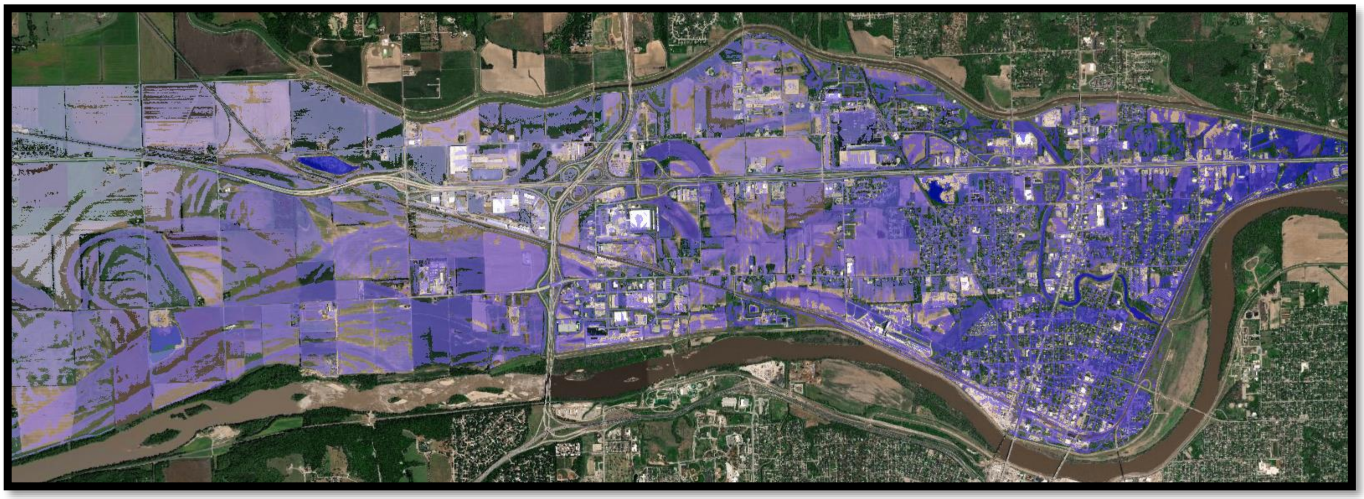
North Topeka, KS

Technical Assistance Project

June 2020



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Kansas Department of Agriculture
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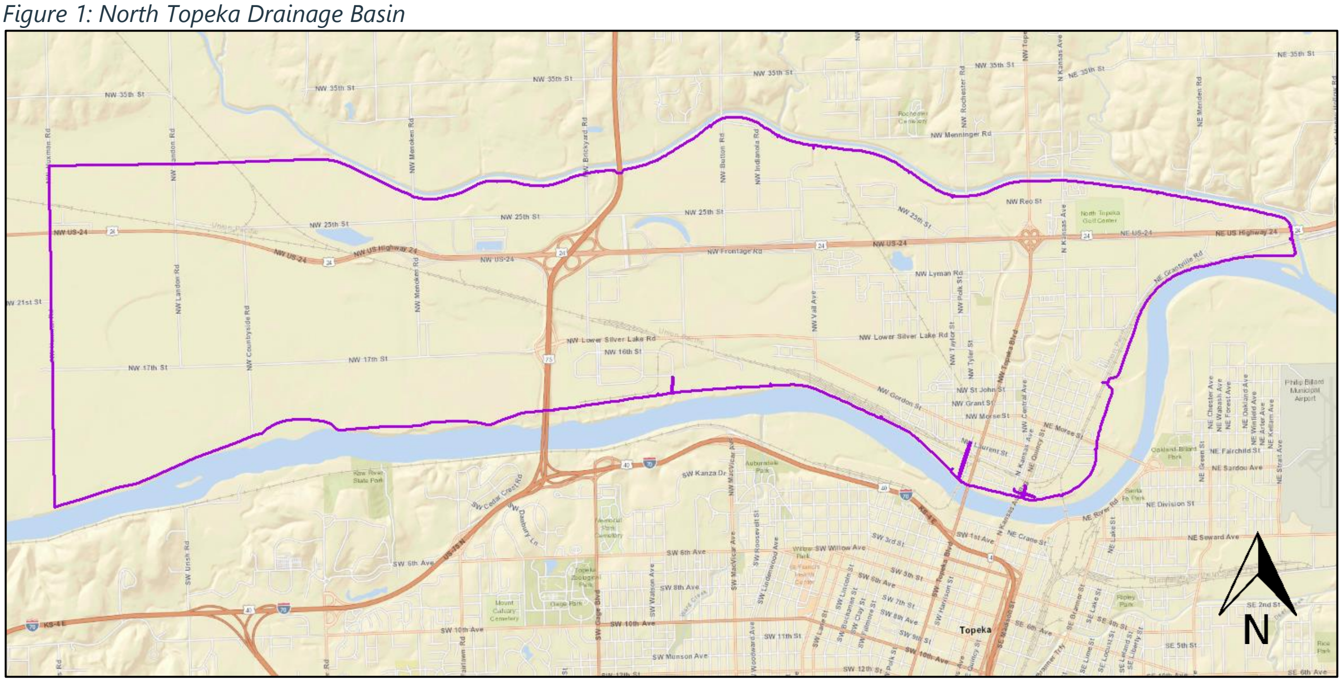
Introduction

The Kansas Department of Agriculture (KDA) received funding from FEMA to complete a technical assistance project for the City of Topeka, to help better understand and reduce flooding issues within North Topeka. There is no funding match requirement and no cost to the City of Topeka for this project. The intent of this project is to provide a useful product and assessment to the City, which can be expanded and built upon to help reduce future flood risk.

KDA contracted with Wood Environment and Infrastructure Solutions Inc. (Wood) to develop a HEC-RAS 2D flow model for the North Topeka drainage basin, which is identified in Figure 1. The scope of work included the use of “excess rainfall on grid” hydrology and HEC-RAS 5.0.7 2D hydraulic modeling. All detention and storage areas were to be captured in the modeling. Manning’s n values were to be customized for the City, based on available GIS data. Culverts and bridges were simulated based on an algorithm developed by Wood that creates an opening through the embankment to a size that mimics culvert capacity. Structures deemed critical for modeling purposes were included in the 2D model. Tailwater elevations were to be set in the modeling based on the PC-SWMM levee modeling that was completed for the City of Topeka’s levee certification project.

Figure 1: North Topeka Drainage Basin



As part of the deliverables outlined in the scope of work, a variety of grids were generated from the HEC-RAS 2D model, including water surface elevation grids, depth grids, velocity grids, flow accumulation grids, shear stress grids and stream power grids. In addition, streamlines for drainage areas up to 1 sq mile, 320 acres, 160 acres, and 40 acres were developed. It should be noted that only streamlines having a well-defined bed and well-defined banks, with natural riparian areas, are included in the streamline shapefiles. The modeling was done to provide the City with valuable information and tools to assist in development of new science-based design criteria for the City of Topeka that will protect future development from worsening the flood risk to residents and businesses within the City. To compliment the peak flow and volume sensitivity analysis done for the portion of Topeka south of the Kansas River, documented in the September 2019 Topeka Technical Assistance Report; a similar analysis was done for the North Topeka basin, so a determination could be made on the recommended controls for the North Topeka basin.

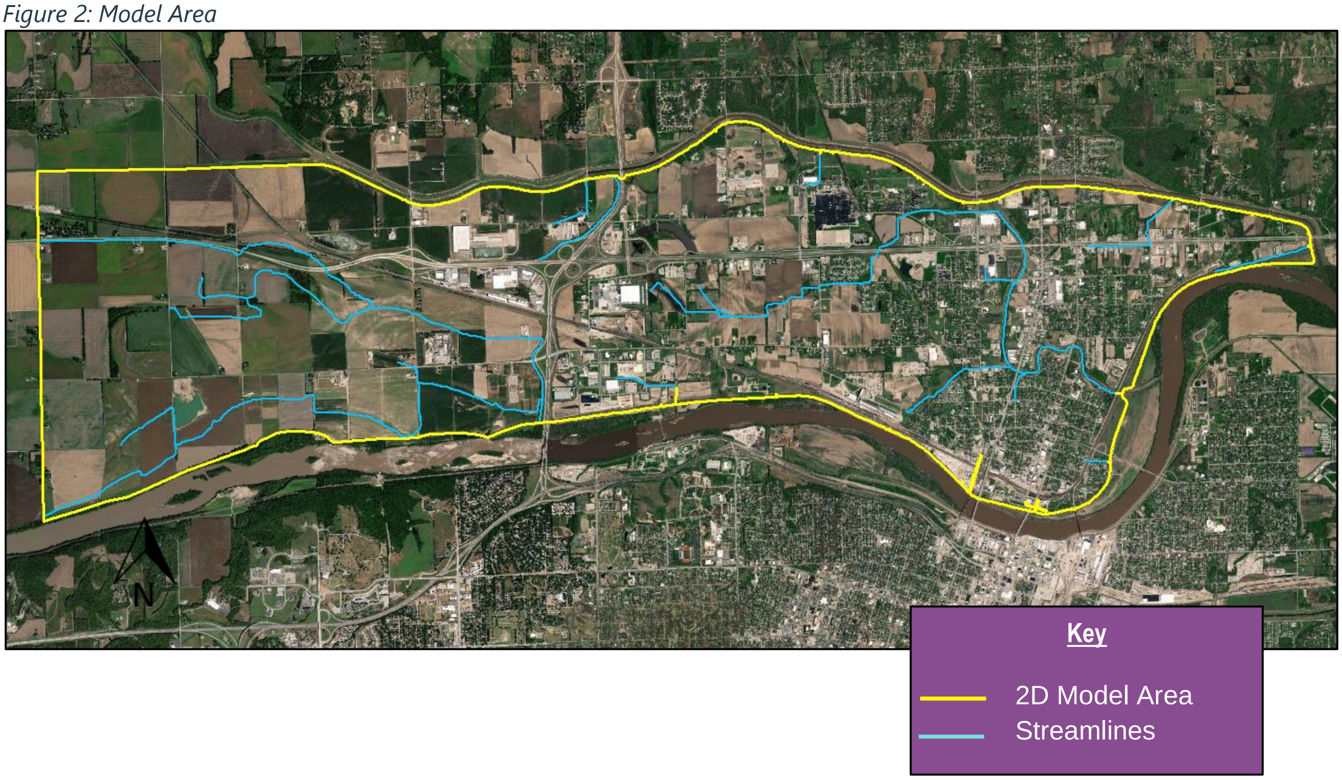
Rain on Grid Hydrologic Analysis

The rain on grid capabilities of Hydrologic Engineering Center's River Analysis System (HEC-RAS), version 5.0.7 (Hydrologic Engineering Center (HEC), 2019) published by the United States Army Corps of Engineers (USACE) was utilized for the hydrologic modeling for this study area. In the HEC-RAS rain on grid 2-dimensional (2D) flow module, the excess rainfall hyetograph is applied to each 2D area of the model as a boundary condition. One HEC-RAS model was developed for this study. The following sections describe the process used to develop the excess rainfall hyetograph used in this study.

Drainage Area

Extents of the 2D area was based on watershed delineations using the 2015 1-meter LiDAR acquired through the Kansas Data Access and Support Center (State of Kansas, 2018). The basin boundary follows the interior side of the levee systems along the Kansas River and Soldier Creek, and the western edge of the apparent drainage area.

Figure 2: Model Area



Rainfall Depth

Rainfall depths for the 1% annual chance storm event were developed by taking the average values of the partial-duration gridded rainfall data developed by the National Oceanic and Atmospheric Administration (NOAA) as part of Atlas 14, Volume 8: Precipitation-Frequency Atlas of the United States (National Oceanic and Atmospheric Administration (NOAA), 2013) for the basin area.

Curve Number

Because the HEC-RAS rain on grid model does not account for infiltration and evapotranspiration losses in the rainfall, these losses must be accounted for in the input hyetograph. The U.S. Department of Agriculture Soil Conservation Service (SCS) Curve Number Method, detailed in the National Engineering Handbook Part 630, Chapter 10 (Natural Resources Conservation Service (NRCS), 2004), was used to model these losses. The curve number is a function of both hydrologic soil group and land use. To determine the curve number, an antecedent runoff condition (ARC) of II was assumed as it is representative of typical conditions, rather than the extremes of dry conditions (ARC I) or saturated conditions (ARC III).

Land use data was taken from the 2011 National Land Cover Database (United States Geological Survey (USGS), 2018). Local land use data for the City of Topeka was also incorporated. Soils data was obtained in shapefile and database format from the United Stated Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Web Soil Survey (Natural Resources Conservation Service (NRCS), 2018), which includes an aggregate hydrologic soil group for individual soil series. Area weighted curve numbers was developed for the basin using geographic information systems (GIS) processes.

Excess Rainfall

CN was used to determine initial and continuous abstractions that approximate rainfall infiltration and interception losses. The initial abstraction, I_a, was calculated as 0.2S, where S is the maximum potential retention, calculated as

$$S = \left({}^{1000}/_{CN}\right) - 10 \quad .$$

Based on details in the National Engineering Handbook Part 630, Chapter 10 (Natural Resources Conservation Service (NRCS), 2004), the continuous abstraction (also referred to as actual retention after runoff begins), F_a, was calculated as

$$F_a = S\left({}^{(P - I_a)}/_{(P - I_a + S)}\right).$$

For this study area, the distribution developed by NRCS (Moody, 2015) based on a regional analysis of the Atlas 14 rainfall data (National Oceanic and Atmospheric Administration (NOAA), 2013) was selected for the rainfall hyetograph. This study is in Midwest and Southeast Region 4.

Table 1: North Topeka Basin Curve Number, 1% Rainfall Depth, and 1% Excess Rainfall Depth

Basin Area (sq. mi)	Curve Number	1% Rainfall Depth (in)	1% Excess Rainfall Depth (in)
15.9	75	7.85	4.91

After removing the losses, the excess rainfall hyetograph was applied directly to the 2D area in HEC-RAS as a precipitation boundary condition time series. The model was ran for the 1% annual chance storm event only.

Hydraulic Analysis

For this analysis, the 2D capabilities of Hydrologic Engineering Center's River Analysis System (HEC-RAS), version 5.0.7 (Hydrologic Engineering Center (HEC), 2019) published by the United States Army Corps of Engineers (USACE) was utilized for the hydraulic analysis.

Terrain Layer

The accuracy and detail of the terrain model is critical in creating an accurate and detailed 2D model. High-resolution (one-meter) bare-earth LiDAR datasets were obtained from the Kansas Data Access and Support Center (State of Kansas, 2018) and used in the modeling. These datasets provide precise and comprehensive information on the topography of the study area.

Within the LiDAR data, hydraulic structures that allow flow through an embankment are typically not represented. Because of this, incorporating the raw LiDAR into the 2D terrain model can overestimate storage behind these embankments and redirect flow erroneously. Therefore, the LiDAR dataset was modified at locations with structures through embankments to allow flow to pass through them (a.k.a. hydro-enforced). This hydro-enforcement utilized a minimum opening width of 2 cells, or 6.5 feet, with additional refinements based on aerial imagery. A cut was made through the embankment to the elevation of the downstream invert of the structure. Once these items were done, the LiDAR was loaded into the model as the terrain layer.

Land Use Layer

Manning's roughness coefficients were defined across the study area for use in the 2D calculations. Roughness values were defined based on the land use across the region and taken primarily from Chow's *Open-Channel Hydraulics* (G.W. Brunner, 2016). Land use was determined using a combination of data obtained from the National Land Cover Dataset (United States Geological Survey (USGS), 2018), data obtained by the City of Topeka, GIS processing, and aerial photography. Buffers around the streamline were incorporated into the land use layer, so separate roughness coefficients could be assigned to the channels. The roughness coefficients used for the channels was 0.045. Once all coefficients were assigned, the Manning's layer was then incorporated into the HEC-RAS model. Table 2 includes the manning's n values used for the various land use designations.

Table 2: Manning's Roughness Values

Land Use Designation	Manning's 'n'
Open Water	0.030
Developed, Open Space	0.040
Developed, Low Intensity	0.100
Developed, Medium Intensity	0.080
Developed, High Intensity	0.150
Barren Land	0.030
Deciduous Forest	0.160
Evergreen Forest	0.160
Mixed Forest	0.160
Shrub/Scrub	0.100
Grassland/Herbaceous	0.050
Pasture/Hay	0.050
Cultivated Crops	0.050
Woody Wetlands	0.120
Small Channel	0.045
Roads	0.015

Computational Mesh

The 2D computational mesh was generated within HEC-RAS using the lidar elevation data (State of Kansas, 2018). A 100-foot square mesh was generated on the terrain. All hydraulically significant embankments, such as roads, dams, and levees, were enforced in the mesh using breaklines to ensure that the crests of these embankments were represented in the cell faces. This allows for a much more detailed model than a standard square mesh can produce. Additional detail was added into the mesh by enforcing the scoped stream network at a 50-foot cell size. This forced the cells to align to the flow in the channel and created added detail in the channel areas.

Downstream Boundary Conditions

A boundary condition was used in the HEC-RAS models at each section along the 2D area boundary where water can leave the system. Since water leaves the model through levee structures, the boundary conditions each utilize a stage hydrograph from the PC-SWMM probabilistic modeling developed as part of the levee certification project to ensure that the levee structures and tail water conditions are properly represented in the HEC-RAS modeling.

Hydraulic Structures

Hydraulic structures were added to the model for those structures determined to have hydraulic significance to the modeling. Internal 2D area connections with hydraulic structures were placed at hydraulically significant bridge and culvert structures. Information obtained included structure dimensions, channel geometry, and structure material (i.e. corrugated metal pipe, concrete box culvert, etc), to accurately represent the structures within the HEC-RAS model. It should be noted that HEC-RAS 5.0.7 cannot currently model bridges in an internal 2D area connection. Therefore, bridges were modeled as culverts that had roughly the same size opening as the bridge opening.

Computational Settings

HEC-RAS 2D model solves either the Saint Venant equations (Full Momentum) or the Diffusion Wave equations. For this project, the Diffusion Wave equations were used. The Diffusion Wave equations run faster and more stable than the Full Momentum equations, and there are no sudden changes in flow, abrupt contractions and expansions, or very steep slopes in these models, which would give better results with the Full Momentum equations (Hydrologic Engineering Center (HEC), 2018).

The time step was selected based on the general guidance of keeping the Courant Number under 3 using the following equation (Hydrologic Engineering Center (HEC), 2018):

$$C = \frac{V\Delta T}{\Delta X}$$

Where:

$$C \ = Courant\ Number$$

$$V = Flood\ Wave\ Velocity\ (wave\ celerity)({}^{ft}/_{s})$$

$$\Delta T = Computational\ time\ step\ (s)$$

$$\Delta X = Average\ cell\ size\ (ft)$$

A base time step of 15 seconds was chosen with the variable time step option allowing the time step to adjust as needed to keep the courant number near 1. The model simulation time was 2 days to allow enough time for the flood wave to reach the peak before the end of the modeled area. The model that was ran for the 1% annual chance storm event only.

2D Modeling Deliverables

A variety of useful grids were derived from the HEC-RAS modeling and are provided as deliverables for this project; including water surface elevation grids, depth grids, velocity grids, flow accumulation grids, shear stress grids and stream power indexes. Examples of these grids are provided in Figures 3, 4, 5, 6, 7 and 8. These grids can be classified and symbolized in a variety of ways. These grids are rasters, and each raster cell has a value that can be identified. Streamlines of varying drainage extents; including the 1-square mile extent, the 320-acre extent, the 160-acre extent, and the 40-acre extent; are also provided as deliverables. An example of the varying streamline extents is shown in Figure 9. It should be noted that flows are available for any drainage area within the 2D model area, regardless of size.

Figure 3: Water Surface Elevation Grid Example

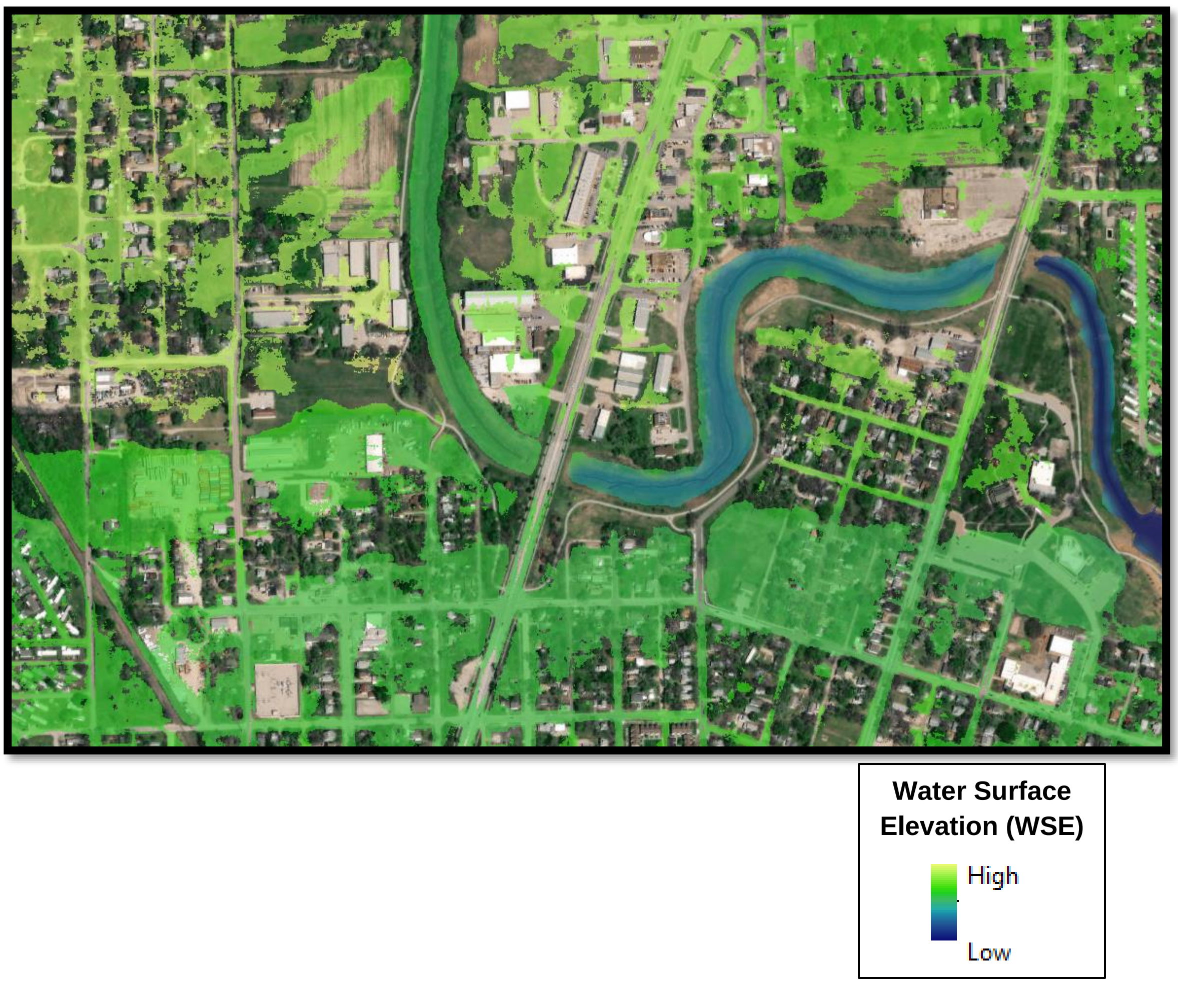


Figure 4: Depth Grid Example

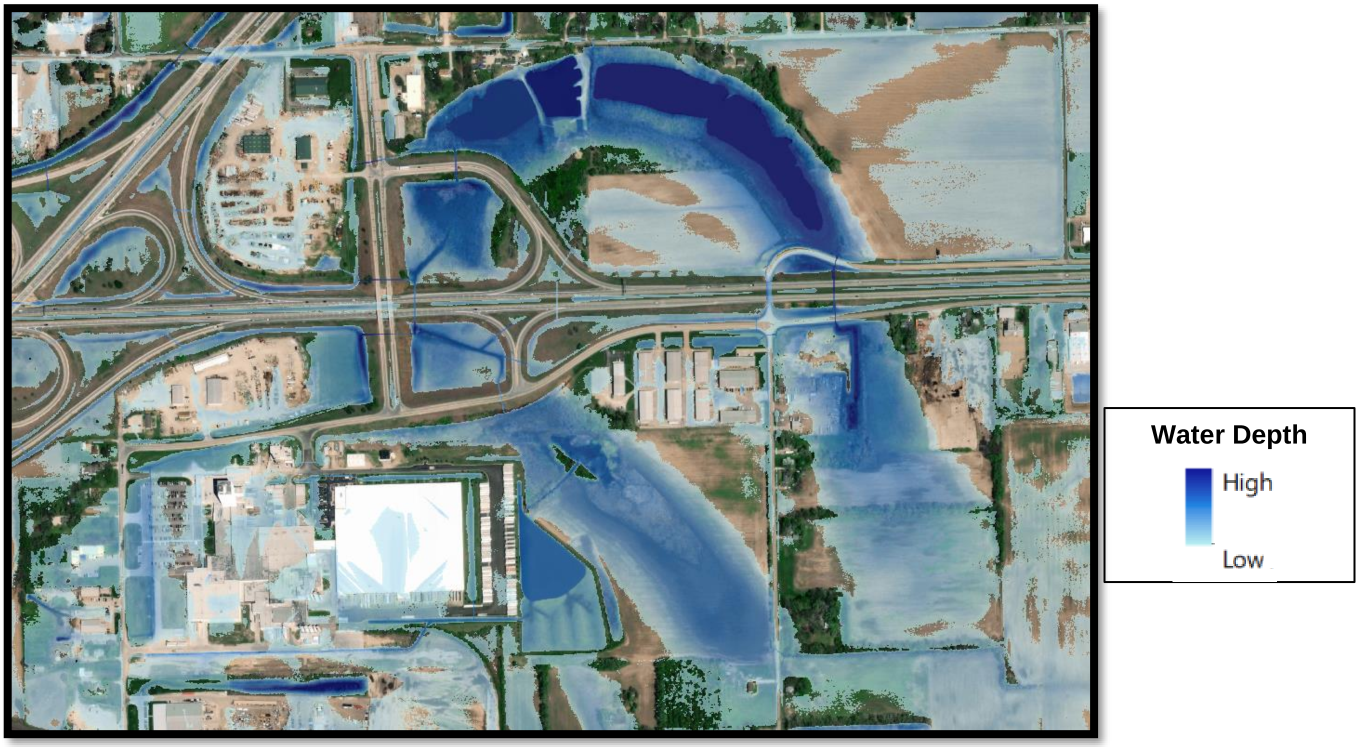


Figure 5: Velocity Grid Example

Figure 6: Flow Accumulation Grid Example

Figure 7: Shear Stress Grid Example

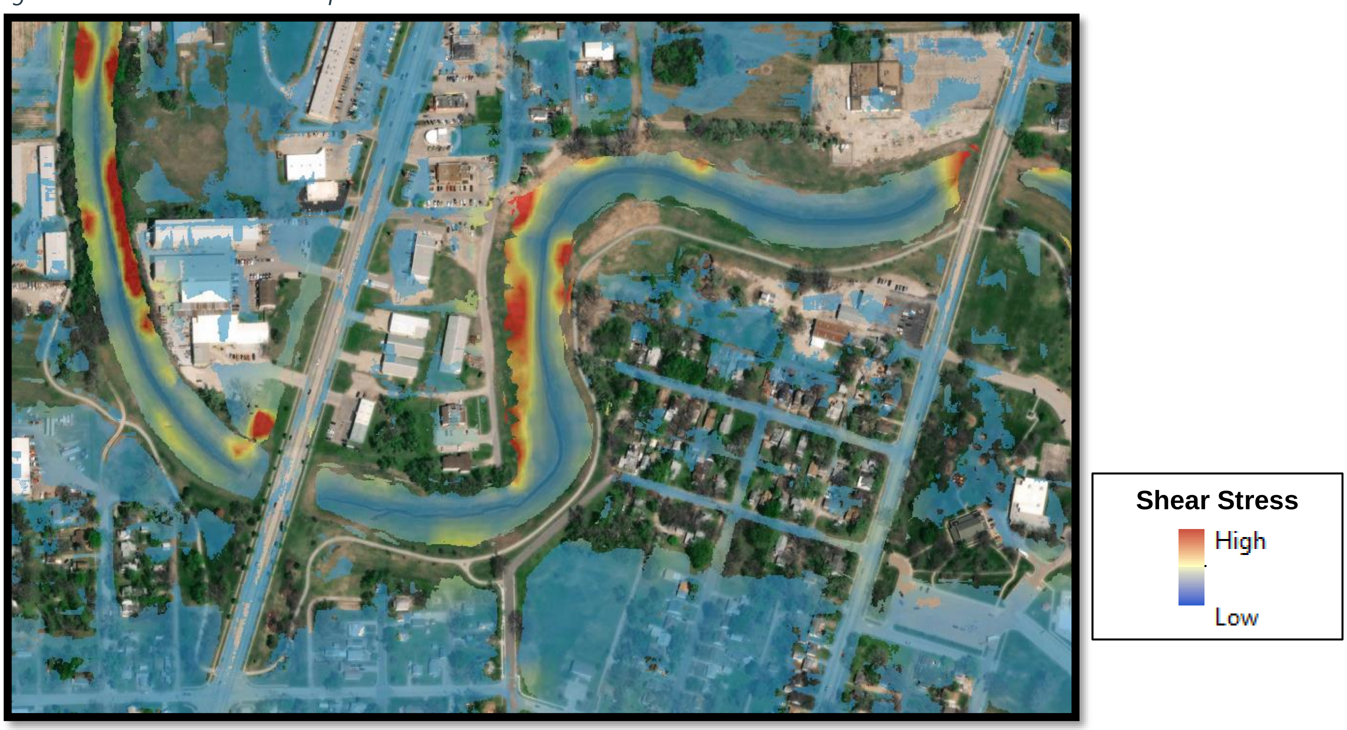


Figure 8: Stream Power Indexes Example

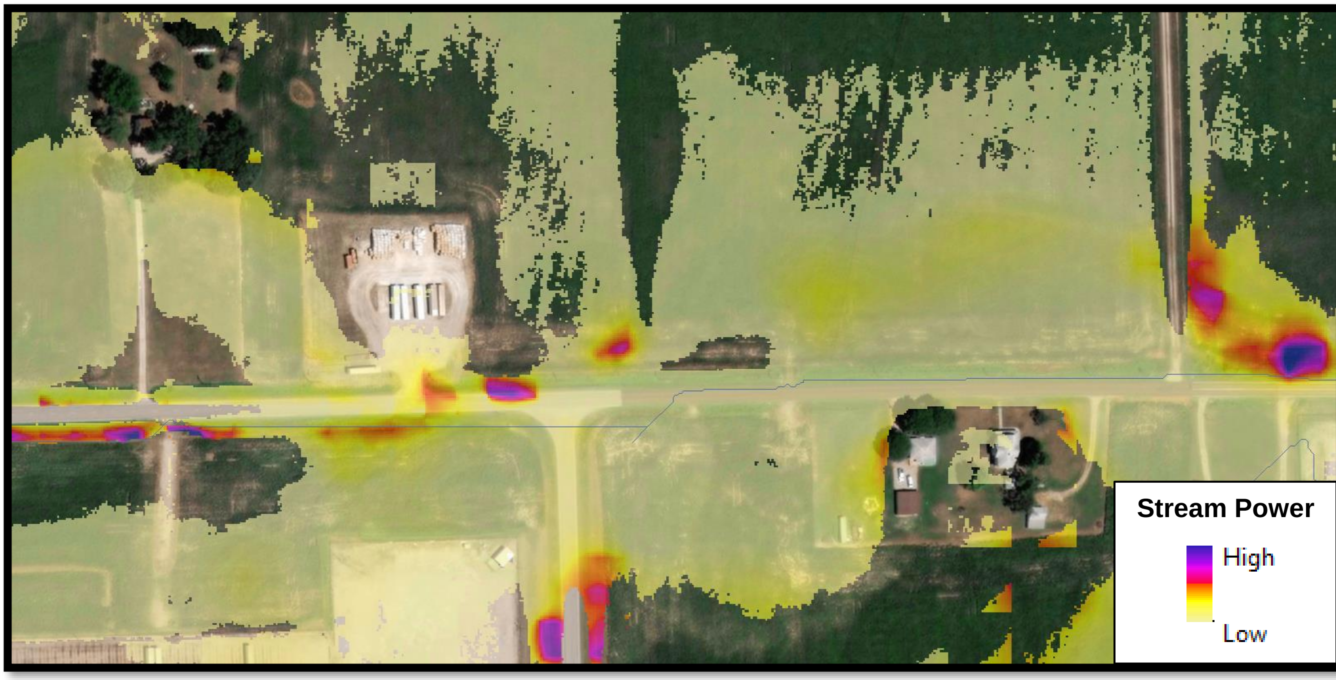
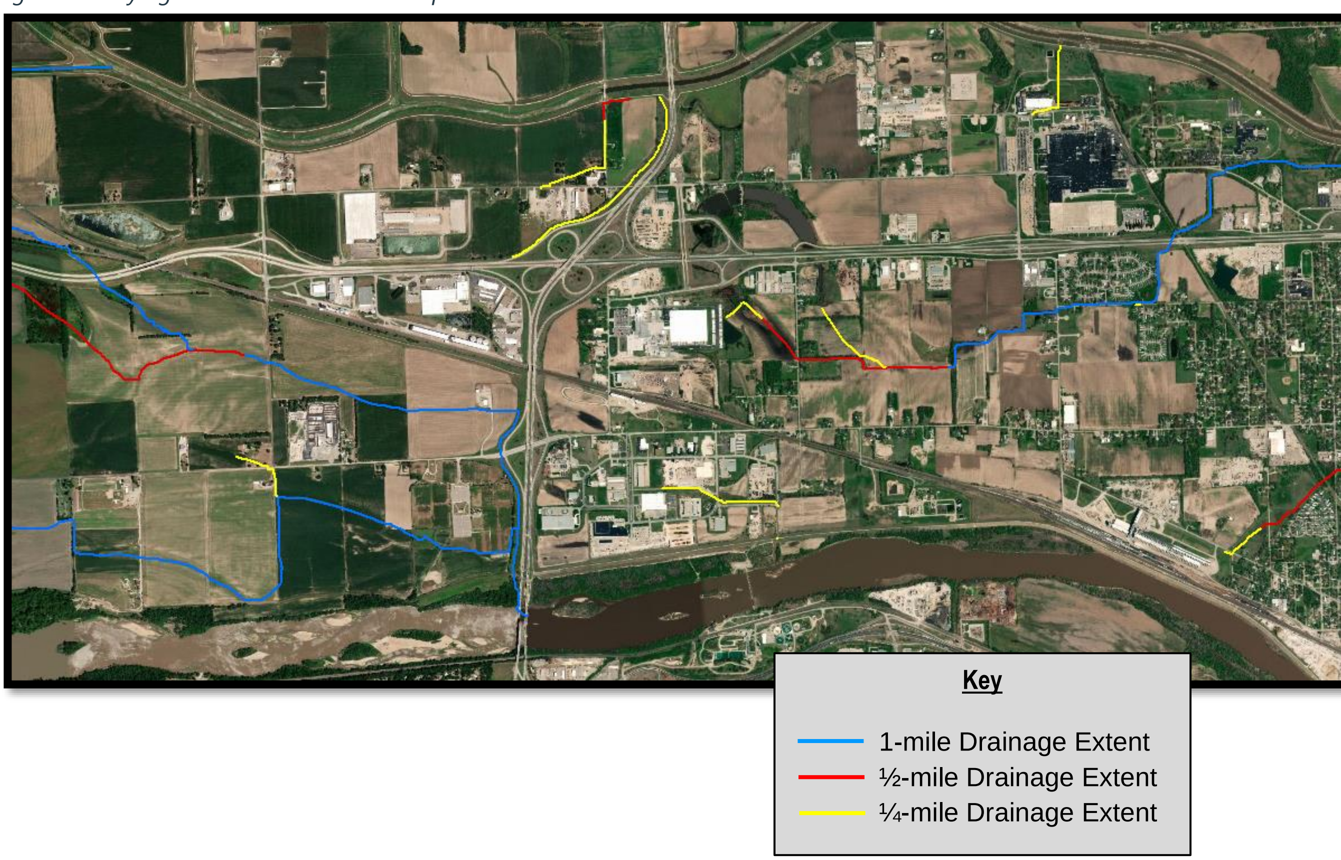


Figure 9: Varying Streamline Extents Example



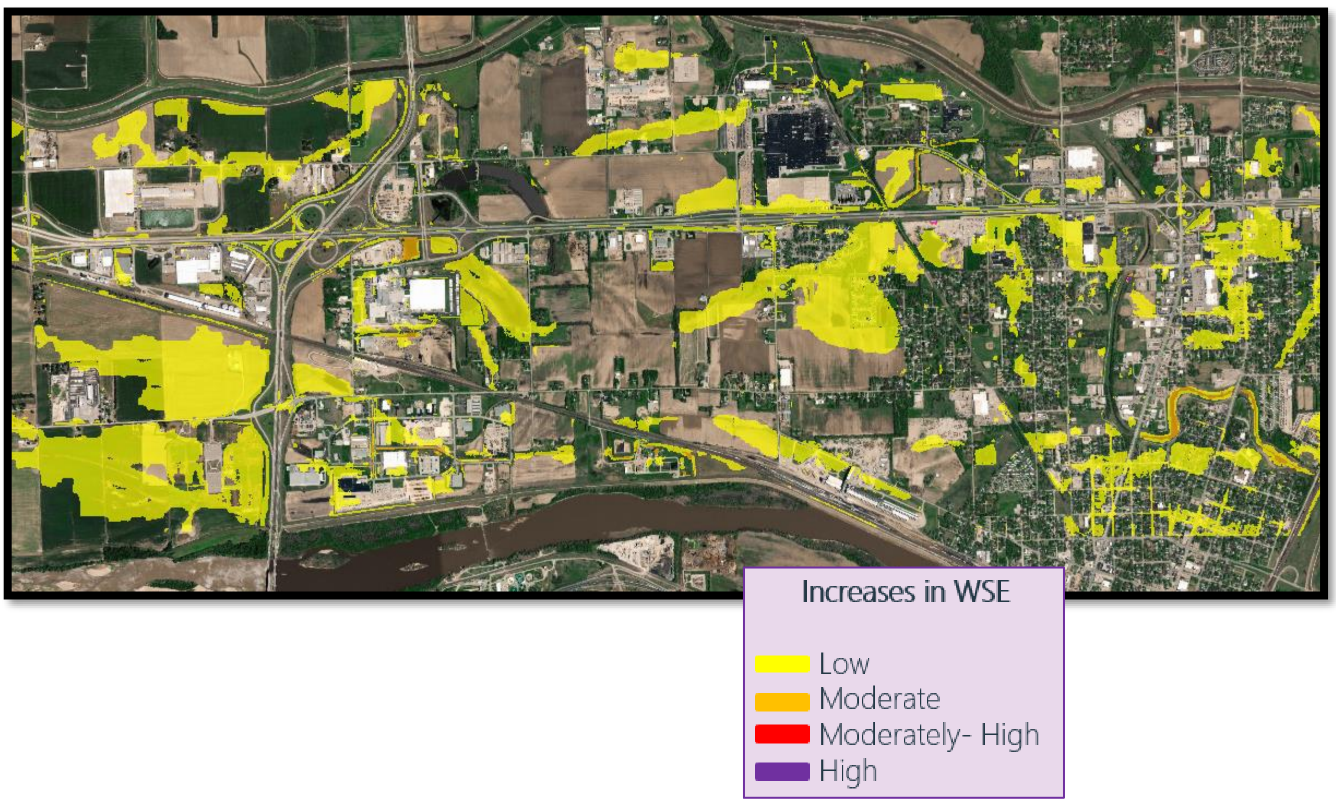
Peak Flow and Volume Sensitivity Analysis

To assist the City of Topeka in determining whether changes should be made to the current stormwater criteria related to peak control requirements and volume control requirements, an analysis was conducted to evaluate the peak flow sensitivity and volume sensitivity for each basin within the City. The analysis for all the basins located south of the Kansas river are included in the September 2019 Topeka Technical Assistance Report and deliverables. This report includes the analysis for the North Topeka basin.

Peak Flow Sensitivity

An analysis was performed to evaluate North Topeka's sensitivity to changes in the peak flow. To analyze these changes, modifications were made to the excess rainfall hyetographs to increase the peak flow for the 1% annual chance storm event by 10%, while maintaining the same volume of runoff. Likewise, modifications were made to decrease the peak flow for the 1% annual chance storm event by 10%, while maintaining the same volume of runoff. The modified hyetographs were applied as precipitation boundary conditions to the models. Comparisons were then made between the water surface elevations (WSE) in the models that used the modified excess rainfall hyetographs verses the base models to identify those areas that are sensitive to changes in the peak flows. Figure 10 illustrates North Topeka's sensitivity to changes in the peak flows.

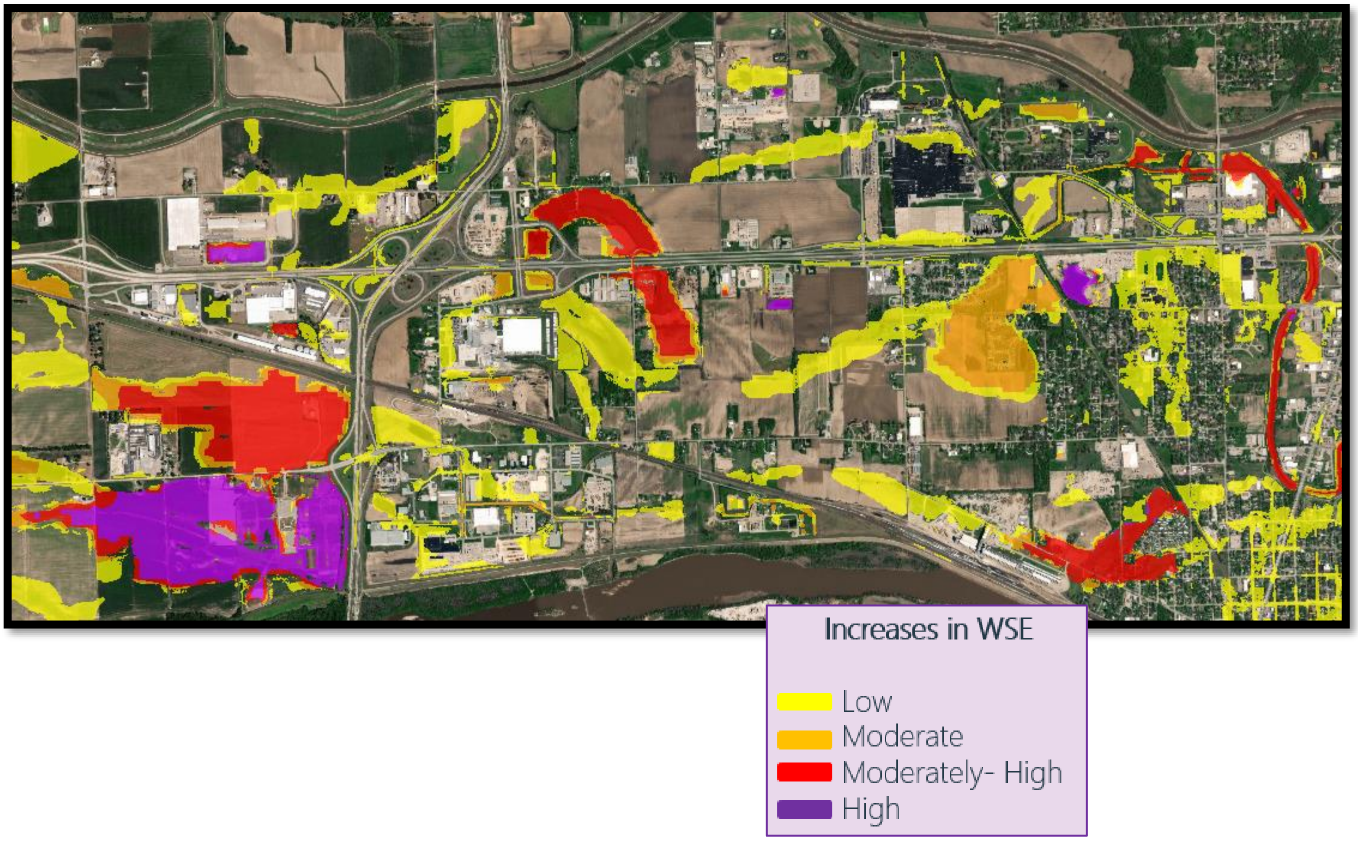
Figure 10: Peak Flow Sensitivity for North Topeka



Volume Sensitivity

An analysis was performed to evaluate North Topeka's sensitivity to changes in the volume. To analyze these changes, modifications were made to the excess rainfall hyetographs to increase the total volume of runoff for the 1% annual chance storm event by 10%, while maintaining the same peak flow. Likewise, modifications were made to decrease the total volume of runoff for the 1% annual chance storm event by 10%, while maintaining the same peak flow. The modified hyetographs were applied as precipitation boundary conditions to the models. Comparisons were then made between the water surface elevations (WSE) in the models that used the modified excess rainfall hyetographs verses the base models to identify those areas that are sensitive to changes in the total volume of runoff. Figure 11 illustrates North Topeka's sensitivity to changes in the total volume of runoff.

Figure 11: Volume Sensitivity for North Topeka



Recommended Controls

The peak flow sensitivity analysis and volume sensitivity analysis were utilized, in combination with other considerations, to develop a recommendation to the City of Topeka for appropriate stormwater controls by basin.

Interior ponding areas developed as part of the levee certification analysis are considered to be volume sensitive areas by nature, as flow is dependent on the operation of the structures through the levee. During high flow events for the Kansas River, water will simply pond in these areas. Any increase to the volume of total runoff for these areas will increase the impact of flood waters. Figure 12 illustrates the Zone AH ponding areas in North Topeka.

Figure 12: Zone AH Ponding Areas

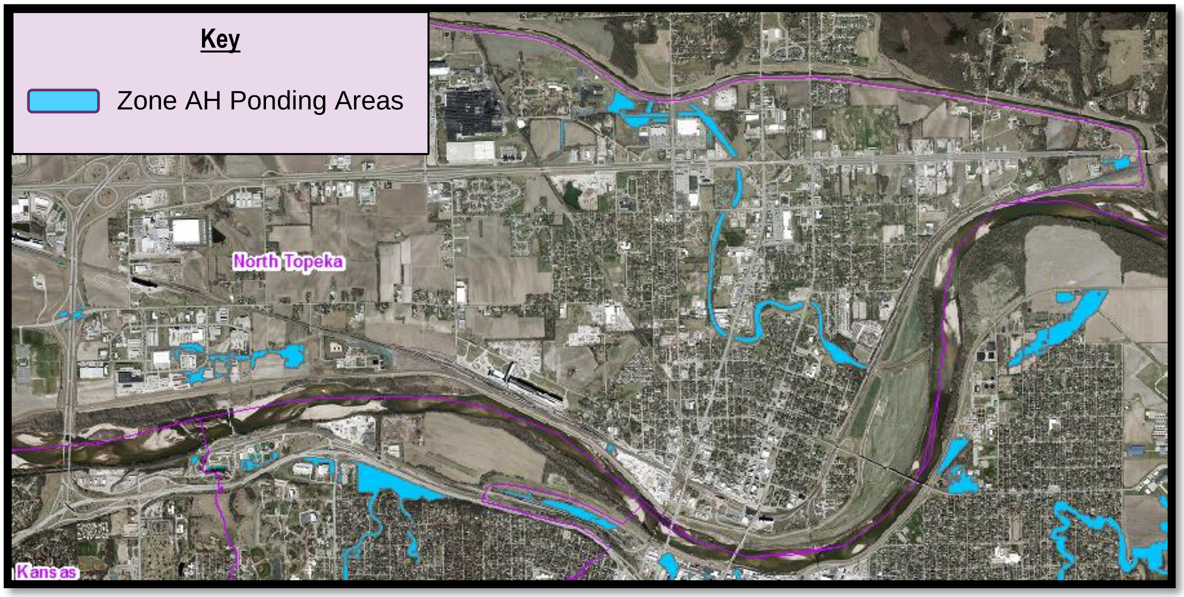
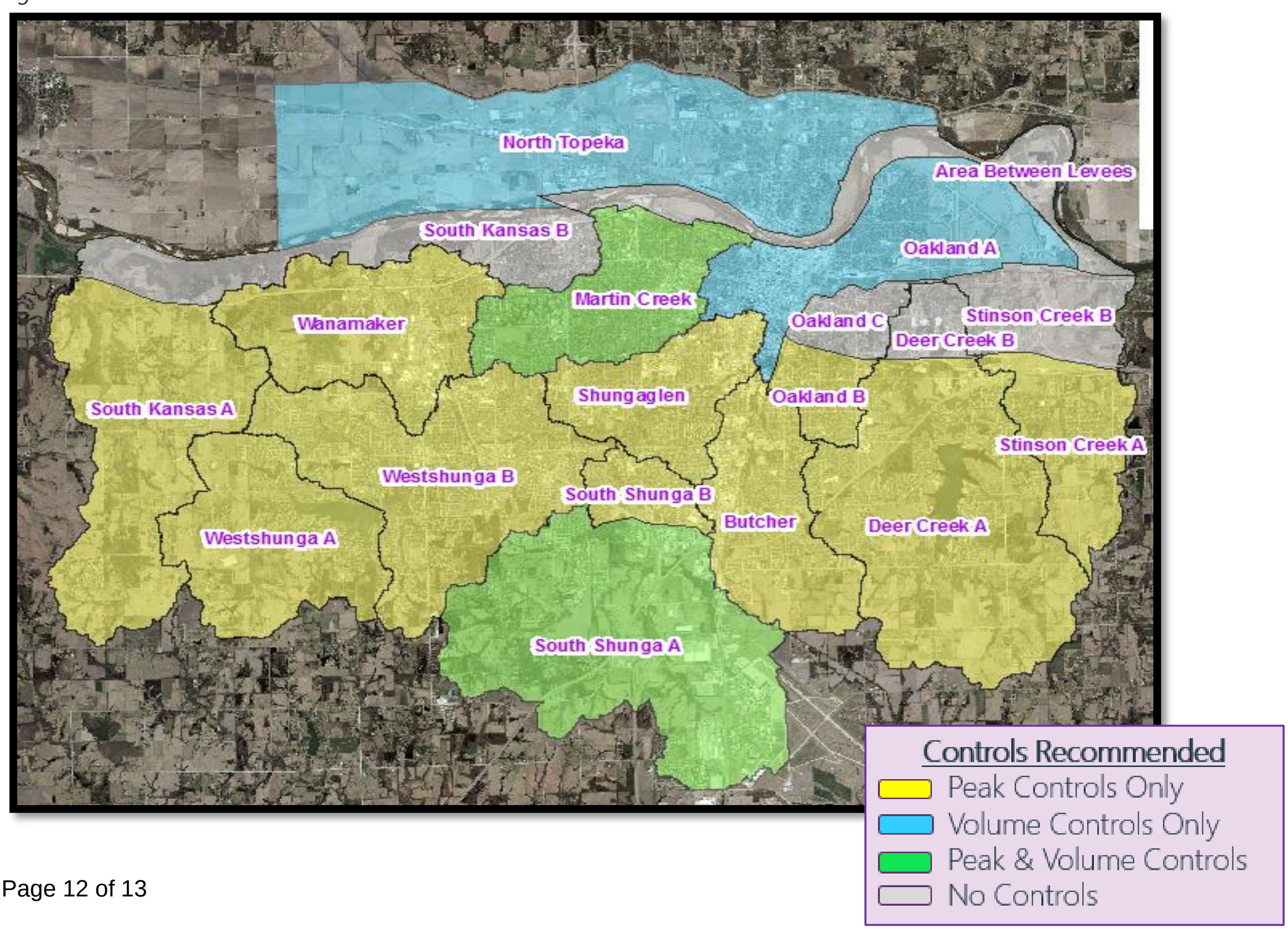


Figure 13 provides a visual of the recommended controls for each Sub-Basin in Topeka. For the North Topeka basin, volume controls are recommended as the basin is particularly sensitive to increases in total volume of runoff. Peak controls are not recommended, as the basin does not appear to be very sensitive to increases in peak flows.

Figure 13: Peak Flow and Volume Control Recommendations



Conclusion

The 2D modeling performed as part of this project is a valuable resource for the City of Topeka. With this modeling, 1% annual chance water surface elevations can be identified for any area within the North Topeka model area, beyond the FEMA mapping extents. Likewise, a variety of other parameters can be identified, such as depth, velocity, drainage area, shear stress and stream power. These are all useful data sets.

The peak flow and volume sensitivity analysis provides justification for volume control requirements for the North Topeka basin, based on the sensitivity the basin experienced to the peak flow and total volume changes. This analysis provides valuable, science-based information for modifying current stormwater criteria for the City of Topeka. The requirement to install volume controls for new development in the North Topeka basin will reduce the impact of new development on current water surface elevations.

It is recommended that the City utilize the 2D model developed as part of this project for other analyzes and studies that could prove beneficial for the community. For instance, regional detention opportunities can be analyzed. Other flood mitigation projects can be analyzed. The modeling can be updated to reflect new construction and used as a working model to track cumulative changes. It is the City's decision whether the modeling be provided to others and in what ways it will be used. The deliverables that are included as part of this project are listed in Appendix 1.

Appendix 1- Electronic Deliverables

Task Documentation

- **Technical Assistance Report**

RAS Model

RAW Grids

- **WSE Grid**
- **Depth Grid**
- **Velocity Grid**
- **Flow Accumulation Grid**
- **Shear Stress Grid**
- **Stream Power Grid**

Streamlines

- **1 square mile streamlines**
- **0.5 square mile (320 acre) streamlines**
- **0.25 square mile (160 acre) streamlines**
- **40 acre streamlines**

Alternative- Peak Flow and Volume Sensitivity

- **Hyetograph Spreadsheet**
- **Proposed Basin Shapefile**
- **Levee Ponding Area Shapefile**
- **Water Surface Elevation Difference Grids for:**
    - **Increasing Peak Flow**
    - **Decreasing Peak Flow**
    - **Increasing Volume**
    - **Decreasing Volume**