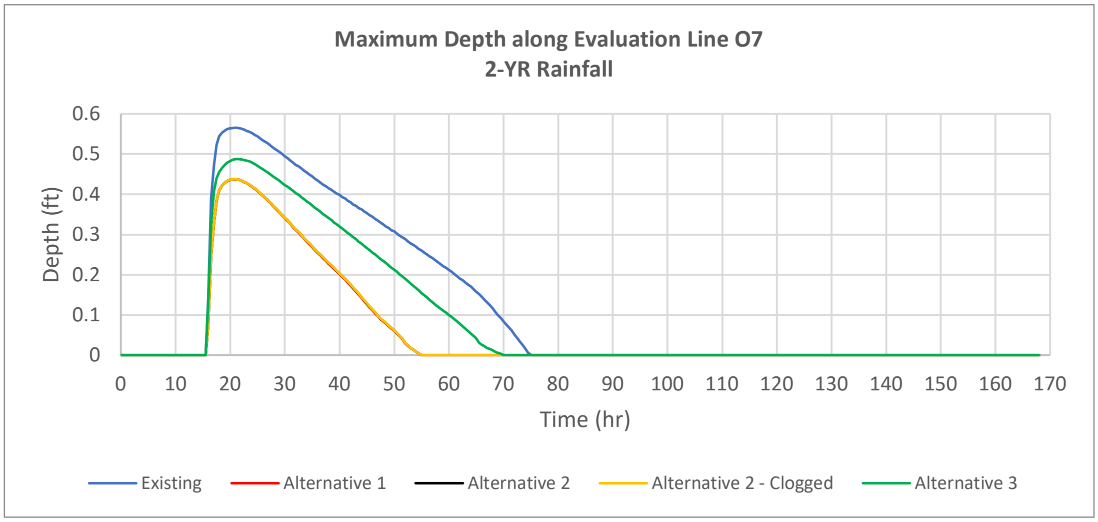




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

## Figure A29

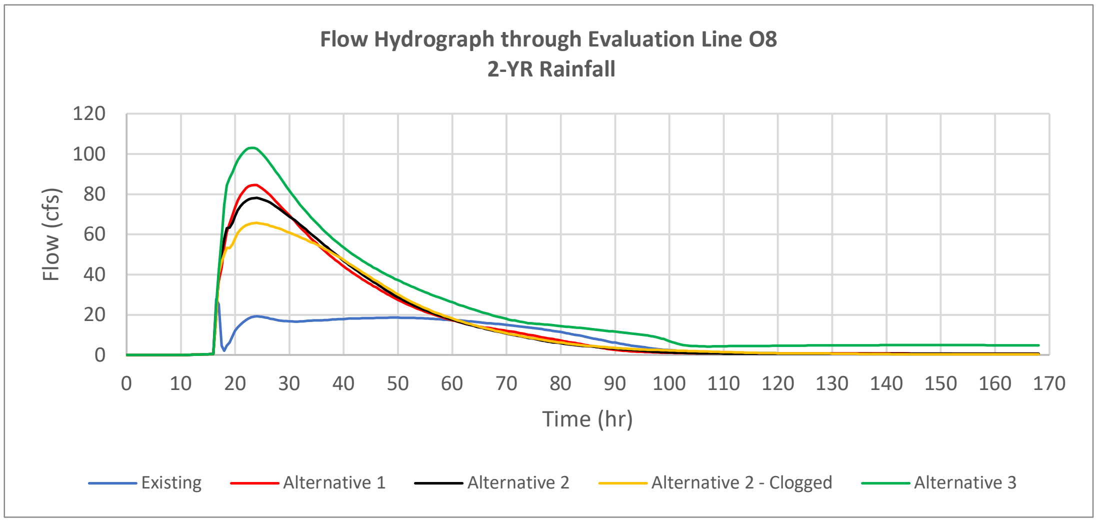


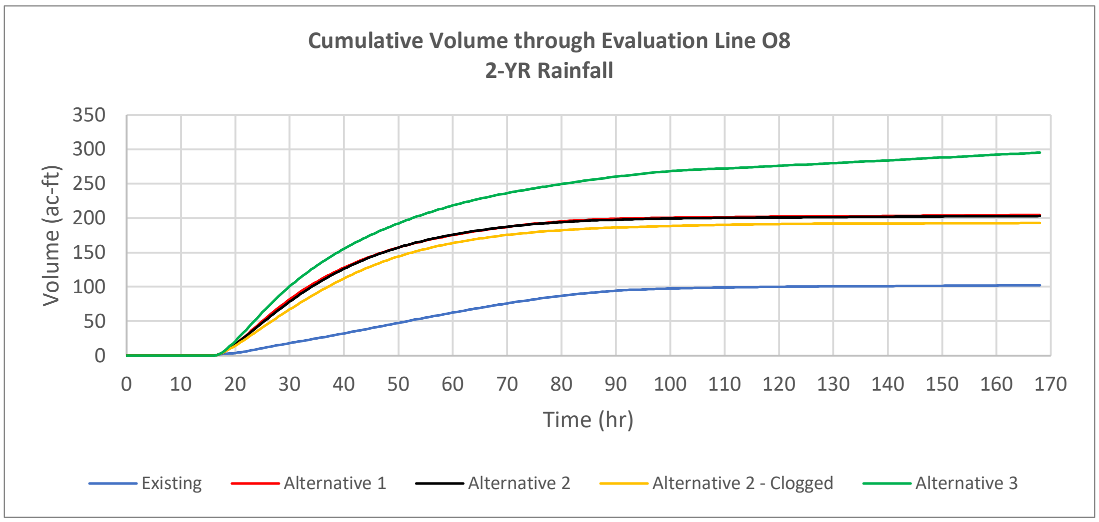



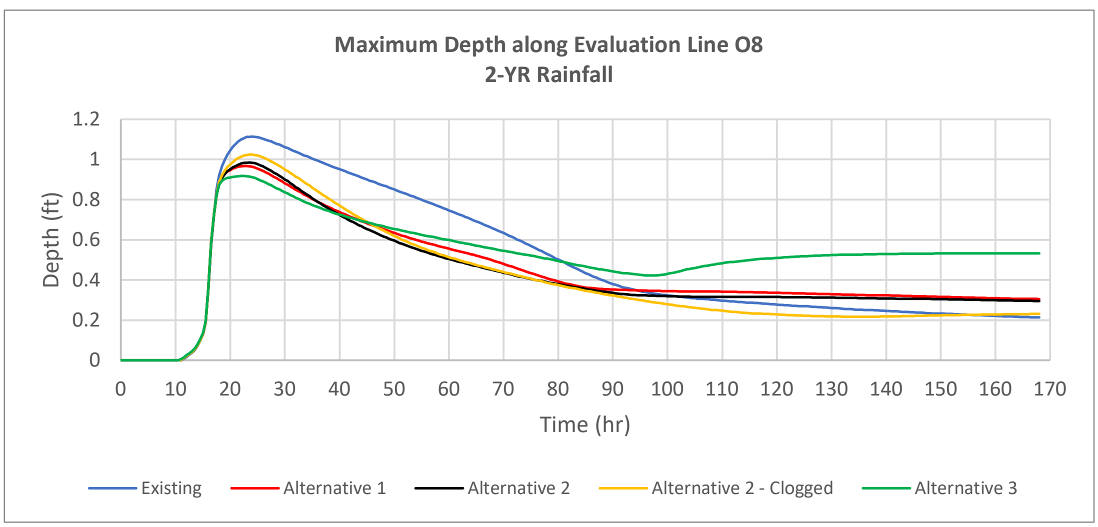




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A30**

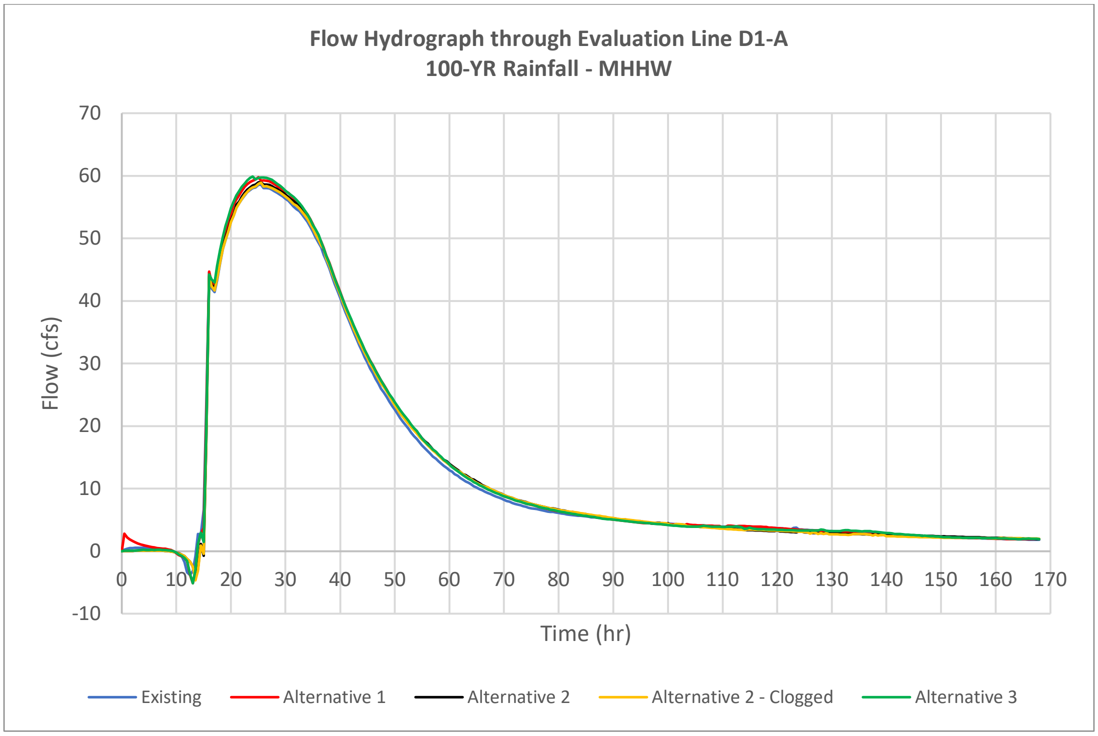


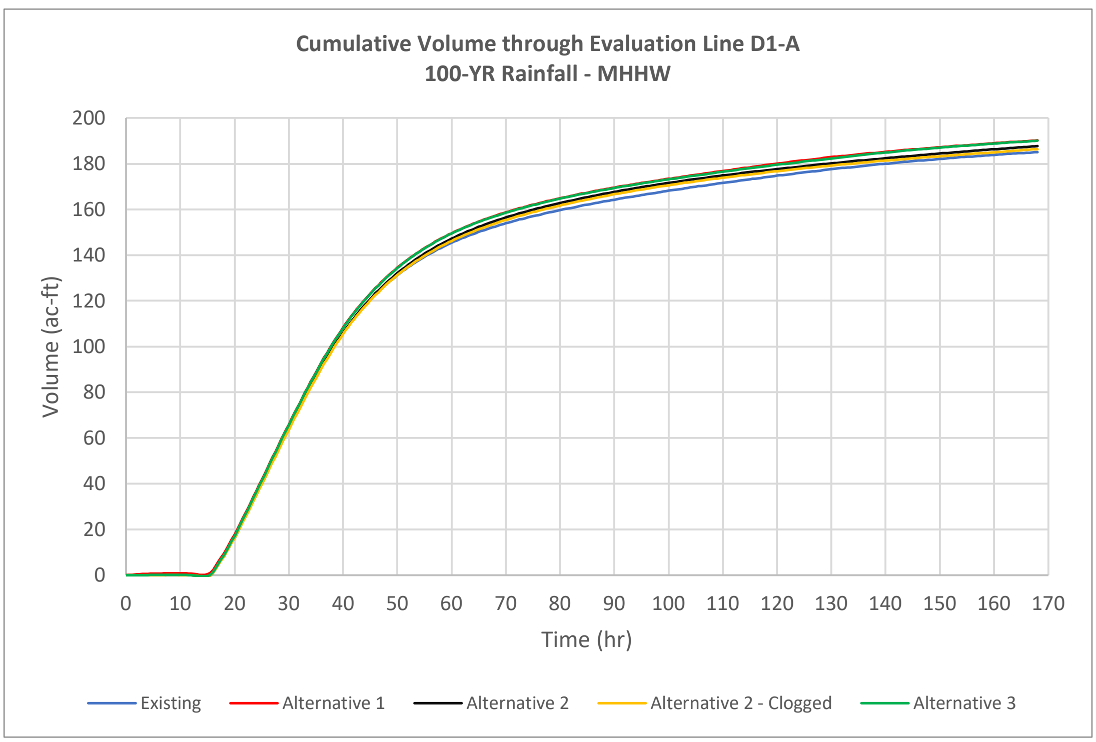




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

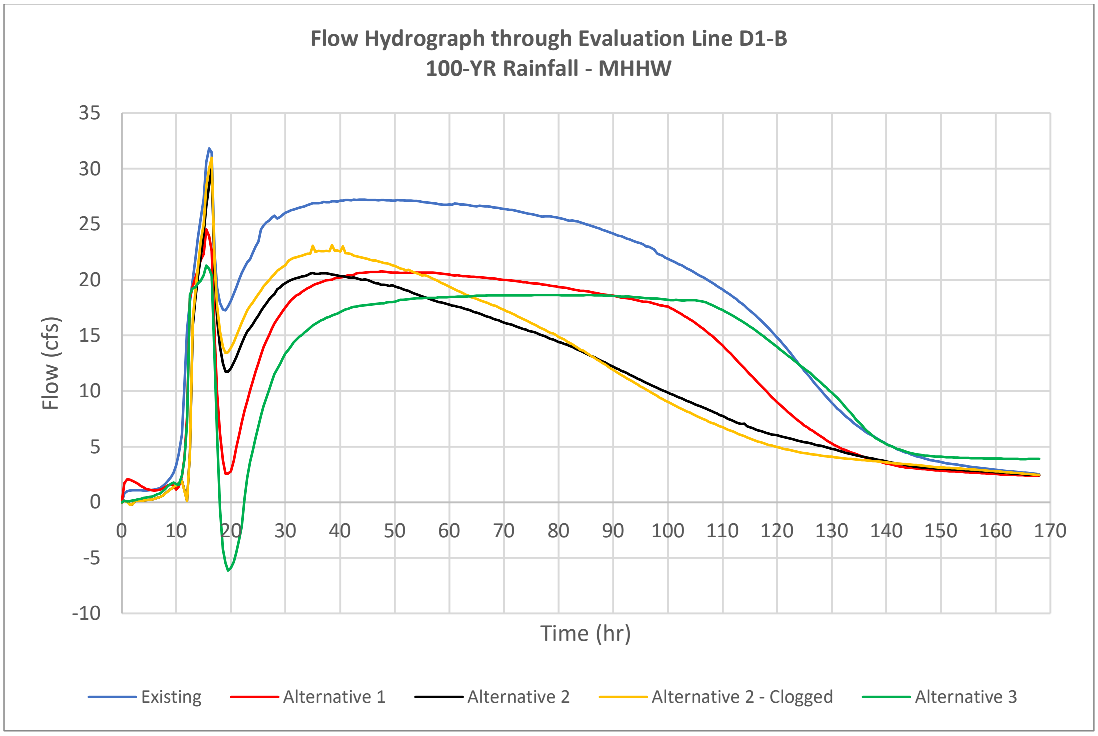
**Figure A31**

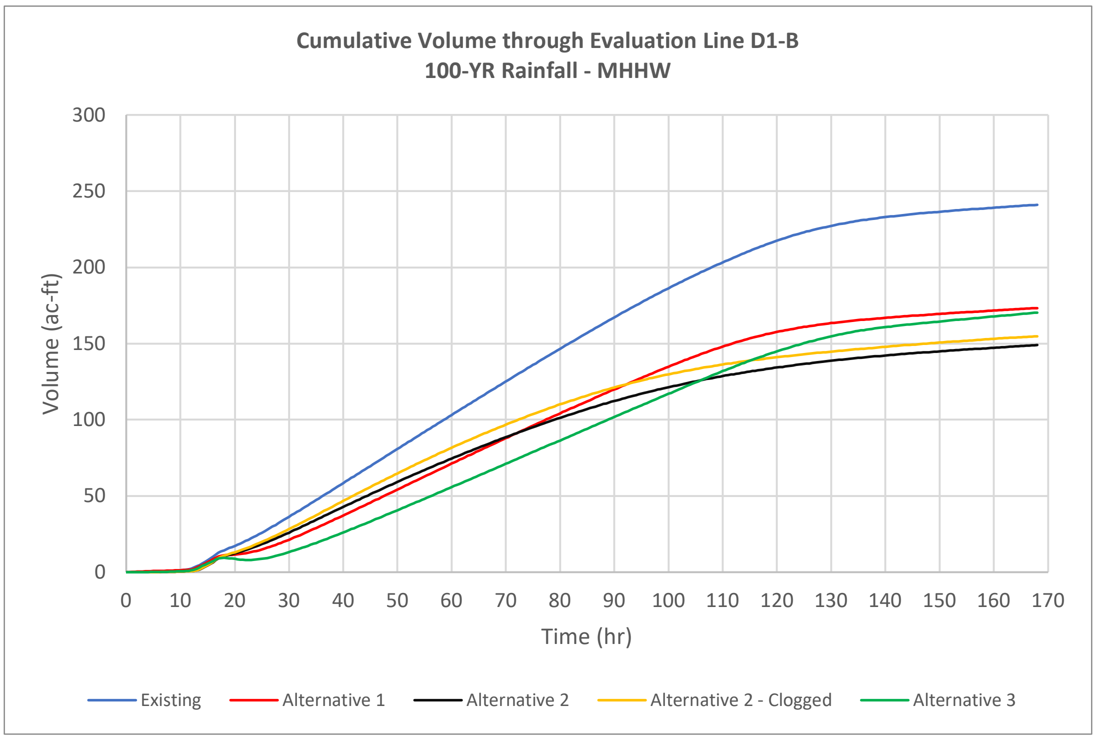



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

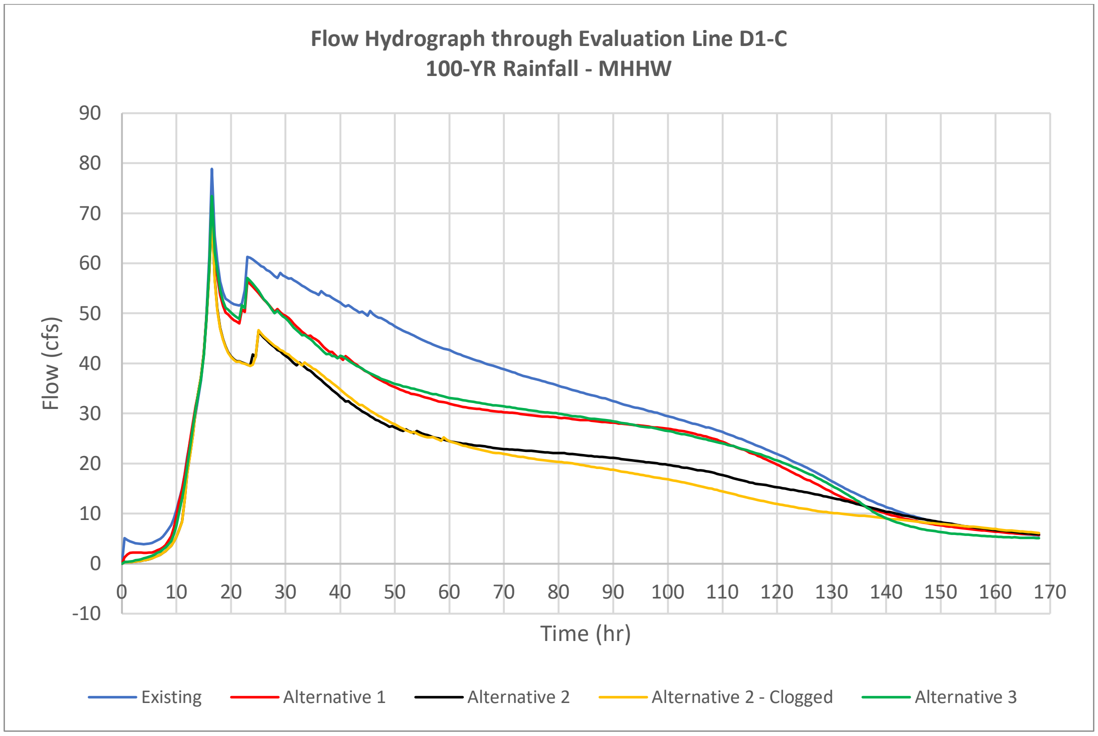
**Figure A32**

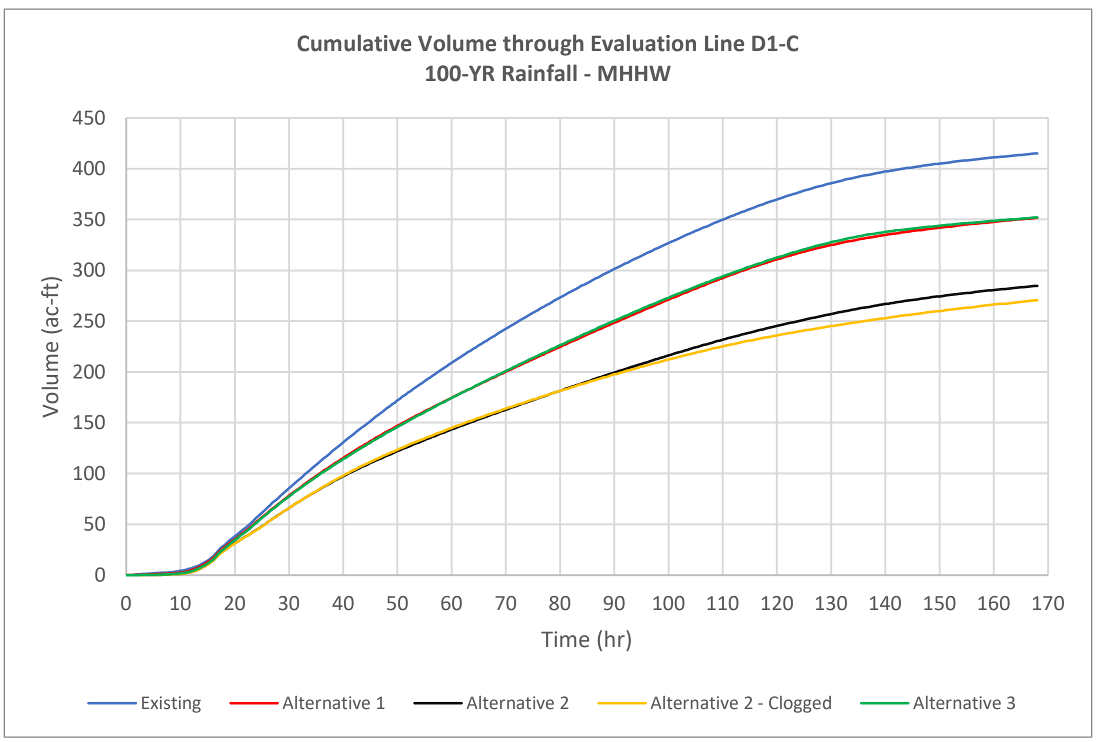



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

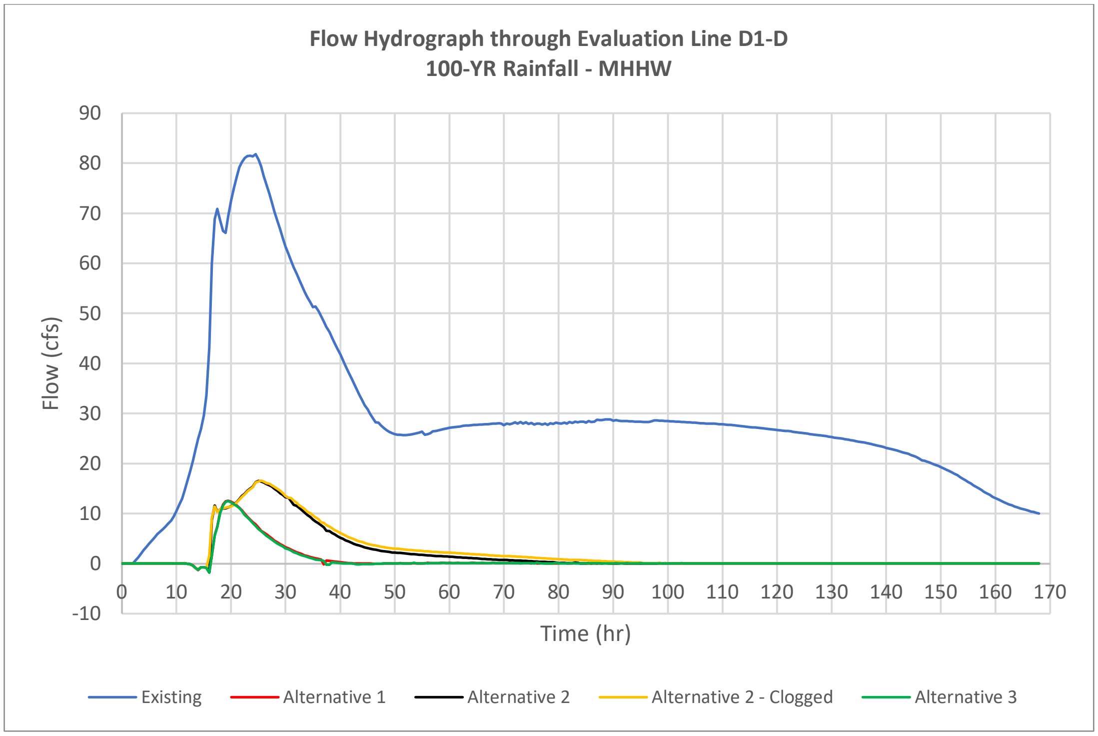
**Figure A33**

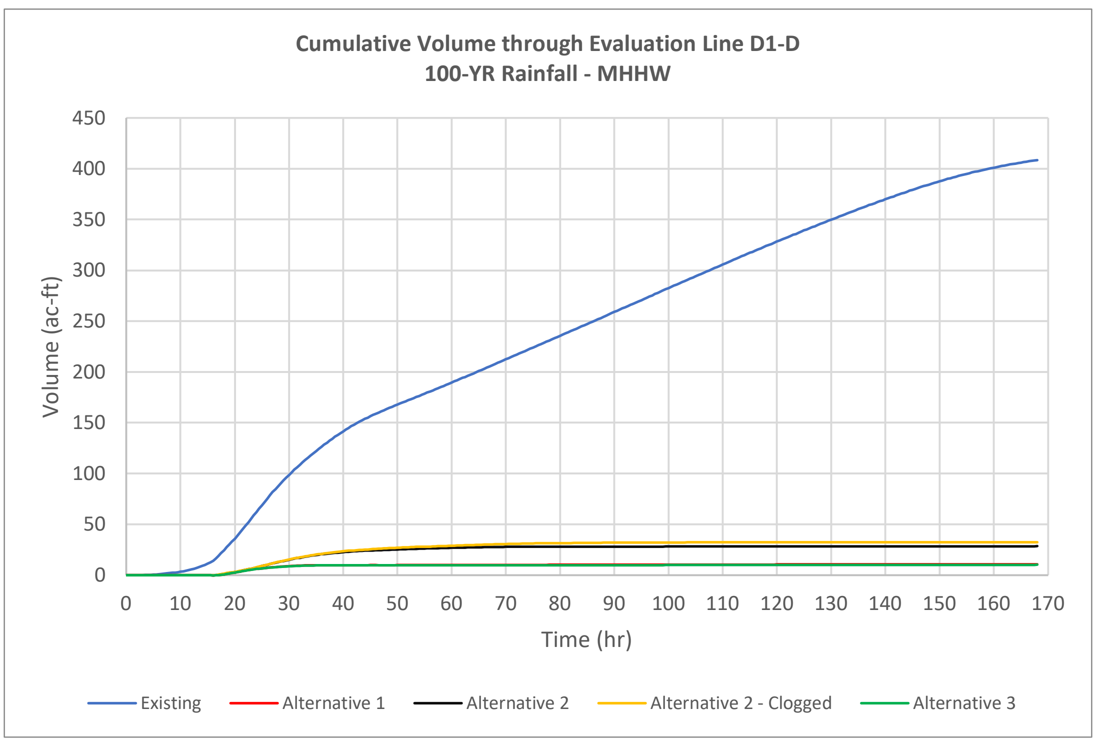



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

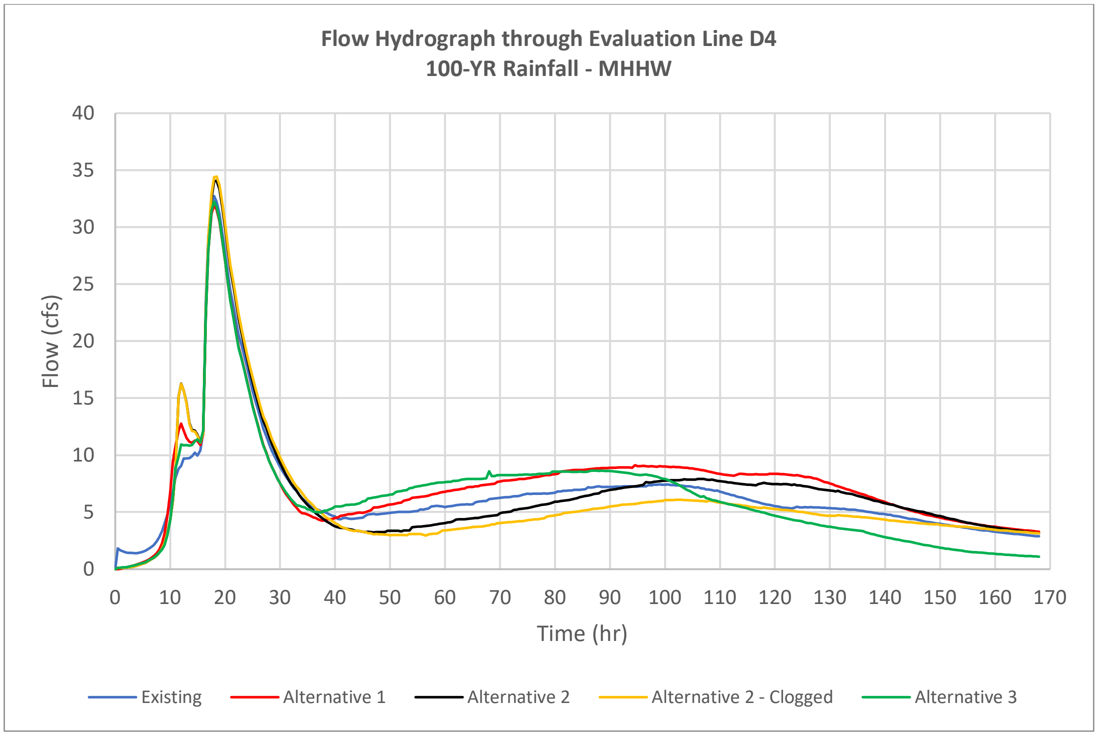
**Figure A34**

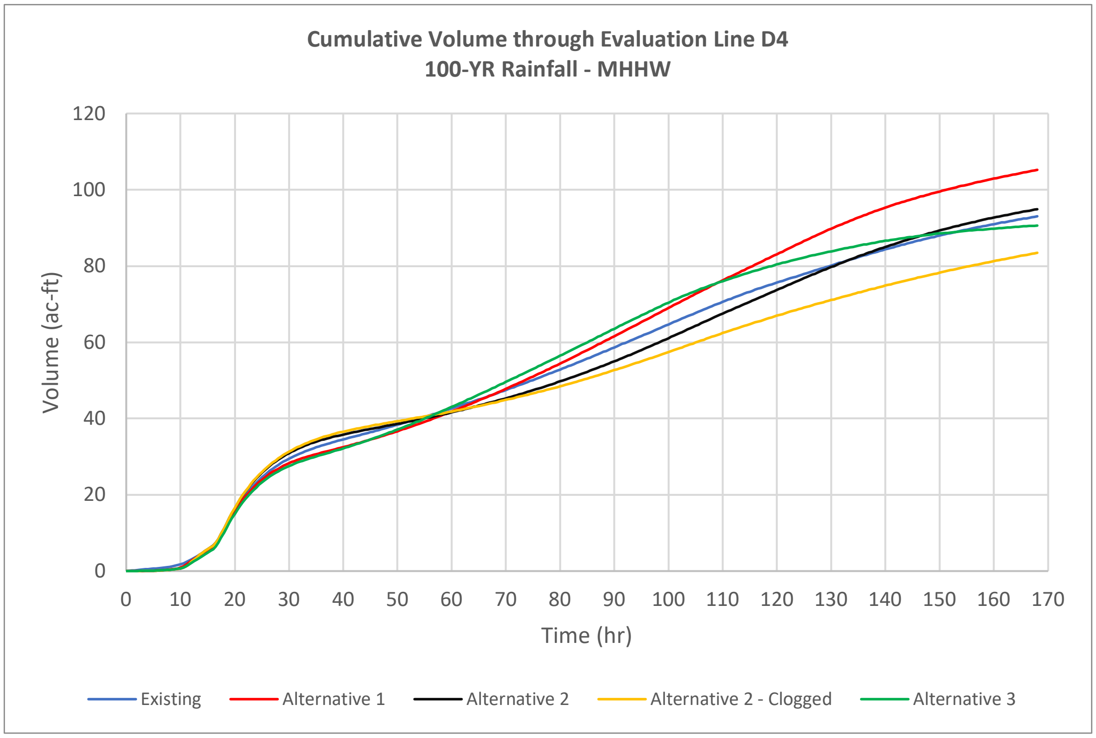



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

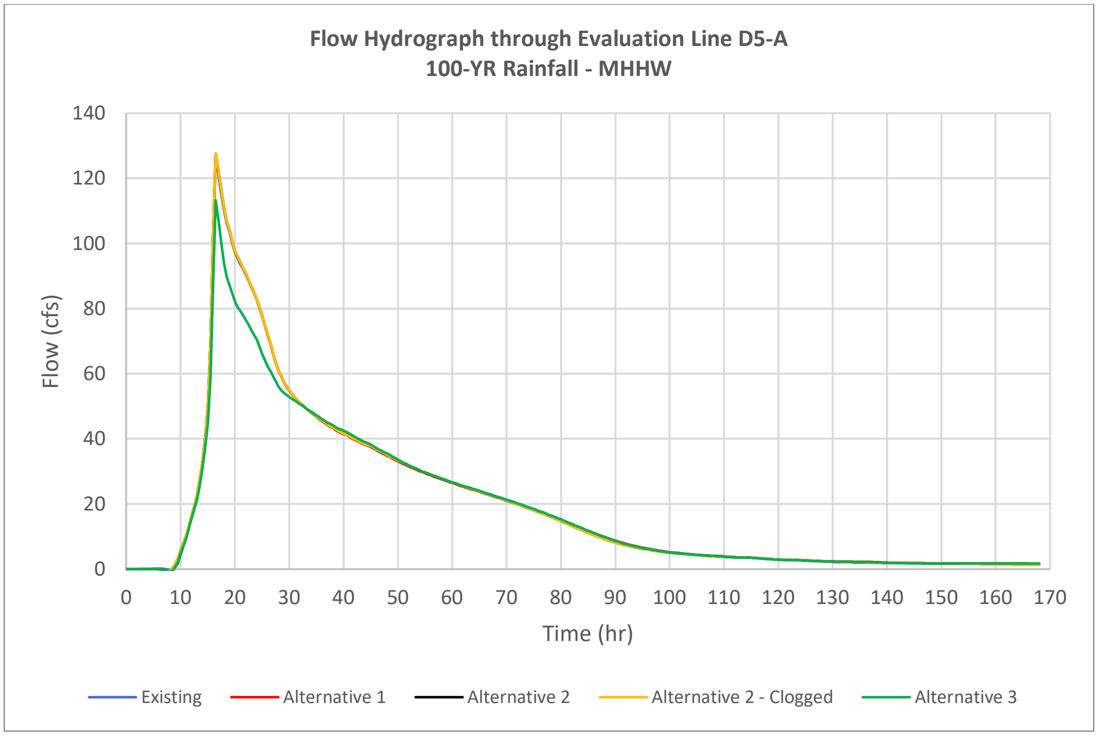
**Figure A35**

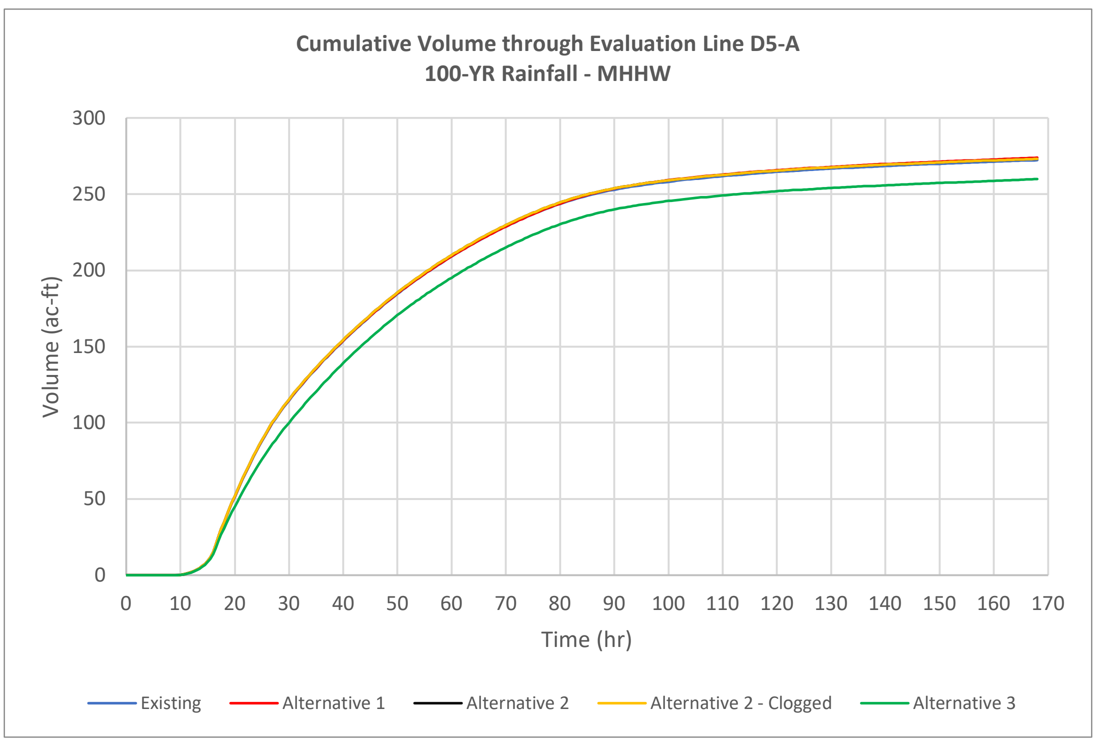



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

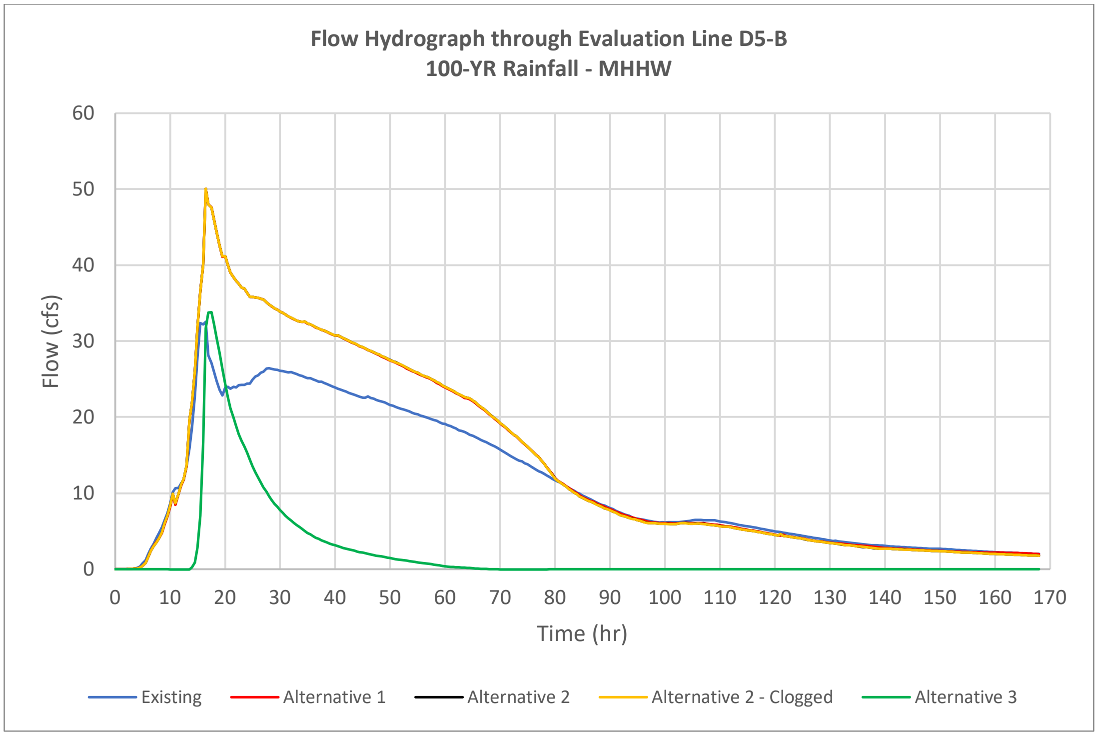
**Figure A36**

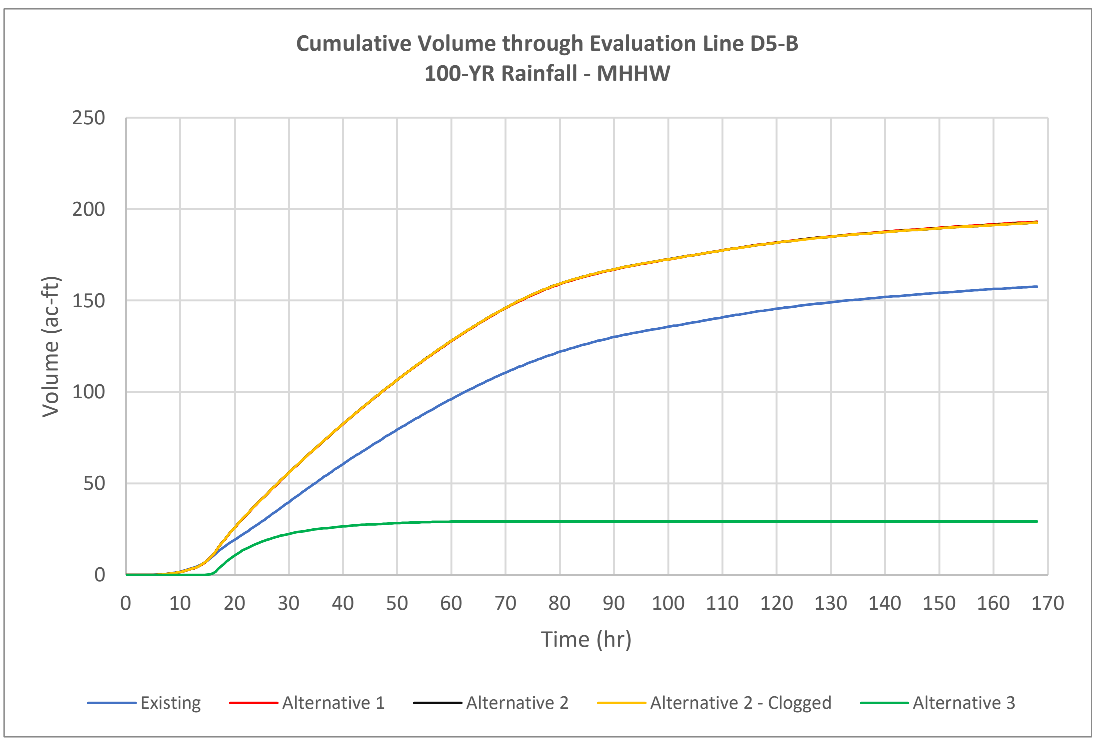



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

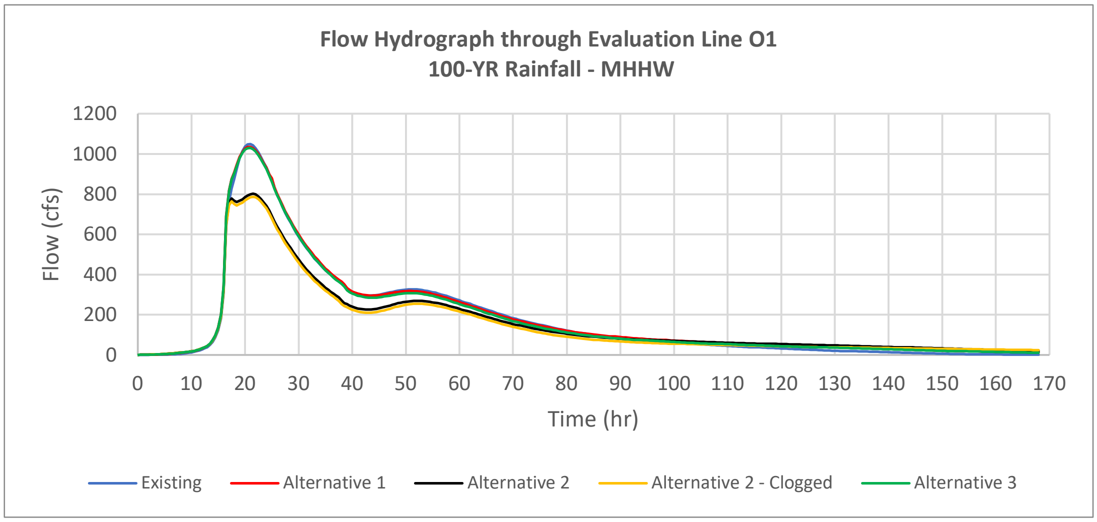
**Figure A37**

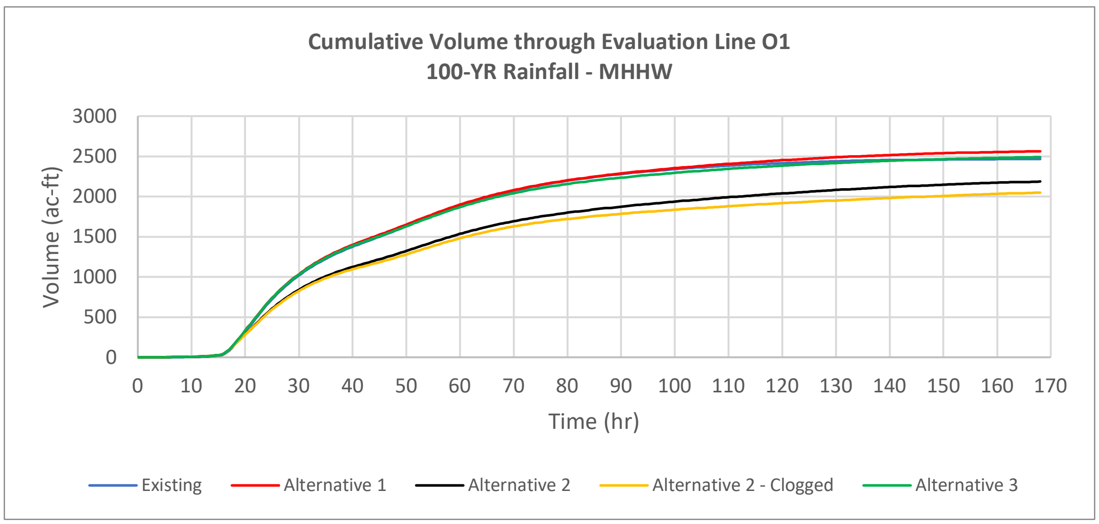


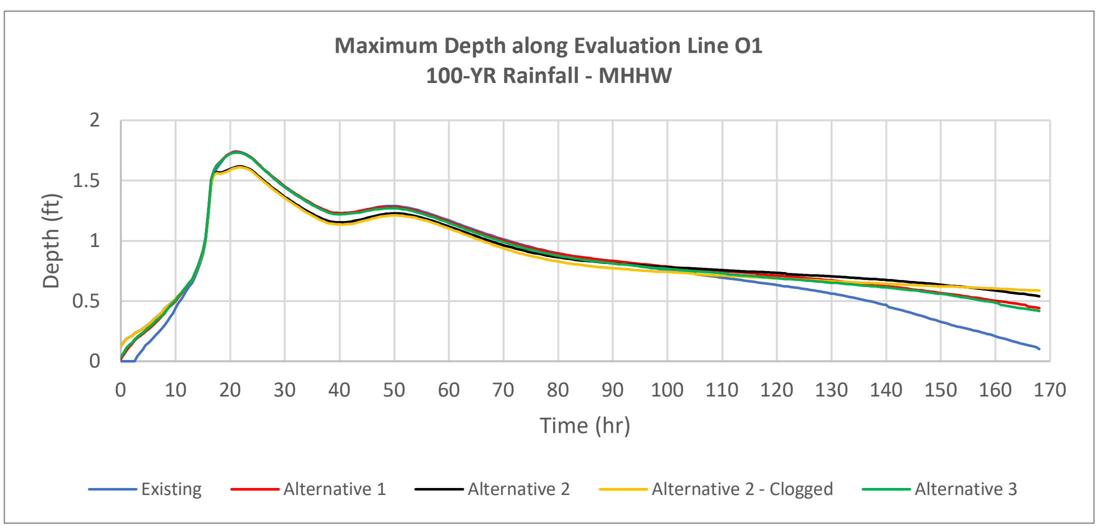




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A38**

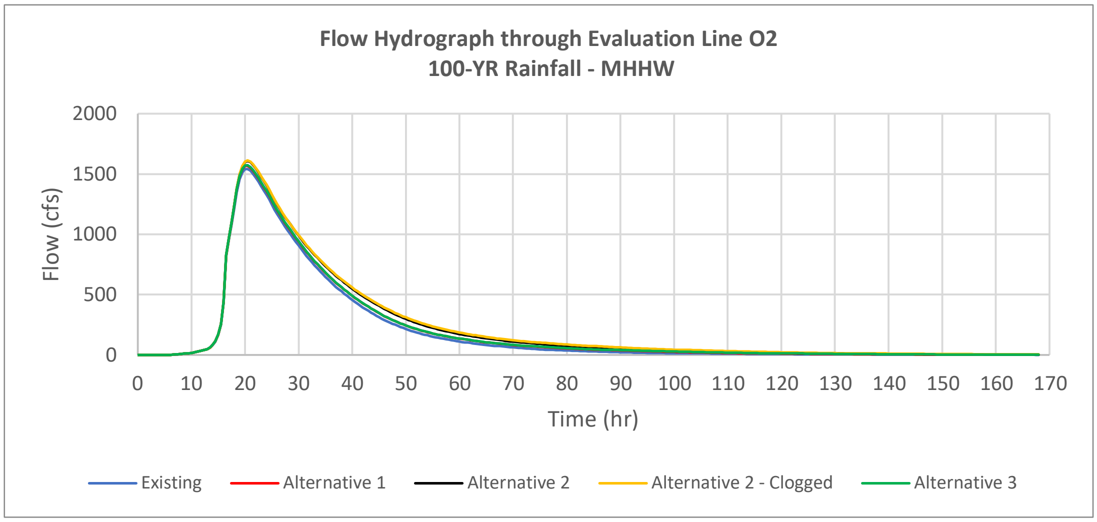


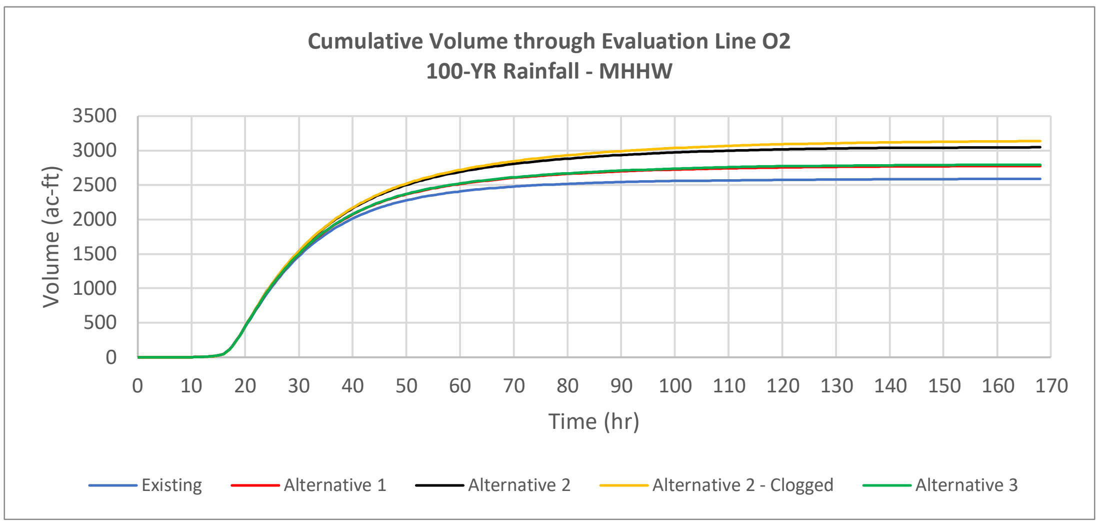



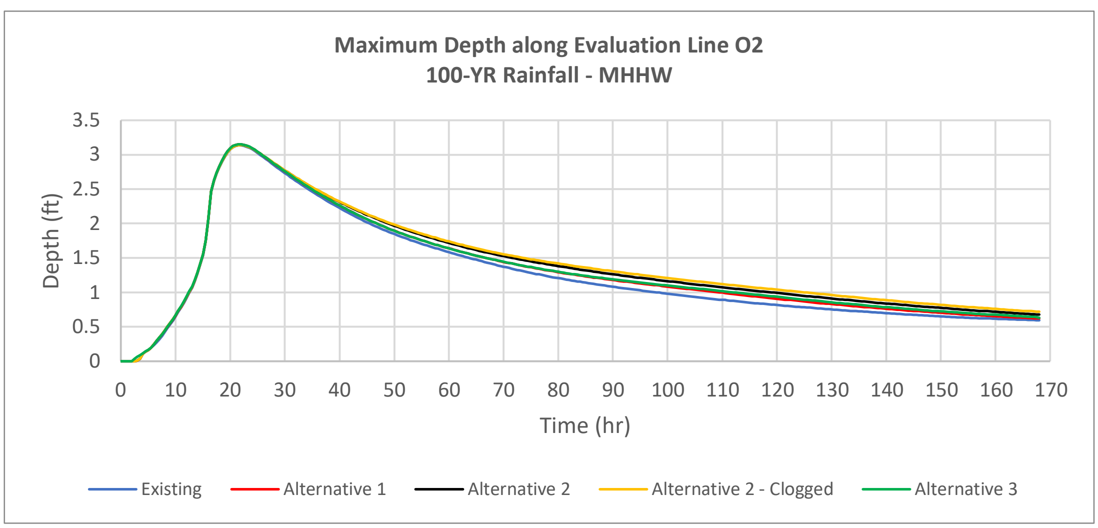




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A39**

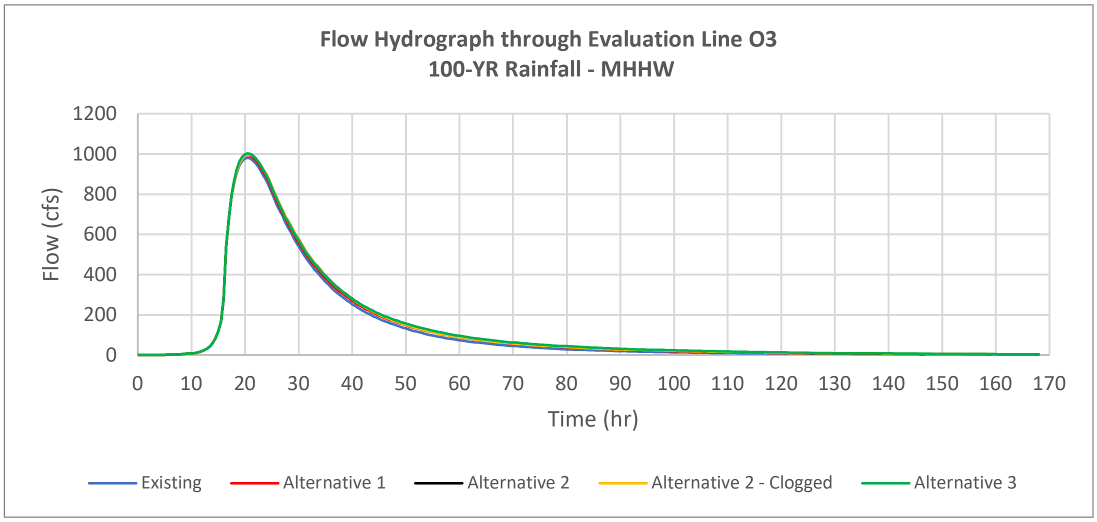


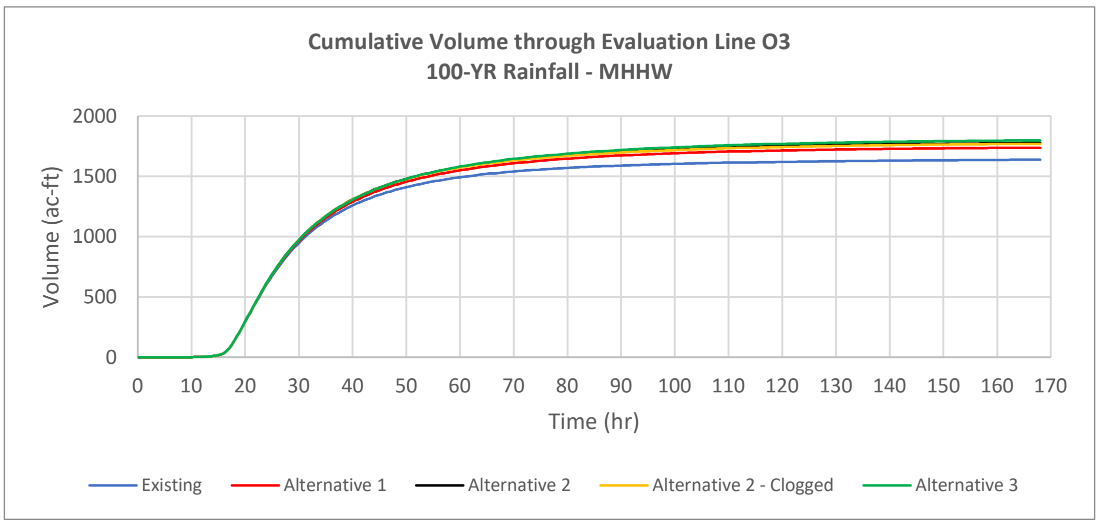



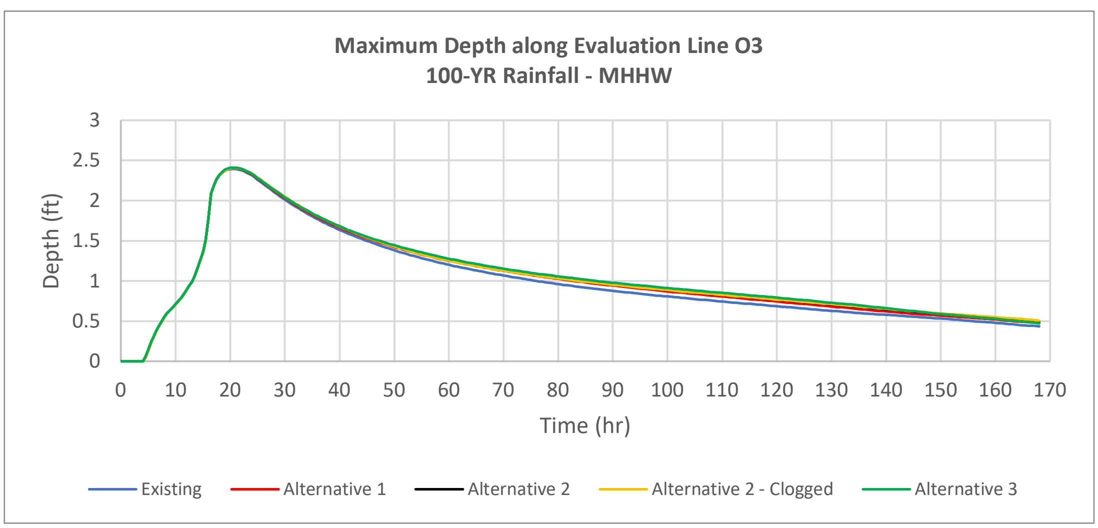




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A40**

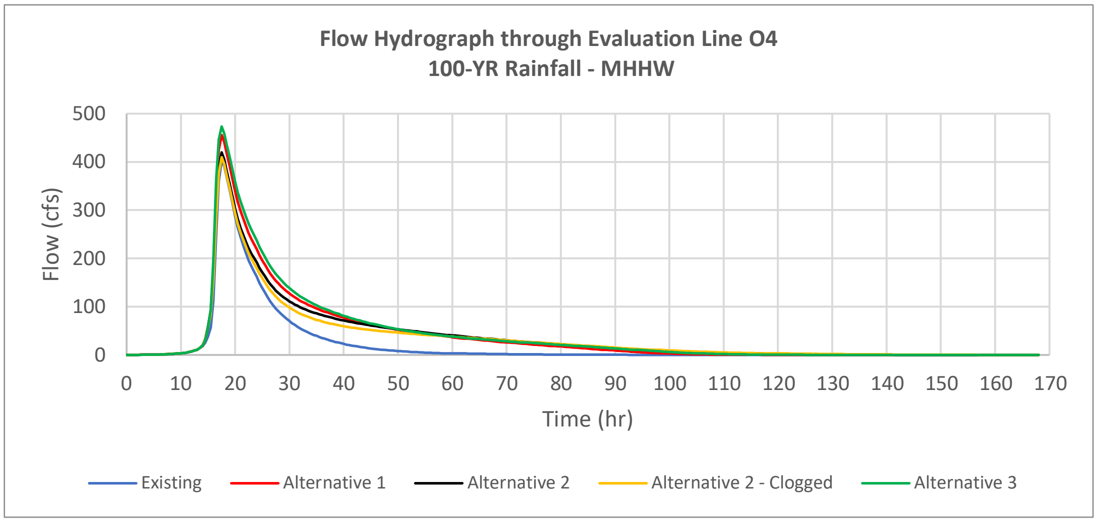


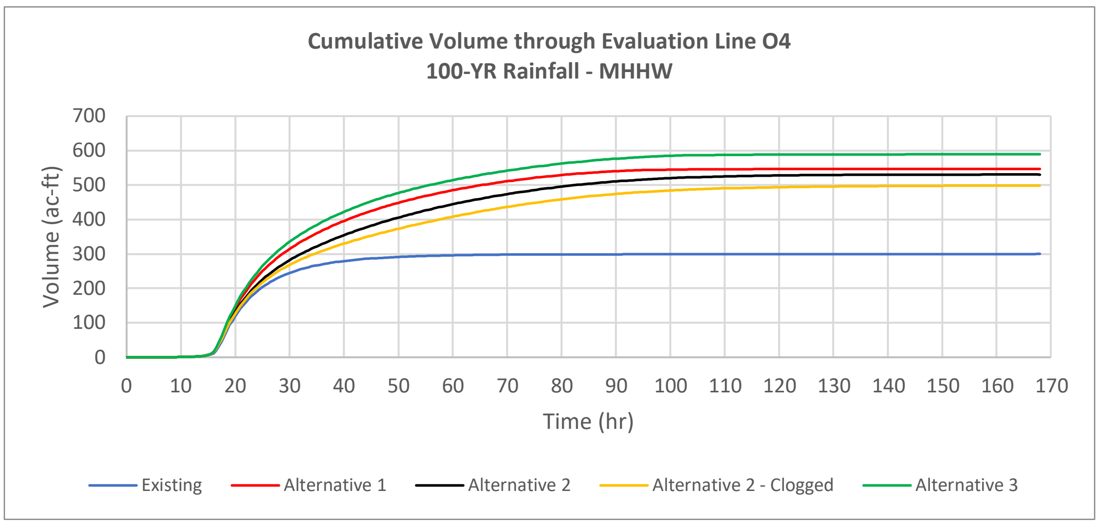



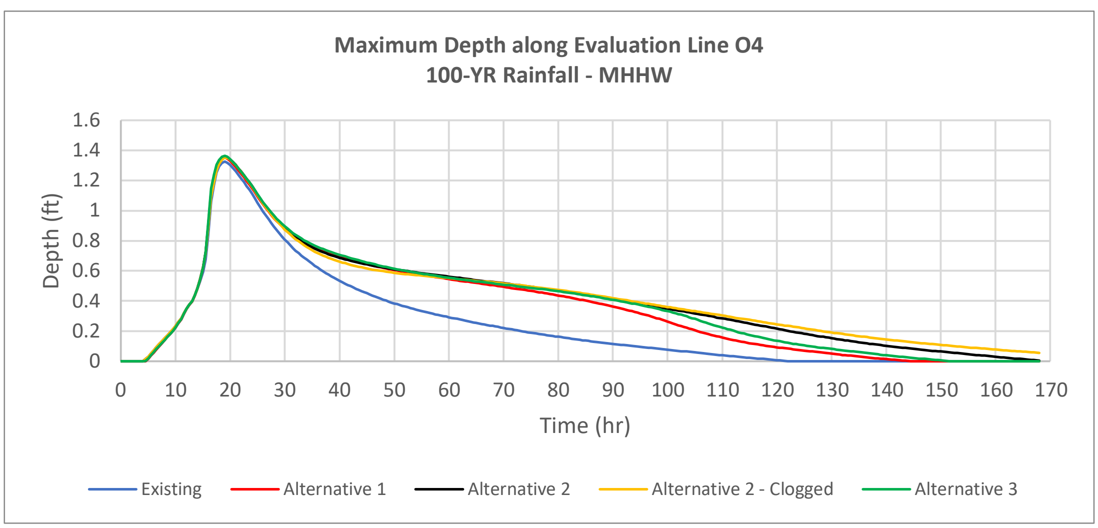




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A41**

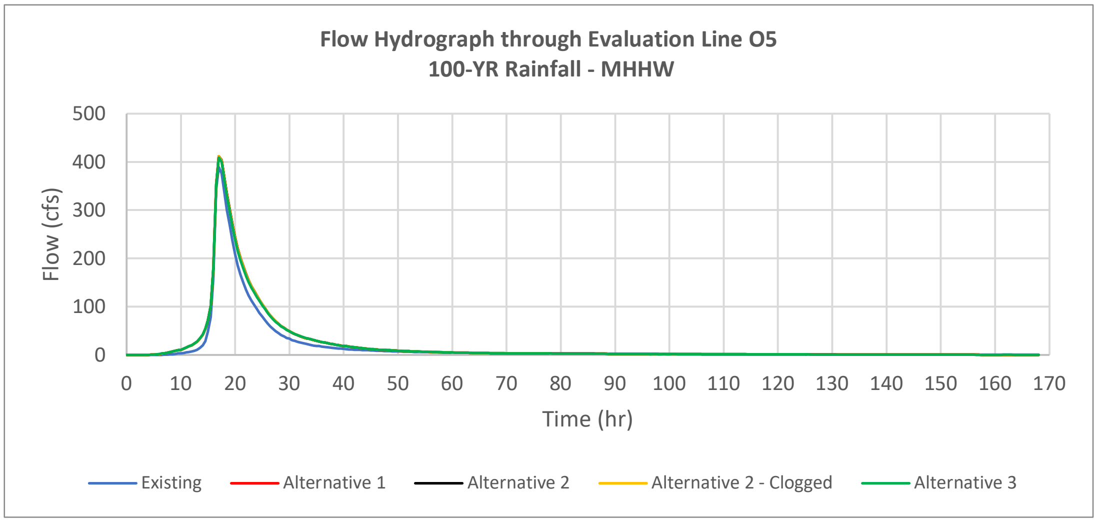


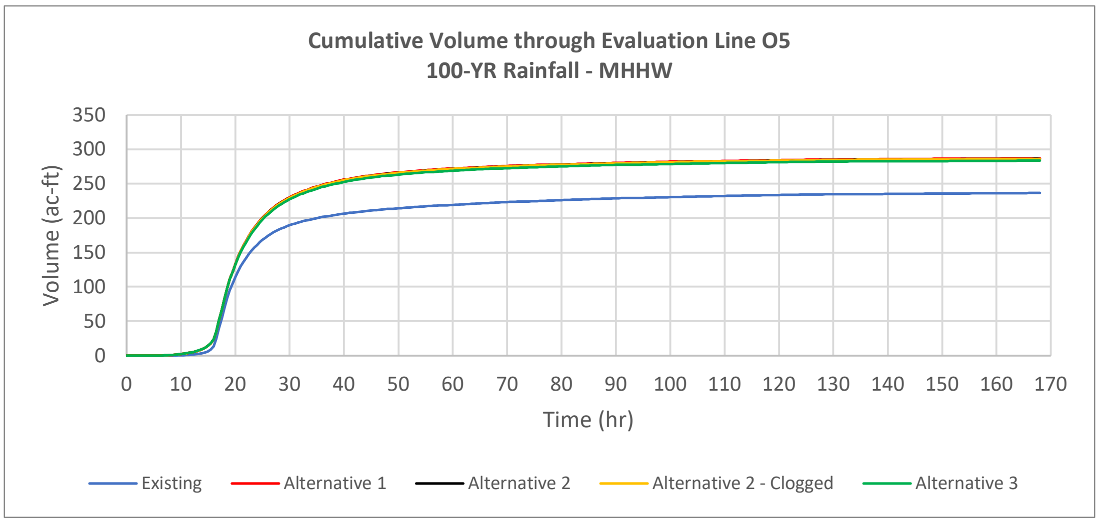



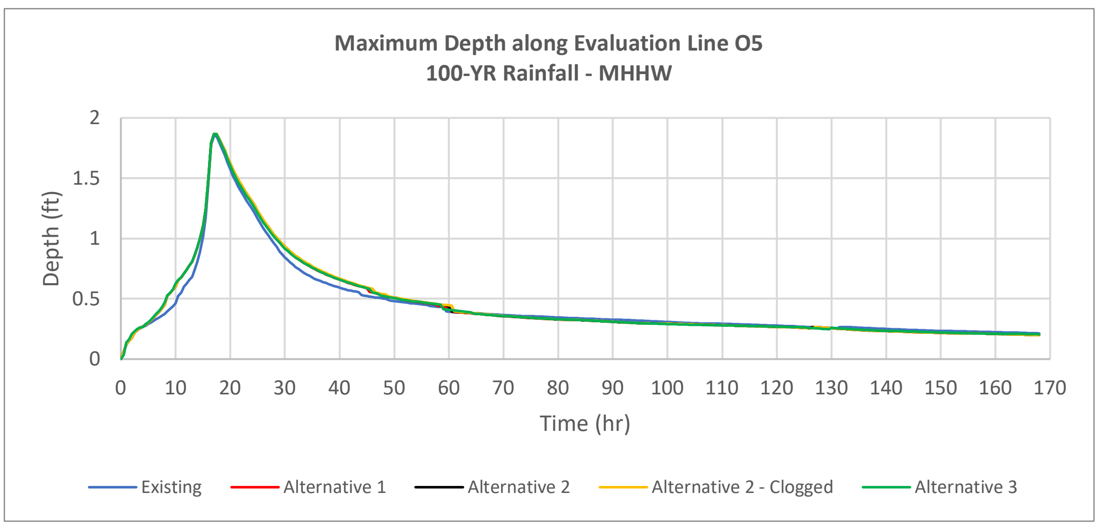




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

## Figure A42

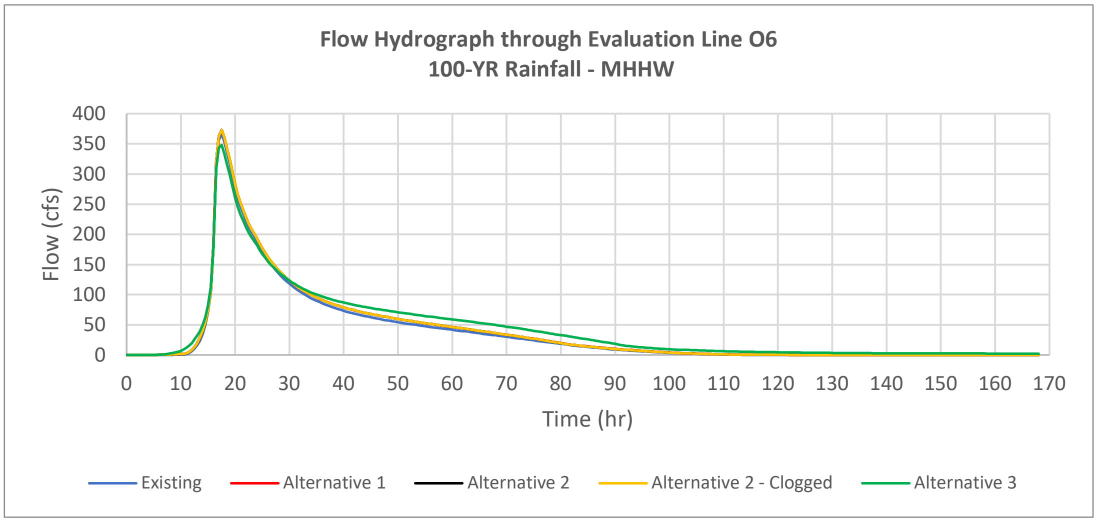


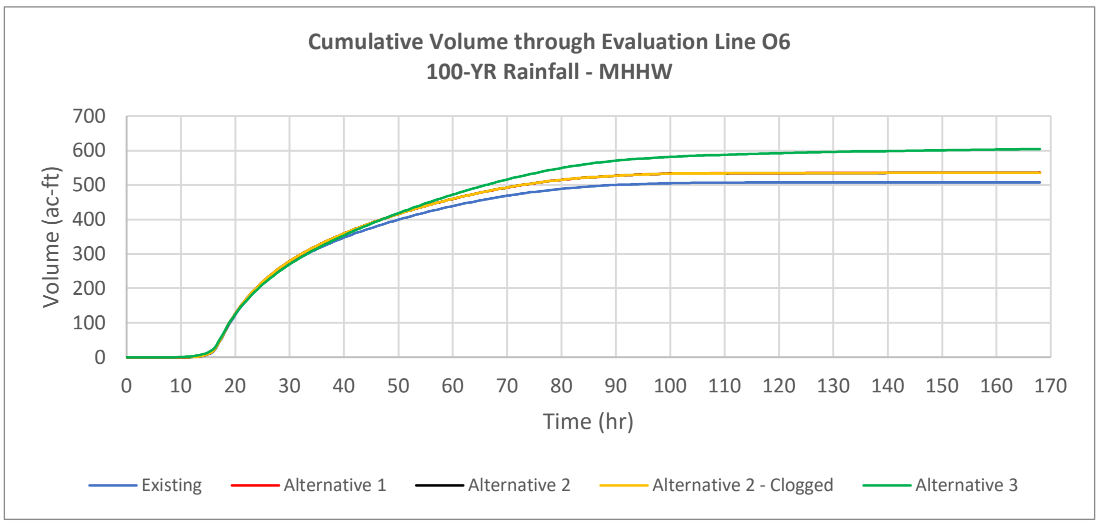



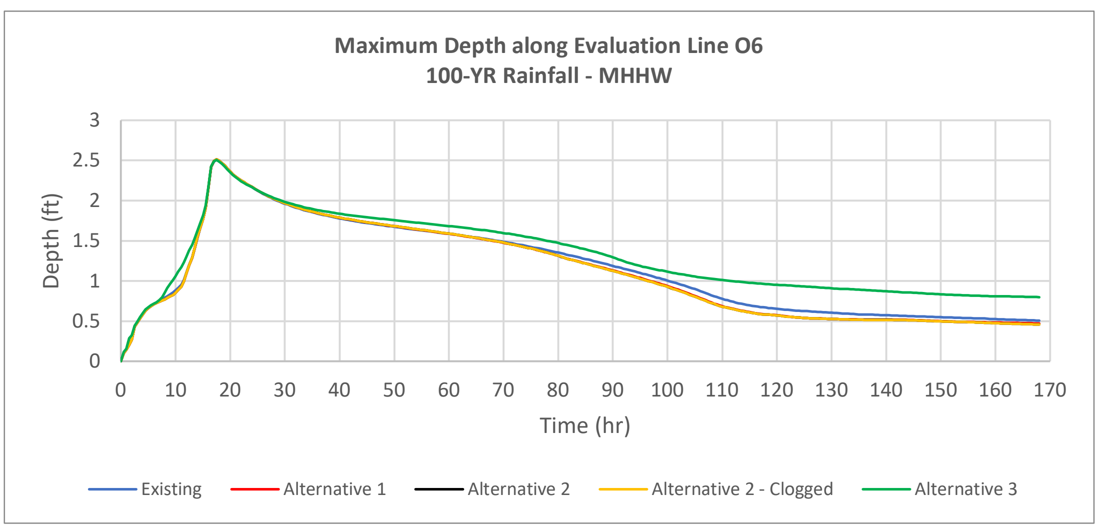




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A43**

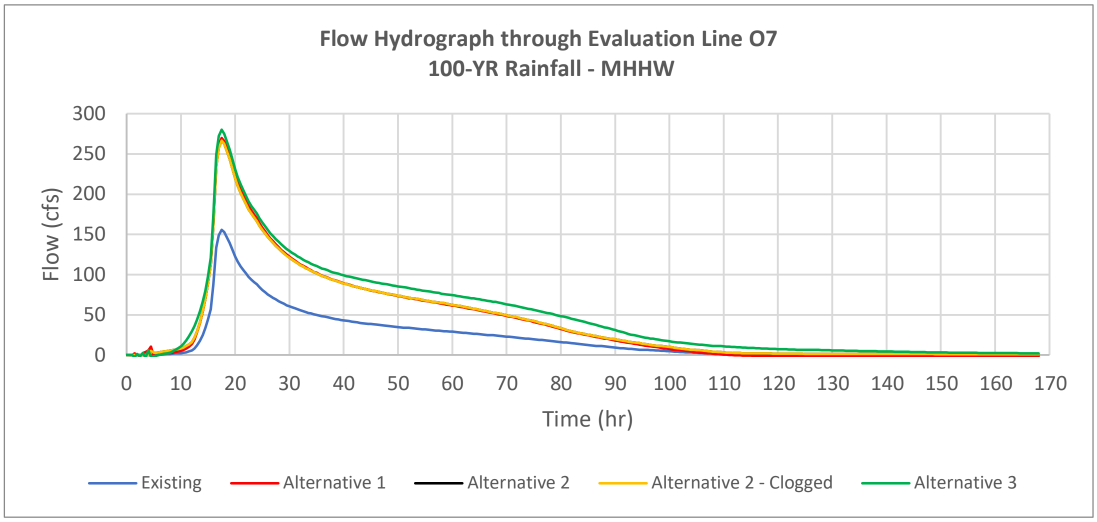


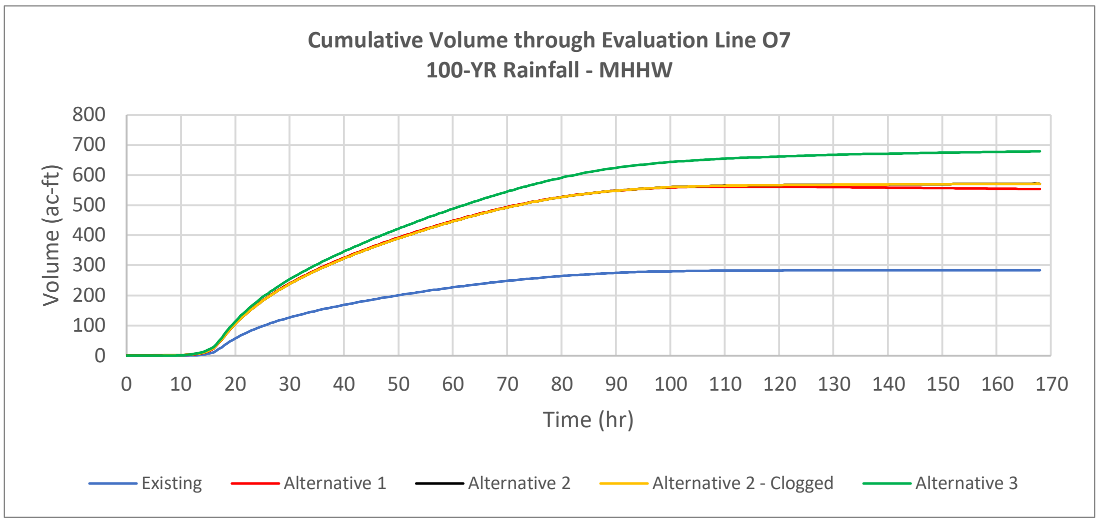



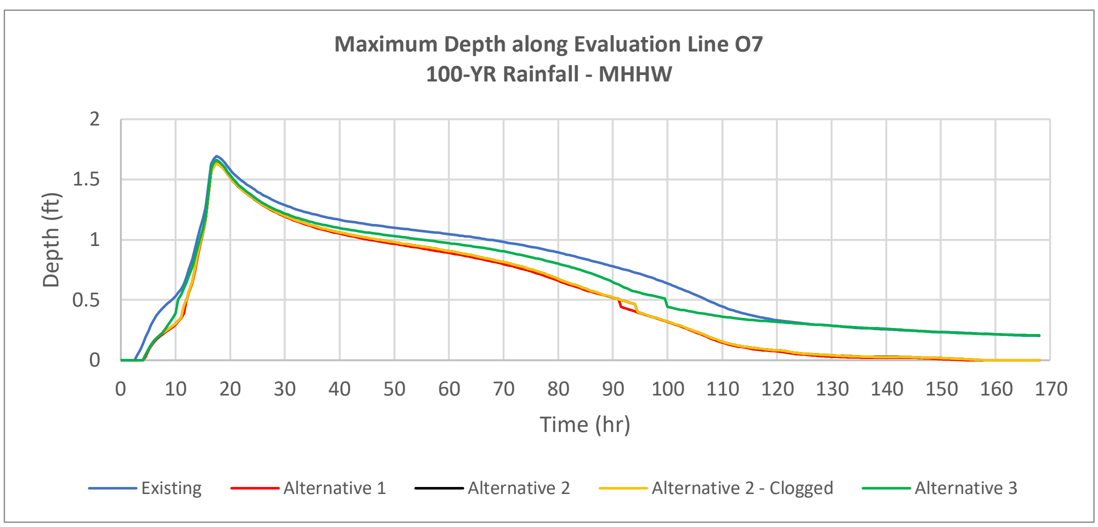




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A44**

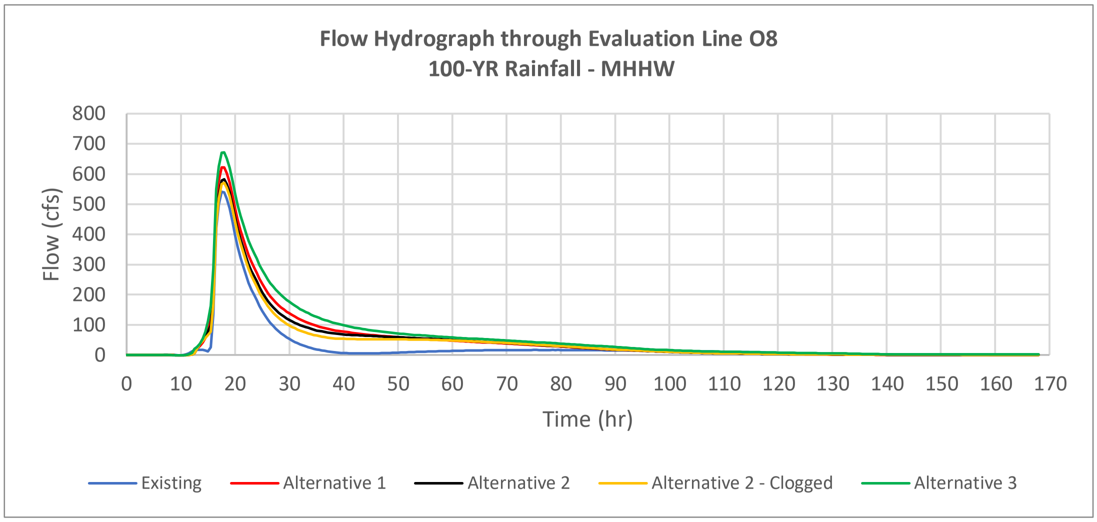


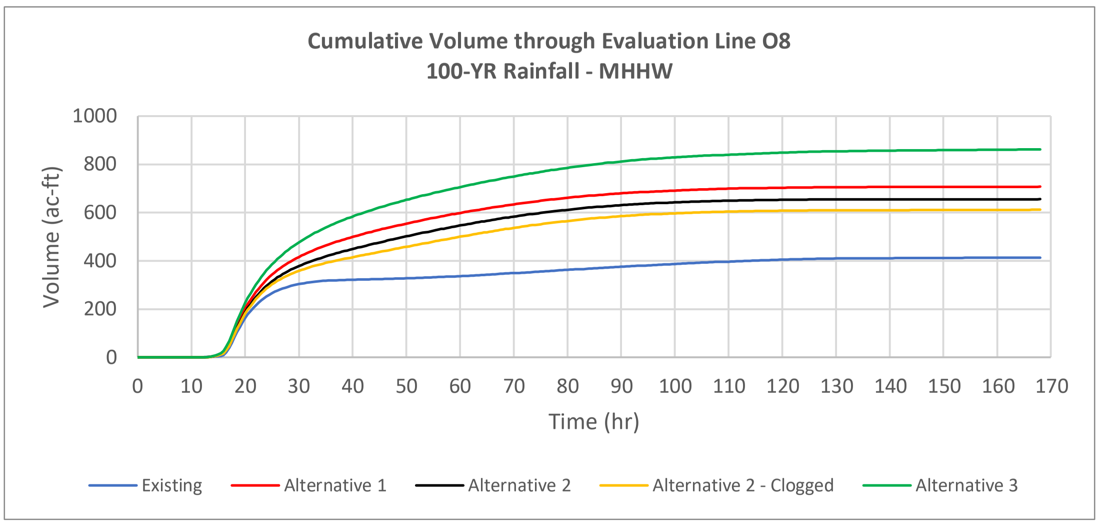



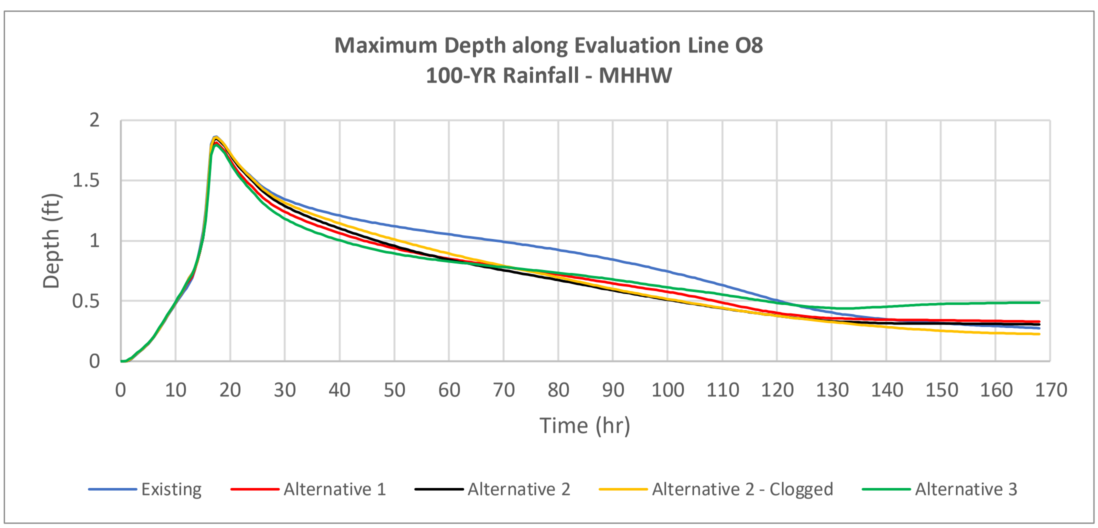




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A45**

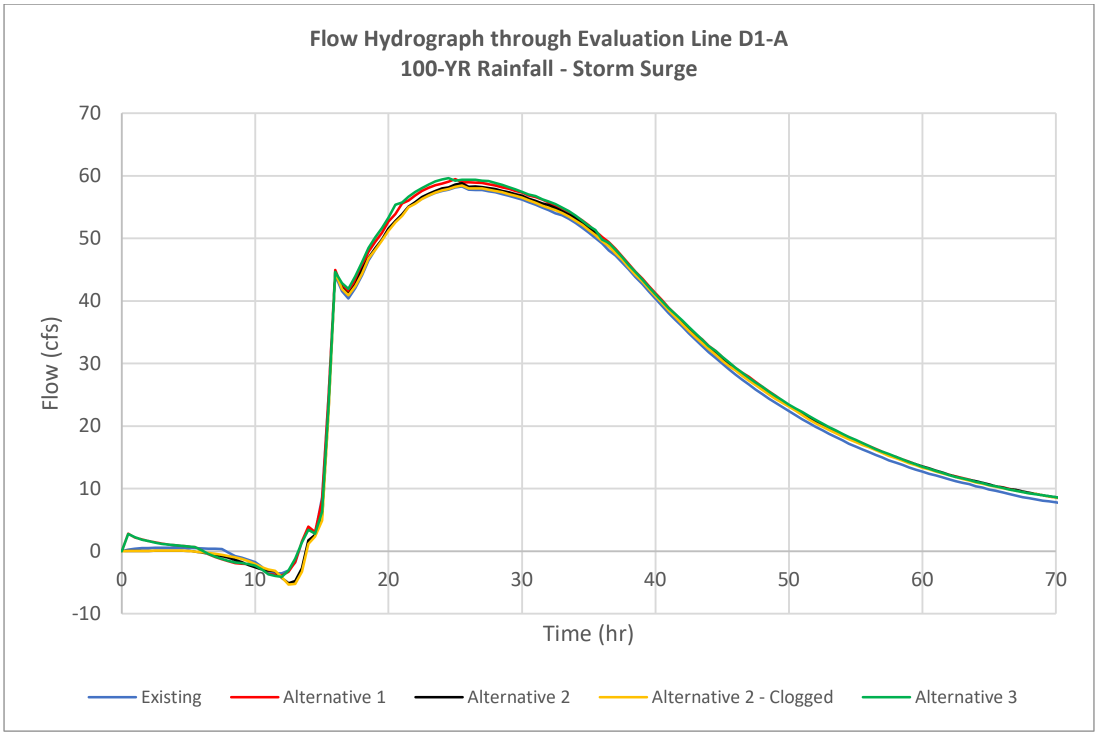


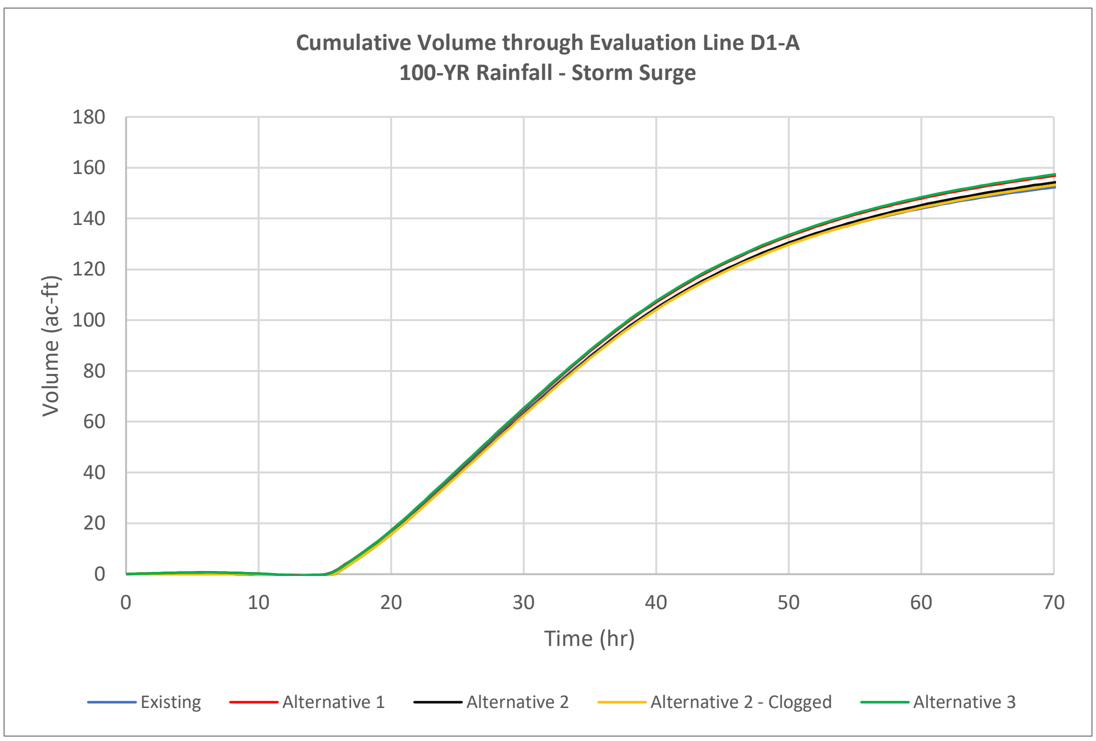




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

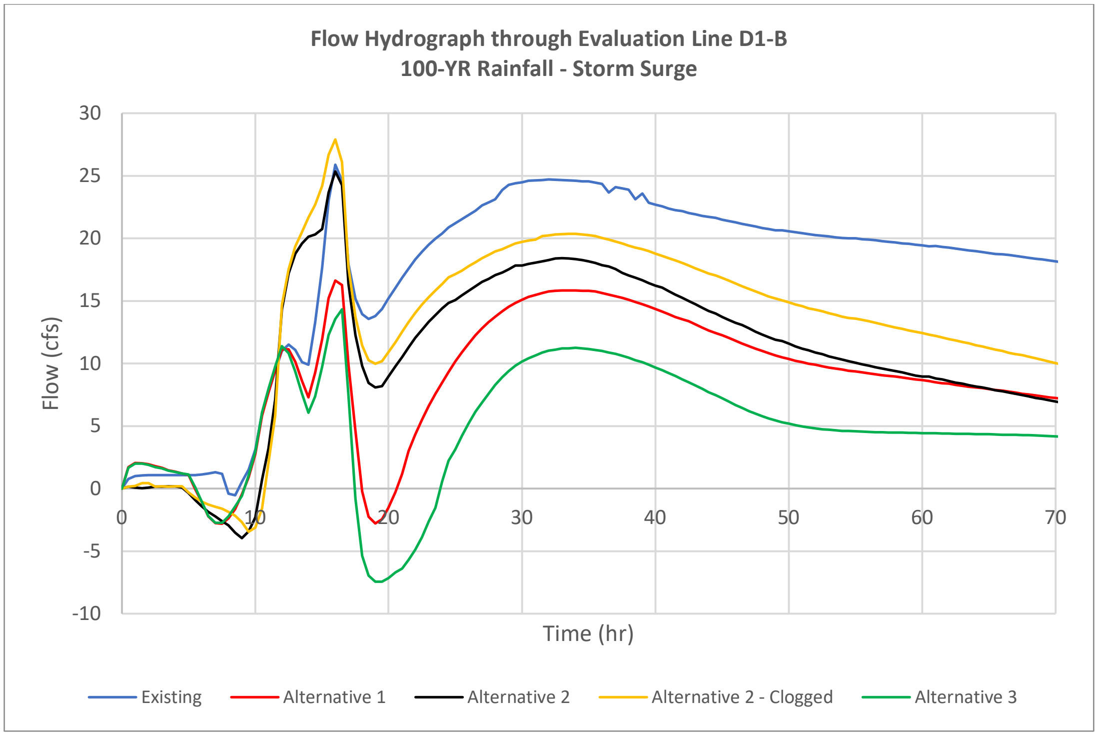
**Figure A46**

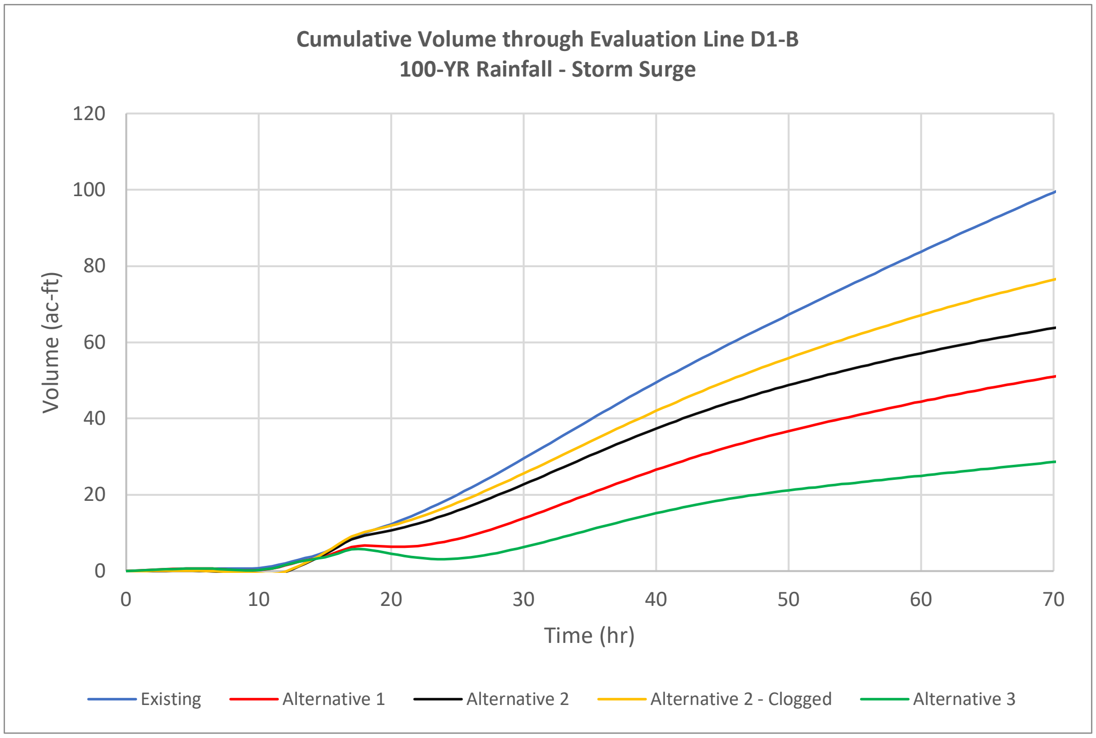



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

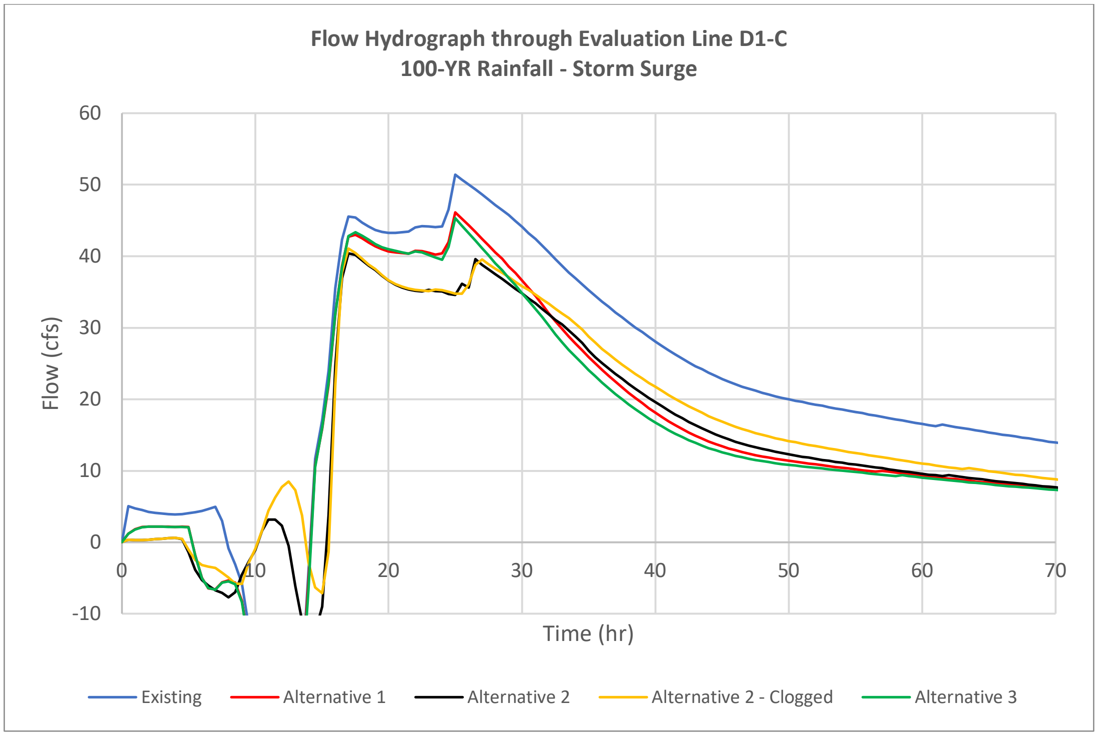
**Figure A47**

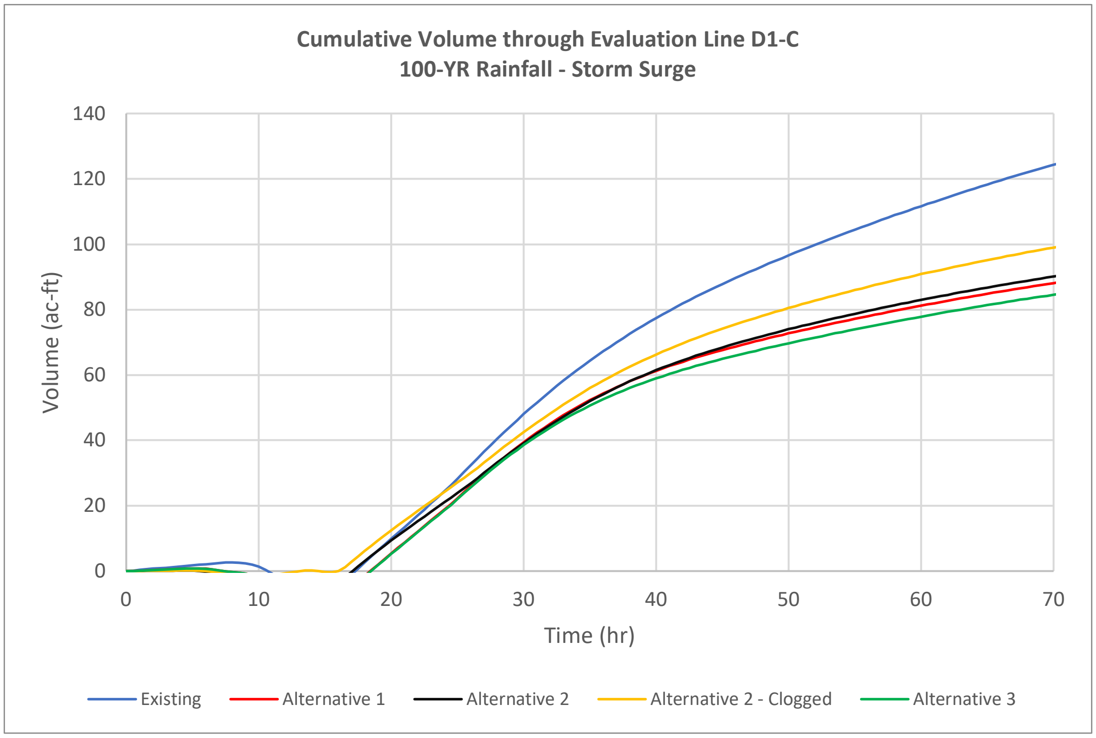



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

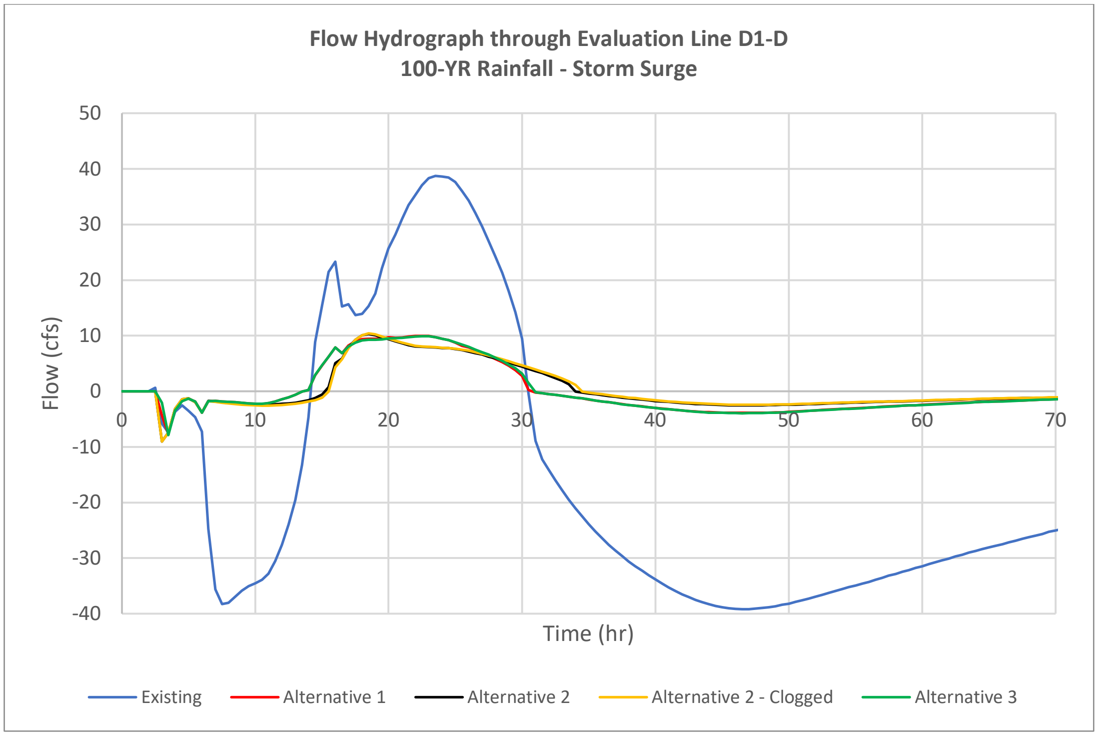
**Figure A48**

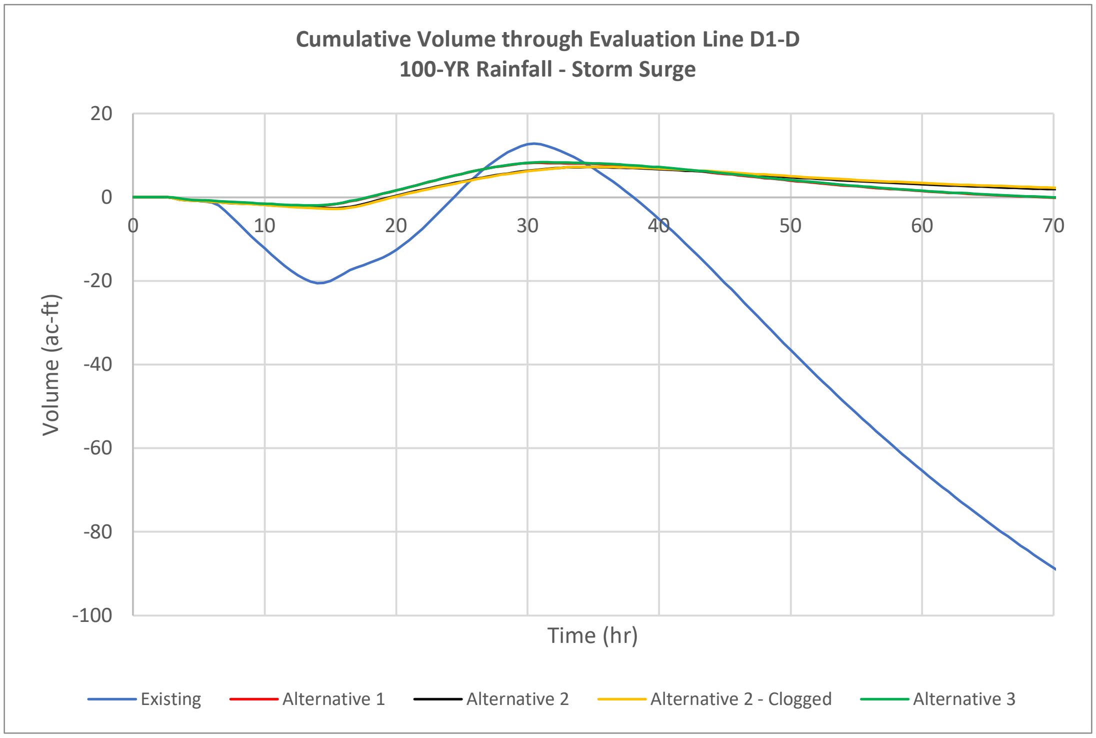



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

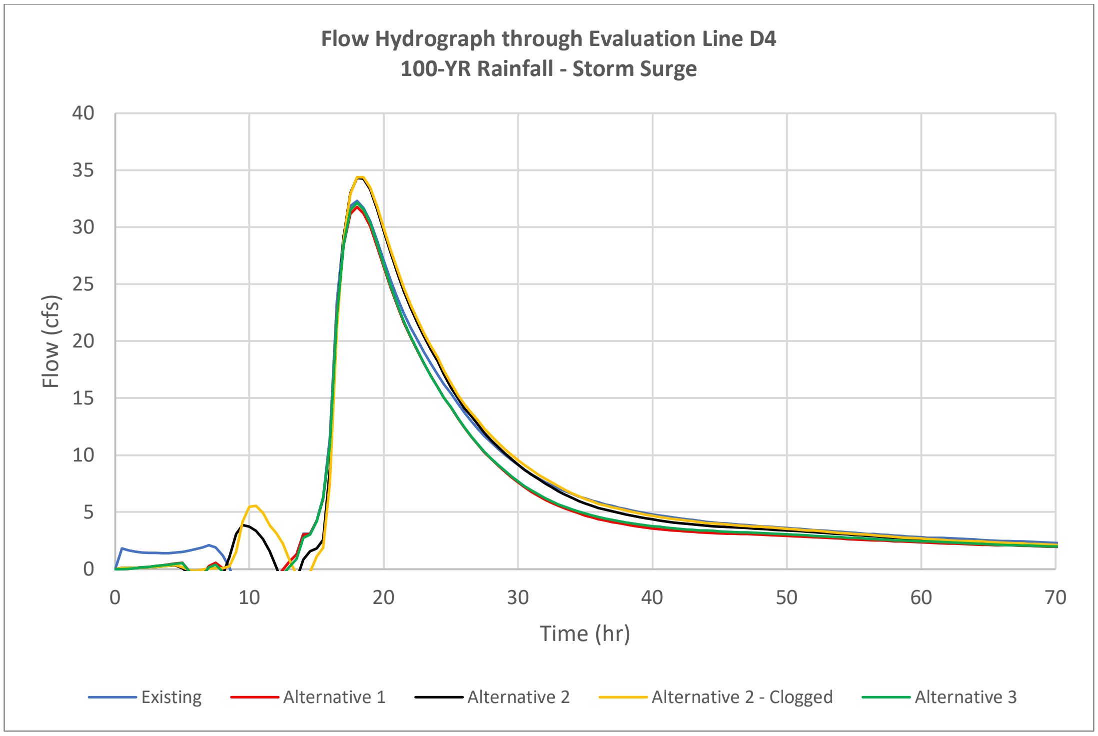
**Figure A49**

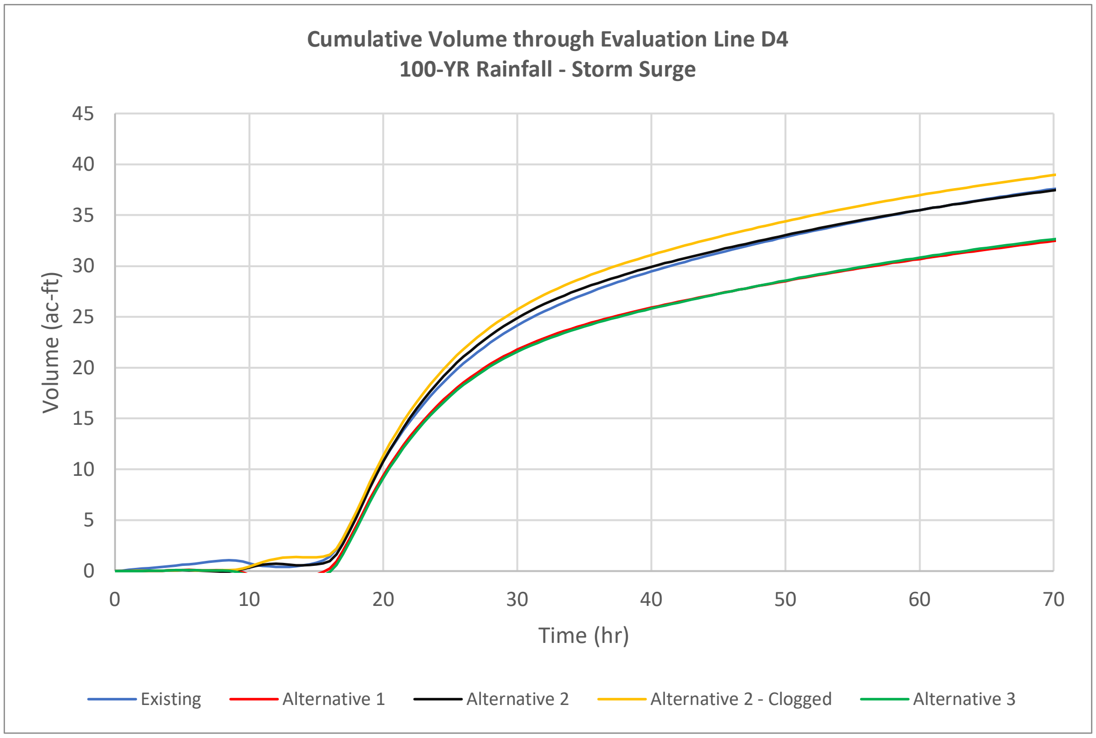



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

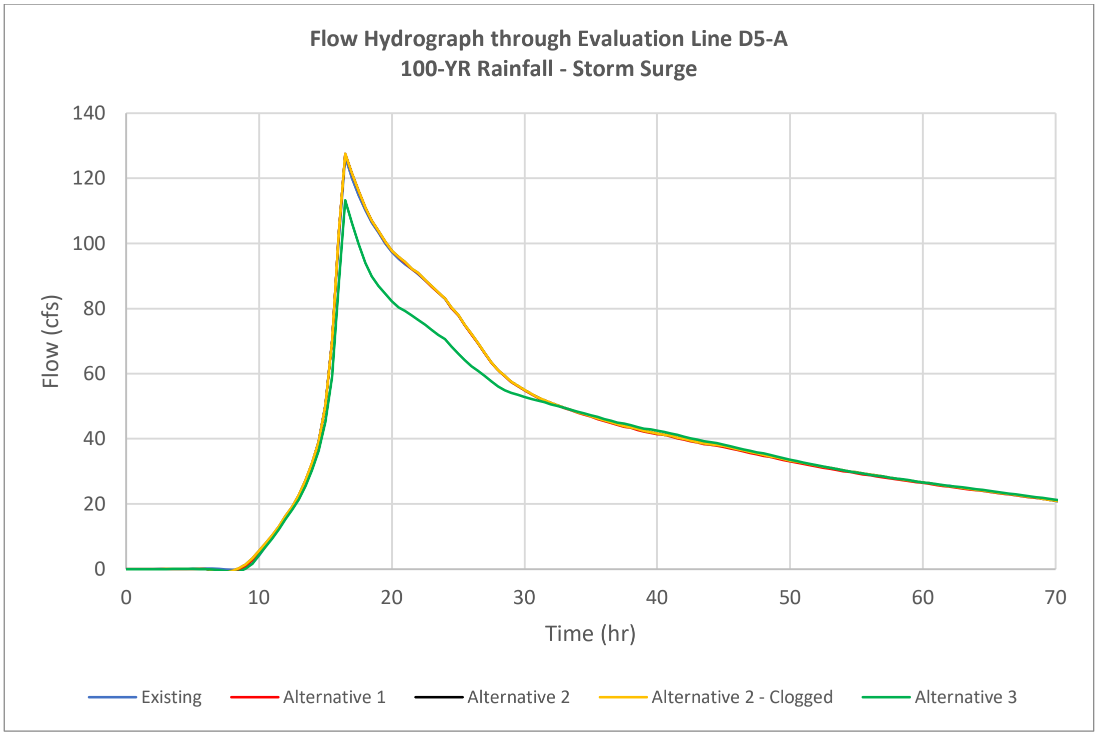
**Figure A50**

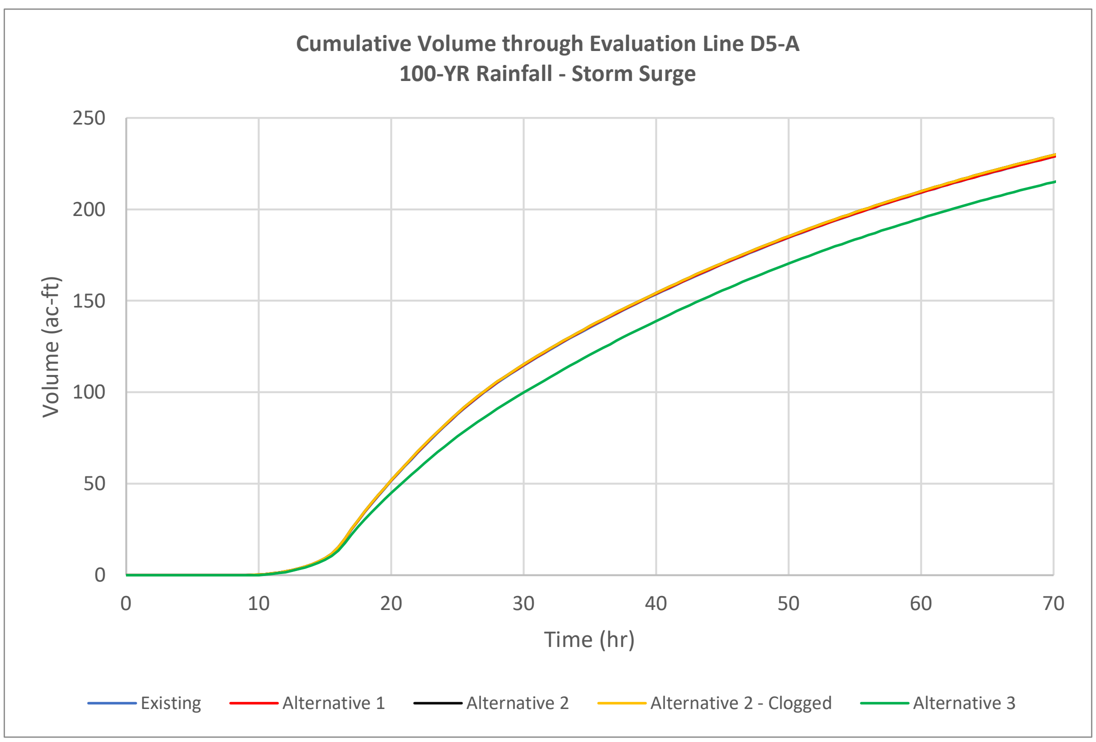



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

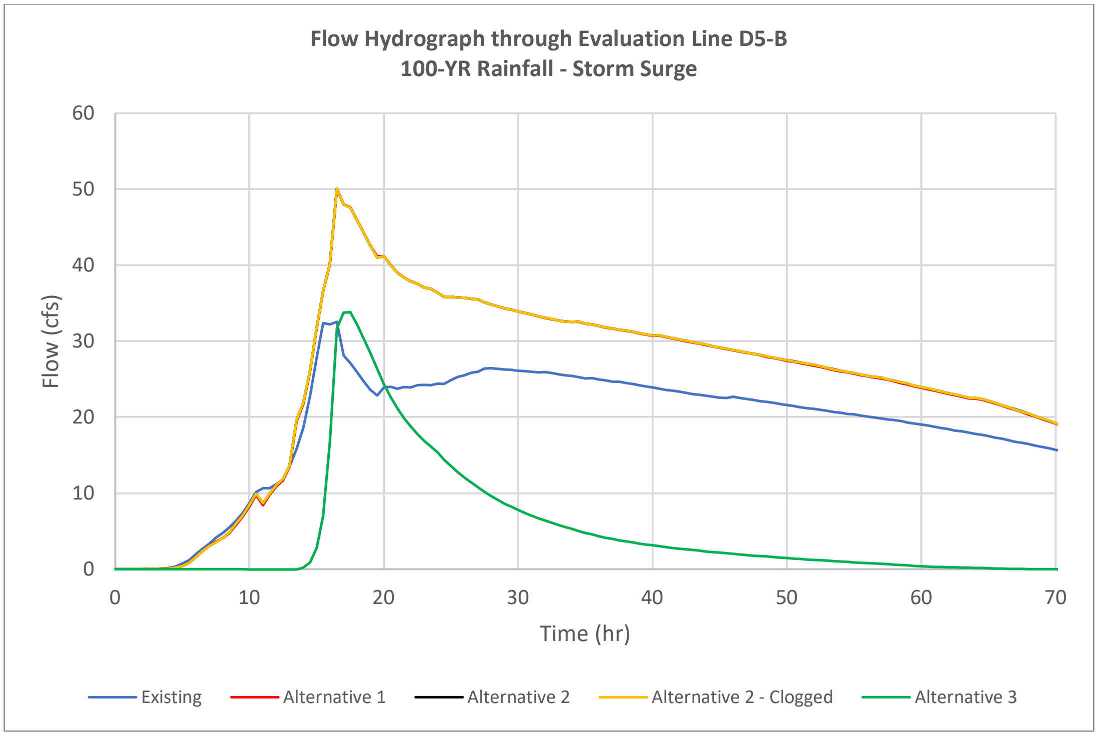
**Figure A51**

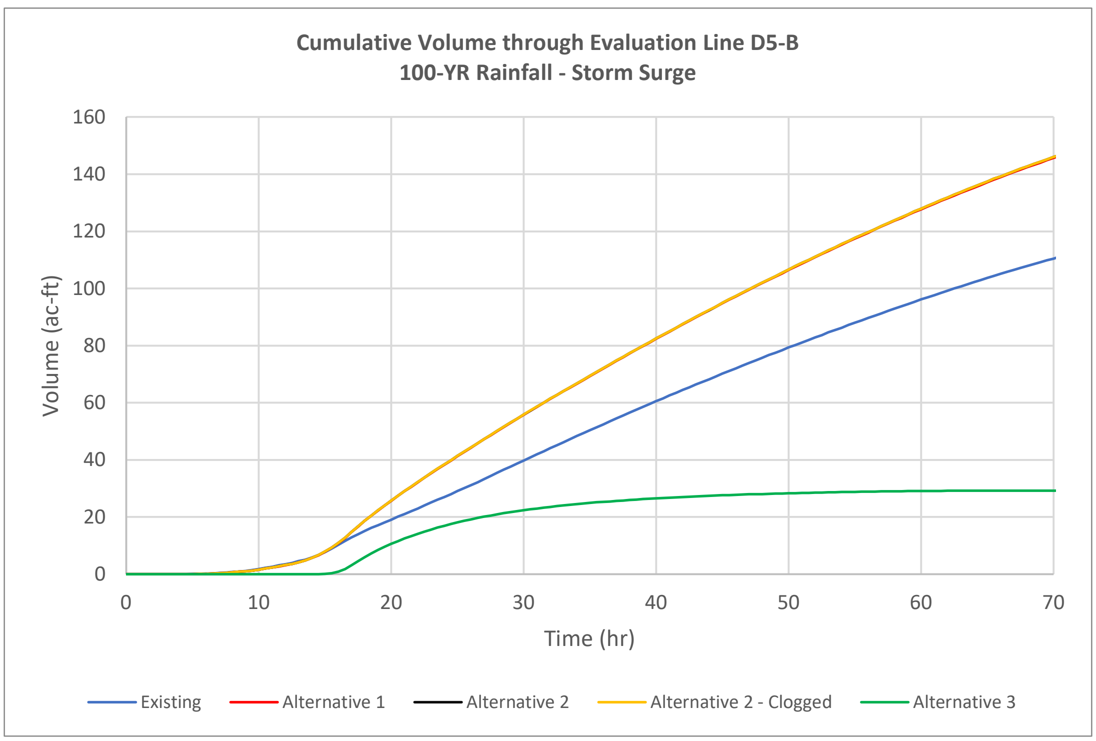



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

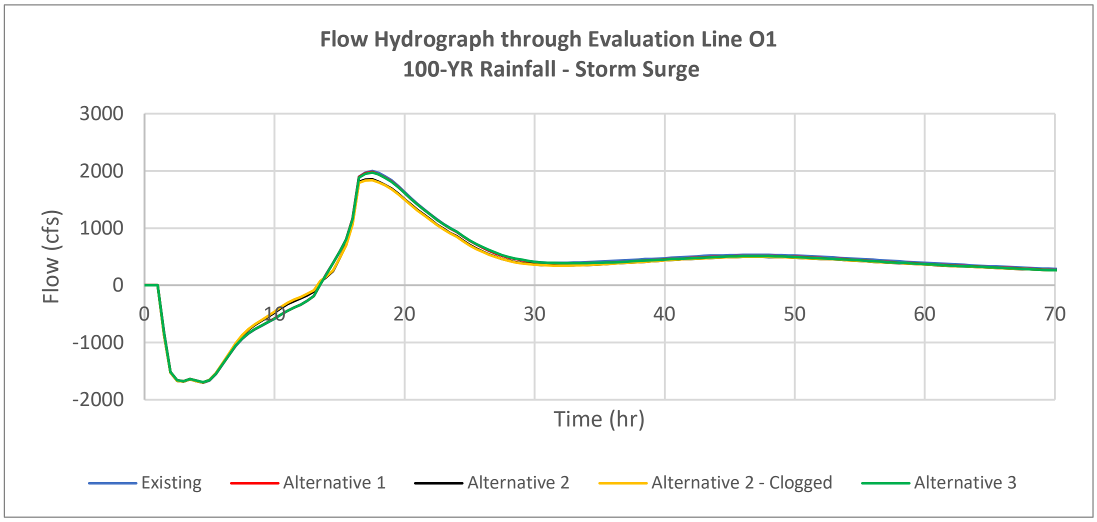
**Figure A52**

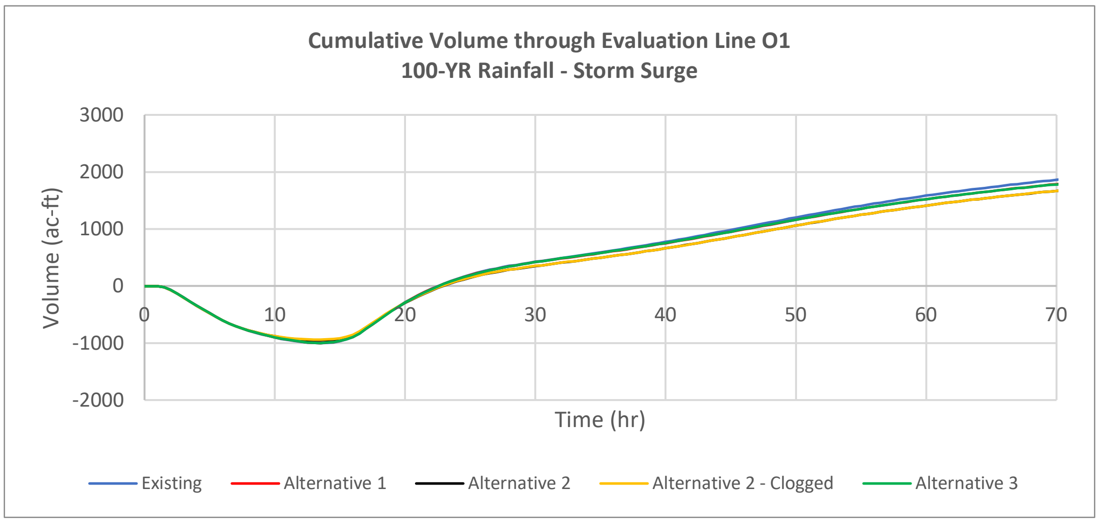


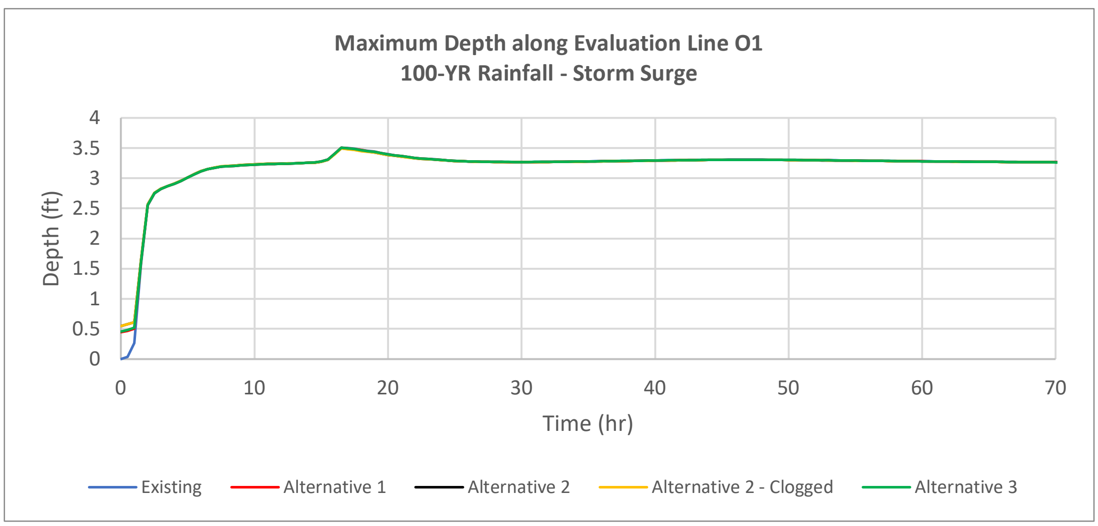




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A53**

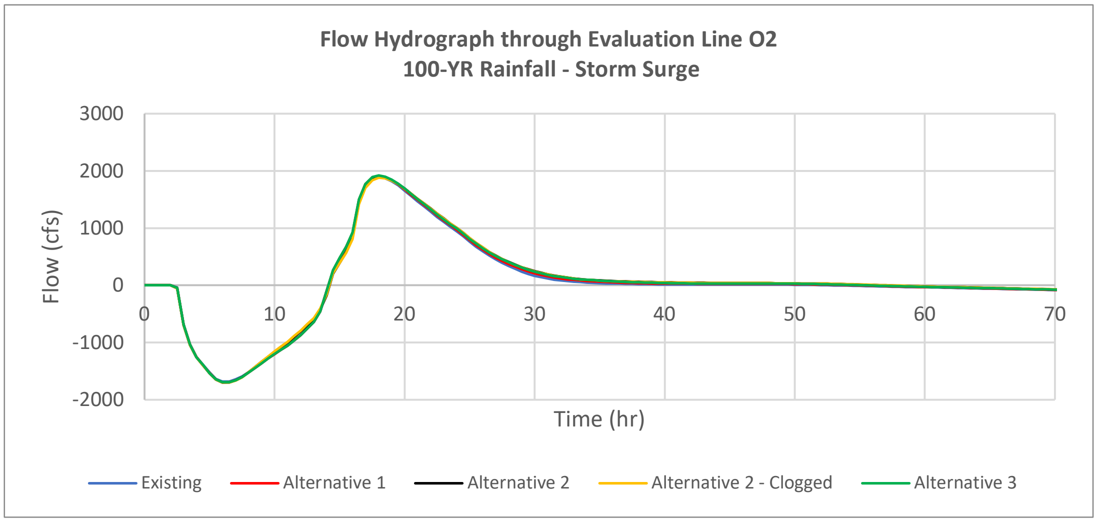


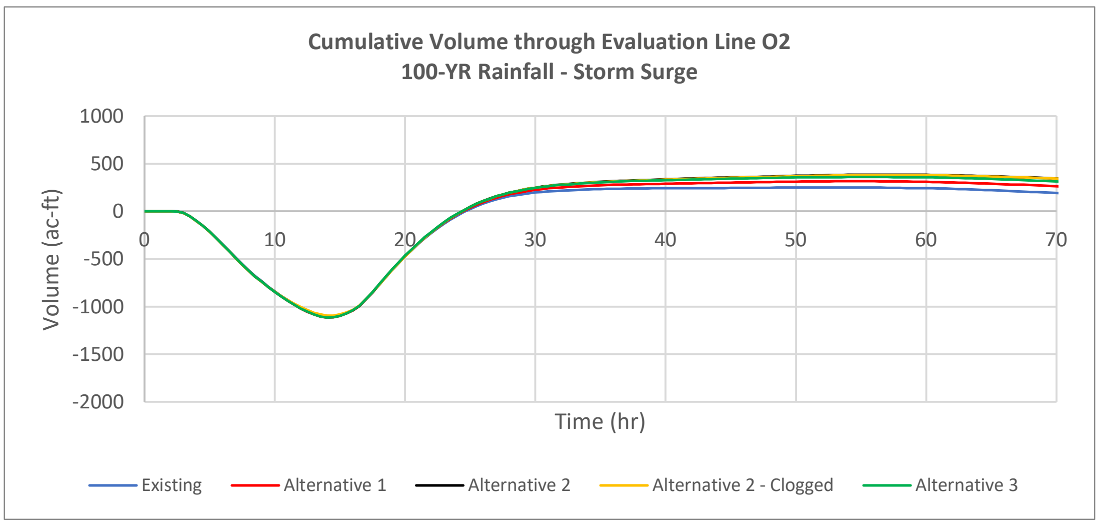



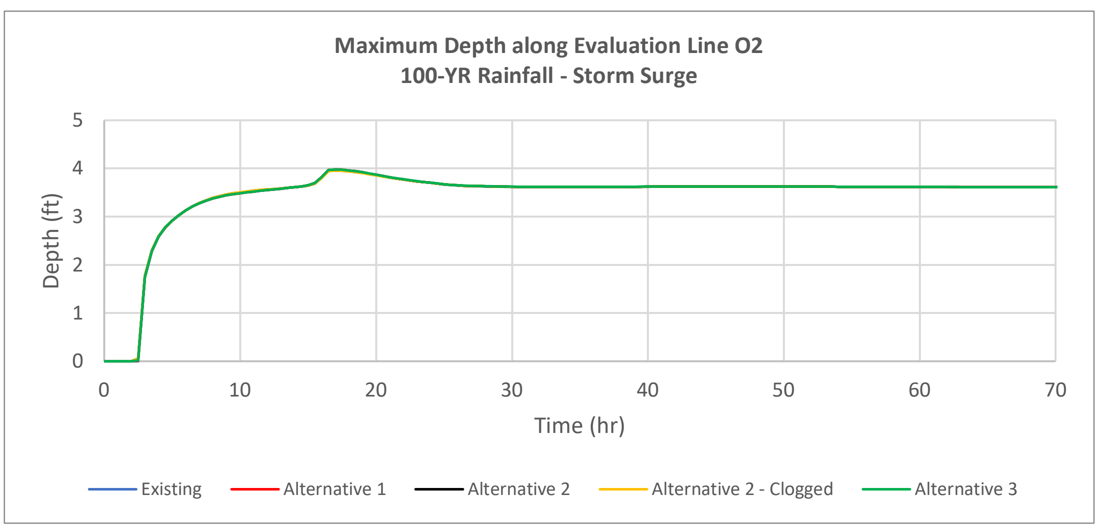




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A54**

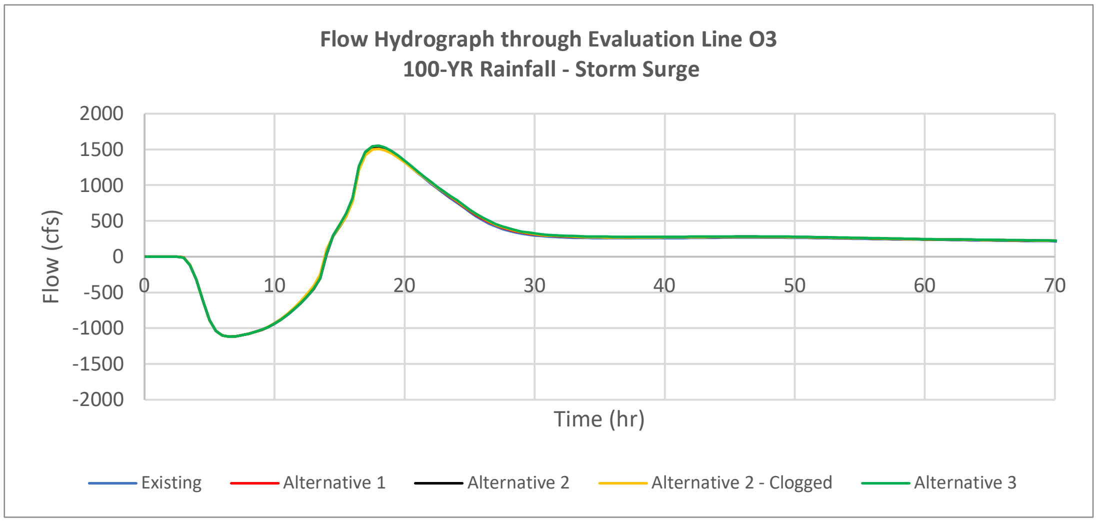


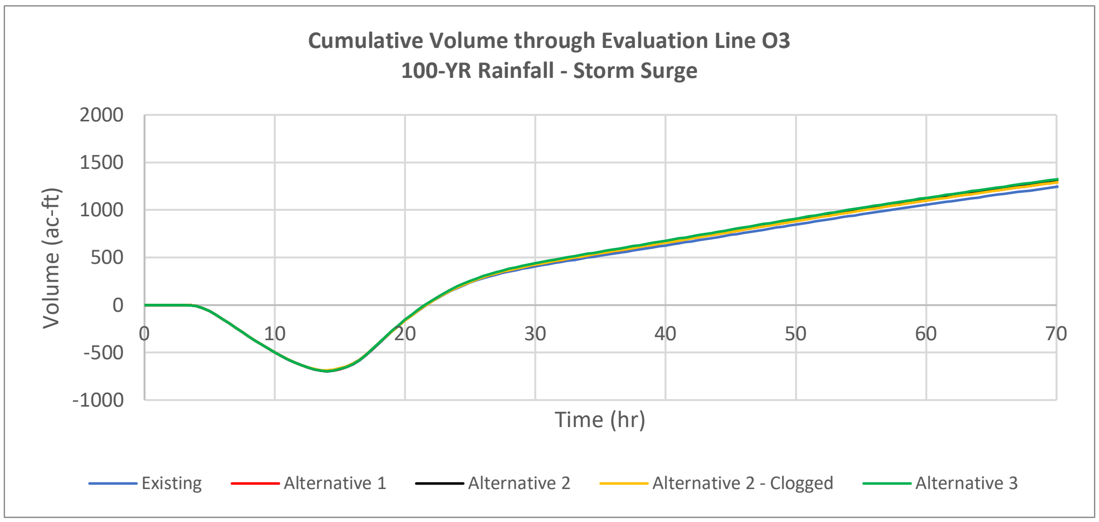



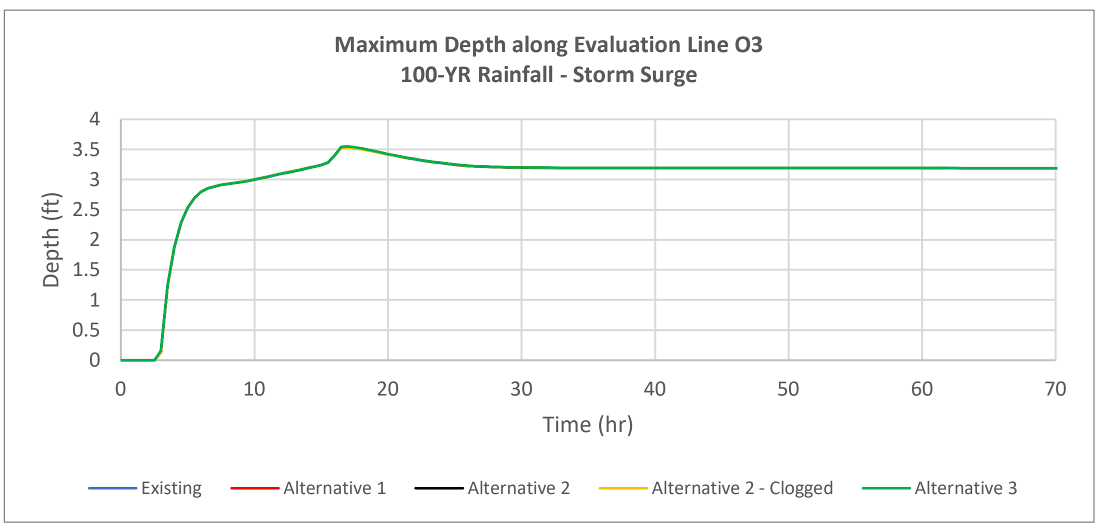




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A55**

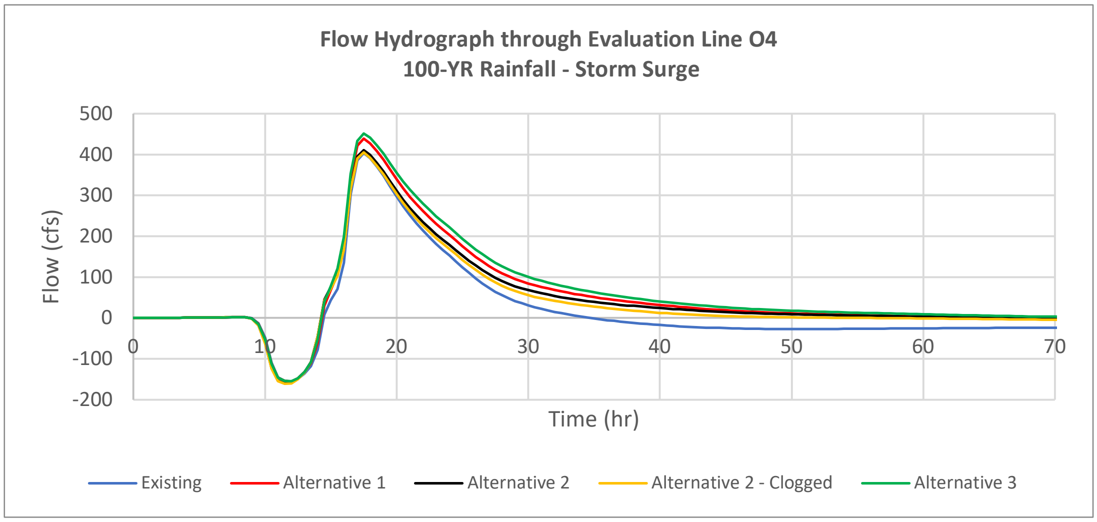


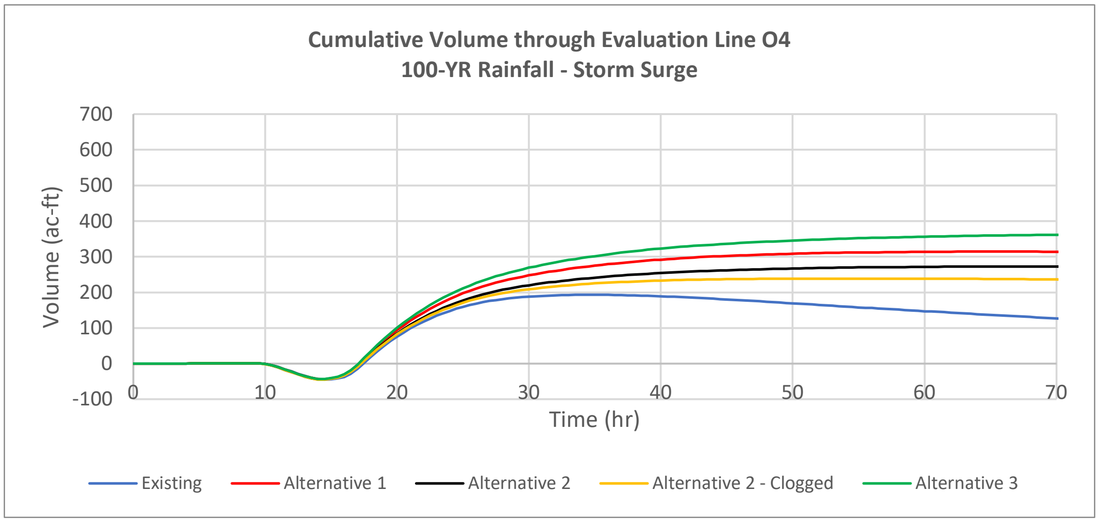



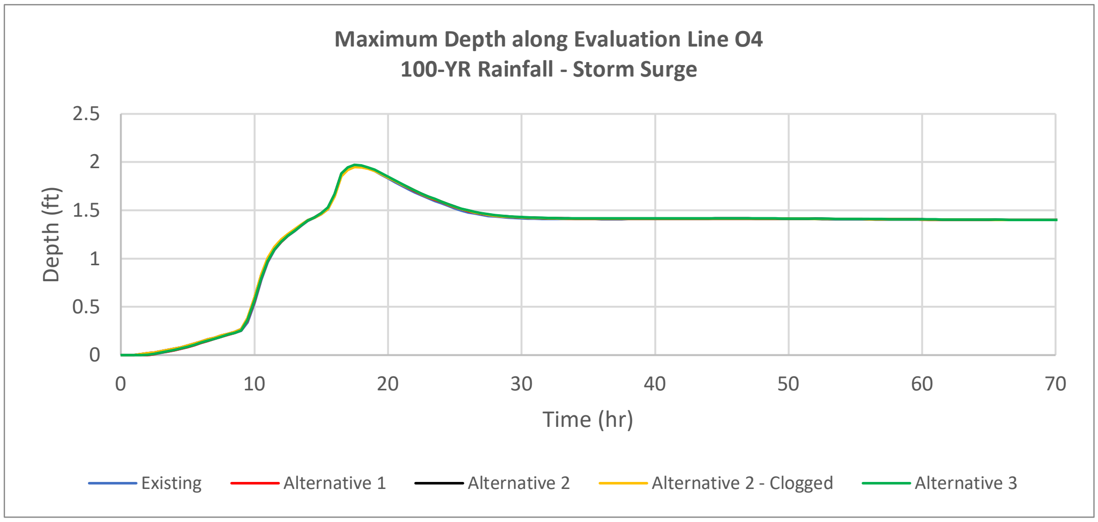




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A56**

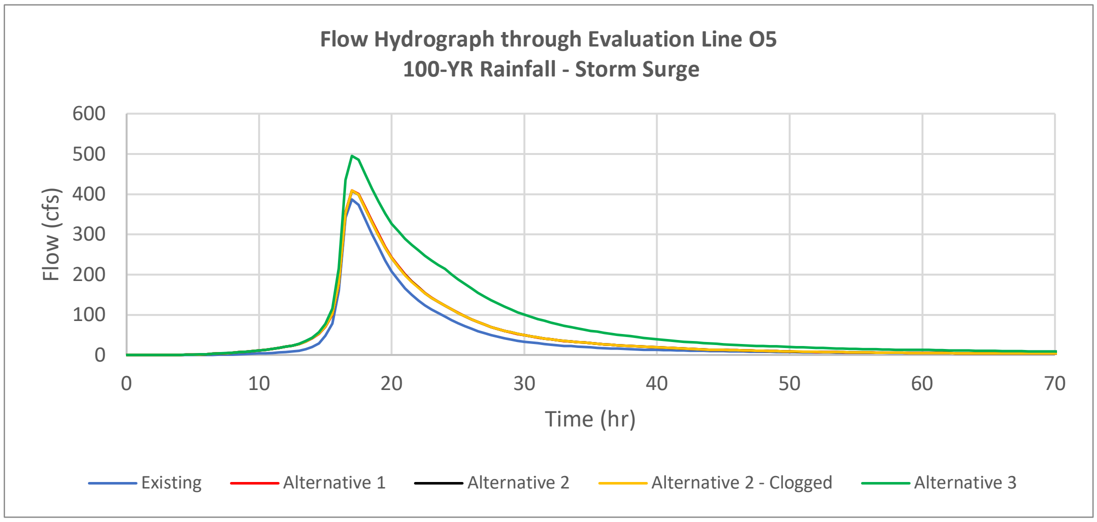


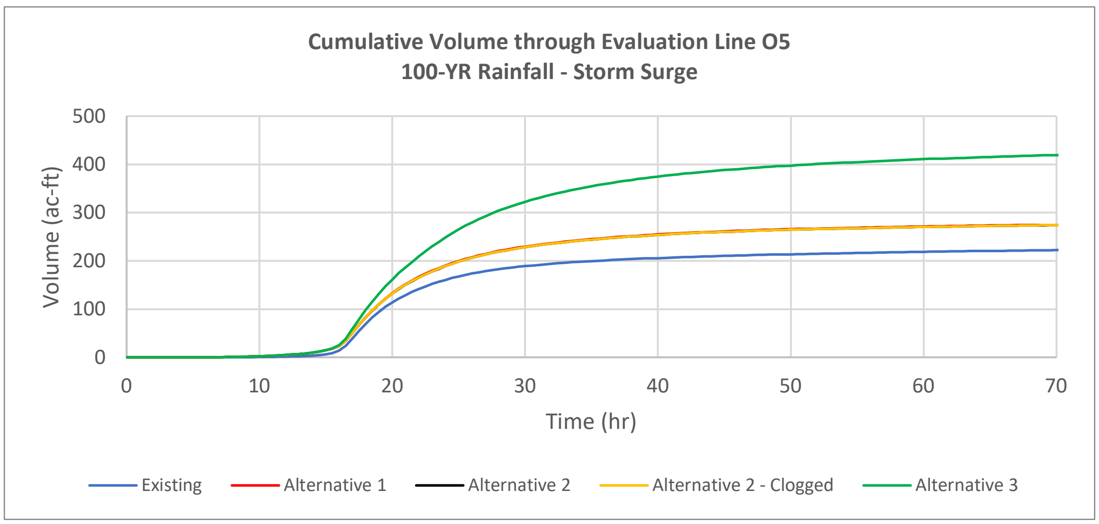



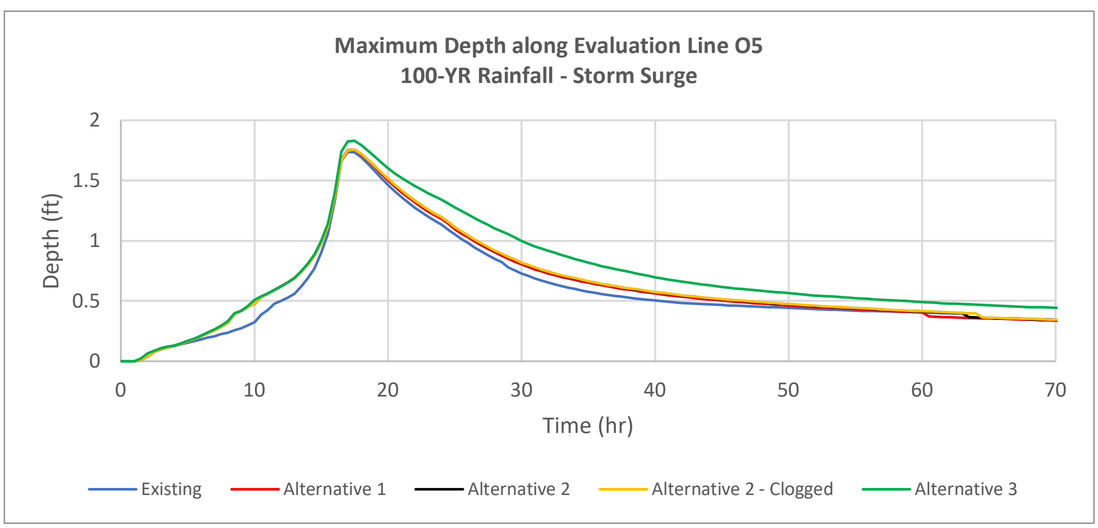




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A57**

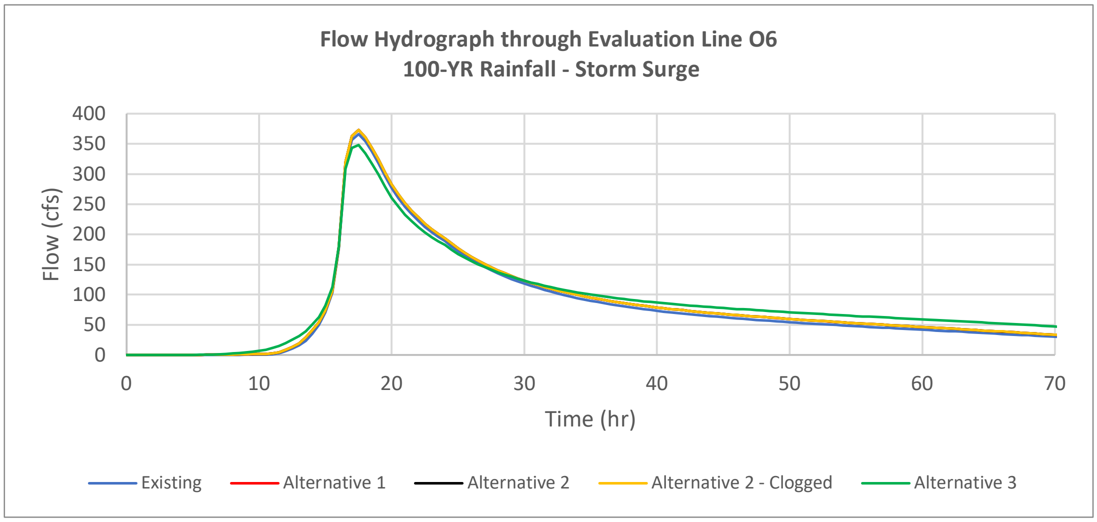


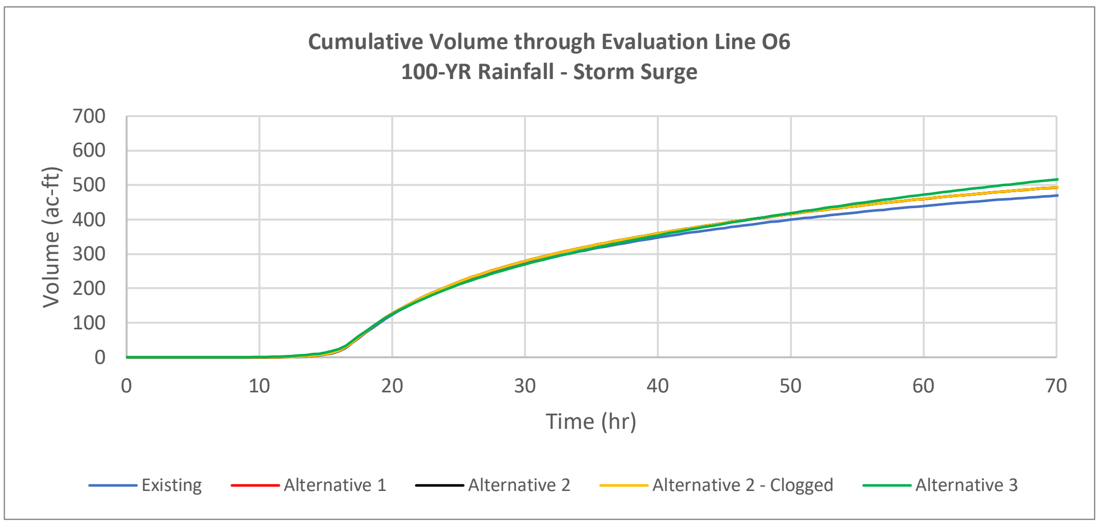



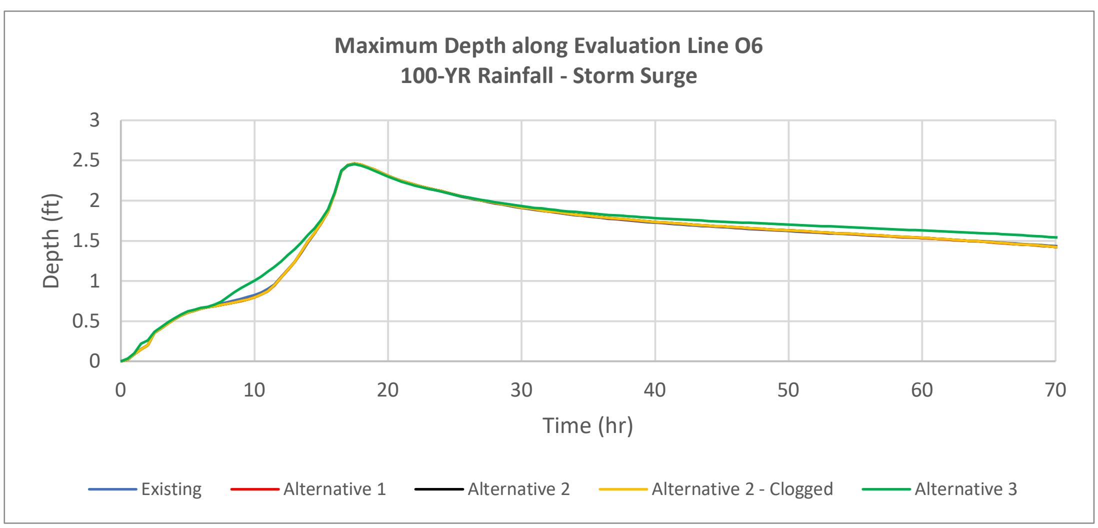




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A58**

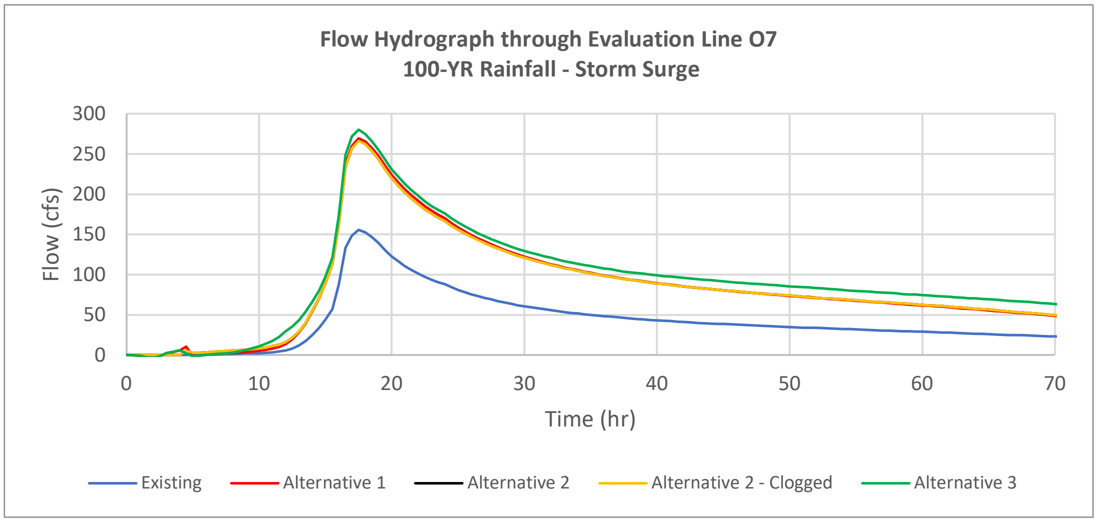


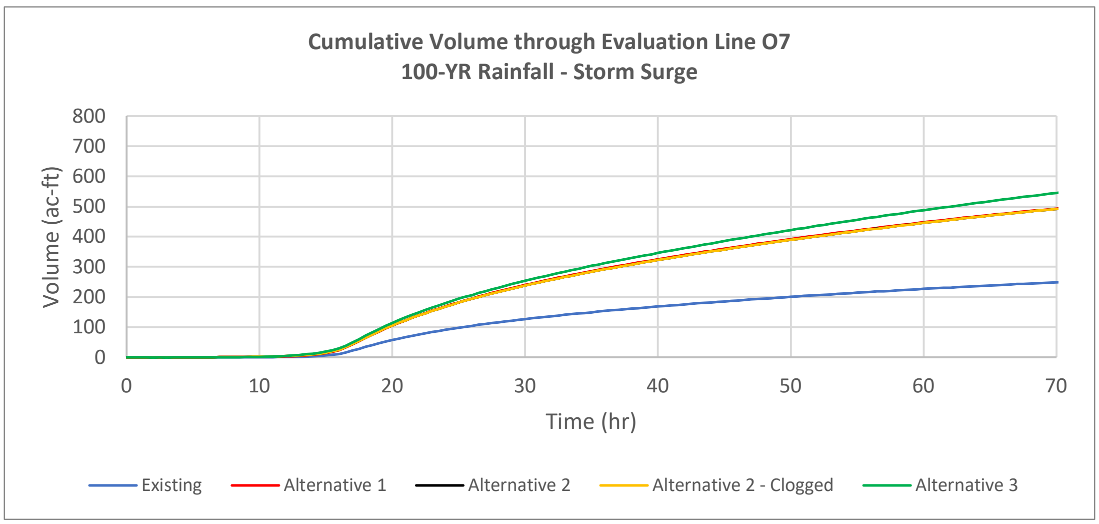



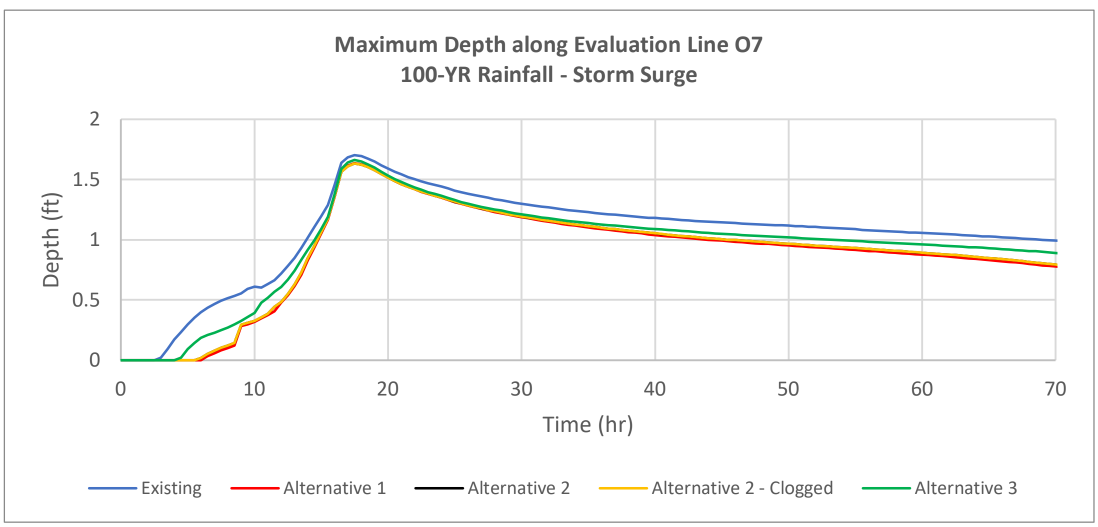




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

## Figure A59

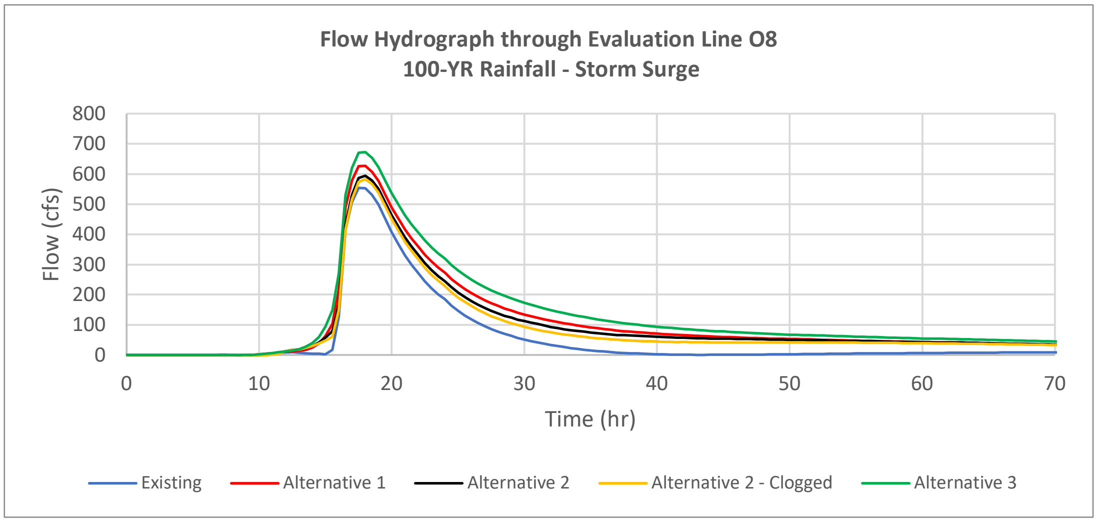


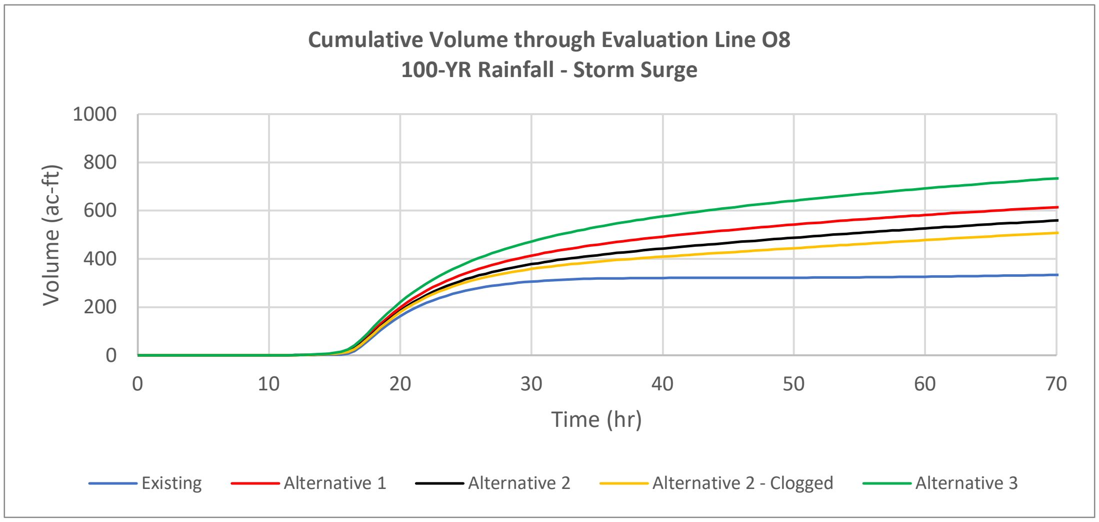



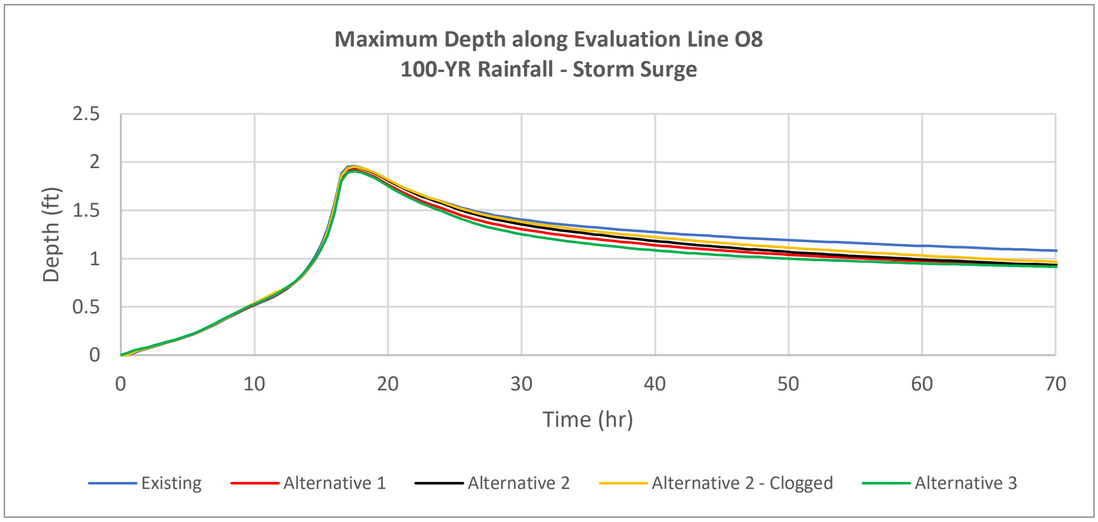




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A60**

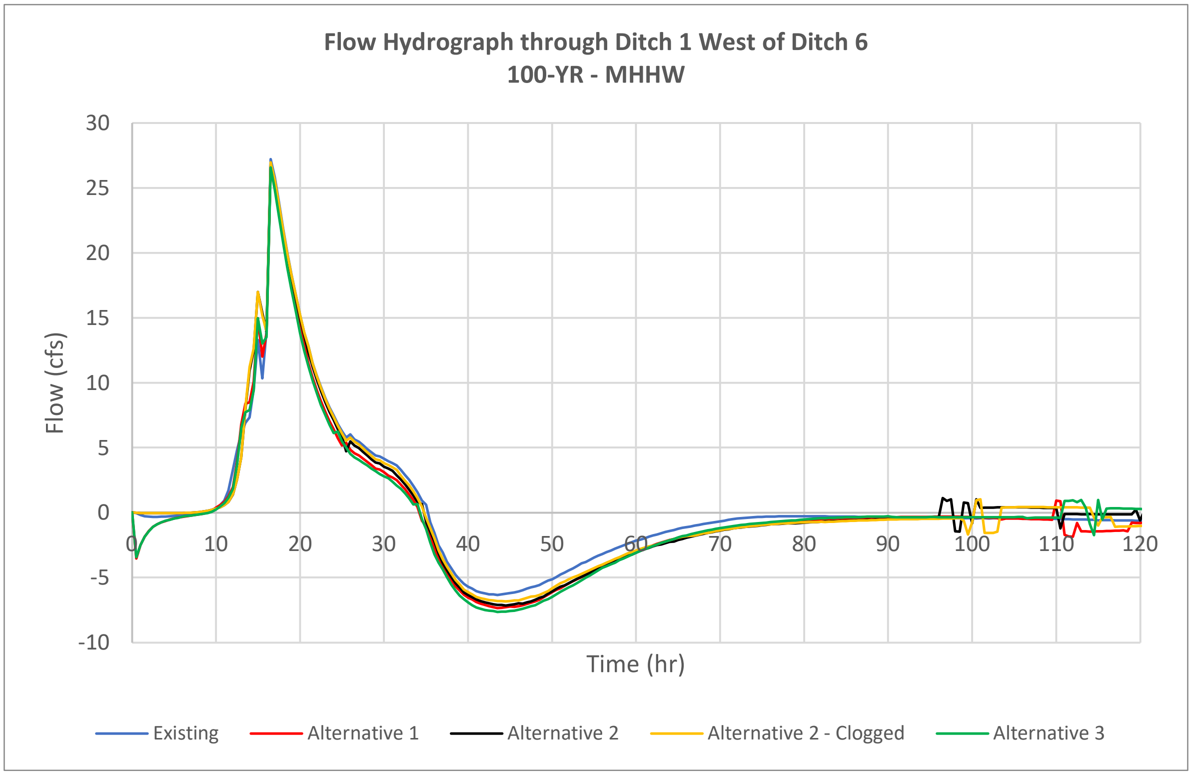


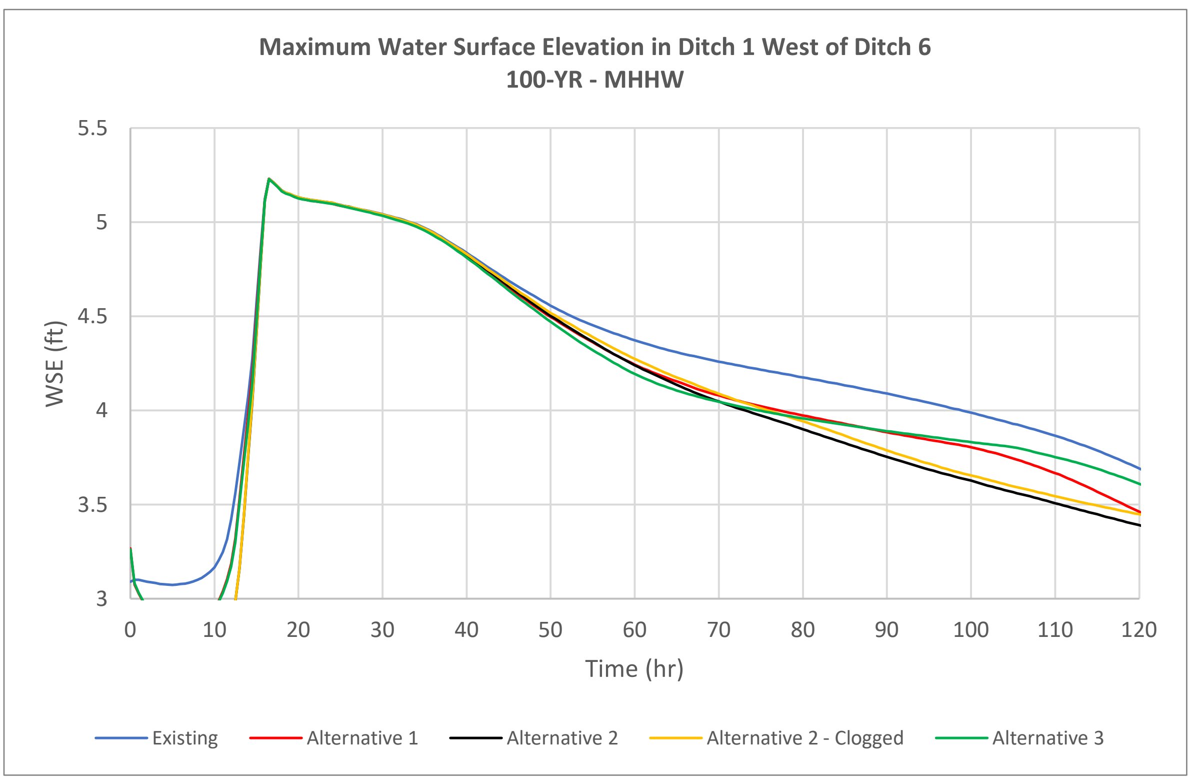




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

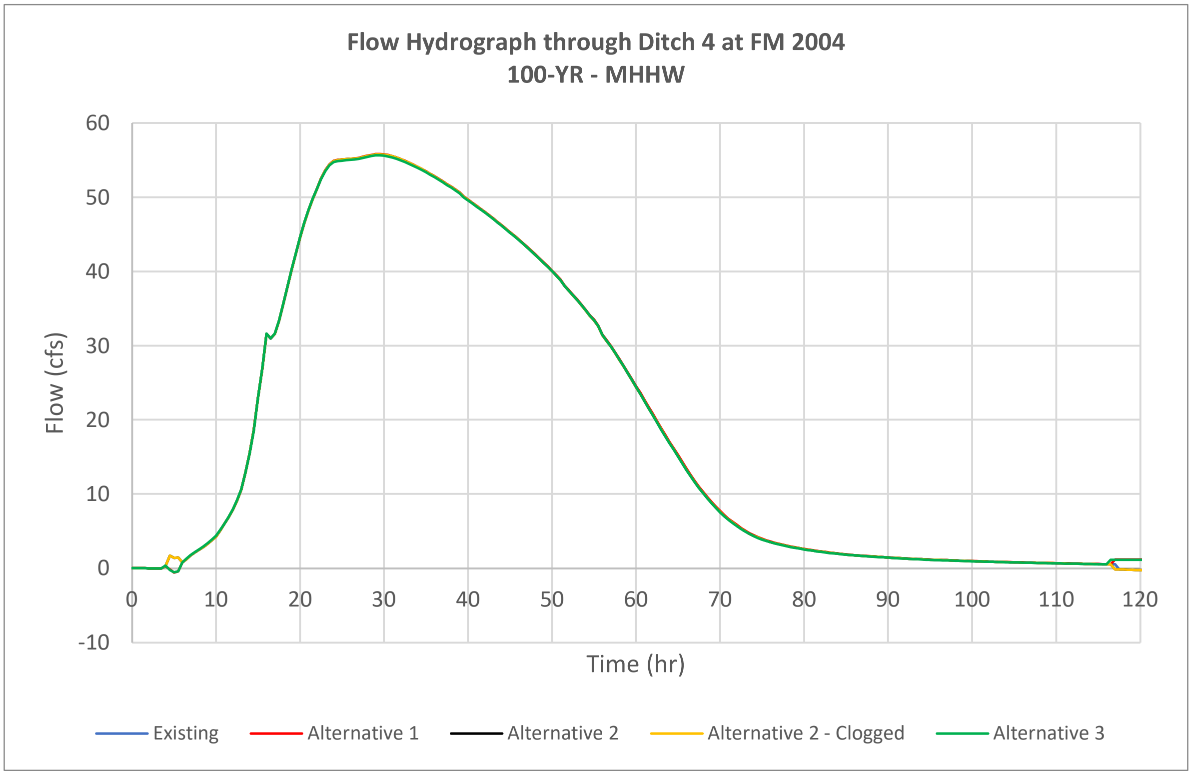
**Figure A61**

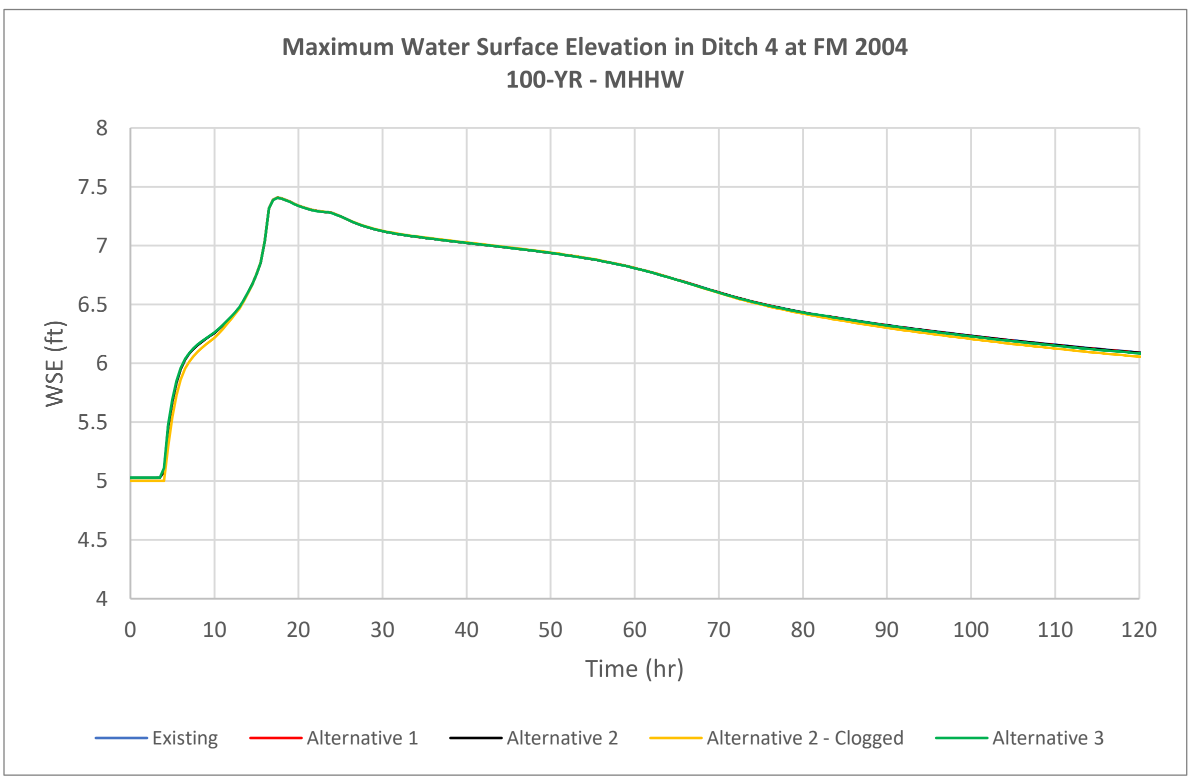



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

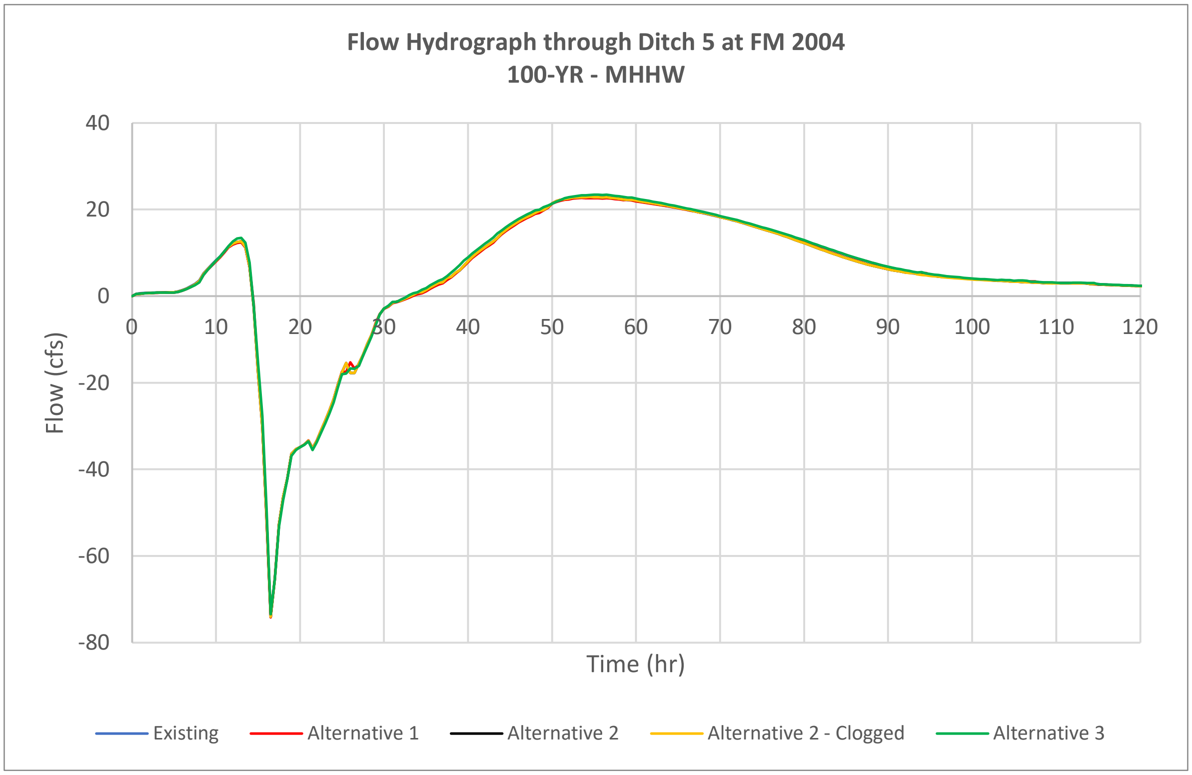
**Figure A62**

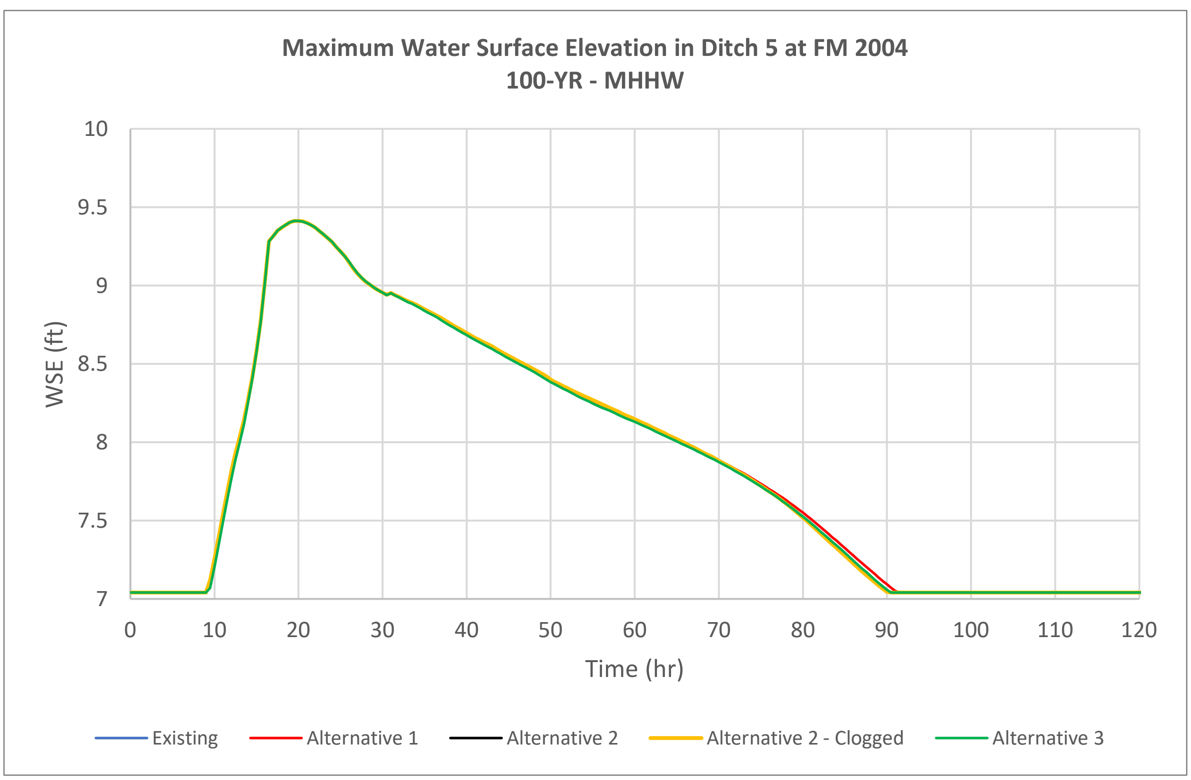



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

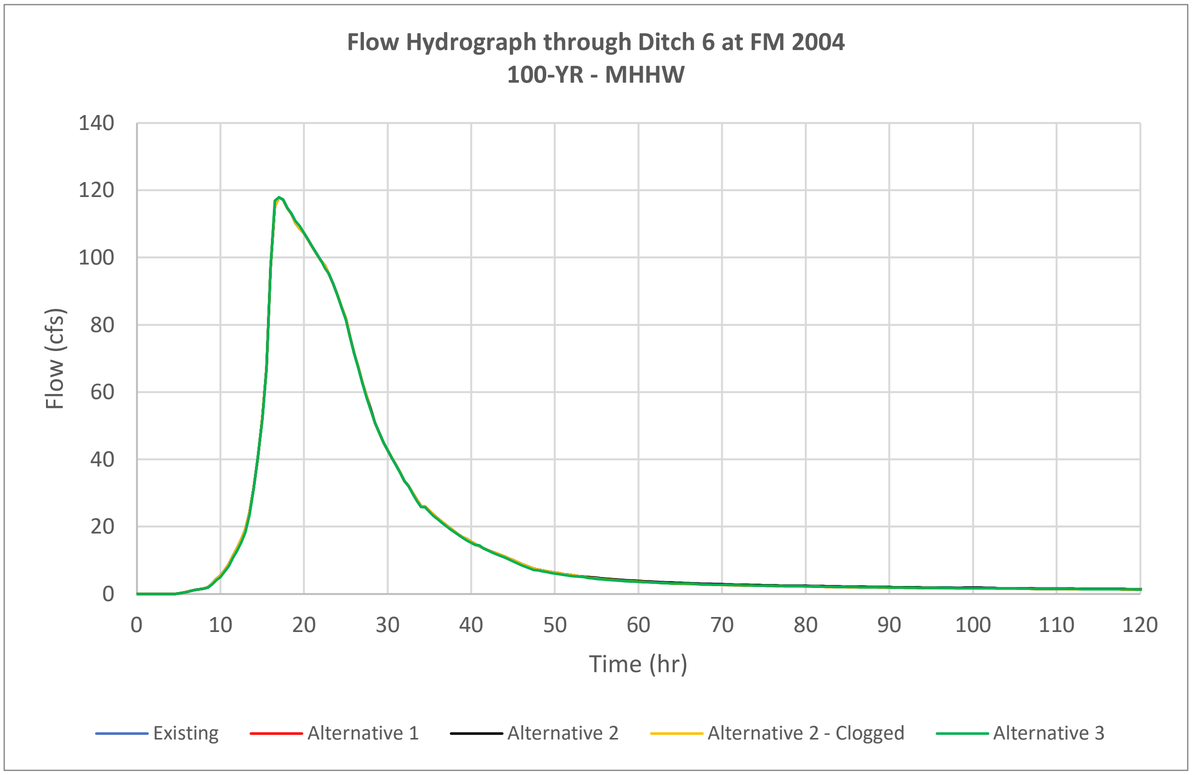
**Figure A63**

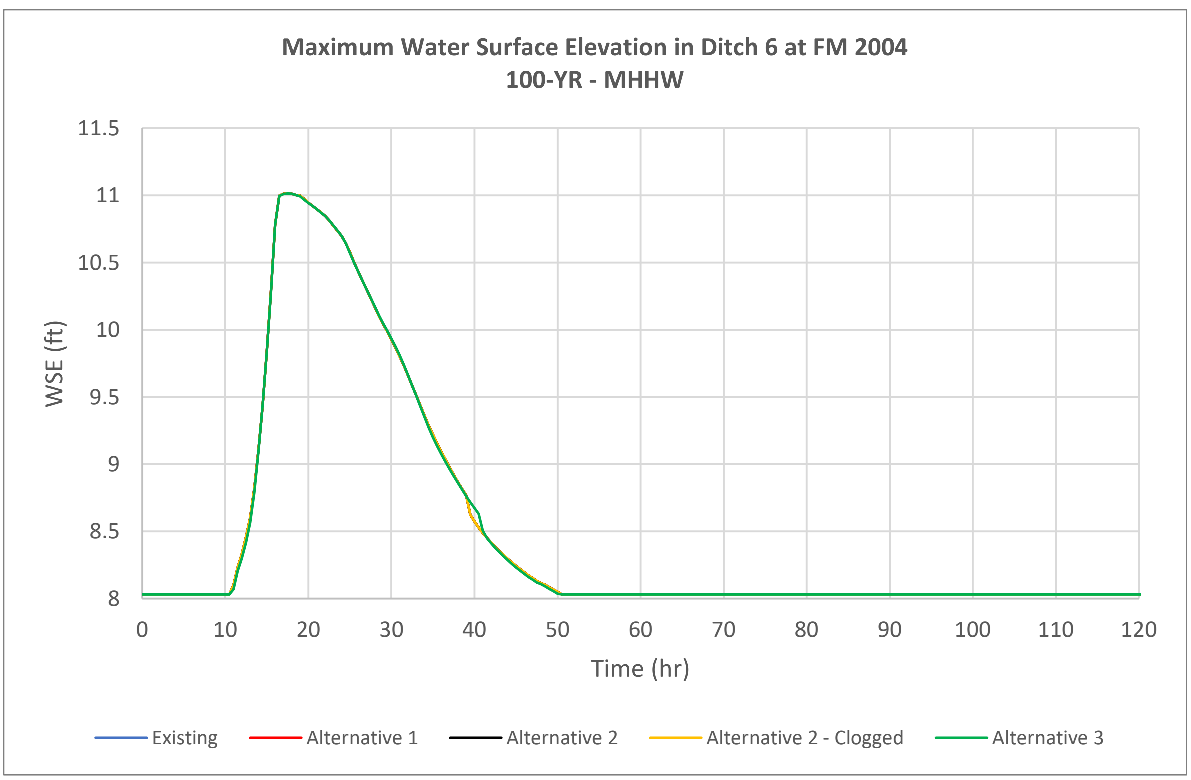



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

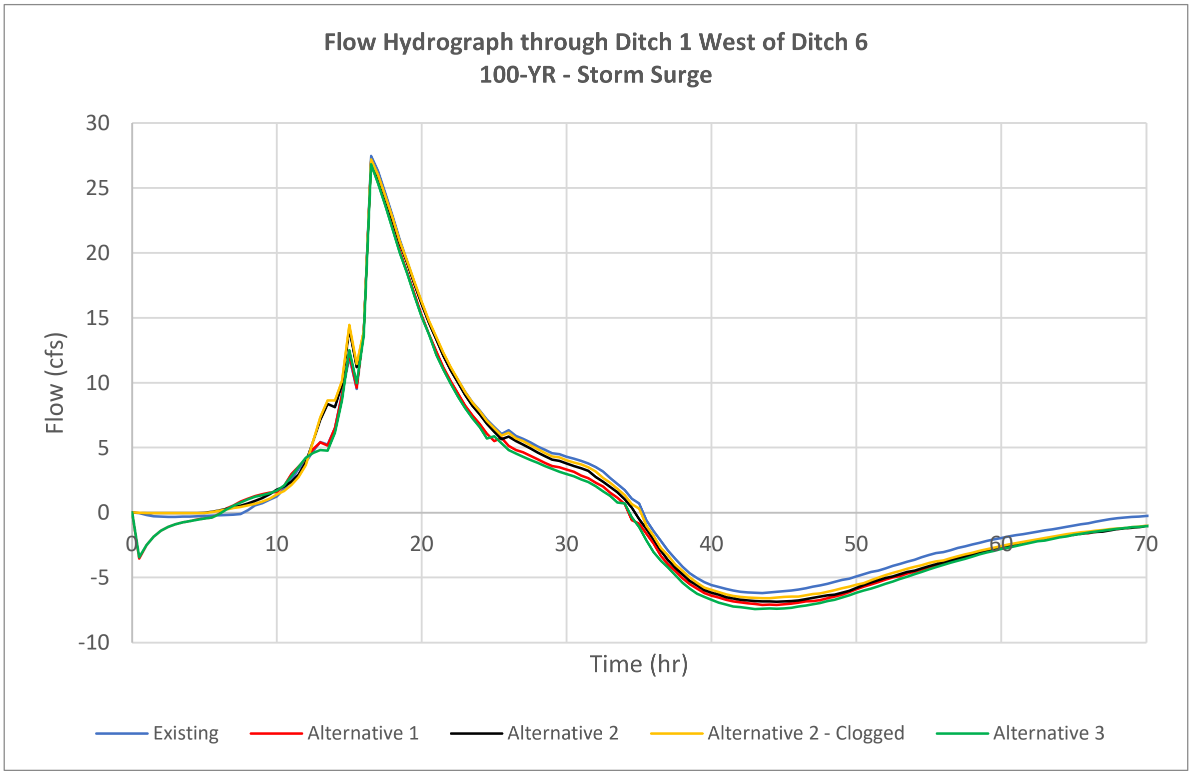
**Figure A64**

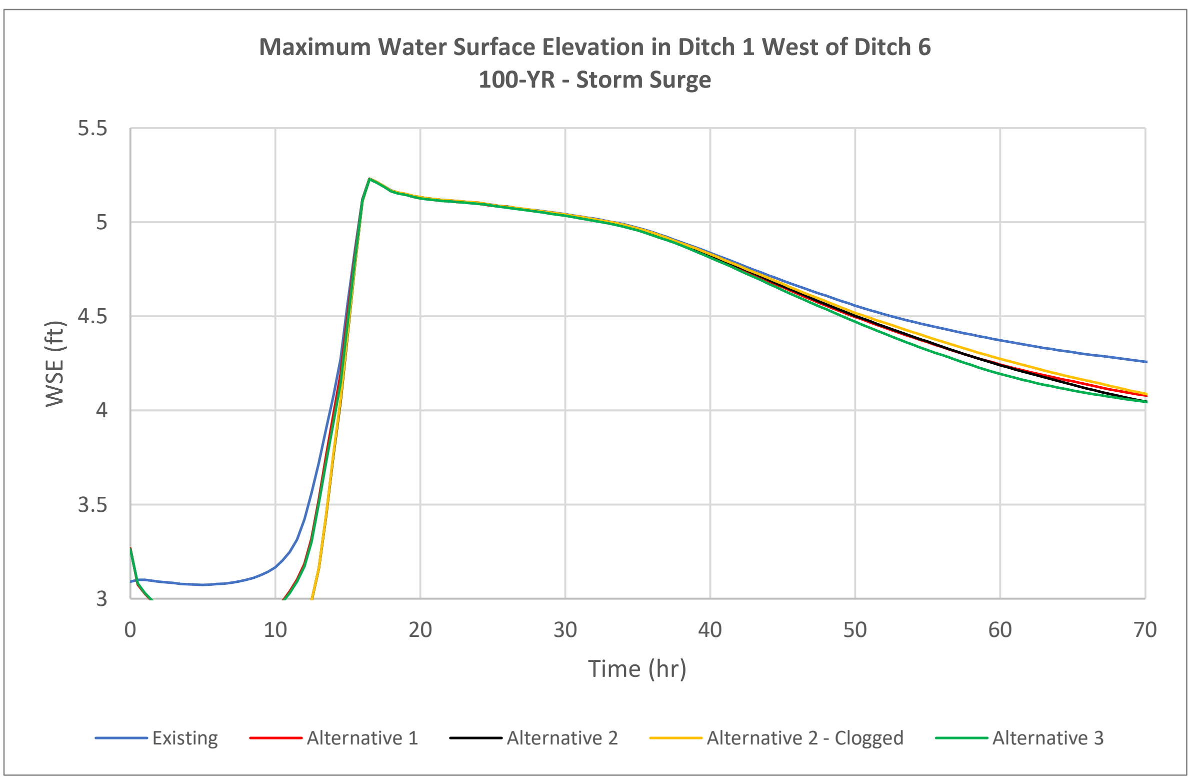



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

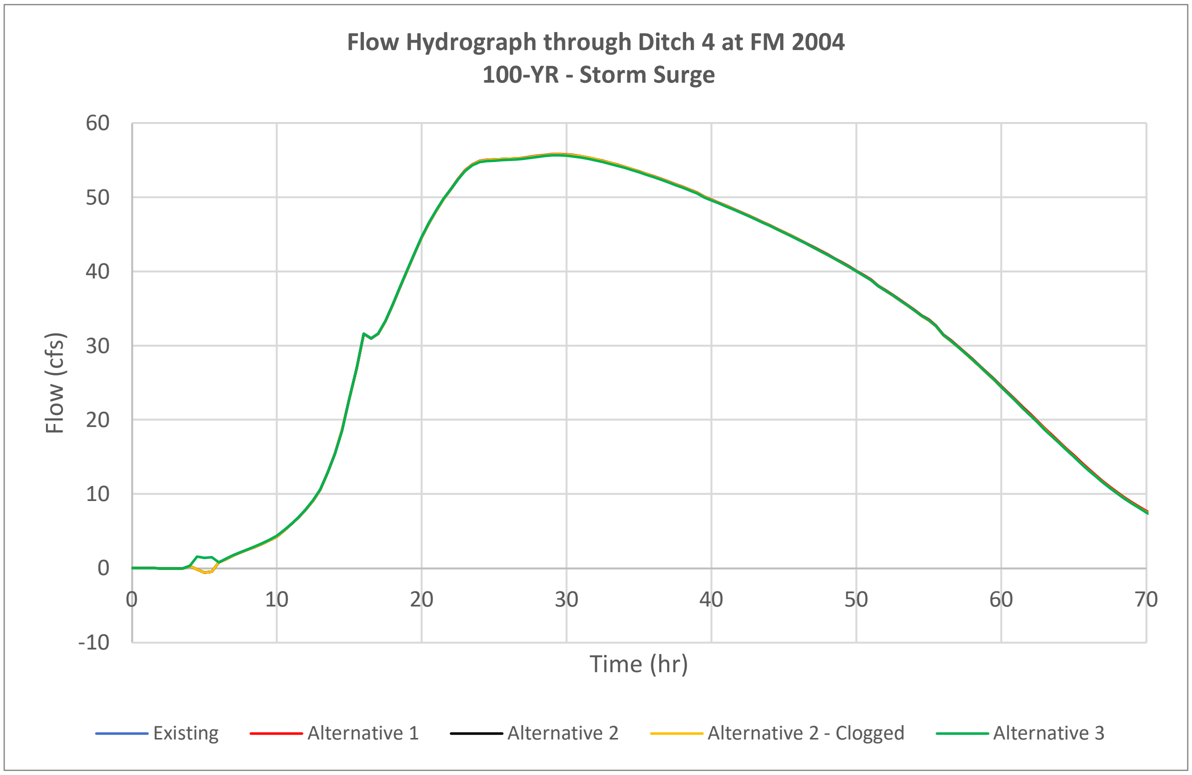
**Figure A65**

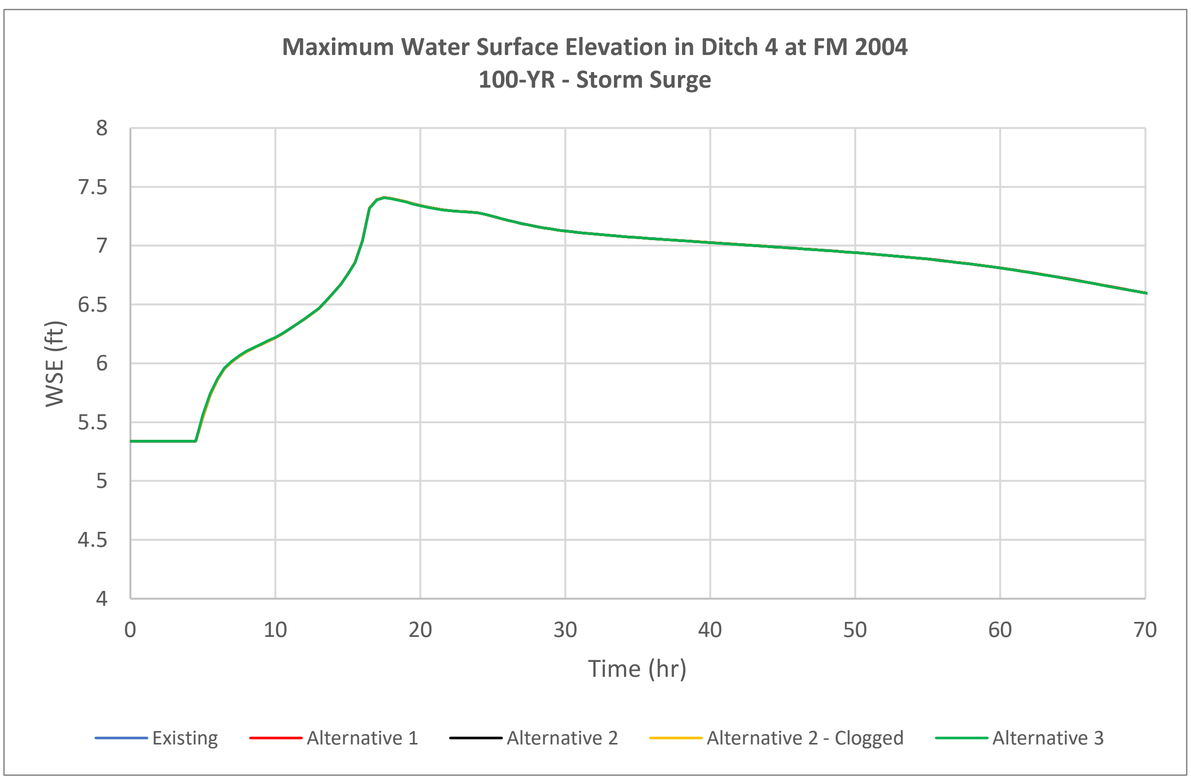



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

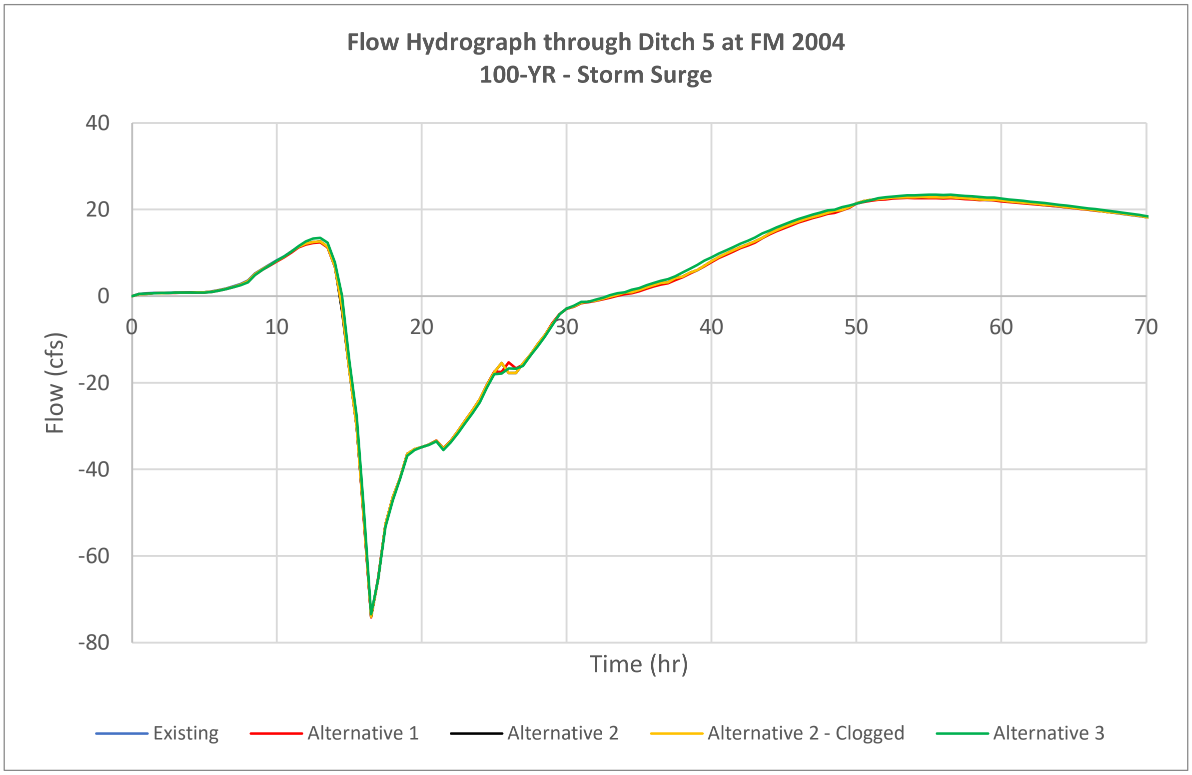
**Figure A66**

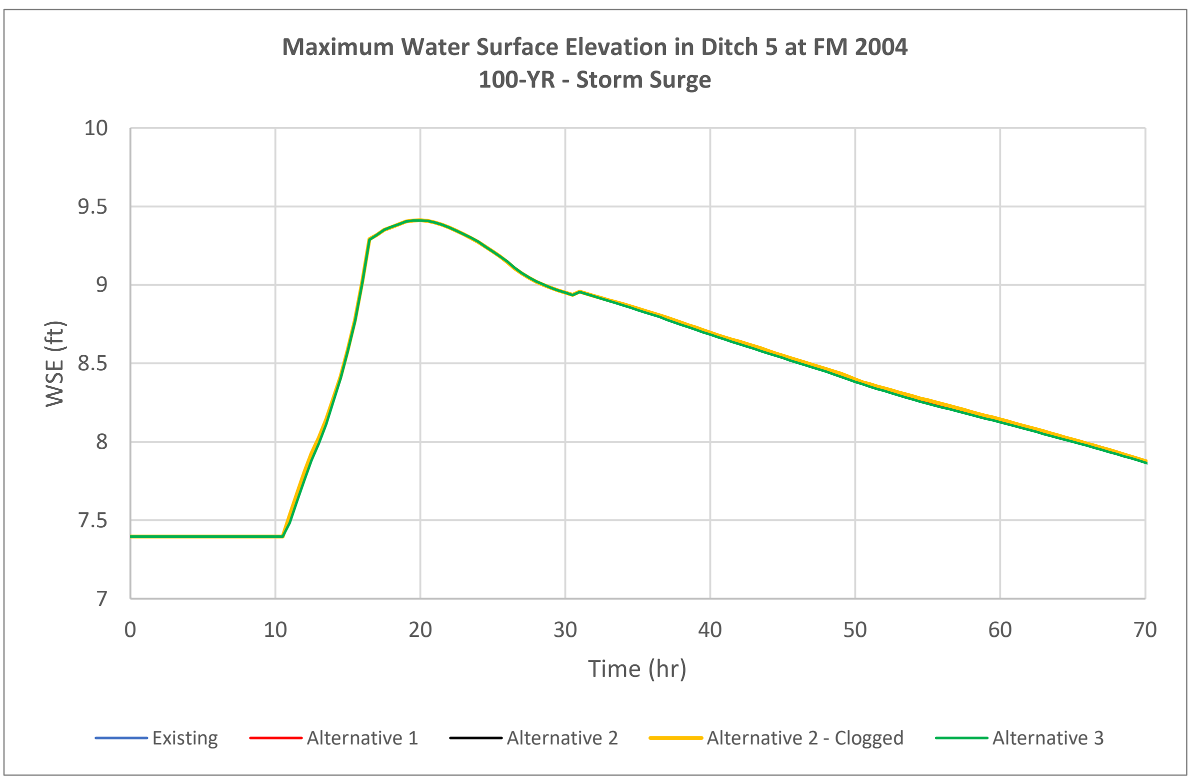



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

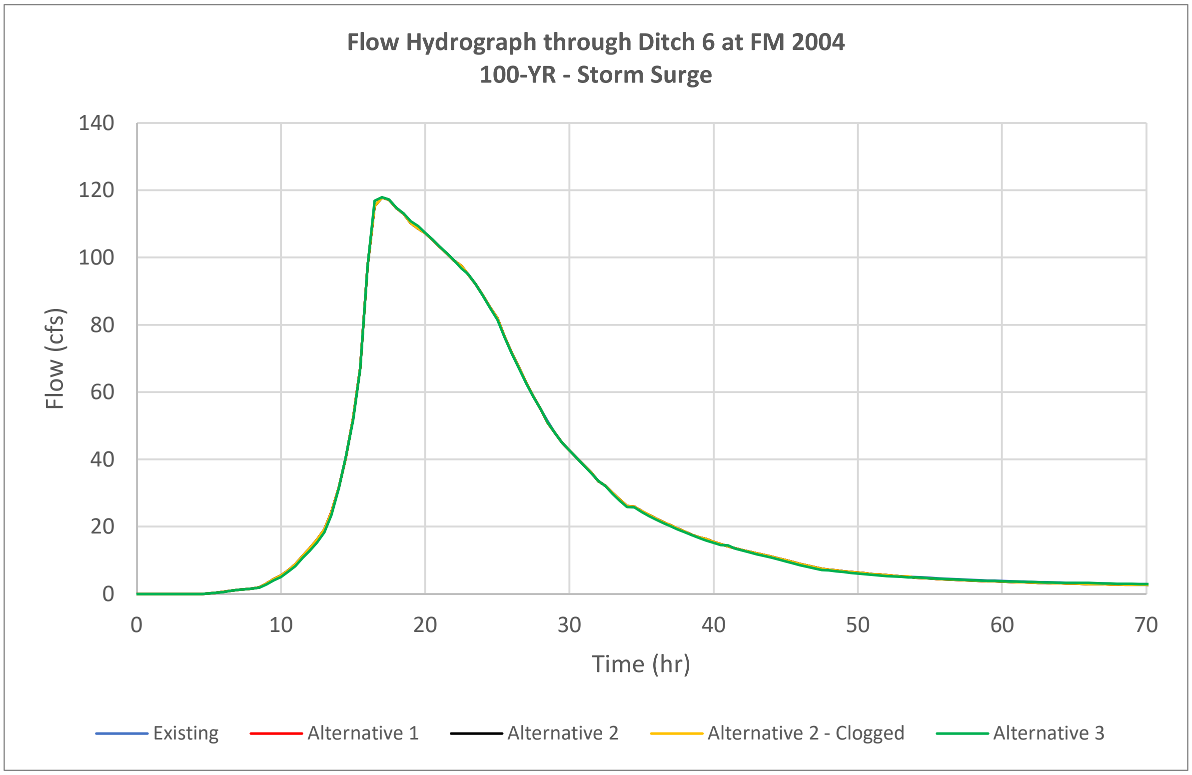
**Figure A67**

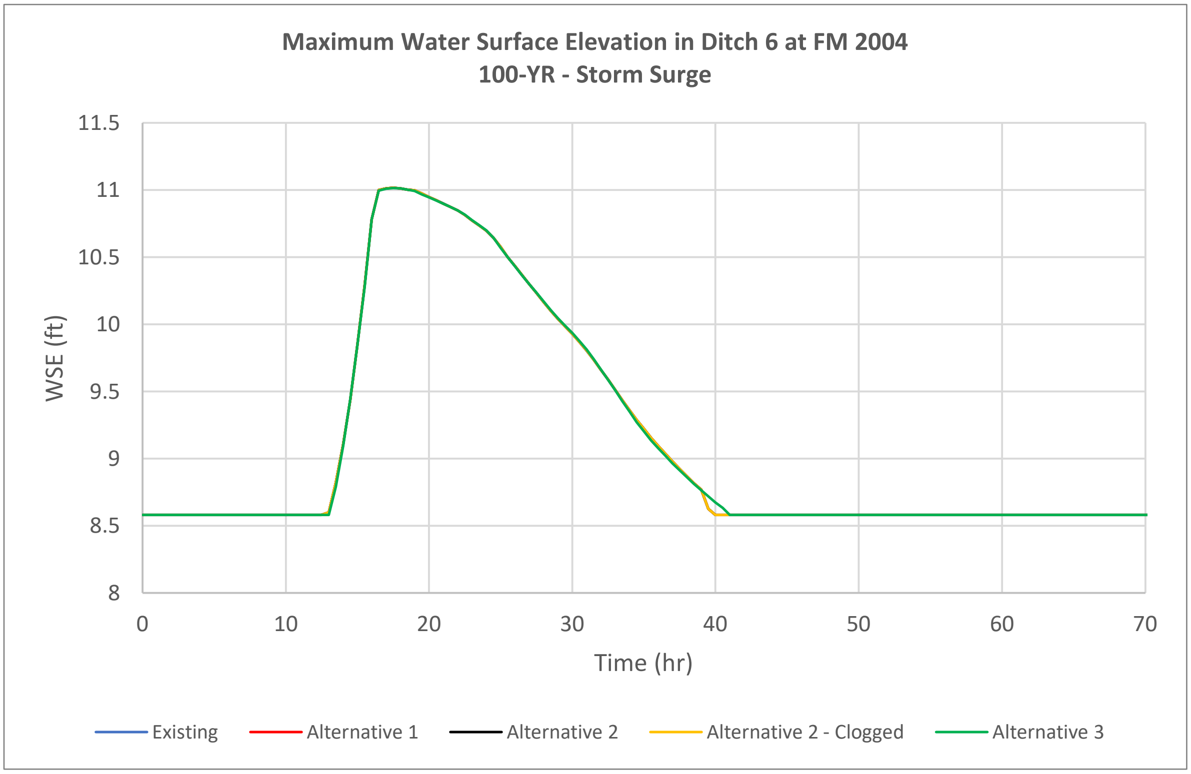



*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*

**Figure A68**




*Note: Each plot shows hydrographs for all five hydraulic conditions. Plots that appear to show fewer than five hydrographs indicate overlapping hydrographs with minimal to no difference.*