Douglas County Wakarusa Corridor Assessment

Prepared for:

Kansas Department of Agriculture -
Division of Water Resources
Douglas County, Kansas

Prepared by:

Chris Shultz, PE, CFM:
cshultz@jeo.com
785.806.9733

Jacob Fuchs, EIT:
jfuchs@jeo.com
913.243.0035

Reviewed by:

John Callen, PE$^{(NE)}$, CFM
Ann Nissen, PE$^{(NE)}$

JEO Consulting Group, Inc.
2033 Becker Dr. Suite 201
Lawrence, KS 66047
785.330.5666

Offices in Nebraska, Iowa, South Dakota, and Kansas

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1.0 BACKGROUND AND EVALUATION PURPOSE

The Wakarusa River corridor generally consists of undeveloped floodplain and agricultural land with scattered rural residential development. With continued urbanization and development pressure along the southern boundary of Lawrence approaching K-10 highway and the Wakarusa River valley, Douglas County desired to perform a hydrologic and hydraulic flood risk assessment to gain a better understanding of the effects of existing development and potential impacts from future development decisions. The overall goal is to reduce flood risk and increase resilience to future flood events, through informed long-range planning and policy discussions rather than site specific decisions or regulatory enforcement. The assessment covers the Wakarusa River corridor between the outlet works of Clinton Lake to the confluence with the Kansas River at Eudora and was completed in coordination with Biohabitats, who are reviewing other important pieces related to the stream reach ecosystem in the evaluation of land conservation within the corridor. The Technical Assistance project was approved, and FEMA provided funding to KDA through the Cooperating Technical Partner grant EMK-2024-CA-05001.

As part of the assessment, JEO leveraged existing flood risk modeling and refined the current available models, considering both natural flow events (10-year, 25-year, and 100-year) alongside Clinton Lake flood control releases based on the Clinton Lake Water Control Manual. Coincident timing of flow sources or impacts of sequential rain events can cause unforeseen impact areas. For more frequent flood events such as the 10-year storm this consideration can be more notable due to the magnitude of uncontrolled runoff flows compared with Clinton Lake releases. The evaluation also included a review existing of conditions flood risk and the flood risks associated with both changes in the watershed and model uncertainty including potential development changes and precipitation variability. This full suite of model simulations, including variants of natural flow, Clinton Lake releases, and watershed conditions allowed for a comprehensive understanding of flood risk variability throughout the watershed area.

This assessment utilized draft floodplain models provided by the Kansas Department of Agriculture Division of Water Resources (KDA-DWR) delivered in November 2024 (except 22A which was delivered July 2025), with the finalized model versions planned to be used for changes to the regulatory flood maps for Douglas County. The primary outcome of the assessment is hazard classification maps for the simulated storm events showing the relative risk considering metrics such as flood depth and velocity. Also included is a review of roadway overtopping during the simulated July/August 2019 storm event. The results provide a more detailed understanding of flood risk impact areas within the Wakarusa River corridor with the aim of providing a resource that the County can leverage within their planning and decision-making process to reduce the risk of flood damages for future development. Alongside this report, a web map was also developed to allow users to rapidly review flood risk assessment results and locate specific areas.

2.0 FLOOD RISK DATA REVIEW

To support flood risk assessment and set mitigation action priorities, JEO worked collaboratively with the KDA-DWR floodplain group and Douglas County to aggregate and review background information and resources which were incorporated into the floodplain modeling. Data and information provided include: flooding/damage photos and background information for the July 31st to August 1st, 2019 flood event that occurred on the Wakarusa River and tributaries, drainage information from the ongoing K-10 widening project, draft floodplain modeling dated November 2024/July 2025 utilized during the modeling effort, information on draft floodplain/floodway map updates which are being developed in a concurrent effort, and stream velocity/erosion hotspots along the Wakarusa River.

Below is an overall background of the primary datasets utilized during the effort. In later sections, more detail is provided on the data incorporated into the flood risk assessment modeling.

2.1 FLOOD RISK MODEL REVIEW

As part of the project, JEO leveraged the draft corridor flood risk models provided by KDA-DWR for the assessment. Based on discussions during the scoping phase of the project, the models utilized were those delivered in November 2024/July 2025, which at the time of delivery had not undergone the Independent Technical Review process. The models leveraged in the project are shown in Table 1 and Figure 1. Delivered models were provided in HEC-RAS version 6.3.1; this version was utilized throughout JEO's assessment to avoid any incidental changes or errors in model results. The models provided are 2-Dimensional rain-on-mesh models covering the entire extent of the Wakarusa River watershed. Concurrent to the JEO assessment, KDA-DWR continued finalization of the models, with their planned use as the basis for regulatory floodplain map products. This assessment involved limited model review and updates beyond what is described below, with the models generally used as delivered. During the course of the analysis, JEO discovered missing culvert barrels in delivered 23A model. These are likely not significant in the scope of this effort, however, in future site-specific planning, these culverts should be included in order to review localized impacts at the affected crossings.

Risk assessment analysis was limited to the Wakarusa Corridor, from Clinton Lake to Eudora, and its tributaries; other adjacent models were requested during the project and were utilized to provide more refined downstream boundaries conditions for the 2019 simulation.

Model Name	Basin	Model Use
22A	Captain Creek	2019 Simulation
22B	Coal Creek	Hazard Review, 2019 Simulation
22C	Little Wakarusa Creek	Hazard Review, 2019 Simulation
23A	Wakarusa River from Clinton Lake to Kansas River	Hazard Review, 2019 Simulation
23B	Washington Creek	Hazard Review, 2019 Simulation

Table 1: Models Leveraged in the Project

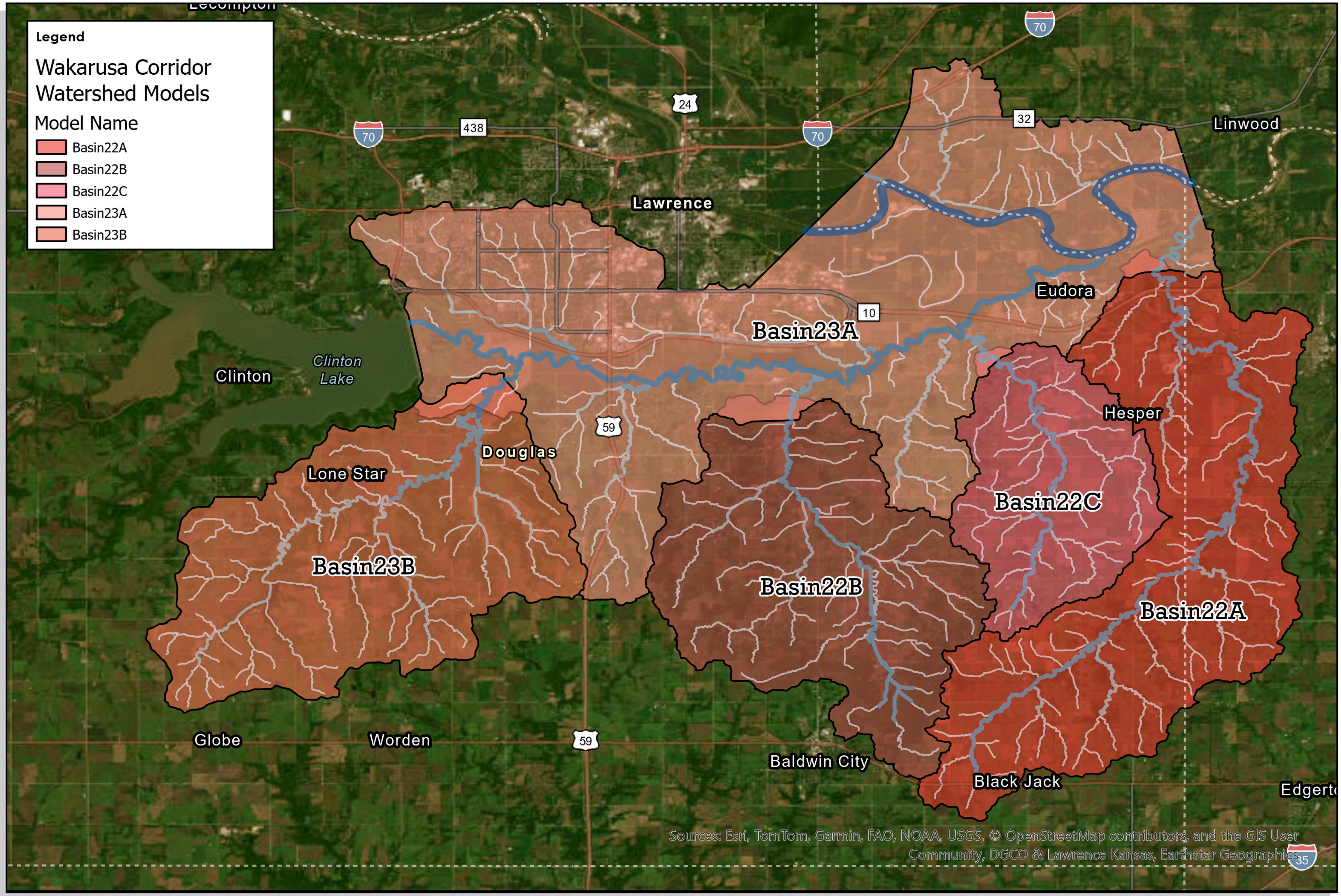

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Figure 1: Wakarusa Corridor Watersheds

Douglas County, KS

0 2.5 5 Miles

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2.2 PRECIPITATION DATA REVIEW

A review of sensitivity to precipitation variability was conducted as part of this assessment. The goal of the review was to better understand flood risk and hazard areas using both the best estimate of precipitation depth using NOAA Atlas 14 as well as a more conservative precipitation depth based on the NOAA Atlas 14 upper bounds 90% confidence interval (later referred to as Atlas 14 upper bounds). In a previous KDA-DWR Technical Assistance study *Watershed Mitigation Solutions Identification*, a climate projection was utilized in the review of the Washington Creek tributary to the Wakarusa River. A tabular comparison of NOAA Atlas 14 precipitation depths alongside a climate projection used in the previous assessment for Washington Creek is shown in Table 2. Atlas 14 upper bounds were utilized for the fully developed land use scenario (see Section 3.3 for details on this scenario) as it provides a more conservative estimate of precipitation and model hazard, providing a baseline for increased resiliency for future development when utilized for planning purposes.

	Precipitation (Inches)		
	10-Year	**25-Year**	**100-Year**
NOAA Atlas 14 *Base Estimate*	5.17	6.26	8.05
NOAA Atlas 14 *Upper Bounds 90% Confidence*	6.18	7.67	10.00
Climate Projection *Used in Past Washington Creek Study*	5.52	6.74	8.73

Table 2: Precipitation Scenario Comparison

2.3 CLINTON LAKE DAM OPERATIONS

The U.S. Army Corps of Engineers (USACE) regulates flows in the Wakarusa River based on the Clinton Lake Water Control Manual. During times of elevated natural flows, the USACE stores flood water in Clinton Lake. Flood control storage and releases (above the normal pool elevation of 875.5 feet NGVD 1929) are managed by phase based on the lake elevation. Releases are limited based on maximum flows at downstream target locations such as the Wakarusa River at the US-59 highway crossing and the Kansas River at De Soto. Clinton Lake release phases are described below based on the flow targets at the Wakarusa River at the US-59 highway crossing:

- No Release: no releases from Clinton Lake.
- Phase 1 Release: Clinton Lake release of 2,800 cubic feet per second (cfs).
- Phase 2 Release: Clinton Lake release of 4,000 cfs.
- Phase 3 Release: Clinton Lake release of 7,000 cfs.

For the development of the July/August 2019 flood model simulation, historical Clinton Lake releases were requested and received from the Kansas Water Office for incorporation into the model simulation. During this storm event, Clinton Lake releases included the Phase 1 flows of approximately 2,800 cfs on July 25th, 2019 which were ongoing until the natural flow event which began in the overnight hours of July 31st/August 1st, 2019. Once natural flows reached the Wakarusa River at US-59 highway crossing, releases from Clinton Lake were reduced. The flow hydrograph is shown below in Figure 2.

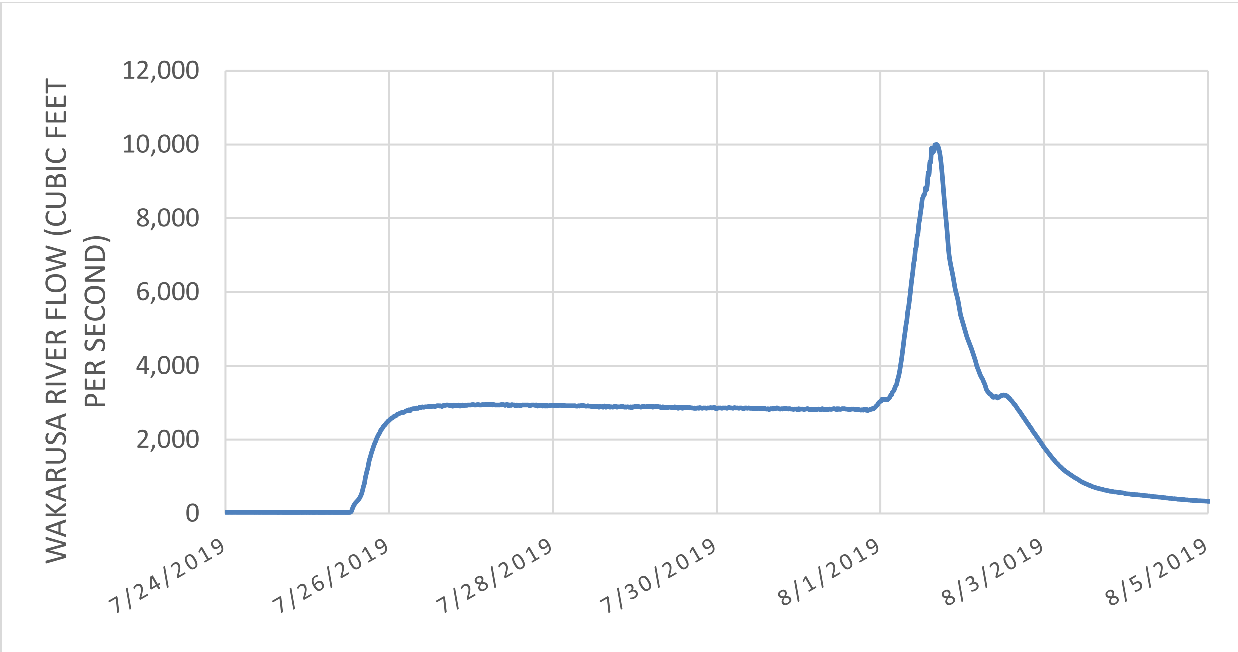

Figure 2: July/August 2019 Event Hydrograph

2.4 2019 Flood Event Input Data

The scope of the project included a roadway overtopping analysis for the July/August 2019 storm event, which occurred in the Wakarusa River corridor and its tributaries. In the development of the 2019 model simulation, several datasets were utilized. Multi-Radar/Multi-Sensor (MRMS) 1.0-kilometer hourly precipitation data was incorporated into the model as an event condition for the period of July 31st, 2019 to August 7th, 2019. MRMS is an advanced historical precipitation dataset which uses multiple radars and detection systems to develop quantitative precipitation estimates alongside other risk products. This dataset was incorporated into the models alongside historical data related to Clinton Lake releases mentioned above. Additionally, a review of Soil Moisture Active Passive (SMAP) soil moisture data was conducted to confirm the antecedent moisture conditions preceding the storm compared to the default normal condition that is typically assumed in developing the infiltration curve numbers in the models.

2.5 Coordination with Biohabitats

A key component of this assessment was coordination with Biohabitats, who were performing an extended Wakarusa River corridor planning effort with Douglas County during the JEO flood risk assessment (this study). As part of the project, there were several coordination discussions to review preliminary results and determine how the results of the two studies would best fit together. Results from the JEO flood risk assessment were provided to Biohabitats for their incorporation into the broader Wakarusa Vision Plan.

3.0 FLOOD RISK ASSESSMENT

As discussed in the previous section, the draft Wakarusa River watershed flood risk models provided by KDA-DWR were refined based on various input data to create model scenarios for the purposes of additional flood risk assessment. For the open space conservation assessment, two core scenarios were developed: existing conditions (including the ongoing work on K-10 highway) and fully developed conditions which includes the incorporation of future land use alongside the Altas 14 upper bound precipitation depths. The aim of incorporating these separate events was to reflect current conditions alongside a more conservative estimation of risk so as not to confine the understanding of flood risk/hazard areas to existing conditions.

As part of the assessment, JEO focused efforts on the 10-year, 25-year, and 100-year model runs, with limited runs on the 500-year event. This range of smaller but more frequent events with larger but less frequent events was selected to provide an understanding of overall flood risk along with information about flooding frequency, depth, and velocity.

Another important consideration for flood risk for conservation areas is a review of both natural and regulated flows. The flood risk assessment included the evaluation of both natural flows along with Clinton Lake release phases and their potential coincidence, which occurred in both the July/August 2019 storm event. The assessment also included an evaluation of roadway overtopping risk using input data used to simulate the hydraulic conditions which led to the widespread flooding that occurred in July/August 2019.

3.1 PRECIPITATION MODELING

Model simulations were reviewed and developed for the 10-year, 25-year, 100-year, and 500-year storm events. As described above, the two primary precipitation scenarios are existing conditions and fully developed conditions which utilizes the Atlas 14 upper bounds precipitation value. The existing conditions simulation utilized the precipitation values which were provided in the draft flood risk models. Precipitation for the fully developed conditions utilized the same precipitation distribution (relative percentage) as existing conditions, with the larger precipitation depth based on the Atlas 14 upper bounds precipitation value.

3.2 CLINTON LAKE DAM OPERATIONS

Clinton Lake releases are governed by reservoir operating phases based on the lake elevation with releases allowed based on maximum flows at downstream target locations such as the Wakarusa River at the US-59 highway crossing.

For each precipitation event simulation, all coincident Clinton Lake release cases were also created. The exception to this is the 500-year event which was used for producing the max extent of flooding so Clinton Phase 3 release was the only coincident flow. Clinton Lake release scenarios are described below:

- No Release: no releases from Clinton Lake.
- Phase 1 Release: Clinton Lake release of 2,800 cfs.

- Phase 2 Release: Clinton Lake release of 4,000 cfs.
- Phase 3 Release: Clinton Lake release of 7,000 cfs.

Releases from Clinton Lake are dictated by natural flows on the Wakarusa River at Lawrence, on the Kansas River at De Soto, and the Missouri River at Kansas City and Waverly, Missouri. By utilizing the flow targets for the Wakarusa River at the US-59 highway crossing as the Clinton Lake releases, the assessment uses the conservative assumption of limited natural flow within the Wakarusa River and no flow constraints further downstream. This scenario is generally what occurred preceding the July/August 2019 flood event on the Wakarusa River.

Phase 1, 2, and 3 releases were also simulated without rainfall, and those results were used as the starting state of the model for the corresponding existing and fully developed scenarios. Coincident occurrence of Clinton Lake releases and natural flows is generally representative of real-world conditions, since a stored flood event can take weeks or months to release out of Clinton Lake based on the downstream flow targets. In those conditions, flows/stages will likely reach a steady-state condition similar to what is assumed during the model simulation. The release cutoff timing was adjusted to be realistic with regards to downstream flow targets and the Water Control Manual.

3.3 Growth and Development Modeling

3.3.1 K-10 CLOMR

JEO received proposed channel grading for KDOT's K-10 widening project. As part of the plans for the K-10 improvement, south of W 27th St., Yankee Tank Creek will be realigned, and an overflow channel will be added. The terrain and Manning's "n" values were updated in existing and fully developed scenarios to reflect the proposed changes. Figure 3 shows the geometry updates which were included in the model.

3.3.2 Plan 2040

The best available potential development data was collected and reviewed. Douglas County and the City of Lawrence *Plan 2040* Comprehensive Plan Urban Growth Area boundaries, including accompanying GIS layers, were utilized for projected future growth areas in this project, which is shown in Figure 4. Tier 1 (blue) is already developed and within city limits. Tier 2 (green) is outside city limits but readily serviceable by utilities. Tier 3 (light brown) is beyond the 2040 horizon, needs utility and municipal service enhancement, but is identified for future growth.

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Figure 3: Yankee Tank Creek Updates

Douglas County, KS

0 500 1,000 1,500 Feet

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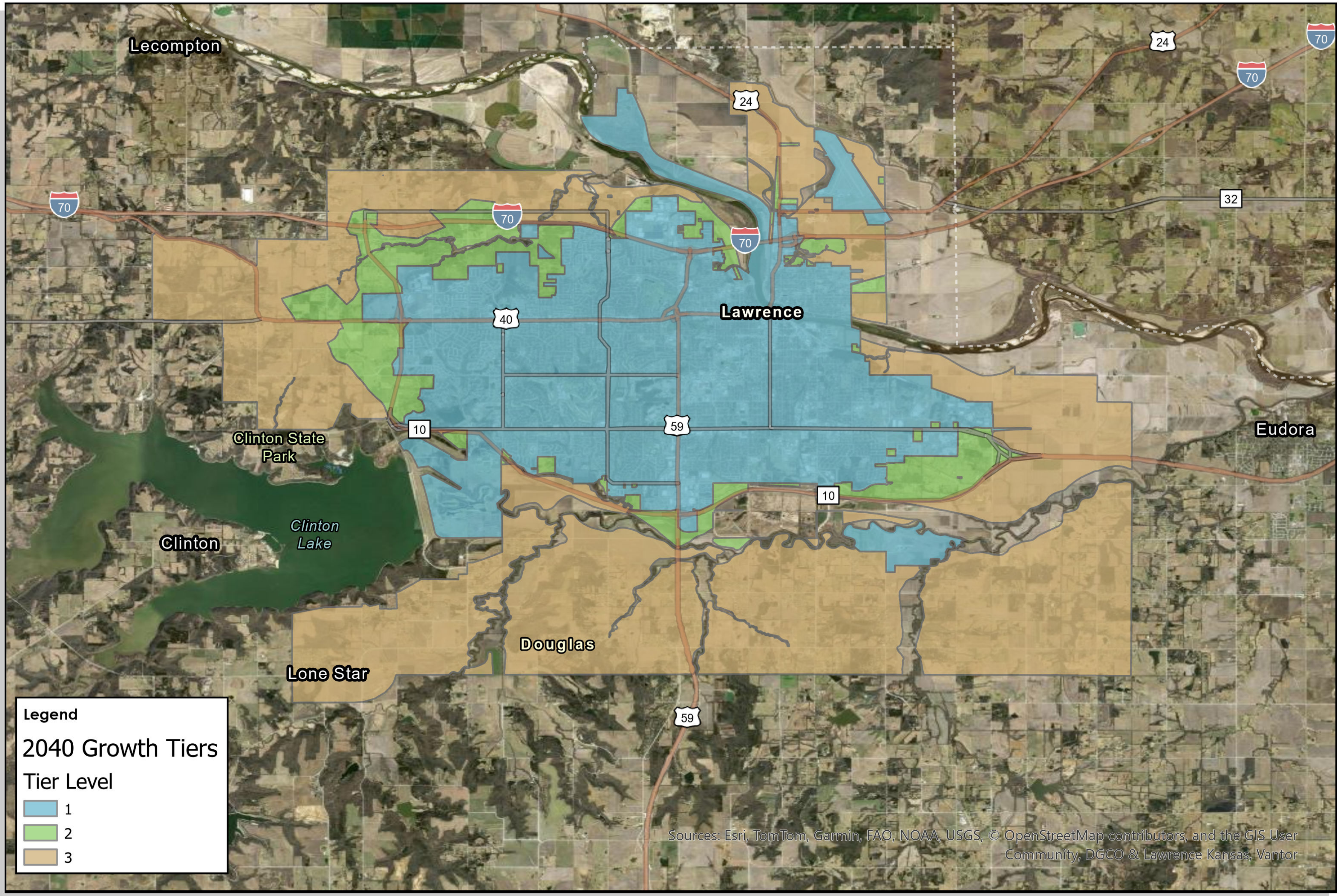

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Figure 4: Plan 2040 Growth and Development

Douglas County, KS

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Historical growth patterns in Lawrence were evaluated to understand and represent potential future growth in the open space of the watershed. Geographic areas were selected to represent historical types of growth around Lawrence as shown in Figure 5 and Figure 6.

- Area 1 represents a more dense corridor of development with a greater portion being commercial. It is approximately bounded by K-10 on the west, Rock Chalk Dr and W Peterson Rd on the north, Kasold Dr on the east, and US-40/6th St on the south.
- Area 2 represents mid-density, primarily residential development with ponds and greenspace preserved. It is bounded by K-10 on the south and west, US-40/6th St on the north, and Wakarusa Dr on the east.
- Area 3 is the lowest density due to proximity to the Wakarusa floodplain. A larger portion of it is undeveloped. It is bounded by Wakarusa Dr on the west, W Clinton Pkwy on the north, Kasold Dr on the east, and K-10 on the south.

Land cover data within the model was updated to provide a simplified representation of the infiltration and land cover roughness changes associated with development. These changes involved updates to the spatially varying Manning's roughness coefficients and curve numbers (CN) in the model. Manning's roughness coefficient, or n-value, is a parameter used in hydraulic models to represent flow resistance and is typically correlated with land cover such as the National Land Cover Database (NLCD). The CN is a composite value that incorporates antecedent moisture condition, soil type, and land cover to represent the balance precipitation infiltration and runoff.

These two variables were adjusted in the fully developed condition using the NLCD data layers from 1985 to 2023. Manning's roughness values were increased based on the average change calculated in the representative areas from 1985 to 2023. The CN of the representative areas was averaged and weighted for percentage of each soil type. The 1985 to 2023 increase was calculated and added to the weighted average for a blanket value applied to the fully developed areas.

Using the three historical development areas as templates for growth types, assumptions of similar growth patterns were applied to *Plan 2040's* Tier 2 and 3 growth areas. Figure 7 shows the extents of the applied development changes, with red and pink showing areas of increased development. Where available, planned development information was incorporated into the dataset to represent anticipated future growth. In other areas, historical growth areas were applied to future growth areas based on their proximity to the Wakarusa River and major roadways. Area 1 was applied to the corridor around US-59 and N 1100 Rd, Area 3 to the Wakarusa River corridor, and Area 2 to all remaining areas.

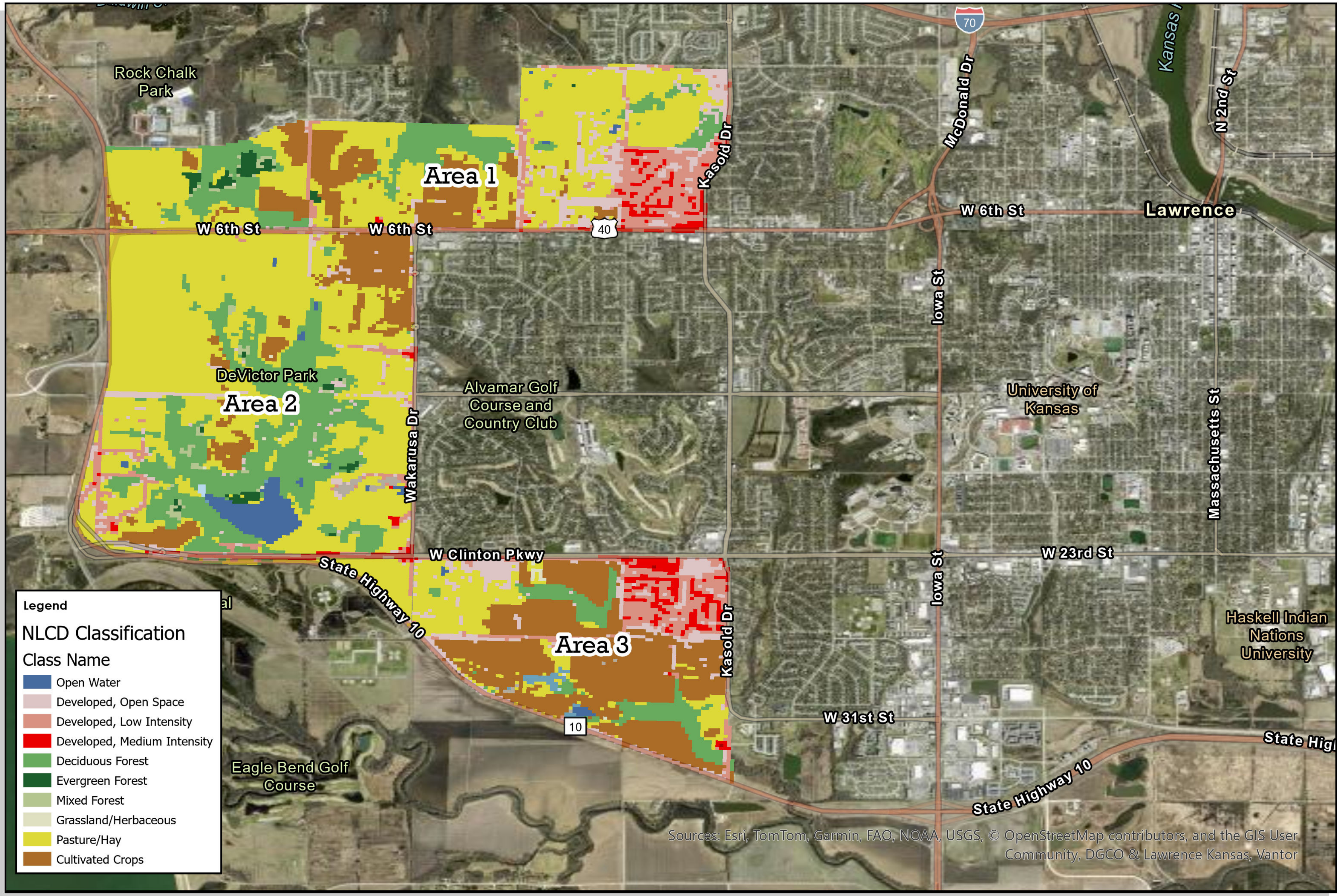

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Figure 5: Representative Growth Areas 1985

Douglas County, KS

0 0.5 1 Miles

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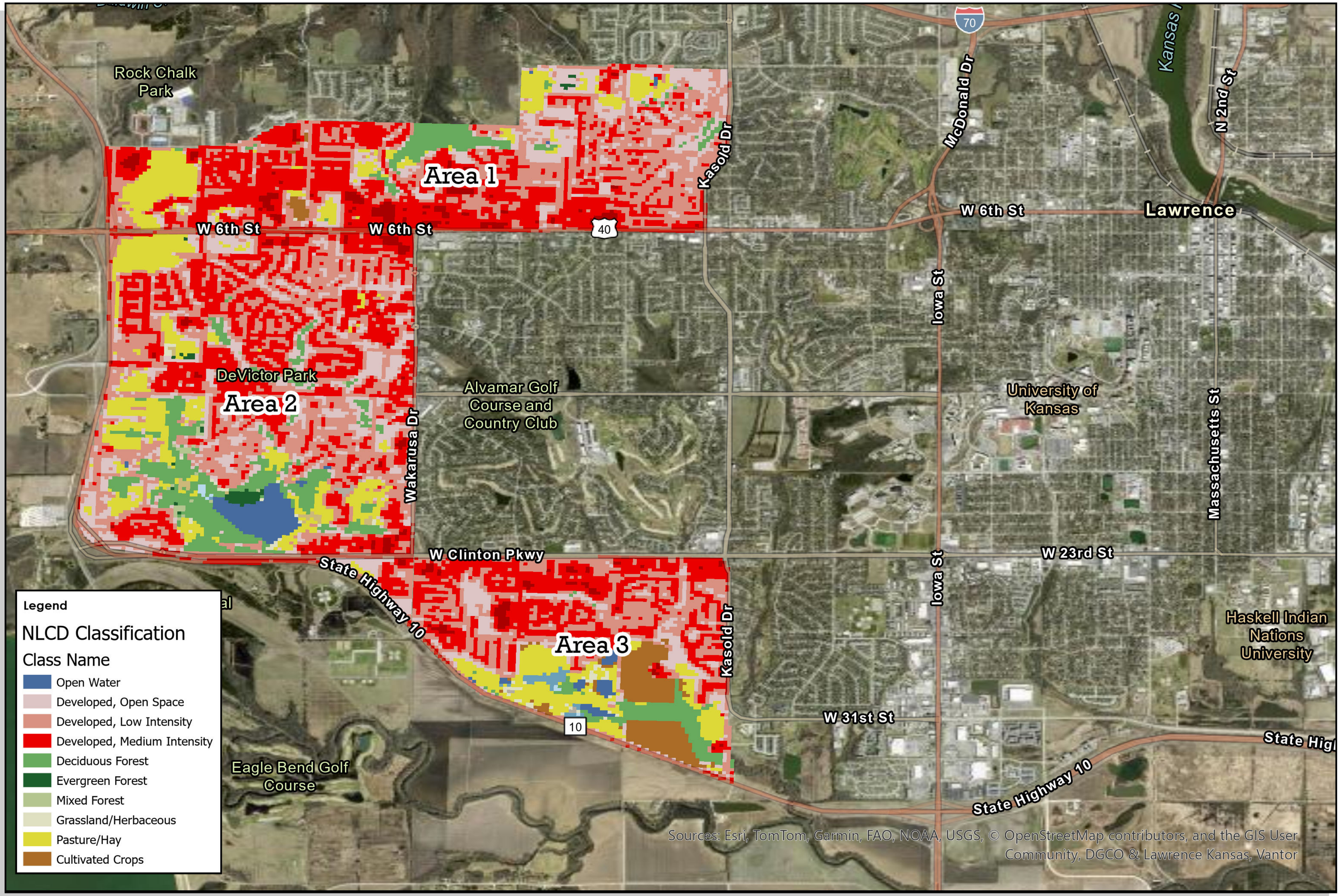

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Figure 6: Representative Growth Areas 2023

Douglas County, KS

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3.4 2019 FLOOD EVENT MODELING

For the development of the July/August 2019 model scenario, various datasets were retrieved as described in Section 2 of this report. Retrieved MRMS data was loaded into HEC-RAS as gridded precipitation. This enables the HEC-RAS model to simulate real historical precipitation data using the previously developed model geometry. All model basins were simulated using the MRMS data, with the exception of the Kansas River model, which was handled with real-time recorded gage data (Kansas River at Lawrence, KS – USGS 06891080) at the boundary condition.

Alongside precipitation data, several other datasets were reviewed and/or utilized in developing the 2019 storm model simulation. Clinton Lake releases based on the historical record provided by the Kansas Water Office were also leveraged in the model simulation. The daily releases provided were divided into hourly releases based on the assumption that single gate changes occurred to increase or reduce releases. Additionally, SMAP soil moisture data was reviewed to understand the initial conditions of the soil prior to the storm event (due to the potential effects on runoff).

Once the 2019 model simulation was developed and run, results were reviewed and compared to observations. Two observation datasets were available: 1) Wakarusa River near Lawrence, Kansas – USGS 06891500, which is the USGS stream gage at US-59 highway south of Lawrence, and 2) several photos and videos captured during and after the 2019 storm event which show inundation impacts, highwater marks, and flood damage areas.

Generally, the model performed well at matching inundation impacts observed during the 2019 flood event. Figure 8 shows a comparison of the simulated versus observed stage at the USGS stream gage at US-59 south of Lawrence. The figure shows a fairly similar match to the peak water surface elevation and timing at the gage when comparing the two. Additionally, a Python programming script was utilized to retrieve photo location and date/time stamp metadata and develop a shapefile which contains the links to photos within GIS, allowing for a simple one-to-one comparison of simulation results versus observed impacts. Figure 9 shows an example comparison of a photo location to the model output. In many locations, model output inundation matched the images very well including in Figure 9.

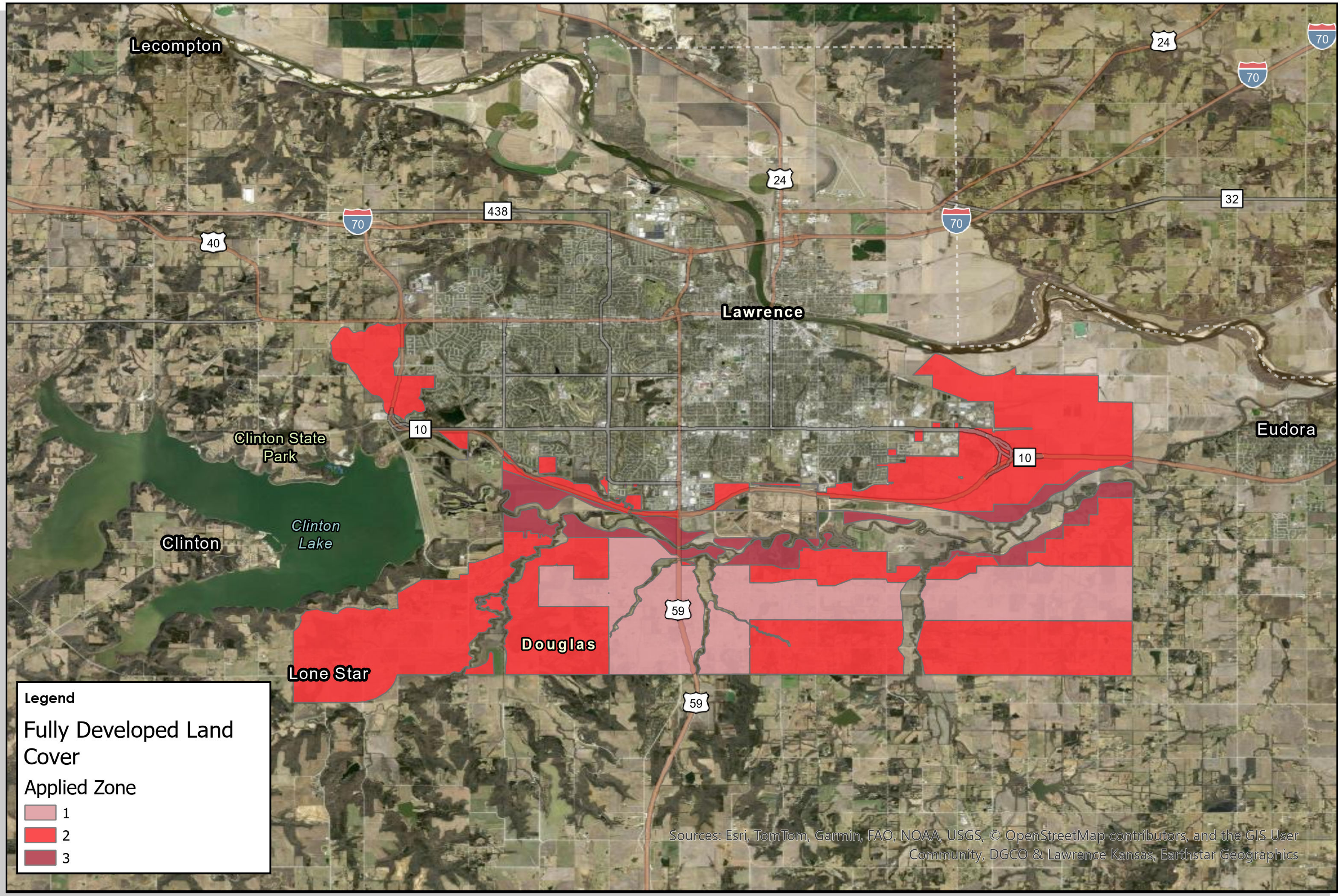

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Figure 7: Fully Developed Land Cover Area

Douglas County, KS

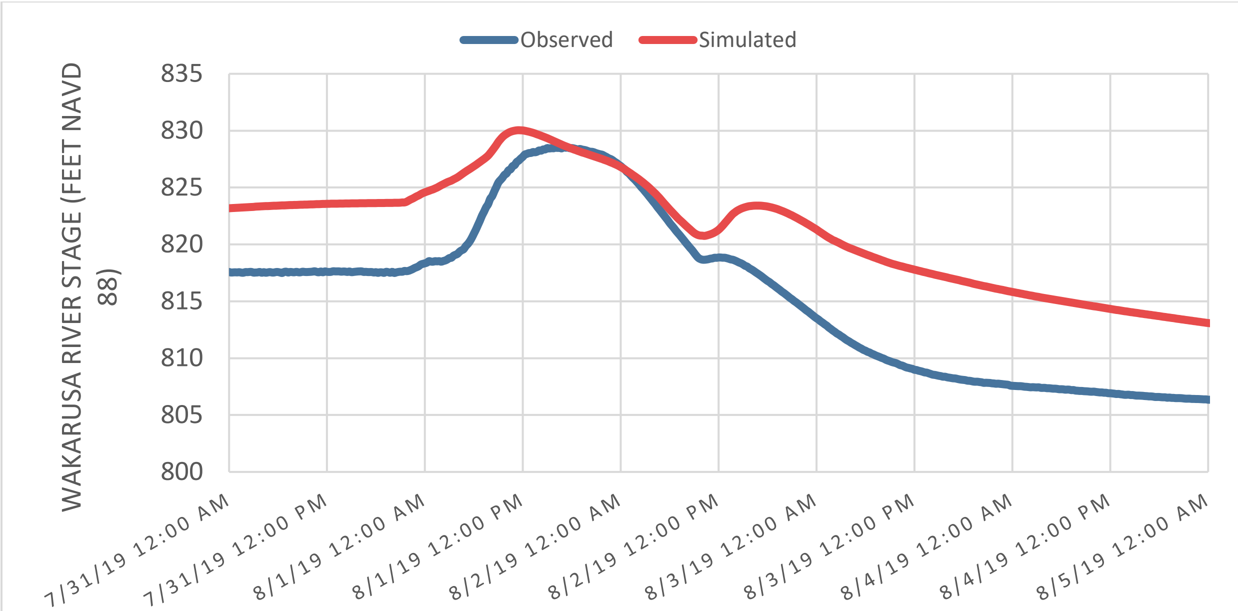

Figure 8: Wakarusa River near Lawrence, Kansas – Comparison of Simulated and Observed Flows

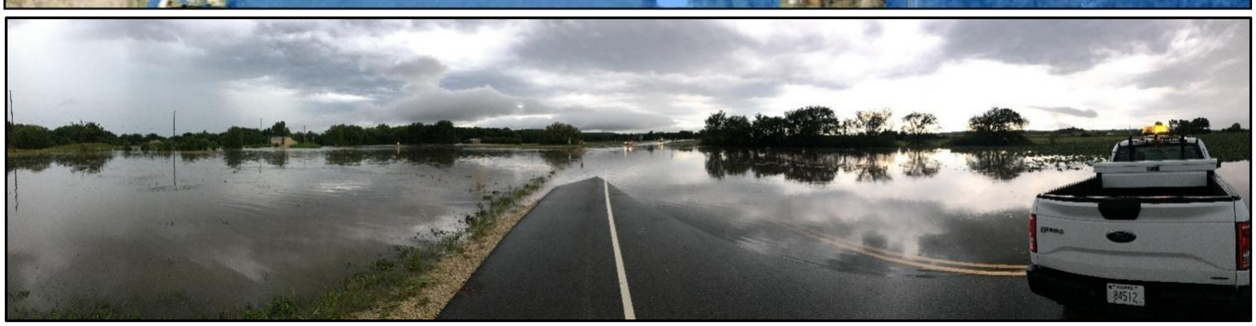

Figure 9: Example 2019 Inundation Photo Comparison

4.0 FLOOD RISK ASSESSMENT FINDINGS

Once model simulations were completed and reviewed, depth, velocity, and depth times velocity grids were extracted from the models for use in the assessment findings review. To focus results on Wakarusa River corridor flooding, model outputs were clipped to remove urban tributary flood risk extents. The urban tributary extents of the raw outputs may overstate flooding for those tributaries due to lack of inclusion of storm drain system geometry. A clipping layer was developed based on the water surface elevation within the Wakarusa River during 500-year simulation results; this layer was leveraged to generally remove tributary impacts from the finalized results. Table 4 in Appendix A shows finalized HEC-RAS plans.

4.1 FLOOD HAZARD CLASSIFICATION

As part of the open space assessment, flood hazard impact layers were created to visualize and better communicate descriptive characteristics of flood hazard risk during the simulated floods. To do this, FEMA's Flood Severity Raster method (FEMA, 2024) was utilized. It uses depth, velocity, and depth times velocity to categorize areas of "Low, Medium, High, Very High, and Extreme Hazard" to "humans, vehicles, and buildings". Figure 10 below shows the classifications used within this approach.

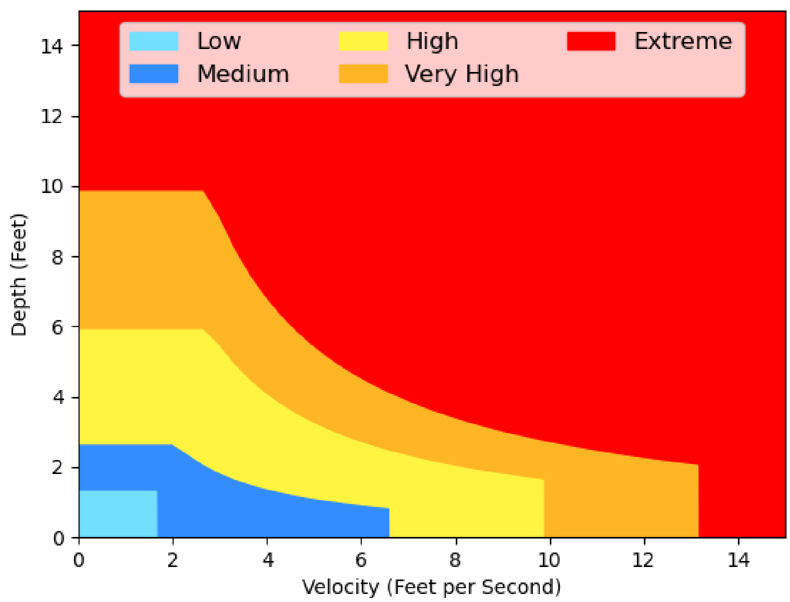

Figure 10: FEMA Hazard Classifications (FEMA, 2024)

The purpose of this approach is to better quantify and classify high risk areas within the Wakarusa River corridor. A hazard classification layer was calculated for every model plan created. Results are shown for the 100-year fully developed conditions under the Phase 1 Release Clinton Lake release scenario in Figure 11. As described in the next section, further results are shown in the web map which was developed for the project.

4.2 WEB MAP

As part of the results presentation, JEO developed a web map to more easily view and compare model outputs. An ArcGIS Online Web Map was created for viewing depth, velocity, and hazard classification layers for all processed Wakarusa corridor existing and fully developed results.

4.3 QUANTIFICATION OF ECOSYSTEM SERVICES BENEFITS

To enable the quantification of the potential open space conservation benefits, the assessment team utilized benefit valuations from the *FEMA Ecosystem Service Value Updates* report (FEMA, 2022). Conserved land use values from the report are summarized in Table 3 below which can be utilized to quantify the benefits provided from non-agricultural open space within the corridor. These benefit values can be used on a site by site basis alongside a land cover dataset to determine the existing benefit/value of open space.

Land Cover Category	Benefit (2021 $/acre/year)
Forest	$12,589
Urban Green Open Space	$15,541
Rural Green Open Space	$10,632
Riparian	$37,199

Table 3: Value of Conserved Land by Category from *FEMA Ecosystem Service Value Updates*

4.4 2019 OVERTOPPING ANALYSIS

An analysis of roadway overtopping during the simulated 2019 event was also completed as part of this assessment. Stream crossings were generated from the intersection of a road centerlines shapefile provided by Douglas County and mapped streamlines provided by KDA-DWR. The intention was to validate the model using actual flood conditions and to indicate general patterns of concern for large flood events. These intersection points were given a buffer judged large enough to capture the maximum elevation of the roadway embankment from LiDAR and compare it to the maximum water surface elevation (WSE) produced by the simulation. If model WSE was greater than roadway embankment elevation, the intersection was classified as overtopped. A thorough review of results was conducted to ensure that low elevations such as sags next to bridges were included in the roadway overtopping assessment. In addition, flows at each crossing were recorded from the HEC-RAS model and added to the intersection attribute table. Flows recorded represent the local flows at the hydraulic structures rather than entire riverine inundation area due to complex flow patterns that occur during highwater which created overflow paths between streams and tributaries in some cases, making it difficult to differentiate between the flow sources. See Table 5 in Appendix B for a full list of crossings.

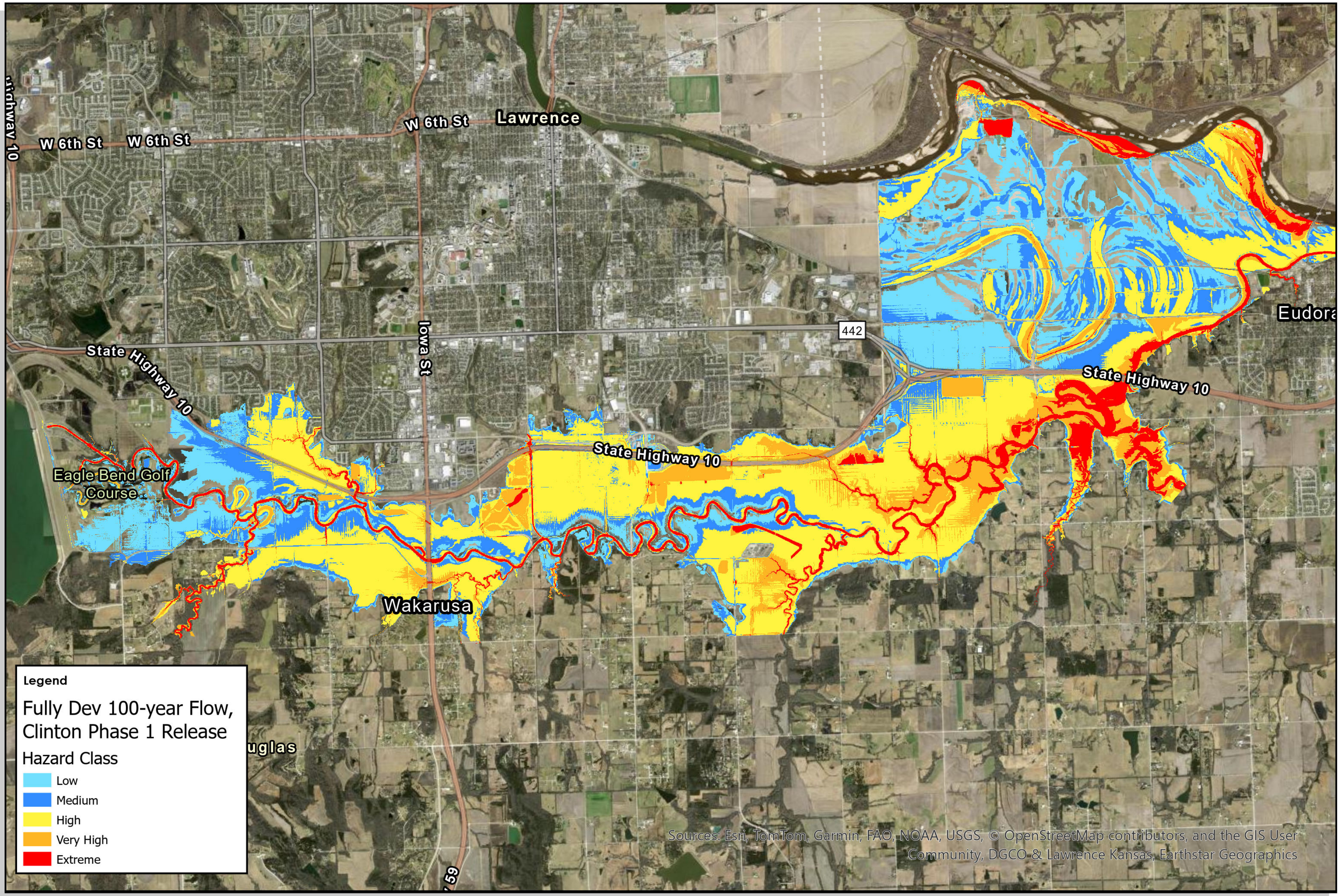

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Figure 11: Fully Developed 100-year Precipitation, Clinton Phase 1 Release

Douglas County, KS

0 1 2 Miles

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Figure 12 shows a summary map of the roadway overtopping assessment results based on the developed model simulation. When a sag in the roadway caused overtopping near (within 500 feet) the crossing overtopping locations are shown in red, other locations where roadway overtopping occurs further than 500 feet from the crossing the location are marked in yellow. As mentioned above, urban stormwater flood impacts may be overstated due to the limitations of the model. During a review of results, it was discovered that the delivered 23A model (mainstem Wakarusa River) lacked culvert barrels on a number of crossings associated with small tributaries. These crossings were omitted from the final results.

4.5 FLOOD RISK SUMMARY

Following the flood hazard and 2019 flood analysis, finalized flood risk maps were developed for the 10-year, 25-year, and 100-year storm events to show areas of high and frequent flood risk. These maps were developed collaboratively with Douglas County to summarize model output datasets for future planning. Figure 13, Figure 14, and Figure 15 show results for the 10-year, 25-year, and 100-year events, respectively. These maps show high hazard areas (high, very high, or extreme hazard classifications) for the respective storm events for existing and fully developed model simulations, with small ponding areas of less than an acre removed. Figure 16 shows the same 100-year results shown in Figure 15 but also includes descriptions and explanations of risk areas within the map based on observations during the modeling and review process.

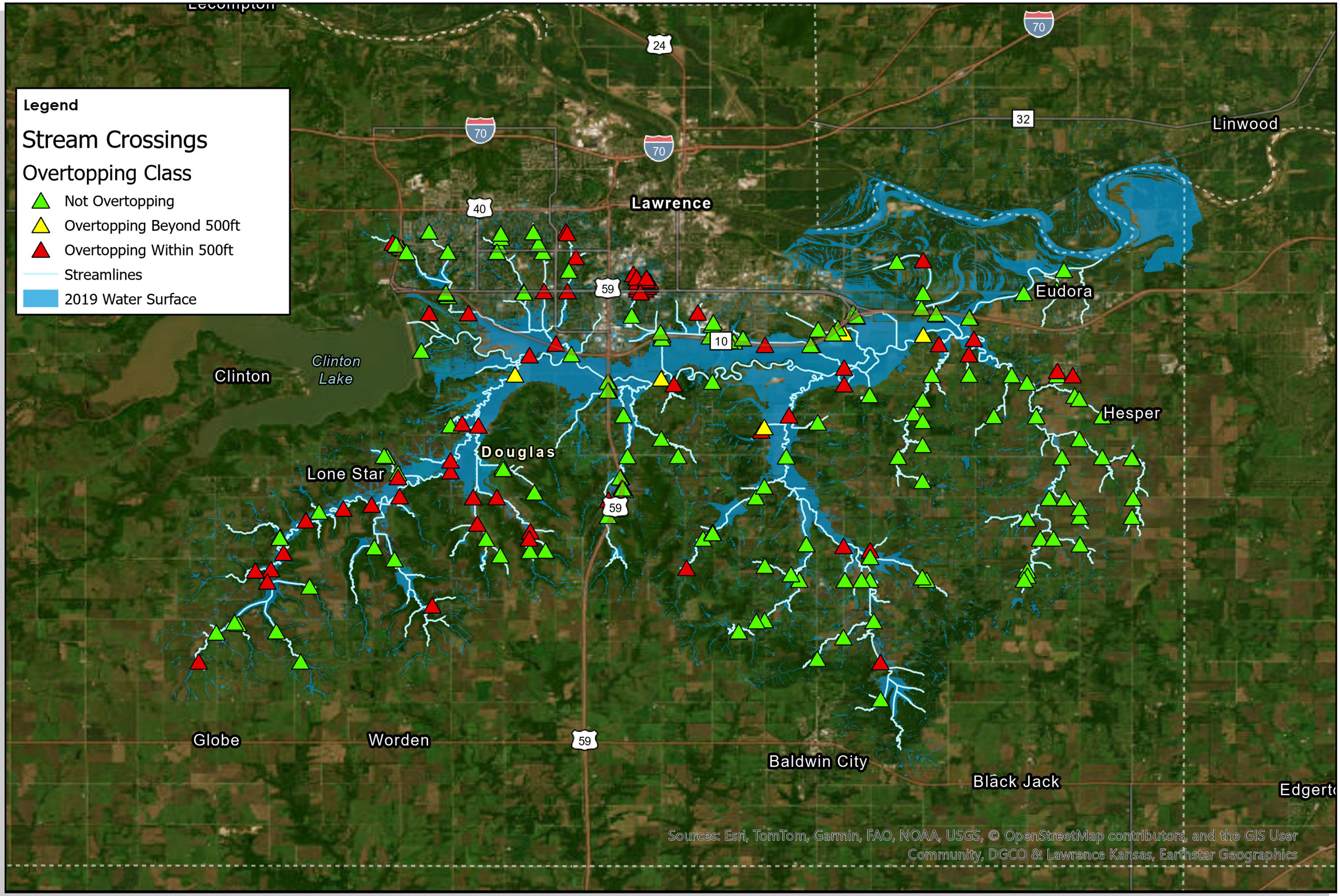

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Figure 12: 2019 Roadway Overtopping Results

Douglas County, KS

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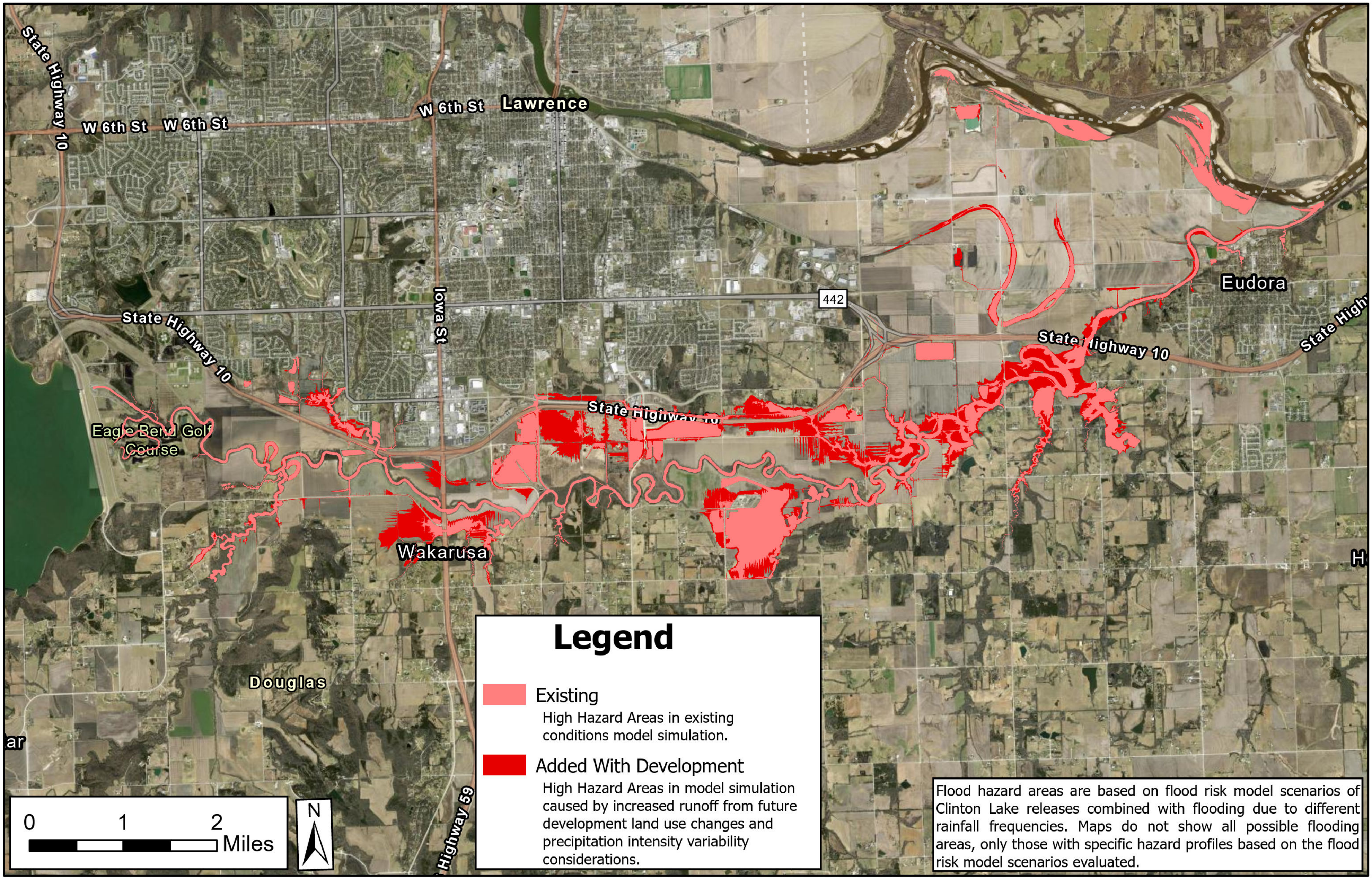

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Revised: 3/9/2026
Software: ArcGIS Pro
File: RiskAreas

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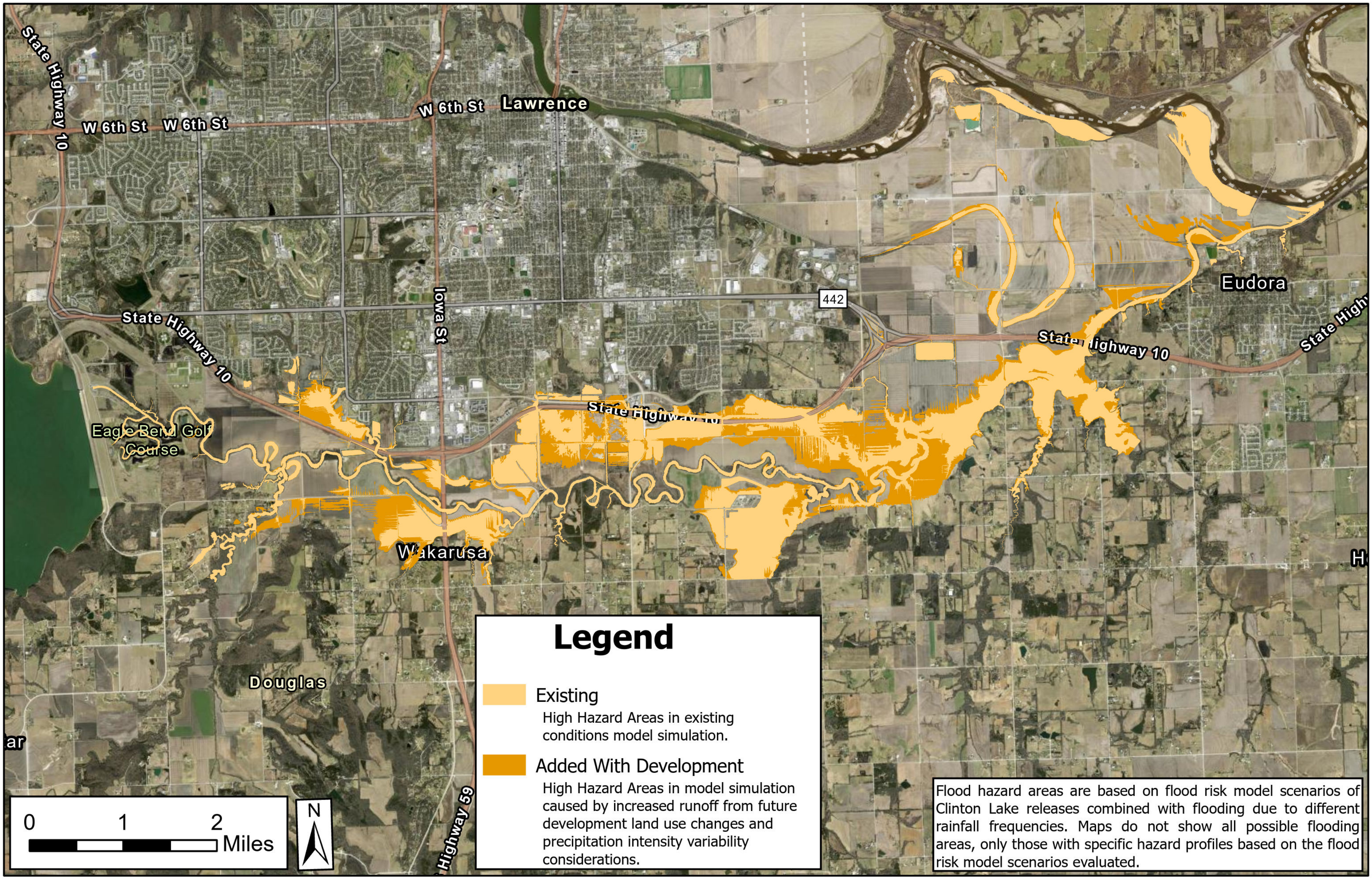
Figure 13: Wakarusa Corridor High Hazard Areas
10-Year Phase I Release

Douglas County, KS

JEO CONSULTING GROUP



Created By: CDS
Date: 2/17/2026
Revised: 3/9/2026
Software: ArcGIS Pro
File: RiskAreas

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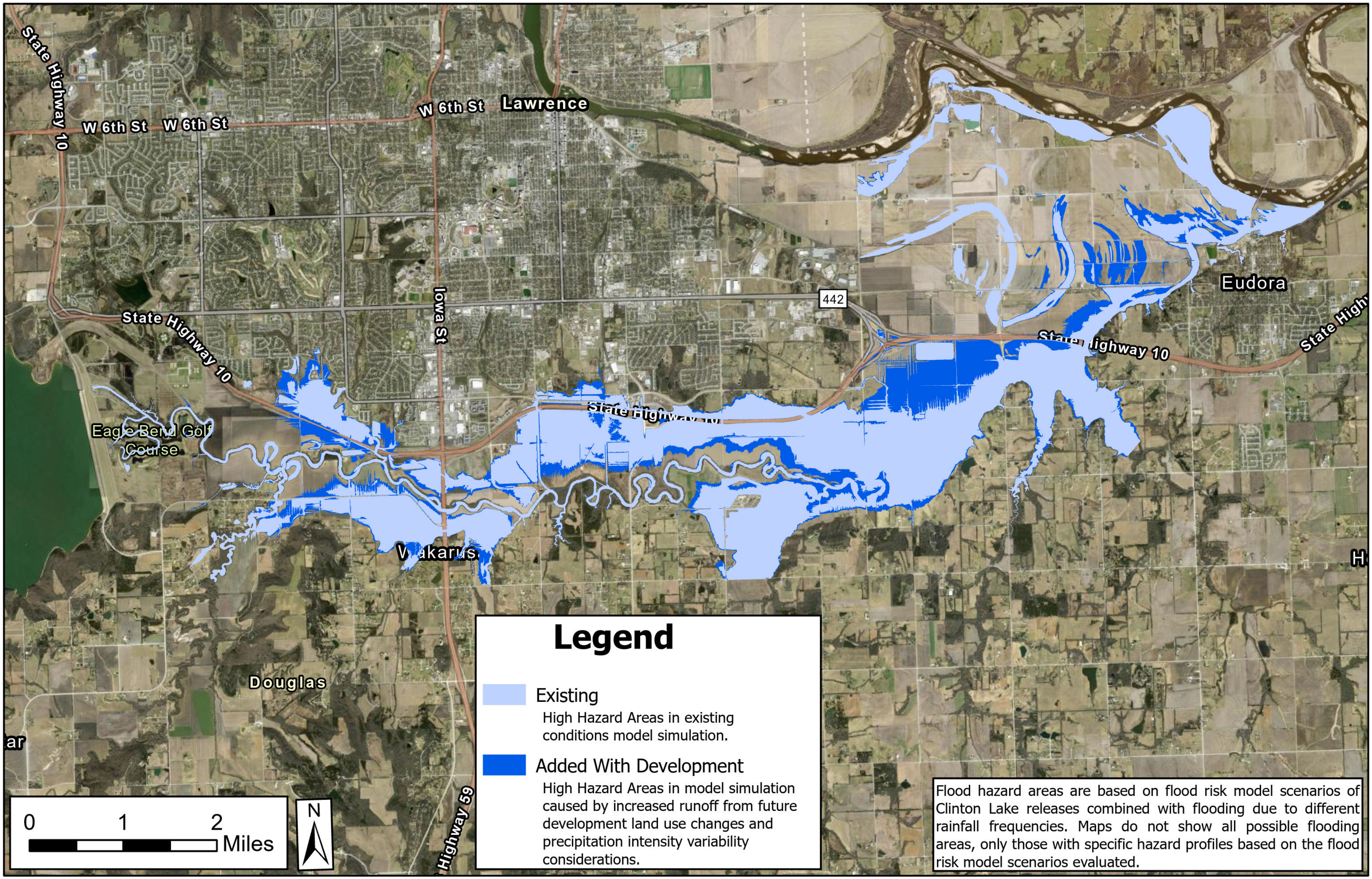
Figure 14: Wakarusa Corridor High Hazard Areas
25-Year Phase I Release

Douglas County, KS

JEO CONSULTING GROUP



Created By: CDS
Date: 2/17/2026
Revised: 3/9/2026
Software: ArcGIS Pro
File: RiskAreas

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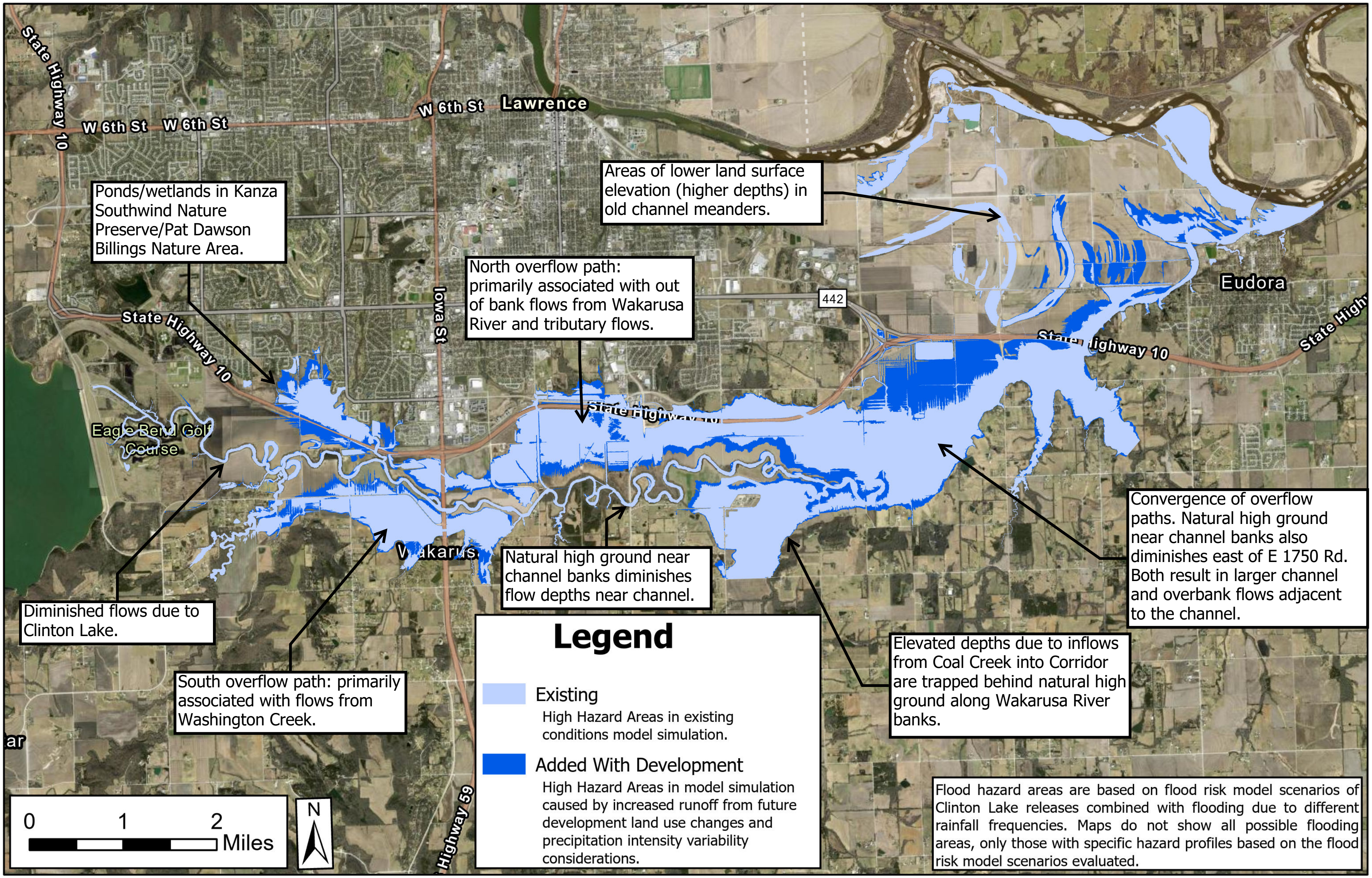
Figure 15: Wakarusa Corridor High Hazard Areas 100-Year Phase I Release

Douglas County, KS

JEO CONSULTING GROUP



Created By: CDS
Date: 2/17/2026
Revised: 3/9/2026
Software: ArcGIS Pro
File: RiskAreas

Figure 16: Wakarusa Corridor High Hazard Areas 100-Year Phase I Release Notes

Douglas County, KS

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5.0 CONCLUSIONS AND NEXT STEPS

5.1 KEY FINDINGS

Review of modeling results on the large number of natural flow and reservoir release scenarios revealed findings which aid in the understanding of hazard classification and flood risk areas, beyond typical regulatory floodplain mapping products.

Results revealed that there are similar inundation patterns in frequent, smaller flood events such as the 10-year when compared with larger events such as the 100-year. Additional peak flows during large events are much more associated with larger floodplain depths and velocities, rather than additional inundation extent. Overall, there are limited terrain elevation differences across the river valley so once flows go out of bank, the inundation impacts are fairly widespread for both frequent and infrequent flood events. Additionally, the 2-Dimensional rain-on-mesh modeling illustrated a number of overflow paths and atypical riverine type flooding geometry conditions which impact the areas potentially damaged in flood events. This portion of the river valley is unique in that the mainstem Wakarusa River is highly regulated so almost all flows enter from tributaries. As flows from tributaries enter the Wakarusa River corridor, bridge/culvert crossings and roadway embankments cause impediments and diversions, affecting the flow paths and the location and extent of inundation impacts.

As shown in Section 4, a number of scenarios were developed as part of the risk review. Hazard result and classifications can be used to provide a framework for understanding key flood risk and damage potential areas. This review aids in identifying patterns under a variety of scenarios in order to inform conservation decision making. Regulatory maps should be consulted separately for cases of site specific review.

5.2 NEXT STEPS

The purpose and scope of this study was to gain a refined understanding of flood risk/hazard areas within the Wakarusa River corridor to help inform planning for future developments. There are other future steps which could be undertaken to further understand flood risk areas.

In the future, the assessment area could be further expanded to better understand flood risk areas on tributaries alongside urban flood sources in Lawrence. With the model simulations complete on the tributaries, the hazard analysis and classification could also be performed on tributaries within the modeled area such as Washington Creek and Coal Creek. Other modeling could also be utilized for the urban stormwater environment in Lawrence.

Future work could also be performed to identify actions that could mitigate flood damage risks for the existing conditions of flood risk areas. Results from model simulations including the July/August 2019 storm show existing flood risk damage potential which was confirmed by observations during the event. Work could be performed to assess potential mitigation strategies (structural or nonstructural) to reduce existing conditions flood risk to homes and businesses in the corridor. These actions could also consider precipitation variability and flood risk variability to promote long term resilience.

6.0 REFERENCES

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APPENDICES

APPENDIX A: TABLE OF HEC-RAS PLANS

Plan Name	Description
ExCorr_Ph1_Base	Existing Conditions, No Precipitation, Clinton Phase 1 Release
ExCorr_Ph2_Base	Existing Conditions, No Precipitation, Clinton Phase 2 Release
ExCorr_Ph3_Base	Existing Conditions, No Precipitation, Clinton Phase 3 Release
Corr_2019	2019 Event Scenario
ExCorr_10yr_Ph0	Existing Conditions, 10-year Precipitation, Clinton No Release
ExCorr_10yr_Ph1	Existing Conditions, 10-year Precipitation, Clinton Phase 1 Release
ExCorr_10yr_Ph2	Existing Conditions, 10-year Precipitation, Clinton Phase 2 Release
ExCorr_10yr_Ph3	Existing Conditions, 10-year Precipitation, Clinton Phase 3 Release
ExCorr_25yr_Ph0	Existing Conditions, 25-year Precipitation, Clinton No Release
ExCorr_25yr_Ph1	Existing Conditions, 25-year Precipitation, Clinton Phase 1 Release
ExCorr_25yr_Ph2	Existing Conditions, 25-year Precipitation, Clinton Phase 2 Release
ExCorr_25yr_Ph3	Existing Conditions, 25-year Precipitation, Clinton Phase 3 Release
ExCorr_100yr_Ph0	Existing Conditions, 100-year Precipitation, Clinton No Release
ExCorr_100yr_Ph1	Existing Conditions, 100-year Precipitation, Clinton Phase 1 Release
ExCorr_100yr_Ph2	Existing Conditions, 100-year Precipitation, Clinton Phase 2 Release
ExCorr_100yr_Ph3	Existing Conditions, 100-year Precipitation, Clinton Phase 3 Release
ExCorr_500yr_Ph3	Existing Conditions, 500-year Precipitation, Clinton Phase 3 Release
DevCorr_10yr_Ph0	Fully Developed Conditions, 10-year Precipitation, Clinton No Release
DevCorr_10yr_Ph1	Fully Developed Conditions, 10-year Precipitation, Clinton Phase 1 Release
DevCorr_10yr_Ph2	Fully Developed Conditions, 10-year Precipitation, Clinton Phase 2 Release
DevCorr_10yr_Ph3	Fully Developed Conditions, 10-year Precipitation, Clinton Phase 3 Release
DevCorr_25yr_Ph0	Fully Developed Conditions, 25-year Precipitation, Clinton No Release
DevCorr_25yr_Ph1	Fully Developed Conditions, 25-year Precipitation, Clinton Phase 1 Release
DevCorr_25yr_Ph2	Fully Developed Conditions, 25-year Precipitation, Clinton Phase 2 Release
DevCorr_25yr_Ph3	Fully Developed Conditions, 25-year Precipitation, Clinton Phase 3 Release
DevCorr_100yr_Ph0	Fully Developed Conditions, 100-year Precipitation, Clinton No Release
DevCorr_100yr_Ph1	Fully Developed Conditions, 100-year Precipitation, Clinton Phase 1 Release
DevCorr_100yr_Ph2	Fully Developed Conditions, 100-year Precipitation, Clinton Phase 2 Release
DevCorr_100yr_Ph3	Fully Developed Conditions, 100-year Precipitation, Clinton Phase 3 Release
DevCorr_500yr_Ph3	Fully Developed Conditions, 500-year Precipitation, Clinton Phase 3 Release

Table 4: HEC-RAS Plans Utilized in Model 23A

APPENDIX B: 2019 OVERTOPPING CROSSING

Stream Name	Roadway Name	Stream Flow (CFS)**	Stream Water Surface Elevation (Feet NAVD88)	Depth of Overtopping (Feet)	Lat	Long	Note
Eudora Middle Tributary	W 9th St	37.16	814.10	0.00	38.94350	-95.10140	
Little Wakarusa Creek	N 1000 Rd	1,315.37	855.51	0.00	38.88410	-95.09950	
Little Wakarusa Creek	E 2100 Rd	121.04	925.93	0.00	38.84400	-95.11180	
Little Wakarusa Creek	N 800 Rd	306.15	901.64	0.00	38.85530	-95.10730	
Little Wakarusa Creek	N 900 Rd	1,244.04	880.03	0.00	38.86960	-95.10410	
Little Wakarusa Creek	N 1100 Rd	1,709.01	829.51	0.00	38.89870	-95.10870	
Tributary 1 To Little Wakarusa Creek	N 1200 Rd	49.37	842.15	0.00	38.91340	-95.13250	
Tributary 1 To Little Wakarusa Creek	N 1250 Rd	68.71	813.25	0.84	38.92070	-95.13260	Overtopping
Little Wakarusa Creek	N 1200 Rd	2,004.87	813.52	0.00	38.91330	-95.11740	
Little Wakarusa Creek	E 2000 Rd	537.01	813.25	0.50	38.92610	-95.13080	Overtopping 350 ft Southwest
Little Wakarusa Creek	E 2100 Rd	1,755.27	815.00	0.00	38.91060	-95.11200	
Little Wakarusa Creek Tributary 2	W 28th St	6.46	860.19	0.00	38.91320	-95.10130	
Little Wakarusa Creek Tributary 2.2	W 28th St	9.17	876.10	0.29	38.91320	-95.09570	Overtopping
Little Wakarusa Creek Tributary 2	Montrose Dr	14.85	866.57	0.19	38.91470	-95.10130	Overtopping
Little Wakarusa Creek Tributary 2.2	N 1200 Rd	9.17	876.08	0.27	38.91320	-95.09570	Overtopping
Little Wakarusa Creek Tributary 4.2	N 1000 Rd	13.04	892.25	0.00	38.88410	-95.07460	
Little Wakarusa Creek Tributary 2.1	N 1150 Rd	57.22	854.54	0.00	38.90600	-95.09510	
Little Wakarusa Creek Tributary 2.1	E 2200 Rd	52.91	858.23	0.00	38.90480	-95.09340	

Little Wakarusa Creek Tributary 2.1	N 1100 Rd	7.18	887.09	0.00	38.89870	-95.08530	
Little Wakarusa Creek Tributary 1	N 1100 Rd	147.37	859.84	0.00	38.89870	-95.12380	
Little Wakarusa Creek Tributary 5	N 900 Rd	119.06	882.69	0.00	38.86950	-95.09860	
Little Wakarusa Creek Tributary 5	E 2200 Rd	35.89	902.68	0.00	38.86310	-95.09320	
North Spring Creek Tributary 5	E 1900 Rd	208.17	889.52	0.00	38.87570	-95.14910	
Little Wakarusa Creek Tributary 5.1	E 2200 Rd	44.91	896.69	0.00	38.86610	-95.09330	
Little Wakarusa Creek Tributary 6	E 2100 Rd	477.48	884.81	0.00	38.86230	-95.11180	
Little Wakarusa Creek Tributary 7	N 800 Rd	272.51	895.93	0.00	38.85530	-95.10260	
Little Wakarusa Creek Tributary 7	E 2200 Rd	200.20	909.71	0.00	38.85320	-95.09320	
Little Wakarusa Creek Tributary 4	E 2300 Rd	84.82	891.41	0.00	38.88380	-95.07480	
Little Wakarusa Creek Tributary 4	N 900 Rd	112.33	925.31	0.00	38.86960	-95.07430	
Little Wakarusa Creek Tributary 4	N 1000 Rd	144.99	874.97	0.00	38.88410	-95.08530	
Little Wakarusa Creek Tributary 4.4	E 2300 Rd	13.32	939.81	0.00	38.86300	-95.07470	
Little Wakarusa Creek Tributary 4	E 2200 Rd	154.49	856.00	0.00	38.89060	-95.09340	
Little Wakarusa Creek Tributary 9	E 2100 Rd	77.38	927.76	0.00	38.84210	-95.11180	
Little Wakarusa Creek Tributary 9	N 700 Rd	66.90	931.03	0.00	38.84070	-95.11300	
Wakarusa River Tributary 1	E 1750 Rd	446.56	816.14	4.50	38.91590	-95.17690	Overtopping
Wakarusa River Tributary 1	E 1500 Rd	906.84	821.89	0.00	38.92560	-95.22040	
Wakarusa River Tributary 1	WB K10 to Haskell Ave Ramp	894.97	824.41	0.00	38.92520	-95.21600	
Wakarusa River Tributary 1	Haskell Ave to WB K10 Ramp	899.71	820.85	0.00	38.92530	-95.21760	
Wakarusa River Tributary 1	State Highway 10	4,254.66	825.65	0.00	38.92390	-95.18820	
Wakarusa River Tributary 1	State Highway 10	4,255.42	825.42	0.00	38.92400	-95.18880	

Wakarusa River Tributary 1	N 1300 Rd	532.23	823.71	0.00	38.92700	-95.22450	
Wakarusa River Tributary 1	E 31st St	532.23	823.71	0.00	38.92700	-95.22450	
Wakarusa River Tributary 1	E 1600 Rd	462.39	818.76	1.71	38.92400	-95.20500	Overtopping
Wakarusa River	E 1750 Rd	6,547.54	816.34	1.30	38.91000	-95.17690	Overtopping 450 ft North
Unnamed Tributary 3 To Wakarusa River	N 1150 Rd	145.91	823.73	0.00	38.90620	-95.16780	
Wakarusa River	US Highway 59	8,732.29	832.67	0.00	38.91100	-95.26050	
Wakarusa River	US Highway 59	8,732.31	833.08	0.00	38.91100	-95.26070	
Wakarusa River	E 1150 Rd	4,433.80	834.79	2.09	38.92030	-95.28850	Overtopping 375 ft Northeast of crossing on N 1250 Rd
Wakarusa River	E 1900 Rd	13,327.87	815.19	0.00*	38.92760	-95.14880	Overtopping 650 ft North
Wakarusa River	E 1500 Rd	4,889.06	828.62	0.00	38.91090	-95.22360	
Wakarusa River	N 1400 Rd	12,346.88	808.59	0.00	38.94240	-95.11320	
Wakarusa River	E 2200 Rd	11,943.14	802.32	0.00	38.95060	-95.09890	
Wakarusa River	State Highway 10	12,509.48	819.68	0.00	38.93390	-95.13230	
Wakarusa River	State Highway 10	12,509.48	819.68	0.00	38.93370	-95.13240	
Wakarusa River	E 1400 Rd	6,829.33	827.96	0.00*	38.91210	-95.24180	Overtopping 1700 ft Northeast of crossing on 1350 Rd
North Spring Creek Tributary 4	E 1900 Rd	145.07	864.69	0.00	38.88850	-95.14900	
North Spring Creek	N 1200 Rd	952.64	817.92	0.00	38.91330	-95.14580	
North Spring Creek	N 1100 Rd	844.03	837.41	0.00	38.89970	-95.15220	
North Spring Creek	N 1000 Rd	411.22	860.60	0.00	38.88430	-95.15770	
North Spring Creek Tributary 2	E 1900 Rd	82.22	853.91	0.00	38.89700	-95.14900	
North Spring Creek	E 1900 Rd	875.06	830.17	0.00	38.90460	-95.14900	
North Spring Creek	N 1275 Rd	686.58	813.30	0.76	38.92430	-95.14320	Overtopping 250 ft East
Wakarusa River Tributary 13	E 1700 Rd	248.60	832.04	0.00	38.92950	-95.18610	
Wakarusa River Tributary 13.1	State Highway 10	122.54	831.33	0.00	38.92960	-95.17900	
Wakarusa River Tributary 13	State Highway 10	247.36	830.65	0.00	38.92810	-95.18050	
Wakarusa River Tributary 13	E 1750 Rd	380.65	819.94	0.00*	38.92810	-95.17690	Overtopping 950 ft South
Wakarusa River Tributary 13.1	State Highway 10	121.63	830.48	0.00	38.92990	-95.17910	
Wakarusa River Tributary 13	State Highway 10	247.41	824.72	0.00	38.92810	-95.18090	

Coal Creek Tributary 8	N 1060 Rd	201.70	821.60	0.58	38.89360	-95.20630	Overtopping 160 ft East
Coal Creek Tributary 8	E 1600 Rd	407.69	819.97	0.00*	38.89480	-95.20520	Overtopping 800 ft North
Unnamed Tributary 1 To Wakarusa River	E 23rd St to EB K10 Ramp	14.42	824.25	0.00	38.93570	-95.17360	
Unnamed Tributary 1 To Wakarusa River	EB K10 to E 23rd St Ramp	47.18	818.58	0.00	38.93410	-95.17240	
Unnamed Tributary 1 To Wakarusa River	State Highway 10	47.17	818.58	0.00	38.93400	-95.17240	
Unnamed Tributary 1 To Wakarusa River	State Highway 10	47.19	819.50	0.00	38.93430	-95.17260	
Coal Creek Tributary 1	E 1700 Rd	90.07	841.12	0.00	38.89640	-95.18630	
Unnamed Stream 1	N 1400 Rd	3.48	806.77	0.00	38.94240	-95.14890	
Unnamed Stream 1	State Highway 10	180.89	817.89	0.00	38.93480	-95.14410	
Unnamed Stream 1	E 1900 Rd to EB K10 Ramp	180.89	817.56	0.00	38.93480	-95.14410	
Unnamed Stream 1	State Highway 10	180.91	816.02	0.00	38.93510	-95.14420	
Unnamed Stream 1	WB K10 to E 1900 Rd Ramp	180.91	816.02	0.00	38.93510	-95.14420	
Unnamed Stream 1	E 1900 Rd	40.01	806.10	1.35	38.95410	-95.14890	Overtopping
Unnamed Stream 1	E 1850 Rd	51.89	806.37	0.00	38.95350	-95.15820	
Unnamed Stream 1	E 1900 Rd	3.48	810.57	0.00	38.93980	-95.14920	
Haskell Tributary	Kiowa Ave	14.31	834.92	0.35	38.93540	-95.22880	Overtopping 25 ft East
Pleasant Grove East Tributary 1	N 1000 Rd	162.86	879.33	0.00	38.88460	-95.23580	
Wakarusa River Tributary 2	Driveway	228.05	825.18	4.75	38.91010	-95.23730	Overtopping
Unnamed Tributary Wakarusa River Tributary 1	E 31st St	78.20	827.49	0.00	38.92630	-95.21280	
Unnamed Tributary Wakarusa River Tributary 1	E 31st St	78.22	827.49	0.00	38.92630	-95.21280	
Haskel Tributary Tributary 1	E 29th St	161.11	833.89	0.00	38.93120	-95.22370	
Haskel Tributary Tributary 1	Haskell Ave	155.90	837.17	0.00	38.93190	-95.22330	
East Fork Vinland Creek	N 700 Rd	1,839.17	860.26	0.00	38.84050	-95.19280	
Vinland Creek	N 790 Rd	3,391.81	846.83	0.00	38.85330	-95.19030	
Coal Creek	N 500 Rd	215.98	906.53	0.18	38.81140	-95.16400	Overtopping 125 ft East
West Fork Vinland Creek	E 1650 Rd	861.67	860.41	0.00	38.84260	-95.19580	
West Fork Vinland Creek	E 1600 Rd	387.21	882.97	0.00	38.84560	-95.20500	

Coal Creek	E 1750 Rd	2,104.19	845.71	0.42	38.85260	-95.17710	Overtopping 250 ft South
Coal Creek	N 1100 Rd	539.84	820.46	2.65	38.89900	-95.19640	Overtopping 260 ft West
Coal Creek	N 600 Rd	2,005.37	877.95	0.00	38.82600	-95.16640	
Coal Creek	N 700 Rd	2,359.92	860.69	0.00	38.84060	-95.16770	
Coal Creek	N 1000 Rd	3,447.72	823.28	0.00	38.88440	-95.19740	
Coal Creek Tributary 10	N 700 Rd	300.45	859.22	0.00	38.84050	-95.17070	
Coal Creek Tributary 4.1	E 1800 Rd	243.23	850.62	0.71	38.85110	-95.16760	Overtopping
East Fork Vinland Creek Tributary 1	E 1600 Rd	1,369.36	893.64	0.00	38.82630	-95.20510	
East Fork Vinland Creek Tributary 1	E 1550 Rd	929.86	922.17	0.00	38.82230	-95.21430	
East Fork Vinland Creek Tributary 1	N 600 Rd	1,285.39	898.94	0.00	38.82590	-95.20810	
Coal Creek Tributary 14	E 1750 Rd	772.61	907.92	0.00	38.82020	-95.17710	
Coal Creek Tributary 14	E 1700 Rd	620.79	947.28	0.00	38.81260	-95.18640	
Coal Creek Tributary 4	E 1800 Rd	14.53	848.55	0.00	38.84870	-95.16770	
Coal Creek Tributary 4	N 700 Rd	267.87	880.84	0.00	38.84060	-95.14760	
Coal Creek Tributary 4	E 1900 Rd	282.70	876.58	0.00	38.84150	-95.14920	
Coal Creek Tributary 13	E 1814 Rd	116.07	959.54	0.00	38.79820	-95.16400	
Coal Creek Tributary 12	N 700 Rd	127.27	861.91	0.00	38.84050	-95.17660	
Unnamed Tributary To Yankee Tank Creek East Branch 2	Harvard Rd	249.91	920.55	1.56	38.96430	-95.27560	Overtopping 20 ft East
Unnamed Tributary To Yankee Tank Creek East Branch 2	Lawrence Ave	304.01	920.32	1.89	38.96360	-95.27510	Overtopping 50 ft North
Unnamed Tributary To Yankee Tank Creek East Branch	Westbrooke St	176.43	884.85	0.21	38.95510	-95.27210	Overtopping 50 ft North
Hidden Valley Tributary	Inverness Dr	180.94	908.45	0.00	38.95900	-95.29940	
Hidden Valley Tributary	W 12th St	163.49	936.35	0.00	38.96200	-95.29880	
Hidden Valley Tributary	Vantuyl Dr	143.44	942.98	0.00	38.96350	-95.29880	
Hidden Valley Tributary	Bob Billings Pkwy	549.53	913.57	0.00	38.95690	-95.30010	
Hidden Valley Tributary	Bob Billings Pkwy	549.54	912.33	0.00	38.95710	-95.30010	
Pleasant Grove East Tributary	E 1400 Rd	624.71	849.85	0.00	38.89070	-95.24180	
Pleasant Valley Tributary	US Highway 59	2,451.43	830.18	0.00	38.90780	-95.26040	

Pleasant Valley Tributary	US Highway 59	2,345.98	830.88	0.00	38.90780	-95.26070	
Pleasant Valley Tributary	E 1300 Rd	2,451.43	830.18	0.00	38.90780	-95.26040	
Pleasant Valley Tributary	E 1300 Rd	2,345.98	830.98	0.00	38.90780	-95.26080	
Pleasant Grove West Tributary	N 1100 Rd	531.35	833.71	0.00	38.89910	-95.25520	
Pleasant Grove West Tributary	E 1299 Rd	193.09	889.56	0.54	38.86900	-95.26050	Overtopping
Pleasant Grove West Tributary	E 1299 Rd	377.94	905.03	0.00	38.86330	-95.26070	
Pleasant Grove West Tributary	US Highway 59	1,255.92	866.93	0.00	38.87700	-95.25610	
Pleasant Grove West Tributary	N 1000 Rd	1,164.02	853.52	0.00	38.88450	-95.25380	
Pleasant Grove West Tributary	US Highway 59	1,256.06	867.39	0.00	38.87690	-95.25640	
Yankee Tank Creek	US Highway 40	2,052.70	832.12	0.00	38.92070	-95.27370	
Hidden Valley Tributary	Clinton (Frontage) Pkwy	867.79	854.70	0.00	38.94290	-95.29070	
Hidden Valley Tributary	Clinton Pkwy	882.99	854.66	0.00	38.94270	-95.29060	
Hidden Valley Tributary	Clinton Pkwy	883.34	854.24	0.00	38.94260	-95.29050	
Yankee Tank Creek	E 1200 Rd	846.59	832.24	3.51	38.92450	-95.27920	Overtopping
Yankee Tank Creek East Branch	Clinton (Frontage) Pkwy	160.41	855.98	0.56	38.94300	-95.27500	Overtopping
Quail Creek	W 22nd St	360.11	854.81	0.86	38.94310	-95.28340	Overtopping
Quail Creek	Bob Billings Pkwy	383.14	902.24	0.00	38.95700	-95.28380	
Quail Creek	Tiffany Dr	254.54	921.83	0.00	38.95990	-95.28540	
Quail Creek	Harvard Rd	195.16	944.22	0.00	38.96400	-95.28720	
Yankee Tank Creek East Branch	Private	937.14	864.74	0.00	38.95030	-95.27460	
Naismith Creek	N 1300 Rd	713.41	822.86	0.00	38.92760	-95.24150	
Naismith Creek	W 31st St	713.41	822.86	0.00	38.92760	-95.24150	
Naismith Creek	State Highway 10	707.03	825.75	0.00	38.92650	-95.24160	
Naismith Creek	State Highway 10	706.00	825.96	0.00	38.92630	-95.24160	
Naismith Creek	W 19th Ter	35.52	877.47	1.29	38.94910	-95.25170	Overtopping
Naismith Creek	W 27th St	739.87	835.61	0.00	38.93440	-95.25230	
Naismith Creek	W 22nd Ter	154.16	856.37	0.96	38.94370	-95.25020	Overtopping 40 ft West
Naismith Creek	W 22nd St	138.05	859.44	3.31	38.94460	-95.25020	Overtopping 40 ft East
Naismith Creek	W 21st St	42.20	859.33	0.47	38.94640	-95.25030	Overtopping 40 ft East/West
Naismith Creek	Naismith Dr	0.15	872.61	0.02	38.94790	-95.25060	Overtopping

Naismith Creek	Louisiana St	910.78	822.92	0.00	38.92850	-95.24210	
Naismith Creek Tributary 4	W 23rd St	294.57	851.38	0.45	38.94280	-95.24900	Overtopping
Naismith Creek Tributary 4	W 22nd Ter	180.39	855.84	0.97	38.94370	-95.24750	Overtopping
Naismith Creek Tributary 4	Alabama St	197.91	857.01	2.01	38.94450	-95.24660	Overtopping
Naismith Creek Tributary 4	W 22nd St	258.42	857.06	0.14	38.94460	-95.24660	Overtopping
Naismith Creek Tributary 4	Carolina St	245.77	860.07	1.73	38.94540	-95.24590	Overtopping
Naismith Creek Tributary 4	Greever Ter	211.62	860.24	1.55	38.94560	-95.24590	Overtopping
Naismith Creek Tributary 4	Carolina St	150.58	862.13	3.06	38.94600	-95.24590	Overtopping
Naismith Creek Tributary 4	W 21st St	208.36	862.28	1.48	38.94650	-95.24580	Overtopping
Naismith Creek Tributary 4	Alabama St	192.46	865.38	1.30	38.94680	-95.24710	Overtopping
Naismith Creek Tributary 4	Alabama St	188.99	867.52	1.02	38.94780	-95.24700	Overtopping
Naismith Creek Tributary 4	Private	294.57	851.30	0.47	38.94270	-95.24920	Overtopping
Washington Creek Tributary 3	E 1000 Rd	264.71	846.37	0.00	38.89550	-95.31660	
Washington Creek Tributary 2.1.1	E 1100 Rd	343.88	867.42	0.00	38.88090	-95.29790	
Yankee Tank West Branch	E 1048 Rd	134.73	858.80	0.00	38.94130	-95.31750	
Yankee Tank West Branch	US Highway 40	74.47	873.02	0.00	38.94210	-95.31810	
Yankee Tank West Branch	YSC Access Rd	185.97	845.19	0.32	38.93520	-95.31020	Overtopping 230 ft South
Yankee Tank West Branch	Clinton Pkwy	74.14	870.74	0.00	38.94260	-95.31830	
Yankee Tank West Branch	Clinton Pkwy	74.15	869.64	0.00	38.94250	-95.31830	
Pleasant Grove West Tributary 1	E 1300 Rd	402.87	879.18	0.00	38.87260	-95.25480	
Pleasant Grove West Tributary 1	US Highway 59	455.01	875.87	0.00	38.87330	-95.25580	
Pleasant Grove West Tributary 1	US Highway 59	454.59	880.04	0.00	38.87310	-95.25550	
Washington Creek Tributary	N 900 Rd	2,022.62	867.12	0.84	38.86990	-95.30850	Overtopping
Washington Creek Tributary	N 1075 Rd	5,054.09	845.83	1.06	38.89540	-95.30670	Overtopping
Washington Creek Tributary 2.3.1	E 1100 Rd	348.87	941.13	0.00	38.84930	-95.29890	
Washington Creek Tributary 2.2.2	Driveway	478.14	961.75	0.00	38.85100	-95.28290	
Washington Creek Tributary 2.1	E 1100 Rd	799.74	867.52	0.00	38.88000	-95.29790	

Washington Creek Tributary 2.2	E 1150 Rd	1,865.30	908.80	0.26	38.85780	-95.28820	Overtopping 260 ft South
Washington Creek Tributary 2.2	E 1150 Rd	1,064.58	933.54	0.00	38.85090	-95.28840	
Washington Creek Tributary 2.2	E 1150 Rd	1,041.79	919.73	0.42	38.85530	-95.28870	N 798th St Overtopping 55 ft Northwest
Washington Creek Tributary 2.2	N 900 Rd	2,087.78	871.41	1.03	38.86990	-95.30020	Overtopping 125 ft West
Washington Creek Tributary 2.1	Driveway	281.51	927.56	0.00	38.87160	-95.28680	
Washington Creek Tributary 2.3	N 800 Rd	1,024.87	897.41	0.00	38.85520	-95.30400	
Chicken Creek Tributary 5	N 640 Rd	592.73	951.49	0.62	38.83150	-95.32310	Overtopping
Washington Creek Tributary 2.3	E 1050 Rd	1,059.96	885.55	4.52	38.86060	-95.30710	Overtopping 480 ft North
Coal Creek Tributary 2	N 800 Rd	948.15	874.57	0.00	38.85520	-95.22690	
Coal Creek Tributary 2	N 900 Rd	219.01	831.03	0.00	38.86990	-95.20820	
Coal Creek Tributary 2	E 1600 Rd	562.00	828.23	0.00	38.87380	-95.20520	
Coal Creek Tributary 2	E 1450 Rd	544.03	909.51	0.47	38.84480	-95.23280	Overtopping 80 ft North
Coal Creek Tributary 2.2	E 1500 Rd	298.63	864.08	0.00	38.85760	-95.22360	
Coal Creek Tributary 2	E 1500 Rd	1,006.32	864.44	0.00	38.85720	-95.22350	
Yankee Tank West Branch	E 900 Rd	124.11	959.37	5.29	38.96030	-95.33710	Overtopping
Yankee Tank West Branch	NB US40 to Bob Billings Pkwy RAMP	380.49	939.98	0.00	38.95820	-95.33360	
Yankee Tank West Branch	US Highway 40	379.64	945.38	0.00	38.95860	-95.33430	
Yankee Tank West Branch	Bob Billings Pkwy to SB US40 RAMP	379.98	954.88	0.00	38.95930	-95.33540	
Yankee Tank West Branch	Bob Billings Pkwy	417.65	959.36	0.00	38.95960	-95.33600	
Yankee Tank West Branch	N 1500 Rd	356.12	916.31	0.00	38.95690	-95.33220	
Wakarusa River Tributary 15	YSC Access Rd	66.84	868.14	0.50	38.93530	-95.32410	Overtopping 140 ft West
Wakarusa River Tributary 14	E 902 Rd	22.34	840.66	0.00	38.92200	-95.32700	
Yankee Tank West Branch Tributary 1	Bob Billings Pkwy	656.13	914.69	0.00	38.95700	-95.31760	
Yankee Tank West Branch Tributary 1	Harvard Rd	215.06	966.04	0.00	38.96420	-95.32420	
Washington Creek	N 1075 Rd	4,647.51	846.23	15.59	38.89610	-95.31250	Overtopping
Washington Creek	E 850 Rd	5,636.88	870.93	0.24	38.86720	-95.34460	Overtopping 220 ft North
Washington Creek	E 800 Rd	7,738.09	881.76	1.71	38.86590	-95.35460	Overtopping 150 ft North

Washington Creek	E 661 Diagonal Rd	5,060.50	909.33	0.59	38.84440	-95.38030	Overtopping
Washington Creek	E 900 Rd	6,679.65	867.97	1.09	38.87030	-95.33460	Overtopping 90 ft West
Washington Creek	N 1200 Rd	7,634.44	840.53	0.00*	38.91340	-95.29370	Overtopping 1300 ft East
Washington Creek	E 1000 Rd	6,192.99	856.37	0.60	38.87910	-95.31660	Overtopping 320 ft North
Washington Creek	Driveway	2,762.35	902.01	1.67	38.85020	-95.37590	Overtopping
Washington Creek	Driveway	4,375.84	892.67	1.74	38.86170	-95.36790	Overtopping
Washington Creek Tributary 8	E 661 Diagonal Rd	696.31	888.44	0.00	38.86480	-95.36330	
Washington Creek Tributary 5	E 900 Rd	1,344.85	864.68	0.00	38.87850	-95.33520	
Washington Creek Tributary 5	N 1000 Rd	787.77	881.83	0.00	38.88430	-95.33910	
Washington Creek Tributary 5	Driveway	530.36	883.54	0.00	38.88460	-95.34020	
Washington Creek Tributary 5.1	E 900 Rd	144.56	864.18	1.68	38.87710	-95.33520	Overtopping
Washington Creek Tributary 4	E 1000 Rd	1,323.06	855.27	4.21	38.88300	-95.31660	Overtopping
Chicken Creek	N 750 Rd	1,908.16	893.95	0.00	38.84790	-95.33650	
Washington Creek Tributary 10	N 775 Rd	1,504.92	897.83	0.72	38.85590	-95.37710	Overtopping
Washington Creek Tributary 10	E 661 Diagonal Rd	1,599.11	897.42	0.00	38.85550	-95.37720	
Chicken Creek Tributary 1	E 850 Rd	319.98	889.34	0.00	38.85220	-95.34360	
Lonestar Tributary Southwest Tributary 1	N 600 Rd	812.32	959.50	0.00	38.82500	-95.39200	
Lonestar Tributary Southeast	N 600 Rd	1,335.99	960.88	0.00	38.82230	-95.37840	
Lonestar Tributary Southeast	N 500 Rd	659.66	1017.57	0.00	38.81160	-95.36980	
Lonestar Tributary Southwest	N 600 Rd	2,027.10	959.35	0.00	38.82550	-95.39320	
Lonestar Tributary Southwest	N 500 Rd	503.54	1026.37	0.15	38.81160	-95.40590	Overtopping
Lonestar Tributary Southwest	E 550 Rd	1,668.69	977.89	0.00	38.82190	-95.39970	
Lonestar Tributary Southwest	E 582 Rd	128.97	957.50	5.27	38.84000	-95.38160	Overtopping
Washington Creek	Driveway	752.62	918.96	2.86	38.84390	-95.38590	Overtopping
Unnamed Tributary to Lonestar Tributary Southwest	E 715 Rd	815.95	959.65	0.00	38.83820	-95.36660	

*Overtopping over 500 feet from crossing

**Flow located at hydraulic structure only

Table 5: Roadway Stream Crossings Analyzed for Overtopping in the 2019 Simulation