HEC-RAS 2D
MODELING GUIDELINES
for Site Development

HARRIS COUNTY FLOOD CONTROL DISTRICT

June 2019

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SECTION 1 - INTRODUCTION

1.1 Preface

The *Two-Dimensional Modeling Guidelines for Site Development* document establishes standardization for the submittal of the Hydrologic Engineering Center's River Analysis System (HEC-RAS) two-dimensional (2D) models submitted to the Harris County Flood Control District (HCFCD). These guidelines will maintain consistency in the approach, parameters, and supporting data used by the engineering community. These guidelines assume the reader knows how to use HEC-RAS to perform one-dimensional (1D) unsteady flow modeling and focuses on HEC-RAS 2D modeling capabilities.

HCFCD has developed the following guidelines to define the requirements for submitting HEC-RAS 2D models to HCFCD for reviews, approvals, and/or permits. These standards help ensure models and supporting information are consistent for ease of understanding, updating, and incorporating the models into future changes.

All engineering submittals should follow good engineering and modeling practices, and projects must be designed to support the conclusions of the modeling. These particular modeling standards apply within the jurisdictional limits of Harris County.

HCFCD highly recommends that at the project initiation phase a meeting be held with HCFCD Watershed Management Department. At this meeting HCFCD will indicate when a 2D analysis must be included to support No-Adverse Impact (NAI) drainage reports.

1.2 Application of HEC-RAS 2D

The use of HEC-RAS 2D to document or support Hydrologic and Hydraulic (H&H) studies and designs is allowed by HCFCD. Currently, the use of HEC-RAS 2D will not be accepted for modification of Federal Emergency Management Agency (FEMA) mapping or models through HCFCD's Letter of Map Revision (LOMR) Delegation Program. However, a HEC-RAS 2D model can be used in support of modifications made to FEMA models and mapping. The use of HEC-RAS 2D can also be used in support of No Adverse Impact studies with prior permission of HCFCD. Regardless, the modeling should be performed using the most current version of the software available from United States Army Corps of Engineers (USACE) Hydrologic Engineering Center (HEC). Many projects that may require the use of the HEC-RAS 2D program could include, but not be limited to, projects with large offsite drainage areas, projects modifying sheet flow patterns, and linear projects. A pre-project meeting is ***highly recommended*** with HCFCD when using HEC-RAS 2D to discuss the approach and assumptions.

These Modeling Guidelines provide a recommended minimum level of analysis and provide an insight into the expectations of the reviewers when using HEC-RAS 2D. In addition, the engineer must demonstrate that the proposed project is in conformance with both Harris County Regulations or others as applicable and the Harris County Flood Control District (District) Policy Criteria & Procedures Manual (PCPM) and that the proposed project will not adversely impact flood risk upstream, downstream, and adjacent to the project.

When the HEC-RAS 2D model is to be used as a tool to support HEC-RAS 1-D modeling impact analyses, the HEC-RAS 1D model must show no adverse impact. In addition, the goal is to demonstrate no increase in any cell grid within the HEC-RAS 2D model, when used as a tool to support the HEC-RAS 1D model. Given the large number of cells typically used in 2D modeling, it is conceivable some may show a slight increase or decrease based upon computational accuracy. In instances where minimal impacts occur, the engineer must develop alternatives to reduce the impacts within the mathematical limits of the model. The engineer shall document the computational nuances with a qualitative analysis. The engineer must explain and justify any increase and validate that it does not represent a change in flood risk.

When the HEC-RAS 2D model is to be used as the impact analysis by itself, the HEC-RAS 2D model must show no adverse impact upstream, downstream, and adjacent to the project. An adverse impact is defined as a water surface increase greater than 0.00 feet.

SECTION 2 - SUPPORTING DATA FOR MODELING

2.1 Introduction

Various types of supporting maps and datasets are required for the development, update, use, and proper understanding of H&H models. The following sections outline the available datasets, providing information on how to obtain each relevant dataset as well as providing specific guidance on dataset usage.

2.2 Topography

2D modeling is highly dependent on the resolution and detail of the underlying Digital Elevation Model (DEM). For each computation cell within a HEC-RAS 2D model, a stage storage curve and terrain profile along each cell face is computed. The data is extracted from the underlying terrain to develop geometric property tables for each cell and cell face. The highest resolution light detection and ranging (LiDAR) data available should be used when performing 2D modeling. **Within Harris County the Houston-Galveston Area Council (H-GAC) provides Non-Uniform Subsidence Adjustment (NUSA) 2008 LiDAR Data at a 5-foot resolution and NUSA 2018 LiDAR available at a 3-foot resolution.** The modeler should obtain the LiDAR dataset from H-GAC and coordinate with HCFCD concerning which data set to use. If alternate topography for 2D modeling is being used coordinate with HCFCD. Care must be taken to verify that terrain data is on a consistent datum and the same as that of any 1D modeling that is to be used or compared to when performing impact analysis. H-GAC NUSA 2008 LiDAR is available on NAVD 88, 2001 adjustment (GEOID99) datum and 2018 LiDAR are available on both NAVD 88, 2001 adjustment and NAVD 88 (GEOID12B). Note that as of October, 2018, the NAVD 88, 2001 adjustment must be used for FEMA submittals, as required by FEMA.

Terrain data must fully encompass the area being modeled in 2D. The 2D extents should encompass the potential contributing drainage area to project areas for the 1-percent annual exceedance probability (AEP) event at a minimum. Flow tracings can be used to verify that contributing areas have been fully captured in the 2D flow area when precipitation is being employed as a boundary condition.

Note that reprocessing the LiDAR data set to a larger pixel size than that provided by H-GAC is generally not accepted and would require approval by HCFCD. It should also be noted that when merging terrain data sets in HEC-RAS Mapper, output files will adopt the smallest resolution of the combined terrain files. This can result in significant increases in model output file sizes. It is highly recommended that when combining terrain files, the supplemental terrain(s) match the resolution of the H-GAC LiDAR being used.

2.2.1 Pre-Project

Use the H-GAC LiDAR NUSA dataset (2008 or 2018) as the base topographic dataset for modeling purposes unless otherwise directed by HCFCD. The use of any topographic data source other than the current version provided by H-GAC will require special permission from HCFCD prior to submittal of HEC-RAS 2D models.

Additionally, known grading from projects not reflected in the 2008 or 2018 LiDAR are to be added to the existing Terrain layer as part of the pre-project conditions; this can be done directly within HEC-RAS Mapper by adding a raster elevation grid of the project area to the base LiDAR when creating a terrain layer. Coordinate with HCFCD for inclusion of any significant existing grading projects that are to be included in the base condition analysis.

2.2.2 Post-Project

Modeling of proposed sites requires modification to the 2008 or 2018 LiDAR datasets to reflect the proposed conditions grading. New topography may be created by supplementing the existing conditions model terrain within HEC-RAS Mapper's New Terrain tool or by using traditional software, such as Civil 3D or ARCGIS. Any topography which is not part of the modeler's project should be considered pre-project in order to isolate the impacts of the proposed project.

SECTION 3 - MODEL DEVELOPMENT AND MANAGEMENT

3.1 Introduction

The following section is designed to standardize the methodologies and assumptions used for developing HEC-RAS 2D models within Harris County.

3.2 Model Naming Convention

The enforcement of a unique naming convention for all watersheds, streams, and major H&H modeling elements is essential for the proper handling of modeling data in a geospatial environment. The traditional system for the naming of first, second, and third order streams, and then major watersheds and sub-basins has been adopted as the basis for the HCFCD Model and Map Management (M3) system.

The naming convention for components of the HEC-RAS 2D model are to be consistent with those detailed in Appendix A of the HCFCD *Hydrologic and Hydraulic Modeling and Management Guidelines*, dated January 2008. Additional element names within HEC-RAS are:

- 2D Flow Area

  Represents digitized regions within the HEC-RAS model simulating flow using 2D equations and a non-uniform computational mesh. A model can have one or multiple 2D flow areas depending on modeling requirements and modeler preferences. The 2D flow areas may also be combined with 1D river reaches with 1D cross-sections.

- Internal Flow Area Connector

  Used within 2D flow areas to pass flow from one or more cells, through a user-defined structure, to one or more adjacent cells. Typical use would be modeling culvert crossings and/or a proposed roadway embankment within the 2D area. An additional use for internal connectors is to identify locations where flow results within the 2D area are quantified and stored for review. When culvert geometry is included in a connector the modeler can provide individual barrel centerline coordinates. By providing coordinates the culvert can accept and deliver flow to cells not located directly adjacent to the connector. This is useful for when culverts span multiple 2D flow area cells.

- External Storage Area Connectors

  Used to hydraulically connect storage areas, either a 1D storage area, a 2D flow area, or a combination thereof.

3.2.1 2D Flow Areas

Name 2D flow areas based on the single letter unit name of the watershed combined with the four-digit identifier assigned to the 2D flow area. The four-digit identifier will be an integer beginning with the number six (6). 2D areas may include portions of multiple watersheds. In most cases where this occurs, there may be a diversion from one watershed to another. The preferred identifier is to use the watershed unit name for the watershed that is diverting flows.

For example, E6001 represents an area in White Oak Bayou where:

- E indicates the 2D area is in White Oak Bayou,
- 6 indicates the element as a 2D area, and
- 001 (the three digits after the 6) uniquely identifies the 2D area within the watershed.

3.2.2 Internal 2D Flow Area Connectors

Identify the internal 2D flow area connector by using the 2D flow area four-digit identifier described in Section 3.2.1 and combine with _ICXXX. The last three digits correspond to the connector number.

For example, E6001_IC001 refers to internal connector 001 within 2D storage area E6001, where:

- IC represents the internal connector, and
- 001 (the three digits after the IC) uniquely identifies the connector.

3.2.3 External Storage Area Connectors

Identify the connected 1D storage or 2D flow areas using the 1D or 2D area's four-digit identifier described in Section 3.2.1 and combine with _ECXX_.

For example, E6001_EC01_W6002 where:

- EC indicates an external connector connecting 2D areas in White Oak and Buffalo Bayous, and
- 01 (the two digits after the EC) uniquely identifies the external connector.

3.2.4 Land Use Roughness Classification

Users must have land cover dataset(s) to utilize spatially varying Manning's n values within 2D flow areas. Land cover data is also required to utilize the Manning's n Regions tool within HEC-RAS's geometry editor to specify user-defined n value overrides used to assist in calibrating a model for specific regions of a 2D flow area. When generating the Land Use raster file within HEC-RAS 2D, a raster cell size of 10 feet or less is required.

Table 3-1 provides suggested Manning's n values for typical land use classifications within Harris County based on H-GAC Land Classifications. The land classifications listed in Table 3-1 are based on the H-GAC Land Classifications taken from the *H-GAC Land_Cover_2015_10_Class_HGAC.gdb*. Updated versions may be available and the modeler should rely on the most recent available data. Note that for the Developed Intensity classification, the High, Med, and Low qualifiers refer largely to the percent impervious cover present. For example, a Developed High Intensity land classification refers to large commercial areas such as shopping centers that are made up largely of paved areas. It is recommended that the H-GAC land classifications be supplemented to include large building footprints in order to force ineffective flow computations through the structure footprint area. See Appendix A for examples of typical land classifications using aerial photography as it pertains to the H-GAC land classifications.

Table 3-1 - Manning's n value suggestions for flood routing within a 2D domain

Land Classification	HGAC Code	Minimum Manning's n-Value	Recommended Manning's n-Value	Maximum Manning's n-Value
Open Water	1	0.01	0.02	0.03
Developed High Intensity	2	0.02	0.03	0.06
Developed Med Intensity	3	0.06	0.18	0.20
Developed Low Intensity	4	0.06	0.16	0.20
Developed Open Space	5	0.04	0.06	0.10
Barren Lands	6	0.02	0.03	0.04
Forest/Shrubs	7	0.18	0.25	0.30
Pasture/Grasslands	8	0.15	0.22	0.30
Cultivated Crops	9	0.1	0.17	0.30
Wetlands	10	0.03	0.08	0.10
Building	N/A	10	10	10
Pavement	N/A	0.015	0.02	0.025

The modeler must coordinate with and obtain concurrence from HCFCD for assigned land uses within the limits of the HEC-RAS 2D model differing from the values in table Table 3-1. Single n values are defined for various land classification to provide uniformity in model development by various modelers. It is recommended to adhere to the recommended values in Table 3-1 unless gage data is available for model calibration. In cases where the modeler feels other n values are necessary or adjustment is needed, explanation must be provided explaining the need to define values beyond the minimum and maximum values presented in Table 3-1. The suggested Manning's n values were calculated by interpreting information from the "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains" produced by the U.S. Department of Transportation, Report No. FHWA-TS-84-204. The referenced values were related to interpretation of values for calculating n value in floodplains.

HEC-RAS 2D currently allows for only a single n value to be assigned to a cell face. The cell face n value is selected based on the n value which covers the largest percentage of the cell face. When modeling mixed-use areas, smaller 2D mesh cell sizes may be required to account for differences in n values. 2D flow area cells may experience a wide range of flow depths over the time series for which the model is being run. Currently, HEC-RAS does not allow for a depth varied Manning's n value. As such, the modeler must use judgement in selecting a proper n value for evaluation. Final n value selection may need to be selected based on previous model results and review of the flood depth durations. Generally, the shallower the flow the higher the Manning's n value would be.

The n values on the following page are recommended values for use in the 2D domain for both "Riverine" and "Precipitation on Grid" flood modeling. The recommended values represent a composite n value for the various land classifications. These recommended composite n values will be most commonly applied to watershed wide models within Harris County. Manning's n value selection has a large influence on flow rates in HEC-RAS 2D when a precipitation on grid boundary condition is applied. When attempting to use precipitation on grid to develop runoff hydrographs, the n values will likely require adjustment to provide reasonable comparison to standard Harris County methodology for computing peak flow. When an impact analysis is being performed, it is likely that more detailed definition of n values will be required along with higher resolution in the 2D domain mesh in the project vicinity such that individual cell faces can represent the underlying land classification. The Manning's n values within the project area for impact analysis should be based on the actual underlying surface cover (grass, concrete, etc) and not the composite Manning's n values presented in the following table.

3.3 Hydrology

In addition to providing flow to a 2D flow area by connecting to 1D river reaches and storage areas, there are three methods for assigning hydrographs to a 2D surface. These methods allow the user to develop a 2D model without the need for 1D river reaches.

3.3.1 External 2D Flow Hydrographs

External 2D flow hydrographs are assigned to the boundary of a 2D flow area. The cell limits along the boundary to which the external hydrograph is applied should consider the likely area of inundation, similar to how a 1D cross-section would be drawn across a floodplain. Flow hydrograph boundary conditions also require an estimated energy slope for computing normal depth. The energy slopes should be estimated in the direction of flow from the terrain in the area where flow concentration is anticipated or from previous/alternate model results.

The flow hydrographs can be read directly from HEC-HMS DSS files or manually entered. The modeler must confirm the correct junction or watershed from HEC-HMS is entered into the model. The hydrographs being entered must be for flow upstream of the 2D area and not include reach routings through the same area being modeled as a 2D flow area. This is to avoid "double routing" the hydrograph, i.e., routing the hydrograph first in HEC-HMS and then again in HEC-RAS through the 2D flow area.

3.3.2 Internal 2D Flow Hydrographs

Internal 2D flow hydrographs are assigned within the boundary of a 2D flow area using an internal boundary condition line. This is often useful for 2D modeling of channels and detention basins when hydrographs are applied directly within the 2D domain. The assigned internal flow hydrograph is distributed across the cells based on the percentage of line length that crosses the cells. Flow hydrograph boundary conditions also require an estimated energy slope for computing normal depth. The energy slopes should be estimated from the terrain in the direction of flow in the area where flow concentration is anticipated or from previous/alternate model results. The flow hydrographs can be read directly from HEC-HMS DSS files or manually entered. The modeler must confirm the correct junction or watershed from HEC-HMS is entered into the model. The hydrographs being entered must not include reach routings through the same area being modeled as an internal boundary in the 2D flow area. This is to avoid "double routing" the hydrograph, i.e., routing the hydrograph first in HEC-HMS and then again in HEC-RAS through the 2D flow area.

3.3.3 Precipitation (Internal 2D Flow)

The Precipitation On-Grid boundary condition is particularly useful when evaluating sheet flow patterns within a drainage area. The boundary condition applies precipitation evenly over the 2D area, allowing HEC-RAS to route the rainfall through the mesh, producing runoff hydrographs. The use of precipitation on grid requires careful review of model results when flow rates and volumes are being considered for design.

When 2D modeling includes the Precipitation On-Grid boundary condition, for design of flow conveyance through the project area, flow results must be validated using the current HCFCD PCPM criteria to avoid potential conflicts with existing or future development adjacent to the proposed project. This is to avoid issues where previous or future project designs may be (have been) based on traditional methods presented in the HCFCD PCPM. These traditional methods may produce significant differences in design flow rates as compared to 2D modeling. The 2D model results can however be used to help define drainage limits and confirm no adverse impacts to surrounding peak WSEs due to the project. *Variance from use of HCFCD PCPM methodology for designs using flows predicted by a Precipitation On-Grid 2D model must receive prior approval by HCFCD.* Generally acceptable differences in flow rates computed by traditional and Precipitation On-Grid methodologies for design flow purposes is 5% or less for the 1-percent AEP (100-year) event. A difference in computed flow rates of up to 10-percent may be acceptable for lesser storm events with HCFCD approval.

Currently, HEC-RAS 2D does not calculate loss rates, so the modeler must determine an applicable precipitation rate to use. The amount of initial abstraction occurring within a 2D surface (where sinks and obstructions within ditches are prevalent) can greatly influence runoff rates and volumes in a 2D analysis. This is particularly true for higher frequency events where initial abstraction can make up a large percentage of the total rainfall volume. Often within urban areas, streets are graded to sumps, which are then drained through storm sewers. The sumps can store significant volumes and greatly impact both runoff rates and volumes when subsurface drainage is not being accounted for in the model. Similarly, channels or roadside ditches where driveways or culvert crossings are represented in the LiDAR data can store significant volume upstream of the embankments if not accounting for subsurface structures (e.g., culverts/bridges). Figure 3-1 illustrates how poorly drained terrain can capture a significant amount of precipitation. Unless the area is well drained and initial abstraction within the surface is minimal, precipitation without the consideration of losses is recommended when applying precipitation to grids. Precipitation values without losses can be read directly from the HEC-HMS as PRECIP-INC. Likewise, precipitation, considering losses, can also be read directly from HEC-HMS as PRECIP-EXCESS.

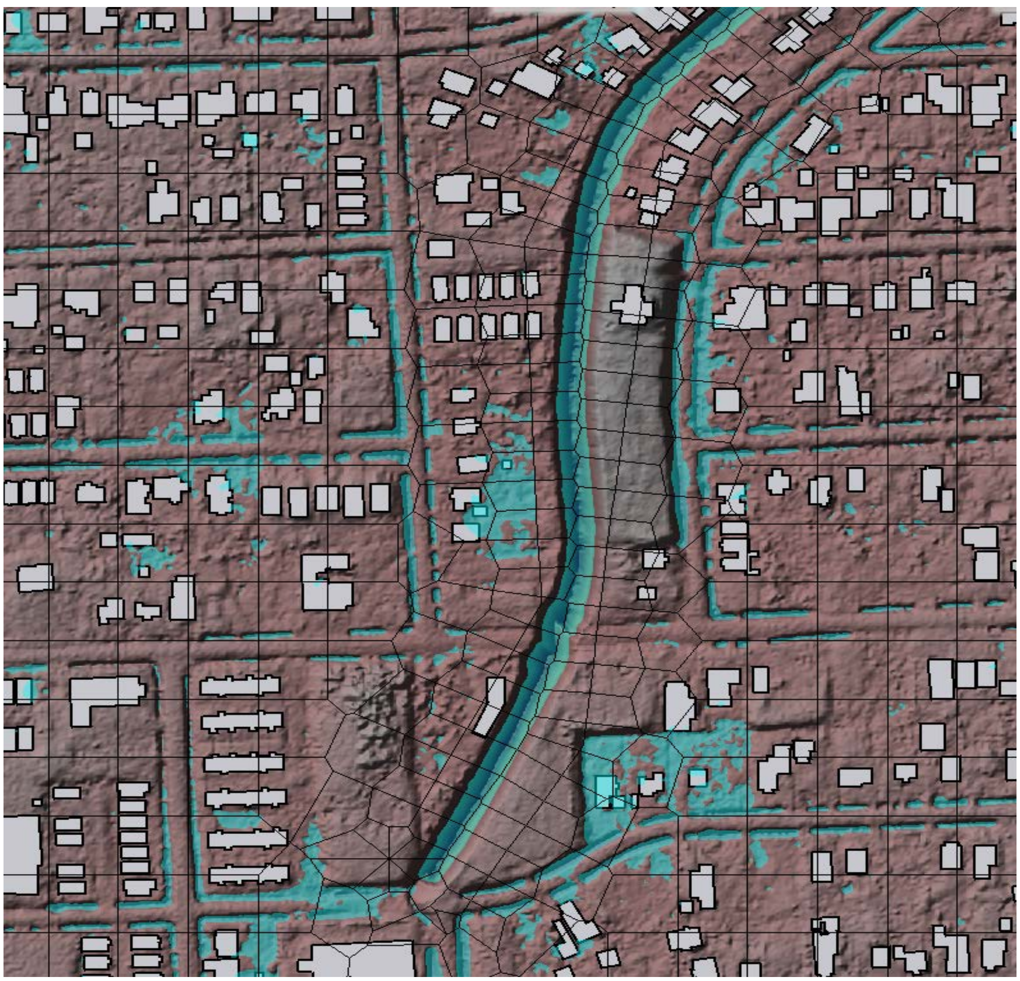

Figure 3-1 - Depiction of Precipitation Volume Captured in Poorly Drained Terrain

Review of the computation log file may provide insight into the amount of initial abstraction that is occurring within the 2D flow area. If the 2D model is allowed to run a sufficient amount of time past the last precipitation depth, such that the "Ending Volume" reported in the log file can be assumed to be representative of the initial abstraction volume, a comparison can be made to the HEC-HMS computed loss rates. Using the "Ending Volume" value to compare to the HEC-HMS computed losses the modeler can make an informed decision as to which precipitation record is most appropriate, Precip-Inc or Precip-Excess. For example, a 24-hour 2-year Precip-Inc depth is applied across an 1,875 acre 2D flow area. The modeled simulation time is 72-hours. The computational log indicates that out of the 687-acft of supplied rainfall volume, 215-acft of volume remains in the 2D flow area portion of the model. This 215-acft is equivalent to 1.4-inches of losses (215/1875 x 12). The HEC-HMS model computed loss rate for a 2-year, 4.4-inch rainfall, up to the start of direct runoff occurring, is 1.1-inches with total losses of 2.1-inches. This comparison indicates that use of the Precip-Inc would underestimate losses by 0.7-inches; 1.4" captured in 2D model versus 2.1" computed in HEC-HMS. Precip-Excess would overestimate losses by 1.4-inches (2.1 computed in HEC-HMS + additional 1.4" captured in 2D model). Under this scenario the Precip-Inc would be the recommended precipitation to use with a closer match to HEC-HMS computed losses.

As of HEC-RAS version 5.0.5, only one rainfall record can be assigned to a single 2D flow area. If multiple rainfall records are needed, the modeler will need to create separate 2D flow areas for each area, and then join the 2D flow areas with external connectors. When selecting the 2D flow area extents for applying multiple rainfall records, the modeler should consider use of either HCFCD watershed catchments or the Thiessen Polygon method to allow varying precipitation rates to be applied within areas modeled in 2D. Future versions of HEC-RAS will allow for spatially varied rainfall to be applied within a single 2D flow area.

The modeler must attempt to validate the peak flow rates computed by the HEC-RAS 2D model against traditional hydrologic methods if the design is to be based on 2D model flow results. For example, if using Precipitation On-Grid, the modeler can use the RAS Mapper particle tracing results of the 2D model to estimate the contributing drainage area, travel path, and velocity. Using these values with traditional hydrologic methods, such as Site Runoff Curves or Rational Method, the modeler can verify the reasonableness of the 2D model computed flow rate at the point of interest. For large events, such as the 1% AEP, 2D model results often match well with the HCFCD Site Runoff Curves. For lesser, more frequent events (such as the 50% and 10% AEP events), RAS 2D tends to predict flows much less than that estimated with the Site Runoff Curves or Rational Method. The lesser agreement in flow rates found in higher frequency rainfall events may be attributed to the RAS 2D flow areas capturing greater losses in the form of initial abstraction due to depression storage. The initial abstraction can be a larger percentage of the total rainfall volume for frequent events than that for larger, less frequent events resulting in lower runoff volumes and greater attenuation. Generally acceptable differences in flow rates computed by traditional and Precipitation On-Grid methodologies for design flow purposes is 5% or less for the 1-percent AEP (100-year) event. A difference in computed flow rates of up to 10-percent may be acceptable for lesser storm events with HCFCD approval.

3.4 Hydraulics

3.4.1 Mesh

Mesh size selection is largely dependent on land use, size of study area and the level of detail the study requires. Cell sizes must be at a scale accounting for the differences in n values within urban areas that the modeler intends to evaluate. It is recommended that in urban areas a cell size be selected, so that cell faces generally represent the street right of way (ROW) and building footprints as separate cell faces, which will allow for the accounting of the structures' impact on flow. Currently, HEC-RAS 2D allows for only a single n value to be assigned to a cell face. The cell face n value is selected based on the n value, which covers the largest percentage of the cell face. When modeling mixed-use areas, smaller 2D mesh cell sizes may be required to account for differences in n values.

In urban areas where the study area is limited to the vicinity of the project site and detailed results are required, for example when performing impact analysis that required evaluating water surface elevations at the individual lot level, the maximum recommended cell size is 100 by 100 feet when breaklines are used to define the street pattern. A breakline cell spacing minimum of 70 feet is recommended. If breaklines are not used, the maximum recommended cell size is 25 by 25 feet. The smaller cell size allows for sufficient n value detail of the street, yard and home patterns to be replicated in the mesh. The modeler must adjust the computation interval accordingly. Note: Use of smaller cell sizes will increase model run times.

In urban areas that are part of a watershed wide scale study and detailed results at the individual lot level are not required, for example 1D/2D modeling of a floodplain where the 2D domain is used to convey out of bank flood flow, the maximum recommended cell size is 100 by 100 feet without the need to supplement with breaklines along street centerlines.

In rural areas, minimum cell sizes can be increased as land classifications and their associated roughness become more uniform. A maximum cell size of 200 by 200 feet is recommended for use in rural areas.

Pre- and post-project mesh sizes outside the project limits must be identical to achieve accurate impact comparisons.

Future versions of HEC-RAS will allow for various mesh resolutions to be defined within a single 2D flow area and ability to have multiple n values assigned to a cell face.

3.4.2 Breaklines

Breaklines must be used to define major drainage ways, elevated berms, raised roadways, and other breaks in grade possibly obstructing or collecting drainage. Once models are run, it is advisable to review the mapping result to determine if additional breaklines are required to reflect high ground in the terrain and to prevent flow “leakage” through cells straddling the high ground ridges.

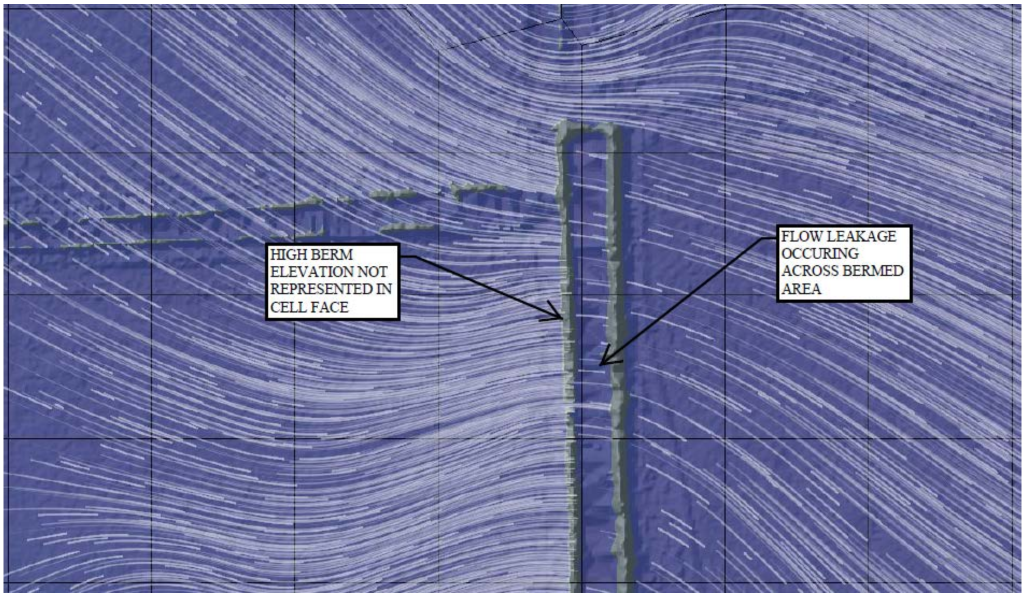

Figure 3-2 - Improper Grid Cell Alignment Allowing Flow “Leakage”

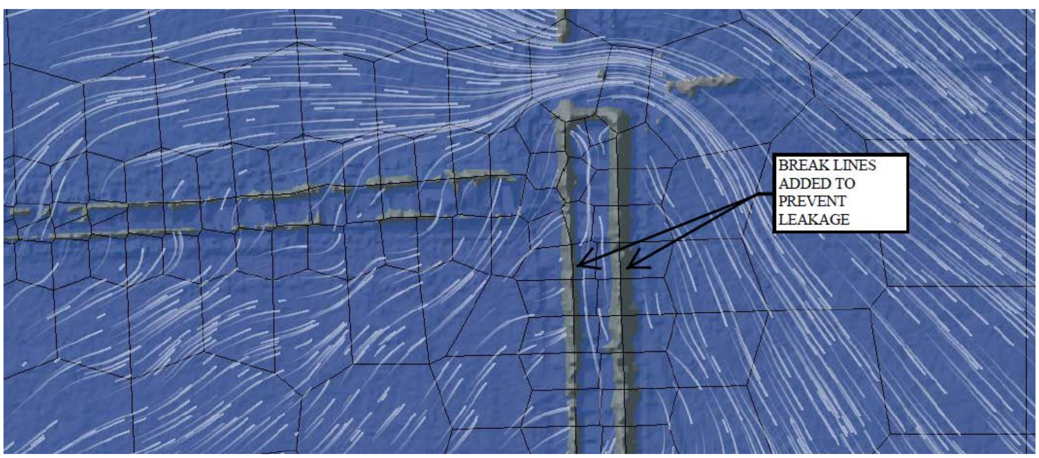

Figure 3-3 - Use of Breaklines to Prevent Flow “Leakage”

In urban areas, breaklines are recommended to be set along the street center line when the study area is limited to the vicinity of the project site and detailed results at the lot level are required for impact analysis. Shapefiles of the roadway and street system within the City of Houston and Harris County are often available to assist in creation of these breaklines. A breakline cell spacing minimum of 70 feet is recommended. The spacing should allow for mixed-use land classification of Manning’s n values along the streets to be adequately represented by cell faces. Breaklines are not necessarily required if the cell spacing is sufficiently small and represents the non-uniformity of the land use present in the urban area when considering the current single Manning’s n value per cell face limitation.

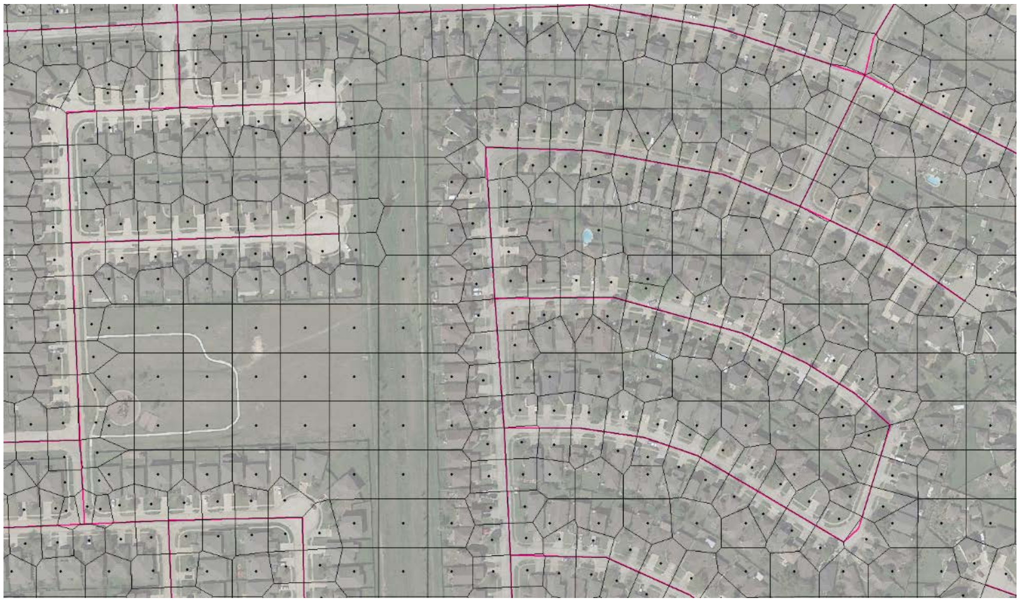

Figure 3-4 - 100’x100’ Grid with 70’ Min Cell Size and Street Center Breaklines

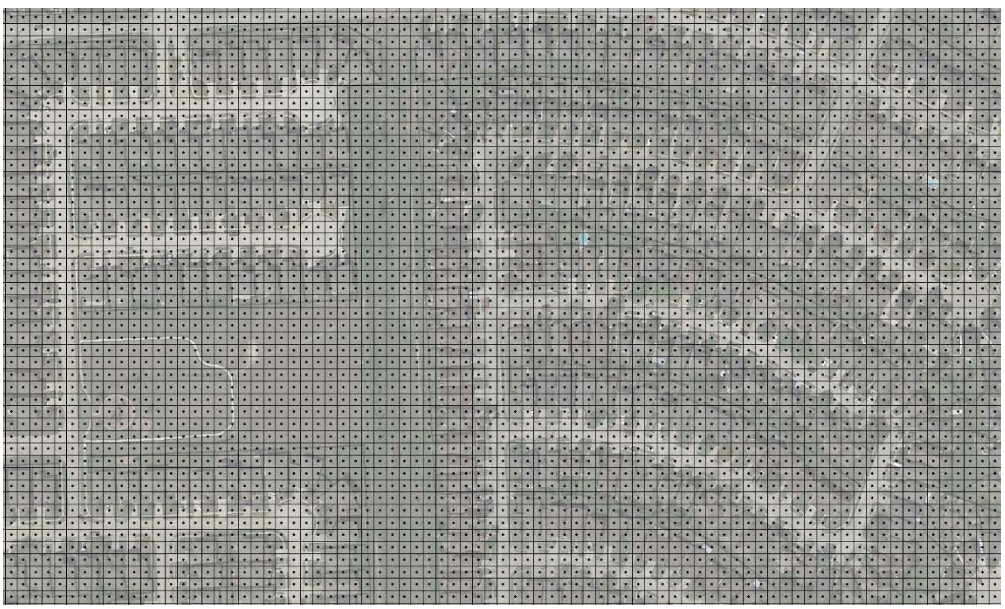

Figure 3-5 - 25’ x 25’ Grid Without Breaklines

3.4.3 Lateral Weirs

Lateral weirs are used to connect 1D riverine models to either 1D or 2D flow areas or to divert flow from the system. When connecting a 1D riverine model to a 2D area, overlap of the 1D cross-sections and 2D area must be avoided, so “double counting” of storage volume does not occur in the overlapping areas. However, a minimal overlap of less than 5-feet is permissible to avoid “slivers in the mapping between the 1D and 2D portions.

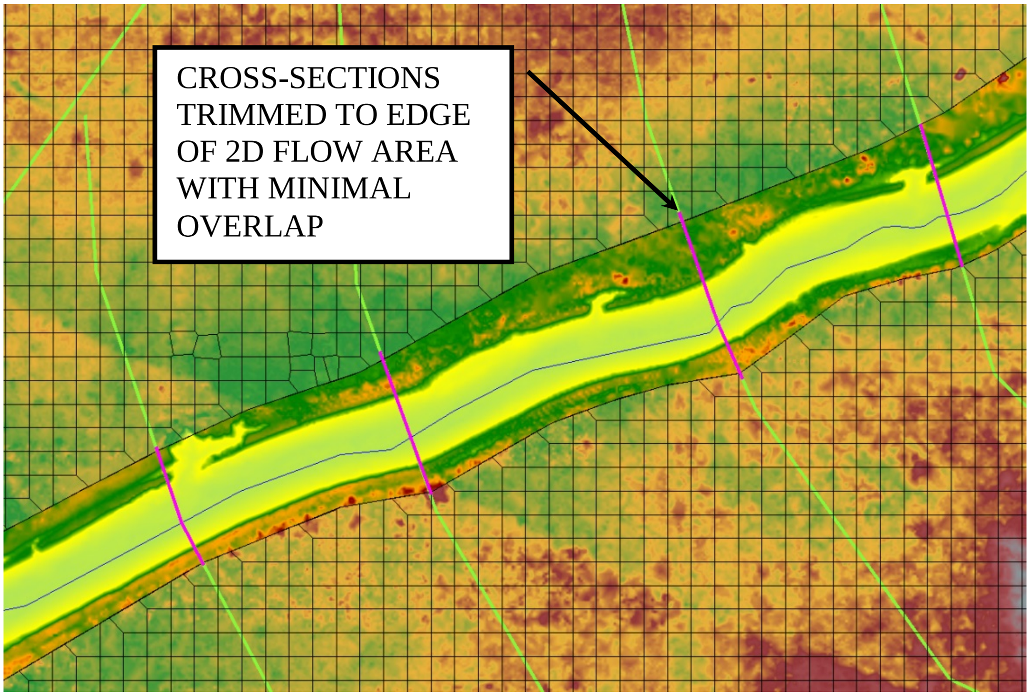

Figure 3-6 - Cross-sections Trimmed to Edge of 2D Flow Area

Lateral weirs may not function as true weirs, and standard weir coefficients may not apply. Care should be used in the proper weir coefficient selection when actual weir flow conditions are not present. The following table provides weir coefficient recommendations as provided in the HEC-RAS *2D Modeling User’s Manual*. The modeler should determine if flow over the lateral structure resembles weir flow or is more representative of the case where flow leaves the channel and enters the floodplain at an overbank elevation near the same elevation as the channel top of bank. Where flow over the lateral can flow through critical depth, the weir equation with a higher standard weir coefficient may be more applicable. The “Use Velocity” toggle is recommended when the lateral is connected to a 2D Boundary.

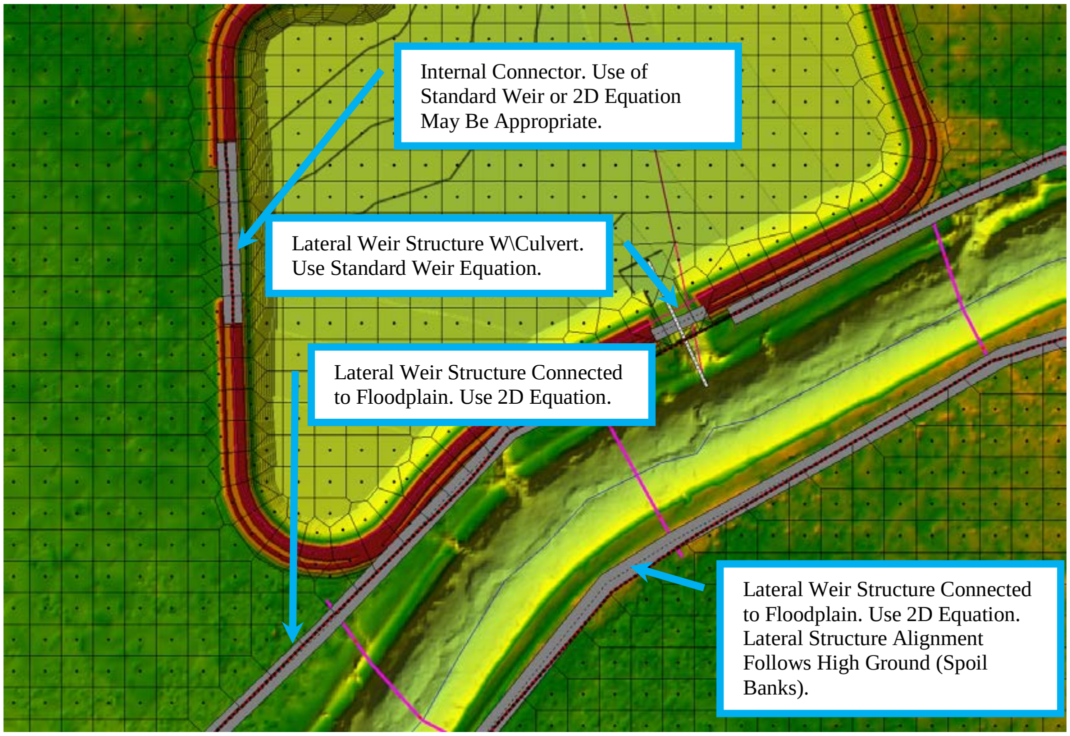

Figure 3-7 - Lateral Weir

Lateral weir lengths should consider logical breaks along the 1D riverine reach and generally be limited to less than a mile in length. By using multiple lateral weirs along a reach versus a single lateral weir, better accounting of the location, flow rate, and volume of diversion to and from the 2D area can be quantified. Laterals crossing channel confluences with a depth greater than 6-feet should be represented as individual lateral weirs. Additionally, it should be noted that no flow transfer occurs across a lateral structure between 1D bounding cross-sections of internal boundaries such as bridges, culverts, and inline weirs. Where flow transfers need to be accounted for near internal structures, the cross-section cut line may need to be graphically adjusted to minimize the distance between bounding cross-sections and allow for full length of lateral to be considered in the flow calculations.

It is recommended that for models of a watershed wide scale, that lateral weirs be modeled using the standard weir equation. The standard weir equation has been found to provide higher model stability than that of the 2D equation. A typical weir coefficient of 0.5 is recommended when the lateral is connecting the channel to the 2D domain at nearly the same elevation as the channel top of bank. The exception being lateral weirs representing channel confluences where the tributary channel depth exceeds 6-foot in depth. For channel confluences where the tributary and main channel flowline elevations are nearly equal, a weir coefficient of 2.0 is recommended. This high weir coefficient results in a minimum head difference being computed as it is likely that the WSE at the confluence are nearly equal in both channels throughout the modeled storm duration.

For site specific studies, the use of the 2D equation on lateral weirs may be more appropriate as the 2D flow area mesh will likely be at a smaller scale and ran with a sufficiently small computation interval capable of providing sufficient model stability. The "Use Velocity" toggle should also be applied when the lateral is connected to a 2D Boundary.

After selecting a lateral weir coefficient or use of the 2D equation, the modeler should review the results to verify model stability. If instabilities are observed though review of the hydrograph over the lateral structure or adjacent 1D cross-sections and in review of velocity in mapper, the use or weir or 2D equation, or change in weir coefficient, and/or time step adjustments may be required. Where model instability is found to be causing large fluctuation in flows over a weir or storage area connector, the modeler may need to activate the 1D/2D iterations options within the Unsteady Flow Analysis editor. The maximum iteration number should be as small as possible (less than 5) to minimize model run times.

Table 3-2 summarizes recommended weir coefficients (as found in the HEC-RAS v5.0 User's Manual).

Table 3-2 - Lateral Weir Coefficients

Item Being Modeled with Lateral Structure	Description	Range of Weir Coefficients
Levee/roadway: 3 feet or higher above natural ground	Broad crested weir shape, flow over levee/road acts like weir flow	1.5 to 2.6 (2.0 default)
Levee/roadway: 1 to 3 feet above natural ground	Broad crested weir shape, flow over levee/road acts like weir flow, but becomes submerged easily	1.0 to 2.0
Natural high ground barrier: 1 to 3 feet high	Does not really act like a weir, but water must flow over high ground to get into 2D flow area	0.5 to 1.0
Non elevated overbank terrain, lateral structure not elevated above ground	Overland flow escaping the main channel	0.2 to 0.5
Tributary	Lateral structure represents the cross-section of a tributary with a depth ≥ 6-ft at the confluence	2.0

3.4.4 Internal 2D Flow Area Connectors

Internal flow area connectors are used to model elevated terrain and crossings not represented in the terrain data within the 2D flow area mesh, such as proposed embankments, roads, weirs, gates, or culverts. Internal flow area connectors can also be used as lines for which hydrographs can be quantified to report flow passing the connectors alignment. For reporting purposes, connectors should be drawn left to right looking downstream. If the connector is drawn opposite, the hydrograph will be reported with negative values, which only effects the reporting of flows through the connector and does not have impacts on the overall model result.

Headwater and tailwater elevations reported on these connectors may not be representative of the entire line. In a 2D model, each cell along the connector can have differing elevations making the single reported value suspect. The reported stage values are from the cell with the lowest elevation along the upstream and downstream side of the connector.

Two options for computing the overland flow hydraulics across the connector are available: normal 2D equation and standard weir equation. Typically, the modeler should use the normal 2D equation except for when the flow overtopping the structure will go into freefall. In a situation like this, the normal 2D equation will have instability and the weir equation should be selected.

Currently, HEC-RAS 2D cannot model bridges within the 2D mesh. As a recommendation for cases where bridge impacts need to be modeled, the modeler could attempt to replicate the bridge opening with box culverts using single or multiple box culvert barrels or by modifying the terrain to represent roadway fill and abutments. If the structure is critical to the design, the modeler should consider modeling the bridge in 1D to verify the 2D results or add a 1D portion to the overall model.

When modeling culverts, the invert elevation must be equal to or greater than the elevation of the connecting 2D mesh cell. The terrain data will likely need to be edited to lower the minimum elevation within the cell to the elevation of the culvert flowline. The editing of the terrain will need to be accomplished outside of HEC-RAS. Additionally, the volume of water in the cells connected to a culvert or gate structure needs to be sufficient to maintain continuity of flow through the culvert. When the computed flow through the culvert exceeds the volume available in a single time step, model instability can occur, particularly in low flow conditions. If encountered, the modeler should review the mesh to determine if the mesh accurately represents the headwater storage on the culvert. Deleting small cells to create larger cells upstream of the culvert may help improve the model. A time step reduction may also be necessary.

Standard 1D modeling parameters should be applied to internal storage area connector culverts. If using the standard weir equation, weir coefficients, as referenced in Table 3-2, should be applied.

3.4.5 External Storage Area Connectors

External storage area connectors are used to connect 2D flow areas or 1D storage areas to other 1D or 2D areas. The modeling of these connectors is similar to internal connectors, but does not provide the normal 2D equation as internal connectors provide. For reporting purposes, connectors should be drawn left to right looking downstream. If the connector is drawn opposite, the hydrograph will be reported with negative values, which only effects the reporting of flows through the connector and does not have impacts on the overall model result.

Suggested weir coefficient values are referenced in Table 3-2.

3.5 Calculation Options and Tolerances

3.5.1 Computational Intervals

The computation interval time step used is critical in running a stable model to accurately predict flood stages. There are two 2D equations available: Full Momentum Saint Venant and Diffusion Wave. The time step can be impacted based on the selected equation. In Harris County, with flat terrain and predominantly low flood plain velocities, the Diffusion Wave equation is the recommended default equation. If modeling areas of high velocities where momentum needs to be considered, the Saint Venant equation may be better suited.

The Courant Number equation, when using the Diffusion Wave equation, can be expressed as

$$C = \frac{V * \Delta T}{\Delta X} \leq 2$$

where C is the Courant Number, V is the flood wave velocity in feet per second, ΔT is the computation time step in seconds, and ΔX is the average cell size in feet.

The modeler should review the Courant Equation provided in the HEC-RAS *2D Modeling User's Manual*, and then select the appropriate time step for the model. A time step corresponding to a Courant Number equal to or less than 1 is considered optimal for stability. In general, if the flood wave is rising or falling slowly a higher Courant number may be capable of providing a stable solution. It is recommended that within Harris County the Courant number generally be kept to less than 3. Using the Advance Time Step Control option, the "Adjust Time Step Based on Courant" may be used to optimize the time step. Refer to the HEC-RAS 5.0.4 Supplemental UM_CPD-68d guidance manual for more information on this option. The Advance Time Step Control should be used only to assist in identifying a maximum fixed time step. Use of a fixed time step allows impact comparisons to be made between models ran with identical time steps.

Alternative to a fixed time step, the user can use the “Adjust Time Step Based on Time Series of Divisors” under Advanced Time Step Control. This feature will allow for setting fixed time steps to be varied during certain portion of the simulation period. The selected times, time steps and divisor steps must be the same between models used for impact analysis. Use of this feature will allow for model comparisons based on identical time step computations while allowing for quicker model run times in some instances. Generally, a 30 second or less fixed time step will often be required to produce a stable 1D/2D model. As cell sizes are reduced so should be the time step.

3.5.2 2D Flow Options

It is recommended that the HEC-RAS computational options and tolerances for General 1D Options and 2D Flow Options should retain the HEC-RAS defaults with the exception of the weir stability and decay factors. These factors should be set to 3.0. If other values are modified from defaults, the modeler needs to describe which defaults were modified and the impact of the change on the model

Review of flow and stage hydrographs across lateral structures and storage area connectors must be reviewed for stability. Computational options and tolerances under 1D/2D Options should be activated when flow and water surface instabilities are present. Refer to the HEC-RAS 5.0 2D Modeling User’s Manual for guidance on selecting tolerances.

SECTION 4 - MODELING STUDY SUBMITTAL STANDARDS

4.1 Introduction

The data submittal standards in the following sections will serve to standardize HEC-RAS 2D modeling submittals within Harris County. The standards outline the requirements for the submittal of models and associated study information. The requirements include the identification of all relevant model files, model linkage information, design events, GIS data, and supporting documentation for the submittal of HEC-RAS 2D models. Additional standards for the study submittal are also included.

4.2 Study Reports

Engineering reports signed and sealed by a professional engineer licensed in Texas must be submitted in support of all modeling studies as required by HCFCD's Policy, Criteria, and Procedure Manual.

4.3 Geographic Information System Data

At a minimum, the geographic information system (GIS) data listed on following page and used in the creation of the HEC-RAS 2D model must be provided with the study for review by HCFCD. All files names should be readily identifiable with the object type contained. For example, the Terrain and Land Use data naming should be readily identifiable as being related to existing, pre-project, or post-project conditions.

4.3.1 Geospatial Data Requirements

All GIS data shall be submitted in the standard coordinate system used for HCFCD data as follows:

- Projection
  - Texas State Plane
  - Zone – South Central
  - Units – U.S. Feet
- Horizontal Datum – North American Datum (NAD) 83 (Grid)
- Vertical Datum – North American Vertical Datum (NAVD) 88 with 2001 adjustment **(GEOID99) datum or NAVD 88 (GEOID12B)**

All naming conventions should be documented in the study report or technical appendix.

Table 4-1 - Geospatial Delivery File Types

HEC-RAS 2D Dataset	Feature Type	Delivery File Type
2D Flow Area	Polygon	Shapefile or File Geodatabase
Breaklines	Polyline	Shapefile or File Geodatabase
Manning’s n Regions	Polygon	Shapefile or File Geodatabase
Land Cover	Multiple	Multiple (see below)
Terrain Model	Raster	Multiple (see below)
Survey	Point	Shapefile or File Geodatabase
Model Limits	Polygon	Shapefile or File Geodatabase
Project Limits	Polygon	Shapefile or File Geodatabase

4.3.2 Land Cover

The Land Cover dataset will include multiple land use files depending on how the modeler generated the data and whether or not multiple land use types or scenarios were considered. The following files should be included:

- *.hdf
    - the land cover dataset, based on one or more *.tif land cover rasters
- *.tif
    - a land use raster, represents unique land cover classifications
    - one or more *.tif rasters are used to create a single land cover *.hdf dataset
- *.shp
    - include if the *.tif land use rasters were generated from a land use shapefile

4.3.3 Terrain Model

The Terrain Model dataset will include multiple terrain files depending on how the modeler generated the data and whether or not multiple terrain sources or scenarios were considered. The report should include a description of how post-project terrain was created. The following files should be included:

- *.hdf
    - the terrain model dataset, based on one or more *.tif terrain rasters
- *.tif
    - a terrain raster, represents unique terrain data
    - one or more can be used to create a single terrain model *.hdf dataset
- *.vrt
    - a 'virtual' terrain file comprising one or more underlying *.tif rasters

4.4 Model Output and Deliverables

The following section describes the information required for a HEC-RAS 2D model at the time of submittal. This section focuses on the actual files for submission and the required information to adequately identify those files. The provided model plan(s), flows, and geometry files must be clearly identified and provide descriptions within each plan. The 2D models must include successful run data, so the reviewer does not need to execute the model prior to review of the output data. The modeler should verify all data and file links are properly set prior to submission.

4.4.1 Pre- and Post-Project Flow Comparison

Identify key upstream and downstream study lines for the analysis. Consider placing the study lines along main channels immediately downstream of the project, at main channels at the perimeter of existing development, and other key points determined by the modeler. The location of these study lines is critical and must be approved by HCFCD prior to the analysis. For each of the study points, prepare a pre- and post- hydrograph comparison for the 1% (100-year) and 10% (10-year) events. At each study line, present comparison tables for peak discharges and volume, and show resultant hydrographs. Where study lines are internal to a 2D flow area, use internal connectors to define limits of flow accounting. Boundary condition lines are to be used to represent study lines along the border of 2D flow areas. Note that profile lines used in RAS Mapper to quantify flow and volume are not accurate when any cell face(s) along the defined profile line includes an internal connector.

4.4.2 Runtime Messages

A print out of the Runtime Messages must be provide for each plan file executed. These message files can be accessed through the Unsteady Flow Analysis Plan Editor by selecting Options and View Runtime Messages. If errors and/or warning messages are present, the modeler must either adjust model accordingly to clear these messages or provide a clear explanation as to the cause for the messages and their potential impact on model results.

4.4.3 Pre-Project Depth Grid

Within 2D study limits, prepare a pre-project depth grid for the 1% (100-year) and 10% (10-year) events. The pre-project depth grid is meant to aid the reviewer in determining areas where significant flow depth is occurring under existing conditions. A hard copy of the depth grid shall be included as an exhibit in the study. The depth layer symbology shown in Table 4-2 shall be used when presenting the pre-project depth grid.

Table 4-2 - Classified Layer Symbology – Depth Grid

Classification		RGB Color Code				Windows 7 Color Name
Value	**Label**	Color	Red	Green	Blue	
value <= 0.25	0.0 to 0.25		190	232	255	Apatite Blue
0.25 < value <= 0.5	0.25 to 0.5		0	197	255	Big Sky Blue
0.50 < value <= 1.0	0.5 to 1.0		0	112	255	Cretan Blue
1.0 < value <= 1.5	1.0 to 1.5		0	77	168	Ultra Blue
1.5 < value <= 2.0	1.5 to 2.0		255	255	0	Solar Yellow
2.0 < value <= 2.5	2.0 to 2.5		255	170	0	Electron Gold
2.5 < value <= 3.0	2.5 to 3.0		230	76	0	Flame Red
3.0 < value <= 5.0	3.0 to 5.0		168	0	132	Cattleya Orchid
value > 5.0	> 5.0		76	0	115	Ultramarine

4.4.4 Pre- and Post-Project Water Surface Elevation Grid Comparison

Develop a water surface elevation grid of the pre- and post-project model for the entire study area. A comparison of the results can be created by subtracting the pre-project elevation grid from the post-project elevation grid. Color code the resulting grid for each grid cell based upon the computed change in WSE.

When producing static Max WSE maps for comparison purposes, RAS-Mapper exports the maps based on the render mode selected within RAS-Mapper under Tools/Render Mode Option. The two WSE maps must use the same render mode. Occasionally, when comparing model result rasters created from mixed resolution terrain models, poor comparisons can be incorrectly noted in areas well away from the project location. These poor comparisons are noticeable with a gridded or stripped pattern. If this is found to occur, the user must not use the *.vrt file for comparison purposes. Comparison should be run using the *.tif file created under the mapping output folders for the two comparison runs including the same base terrain name. As an example, existing conditions are run against a terrain comprised of 5 by 5 resolution LiDAR (EX5x5) and proposed conditions use the same 5 by 5 resolution LiDAR but supplemented with 1 by 1 resolution proposed conditions (1x1prop) with both terrains created within RAS-Mapper. The exported static max WSE for existing conditions will include WSE (Max).vrt and WSE (Max).EX5x5.tif files. For proposed conditions, the exported static max WSE will include WSE (Max).vrt, WSE (Max).EX5x5.tif, and WSE (Max).prop1x1.tif. Comparison would be made by subtracting the WSE (Max).EX5x5.tif found in the existing conditions folder from the WSE (Max).EX5x5.tif found in the proposed conditions folder.

The water surface elevation difference symbology shown in Table 4-3 shall be used when presenting the post-project minus pre-project water surface elevation grid.

Table 4-3 - Classified Layer Symbology – Water Surface Elevation Grid Comparison

Classification		RGB Color Code				Windows 7 Color Name
Value	**Label**	Color	Red	Green	Blue	
value < -0.50	< -0.50		0	38	115	Dark Navy
-0.50 < value ≤ -0.25	-0.50 to -0.25		0	77	168	Ultra Blue
-0.25 < value ≤ -0.10	-0.25 to -0.10		0	112	255	Cretan Blue
-0.10 < value ≤ -0.05	-0.10 to -0.05		0	169	230	Moorea Blue
-0.05 < value ≤ -0.02	-0.05 to -0.02		115	223	255	Apatite Blue
-0.02 < value ≤ -0.01	-0.02 to -0.01		190	232	255	Sodalite Blue
-0.0099 < value ≤ 0.0099	0		255	255	255	Arctic White
0.01 < value ≤ 0.02	0.01 to 0.02		255	190	190	Rose Quartz
0.02 < value ≤ 0.05	0.02 to 0.05		255	127	127	Medium Coral Light
0.05 < value ≤ 0.10	0.05 to 0.10		222	45	38	N/A
0.10 < value ≤ 0.25	0.10 to 0.25		165	15	21	N/A
0.25 < value ≤ 0.50	0.25 to 0.50		190	0	132	N/A
value > 0.50	> 0.50		76	0	115	Ultramarine

The depth difference grid should be developed by subtracting the pre-project depth from the post-project depth (i.e., post minus pre). Note: Where flooding does not occur (i.e., a depth of zero), HEC-RAS assigns the cells a value of NoData instead of zero. When subtracting the pre-project depth grid from the post-project depth grid for areas where the project has mitigated all flooding (i.e., post-project value of NoData), it is possible the depth difference grid will not show a benefit (i.e., NoData minus pre-project value gives NoData). This type of situation would likely occur around the flood fringe. Since the purpose of the depth difference grid is to identify areas where depths may increase, HCFCD may consider this depth difference acceptable. The modeler may reclassify each depth grid's NoData values to zero prior to developing the depth difference grid if desired.

The goal of the comparison is to demonstrate no increase in depth at any grid cell. Given the large number of cells, some data may show a slight increase or decrease based upon computational accuracy. In instances where minimal impacts occur, the modeler must complete various modeling alternatives to reduce the impacts within the mathematical limits of the model. The modeler shall document the computational nuances with a qualitative analysis. The modeler must justify and explain the increase, and then validate a change in flood risk is not represented. For visualization purposes, elevation differences in the range of -0.0099 < value ≤ 0.0099 are considered as a zero impact.

Pre- and post-project mesh sizes outside of the project site should be identical for accurate impact comparisons to be made. Accurate impact comparisons will reduce the number of impacts shown outside the project area related to computational accuracy and mesh size versus real impacts.

4.4.5 Flow Tracings

A flow tracing exhibit is to be provided when modeling precipitation over a 2D flow area. The limits of the 2D flow area(s) should be included in the exhibit(s) at a resolution sufficient such that review can determine the 2D flow area encompasses the entire contributing drainage area to the project site.

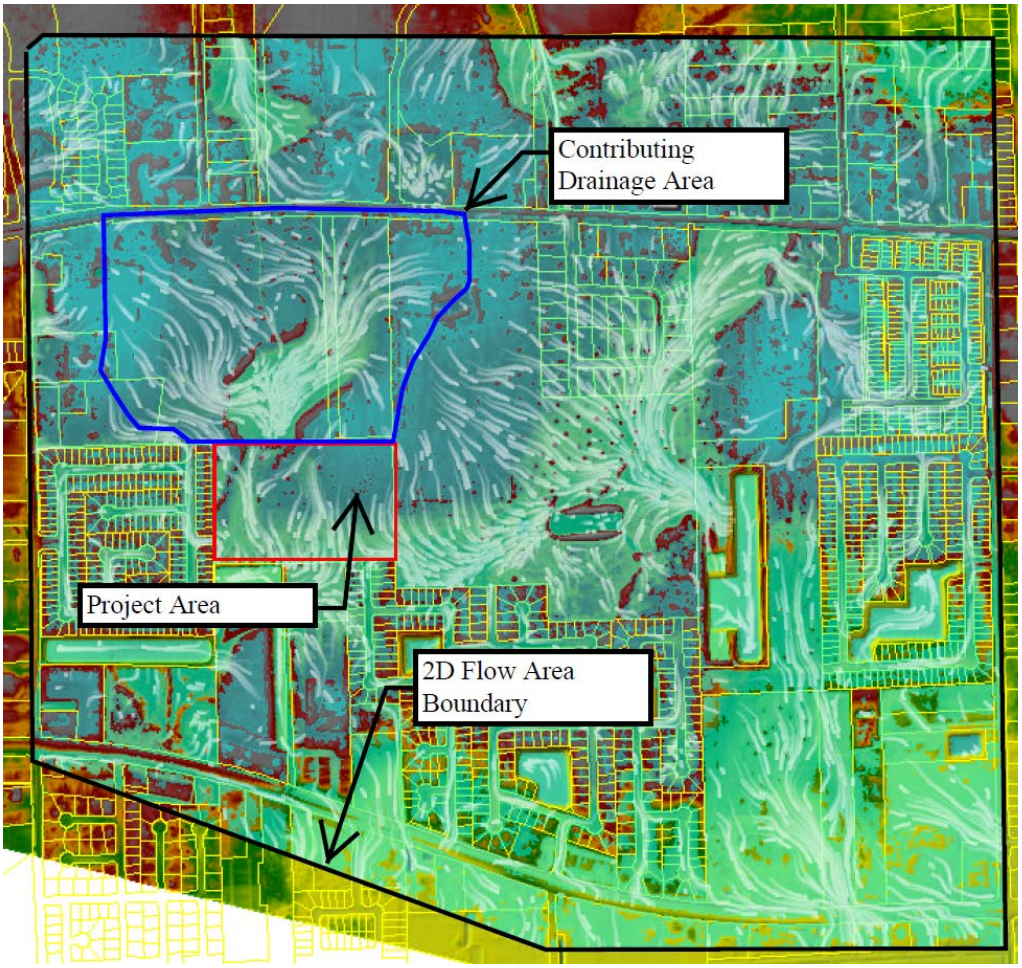

Figure 4-1 - Example Flow Tracing Exhibit

4.5 Model Files

The model files summarized in Table 4-4 and Table 4-5 should be included with the model submittal.

Table 4-4 - Required Model Input Files

File Name	Description
.prj	One **Project** file
.p##	One file for each **Plan** (.P01 to .P99)
.g##	One file for each set of **Geometry** data (.G01 to .G99)
.f##	One file for each set of **Steady flow** data (.F01 to .F99)
.u##	One file for each set of **Unsteady flow** data (.U01 to .U99

Table 4-5 - Required Model Output Files

File Name	Description
.r##	One **Run** file for each **steady flow** plan (.R01 to .R99) where ## is same as plan file number
.x##	One **Run** file for each **unsteady flow** plan (.X01 to .X99) where ## is same as plan file number
.o##	One Output file for each plan (.O01 to .O99) where ## is same as plan file number
.g##.hdf	One corresponding **HDF5** file for each **geometry** file (g##.hdf) where ## is same as geometry number
.p##.hdf	One corresponding **HDF5** file for each **plan** file (p##.hdf) where ## is same as plan file number
.b##	One **Unsteady Boundary Condition** file for each plan file where ## is same as plan file number
.bco##	One **Plan Log Output** file for each plan file where ## is same as plan file number
.c##	One **geometric pre-processor** output file for each set of Geometry data where ## is same as geometry file number
.IC.o##	One **Initial Conditions** file for each unsteady flow plan executed where ## is same as plan file number
.p##.blf	One **binary log** file for each plan executed where ## is same as plan file number
.p##.rst	One restart file (**hot start**) for each unsteady flow plan if option to write is turned on.
.dss	Plan results in DSS format
.comp_msgs.txt	Computational messages

APPENDIX A – 2D LAND USE DEFINITION APPLICATIONS AND EXAMPLES

Overview

The current version of HEC-RAS (V5.0.5) is limited in the ability to assign Manning's n values within a 2D flow area. Only one Manning's n value is assigned per cell face. This limitation requires the modeler to weigh the need for detailed Manning's n value against model run times. To have a highly defined Manning's n value coverage, the 2D flow area cells must be at a high enough resolution that the individual cell faces can be assigned varied Manning's n values. In urban areas, this may require cell sizes of 20' x 20' or less in order to pick up various land uses, such as streets, yards, structures. For small cell sizes, the computation time and model size drastically increases due to the number of cells in addition to the need for smaller time steps in order to meet the Courant Number limits. For smaller model extents, this may not be a significant issue where run times of less than an hour can still be accomplished. For larger study areas, such as whole watersheds, run times may become excessive. To allow for shorter run times, the modeler may wish to use larger cells and approximate Manning's n value using a composite overall value as reflected in the *2D Modeling Guidelines* document. Manning's n values are also sensitive to flow depth, particularly when precipitation on grid is being applied. When using precipitation on grid, large areas of the watershed will experience shallow sheet flow. Small variations in depth over these large areas can have significant impacts on flow attenuation, which will influence predicted flow rates in the receiving channels.

Future versions of HEC-RAS will allow the ability to use multiple n values on cell faces, as well as apply n values that can vary based on flow depth. With these model feature enhancements proposed in future releases, the modeler may wish to apply composite Manning's n values to allow for faster model run times by using larger cell sizes. Once updated versions of HEC-RAS become available, the model can be quickly updated for varied n values without the need to redefine 2D flow area resolutions.

The use of detailed n values largely depends upon the purpose of the 2D model. For approximating drainage area sizes and validating flow rates, larger cells and composite n values have been found to produce results that can be validated against known storm events. When impact analyses are being performed the model may require use of n values based on the actual land cover through the project area and not be composited into a general value.

Manning's n Value Land Use Definition

The following figures provide a general representation of the various land use definitions for assignment of their respective n values.

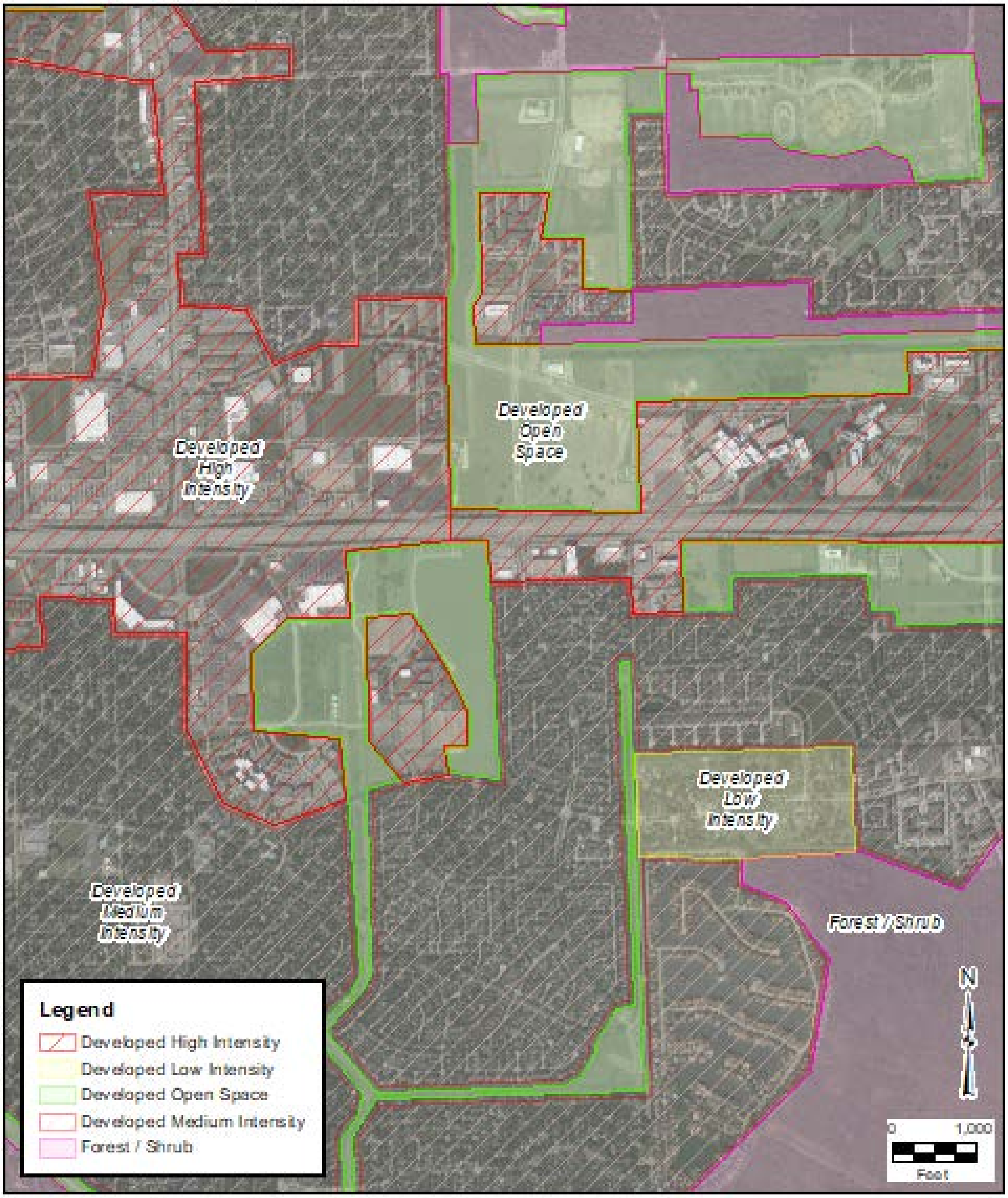

Figure A.1 Land Cover Manning's n Value Classification using H-GAC 2015 Dataset - Urban

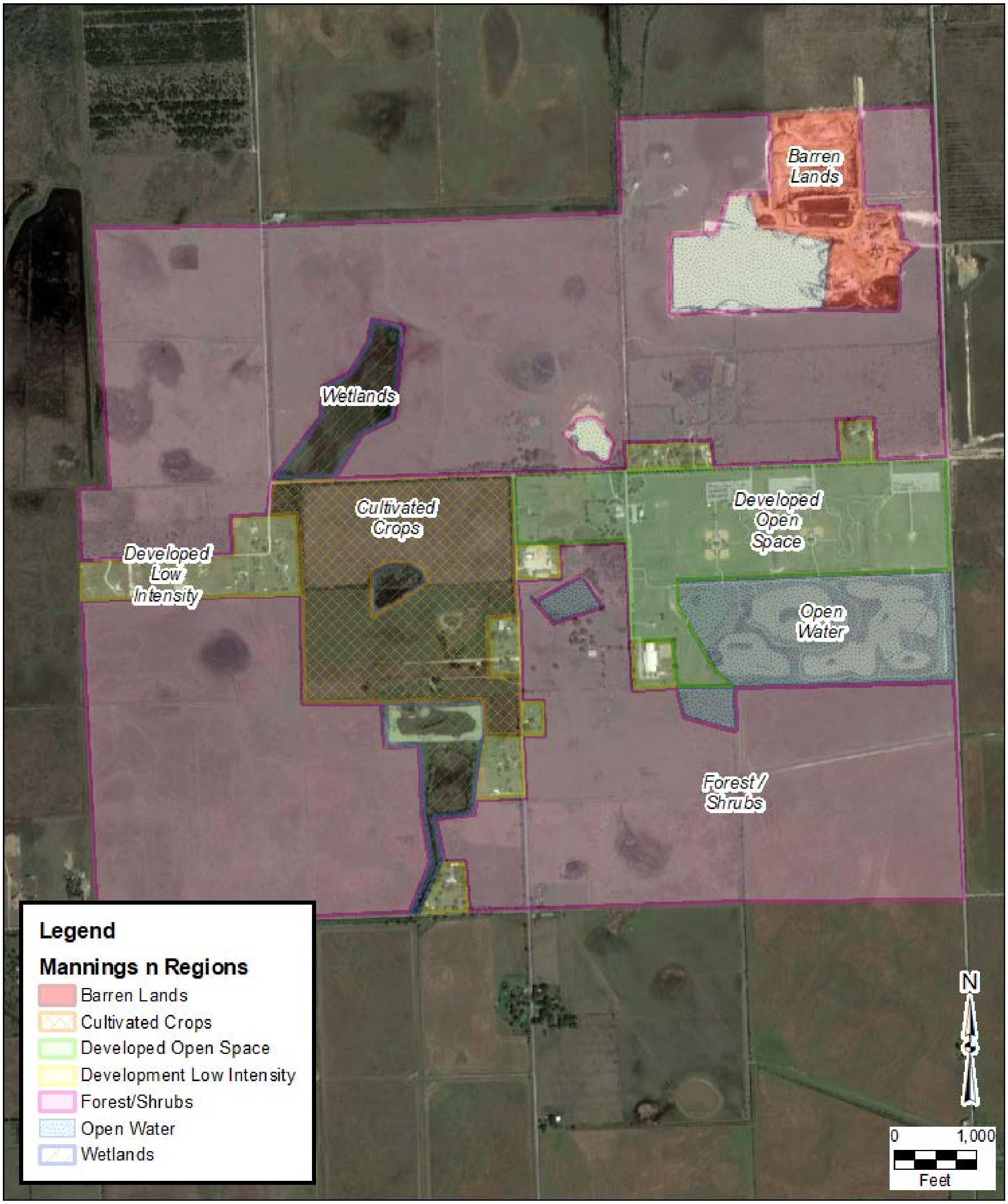

Figure A.2 Land Cover Manning's n Value Classification using H-GAC 2015 Dataset - Rural

APPENDIX B – 2D FLOODPLAIN FILL AND SITE DEVELOPMENT EXAMPLE

Overview

Site development impacts within the floodplain can occur from both loss of floodplain volume and conveyance changes. The following example focuses on identifying impacts due to changes in floodplain volume and conveyance drainage patterns. The example evaluates a new development placed inside of a mapped FEMA floodplain with a mitigation basin placed in the floodplain on the opposite side of the channel. The HEC-RAS 1D/2D coupled model evaluates conveyance and floodplain volume impacts during a 1% AEP rainfall event.

Using HEC-RAS 2D

Existing and proposed conditions models are required to evaluate and identify potential impacts. The models follow the guidance provided in the *2D Modeling Guidelines* document. The project is located within a FEMA studied stream. The model is a HEC-RAS 1D/2D coupled model that uses Manning's n values matching those used in the 1D FEMA HEC-RAS model both in the channel and the overbanks. The FEMA sections throughout the project site are trimmed to the channel banks, and overbanks are replaced with HEC-RAS 2D flow areas. The modeler should strive to produce models in which the 2D grids are nearly identical in cell spacing and location for pre- and post-project conditions, which may require pre-project existing conditions to be rerun again using the post-project grid (once the post-project 2D grid has been defined). By providing identical grids, the differences in computed peak WSE between the two models can be evaluated correctly.

The HEC-RAS 2D model is to be used to properly size and locate mitigation for the proposed site development. Once mitigation has been determined, the proposed improvements are to be inserted into the effective HEC-HMS and 1D HEC-RAS models using traditional steady state methodology as referenced in the HCFCD Hydrology & Hydraulics Guidance Manual. Refer to Section 19 (Report Requirements) for guidance on what to include in the drainage design report.

Site Description

This example is for a proposed single family development located on an undeveloped 105-acre tract shown to be within the FEMA mapped 1-percent floodplain. Mitigation is to be provided within a 30-acre undeveloped track located just downstream of the site on the opposite bank.

The site is located near the confluence of two major HCFCD channels: Z100-00-00 and Z100-02-00. Z100-02-00 is backwater influenced by Z100-00-00. The basin is located adjacent to Z100-02-00 and within the floodplain of both channels. Additionally, a separate unmapped tributary, Z102-01-00, flows through the proposed basin location and outfalls into Z100-02-00.

The project requires mitigation of development, conveyance, and floodplain fill impacts. Because of the complicated hydraulics occurring within the floodplain across the site from two separate flooding sources, 2D modeling was selected to aid in the development of the mitigation plan and to identify potential impacts not readily noted in traditional 1D modeling.

Hydrologic Impact Evaluation

The development's impact on the sub-watershed(s) peak runoff rates, due to impervious cover and revised TC&R values, will be evaluated using HEC-HMS by applying standard HCFCD methods.

The effective HEC-HMS model was obtained from the HCFCD M3 website. It is assumed the modeler is familiar with methods referenced in the HCFCD Hydrology & Hydraulics Guidance Manual for model revisions reflecting revised existing and proposed development conditions.

The 2D model will rely upon the revised HEC-HMS sub-watershed hydrographs applied as uniform lateral and lateral inflow to the 1D portion of the coupled 1D/2D model, as typically done in unsteady state modeling. The impact on routings due to fill placement will be evaluated in the coupled 1D/2D HEC-RAS model.

Hydraulic Impact Evaluation

The effective HEC-RAS models have been downloaded from the HCFCD M3 website for both channels. The effective 1D HEC-RAS model geometries were merged into a single geometric file using a junction to capture the effect the backwater condition of Z100-00-00 has on Z100-02-00. Since this is an impact study to be used for sizing mitigation and guiding development of a 1D model, the model for Z100-00-00 could be truncated to concentrate on the project site. The downstream limit was selected sufficiently downstream, so changes to the normal depth slope assumption had no impact on WSE at the confluence of Z100-02-00. The upstream limit was truncated such that it would not impact mapping through the project location.

HEC-RAS 2D FLOODPLAIN MODEL

LiDAR for Existing Conditions

Step 1: The H-GAC LiDAR NUSA dataset (2008) is used as the base topographic data set for modeling purposes unless otherwise directed by HCFCD. Using GIS, create a LiDAR data subset that fully encompasses the project site and captures floodplain limits and model extents through the project site as illustrated in Figure B.1 below.

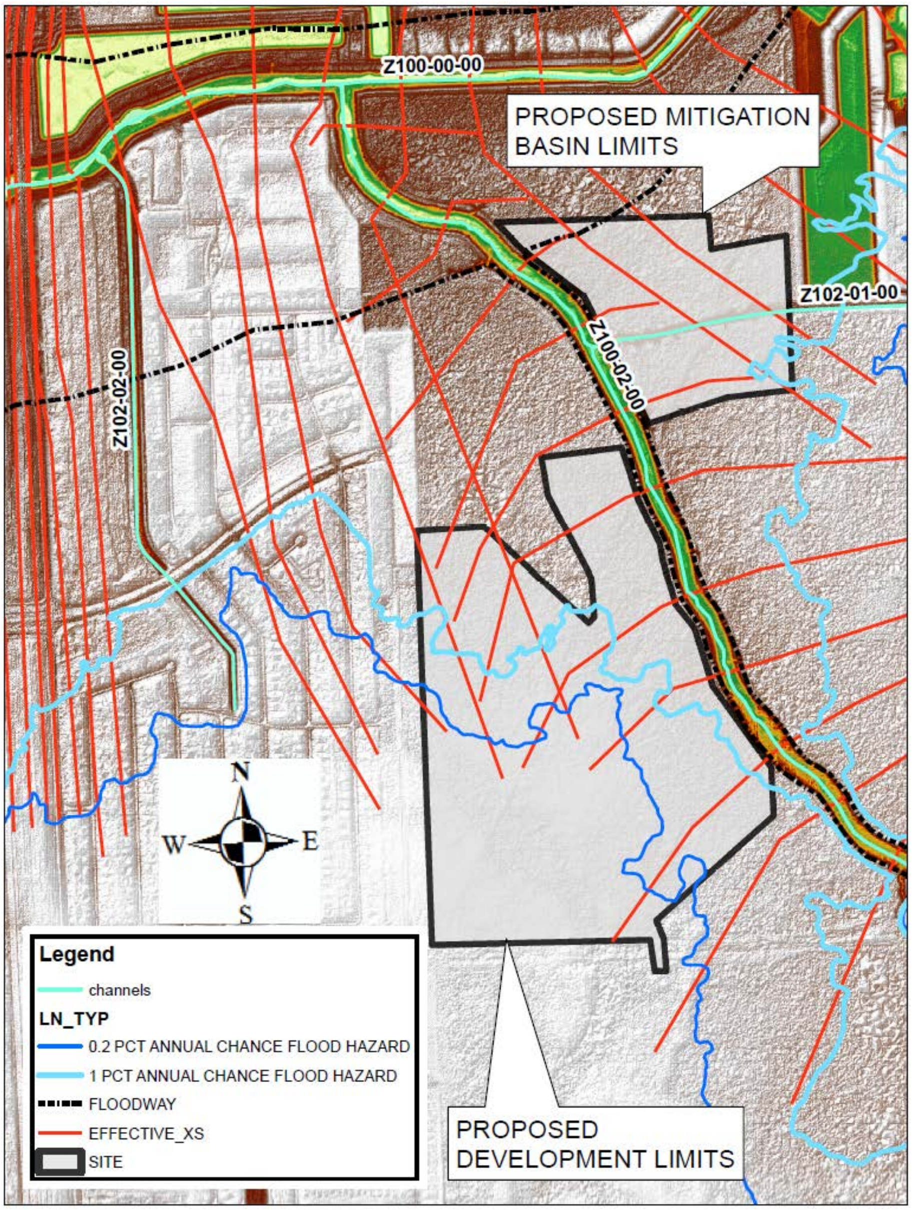

Figure B.1: LiDAR Data Extents

Revise Existing Geometry

Step 2: This step involves creating the 2D flow area limits and editing the 1D effective model cross-section extents.

- Create proposed limits of 2D flow area to encompass the 1% floodplain and proposed project limits. The 2D flow area extents need to be sufficiently offset from project limits to verify no-adverse impacts to adjacent properties.

- Revise effective model cross-sections to accommodate 2D flow areas by trimming cross-sections to the edge of the proposed 2D flow area. A small overlap of the 2D flow area and cross-section limits is permissible to avoid “slivers” in produced mapping. Overlap should be minimized so as not to “double count” the volume modeled in the cross-section with that in the 2D flow area. Care should also be taken to minimize double counting volume where 1D cross-sections transition from/to full width to trim width at the upstream and downstream limits of the 2D flow areas.

A cell size of 50 feet by 50 feet was selected for each 2D flow area based on the estimated level of detail needed for proposed conditions. Breaklines should also be added to define areas impacting flow direction, such as berms, roads, or channels. In this example, a breakline was added along the Z102-01-00 centerline. Figure B.2 on the following page presents the existing conditions 2D flow area and cross-section trimming performed in Step 2 of the existing conditions 2D model creation.

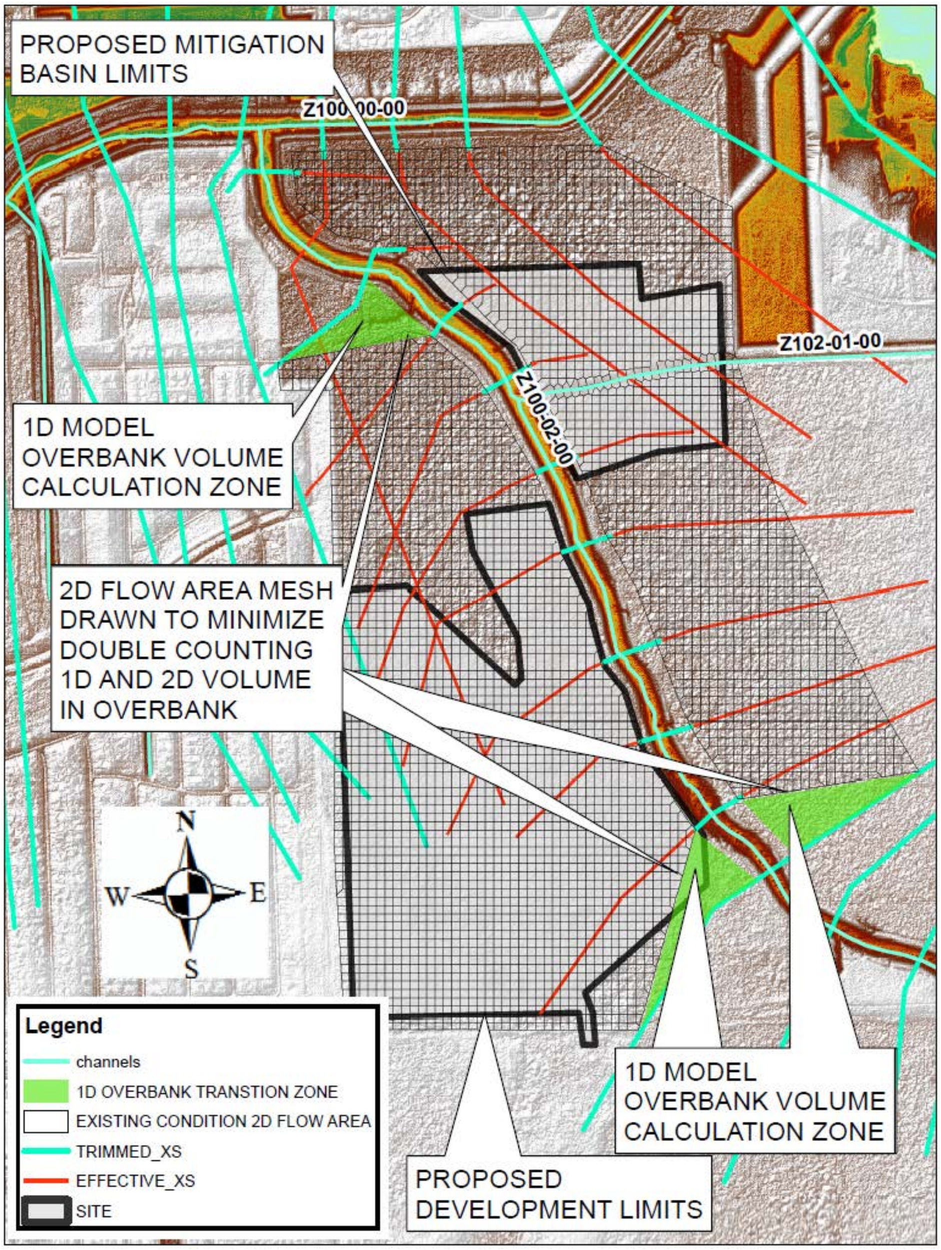

Figure B.2: 2D Flow Area and Cross-Section Trimming for Existing Conditions

Lateral Weir Structure Creation

Step 3: Add lateral structures to couple the 1D and 2D portions of the HEC-RAS model. The lateral structures should follow high ground along the channel banks to pick up their influence of flow being transferred to the 2D areas.

At the upstream and downstream limits of the 2D areas, the lateral weirs and cross-sections should tie into high ground to fully capture conveyance of flow to and from the 1D to 2D portions of the model. This is illustrated in Figure B.3 where lateral structures connect to high points along the 1D cross-sections at the upstream and downstream portions of the 2D flow area.

Where flow into or out of the 2D area does not behave like true weir flow, the 2D equation should be used. Where true weir flow is expected to occur, for instance over a weir into a basin, the weir equation should be selected for the lateral weir. This may require multiple lateral weirs to be defined along the coupling portion of the 1D and 2D model. The use of multiple lateral weirs also allows the modeler to better quantify flow rates where flow is leaving and entering the 2D flow area. Figure B.3 below presents the lateral weir coupling of the 1D and 2D model portions.

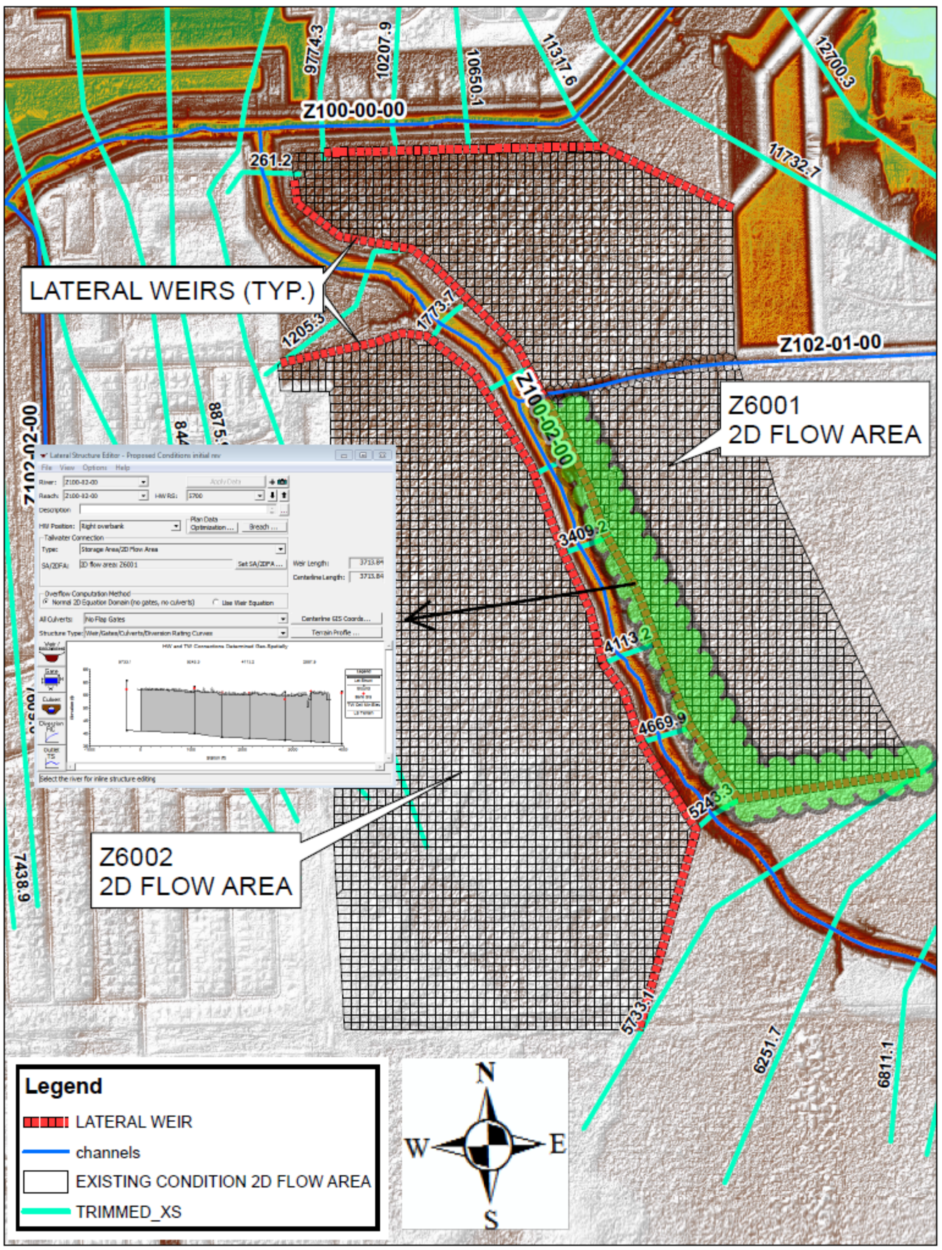

Figure B.3: Lateral Weir Coupling of the 1D and 2D Model Portions

Manning’s n Value Definition

Step 4: Review the Manning’s n value delineation in the effective model and develop the shape file to replicate spatial delineation to be applied to 2D flow area. In this example, the effective model applies a single n value of 0.14 over the entire overbank. A single n value could be assigned to the 2D flow areas within the geometry editor; however, in order to account for changes due to post project conditions, a single polygon was created within ARC-GIS and imported as a land use into RAS-Mapper, which allows the user to use the 2D Area Manning’s n Regions tool to draw areas where alternate n values can be assigned within the geometry editor.

Flow Assignments

Step 5: Existing conditions flows were assigned to the river reaches as is typically done in unsteady state 1D modeling. As an exception, the Z102-01-00’s flows were assigned to the edge of the mesh at the location where the tributary flows through the Z6001 2D flow area from tributary Z102-01-00. This was done to allow for 2D routing of the flow through the 2D flow area and then enter the 1D portion of the model through a lateral structure representing Z102-01-00’s confluence into Z100-02-00. The Z102-01-00 flow was assigned to the 2D mesh using a boundary condition line at the location where the tributary enters the 2D flow area and assigned across the cells that were anticipated to be inundated during the maximum flood stage due to Z102-01-00. An energy grade of 0.002 ft/ft was selected for the boundary based on the natural ground slope of the channel and overbanks in the vicinity. Figure B.4 on the following page shows the Z102-01-00 boundary condition flow assignment location.

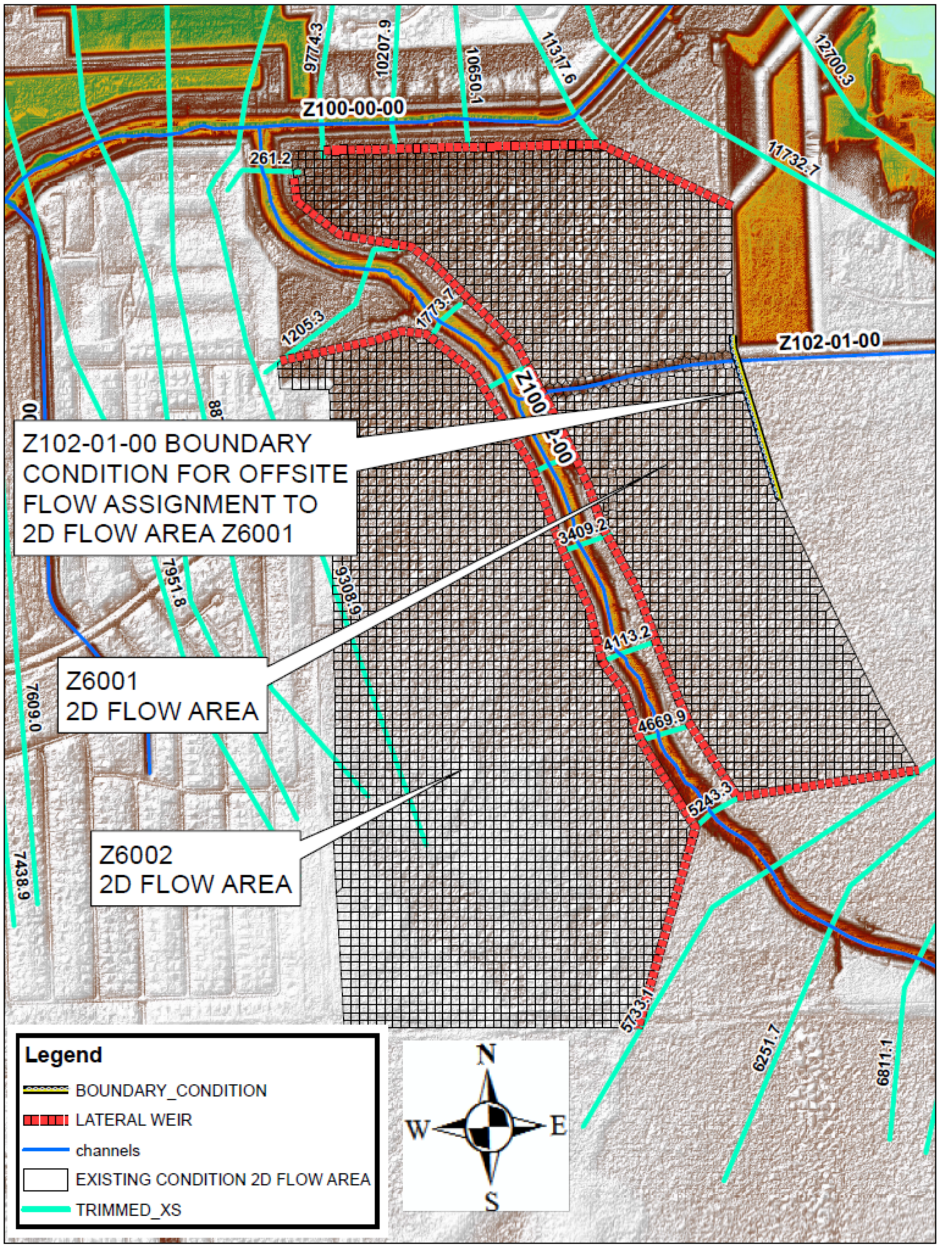

Figure B.4: Z102-01-00 Boundary Condition Flow Assignment Location

Model Execution and Review

Step 6: The default computation options and tolerances were selected, and Diffusion Wave was selected for the 2D equation set. The effective model overbank peak velocities in the project reach is approximately 2-3 feet per second in the channel and overbanks. A 15-second time step was selected to provide a Courant Number (C) ≤ 2. A Courant Number near 1 selected as runtime for a model of this size is not anticipated to be extensive and, by reducing the time step, improved model stability is likely. See HEC-RAS 5.0 *2D Modeling User's Manual* document for further description and additional information concerning the Courant Number selection. The Courant Number equation is shown below when using the Diffusion Wave equation:

$$C = \frac{V * \Delta T}{\Delta X} \leq 2$$

The model was run, and a number of cells were reported to have significant errors as shown below.

Performing Unsteady Flow Simulation HEC-RAS 5.0.3 September 2016

Maximum iterations of 20		**RS (or Cell)**	**WSEL**	**ERROR**	
01JUN2007 22:21:45 Z6001	Cell #	1391	85.66	26.5944	2
01JUN2007 22:23:00 Z6001	Cell #	1392	59.93	4.7775	2

Finished Unsteady Flow Simulation

Writing Results to DSS
Finished Writing Results to DSS

Reading Data for Post Process

Running Post Processor HEC-RAS 5.0.3 September 2016

Finished Post Processing

Computations Summary

Computation Task	Time(hh:mm:ss)
Completing Geometry	1
Preprocessing Geometry(64)	<1
Unsteady Flow Computations(64)	1:10
Writing to DSS(64)	1
Post-Processing(64)	<1
Complete Process	1:15

Review of the cell locations did not indicate issues with the terrain that may be causing the errors. A further review of the velocity mapping within RAS Mapper highlighted the error location as shown in Figure B.5 on the following page.

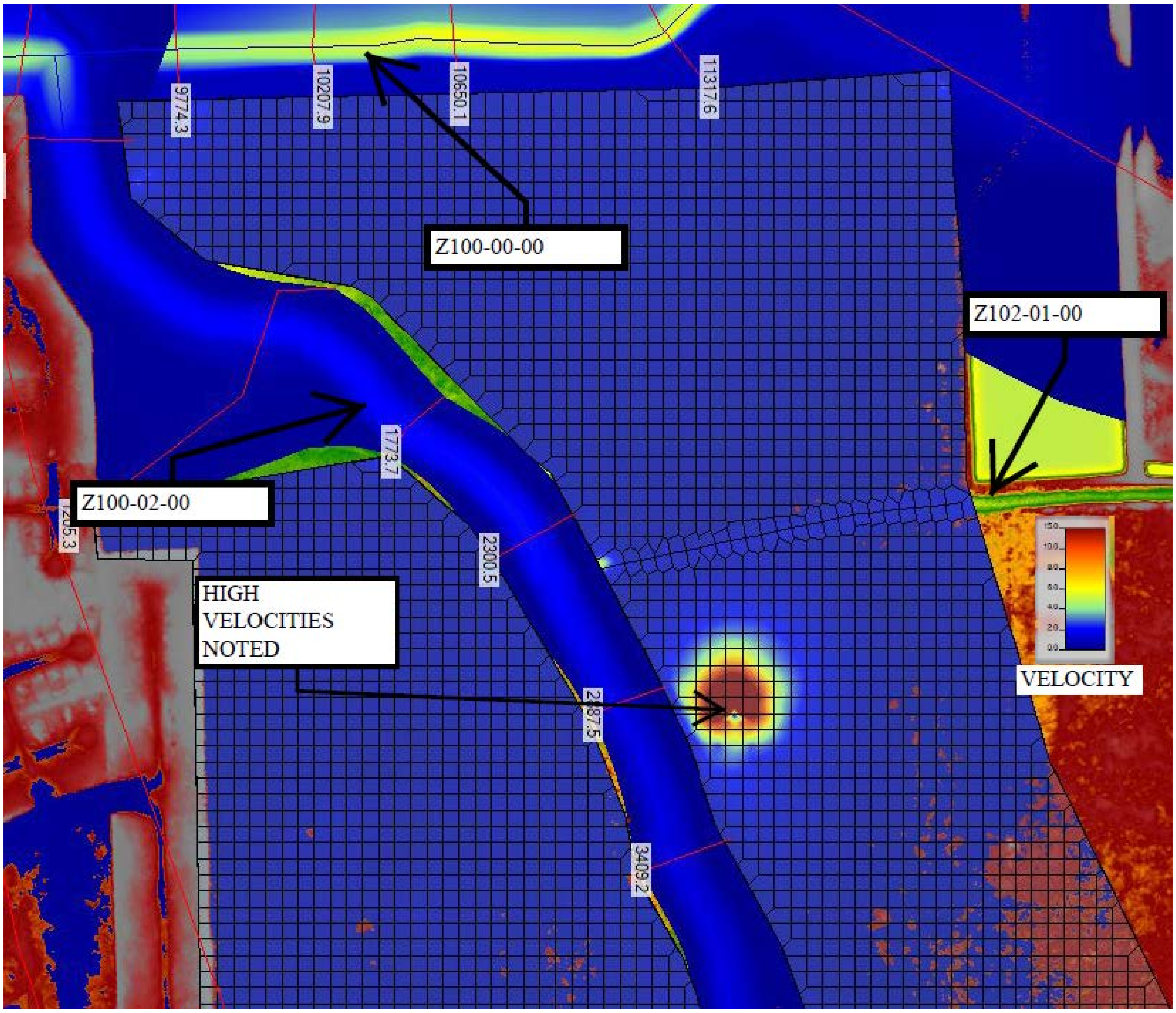

Figure B.5: High Velocity Location

In an attempt to resolve the instability, time steps were initially adjusted, resulting in the same cell instability issues. The mesh was then edited by moving cell centers slightly in the area, which resulted in an elimination of the errors in this specific location. However, cells located along the 1D portion of the model were now in error and required cell center adjustments to eliminate the error. Figure B.6 on the following page shows the areas where mesh edits were necessary to eliminate the errors.

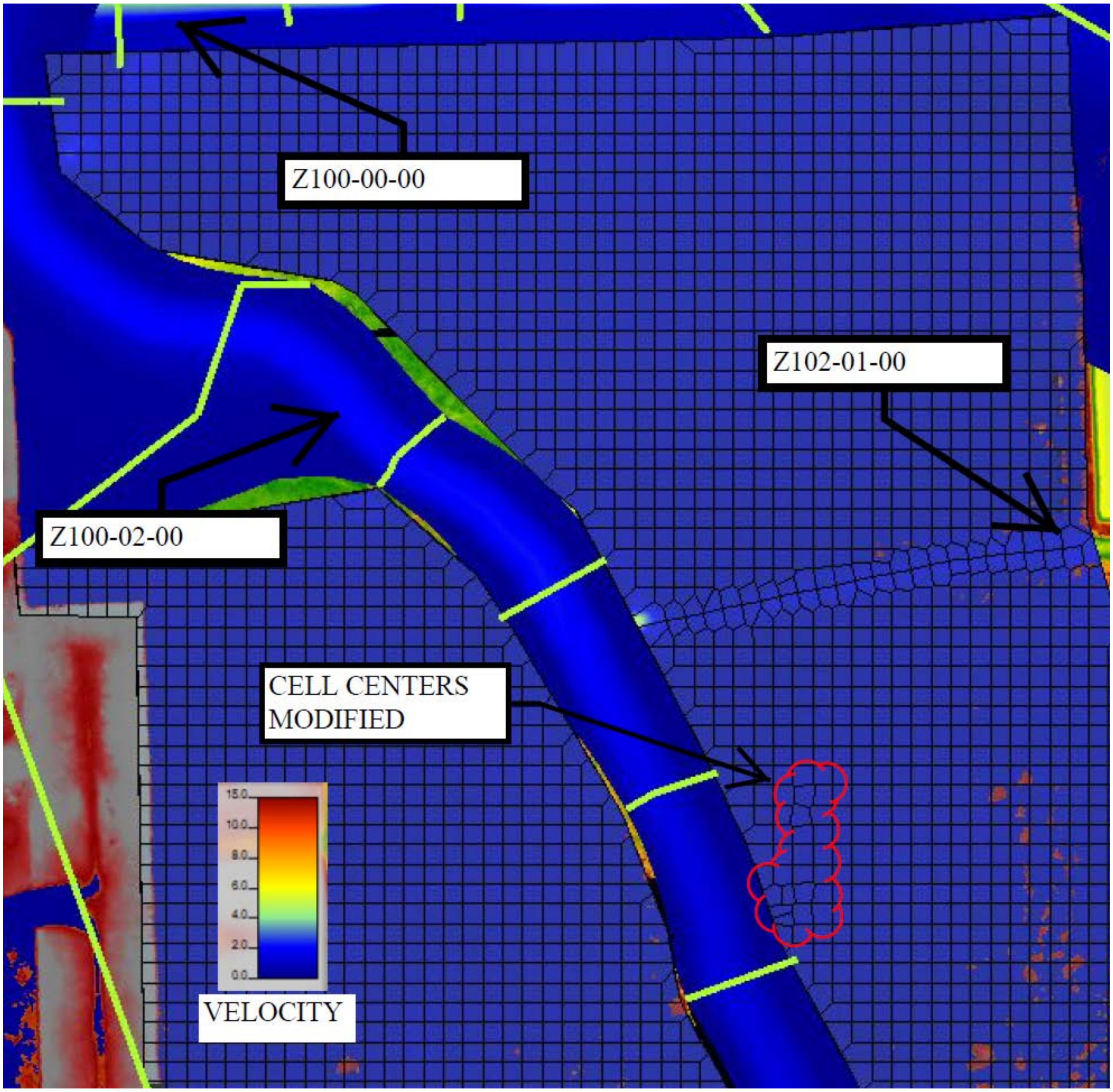

Figure B.6: Modified Cell Locations

Additional review was done by plotting the maximum WSE with 0.1' contour intervals within RAS Mapper. A 0.1' interval was necessary due to the flat WSE at the confluence of the two channels. The contouring indicates areas where modification to the mesh boundary was necessary. The mapping also shows areas where "slivers" between the 1D and 2D mapping exist, which can be rectified by either extending the 1D cross-sections or editing the mesh boundary. Figure B.7 on the following page shows the areas where edits can be made to improve the model and mapping.

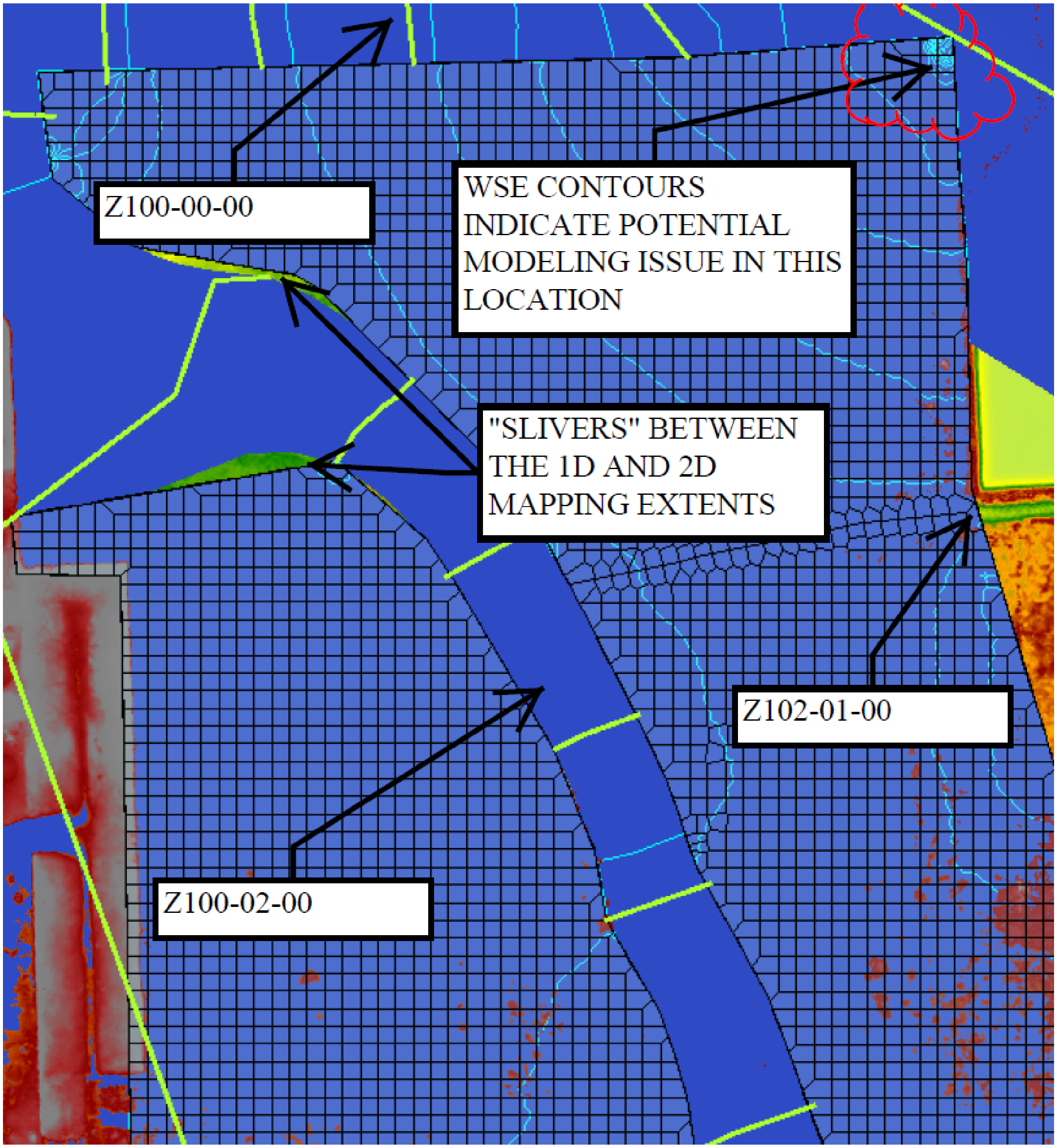

Figure B.7: Locations Where Improvements to Model and Mapping Can Be Made

The mesh was revised to better transition between the trimmed and full cross-section along Z100-00-00 (NE corner), and cross-sections were extended to provide overlap with the 2D mesh eliminating the model issue noted in the NE corner and mapping issue of "slivers" between the 1D and 2D mapping. Figure B.8 shows the revised model and mapping results for existing conditions.

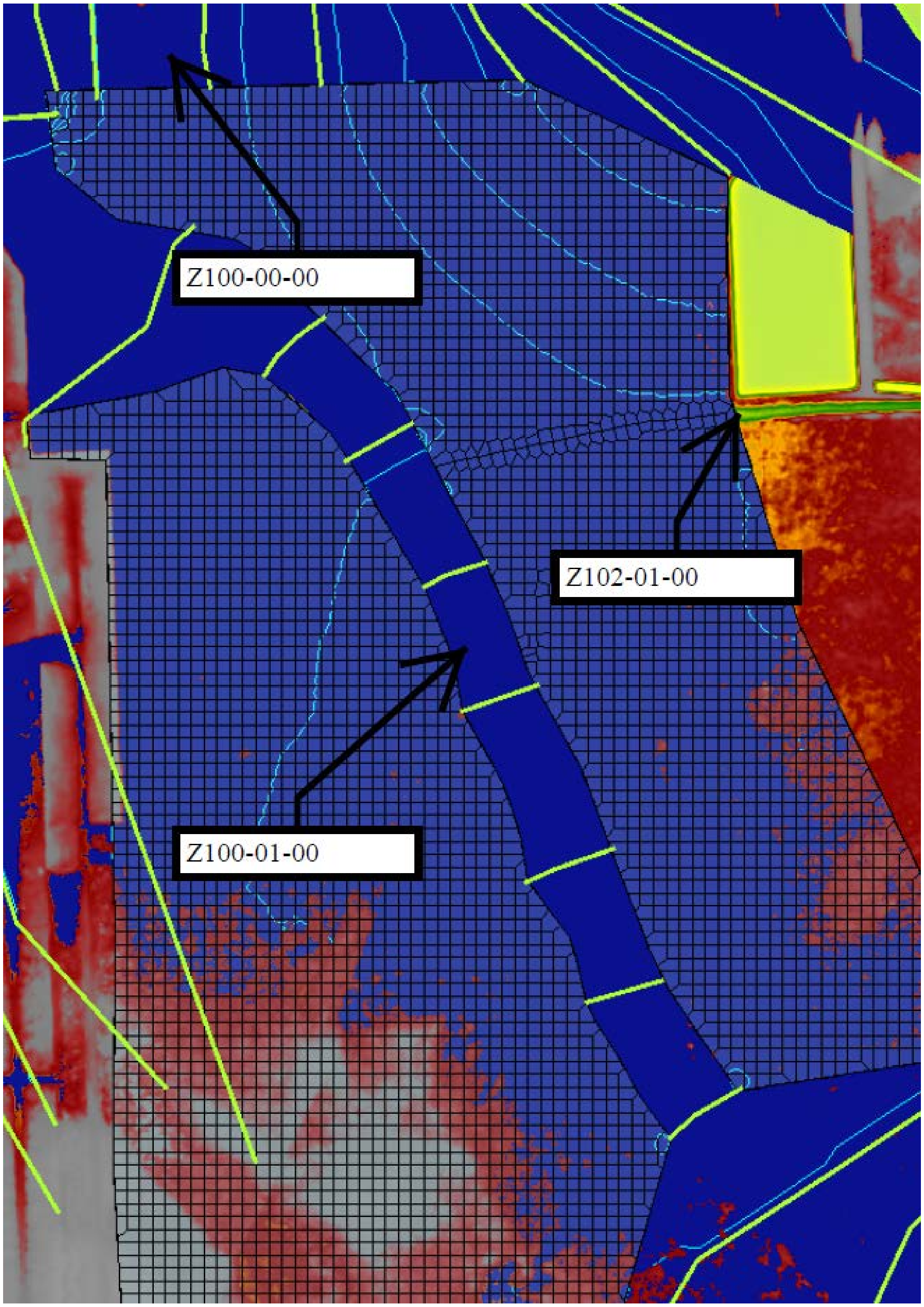

Figure B.8: Final Existing Conditions Model/Mapping

Once existing conditions model and mapping were complete a depth grid was created. Figure B.9 shows the existing condition 100-year depth grid. It was mapped in Arc-GIS by importing the static maximum depth raster. The maximum depth raster was created in RAS-Mapper by adding a new results map layer, selecting maximum depth, and then saving it as a raster based on terrain. Once imported into Arc-GIS, the symbology was changed from “stretched” to “classified,” and the classifications were set to those referenced in Table 4-2

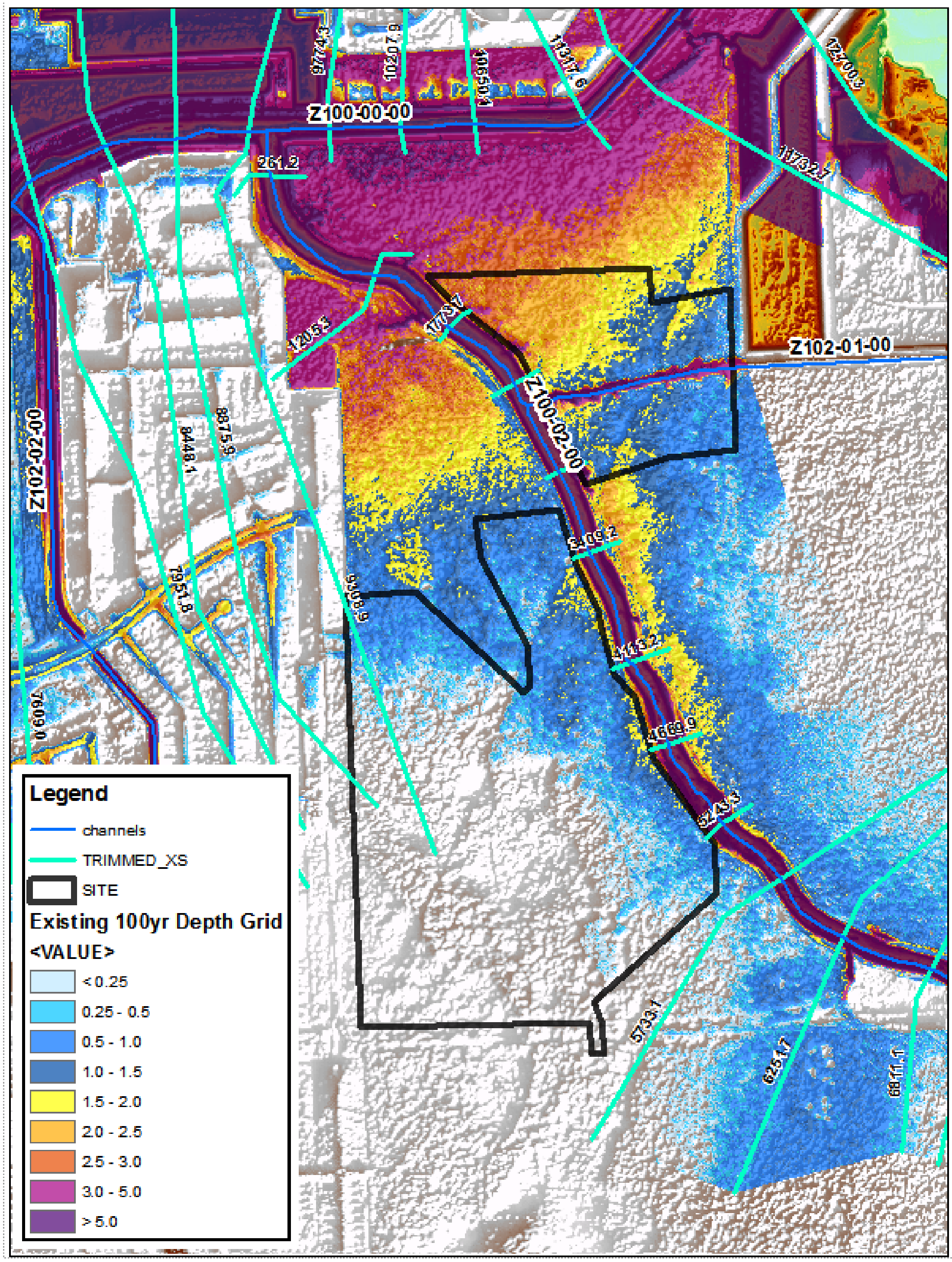

Figure B.9: Final Existing Conditions Model Depth Grid Mapping

Proposed Conditions

Step 7: Terrain data for proposed conditions was created within AutoCADD Civil 3D through the following process:

- The terrain surface TINs for the development and basin grading were created in Civil 3D and exported as a LandXML file.
- The proposed surface LandXML files were imported into ARCMAP, using 3D Analyst's LandXML to TIN tool to generate TINs of the two surfaces.
- TIN surfaces were converted to raster files using ARCMAP's 3D Analyst TIN to Raster conversion tool.
- The rasters were imported into HEC-RAS to create a proposed condition surface.

The mitigation basin is also to be used as "borrow" for the proposed development. The basin was initially sized to provide mitigation of floodplain fill at a 1:1 acre-foot per acre-foot ratio and development mitigation volume assuming a 1.35 ac ft/ac rate. The high development rate factor was used to provide an initial estimate for conveyance impacts as well. Figure B.10 on the following page provides the proposed terrain that is to be modeled.

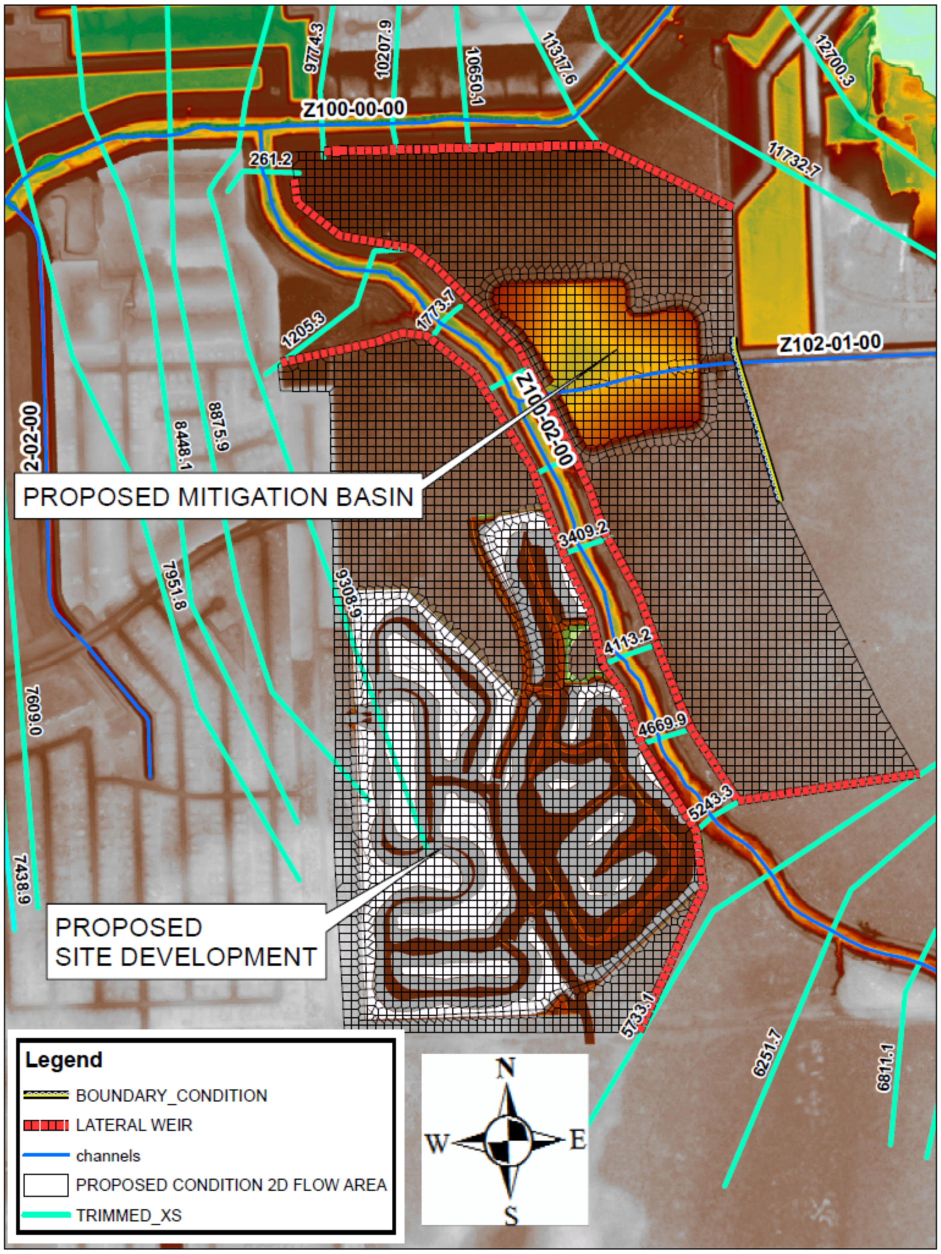

Figure B.10: Proposed Conditions Terrain

Step 8: Using the Manning's n regions tool in HEC-RAS's geometry editor, n values of 0.04 were assigned to the proposed basin area and n values of 0.18 to the development footprint limits. Additional breaklines were also added around the perimeter of the proposed grading. Figure B.11 on the following page provides the model geometry schematic for the project area.

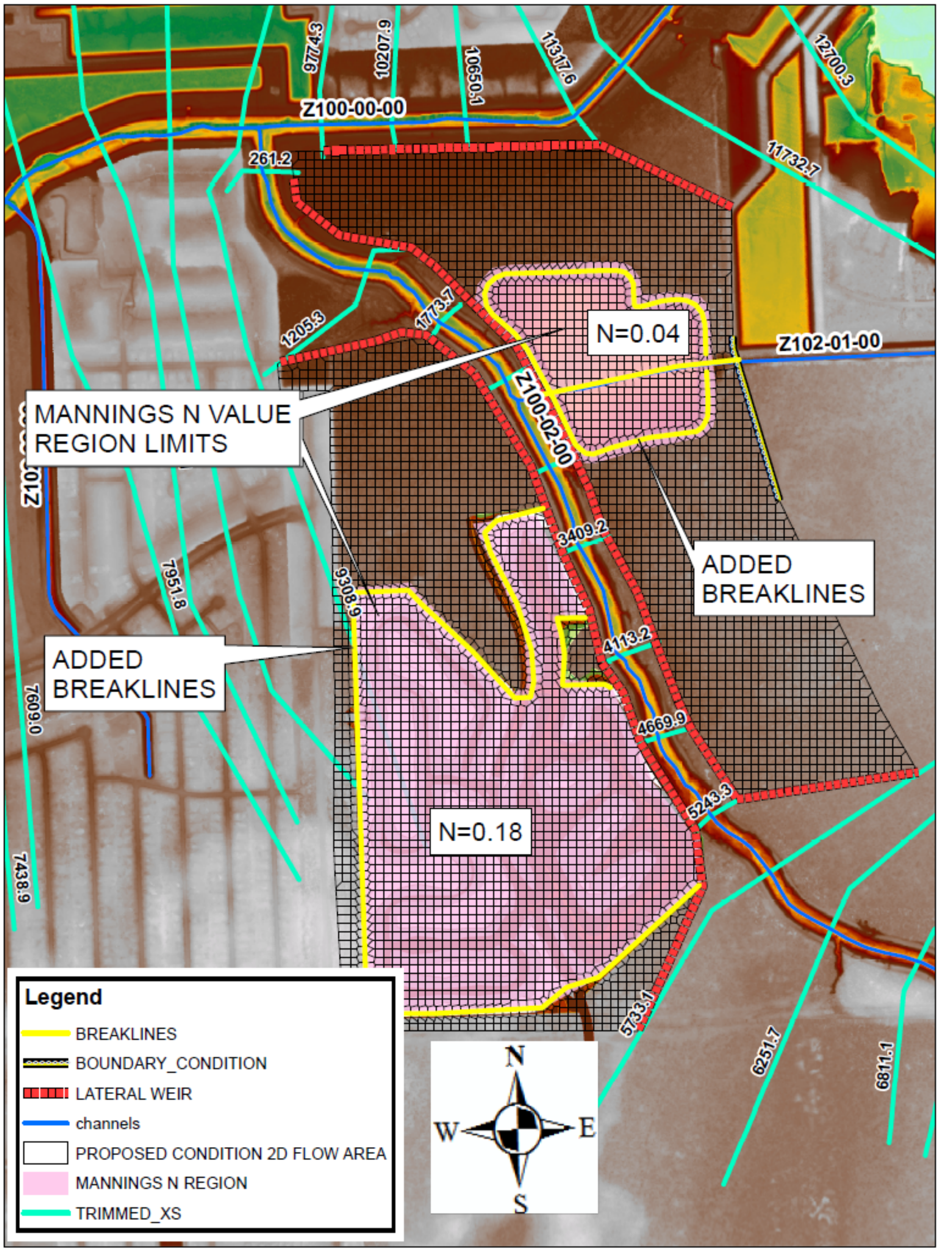

Figure B.11: Initial Proposed Geometry Schematic for Project Area

Flow Assignments

Step 9: Proposed condition's unmitigated flows from the HEC-HMS model, representing the impact of development on the various sub-watersheds, were assigned to the river reaches, using typical unsteady state 1D modeling flow assignment methodology. As an exception, the Z102-01-00's flows were assigned to the edge of the mesh at the location where the tributary flows through the Z6001 2D flow area from tributary Z102-01-00. This was done to allow for 2D routing of the flow through the 2D flow area, into the proposed mitigation basin, and then entering the 1D portion of the model through a lateral structure representing a control structure into Z100-02-00. The Z102-01-00 flow was assigned to the 2D mesh using a boundary condition line with the same limits and energy grade slope as was used for existing conditions.

Model Execution and Review

Step 10: The model was then executed and impacts evaluated in ARC-MAP by subtracting the initial proposed conditions Maximum WSEL raster from the existing conditions Maximum WSEL raster. The resulting raster symbology was changed from "stretched" to "classified," and the classifications were set to those referenced in Table 4-3.

By reviewing hydrographs in the 1D model at cross-sections downstream of the basin, it was found that the basin was filling early in the storm event and not reducing the peak flood waves of the two channels to provide the necessary reduction in flows for mitigation of the floodplain fill and development impacts. Figure B.12 on the following page provides the indicated changes in maximum 100-year WSE. The red colors indicate areas with increased WSEL while the blue are areas with reduction in WSEL. Impacts were expansive but with minimal stage increase of generally less than 0.05 feet noted.

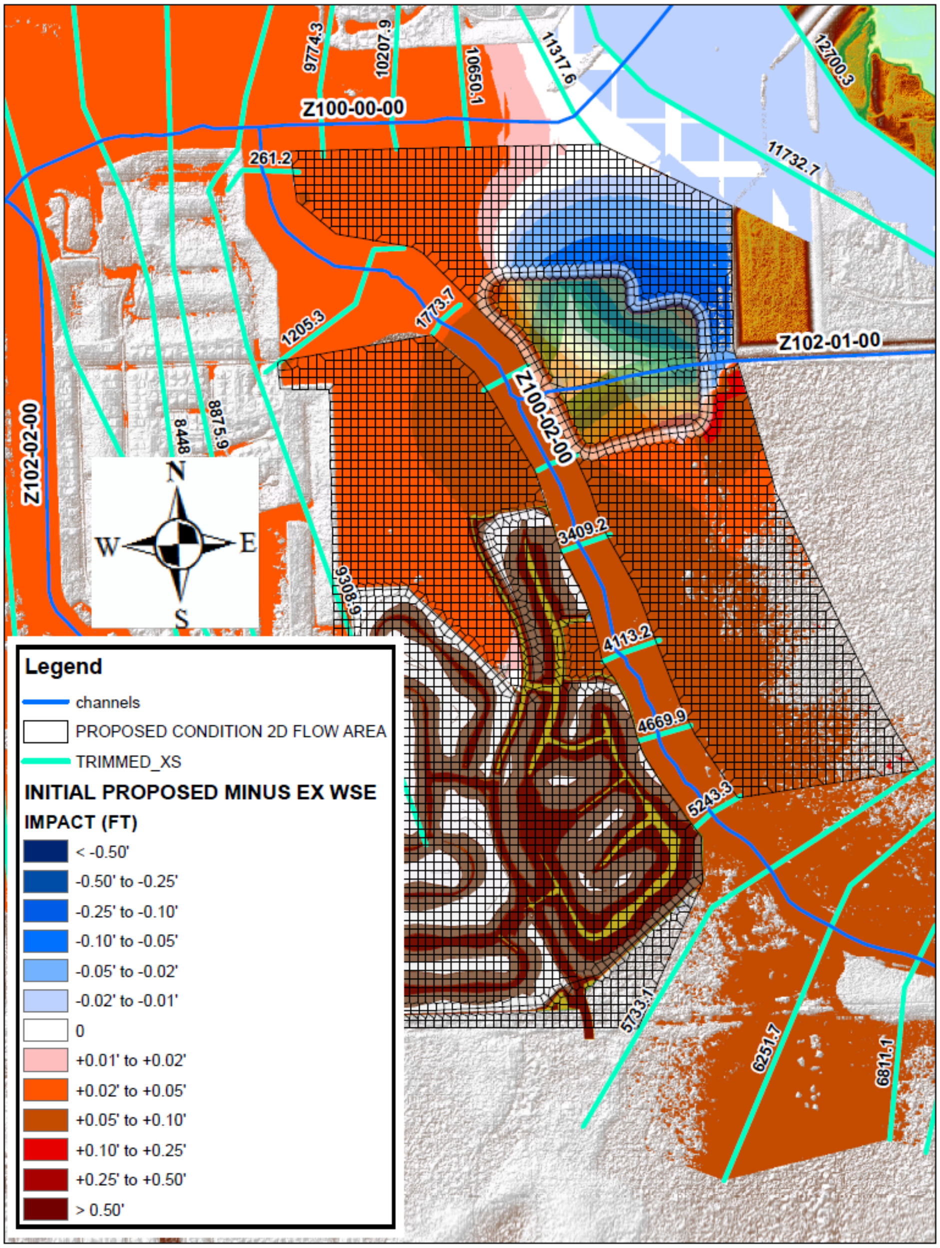

Figure B.12: Difference Between Initial Proposed and Existing Conditions WSE

To better control the timing of diversion into the basin from the adjacent floodplains, berms were added to the basin. The berms allow for a controlled flow conditions, preventing uncontrolled flow from entering along all edges of the basin, which could result in potential erosion of the banks.

The berms were modeled using internal storage area connectors with weir elevations set above the 100-year WSEL to prevent overtopping. Modeling of the berms could have also been accomplished by adding the berm grading to the terrain file. By using connectors, modifying the size and location of the berms and control structures is greatly simplified by not requiring multiple edits to the associated terrain file. Once final size and location of berms and control structures is determined, the terrain data will be modified for improved mapping purposes.

Two control structures were added to the model to control the location and amount of flow to and from the basin from both floodplain flooding sources, Z100-00-00 and Z100-02-00. The first, Control Structure #1, is modeled with a lateral weir that uses the weir equation and is located at Station 2350 along Z100-02-00. This structure models the weir and low-flow pipe outfall for flows to and from Z100-02-00 and the basin. The weir has a 50-foot crest length set approximately 2 feet below the existing natural ground elevation. A 60-inch outfall pipe allows for low-flow and post-storm events to drain. This structure is assumed to operate as a true weir, and the default HEC-RAS lateral weir coefficient of 2.0 was used. As a side note, HEC-RAS currently does not allow the use of the 2D equation on lateral weirs, which include culverts.

A second control structure, Control Structure #2, was modeled with an internal connector also using the weir equation and added along the north edge of the basin to accept flows from the floodplain of Z100-00-00. It was also assumed to operate as a true weir, and a weir coefficient of 2.0 was assigned. Control Structure #2's location and size were initially selected by reviewing the particle tracing feature in RAS-Mapper to determine where the main flow concentration intersected the basin. This weir has a crest length of 200 feet and is set at the approximate natural ground elevation. See Figure B.13 on the following page for the HEC-RAS 2D model schematic for location of berms and control structures.

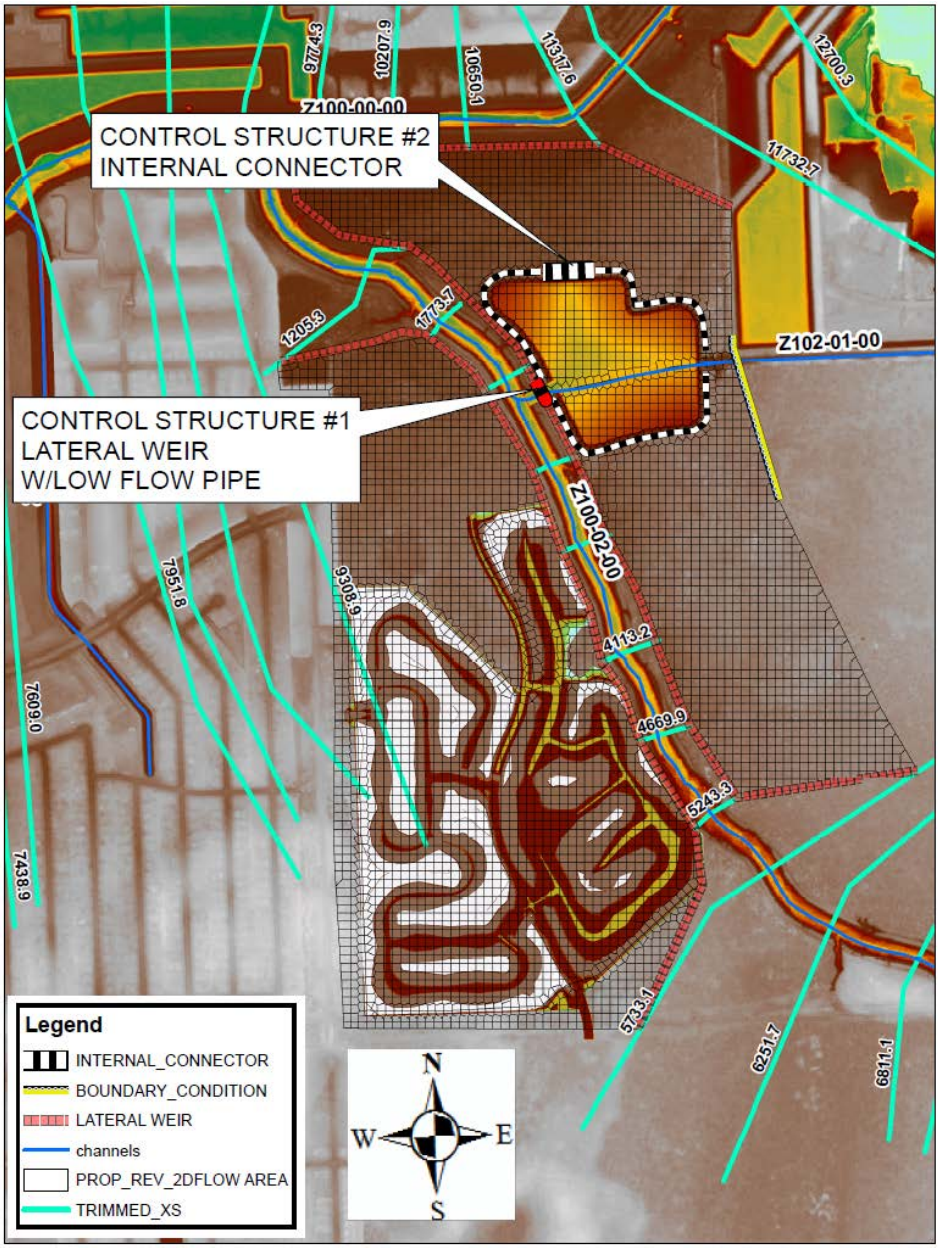

Figure B.13: Geometry Used in the Modeling of Proposed Conditions

The resulting model showed some instability occurring when using the normal weir equation on Control Structure #2. The flow rate over the weir was found to be highly influenced by tailwater, resulting in large swings in the flow rate across the weir from time step to time step as the basin is nearly full when flow from the Z100-00-00 floodplain began to spill over this connector into the basin. The 2D equation was then selected for this connector and found to be more stable. If the basin stage had been lower and not influencing the tailwater on the weir and true weir flow existed, a weir coefficient of approximately 1.5-2.0 would have been appropriate for this structure. Figure B.14 compares the result using the 2D equation versus weir equation with a coefficient of 2.0

on Control Structure #2. The figure shows that while peak flow rates across the weir are similar, the 2D equation provides a more stable solution for this modeled scenario.

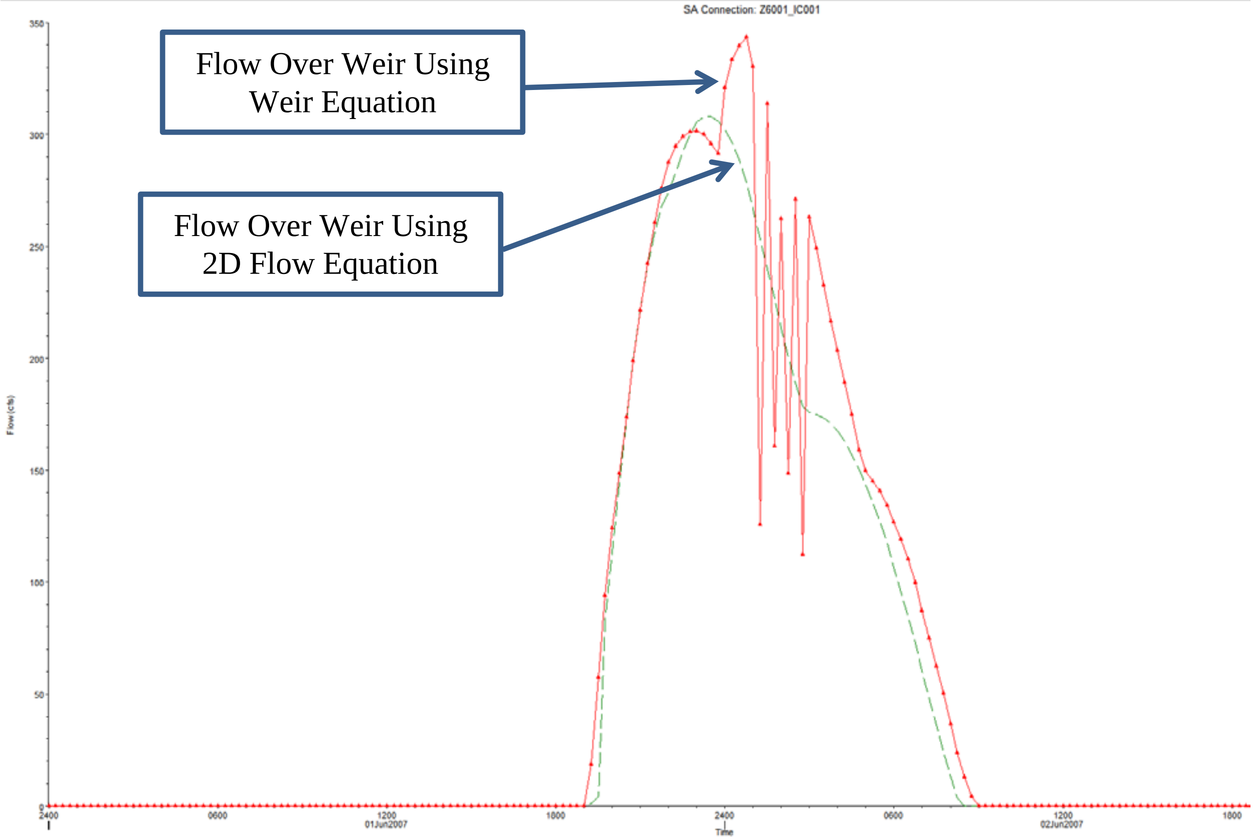

Figure B.14: Flow Results for Internal Connector Using 2D Equation vs. Weir Equation

The location and length of the Z100-00-00 weir, Control Structure #2, was optimized by sliding it along the edge of the basin until a no-impact condition was obtained. Once the control structure configurations were finalized, terrain data was edited to reflect the proposed condition berm and control structure gradings. Figure B.15 on the following page provides a comparison of the revised proposed condition 100-year maximum WSEL to that of existing conditions by subtracting the proposed condition maximum WSE raster from that of existing conditions maximum WSE raster.

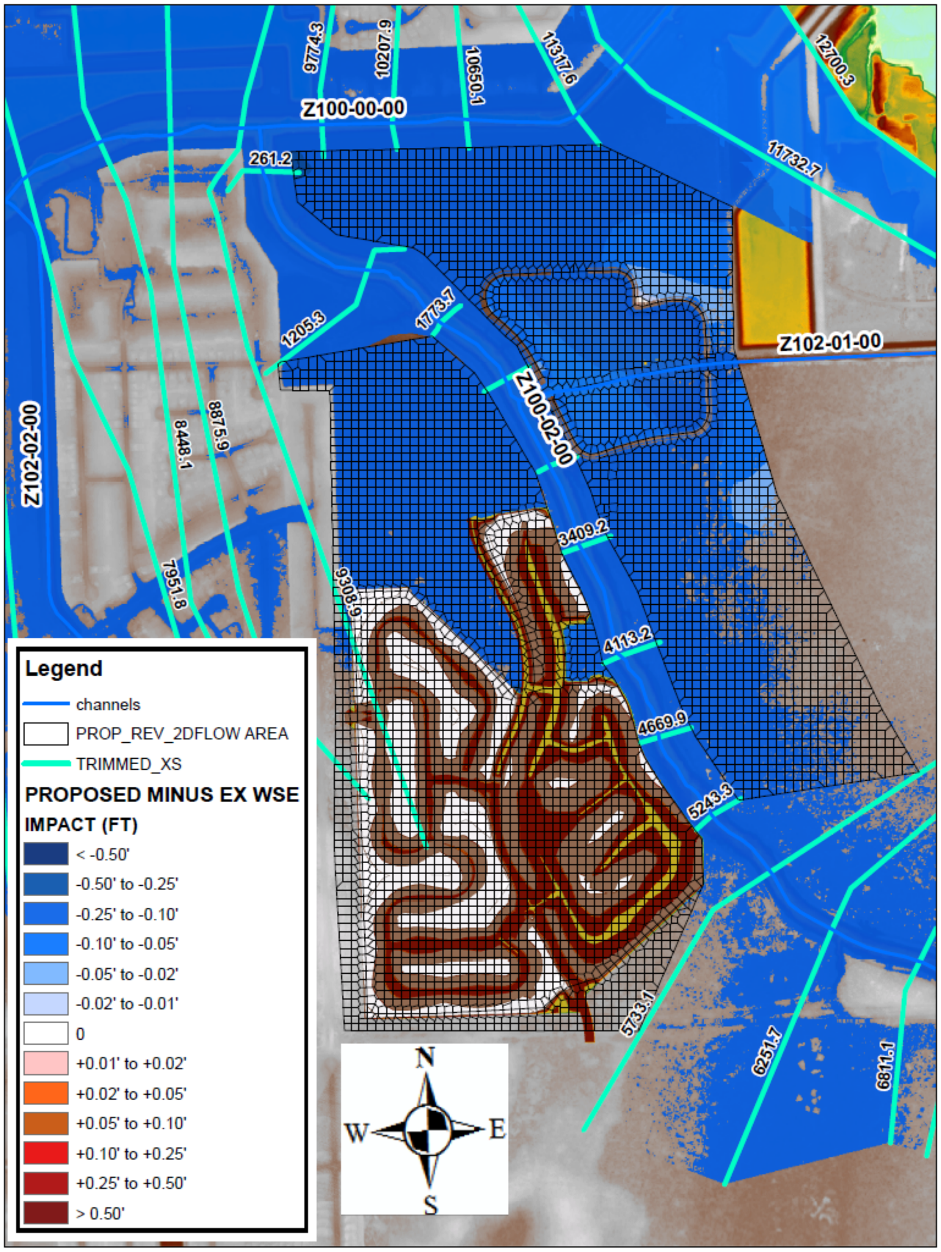

Figure B.15: Difference Between Final Proposed and Existing Conditions WSE

Figure B.16 provides the resulting flow pattern through the project site.

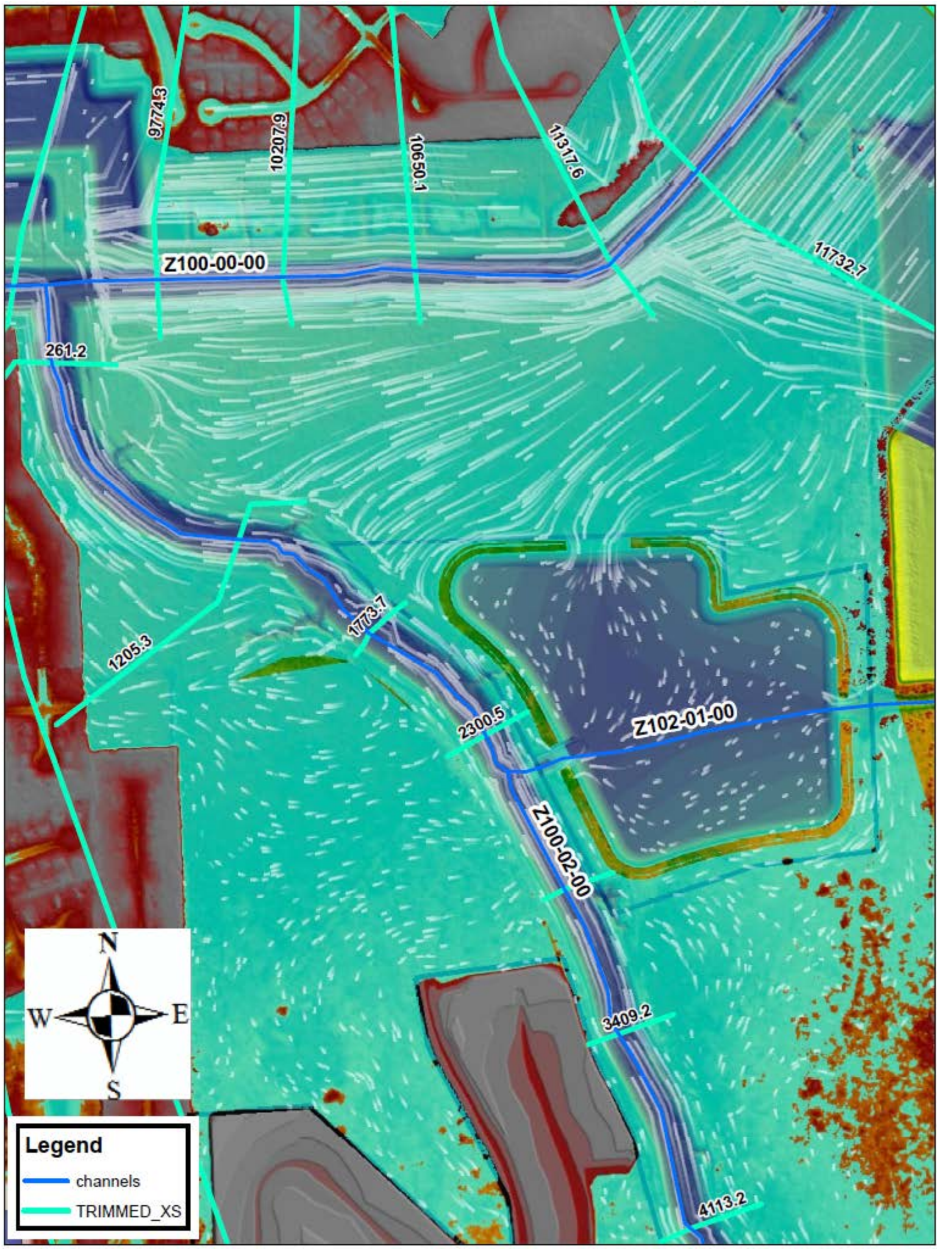

Figure B.16: Proposed Conditions Flow Pattern

Develop HMS model from 2D Results

Step 11: The effective HEC-HMS model was revised to replicate the 2D model's no adverse impact findings. Diversion structures were inserted based on the 2D model's reported flow rates over the control structures. HEC-HMS uses a single-point rating curve for its calculation and cannot model a looped rating curve as is commonly found in Harris County. Due to this inability, weir sizes and coefficients used in HEC-HMS may not necessarily reflect the true proposed conditions geometry as represented in the 1D/2D model. The goal is to replicate to the extent possible the results of the 1D/2D model in the HEC-HMS model and steady state HEC-RAS models that are used for regulatory purposes. The modeler must document the differences in parameters used in HEC-HMS to replicate the 2D model results in the No Adverse Impact Report. Figure B.17 presents the HEC-HMS schematic used to replicate the 2D model flow rates in a 1D model.

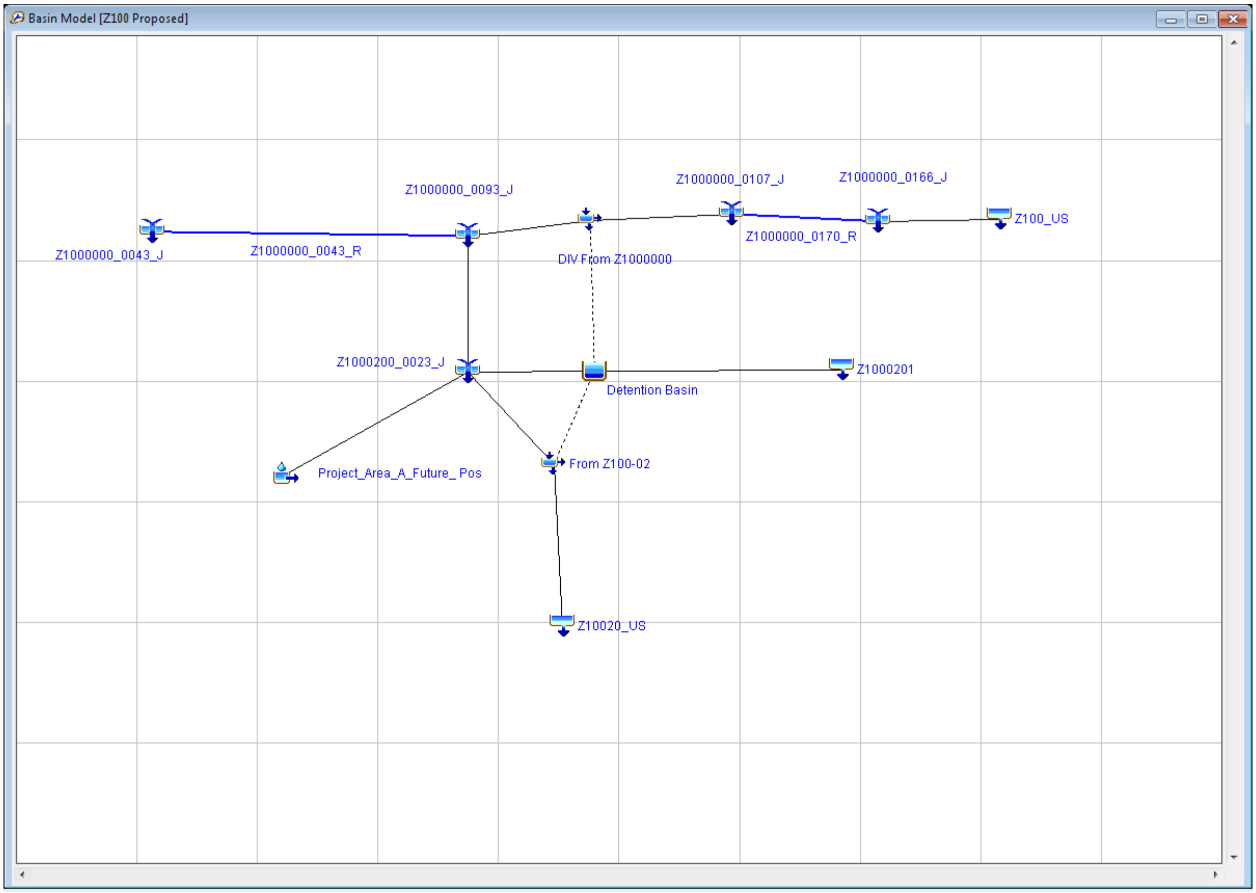

Figure B.17: HEC-HMS Proposed Conditions Schematic

The diversion from Z100-02-00 to the basin was modeled using a broad crested weir with the same dimension as that used in the 2D model. The weir does not include the low flow pipe, which was found to not carry a significant amount of flow from Z100-02-00 into the basin. The weir coefficient used in the HEC-HMS model was set at a C of 1.6. By using a C of 1.6 versus the 2.0 value used in the HEC-RAS 2D model, similar diversion rates and volumes between the two models were achieved. Similarly, the diversion from Z100-00-00 uses the proposed dimension of the weir modeled in HEC-RAS 2D. The weir coefficient was set at a C of 0.45 to closely match with the flow rates indicated in the 2D HEC-RAS model, which modeled this weir using the 2D equation as discussed earlier. The stage versus flow rating curves used for the diversions were created using the results from the 2D HEC-RAS model's 1D cross-sections located near the respective control structures.

The detention basin outfall into Z100-02-00 uses the same geometry as the Z100-02 diversion weir structure but reduces the weir coefficient from 1.6 to 0.45. This structure also includes the low flow 60-inch outfall pipe. The basin outfall in HEC-HMS does not model a tailwater condition (i.e., tailwater condition set to none). By using the same weir as the diversion weir, Z100-02, an approximation for tailwater effects that the weir experiences during filling and draining of the basin can be made. Essentially, the inflow and outflow vectors from these two weirs cancel each other when the stage in the basin balances with the channel stage. The lower weir coefficient used on the basin outfall allowed for the peak predicted stage in the basin to match that predicted in the 2D HEC-RAS model.

Figure B.18 on the following page compares the HEC-HMS flows with the 2D HEC-RAS model at the outlet of Z100-00-00, downstream of the Z100-02-00 confluence. The peak flows between the two models are within 3% of each other; 13,500 cfs HMS versus13,140 cfs RAS for proposed conditions. The flows from HEC-HMS can now be used in the proposed conditions M3 models for documenting a no adverse impact condition.

The No Adverse Impact Conditions Report must follow the HCFCD Policy Criteria & Procedure Manual's various requirements, such as comparing flows at 3 nodes downstream. The report must also provide the required documentation of the HEC-RAS 2D model and deliverables as detailed in the HEC-RAS *2D Modeling Guidelines* document.

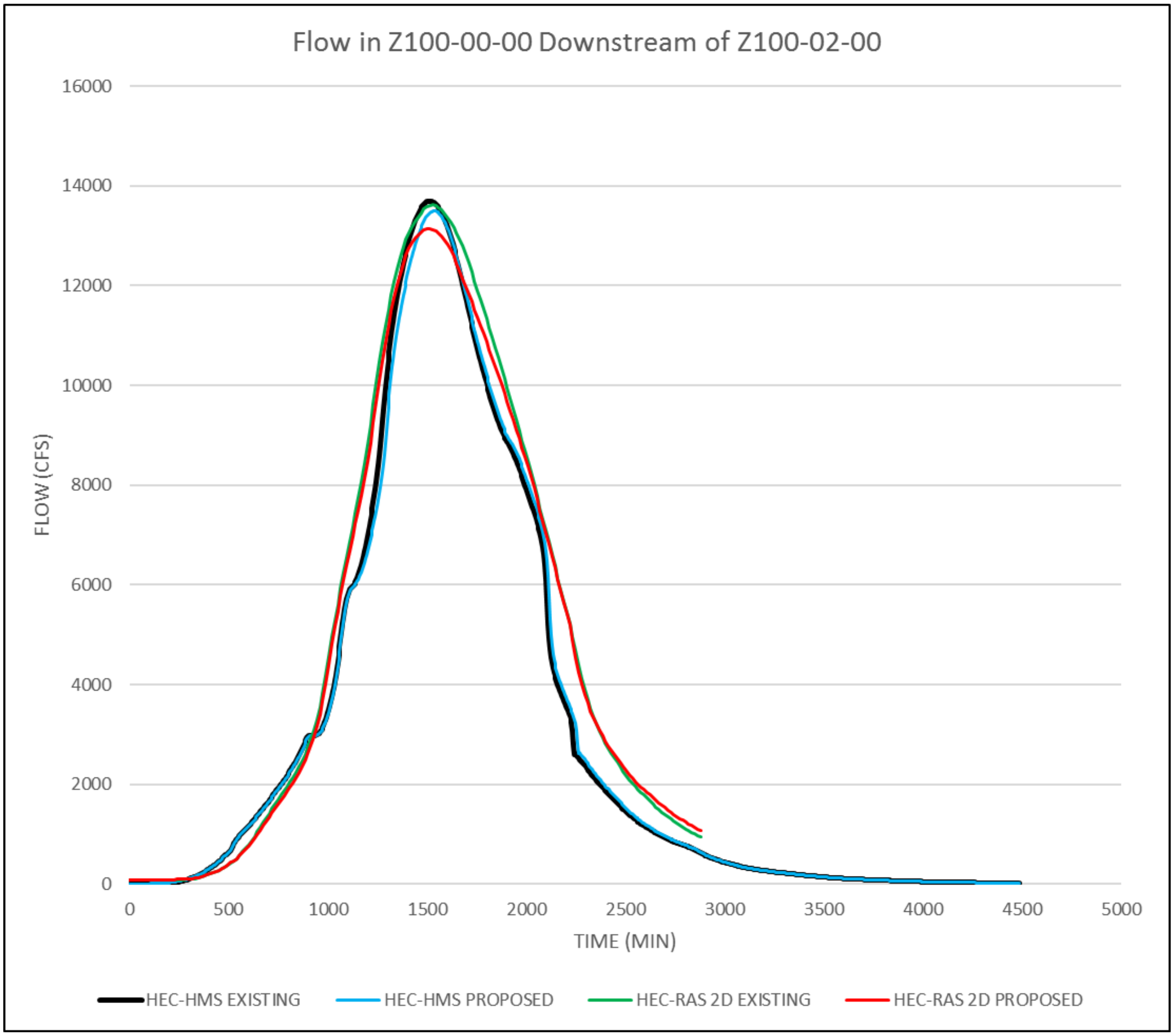

Figure B.18: HEC-HMS vs. HEC-RAS 2D Flows at Z100-00-00 outlet

APPENDIX C – 2D SHEET FLOW APPLICATIONS AND EXAMPLES

Overview

HEC-RAS 2D can be applied to site development applications for overland sheet flow assessments. One application is the use of HEC-RAS 2D to facilitate hydraulic impact of offsite sheet flow, so this water can be accounted for by either passing it through or around the proposed developed. In this example, the Engineer wishes to perform a rapid sheet flow feasibility assessment to evaluate hydraulic impacts and quantify offsite inflows entering the proposed development.

Using HEC-RAS 2D

Existing and proposed conditions' models are required to evaluate and identify potential hydraulic impacts. This example utilizes the 2D rain-on-mesh capabilities of HEC-RAS 2D to simulate the rainfall-runoff response over the study region. The following steps provide cursory instructions for conducting a basic sheet flow analysis.

Site Description

The proposed single family residential development is located on an undeveloped 297-acre tract. Much of the subdivision drains into Z120-00-00, a tributary to Z100-00-00. The study area is shown in the region bounded by the purple polygon in Figure C-1. There is a large drainage area on the east side of the development that drains towards the development.

Establishing Pre-Project Conditions

Step 1: Pre-Project Mesh

The Harris County NUSA dataset (2008) LIDAR dataset was selected for Pre-Project Conditions topography. For this example, the pre-project conditions mesh was generated using a 200 feet x 200 feet grid cell size. Breaklines were added with a 70 feet minimum cell spacing to represent major roads and other high points that could influence runoff paths. Figure C.1 illustrates the extents of the LiDAR dataset and the 2D mesh. Note how the mesh extends sufficiently beyond the project limits in order to capture flows draining into the site.

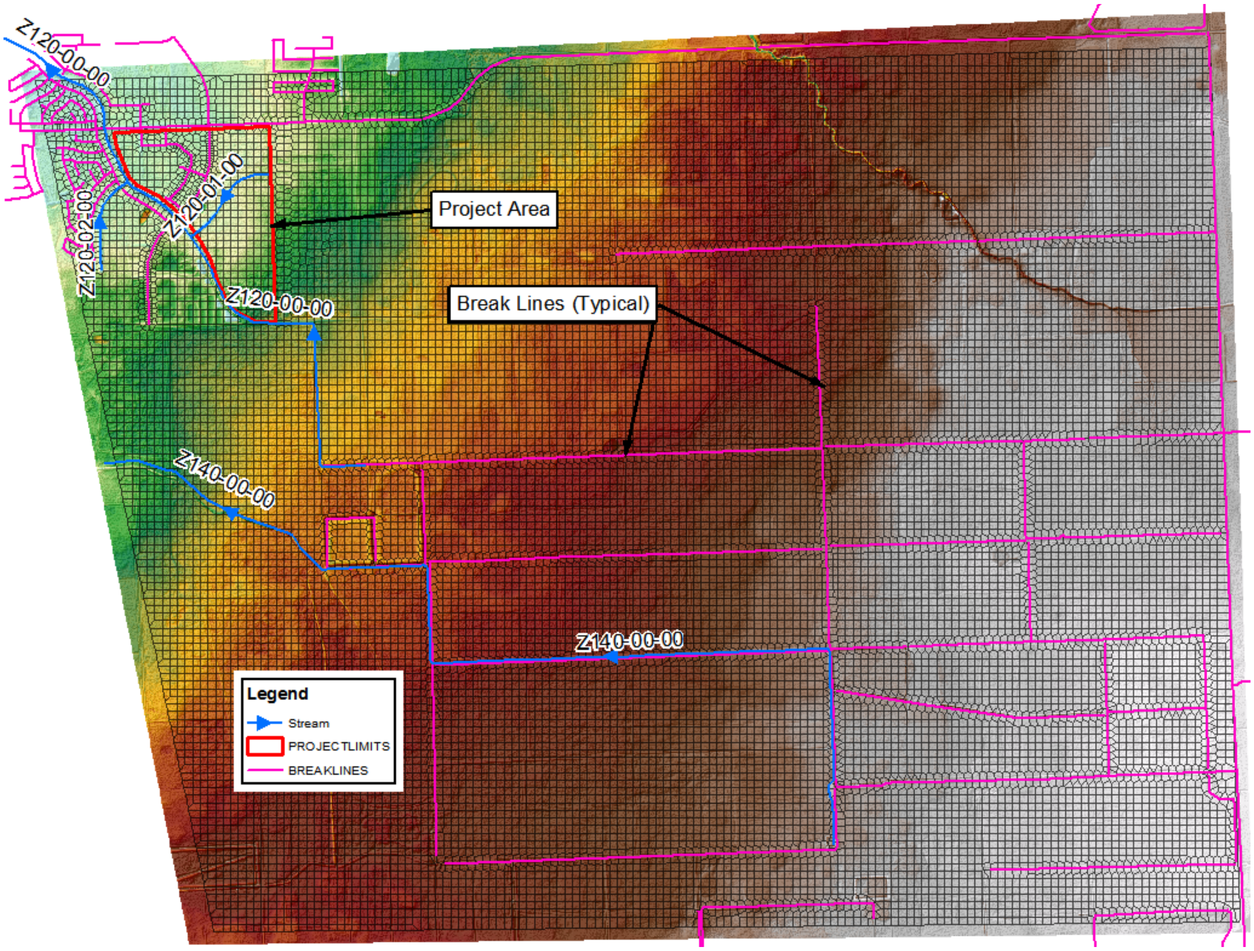

Figure C.1: 2008 LiDAR and Mesh Extent

Step 2: Pre-Project Land Use

Land use classifications for “generic undeveloped” and “generic residential” had n values set to 0.2 and 0.18, respectively. Land use was also specified for designated floodplain and floodway zones, with “floodplain” n values of 0.08 and “floodway” n values of 0.06. Land use areas were digitized in GIS and imported to HEC-RAS to generate a land cover layer. Figure C.2 illustrates this land cover variability.

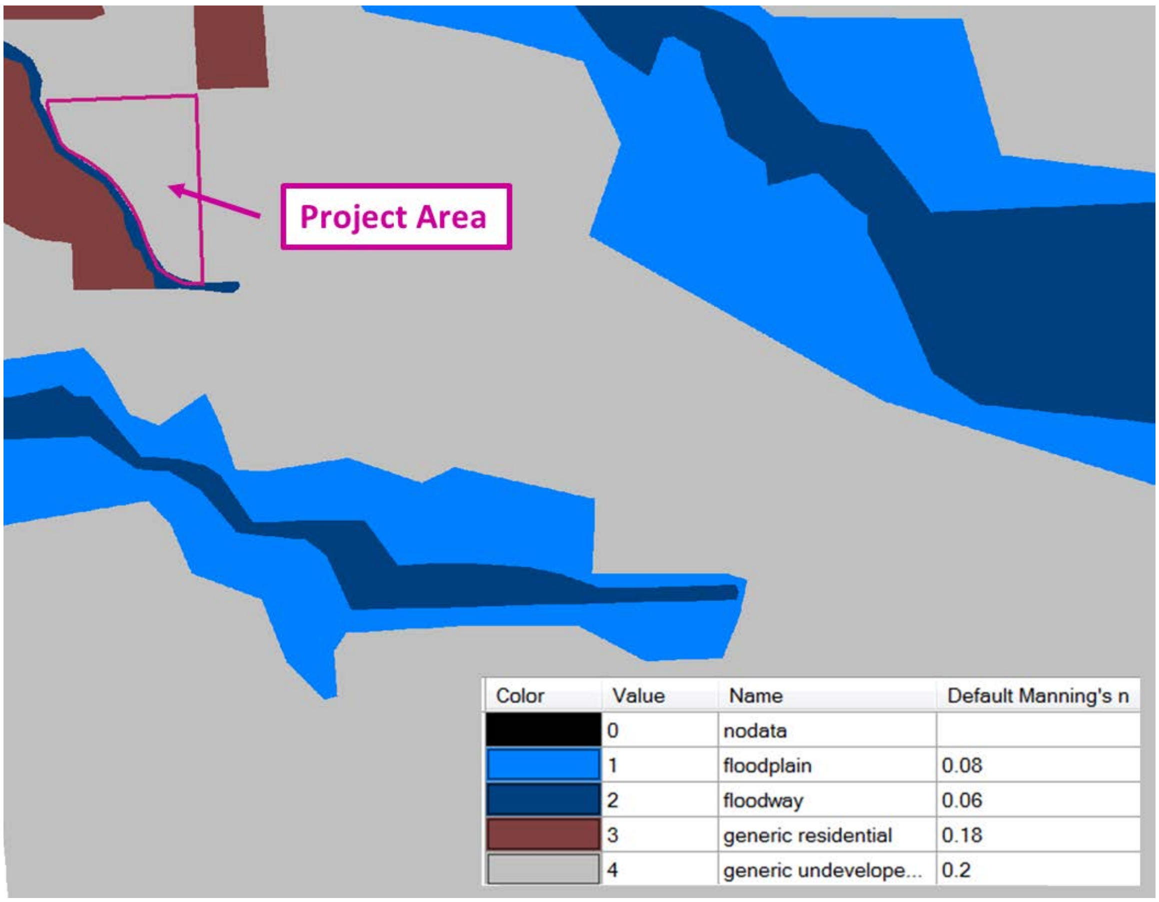

Figure C.2: Pre-Project Land Use

Establishing Post-Project Conditions

Step 3: Post-Project Mesh

Post-project topography was added to the model for the project area's extent, overlaying it onto the 2008 LiDAR, as illustrated in Figure C.3. The post-project conditions mesh was regenerated using the same 200 feet x 200 feet grid cell size. Additional breaklines were added with a 70 feet minimum spacing to represent new roads as indicated in Figure C.4.

Figure C.3: Pre-Project versus Post-Project Topography

Figure C.4: Pre-Project versus Post-Project Mesh and Breaklines

Step 4: Post-Project Land Use

For post-project conditions land use, a Manning's n value region was set for the proposed project area with an n value of 0.18 for representing "generic residential" land type (shown as light brown in Figure C.5). The remaining Manning's n values are unchanged from the pre-project conditions. In HEC-RAS 2D, n value regions were used to overwrite the underlying land cover layer for the specified region. This n value region is indicated in Figure C.5.

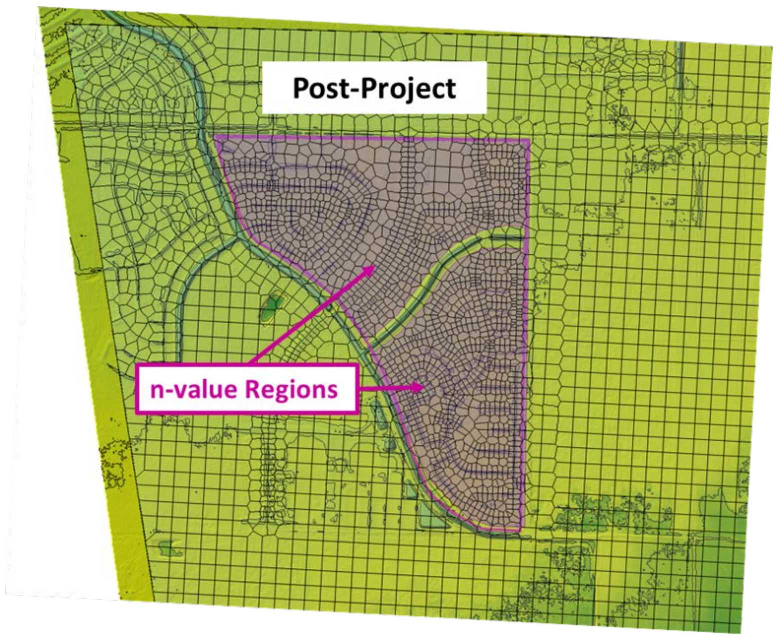

Figure C.5: Post-Project Mesh with Manning's n-Value Regions

Step 5: Boundary Conditions

A boundary condition line was established around the perimeter of the 2D flow area. A normal depth boundary condition with a slope of 0.0005 ft/ft was applied based on natural ground slope in the direction of flow. The boundary condition lines are identified in Figure C.6. The boundary locations were selected along roadways and a distance away from where critical investigations were occurring to limit their influence on results through the area of interest. For precipitation on the mesh, the 100-year storm event precipitation without losses was selected. Losses were not included due to the poorly drained contributing watershed and anticipated initial abstraction.

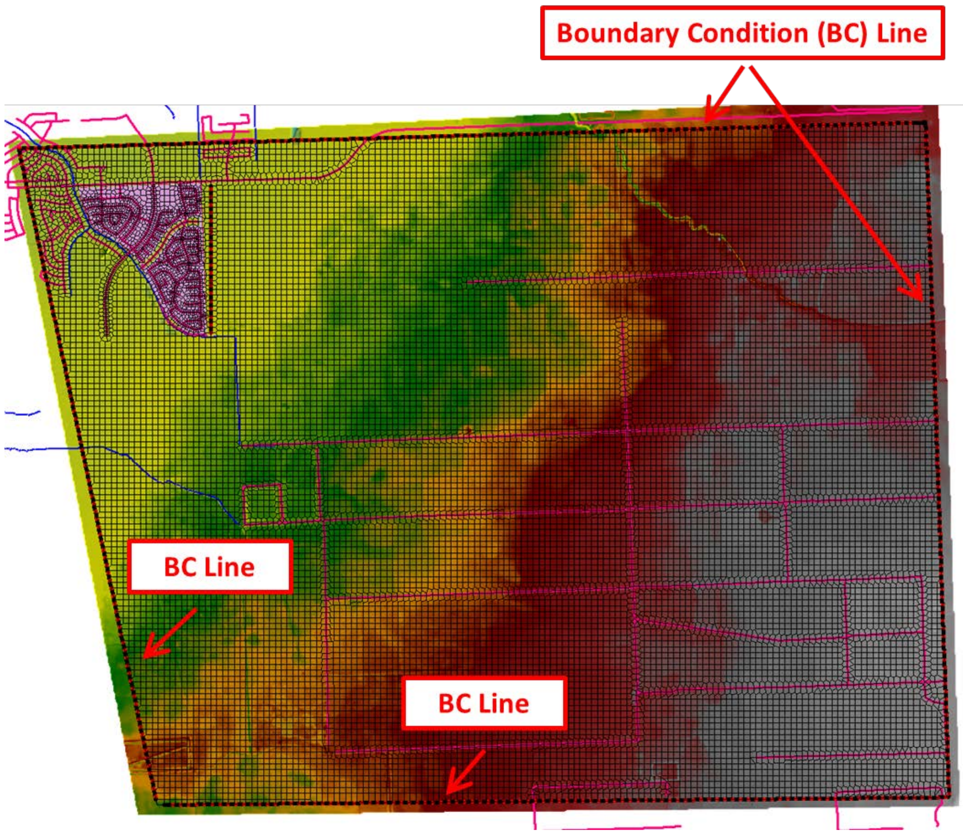

Figure C.6: Post-Project Schematic with Manning's n-Value Regions

Step 6: Model Execution

The default computation options and tolerances were selected and the Diffusion Wave approximation was utilized with a computational time step of 30 seconds, based on anticipated velocities and minimum cell sizes. The model was executed for both the pre-project and post-project conditions.

Step 7: Pre- versus Post-Project Conditions Comparison

After the models were executed for pre- and post-project conditions, peak Water Surface Elevations (WSE) were compared by subtracting the pre-project WSE from the post-project WSE (i.e., post-project minus pre-project). The result is illustrated in Figure C.7, where post-project reductions (negative values) are shown in blue shading, and impacts (positive values) are shown in red shading. In general, impacts are noticeable just upstream of the project area as a result of fill added for the proposed development.

There are numerous areas further away and upstream of the project area reflecting WSEL impacts and reductions, which may indicate potential stability issues. Therefore, the HEC-RAS 2D model was recomputed using a 10-second time step, which resulted in improved model stability, eliminating the changes in WSE that were well away from the project area, as shown in Figure C.8.

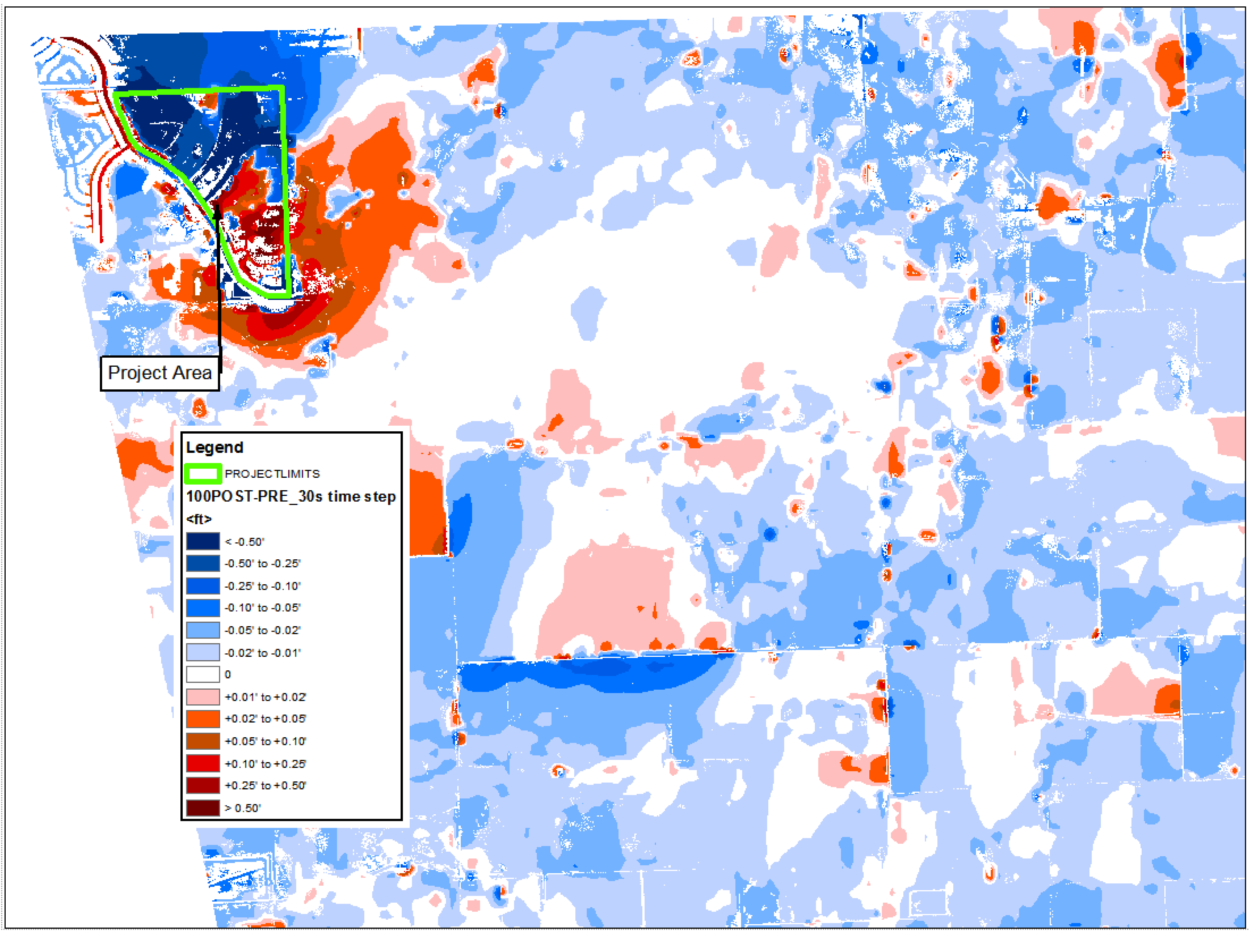

Figure C.7: Pre- versus Post-Project WSE Comparison (ft) (initial run w/ 30s time step)

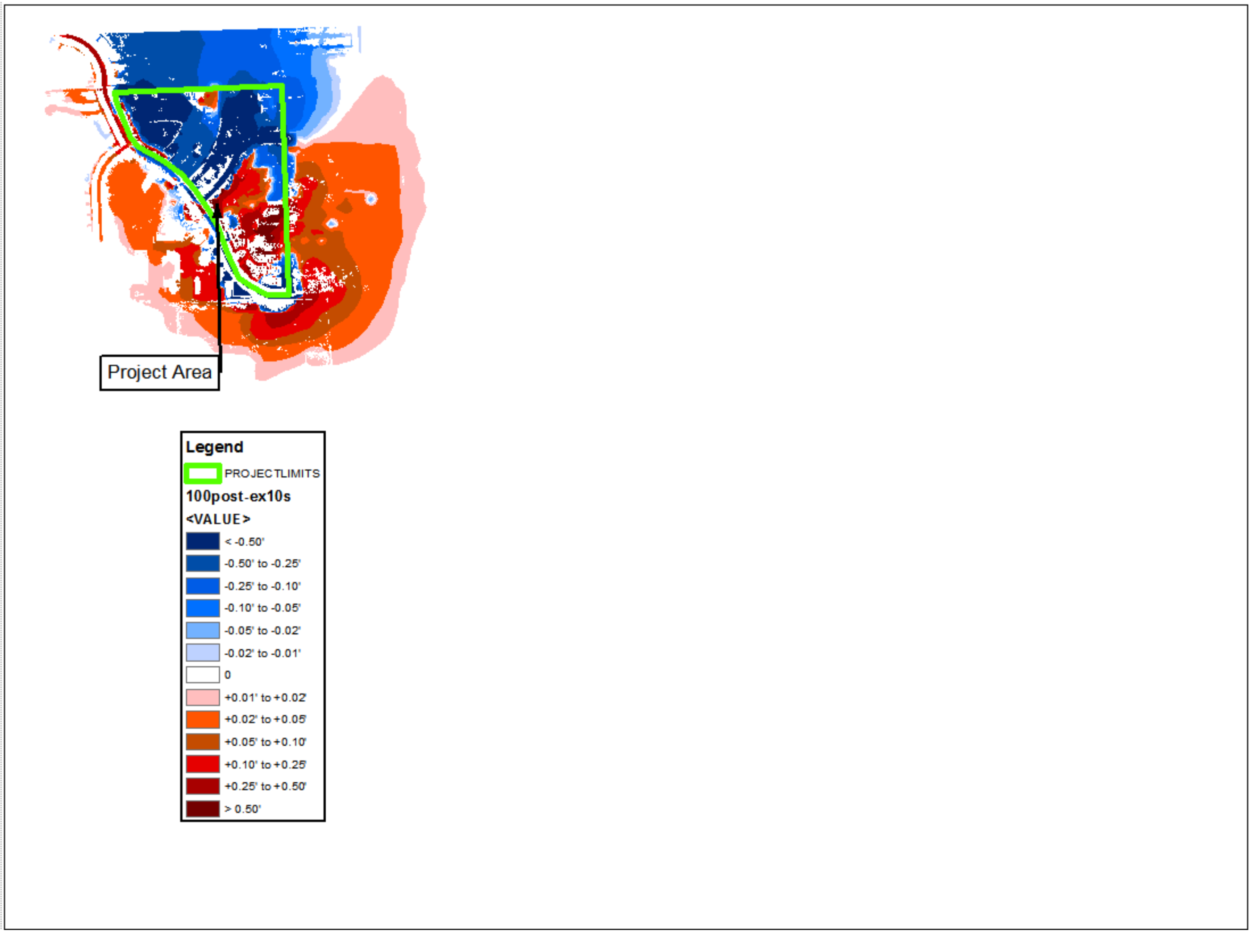

Figure C.8: Pre- versus Post-Project WSE Comparison (ft) (revised run w/ 10s time step)

Validation of HEC-RAS 2D Model to Traditional Methods

Step 8: Catchment Inflows

The particle tracing features in HEC-RAS 2D were used to help guide the delineation process for offsite drainage areas to provide a basis for comparing HEC-RAS 2D computed inflows with traditional methods. The resulting catchments and their respective sizes are illustrated in Figure C.9. Note: These catchment areas were delineated based on the 100-year event. A lesser intense event, such as the 10-year storm, could yield a substantially different catchment delineation. In this example, it is assumed that for design purposes the 100-year event catchment delineation is acceptable for the 10-year event. Storms more extreme than the 100-year storm are beyond typical drainage design standards for a residential development.

Three 2D internal connectors were set along the east side of the property boundary to record inflows entering the project area, also indicated in Figure C.9. These inflows will be compared to flows calculated using traditional methods.

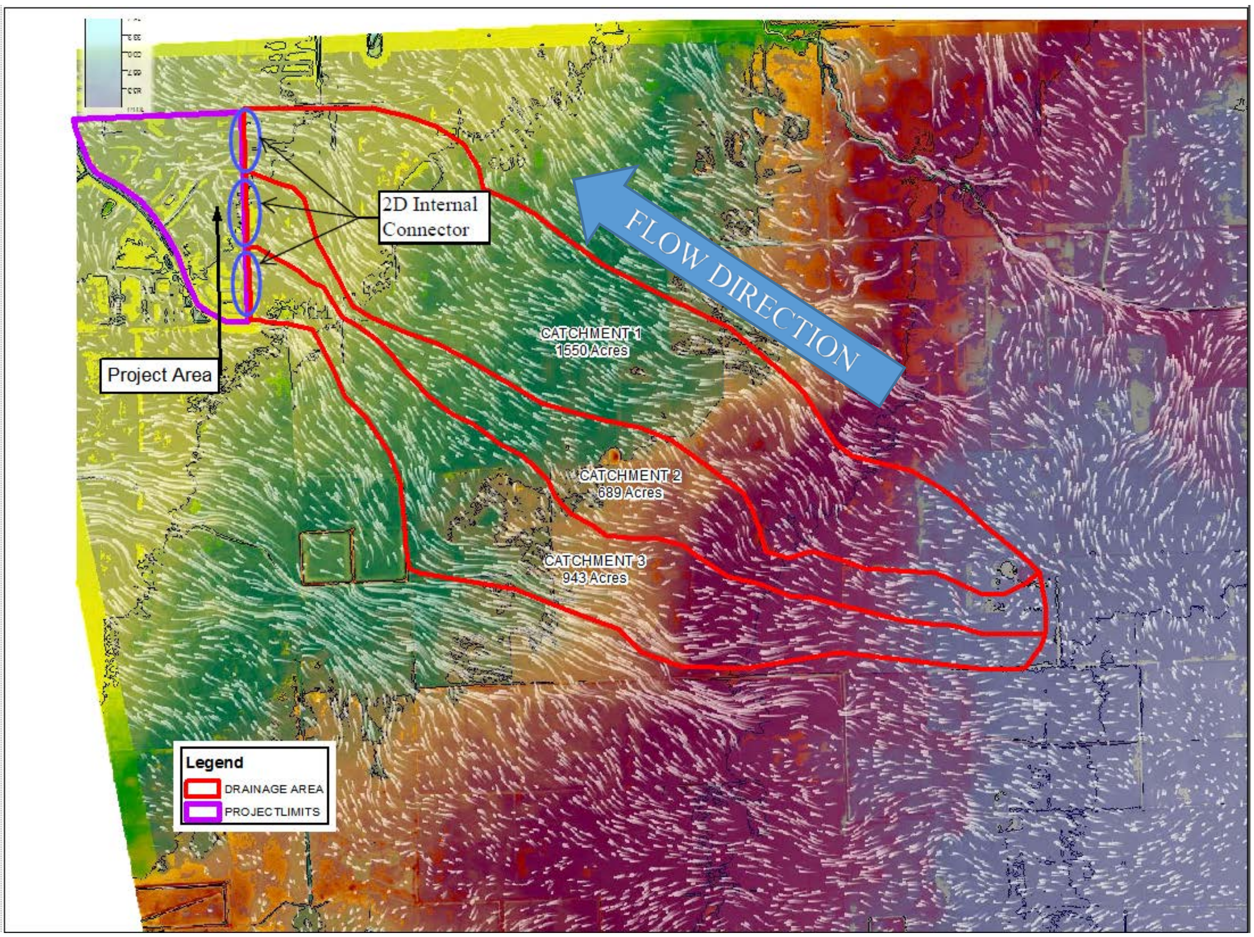

Figure C.9: Flow Tracing for Offsite Catchment Delineation with 2D Internal Connectors Shown

Step 9: Comparing HEC-RAS 2D flows to Site Runoff Curves

Site Runoff Curves are a simplified method to determine peak discharges for relatively small areas involving the design and analysis of stormwater detention facilities or overland sheet flow conditions for new developments. Although site runoff curves are traditionally reserved for drainage areas less than 640 acres, a simple comparison was made to the pre-project conditions HEC-RAS 2D model to compare associated differences between the two approaches. This comparison is shown in Table 1. For this study area, the HEC-RAS 2D model consistently underestimates peak discharges compared to the site runoff curve approach, since HEC-RAS 2D is accounting for storage attenuation occurring in the largely agricultural area with irrigation berms and other depression storage (not accounted for by the site runoff curve methods). As a result, the site runoff curve, as related to this example, was considered a poor method of validation for HEC-RAS 2D.

Table 1. HEC-RAS 2D Pre-Project Conditions versus Site Runoff Curves

		Site Runoff Curve Parameters			100-Year Peak Flows		
Offsite Catchment ID	AREA (acres)	m	Percent Impervious	b (100-yr)	Site Runoff (cfs)	HEC-RAS 2D (cfs)	Percent Difference
Catchment 1	1549	0.823	0.00	3.4	1435.00	644.00	-123%
Catchment 2	689	0.823	0.00	3.4	737.00	243.00	-203%
Catchment 3	943	0.823	0.00	3.4	954.00	290.00	-229%

Step 10: Comparing HEC-RAS 2D flows to TC&R Calculations

To account for the noted attenuation effects, the HEC-RAS 2D model was compared to the Clark Unit Hydrograph (U.H.) methodology for modeling watershed rainfall response. A depth grid was used to identify areas of ponding. Depths ranging from 0 to 1 foot were color coded and where depths greater than 1 foot were shown to drain through areas with depths of less than 0.5 feet the greater than 1-foot depth areas were considered as areas of significant ponding. This is illustrated in Figure C.10. General approximations of the percent ponding for each catchment were factored into the Time of Concentration (TC) & Storage Coefficient (R) calculations. Watershed length (L), length to centroid (Lca), and channel slope (S) were calculated using GIS and the particle tracking features in HEC-RAS 2D. A HEC-HMS model was developed with a sub area for each catchment basin using computed TC&R parameters. As shown in Table 2, this process resulted in a difference for the 100-year peak flow of less than 10% for each catchment when comparing the HEC-RAS 2D pre-project conditions and Clark U.H. peak flows. As a result, HEC-RAS 2D was considered a reasonable alternative for supporting or validating traditional watershed hydrology methods in this example.

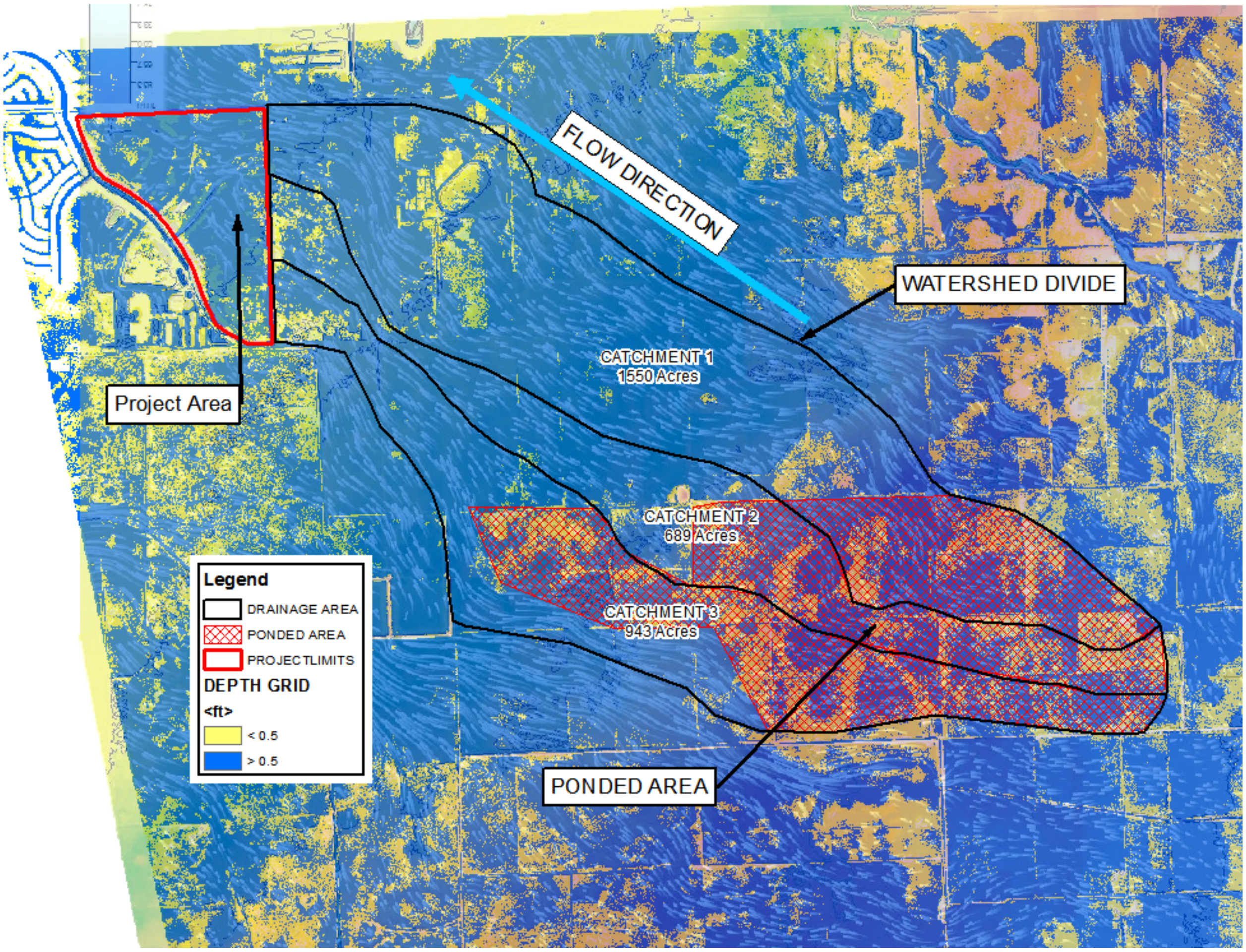

Figure C.10: Depth Grid Reflecting Areas of Ponding

Table 2. HEC-RAS 2D Pre-Project Conditions versus Clark U.H.

		100-Year Peak Flows		
Offsite Catchment ID	AREA (acres)	Clark U.H. (cfs)	HEC-RAS 2D (cfs)	Percent Difference
Catchment 1	1549	598.000	644.00	7%
Catchment 2	689	250.000	243.00	-3%
Catchment 3	943	313.000	290.00	-8%

Accounting for OffSite Drainage

Step 11: Designing Alternatives to Account for Offsite Drainage Impacts

After validating the HEC-RAS 2D model results, the final step is to account for offsite drainage impacts through design. This may include alternatives to divert runoff around the project site or allow it to flow controlled through the project site. Design alternatives should be based on the HCFCD *Drainage Design Criteria Manual* and the HEC-RAS *2D Modeling Guidelines* documents. For example, design flows and associated sizing of any alternatives should be based on the traditional method runoff flow rates, though the HEC-RAS 2D model developed here could be further refined to help inform and guide the design.

APPENDIX D – 2D ELEVATED ROADWAY APPLICATIONS AND EXAMPLES

Overview

Existing roadway improvements or new roadway creation impacts can occur from both blockage of offsite flow coming towards the roadway or increased point discharge locations downstream of the road. This example will focus on identifying impacts due to expansion of an existing two-lane rural roadway into a four-lane boulevard section. The following example is based on a hypothetical roadway expansion of an existing rural two-lane roadway with roadside ditches into an improved four-lane curb and gutter boulevard section. This example evaluates conveyance and WSE impacts of the roadway during a 1% AEP rainfall event.

Using HEC-RAS 2D

New and expansion roadway projects are required to evaluate and identify potential impacts. The modeler should follow the guidance provided in the *2D Modeling Guidelines* document. The project is not located within a FEMA studied stream nor does it have a well-defined channel. The project has shallow sheet flow approaching the roadway and drains across the road through small cross culverts, thus lending the analysis to a pure 2D model.

The modeler should strive to produce models in which the 2D grids are nearly identical for pre- and post-project conditions, which may require the pre-project model to be rerun using the post-project grid once the post-project conditions have been defined. By providing identical grids, differences in computed peak WSE between the two models can be evaluated correctly.

The use of the HEC-RAS 2D model will allow the engineer to properly size culvert crossings, set roadway vertical profile, and locate mitigation for the proposed project. This example does not include design of mitigation features but evaluates impacts on flows and peak water surface elevations.

Site Description

The proposed roadway expansion will replace an existing two-lane rural collector road with roadside ditches with an elevated four-lane curb and gutter section with roadside ditches located near the ROW. Land use immediately upstream and downstream of the roadway is largely undeveloped, but some commercial development exists. Roadside ditches are present along the sides of the existing collector as well as local roads off of the collector. In the vicinity, there are four culvert crossings under the existing roadway, which are located at local low areas or locations where small ditches continue on the opposite side of the road. The project will require mitigation for the increase in impervious cover, conveyance changes, and water surface elevation increases due to blockage of sheet flow, which previously overtopped the roadway.

Roadway Hydrologic Impact Evaluation

The roadway expansion's impact on peak runoff rates is to be evaluated using standard HCFCD methods. The modeler should evaluate the impact of increased impervious cover and the conveyance changes in the roadway to determine the placement and sizing of detention systems to mitigate peak flows. For the purposes of this model, these types of impacts are not being considered. The primary focus of this example is assessing water surface elevation impacts to surrounding property from the proposed roadway grading and changes in roadway cross-section and profile.

Offsite Hydraulic Impact Evaluation

Impact evaluation for new or modified roadways is generally a comparison of pre-project to proposed project water surface elevations. Proposed cross culverts must also be included in the evaluation to determine potential impacts.

The 2D mesh should be large enough to encompass the drainage area coming towards the road and extend sufficiently downstream, such that backwater from the boundary condition does not have an effect on upstream water surface elevations. In this example, the precipitation on the grid is being utilized to calculate the flows.

If the modeler is performing an analysis where a very large drainage area approaches a roadway, traditional hydrologic methods should be used to develop a hydrograph which can be incorporated as an upstream boundary condition and applied to the 2D flow area at the location where offsite flow enters the 2D flow area. Furthermore, drainage patterns should be evaluated to determine if the proposed roadway is diverting flow to another location where it previously did not flow.

Establishing Pre-Project Conditions

Step 1: Project Area Determination and LiDAR for Pre-Project Conditions

The H-GAC LiDAR NUSA dataset (2008) is to be used as the base topographic data set for modeling purposes unless otherwise directed by HCFCD. Using GIS, create a LiDAR data subset that fully encompasses the project site and captures watershed limits and model extents through the project site as illustrated in Figure D.1.

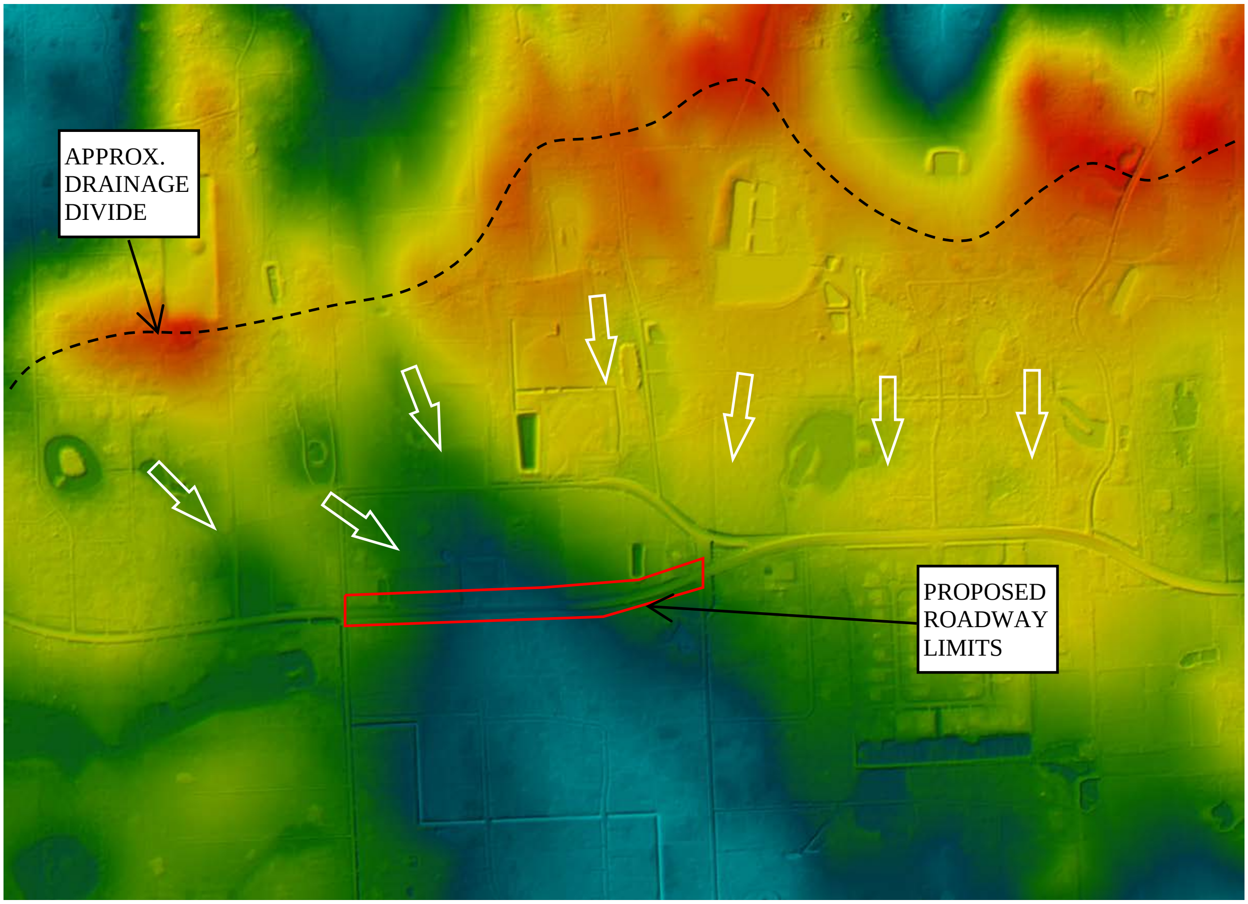

Figure D.1 LiDAR Data Extents

Step 2: Pre-Project Mesh

Create a 2D flow area which encompasses the expected topographic area draining towards the roadway. The 2D flow area extents need to be sufficiently offset from project limits to verify no-adverse impacts to adjacent properties.

A 100’ x 100’ cell size was selected for the 2D area based on the estimated level of detail that would be needed for post-project conditions. Breaklines should also be added to define areas impacting flow direction, such as berms, major roads or channels. In this example, breaklines were added along the centerline of existing roadways to help ensure the crown of the roadway is captured as a local high point. Figure D.2 presents the pre-project conditions 2D flow area.

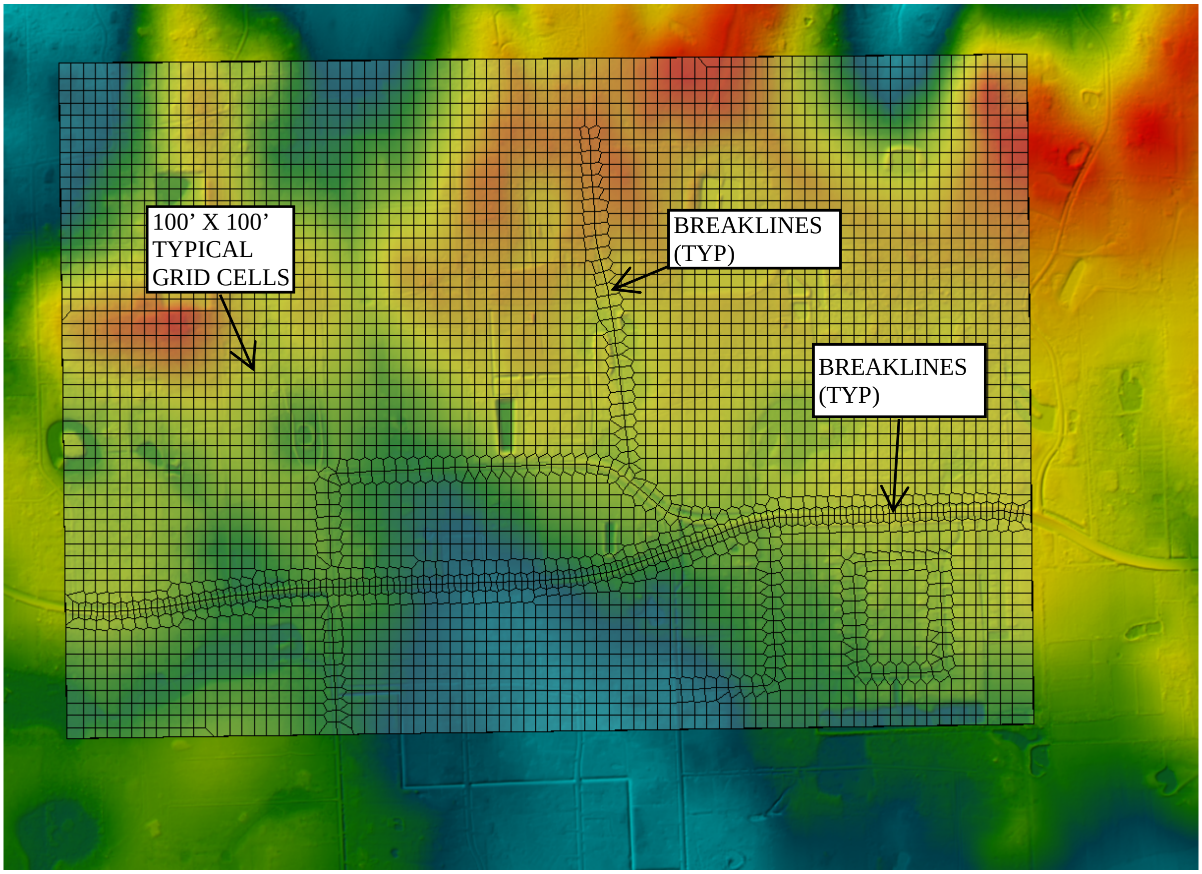

Figure D.2 2D Flow Area

Step 3: Internal Storage Area/2D Area Connector Creation

In the geometry editor, add internal 2D area connector(s) to simulate the roadway with cross culvert(s). Connections with culverts are approximately 150 feet wide while the roadway segments between culvert connections are left to use the 2D mesh (refer to Figure D.3). As is customary with HEC-RAS, connections are drawn from left to right when looking downstream.

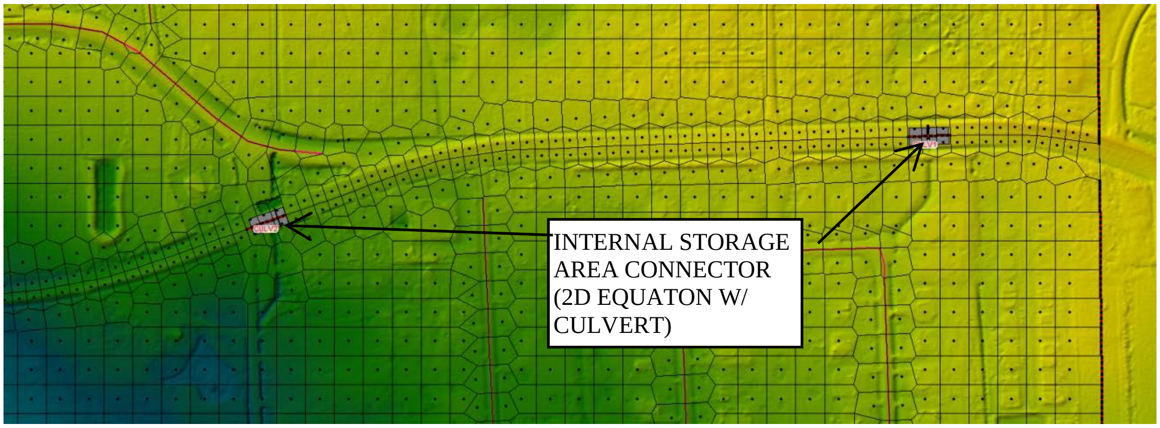

Figure D.3 Internal Boundary Connectors

After the connection is created, the connection data editor was opened. The normal 2D equation domain was selected. The structure type was specified using the drop down as weir and culvert. The weir profile was copied from the underlying terrain and pasted into the weir embankment editor. The 60-foot roadway width was entered as the weir width and the default weir coefficient selected.

Enter the culvert information as well, ensuring the flow line elevations are above the cell elevations at the respective locations. Often, LiDAR terrain is not detailed enough to pick up localized low elevations where culverts are located; thus, cell elevations may be higher than surveyed elevations of culvert crossings. If necessary, the terrain may be edited, so the cell faces are below the actual culvert elevations.

Step 4: Pre-Project Land Use

In this example a shapefile was created covering the model extents with a single land use. The modeler applies a single n value of 0.22 over the entire 2D flow area for the predominately pasture land use. A Manning's n value region was defined for the roadway and an n value of 0.02 assigned for the roadway surface.

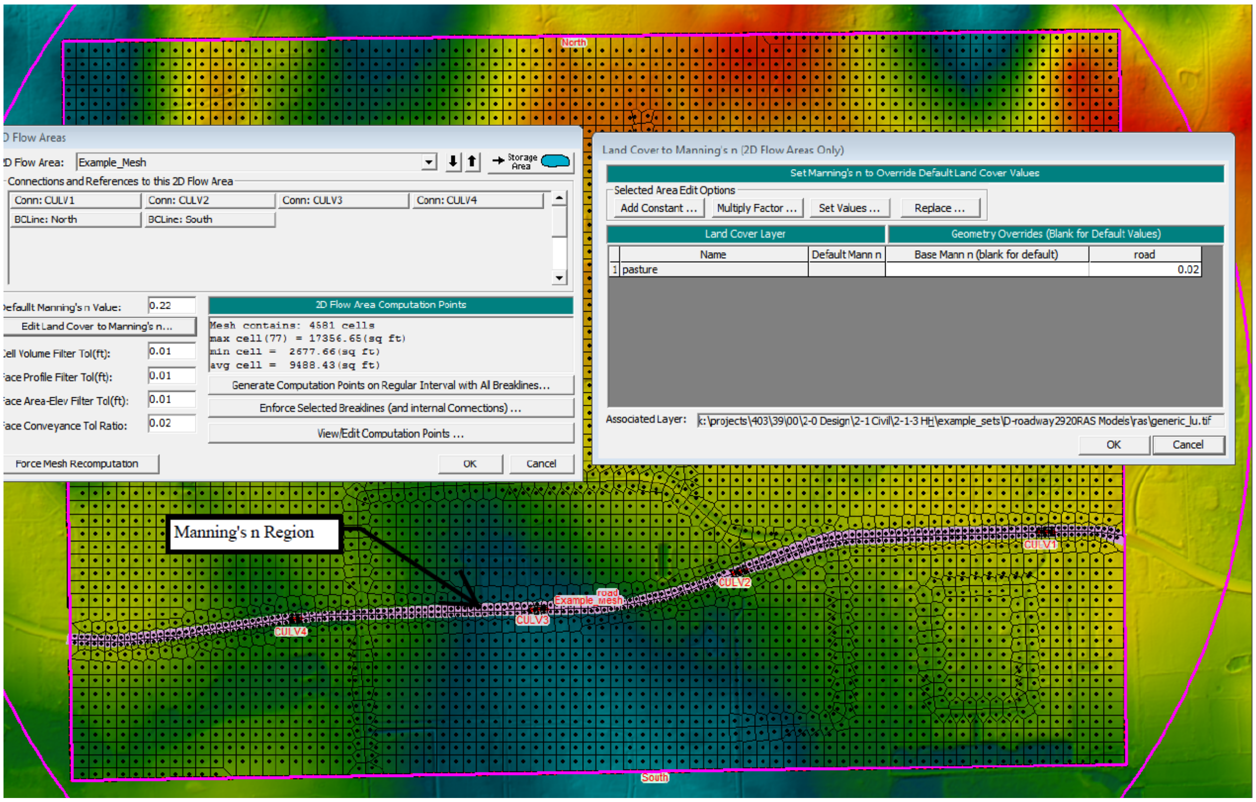

Figure D.4 Manning's n-value Assignment

Step 5: Pre-Project Boundary Conditions and Flow Calculations

The flow was assigned in the unsteady flow data editor using a boundary condition on the 2D mesh. In addition to the flow, boundary conditions at the edges of the mesh, especially areas where flow would continue downstream, are also assigned. An energy grade of 0.005 ft/ft was selected for the boundary based on the natural ground slope of the terrain in the vicinity. Figure D.5 shows the boundary condition flow assignment location.

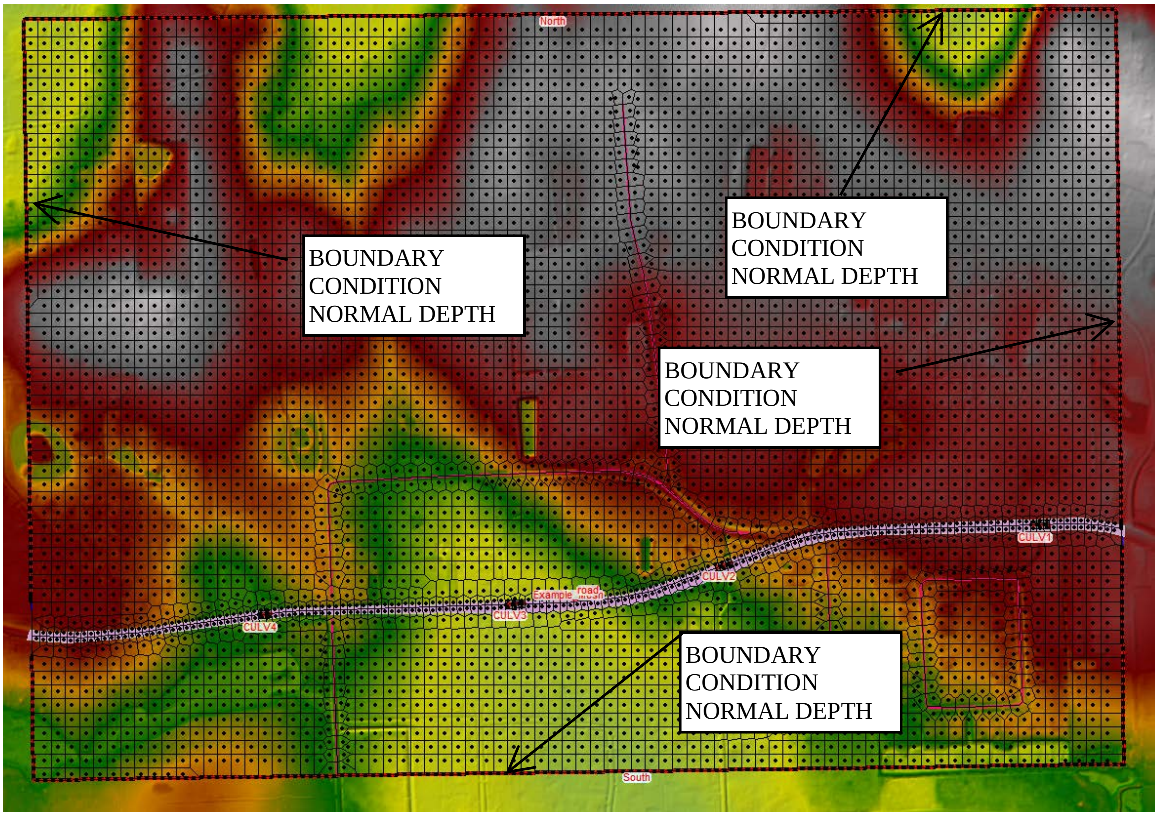

Figure D.5 Boundary Condition Flow Assignment Location

For projects like this example, which solely utilize a 2D mesh, precipitation on the grid can be utilized or a boundary condition with a specified hydrograph can also be used. This model utilizes precipitation on grid, which was generated from a HEC-HMS model in the watershed where this project is located (refer to Figure D.6). Guidance on whether to use actual precipitation or rainfall excess is located in the *2D Modeling Guidelines* document.

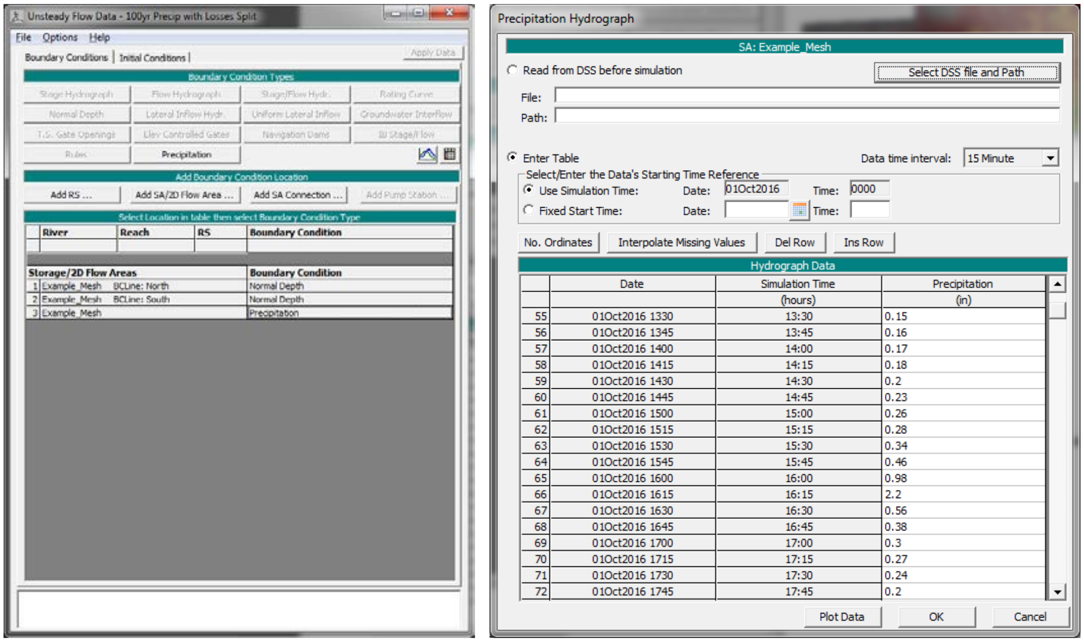

Figure D.6 Precipitation on Grid Flow Assignment

If using a 1D/2D coupled model, the modeler should assign the flow at the appropriate locations on the river reaches as is typically done in unsteady state 1D modeling.

Step 6: Pre-Project Model Execution and Review

The default computation options and tolerances were selected and Diffusion Wave used as the 2D equation set. The model velocities in the project area are approximately 1 ft/s upstream and downstream of the road. A 60-second time step was selected to provide a Courant Number (C) ≤ 1. Additionally, the number of cells within the model is relatively low, so run times are not significant with a lower time step selection. See the HEC-RAS 5.0 *2D Modeling User's Manual* document for more information concerning the Courant Number selection. The Courant Number equation is shown below when using the Diffusion Wave equation.

$$C = \frac{V * \Delta T}{\Delta X} \leq 2$$

The model was run and a few cells were reported to have minor errors. The time step was reduced, and the mesh was edited to eliminate the instabilities. The resulting 2D flow tracking is shown in Figure D.7.

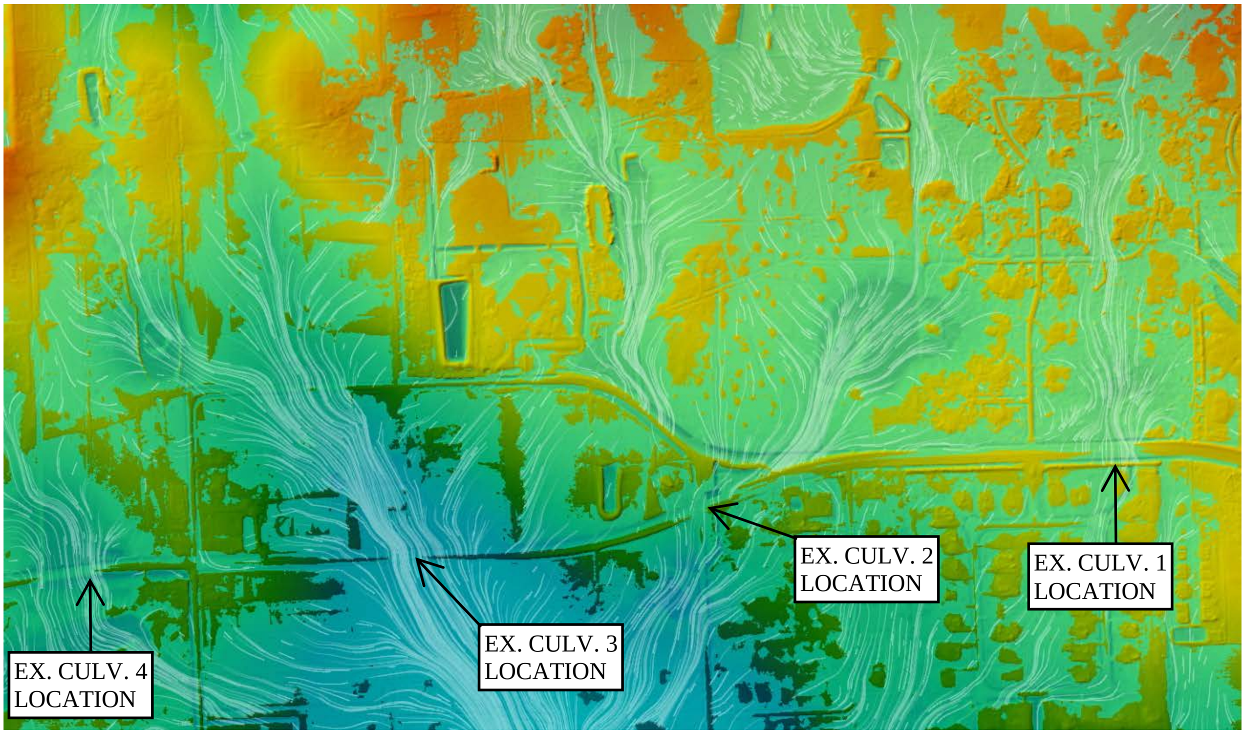

Figure D.7 Pre-Project Conditions Flow Patterns

Establish Post-Project Conditions

Step 7: Post-Project Mesh

Terrain data for post-project conditions was created within AutoCAD Civil 3D. The surface for the roadway was then exported as a LANDXML file. The LANDXML file was imported in GIS, generating a TIN of the two surfaces. These surfaces were converted to raster files using the 3D Analyst extension. The new raster was then merged with the pre-project terrain while being imported into HEC-RAS (refer to Figure D.8). Alternative methods of generating the HEC-RAS post-project conditions terrain exist and are acceptable as long as they retain the level of accuracy inherent in the post-project design surface. The modeler should make every effort to retain the fidelity and resolution of the terrain, while using the 2D flow area mesh size to control model size and run times. Increasing the cell size of the terrain to reduce file size and/or smooth out terrain features is generally not acceptable and would require approval by the HCFCD.

Figure D.8 Post-Project Conditions Terrain

Cross culverts from the pre-project condition were then modified to improve the conveyance of sheet flow through the roadway.

Step 8: Post-Project Breaklines

If necessary, add any additional breaklines to capture newly added local high or low areas from the proposed grading. In this example, Culvert 3 was modified from a single 24" reinforced concrete pipe (RCP) to a multiple box structure to provide more conveyance of flow through the proposed roadway (refer to Figure D.9).

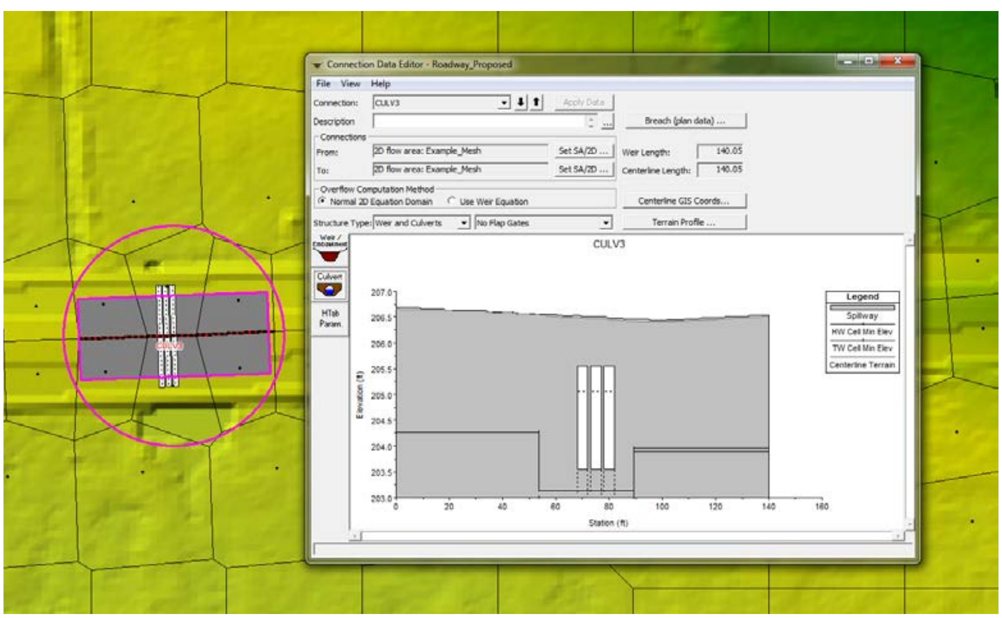

Figure D.9 Post-Project Culvert Modification

Step 9: Post-Project Boundary Conditions and Flow Calculations

The same boundary condition limits and time step as the pre-project run were used for post-project conditions, so off-site flow remains unchanged from pre-project conditions. Since the model applies precipitation on the grid, no changes should be made for an equal comparison between pre-project and post-project conditions.

Step 10: Post-Project Model Execution and Review

The model was then executed and data viewed in RAS Mapper and ArcGIS. Comparison of the pre-project condition versus post-project condition was done using the Spatial Analyst tools to subtract the pre-project conditions maximum WSE from the post-project conditions maximum WSE (i.e., post-project minus pre-project).

Figure D.10 show that the post-project roadway created increases in water surface elevations due to the raising of the road profile, which blocks drainage previously flowing over the roadway. Furthermore, the increase in culvert sizing through the roadway created impacts downstream as more flow was allowed through the structure than previously modeled at concentrated locations. Red colors in Figure D.10 represent increases in WSE, blue colors are decreases in WSE, and white colors are areas with no change in WSE.

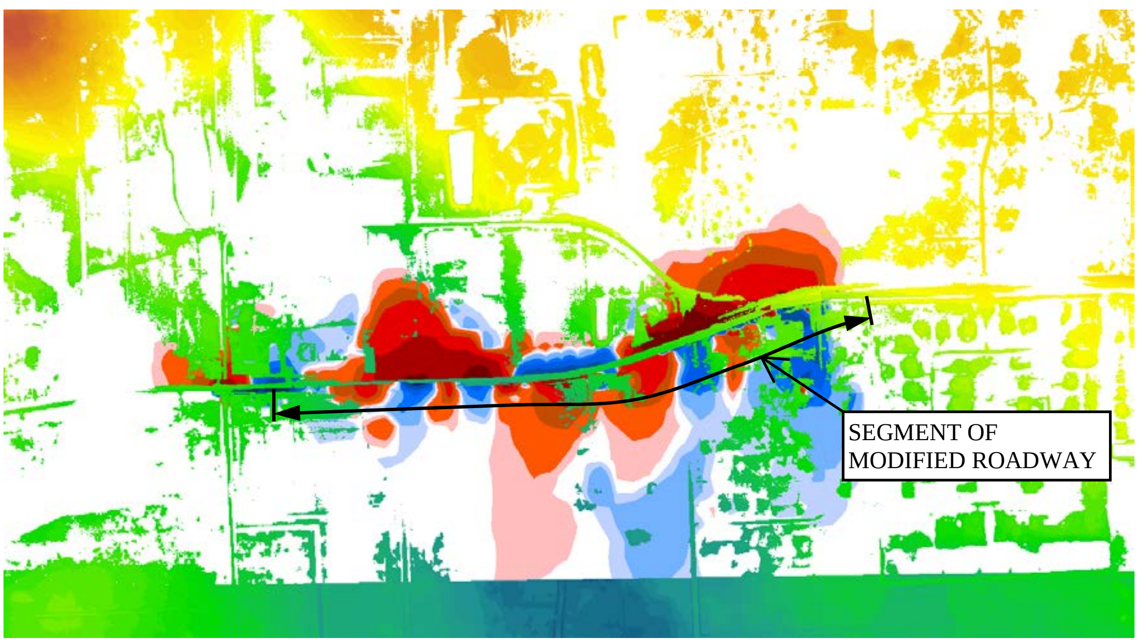

Figure D.10 Pre-Project Conditions vs. Post-Project Conditions Comparison

Step 11: Mitigation Scenarios

The engineer should adequately mitigate these areas with detention and/or flood control systems to reduce peak flows and water surface elevations, such that the project shows no adverse impact to the surrounding areas. Mitigation options include increasing the number of cross culverts and/or sizes, modifying the roadway profile, and improving conveyance features within the roadway. These alternatives can then be assessed using the HEC-RAS 2D model and/or a combination of traditional methods as warranted.

APPENDIX E – 2D DEPRESSED ROADWAY APPLICATIONS AND EXAMPLES

Overview

Existing roadway improvements or new roadway creation impacts can occur from blockage of offsite flow coming towards the roadway, interception/redirection of sheet flow, or increased point discharge locations downstream of the road. This example will focus on identifying impacts due to a new depressed curb and gutter roadway section. The following example is based on a hypothetical roadway, four-lane curb, and gutter boulevard section. This example evaluates conveyance and water surface elevation impacts of the roadway during a 5-year rainfall event. This example project does not evaluate mitigation requirements but focuses on conveyance impacts caused by the vertical profile cutting across minor watershed divides.

Using HEC-RAS 2D

New and expansion roadway projects are required to evaluate and identify potential impacts. The modeler should follow the guidance provided in the *2D Modeling Guidelines* document. The project is not located within a FEMA-studied stream nor does it have a well-defined channel. The project has shallow sheet flow approaching and draining across the proposed ROW, thus lending the analysis to a pure 2D model.

The modeler should strive to produce models in which the 2D grids are nearly identical for pre- and post-project conditions, which may require the pre-project model to be rerun using the post-project grid once the post-project conditions have been defined. By providing identical grids, differences in computed peak WSE between the two models can be evaluated correctly.

The HEC-RAS 2D model is to be used to properly analyze and help establish the roadway vertical profile, preventing the roadway acting as a conduit and redirecting flow towards existing infrastructure not designed to accommodate increased flows.

Site Description

The proposed roadway will create a four-lane boulevard, curb and gutter section. Land use immediately upstream and downstream of the roadway is largely undeveloped pasture land. The proposed roadway will connect to an existing interstate frontage road. The project will require the vertical profile to be set to avoid conveying flows across minor watershed divides towards an existing interstate frontage road intersection.

Roadway Hydrologic Impact Evaluation

The roadway expansion's impact on peak runoff rates is to be evaluated using standard HCFCD methods. The modeler should evaluate the impact of increased impervious cover and the conveyance changes in the roadway to determine the placement and sizing of detention systems to mitigate peak flows. For the purposes of this model, these types of impacts are not being considered. The primary focus of this example is assessing water surface elevation impacts to surrounding property from the proposed roadway grading and changes in roadway cross-section and profile.

Offsite Hydraulic Impact Evaluation

Impact evaluation for new or modified roadways is generally a comparison of pre-project to post-project water surface elevations. The 2D mesh should be large enough to encompass the drainage area coming towards the road and sufficiently downstream such that backwater from the boundary condition(s) do not have an effect on upstream water surface elevations.

If the modeler is performing an analysis where a very large drainage area approaches a roadway, traditional hydrologic methods may be used to develop a hydrograph which can be incorporated as an upstream boundary condition applied to the edge of the 2D flow area. This is discussed further in Step 5. Furthermore, drainage patterns should be evaluated to determine if the proposed roadway is diverting flow to another location where it previously did not flow.

Establishing Pre-Project Conditions

Step 1: Project Area Determination and LiDAR for Pre-Project Conditions

The H-GAC LiDAR NUSA dataset (2008) is to be used as the base topographic data set for modeling purposes unless otherwise directed by HCFCD. Using GIS, create a LiDAR data subset that fully encompasses the project site and captures watershed limits and model extents through the project site as illustrated in Figure E.1.

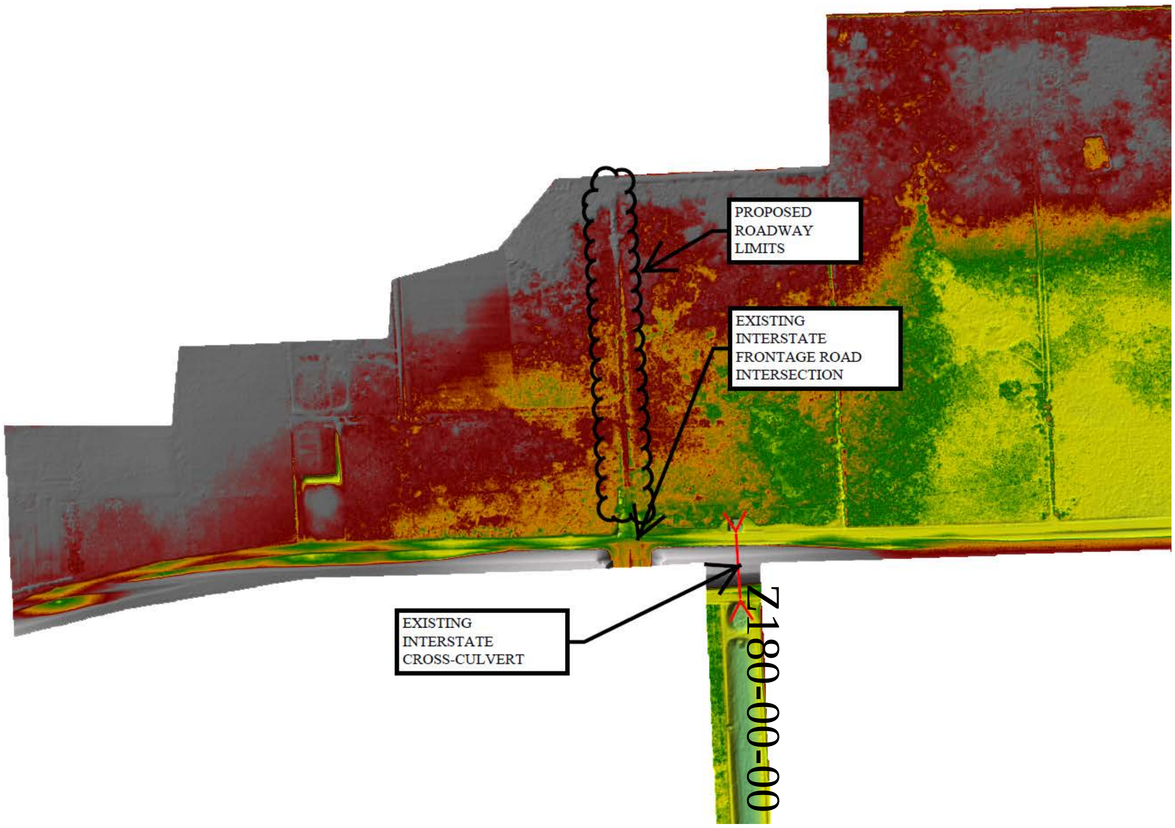

Figure E.1 LiDAR Data Extents

Step 2: Pre-Project Mesh

Create a 2D flow area which encompasses the expected topographic area draining towards the roadway. The 2D flow area extents need to be sufficiently offset from project limits to verify no- adverse impacts to adjacent properties.

A 100' x 100' cell size was selected for the 2D area based on the estimated level of detail needed for post-project conditions. Breaklines should also be added to define areas impacting flow direction, such as berms, major roads or channels. In this example, breaklines were added along the centerline of existing ridges and the edge of the existing frontage road. Figure E.2 presents the pre-project conditions 2D flow area.

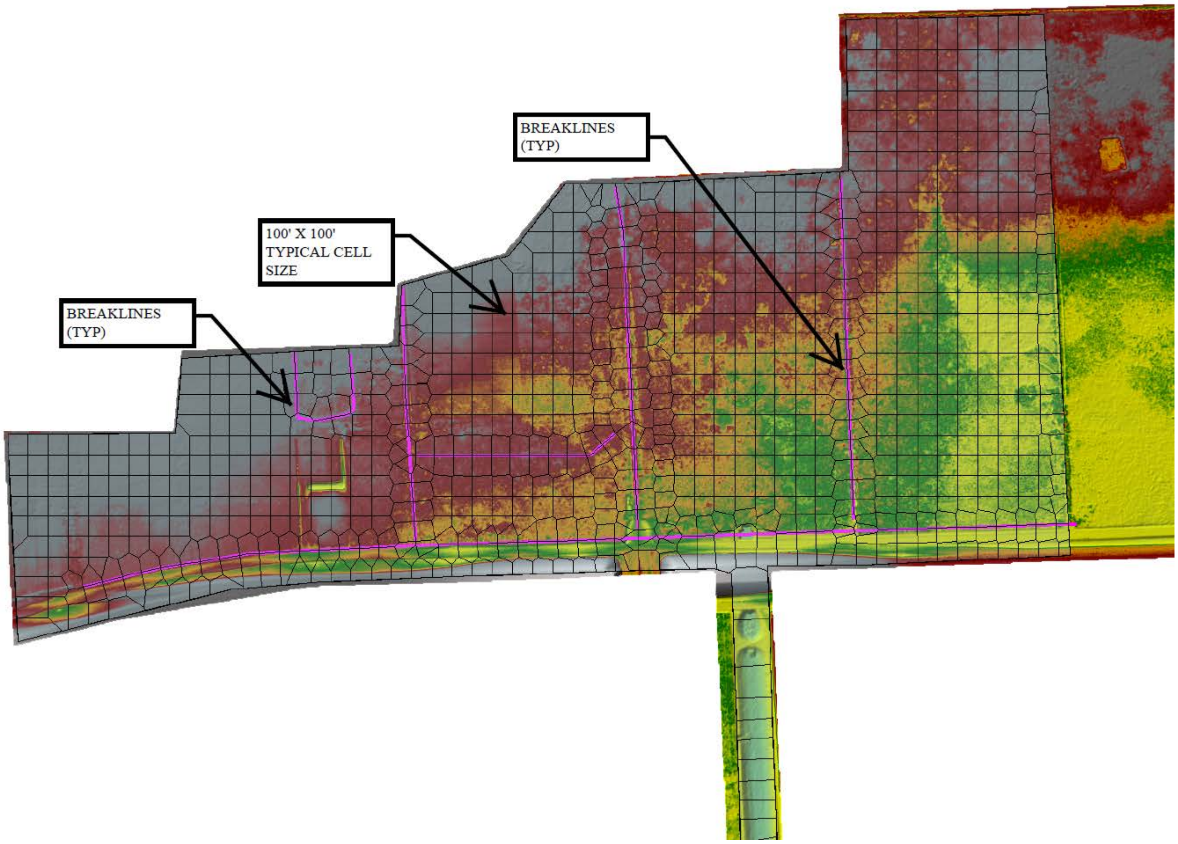

Figure E.2 2D Flow Area

Step 3: Internal Storage Area/2D Area Connector Creation

In the geometry editor, an internal 2D area connector was added to convey flow across the interstate. Due to the large drop in flowline elevation going into the existing cross culvert, an internal weir using the standard weir equation, was added to allow flow to "drop" into the depression at the entrance to the cross culvert. This was necessary as 2D flow equations become unstable when flow across a cell face goes through a significant drop. The weir was modeled using the standard weir equation with a coefficient of discharge set to 0.5. An additional connector was added along a natural ridge that exists along the alignment. This connector is used to compute the pre-project conditions flow crossing the divide and flowing towards the frontage road intersection. Figure E.3 presents the pre-project conditions 2D model schematic with location of internal boundary connectors.

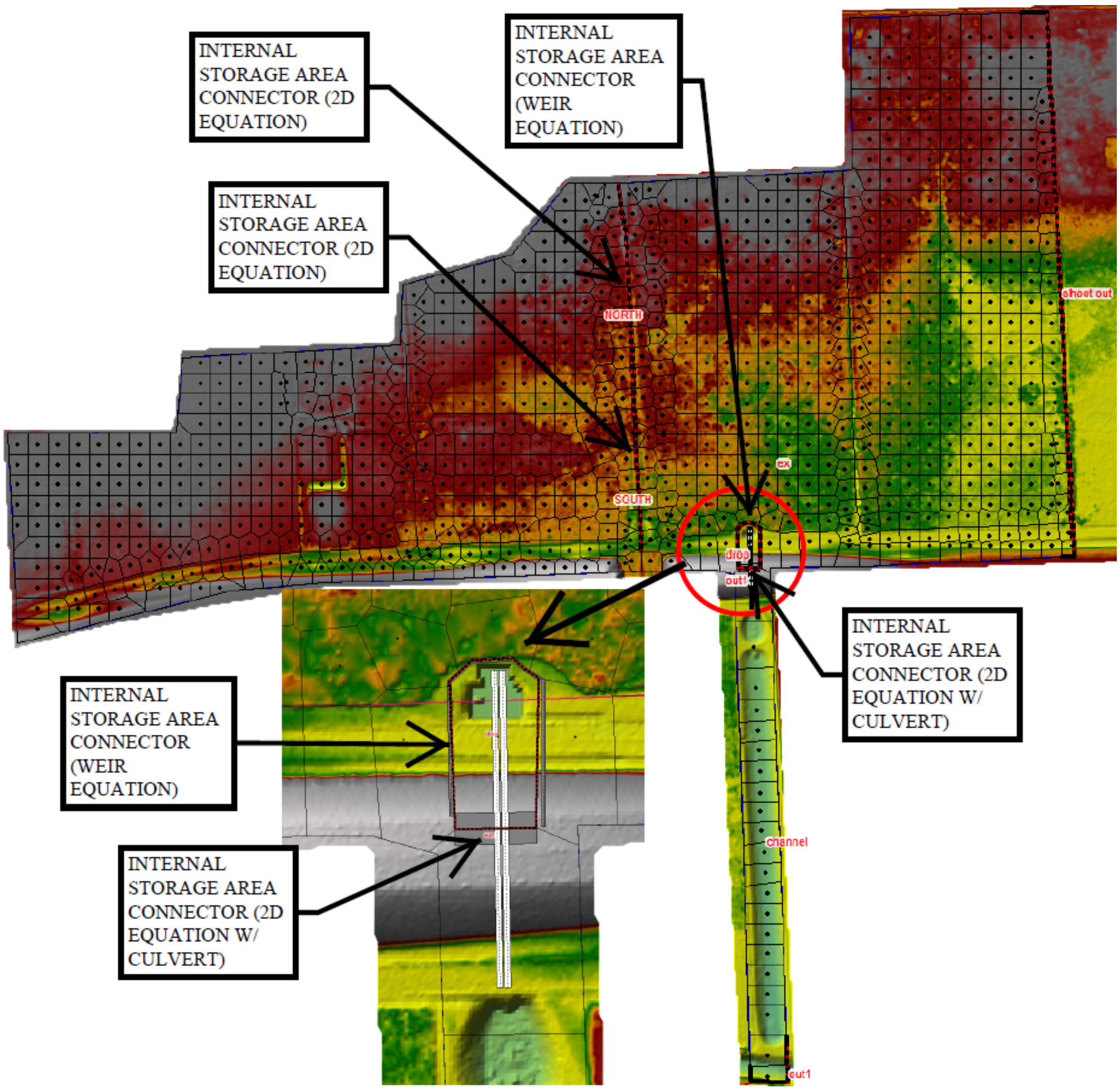

Figure E.3 Internal Boundary Connectors

Step 4: Pre-Project Land Use

A Manning's n value of 0.22 was selected for the pasture land use condition within the 2D flow area. This n value was selected from the *2D Modeling Guidelines* document due to anticipated flow depths and the use of precipitation on grid. A polygon shapefile encompassing the entire geometry was imported in RAS-Mapper with a single land classification. Within the 2D flow area editor, the default Manning's n was set to 0.22. A Manning's n value of 0.04 was applied to the outfall channel by using the Manning's n-Region tool to define the channel limits. Figure E.4 below shows the limits of the Manning's n-Region and n value assignments.

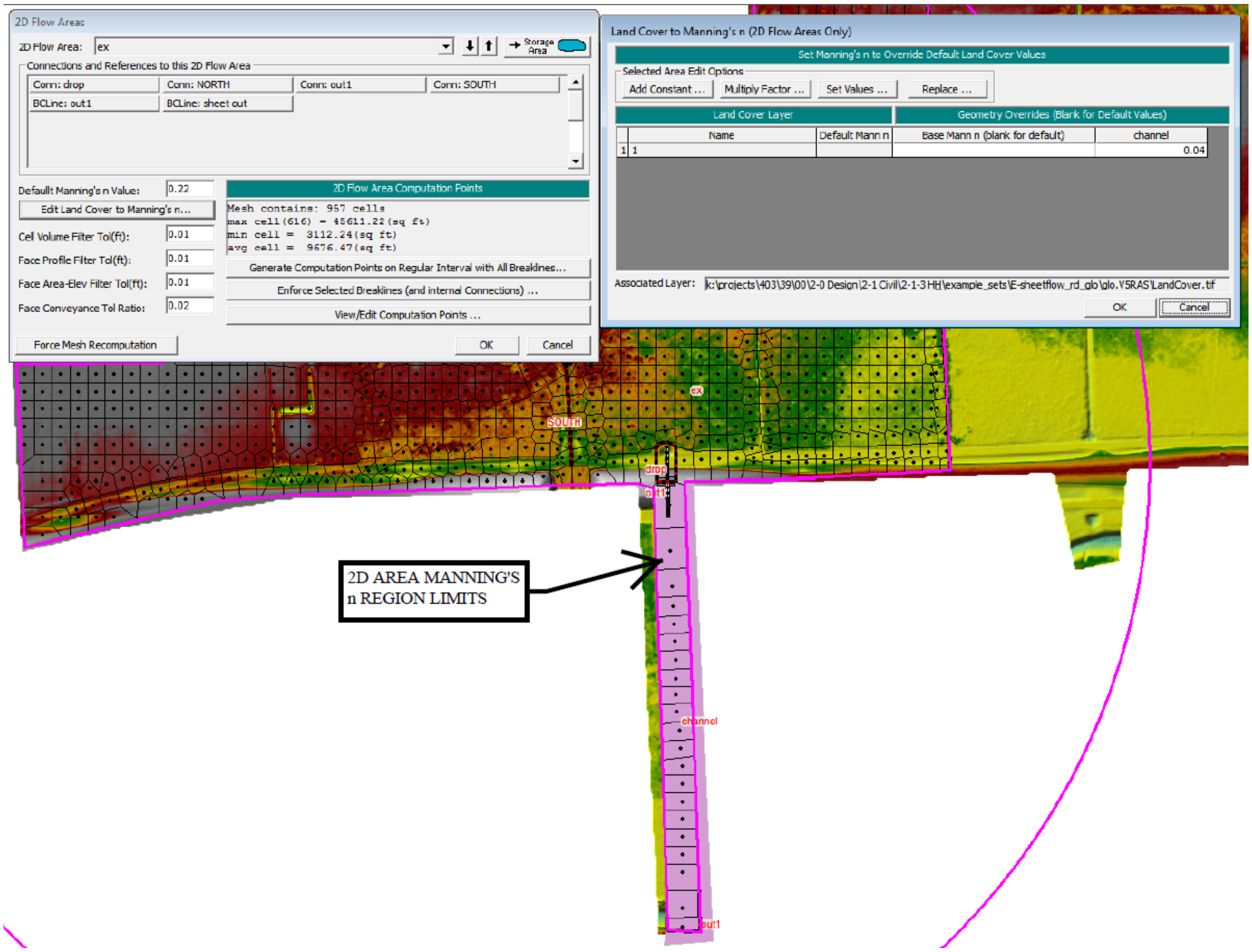

Figure E.4 Manning's n Value Assignment

Step 5: Pre-Project Boundary Conditions

If offsite drainage areas are too large to model entirely with HEC-RAS 2D (i.e., computation time would be too long), it is permissible to apply a boundary condition hydrograph at the edge of the 2D flow area representing the drainage area(s) contributing flow to the project site. The drainage area in this example is relatively small, allowing for the entire watershed to be modeled. This model utilizes precipitation on grid, with precipitation data taken from the effective HEC-HMS model obtained from HCFCD's Model and Map Management (M3) System for the watershed in which this project is located. Guidance on whether to use actual precipitation or rainfall excess is located in the *2D Modeling Guidelines* document. Review of the terrain data showed the area to be relatively well drained with minimal volume captured in "sinks" early in the storm event. Due to these conditions, the excess rainfall data was selected in order to account for losses outside of initial abstraction.

A normal depth boundary condition was selected for the outfall channel. Additionally, flow was found to continue to sheet flow away from the project location, and not all of it was collected in the culvert crossing the interstate. To limit model extents, the 2D flow area west of the roadway has a normal depth boundary condition applied to allow flow to leave the 2D mesh. Figure E.5 below shows the location of the applied boundary conditions.

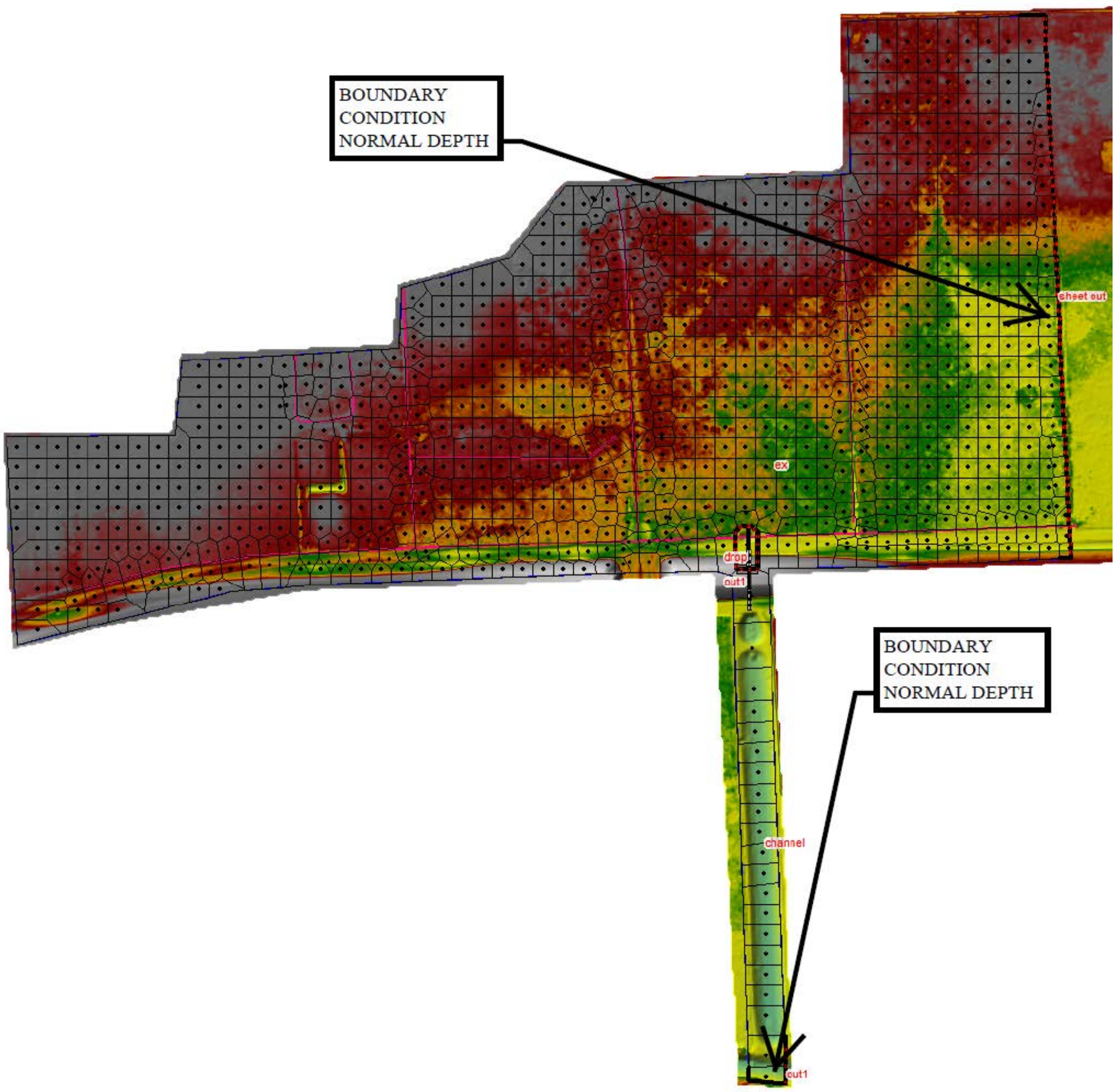

Figure E.5 Boundary Condition Flow Assignment Location

Step 6: Pre-Project Model Execution and Review

The default computation options and tolerances were selected and Diffusion Wave selected as the 2D equation set. The model velocities in the project area are anticipated to be less than 0.5 ft/s upstream and downstream of the road. A 60-second time step was initially selected to provide a Courant Number (C) ≤ 1. Initial model runs were found to be unstable. Review of the model indicated stability issues began occurring near the interstate cross culvert. The weir coefficient was adjusted from its initial estimate of C=0.5 to C=1.5. Water surface elevations computed upstream of the connector were not notably different between the two weir coefficients. The use of the higher coefficient though allowed greater flow into the depression upstream of the culvert during the beginning of the storm, preventing the depression from going "dry". The "dry" condition was caused by the large cross culvert having capacity to convey more volume than was available within the depression in a single time step. By allowing more volume to enter the depression with a higher weir C-Value, model stability was improved. The 60-second time step was also found to be aggravating the "drying" condition discussed above. The time step was lowered to 2 seconds to provide a stable model condition. See HEC-RAS *5.0 2D Modeling User's Manual* document for more descriptive information concerning the Courant Number selection.

Establishing Post-Project Conditions

Step 7: Post-Project Mesh

Terrain data for post-project conditions was created within AutoCAD Civil 3D. The surfaces for the roadway were then exported as a LANDXML file. The LANDXML file was imported into GIS, generating a TIN of the proposed surface. These surfaces were converted to a raster file using the 3D Analyst extension. The post-project condition raster was then imported into RAS-Mapper and combined with the pre-project conditions terrain to create a post-project condition terrain file. Figure E.6 illustrates the post-project conditions terrain.

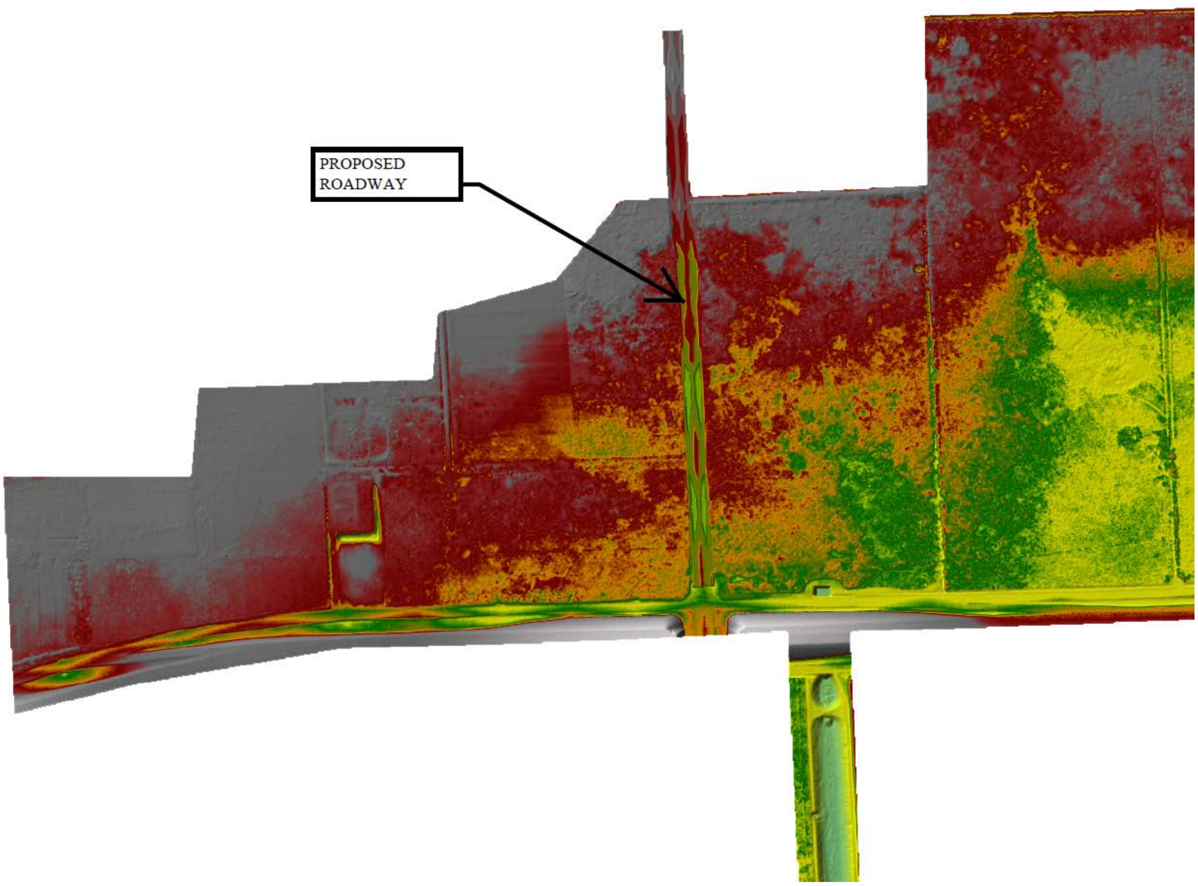

Figure E.6 Post-Project Conditions Terrain

Step 8: Post-Project Land Use

A Manning's n region was added to the model for the area, which includes the proposed roadway. A Manning's n value of 0.021 was applied to the area of the proposed roadway. Figure E.7 illustrates the post-project conditions Manning's n region delineation.

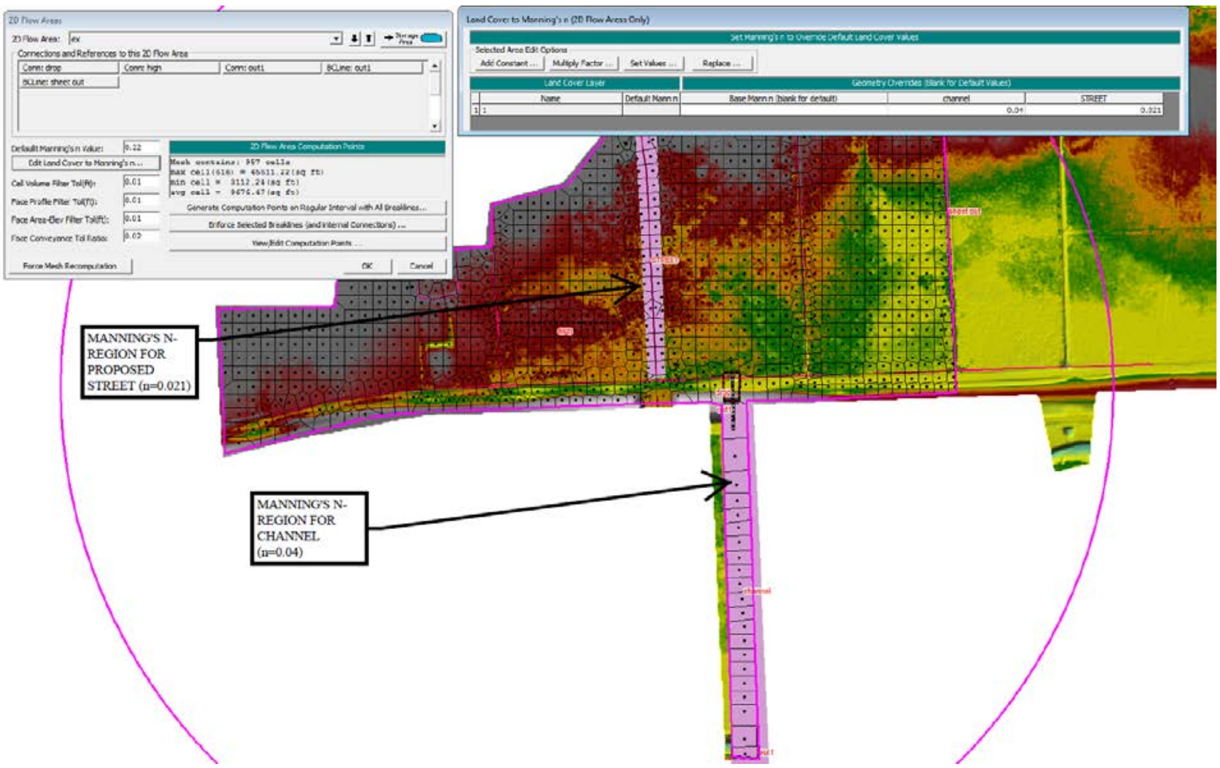

Figure E.7 Post-Project Conditions Manning's n region

Step 9: Post-Project Flow Assignments

In this example, it was assumed that the rainfall losses remain unchanged from pre-project conditions and the same precipitation data was used as in the pre-project conditions model. The focus of this example project is on conveyance impacts of a depressed roadway and does not address potential impacts of increased impervious cover due to the project.

Currently, HEC-RAS does not allow for multiple precipitation boundary conditions within a 2D flow area. Future versions of HEC-RAS will allow for multiple precipitation boundaries to be applied as well as accounting for loss rates directly. When these features become available, the modeler may wish to include the effect of the impervious cover change by applying a second precipitation boundary condition over the project limits to reflect the increased impervious cover.

The same boundary conditions, time step, and model defaults used in the pre-project run are used for post-project conditions.

Step 10: Post-Project Execution and Review

The post-project model was then executed, and results were reviewed in RAS-Mapper. Results show the proposed roadway created increases in flow directed towards the interstate frontage road intersection. Under pre-project conditions, the model indicates approximately 10-cfs flows along the proposed ROW towards the interstate frontage road intersection. Post-project conditions indicate the depressed roadway, as modeled, would carry approximately 47-cfs south towards the intersection. Flow rates can be determined by using the RAS-Mapper Profiles features (refer to the red line in Figures E.8 and E.9) or the modeler can query any internal connectors that cross the area of interest. It can be seen from review of the particle tracings that the proposed roadway profile allows the roadway to capture sheet flow and direct it towards the intersection. The change in flow rates due to the proposed roadway are presented in Figure E.8 and E.9, which illustrate the pre- and post-project flow patterns.

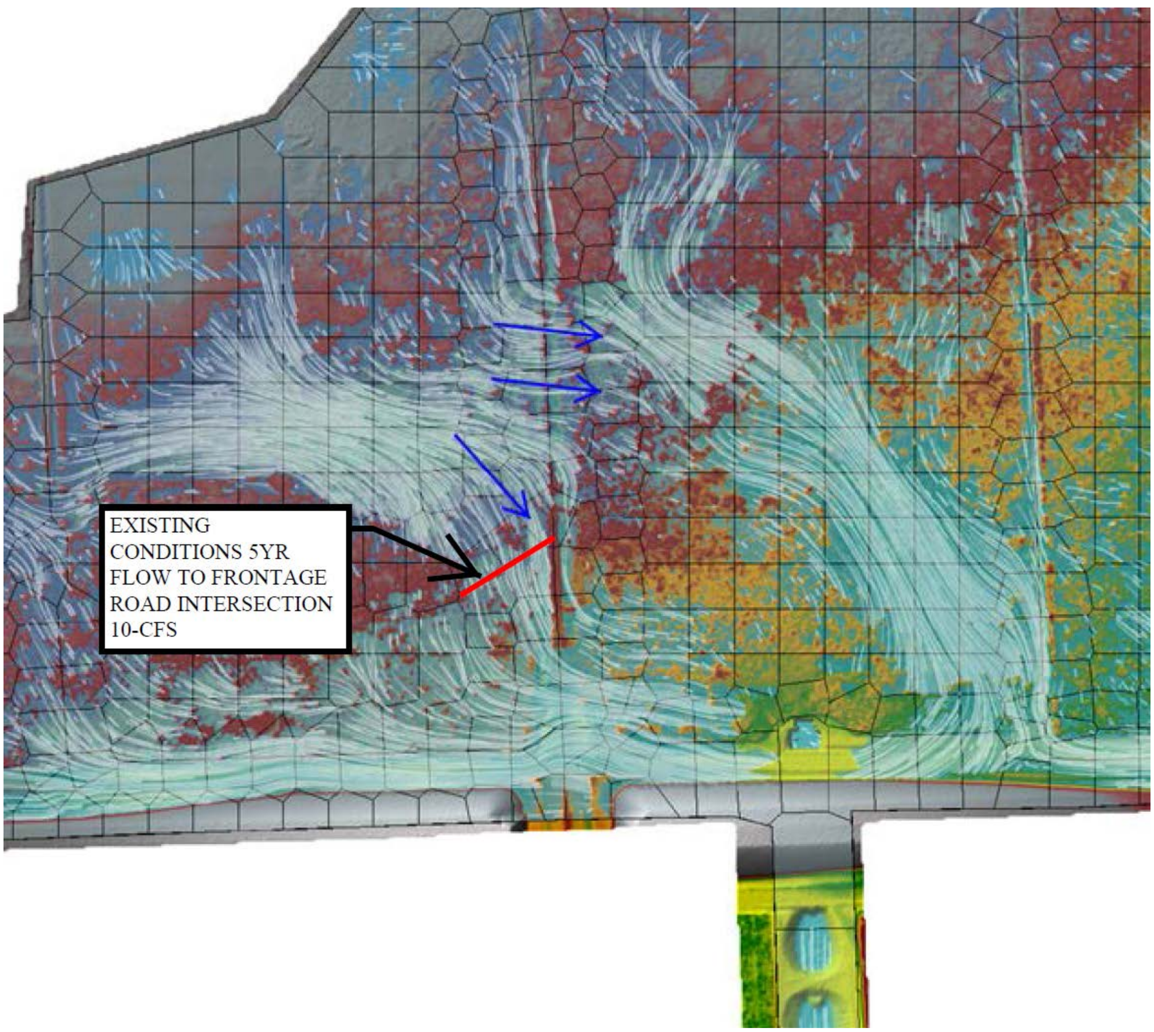

Figure E.8: Pre-Project Conditions Flow Pattern

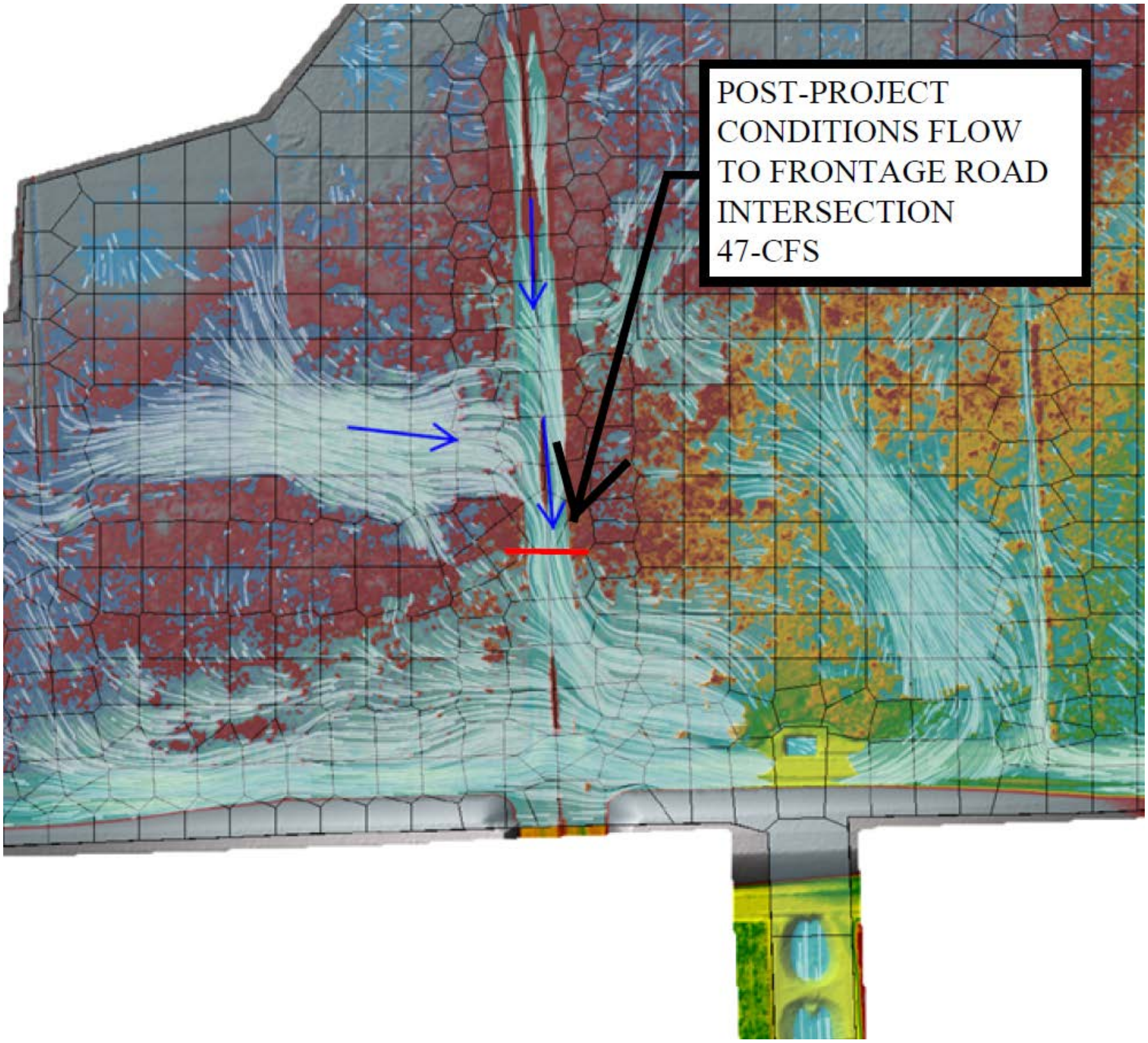

Figure E.9: Post-Project Conditions Flow Pattern

The impact of the increased flow to the frontage road intersection was evaluated by comparing, in GIS, the maximum WSE of pre- and post-project conditions and was established by subtracting the pre-project conditions WSE raster from the post-project conditions WSE raster. Positive values indicate a hydraulic impact while negative values indicate decreases in water surface elevations. The maximum WSE rasters were created within RAS Mapper by adding a new results map layer, selecting maximum WSE, and saving as a raster based on terrain.

Results indicated that the proposed roadway profile directed flows toward the frontage road intersection inducing a 0.15’ increase in the 5-year event. Figure E.10 provides the indicated changes in WSE. The red colors indicate areas with increased WSE while the blue are areas with reductions in WSE.

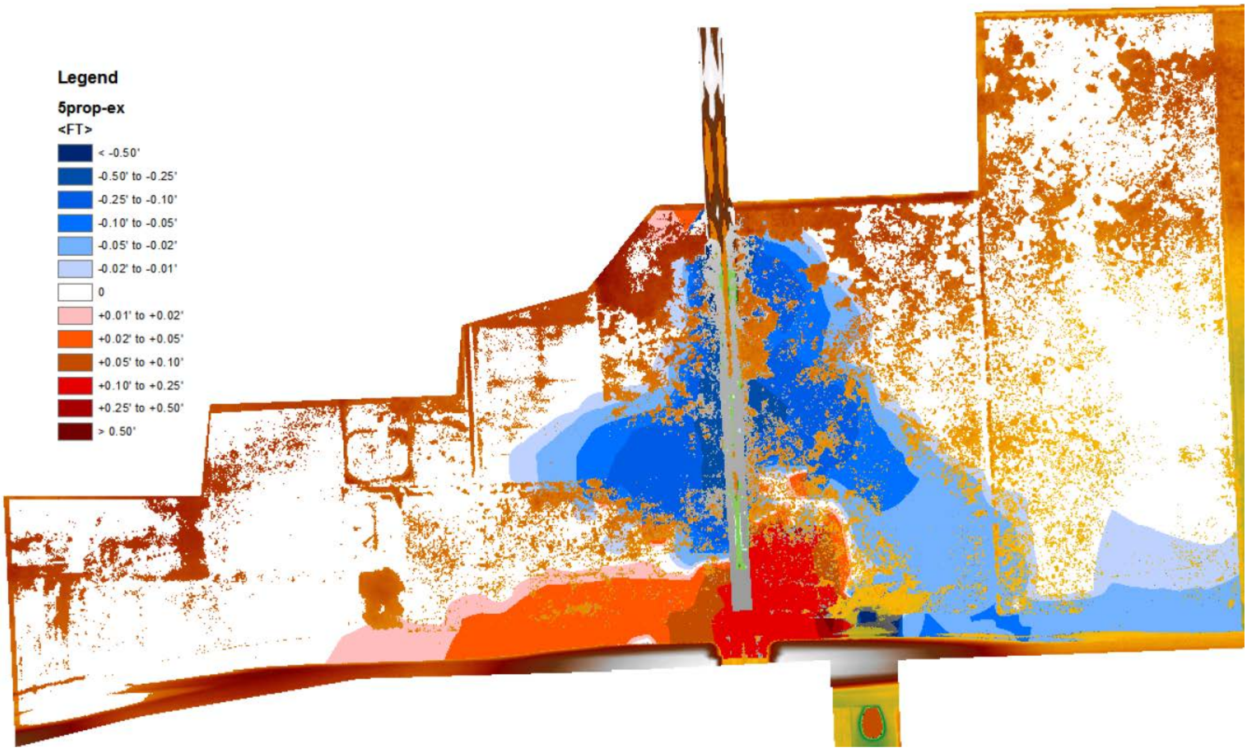

Figure E.10 Difference Between Pre-Project and Post-Project Conditions 5-Year WSE

By reviewing the 2D model results of pre- and post-project conditions insight into proper location and elevation of the roadway profile, high and low points can be gained in order to minimize impacts.

Step 11: Validation of 2D Results

High frequency storm events, such as the 2- and 5-year events, are typically the design storms used for sizing storm sewers. When modeling higher frequency events using a 2D model with precipitation on grid, it has often been noted that computed flow rates can be substantially different from what is computed using traditional methods, such as Rational Method or site runoff curves. The 2D model is capturing the effect of depressions in the terrain surface, which may account for a significant initial abstraction volume. The effect of the assumed Manning's n value can also significantly impact computed flow results. The overriding land classification considered in this example project was pasture land. Clearing of the land and converting it to agriculture or park land would not necessarily require a drainage mitigation plan, but this change in terrain to an improved well-graded area with a lower Manning's n value could result in a significant change in flows coming to the roadway.

For design purposes, traditional modeling methods should be used to quantify design flow rates. The 2D model for this project example is intended to serve as an aid in the design of the roadway. By reviewing the particle tracings, offsite drainage areas and travel paths can be delineated to assist in estimating design flow rates. Velocity was estimated using TR-55 unpaved shallow depth equation and slope along the travel paths for computing Time of Concentration (Tc). Figure E.11 presents the drainage area and travel path delineations using the 2D model flow tracings.

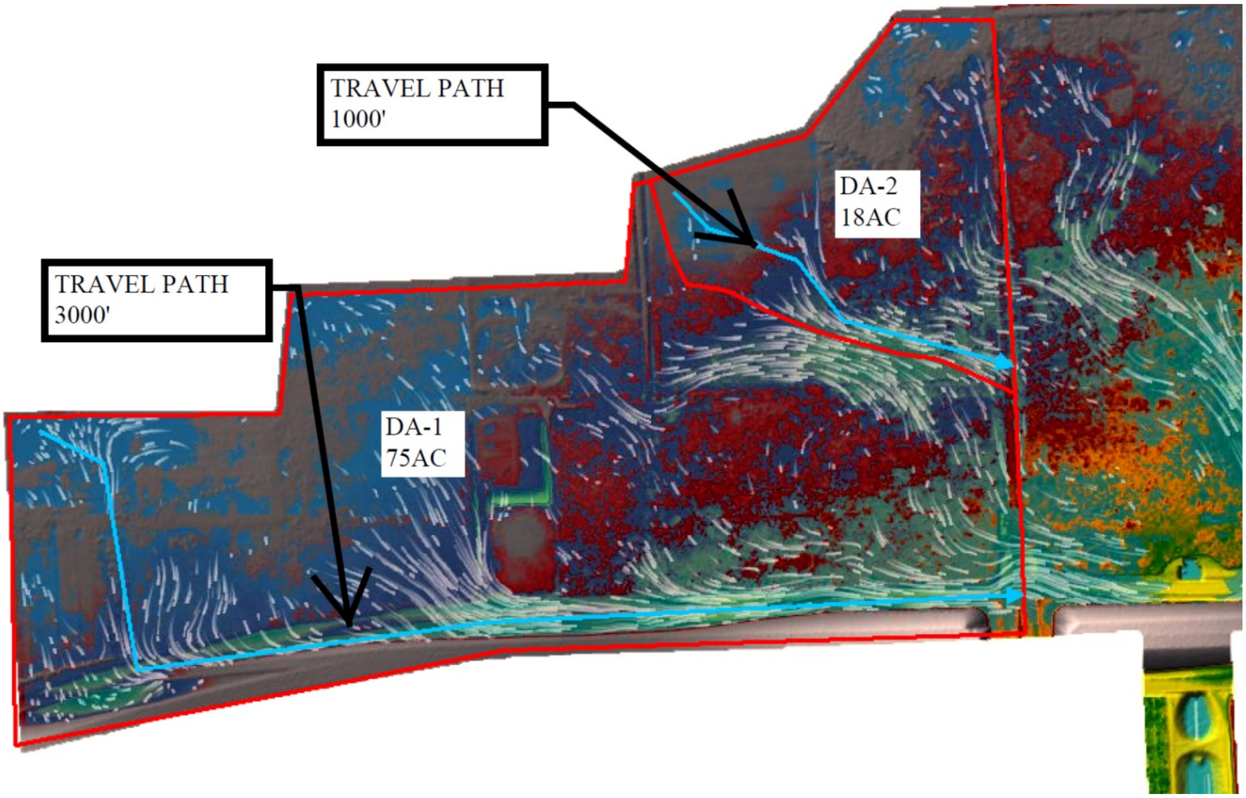

Figure E.11 Post-Project Conditions Drainage Area Delineations

Table E.1 provides comparisons of flow rates computed using traditional Rational Method calculations versus flow rates computed by HEC-RAS 2D. The Rational Method rates for the 2- and 5-year events are significantly higher than those computed by HEC-RAS 2D. The 100-year flows are both lower and higher for the Rational Method computed flows depending on the watershed.

Table E.1: Rational Method vs. HEC-RAS 2D Flows.

2-yr Rational Method Vs. RAS 2D

ID	AREA (ac)	C-VALUE	TRAVEL LENGTH (ft)	AVG V (ft/s)	TIME OF CONCENTRATION (min)	INTENSITY 2YR (in/hr)	RATIONAL METHOD COMPUTED FLOW (cfs)	RAS 2D COMPUTED FLOW (cfs)
DA1	75	0.3	3000	0.5	100	1.39	31.2	14
DA2	18	0.3	1000	0.5	33	2.92	15.8	4

5-yr Rational Method Vs. RAS 2D

ID	AREA (ac)	C-VALUE	TRAVEL LENGTH (ft)	AVG V (ft/s)	TIME OF CONCENTRATION (min)	INTENSITY 5YR (in/hr)	RATIONAL METHOD COMPUTED FLOW (cfs)	RAS 2D COMPUTED FLOW (cfs)
DA1	75	0.3	3000	0.5	100	1.83	41.3	29
DA2	18	0.3	1000	0.5	33	3.79	20.5	8.5

100-yr Rational Method Vs. RAS 2D

ID	AREA (ac)	C-VALUE	TRAVEL LENGTH (ft)	AVG V (ft/s)	TIME OF CONCENTRATION (min)	INTENSITY 100YR (in/hr)	RATIONAL METHOD COMPUTED FLOW (cfs)	RAS 2D COMPUTED FLOW (cfs)
DA1	75	0.3	3000	0.5	100	3.52	79.2	110
DA2	18	0.3	1000	0.5	33	6.93	37.4	31

In a further attempt to validate the model results, average velocities along the travel paths were refined to use the average velocity reported in HEC-RAS 2D. Using the HEC-RAS 2D velocities in the Rational Method, Tc calculation resulted in a closer calibration for the 2- and 5-year events, but the 100-year event was still shown to have a large difference between the two methods. Table E.2 presents the Rational Method versus HEC-RAS 2D using the HEC-RAS 2D velocities in the Rational Method Tc calculation.

Table E.2: Rational Method vs. HEC-RAS 2D Flows using 2D Average Velocities.

2-yr Rational Method Vs. RAS 2D

ID	AREA (ac)	C-VALUE	TRAVEL LENGTH (ft)	AVG V (ft/s)	TIME OF CONCENTRATION (min)	INTENSITY 2YR (in/hr)	RATIONAL METHOD COMPUTED FLOW (cfs)	RAS 2D COMPUTED FLOW (cfs)
DA1	75	0.3	3000	0.2	250	0.70	15.7	14
DA2	18	0.3	1000	0.15	111	1.29	6.9	4

5-yr Rational Method Vs. RAS 2D

ID	AREA (ac)	C-VALUE	TRAVEL LENGTH (ft)	AVG V (ft/s)	TIME OF CONCENTRATION (min)	INTENSITY 5YR (in/hr)	RATIONAL METHOD COMPUTED FLOW (cfs)	RAS 2D COMPUTED FLOW (cfs)
DA1	75	0.3	3000	0.2	250	0.94	21.0	29
DA2	18	0.3	1000	0.15	111	1.70	9.2	8.5

100-yr Rational Method Vs. RAS 2D

ID	AREA (ac)	C-VALUE	TRAVEL LENGTH (ft)	AVG V (ft/s)	TIME OF CONCENTRATION (min)	INTENSITY 100YR (in/hr)	RATIONAL METHOD COMPUTED FLOW (cfs)	RAS 2D COMPUTED FLOW (cfs)
DA1	75	0.3	3000	0.2	250	1.84	41.4	110
DA2	18	0.3	1000	0.15	111	3.28	17.7	31

An additional attempt to validate the model results was conducted using the Harris County Site Runoff Curves. For the 100-year event, the site runoff curve predicted flows were in fair agreement with the HEC-RAS 2D flows. However, the 2-year flows were significantly different. Table E.3 below provides a comparison of the site runoff curves for the 2- and 100-year events.

Table E.3: Site Runoff Curve vs. HEC-RAS 2D Flows

2-yr Site Runoff Curve Vs. RAS 2D

ID	AREA (ac)	% Impervious	b	m	$Q=bA^m$ (cfs)	RAS 2D COMPUTED FLOW (cfs)
DA1	75	0	1.2	0.823	42	14
DA2	18	0	0.6	1	11	4

100-yr Site Runoff Curve Vs. RAS 2D

ID	AREA (ac)	% Impervious	b	m	$Q=bA^m$ (cfs)	RAS 2D COMPUTED FLOW (cfs)
DA1	75	0	3.4	0.823	119	110
DA2	18	0	2	1	36	31

For this example, design flows are recommended to be based on the 2- and 5-year flows computed by the Rational Method with Tc based on the RAS 2D model (Table E.2). The Rational Method flows for this scenario are in fair agreement with the RAS 2D model predicted flows and are slightly more conservative. For the 100-year event, the Harris County Site Runoff Curve flows (Table E.3) are recommended as they are also in fair agreement with the HEC-RAS 2D results and slightly more conservative.

It is advised that prior to adoption of design flows, the findings and recommendations be shared with HCFCD to gain concurrence.