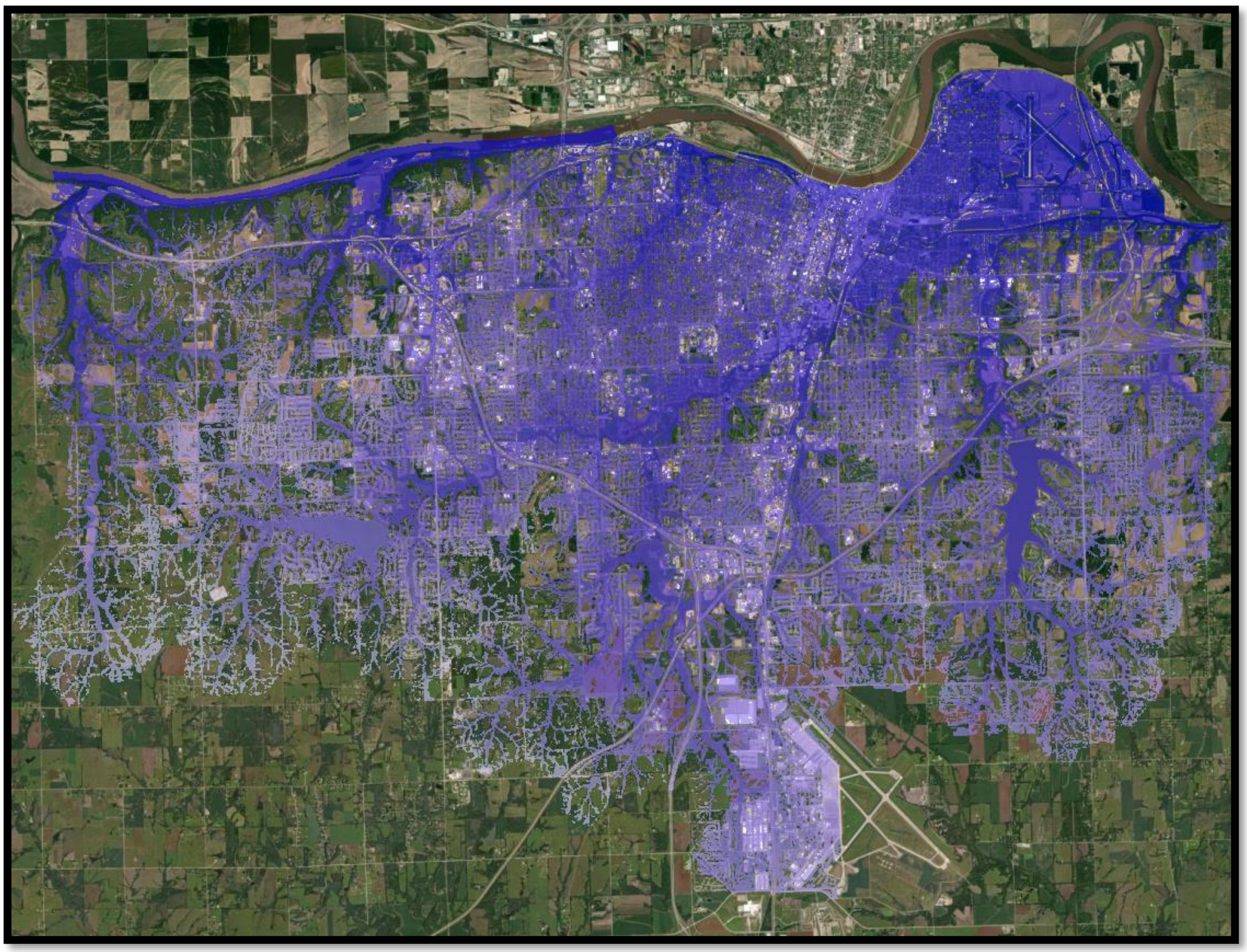
Topeka, KS
Technical Assistance Project

September 2019



Prepared for:
Kansas Department of Agriculture
Division of Water Resources
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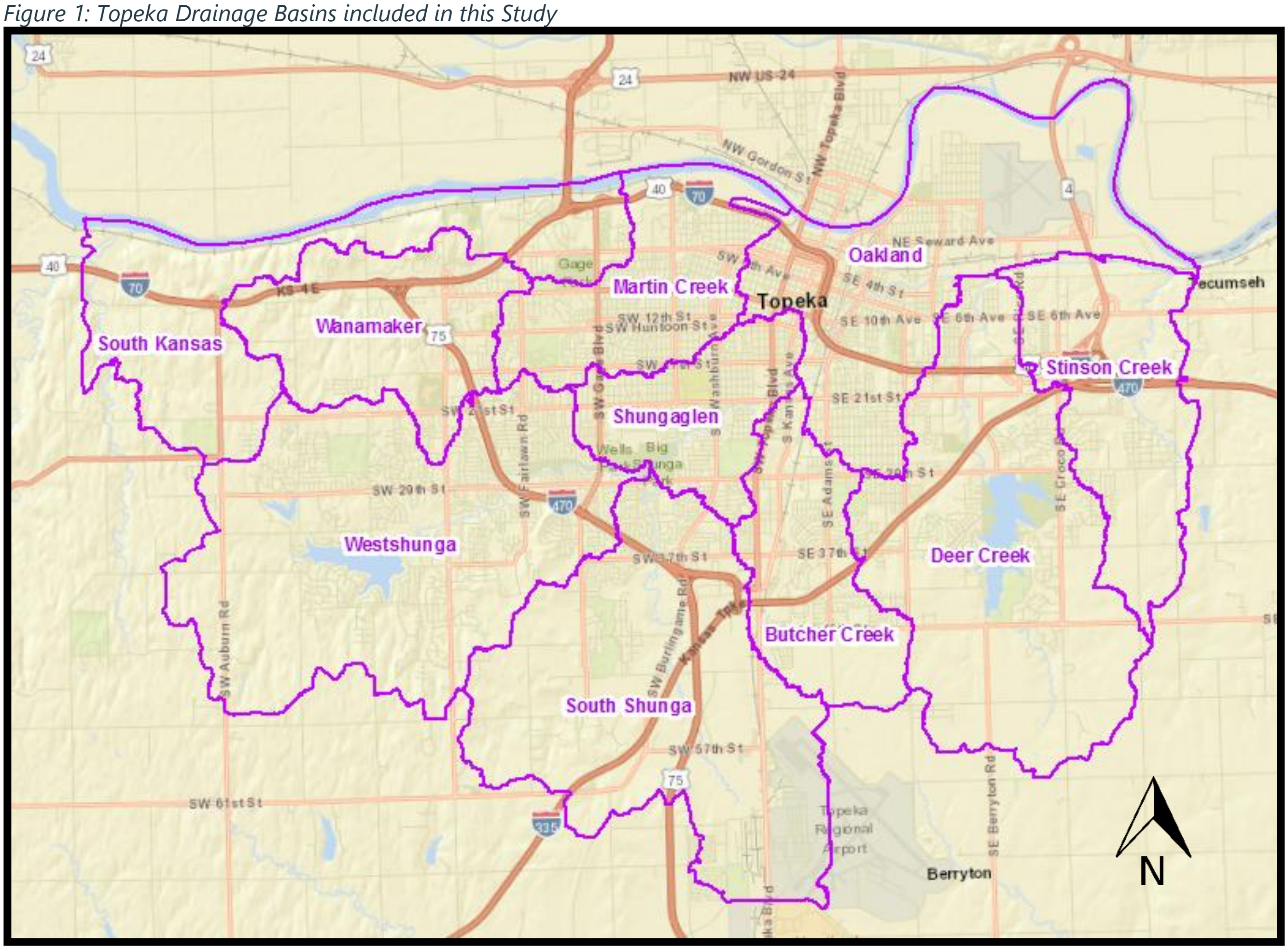
Introduction

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 the City of 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 ten drainage basins identified in Figure 1. The project area covers all the defined Topeka drainage basins located on the south side of the Kansas River. A separate Technical Assistance project was later completed for the North Topeka Basin, which will be discussed in a separate report. The scope of work included the use of "excess rainfall on grid" hydrology and HEC-RAS 5.0.5 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 and calibration purposes were included in the 2D models. Tail water 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: Topeka Drainage Basins included in this Study



As part of the deliverables outlined in the scope of work, a variety of grids were generated from the HEC-RAS 2D models, including water surface elevation grids, depth grids, velocity grids, flow accumulation grids, shear stress grids and stream power grids. In addition, stream lines for drainage areas up to 1 sq mile, 320 acres, 160 acres, and 40 acres were developed. In addition, the scope of work included the development of four sample alternative runs showing the benefit of each alternative. The four alternatives selected for the project included a stream buffer analysis, a sensitivity analysis of all ten watersheds from a peak flow and volume perspective, an analysis of the impacts of green infrastructure, and a compensatory storage analysis for a few Zone AE streams. These alternatives were evaluated in an effort to provide the City with valuable information and tools to assist in development of new science-based design criteria for the City that will protect future development from worsening the flood risk to residents and businesses within the City. This report summarizes the modeling performed, the alternatives selected for analysis, the benefits of those selected alternatives, and recommendations for future uses of the modeling.

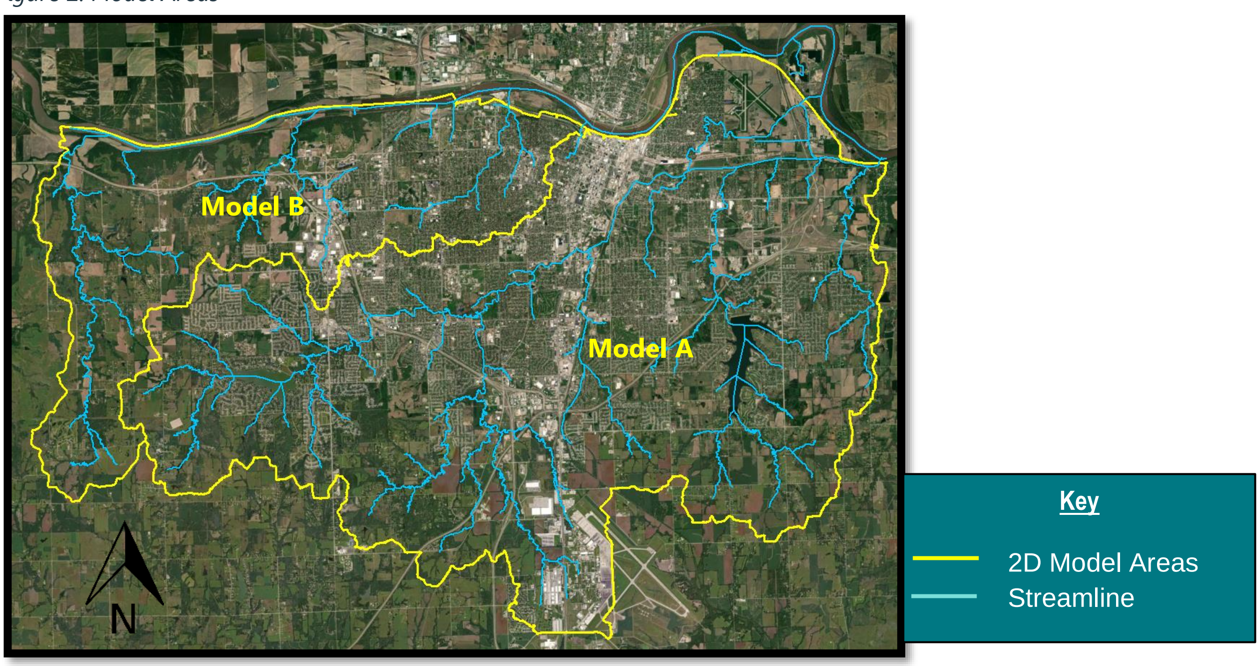
Rain on Grid Hydrologic Analysis

The rain on grid capabilities of Hydrologic Engineering Center's River Analysis System (HEC-RAS), version 5.0.5 (Hydrologic Engineering Center (HEC), 2018) 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. Two HEC-RAS models were developed for this study. One model includes the Shunganunga Creek Watershed, while the other model includes the remainder of the study area. The following sections describe the process used to develop the excess rainfall hyetographs used in this study.

Drainage Area

Extents of the 2D areas are based on watershed delineations using 1-meter LiDAR acquired through the Kansas Data Access and Support Center (State of Kansas, 2018). The basin boundaries were delineated using automated GIS processes based on lidar Digital Elevation Models (DEM), with manual corrections made where necessary.

Figure 2: Model Areas



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 each 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). 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 were developed for each 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: 2D Basin Curve Numbers, 1% Rainfall Depths, and 1% Excess Rainfall Depths

Basin	Basin Area (sq. mi)	Curve Number	1% Rainfall Depth (in)	1% Excess Rainfall Depth (in)
A	75	83	7.87	5.85
B	28	82	7.85	5.72

After removing the losses, the excess rainfall hyetograph was applied directly to the 2D areas in HEC-RAS as a precipitation boundary condition time series. The models were 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 5.0.5 (Hydrologic Engineering Center (HEC), 2018) 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 ranged from 0.035 to 0.045, based on stream size. 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

Land Use Designation	Manning's 'n'
Small Channel	0.045
Medium Channel	0.040
Large Channel	0.035
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. For Basin A, a normal depth boundary condition was used where Shunganunga Creek enters the Kansas River. For Basin B, a normal depth boundary condition was used at 3 locations, two on the far west side of town, and one along the Kansas River. The channel slope in the lidar elevation data was used as the normal depth slope for these boundary conditions. The remaining boundary conditions in which water leaves the system through a levee structure 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 models for those structures determined to have hydraulic significance to the modeling in the areas previously mapped as Zone AE special flood hazard areas on the FEMA maps. These features were important additions to the models to ensure proper calibration with the detailed one-dimensional modeling previously performed and used for the current effective FEMA maps. Internal 2D area connections with hydraulic structures were placed at hydraulically significant bridge and culvert structures, based on the information obtained from the effective one-dimensional FEMA HEC-RAS models. 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 models. It should be noted that HEC-RAS 5.0.5 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. Hydraulic structures were also added to the model for the 5 watershed dams, including Biddle Creek Dam, Burnett Dam, Sherwood Dam, South Branch Dam, and the Lake Shawnee Dam to properly represent storage in these structures.

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 models were ran for the 1% annual chance storm event only.

Hydraulic Comparisons

Comparisons were made between the 1% annual chance water surface elevations (WSEs) in the 2D modeling performed and the effective 1D FEMA HEC-RAS models. For the most part, the WSEs from the 2D models matched very closely to the Base Flood Elevations (BFEs)/WSEs from the 1D models. A sampling of 1% annual chance water surface elevation comparisons is shown in Table 3.

Table *3*: Comparison of 1% WSEs between Effective 1D Study and 2D Study

Location	1% BFE from Effective 1D Study (NAVD88)	1% WSE from 2D Study (NAVD88)
Butcher Creek Just DS of SE 37th Street	951.8	951.9
Colly Creek Just US of SW 45th Street	962.5	962.2
Deer Creek Approximately 1,725 ft US of SE 6th Avenue	889.6	889.6
Indian Hills Tributary Just DS of SW Arvonia Place	967.3	967.3
SW Branch Elevation Creek Approximately 2,025 ft US of SW 41st Street	1027.5	1027.6
Shunganunga Creek Just US of SW Arrowhead Road	950.1	950.2
Wanamaker Main Branch Just DS of SW Huntoon Street	932.2	932.3
Wanamaker Northeast Branch Approximately 230 feet US of SW 10th Ave	927.9	928.0

There are three specific areas in which the WSEs from the 2D HEC-RAS model did not align well with the BFEs from the effective FEMA studies. One area is along South Branch Shunganunga Creek downstream of the South Branch Dam where the 2D WSEs are generally 2 to 3 feet higher than the effective BFEs. However, at the time of the last mapping update for the City of Topeka, the models and floodplains were changed as part of the appeal process. It should be noted that Wood (Amec at the time), was not supportive of this change. When comparing the WSEs from the 2D analysis to the original 1D analysis, prior to the changes from the appeal; the WSEs are within a few tenths of a feet from one another. Another area of disparity is along Shunganunga Creek downstream of the South Branch Shunganunga Creek confluence where the 2D WSEs are generally 2 to 5 feet lower than the effective BFEs. At the time of the last mapping update for the City of Topeka, the FEMA regional requirements would not allow the modeling for Shunganunga Creek to account for storage, which results in a more conservative and higher water surface elevation. Thus, the 2D modeling appears to more accurately reflect actual conditions of the stream, in which storage would be a factor. The final area of dissimilarity is along Shunganunga Creek directly upstream of the Burnett Dam where the 2D WSEs are significantly lower than the effective BFEs. At the time of the last mapping update, the public expressed concerns with the floodplains and BFEs in this area, indicating that the floodplains looked too large based on historical knowledge of the area. Wood (Amec at the time) was the mapping contractor for that project, and while efforts were made to find an error in the modeling, no errors or issues were identified. In recent years, several LOMRs have been done in this area. Therefore, it can be reasoned that the 2D model more accurately represents the flooding in this area when compared to the effective study.

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

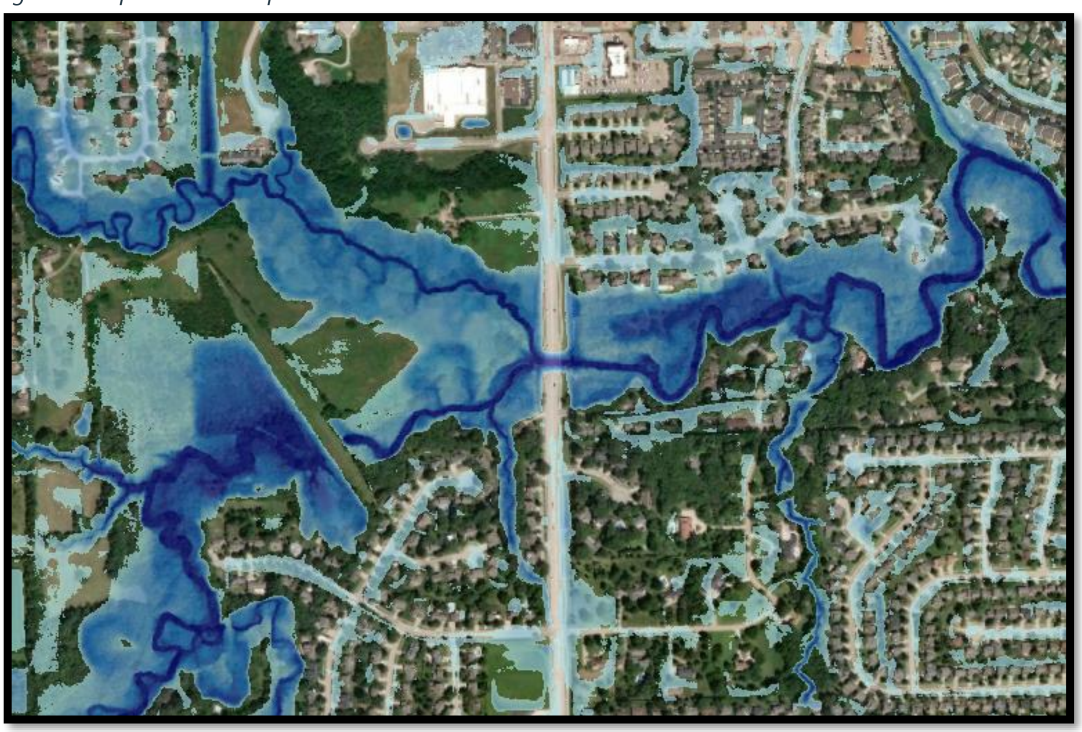


Figure 5: Velocity Grid Example

Figure 6: Flow Accumulation Grid Example

Figure 7: Shear Stress Grid Example

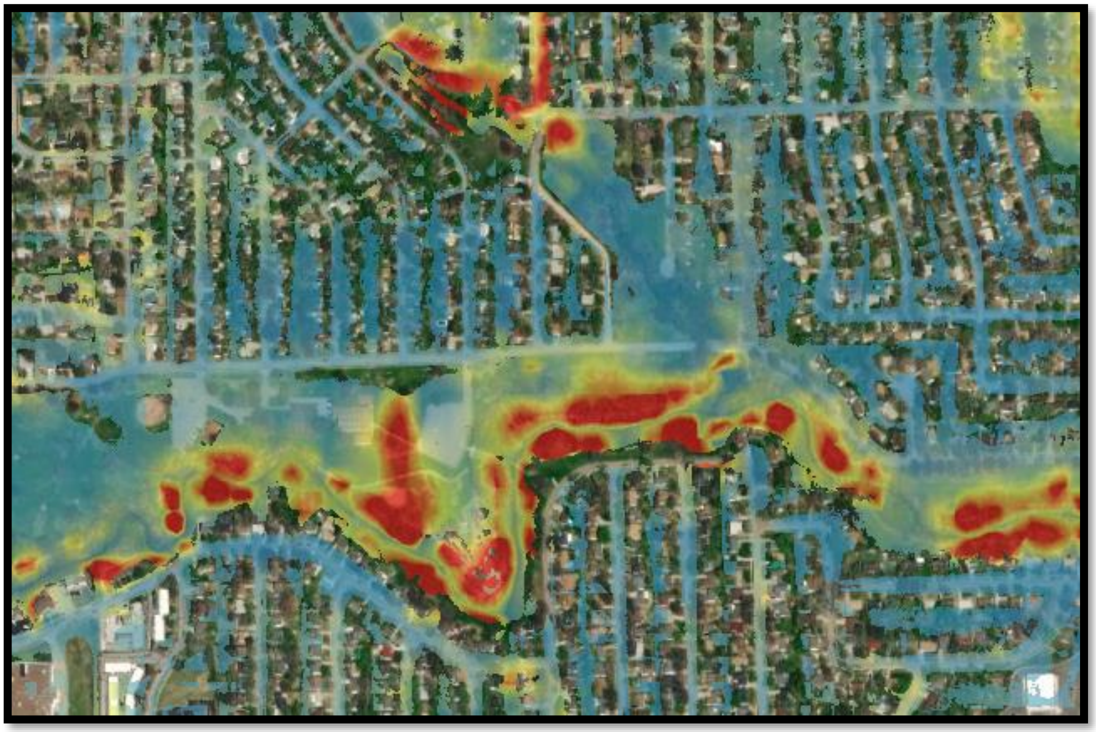
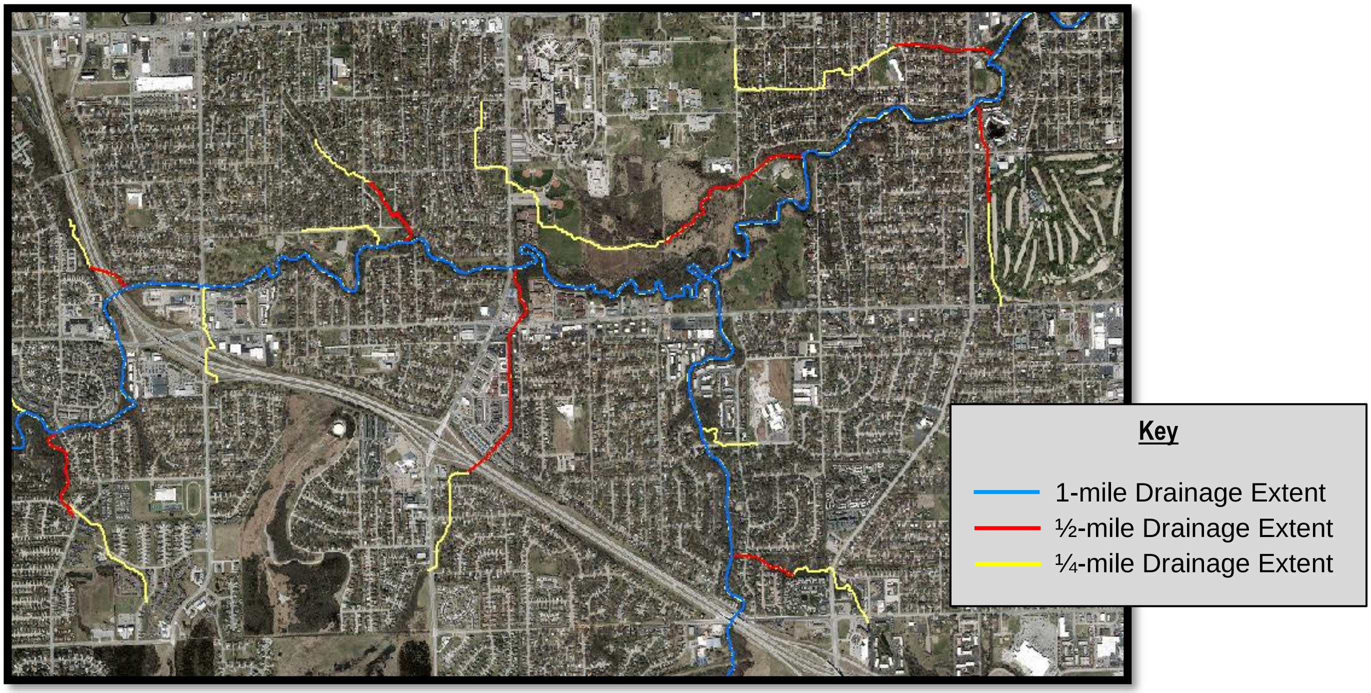


Figure 8: Stream Power Indexes Example

Figure 9: Varying Streamline Extents Example



Stream Buffer Analysis

To assist the City of Topeka in determining whether changes should be made to the current stream setback limits, a GIS-based stream buffer was developed. To develop the stream buffer, an overall risk grid was developed that incorporates a variety of parameters including the stream direction, the maximum flood depth, the maximum water velocity, the ground slope, the ground curvature, the soil erosion index (or soil erodibility), and the maximum shear stress. Some parameters are outputs from the 2D modeling, while some parameters are simply site characteristics. Each parameter is given a weighting factor to determine the combined risk. The magnitude of the stream setback limits was determined by an automated process that evaluated the overall risk along the stream, direction of flow, and minimum bank offset. The automated process creates stream flow projection lines based on the overall risk. A polygon is created by connecting the endpoints of all the flow projection lines to create the recommended stream setback limit. Figure 10 provides an example of the flow projection lines and how they create the stream buffer.

Figure 10: Example of Science-Based Stream Setback Process

Currently, Chapter 17.10 of the Topeka Municipal Code defines "buffer" as a vegetated area, including trees, shrubs, and herbaceous vegetation, which exists or is established to protect a stream system, lake or reservoir. It also defines the buffer for three stream "types". Type I streams are defined as perennial streams shown as solid blue lines on the USGS topographical map. The buffer width for Type I streams is 100 feet on each side of the stream, measured from the outer wet edge of the channel during base flows. Type II streams are defined as intermittent streams shown as dashed blue lines on the USGS topographical map. The buffer width for Type II streams is 50 feet on each side of the stream, measured from the centreline of the channel. Type III streams are defined as waterways or dry channels that have a contributing drainage area of 50 acres or great. The buffer width for Type III streams is 30 feet on each side of the stream, measured from the centreline of the channel. Notice that all the current buffers are measured in linear distance from the channel.

The intent of the science-based stream buffer is to more accurately represent the combined risk at all specific locations of the stream channel, highlighting areas where bank failure is more likely to occur and where additional setback measures are needed to protect the integrity of the stream channel. Regulating to a science-based stream buffer is a proactive approach that could reduce reactive actions and necessary measures in the future. To evaluate the accuracy of the science-based stream buffers generated, the City of Topeka was asked to provide locations of known erosion problems. Comparisons were then made between the current stream buffer and the science-based stream buffer at those locations. Figures 11, 12, 13, and 14 are examples of the current stream buffer verses the science-based stream buffer at some of the known problem areas throughout the City.

Figure 11: Modified Stream Buffer Example near 2512 SW Arrowhead Road

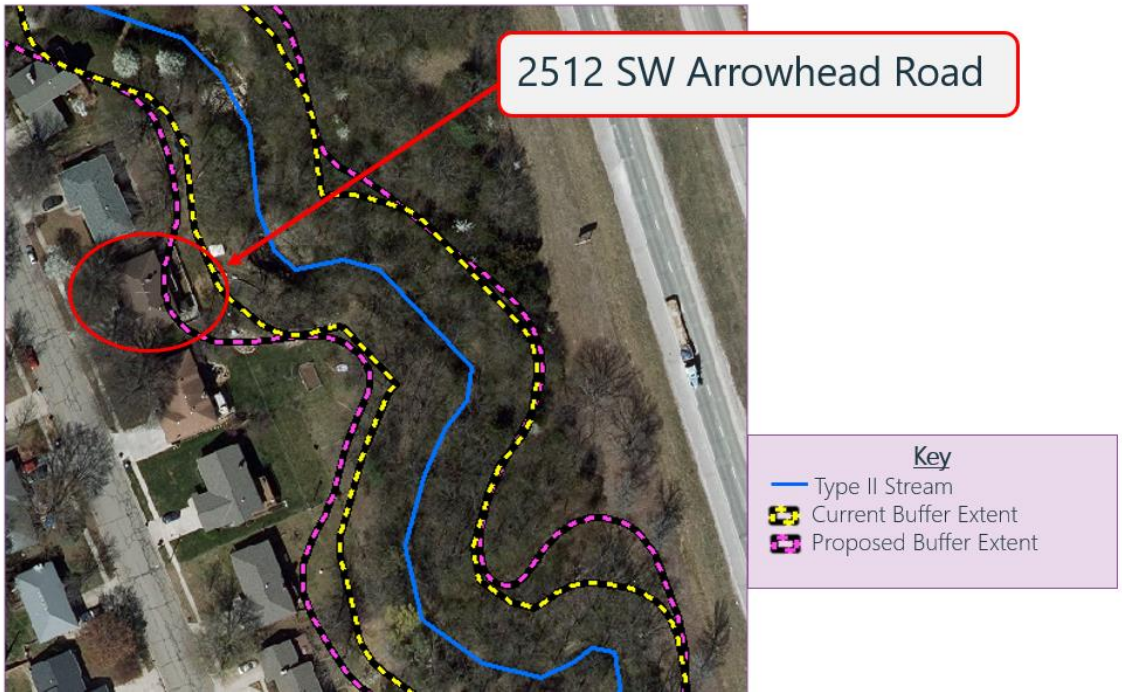


Figure 12: Modified Stream Buffer Example near 3231 SW Arrowhead Road

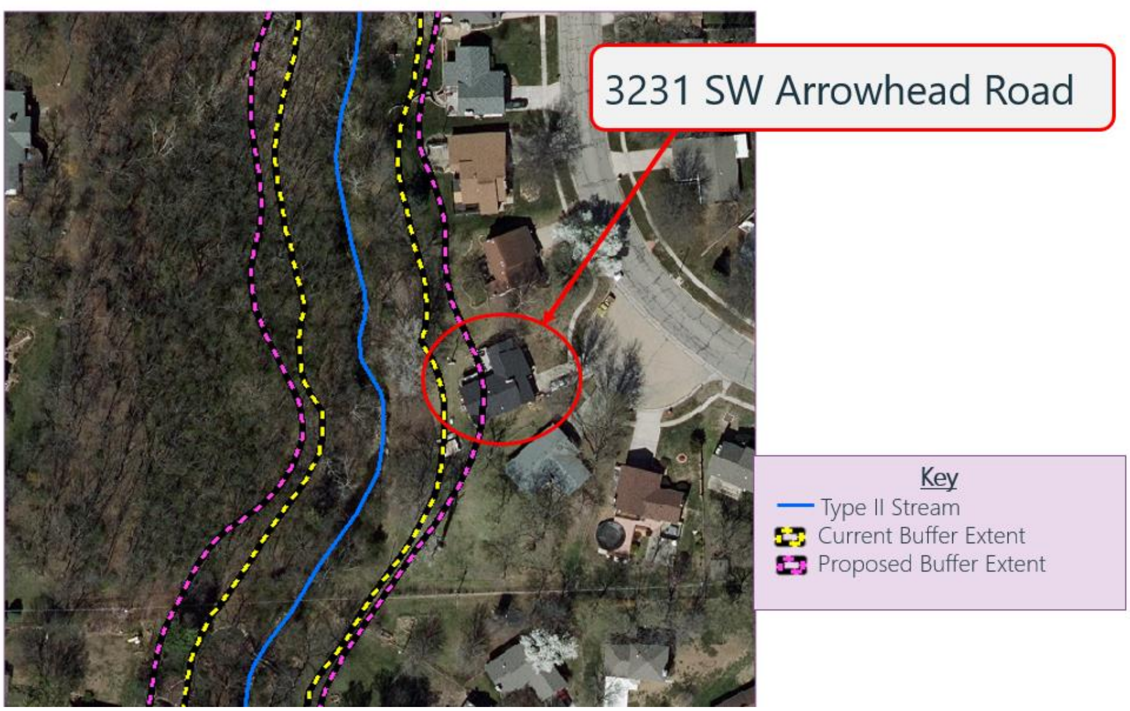


Figure 13: Modified Stream Buffer Example near 2501 SW Pepperwood Court

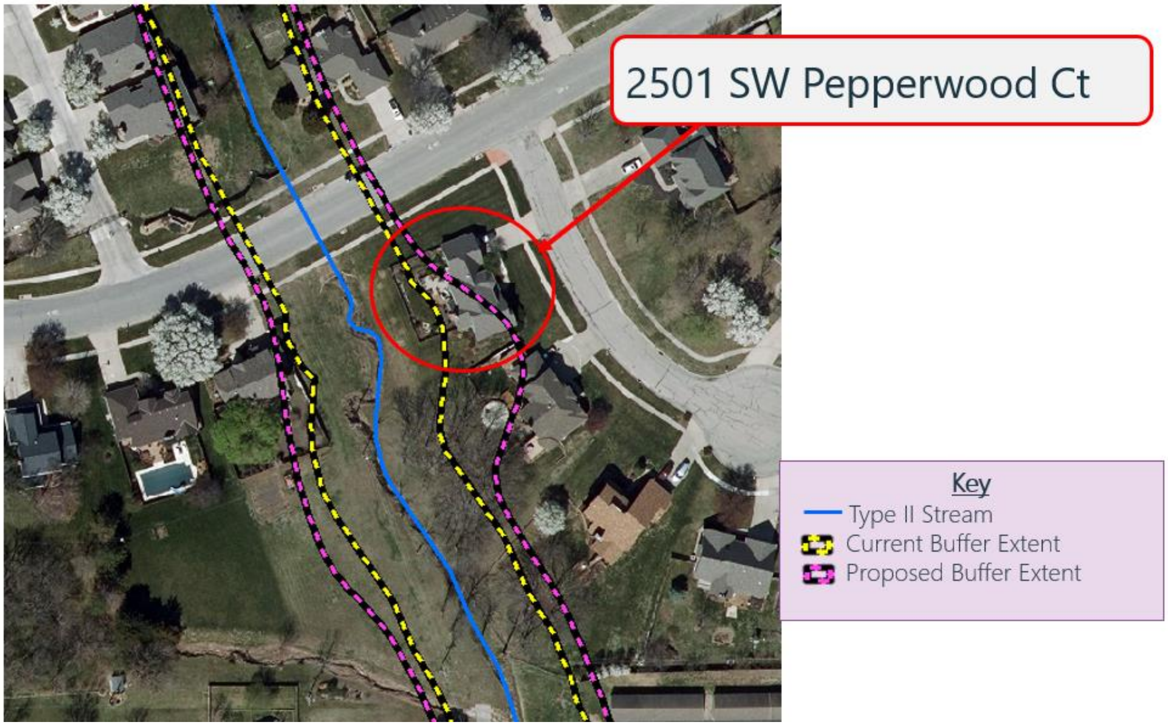
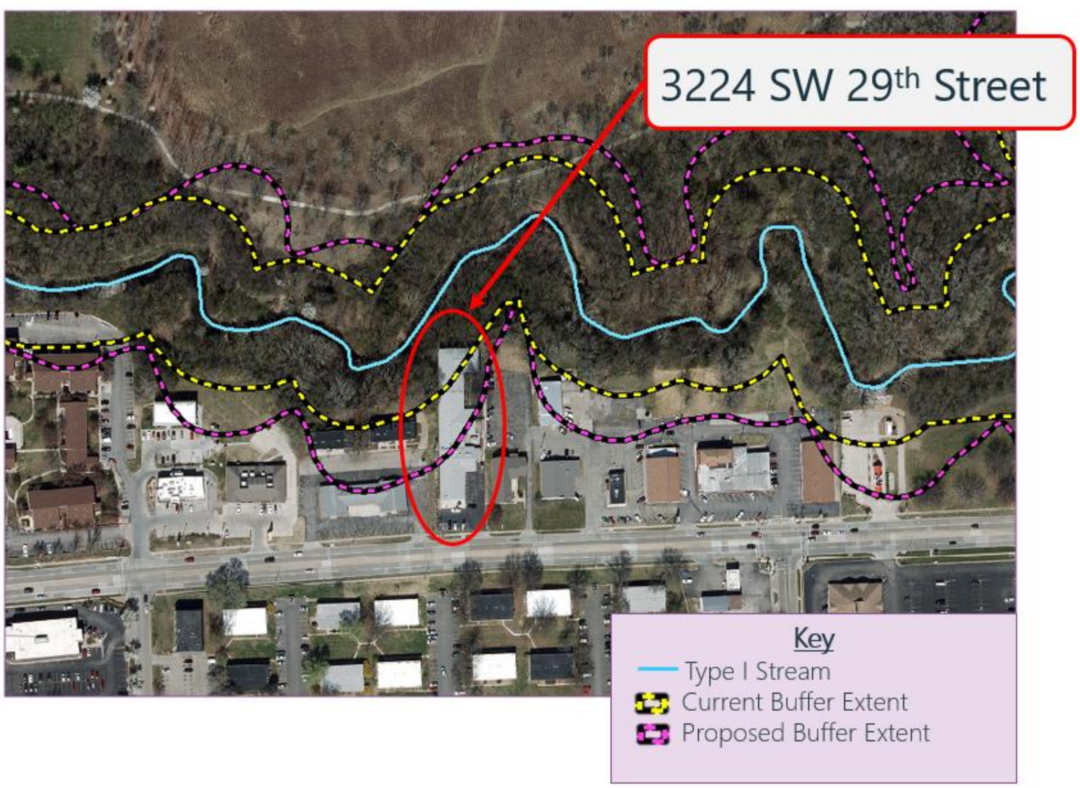


Figure 14: Modified Stream Buffer Example near 3224 SW 29th Street



All of the known erosion problems identified by the City were reflected as such in the proposed science-based stream buffer, with the proposed buffer extending through all of the noted buildings of concern. Had the science-based stream buffer been utilized as the outer setback limit when these areas, and other areas, were developed, there would be far less concern related to potential damages to buildings due to stream erosion.

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.

Peak Flow Sensitivity

An analysis was performed to evaluate each basin's sensitivity to changes in the peak flow. To analyse 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 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. Figures 15, 16, and 17 illustrate a few of the "hot spots" identified as being very sensitive to changes in the peak flows.

Figure 15: Peak Flow Sensitivity for Shunganunga Creek near the Burnett Dam

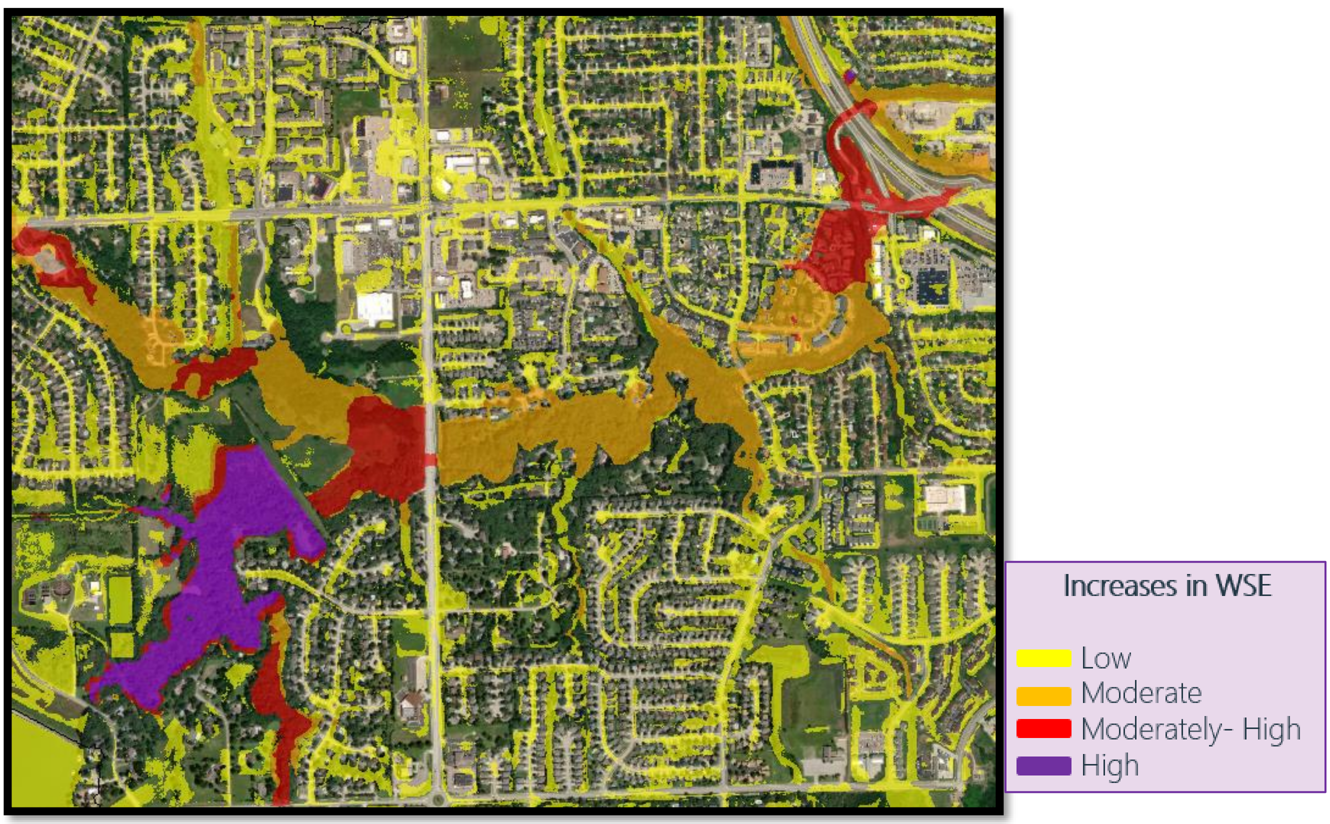


Figure 16: Peak Flow Sensitivity for Deer Creek downstream of Lake Shawnee Dam

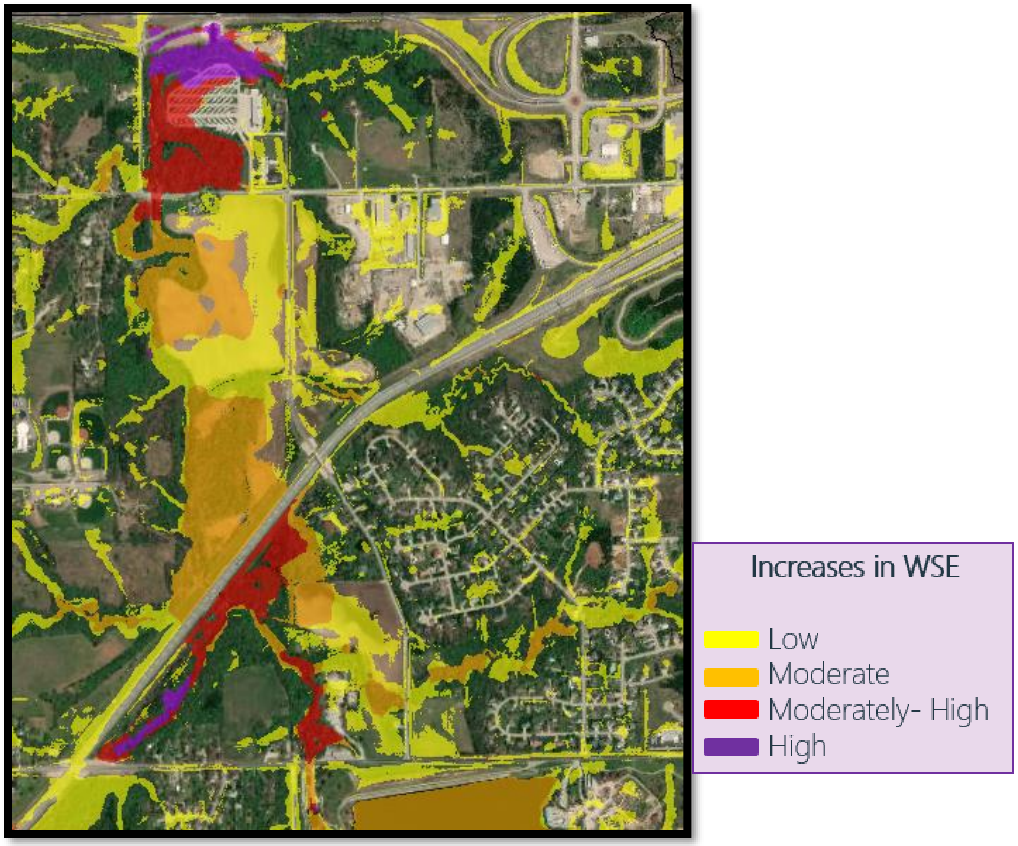
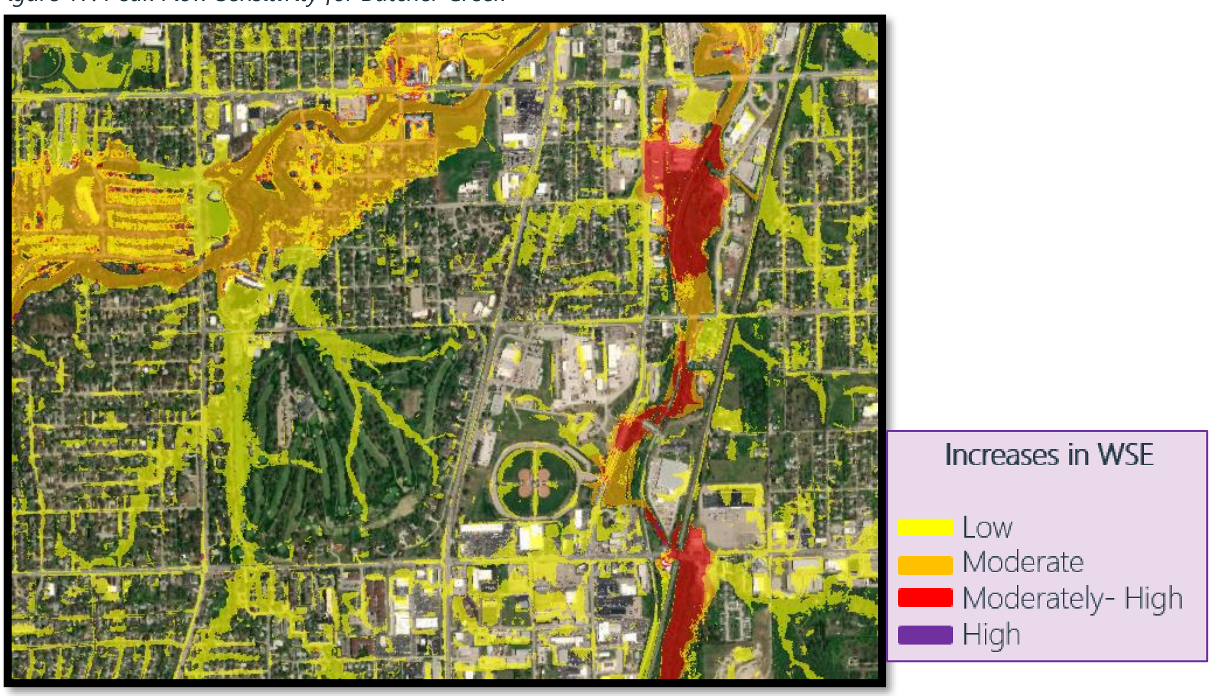


Figure 17: Peak Flow Sensitivity for Butcher Creek



Volume Sensitivity

An analysis was performed to evaluate each basin's sensitivity to changes in the volume. To analyse 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 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. Figures 18 and 19 illustrate a few of the "hot spots" identified as being very sensitive to changes in the total volume of runoff.

Figure 18: Volume Sensitivity for South Branch Shunganunga Creek near the South Branch Dam

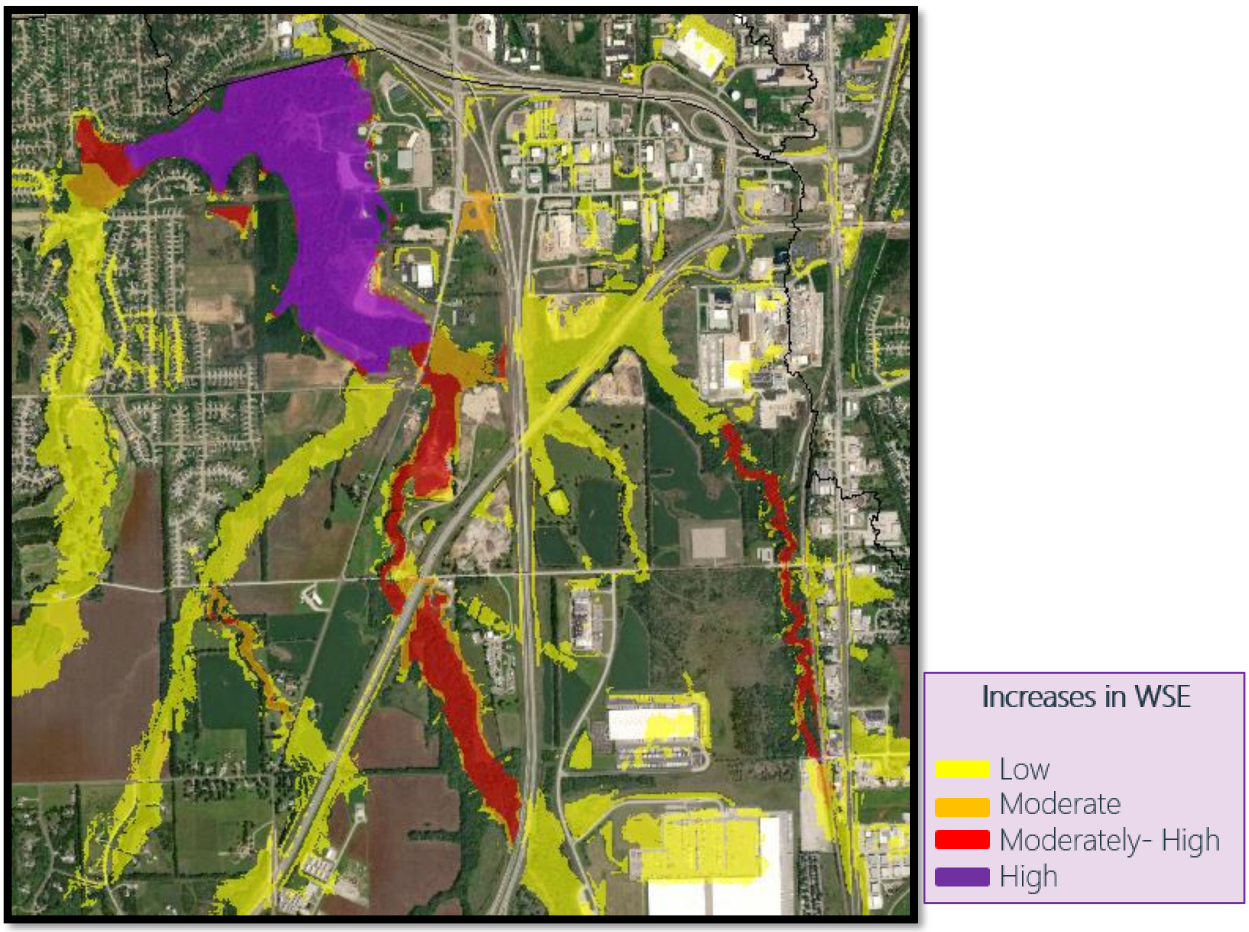
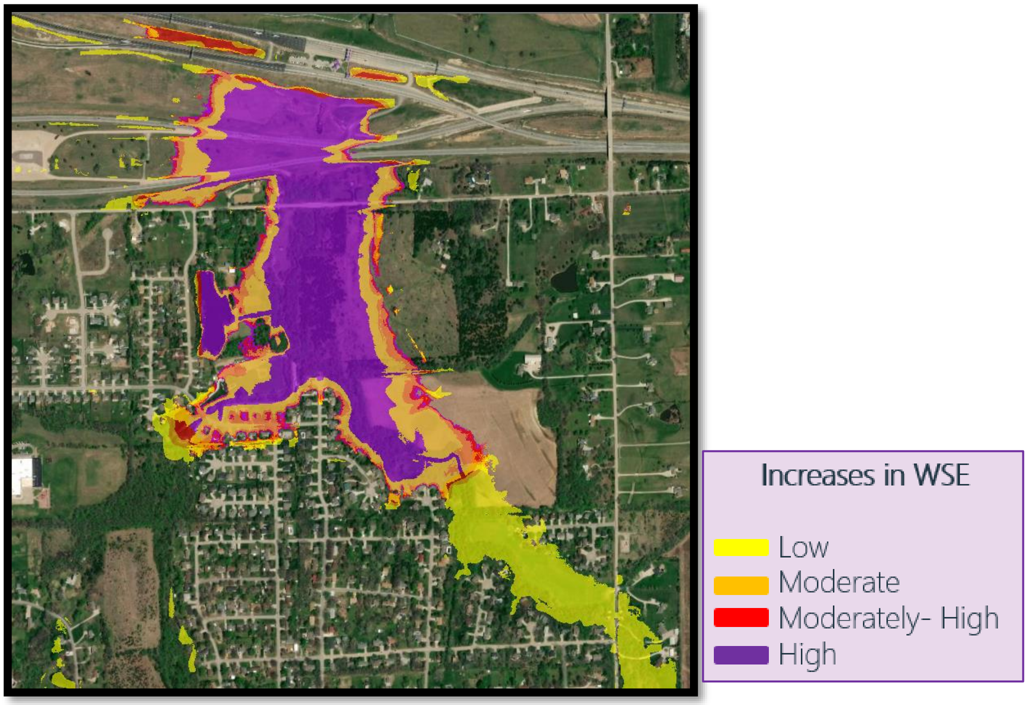


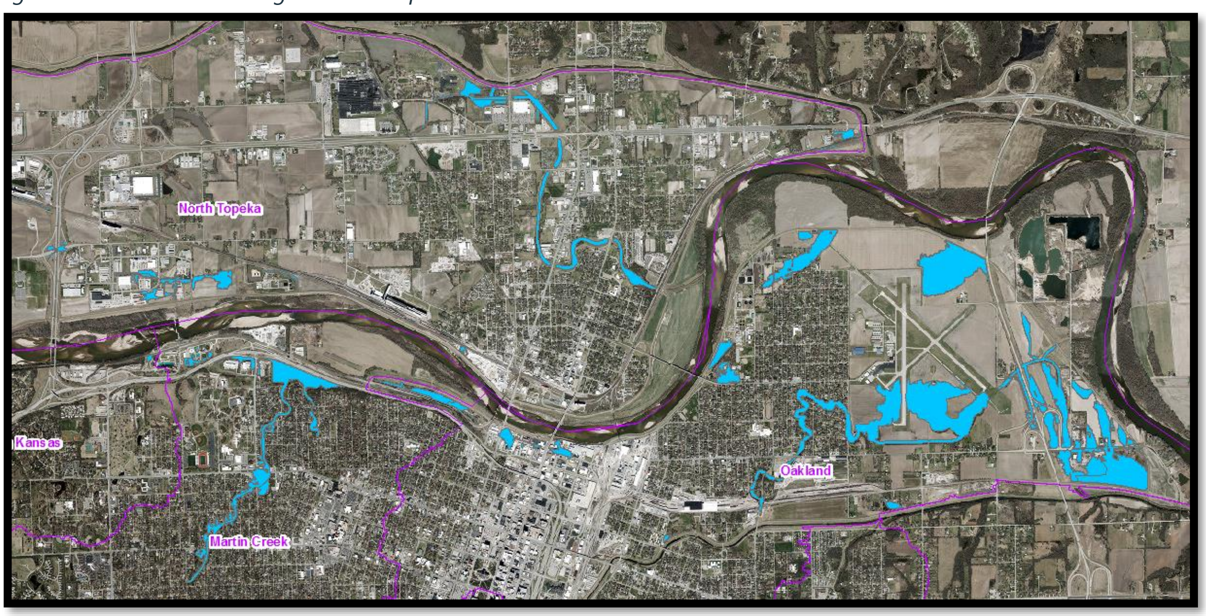
Figure 19: Volume Sensitivity for Stinson Creek Upstream of Interstate-70



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. In doing so, the Topeka Basins were further sub-divided so appropriate controls could be properly recommended for all areas.

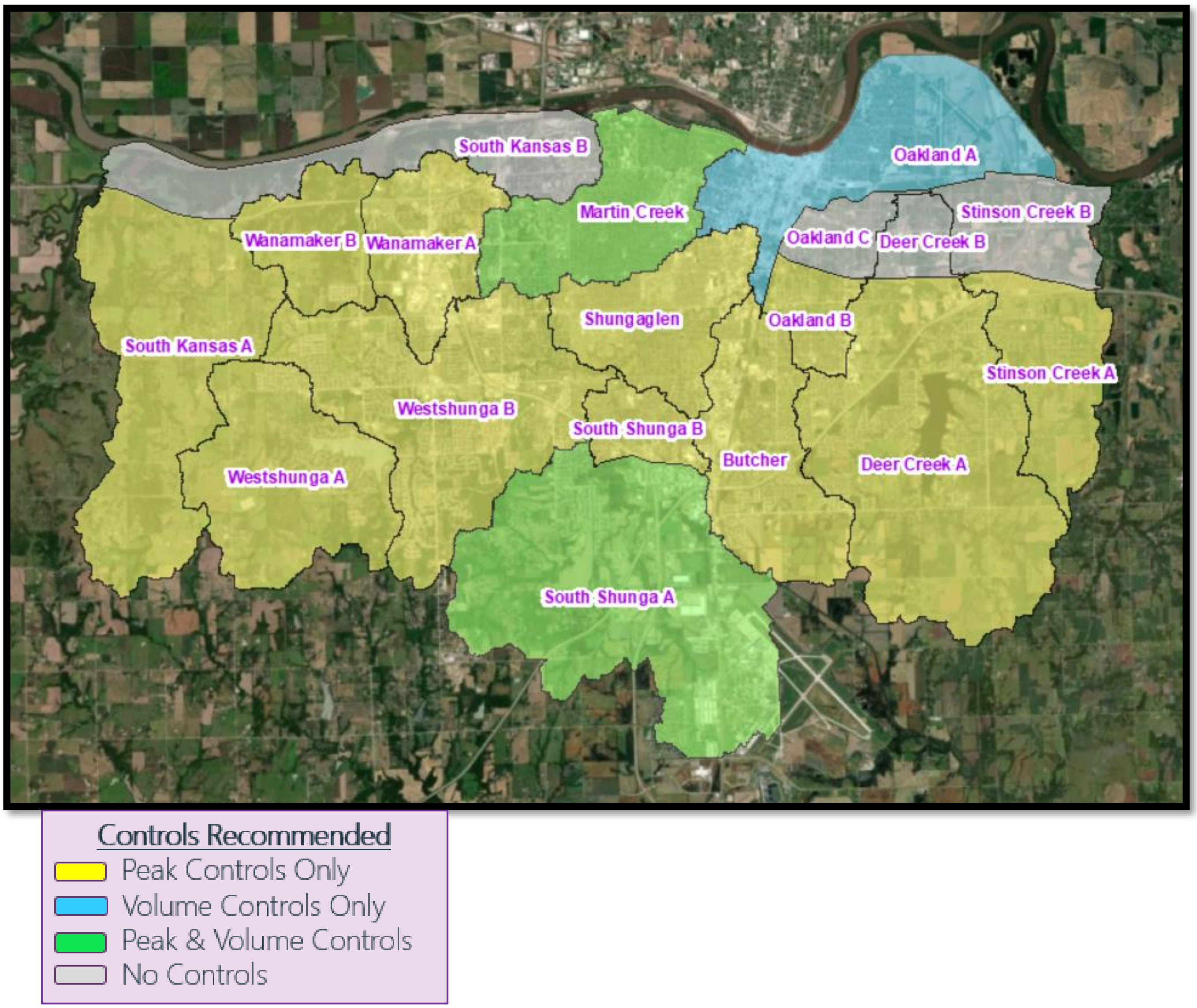
Figure 20: Zone AH Ponding Areas in Topeka



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 20 illustrates the Zone AH ponding areas in Topeka.

Figure 21 provides a visual of the recommended controls for each Sub-Basin. Peak controls are recommended for the majority of the City's Basins, with the exception of those areas within close proximity to the Kansas River or Levee System; including the Oakland A, Oakland C, Deer Creek B, Stinson Creek B, and South Kansas B Basins. Many of the areas within the City are sensitive to increases in peak flows or fall within a drainage area that is sensitive to increases in peak flows. Volume controls are recommended for the Martin Creek, Oakland A, and South Shunga A Basins, as those areas are particularly sensitive to increases in total volume of runoff.

Figure 21: Peak Flow and Volume Control Recommendations

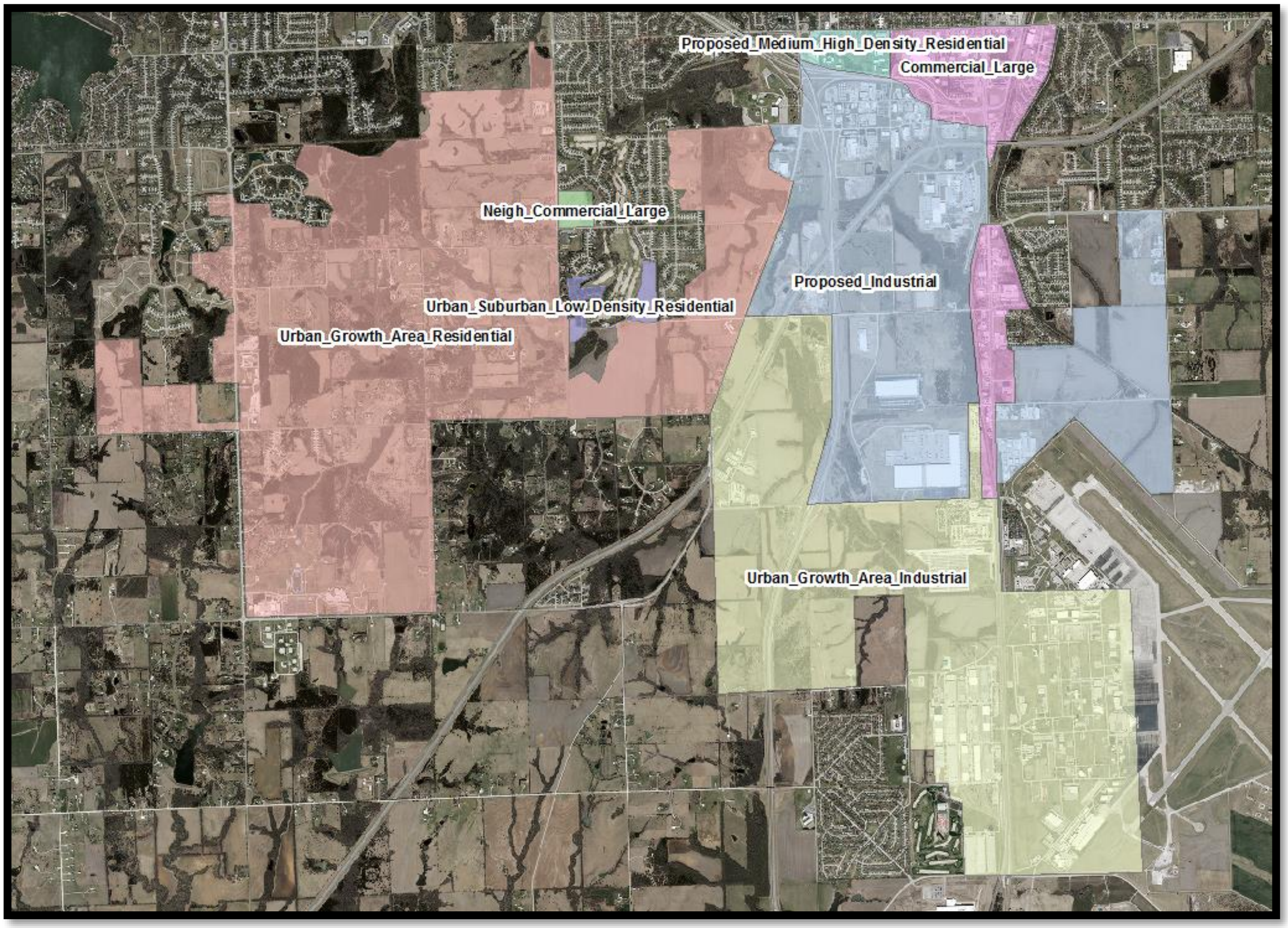


Green Infrastructure Analysis

To assist the City of Topeka in determining whether volume control requirements, such as green infrastructure or low impact development, should be implemented, an analysis was conducted to determine the impacts of green infrastructure/volume controls in areas where potential development is likely in the future.

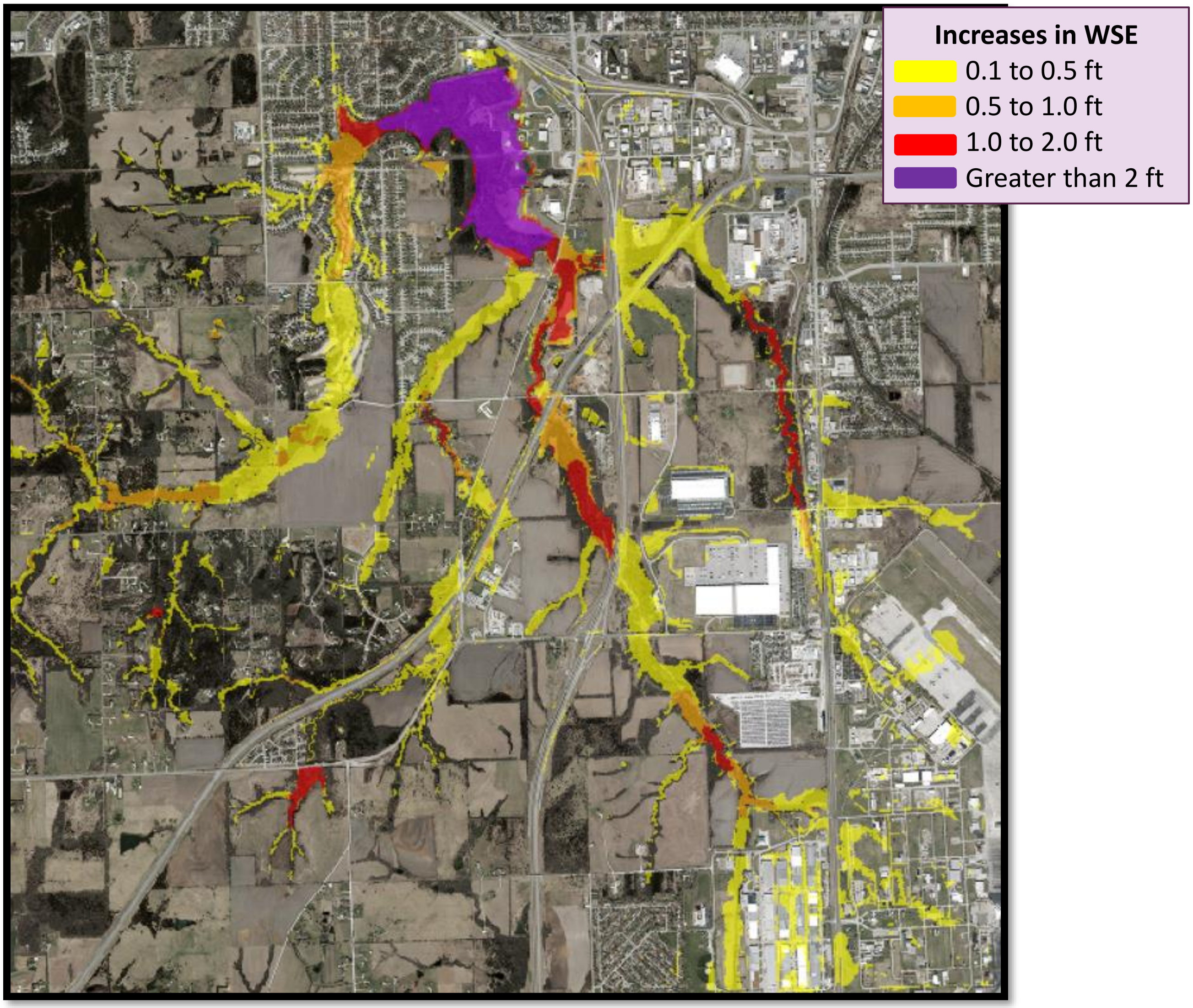
The South Shunga Basin was broken out from the base HEC-RAS 2D modeling for this analysis. The City of Topeka provided a 2040 Land Use Plan. Areas of future development within the South Shunga Basin were identified from the 2040 Land Use Plan and are shown in Figure 22.

Figure 22: Areas of future development based on 2040 Land Use Plan



Utilizing the same parameters as described in the Curve Number sub-section on page 3 of this report, a Curve Number of 80 was calculated for the South Shunga Basin. With the incorporation of the future development identified in Figure 22, a future conditions Curve Number of 88 was calculated for the South Shunga Basin. Excess rainfall hyetographs were developed for the base model and the future conditions model based on the calculated Curve Numbers and were then applied to the HEC-RAS model as precipitation boundary conditions. As expected, the increase in Curve Number for the future conditions increased the water surface elevations in the South Shunga Basin, particularly for the South Shunga Dam, where the water surface elevations increased by more than 2.0 feet for the 1% annual chance storm event. Figure 23 shows the water surface elevation increases for the future conditions model verses the base model.

Figure 23: WSE Increases for Future Conditions Model Verses Base Model



The City of Topeka has adopted the Mid-America Regional Council (MARC) Manual of Best Management Practices for Stormwater Quality into the Post Construction Stormwater Quality Policy. The MARC Manual describes the water quality storm to be 1.37 inches for the area. Traditional green infrastructure/low impact development systems are designed to infiltrate the first 1.37 inches of rainfall during a storm event. To simulate the impacts of green infrastructure as a form of volume control for the South Shunga Basin, the excess rainfall hyetograph for the future conditions model was modified to remove the first portion of the runoff from the hyetograph to represent infiltration achieved. It was determined that approximately 67.8% of the South Shunga Basin is identified as areas of potential development in the 2040 Land Use Plan. Therefore, 67.8% of the 1.37 inches was used as the average amount of infiltration due to green infrastructure in the South Shunga Basin for this analysis, which was 0.93 inches. Thus, 0.93 inches of runoff was removed from the front portion of the excess rainfall hyetograph for the future conditions with green infrastructure model. Figure 24 shows the water surface elevation decreases for the future conditions with green infrastructure model verses the future conditions model, which matches the Figure 23 image, future conditions verses base model, very closely.

Figure 24: WSE Decreases for Future Conditions with Green Infiltration Model Verses Future Conditions Model

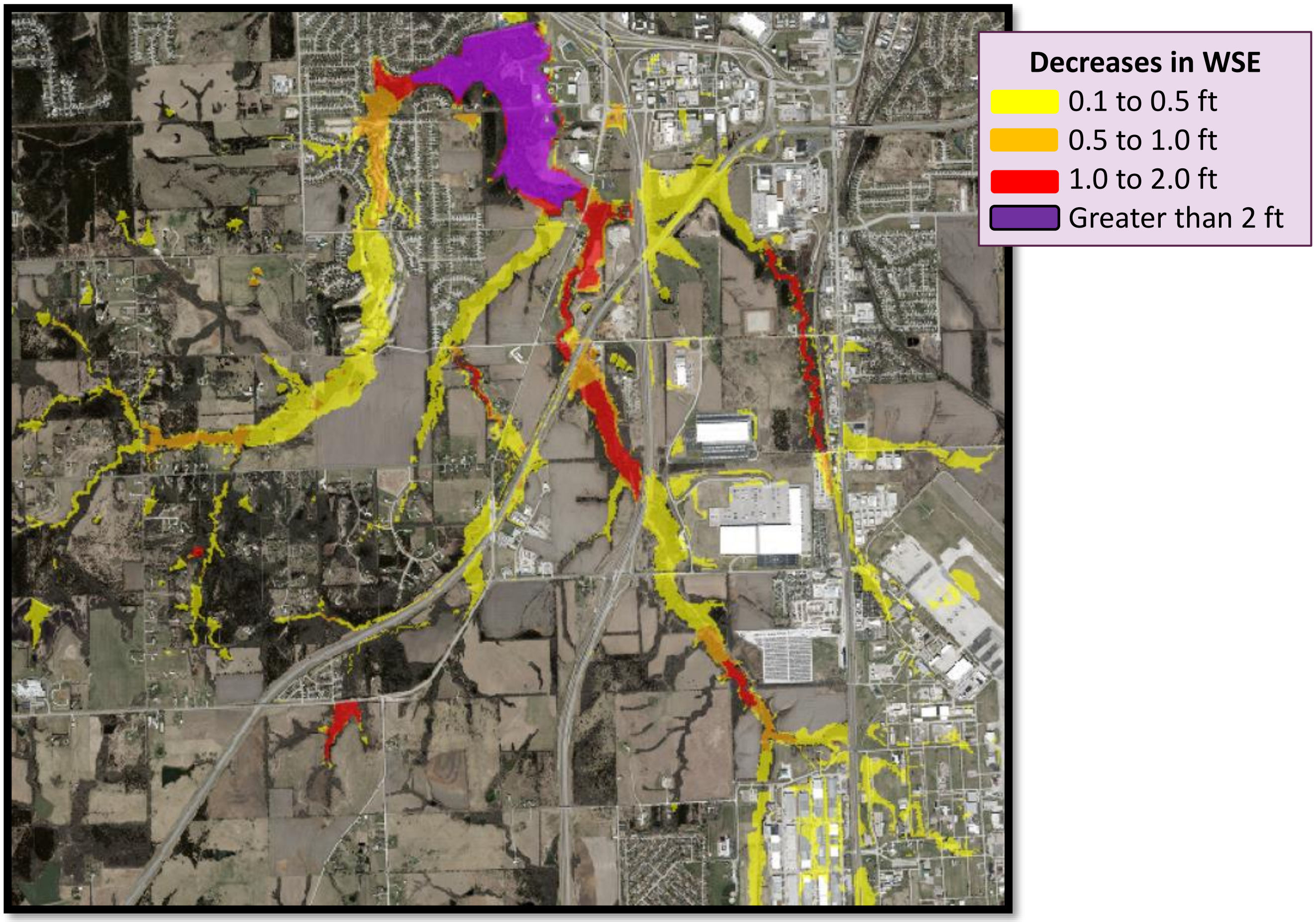
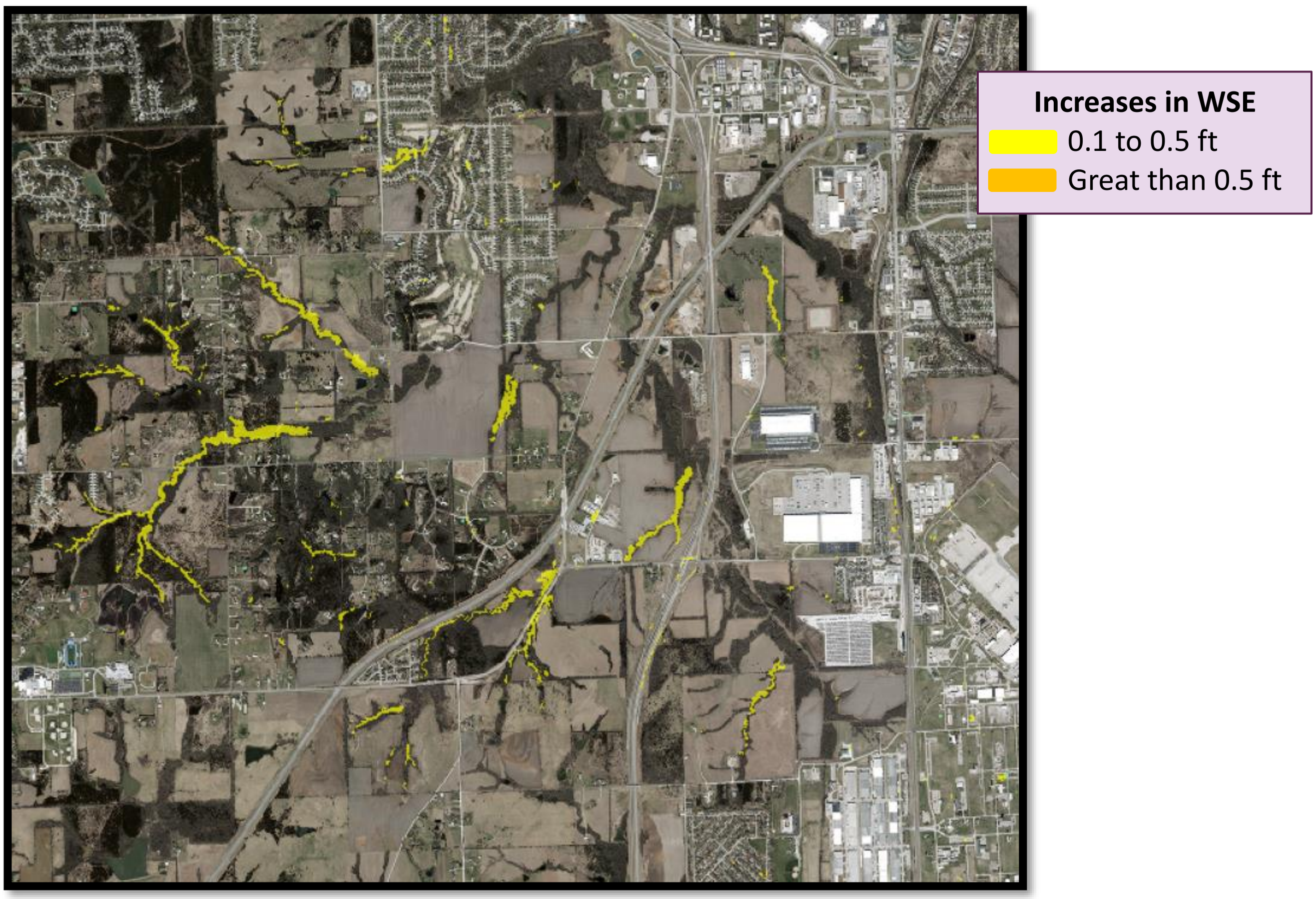


Figure 25 shows the water surface elevation increases for the future conditions with green infiltration model verses the base model, which shows very little increase in water surface elevations throughout the watershed. This analysis provides evidence for the benefits of volume control requirements. Volume controls, such as green infrastructure, can essentially negate the increases in water surface elevations due to future development, specifically for volume sensitive basins such as the South Shunga Basin. This analysis can be used as a tool for the City in promoting, encouraging, or requiring volume controls.

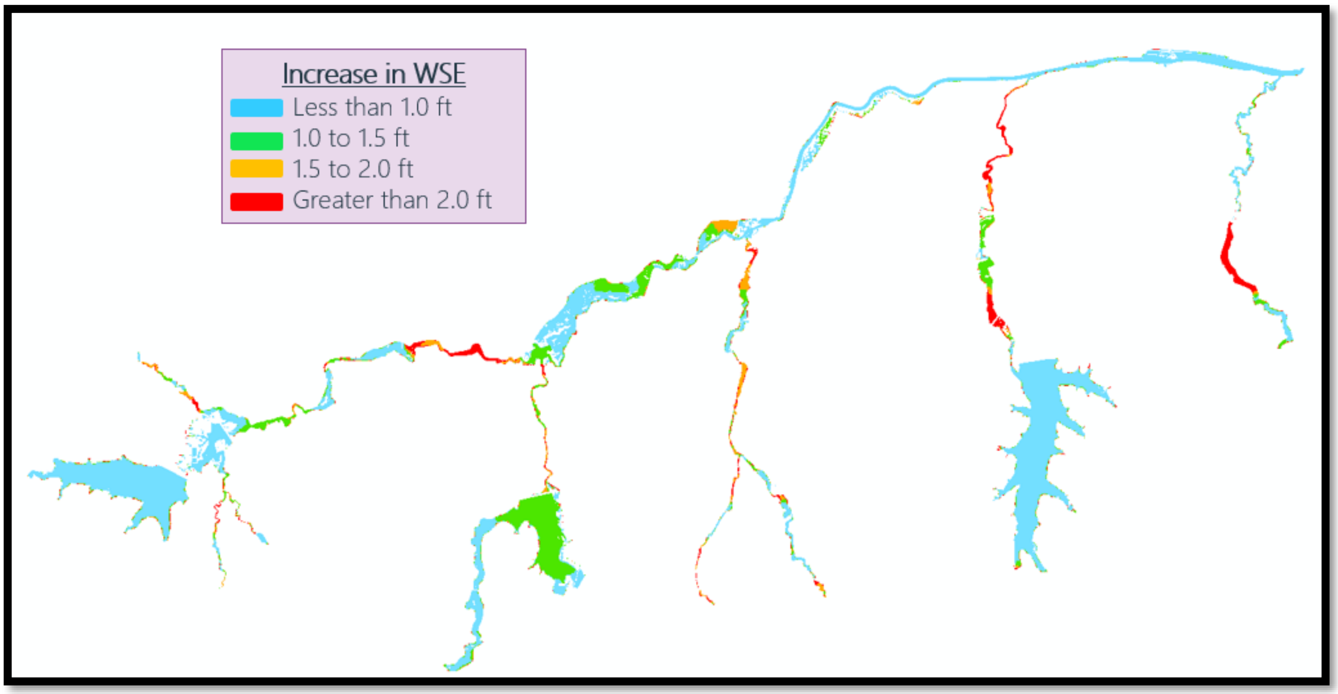
Figure 25: WSE Increases for Future Conditions with Green Infrastructure Model Verses Base Model



Compensatory Storage Analysis

To assist the City of Topeka in determining whether compensatory storage should be a requirement in floodway fringe areas, an analysis was conducted to evaluate the effects from allowing fill in floodway fringe areas. The Shunganunga Creek model was used for this analysis. In the State of Kansas, a regulatory floodway is the channel of a river or other watercourse and the adjacent land areas that is reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than 1.0 foot. For Zone AE designated areas, the modeling has been performed, so the floodway can be shown on the regulatory map. It was the belief for a long time that fill within the floodway fringe, or the areas in the floodplain outside of the floodway, would not create more than a 1.0 ft rise because the modeling indicated such. However, the traditional steady-state one-dimensional models used for most regulatory maps of the past did not account for storage in the floodplain when completing the calculations. When using unsteady-state models, both one-dimensional and two-dimensional, storage in the floodplain area is accounted for in the calculations. As a result, floodways developed using unsteady-state models are often larger than floodways developed using steady-state models. This indicates that the floodways developed using steady-state models are often underpredicting the rise in water surface elevations. To demonstrate the impact from loss of storage when filling in the steady-state 1D floodways, the terrain (ground surface data) was adjusted in the 2D model by filling in all floodway fringe areas (areas in floodplain, but outside of floodway) within the Zone AE designated areas of the Shunganunga Creek Basin. The 1% annual chance storm event was then modeled through the modified terrain. A comparison was then made between the water surface elevations from the model with floodway fringe fill verses the base model. Note that these comparisons were made in the floodway areas only. Figure 26 shows the water surface elevation increases for the model with floodway fringe fill verses the base model.

Figure 26: WSE Increase for Model with Floodway Fringe Fill Verses Base Model



As shown in Figure 26, the loss of storage in floodway fringe areas can have a significant impact on the rise of water surface elevations. While there is a general belief that filling in the floodway fringe will not cause more than a 1-foot rise in the water surface elevations, this is not true when the storage in those areas is also lost. There are many areas in Topeka that would experience a rise greater than 1.0 foot, and even greater than 2.0 feet, if the floodway fringe areas are filled and storage is not being compensated. Therefore, it is recommended that the City consider requiring compensatory storage in floodway fringe areas. This means that any fill in the floodway fringe would need to be offset by compensating cut, to ensure that the same amount of storage is available in the floodplain. Even further, it is recommended that the compensatory storage requirement be frequency/stage based. This means that the loss of storage volume below water surface elevations for small, medium, and large storm events (i.e., 2yr, 10yr, 25yr, 50yr, and 100yr events) be compensated by equal cut or removal of soil below those same corresponding elevations. This requirement would help ensure that structures impacted by flooding during a particular storm event do not experience worse flood conditions than they previously experienced for that same storm event. In other words, a structure's percent annual chance of flooding should not increase due to development. A compensatory storage requirement will minimize the impact that future development will have on base flood elevations throughout town.

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 basins studied, 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 four alternatives analysed provide valuable, science-based information for potentially modifying current stormwater criteria for the City of Topeka. The science-based stream buffer developed in this study provides a stream setback extent that more accurately reflects the areas along the stream channel and bank with risk potential, rather than a standard distance used for all streams of a certain type. It is still recommended that a minimum distance be used as the streamside buffer extent as a water quality corridor, but that the science-based stream buffer be used for the outer buffer extent. The use of this information will protect new development from experiencing issues in the future due to stream bank erosion.

The peak flow and volume sensitivity analysis provides justification for increasing peak flow control and volume control requirements throughout the City, based on the sensitivity that each basin experienced to the peak flow and total volume changes. It is recommended that all development in the basins located south of the Kansas River be required to install peak flow controls, with the exception of the downstream portions of the Stinson Creek Basin, the Deer Creek Basin, the South Kansas Basin, and the majority of the Oakland Basin. It is recommended that all development in the Martin Creek Basin, the lower portion of the Oakland Basin, which drains to the levee system, and the upper portion of the South Shunga Basin, which drains to South Branch dam, be required to install volume controls. These requirements will reduce the impact of new development on current water surface elevations.

The green infrastructure analysis provides model-backed justification for the importance of volume controls, such as green infrastructure and low impact development, for volume sensitive areas. Retention is a common form of volume controls for the City. However, other types of volume control are less common, except where water quality BMPs are required. The analysis performed provides evidence that infiltration measures can help offset the negative impacts that development can have on water surface elevations, showing the importance of green infrastructure and low impact development.

The compensatory storage analysis provides model-backed justification for the importance of maintaining available storage within floodplains. Construction within the floodway requires a no-rise analysis. However, construction within the floodway fringe is allowed. The analysis proves that construction within the floodway fringe can cause more than a 1-foot rise if storage is lost in the floodplain. It is recommended that the City require compensatory storage within the floodway fringe areas to ensure that available storage within the floodplain is being maintaining. It is also recommended that the compensatory storage requirement be frequency/stage based to ensure that development does not increase the percent annual chance of flooding for an impacted structure.

It is also recommended that the City utilize the 2D models developed as part of this project for other analyses and studies that could prove beneficial for the community. For instance, regional detention opportunities can be analysed. Other flood mitigation projects can be analysed. 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 they 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**
- **PowerPoint presentation from 3-28-19**

RAS Models

- **Basin A**
- **Basin B**

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**

Alternatives

- **Alternative 1- Stream Buffer**
  - **Current Buffer**
  - **Proposed Buffer**
- **Alternative 2- 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**
- **Alternative 3- Green Infrastructure**
  - **Hyetograph Spreadsheet**
  - **Future Conditions Shapefile**
  - **Water Surface Elevation Difference Grids for:**
    - **Future Conditions Minus Base Run**
    - **Future Conditions Minus Green Infrastructure Run**
    - **Green Infrastructure Run Minus Base Run**
- **Alternative 4- Compensatory Storage**
  - **Water Surface Elevation Difference Grid in Floodway Area**