City of Norfolk, Nebraska
East Drainage Evaluation
Hydrologic and Hydraulic Analysis

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1. BACKGROUND

The city of Norfolk, located in northeast of Madison County, is looking to evaluate a section of area on the east side of the city, just east of the confluence of the Elkhorn River & North Fork Elkhorn River. This location is currently experiencing growth in multiple areas that are currently under development or will be developed in near future. However, this area has also seen flood damages from as recently as 2019 in which multiple roadways were overtopped with floodwaters and resulted in several properties being threatened. Due to this, the city desired to evaluate the area in order to develop potential improvement recommendations and guidelines for the project area. The following report explains the details of the hydrologic and hydraulics analysis to determine the proposed improvement recommendations. The overall location and approximate boundary of the watershed area is included below in Figure 1.

2. PREVIOUS STUDIES

For this study area, an evaluation was previously conducted in August of 2012 for the flooding needs of the future development space of East Norfolk. Since this previous study coincided with the current east drainage evaluation, it was used as a comparison for the results found in each. The information compiled previously included a hydraulic analysis done by Mainelli Wagner and Associates in February of 2012 that determined the 100-year floodplain along the North Fork Elkhorn River tributary, just northeast of Norfolk. In particular, it covered the tributary area just east of Victory Rd. and south of Benjamin Ave. In this analysis, multiple 100-Year flow rates were reported from various sources, as seen below in Table 1. These include the Nebraska Department of Natural Resources (NDNR), HWS Engineering, and Mainelli Wagner and Associates (MWA) using both TR55 and rational method for flow rate determinations. These results are compared to the current evaluation below in section 5.3.

Table 1: Previous Studies 100-Year Flow Rate Determination

Source	100-yr Flow Rate (cfs)
NDNR	1650
HWS (TR20)	2100
MWA (TR55)	2000
MWA (CiA)	2090

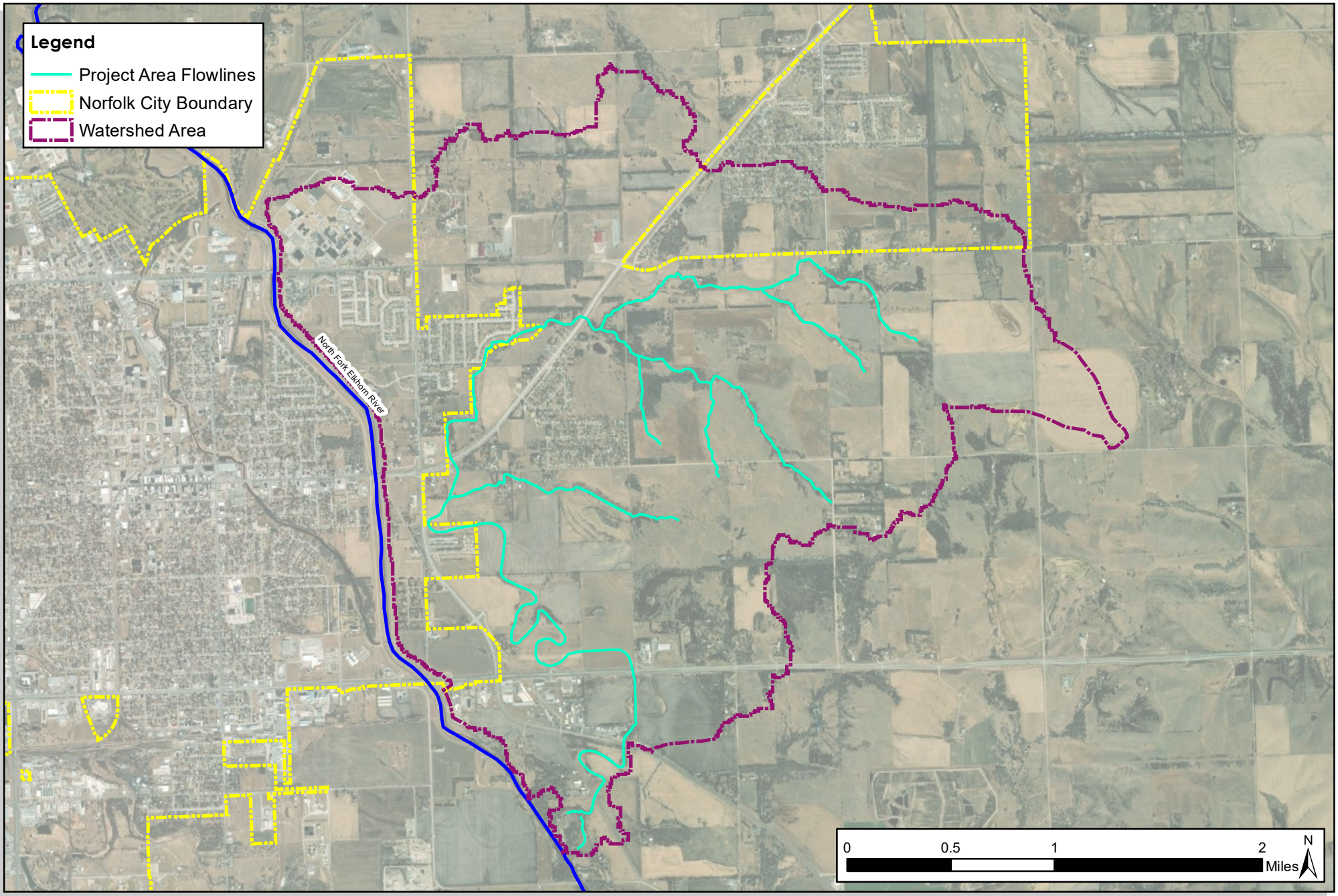

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Figure 1: Study Area Overview

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3. Purpose of Assessment

This assessment is looking to provide recommended improvements and guidelines to reduce the flood risk potential, particularly in the future development areas. These improvements are based on the findings of the site visit conducted on May 10th, 2021, alongside the developed hydrologic and hydraulic analysis. The site visit locations involved several areas that were identified in the early stages of the H&H analysis as potential areas of water ponding, as well as identified culvert structures for the water flow. Any deficiencies and flood risk areas that were determined from the analyses were then used to create several drainage improvement recommendations. The recommendations include possible administrative regulations that can be applied and conceptual construction improvements to offset the increased discharges from the future developments. This report outlines the recommended actions and provides conceptual projects, as well as potential funding sources, below.

4. Study Area Description

The evaluation area includes a significant portion of the surrounding city space and comprised of approximately 7.8 square miles of developed and undeveloped areas. There are approximately 26 identified culverts across the project space that are the major contributors to the direction of flow. Seven of these culverts are along State Highway 35, just northeast of the roundabout at Norfolk Ave. and Victory Rd. The remaining 19 identified culverts are just south of Highway 275 and east of Victory Rd. These culverts convey flows through Highway 275 and State Highway 24, to the confluence of the unnamed project tributary and the North Fork Elkhorn River. In order to properly model these identified culvert structures, they were each surveyed and documented for their length, material type, and size. An overview of these culvert locations and the type of each identified structure can be seen in Table 2 and Figure 2.

Table 2: Culvert ID's with Type and Size

Culvert ID	Culvert Type	Culvert Size
1	Reinforced Concrete Culvert Box	2 - 10'x10' Double Box
2	Reinforced Concrete Culvert Box	2 - 6'x4' Double Box
3-4	Reinforced Concrete Culvert Pipe	4 - 53"x34" RCP with Flared End Section
5	Reinforced Concrete Culvert Box	2 - 13'x8' Triple Box
6	Reinforced Concrete Culvert Box	2 - 8'x6' Double Box
7	Reinforced Concrete Culvert Pipe	2 - 36" RCP
8	Reinforced Concrete Culvert Pipe	2 - 30" RCP
9	Reinforced Concrete Culvert Box	2 - 10'8' Quad Box
10	Reinforced Concrete Culvert Box	2 - 48"x24" Double Box
11	Reinforced Concrete Culvert Box	2 - 48"x30" Double Box
12	Corrugated Metal Culvert Pipe	2 - 24" CMP
13	Reinforced Concrete Culvert Pipe	2 - 24" RCP
14	Corrugated Metal Culvert Pipe	2 - 24" CMP
15	Corrugated Metal Culvert Pipe	2 - 36" CMP
16-17	Reinforced Concrete Culvert Pipe	4 - 30" RCP with Flared End Section
18	Reinforced Concrete Culvert Pipe	2 - 36" RCP with Flared End Section
19	Reinforced Concrete Culvert Box	2 - 6'x4' Single Box
20	Reinforced Concrete Culvert Pipe	2 - 48" RCP with Flared End Section
21	Reinforced Concrete Culvert Box	2 - 8'x3'9" Single Box
22	Reinforced Concrete Culvert Box	2 - 8'x3'9" Single Box
23	Reinforced Concrete Culvert Box	2 - 12'x6' Quad Box
24	Reinforced Concrete Culvert Box	2 - 5'x5' Single Box
25-26	Corrugated Metal Culvert Pipe & Reinforced Concrete Culvert Pipe	2 - 36" CMP & 30" RCP

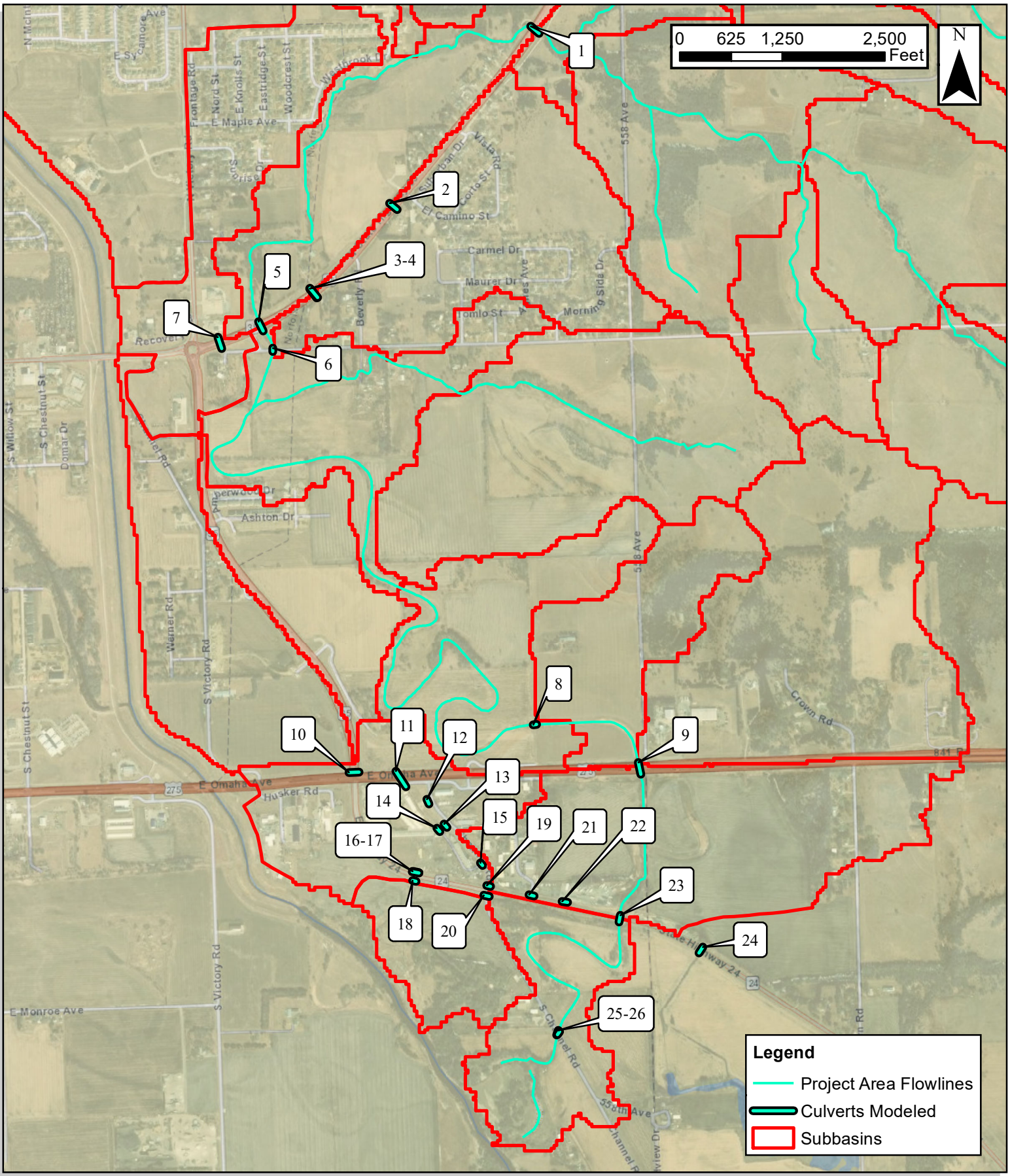

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Figure 2: Drainage Structures Overview

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5. ANALYSIS

For this study, a hydrologic and hydraulic model was developed for analysis using the HEC-HMS and HEC-RAS modeling software, respectively. The HEC-HMS software was run on version 4.7 and the HEC-RAS model was run on version 6.0. The HMS model determines the runoff hydrographs for user defined drainage basins and then used within the 2D RAS model in order to calculate the inundation extents and water surface elevation (WSE) across the drainage area, based upon the land surface.

5.1 Hydrology

The Soil Conservation Service (SCS) Curve Number Method was used to determine the runoff volumes and peak flows from the study area for the 10- and 100-year storm events (10 % and 1% annual chance) using NOAA Atlas 14 Point Precipitation 24-hour rainfall depths of 3.98 and 6.04 inches, respectively. Contributing drainage areas were delineated using LiDAR topographic data and are shown in Figure 3. Composite curve numbers were determined based on the primary land uses obtained from the 2017 Norfolk Comprehensive Plan, for both Existing and Future conditions, and the soil characteristics obtained from the NRCS Web Soil Survey. The land use for both scenarios are shown in Figure 4 and Figure 5 below. In order to determine a worst-case scenario, the future conditions analysis has been performed assuming that no additional site-specific detention has been completed. The Drainage Criteria Manual (adopted August 2020) includes requirements that future developments include detention for the 2-year, 10-year and 100-year events. By analyzing future land use conditions without future detention, the impacts of allowing unchecked development can be determined. The total lag time for each drainage area was calculated as 60% of the summation of sheet flow, shallow concentrated flow, and channel flow as specified by the SCS method. Hydrologic inputs and results for the Existing and Future Conditions are shown in Table 3 and Table 4, respectively.

Table 3: Hydrologic Inputs and Results- Existing Conditions

Existing Conditions						
Basin	Drainage Area (acres)	Curve Number	*10-Year Results*		*100-Year Results*	
			Total Runoff Volume (acre-ft)	Peak Discharge (cfs)	Total Runoff Volume (acre-ft)	Peak Discharge (cfs)
W1010	74.4	55.6	3.4	11.8	9.8	45.6
W500	397.8	61.7	27.8	89.2	69.4	260.4
W510	124.9	72.4	15.3	73.6	31.8	161.8
W520	123.4	77.7	19.0	132.7	36.9	262.9
W540	96.1	65.9	8.5	46.7	19.7	120.6
W550	154.2	61.0	10.3	41.8	26.1	126.8
W560A	166.0	64.5	13.7	73.7	32.3	198.9
W560B	324.7	73.5	41.9	259.3	85.9	555.5
W570	157.5	58.1	8.7	30.9	23.5	105.0
W590	68.7	53.4	2.6	11.2	8.1	52.2
W650	80.1	51.4	2.5	7.1	8.5	36.3
W660	201.2	53.0	7.3	22.7	23.2	103.6
W690A	221.4	54.2	9.0	34.9	27.3	149.9
W690B	90.1	54.8	3.9	17.0	11.5	71.2
W710	181.4	54.3	7.4	25.3	22.5	106.4
W720	168.9	55.1	7.4	19.4	21.8	74.2
W740	75.2	58.7	4.3	25.0	11.5	85.2
W750	190.0	65.7	16.7	73.6	38.7	191.1
W780B	156.6	70.0	17.2	70.1	37.0	162.6
W790	183.7	60.2	11.7	48.0	30.1	150.4
W800	124.0	58.2	6.9	34.5	18.6	119.4
W820	118.1	58.6	6.7	31.0	18.0	104.8
W830	127.1	61.1	8.5	36.4	21.6	110.4
W840	236.8	62.6	17.4	78.9	42.8	226.5
W850	252.9	70.5	28.4	176.1	60.7	402.6
W880	141.6	78.0	22.1	69.1	42.7	137.1
W890	126.6	68.3	12.8	63.0	28.2	152.3
W900	89.3	73.2	11.4	50.6	23.4	109.5
W910	99.1	70.5	11.1	72.4	23.8	165.3
W930A	199.3	73.8	26.0	120.9	53.1	258.5
W930B	93.2	71.9	11.2	34.9	23.5	77.6
W950A	112.2	83.9	21.9	91.7	39.5	165.7
W950B	57.3	65.8	5.1	33.8	11.7	87.4

Table 4: Hydrologic Inputs and Results- Future Conditions

Future Conditions									
Basin	Drainage Area (acres)	Curve Number	Curve Number Percent Increase from Existing to Future	*10-Year Results*			*100-Year Results*		
				Total Runoff Volume (acre-ft)	Total Runoff Volume Percent Increase from Existing to Future (acre-ft)	Peak Discharge (cfs)	Total Runoff Volume (acre-ft)	Total Runoff Volume Percent Increase from Existing to Future (acre-ft)	Peak Discharge (cfs)
W1010	74.4	58.8	106%	4.3	126%	16.7	11.4	116%	55.6
W500	397.8	64.5	105%	32.9	118%	111.8	77.6	112%	298.8
W510	124.9	74.4	103%	16.7	109%	82.1	33.9	107%	173.3
W520	123.4	77.6	100%	18.9	99%	131.6	36.7	99%	261.6
W540	96.1	65.6	100%	8.4	99%	45.7	19.5	99%	119.0
W550	154.2	61.0	100%	10.3	100%	41.9	26.1	100%	126.9
W560A	166.0	64.7	100%	13.9	101%	75.2	32.6	101%	201.4
W560B	324.7	77.0	105%	48.6	116%	308.7	95.1	111%	619.9
W570	157.5	57.9	100%	8.5	98%	30.2	23.3	99%	103.6
W590	68.7	53.4	100%	2.6	100%	11.2	8.1	100%	52.1
W650	80.1	51.4	100%	2.5	100%	7.1	8.5	100%	36.3
W660	201.2	53.0	100%	7.3	100%	22.7	23.2	100%	103.6
W690A	221.4	54.2	100%	9.0	100%	34.9	27.3	100%	149.9
W690B	90.1	54.8	100%	3.9	100%	17.0	11.5	100%	71.2
W710	181.4	55.4	102%	8.1	109%	29.3	23.8	106%	115.1
W720	168.9	64.2	116%	13.7	185%	45.7	32.5	149%	123.5
W740	75.2	58.7	100%	4.3	100%	25.0	11.5	100%	85.2
W750	190.0	68.7	105%	19.5	117%	90.4	43.0	111%	216.4
W780B	156.6	73.5	105%	20.2	117%	85.8	41.4	112%	184.6
W790	183.7	60.2	100%	11.7	100%	48.0	30.1	100%	150.4
W800	124.0	62.9	108%	9.3	135%	53.8	22.7	122%	153.5
W820	118.1	60.3	103%	7.6	113%	36.8	19.4	108%	115.4
W830	127.1	68.1	111%	12.7	149%	62.7	28.1	130%	152.4
W840	236.8	63.2	101%	18.1	104%	83.0	43.8	102%	233.4
W850	252.9	73.0	104%	31.9	112%	203.7	65.9	109%	440.7
W880	141.6	87.3	112%	31.2	141%	100.6	54.1	127%	173.9
W890	126.6	78.9	116%	20.5	160%	111.8	39.1	139%	217.9
W900	89.3	86.6	118%	19.2	168%	91.2	33.6	144%	158.6
W910	99.1	79.8	113%	16.6	150%	116.0	31.4	132%	222.2
W930A	199.3	85.6	116%	41.5	160%	204.2	73.2	138%	359.7
W930B	93.2	79.1	110%	15.2	136%	50.1	28.9	123%	97.6
W950A	112.2	88.1	105%	25.4	116%	106.6	43.7	111%	182.0
W950B	57.3	83.0	126%	10.8	212%	84.2	19.7	168%	153.5

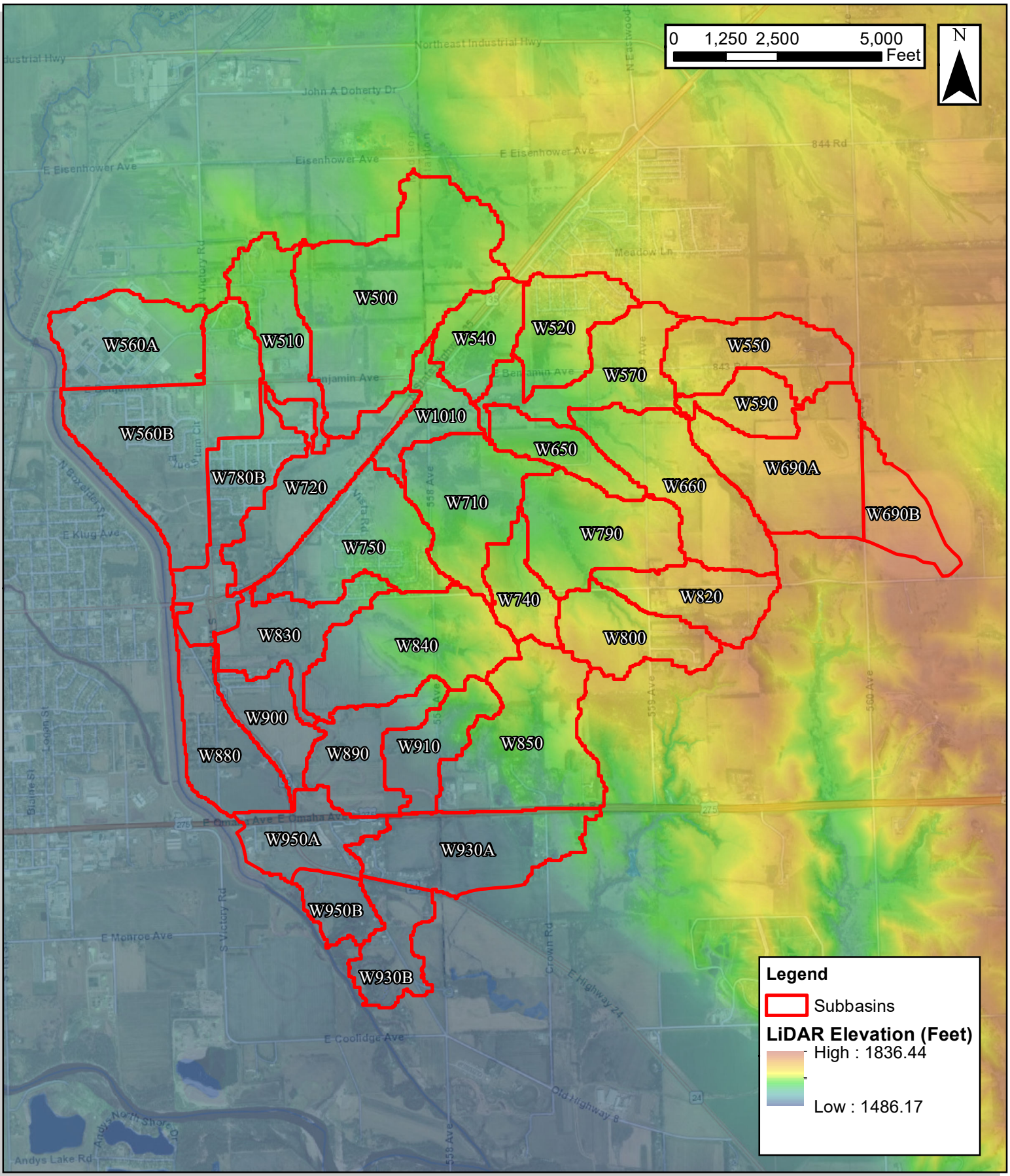

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Figure 3: Basin Delineation Boundaries

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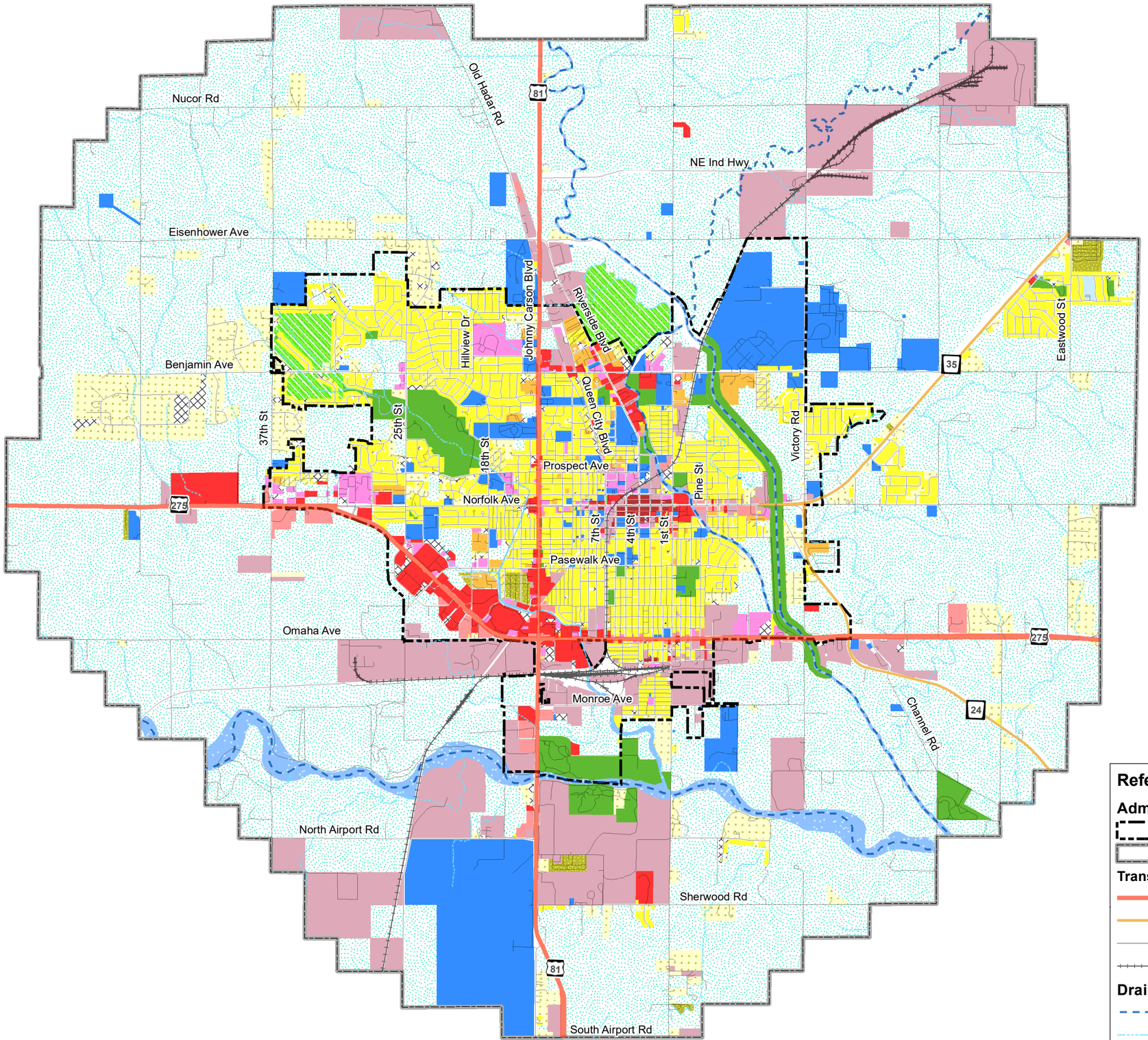
Figure 37: Existing Land Use

Comprehensive Plan
City of Norfolk



Legend

Existing Land Use Categories

- Rural Residential
- Single Family Residential
- Townhomes (2/4 Plex)
- Multi-Family Residential
- Mobile Home Residential
- Automotive Commercial
- General Commercial
- Mixed Use/Downtown
- Office/Services
- Industrial
- Public/Civic Use
- Parks & Recreation
- Golf Course
- Agricultural
- Vacant
- Surface Water

Reference Items

Administrative Bounds

- City Limits
- ETJ

Transportation Network

- US Highway
- State Highway
- Local Road
- Railroad

Drainage System

- Rivers/Streams
- Creeks/Wash

1 inch = 4,000 feet

0 2,250 4,500 9,000 Feet

0 0.375 0.75 1.5 Miles

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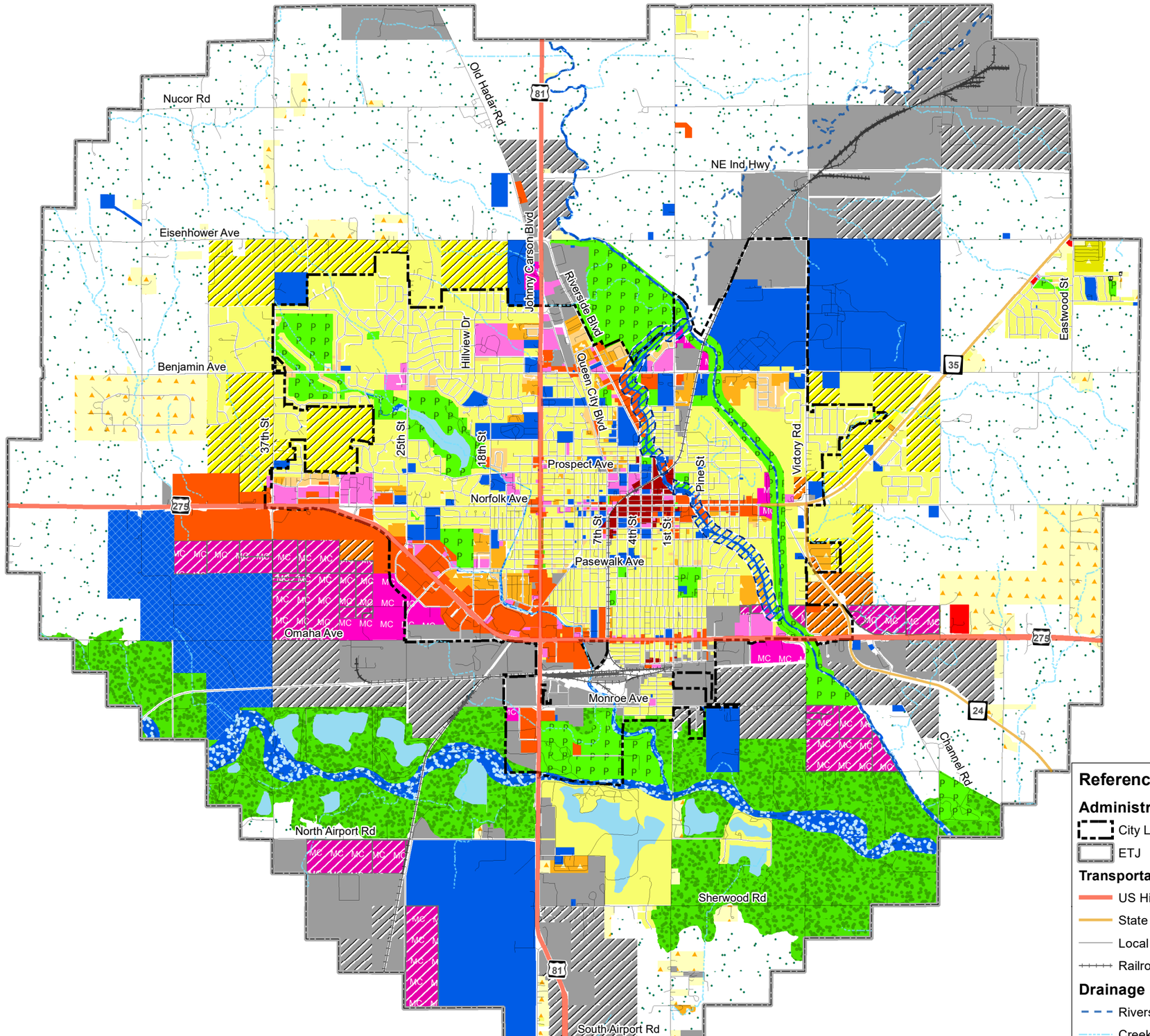

Reference Items

Administrative Bounds

- City Limits
- ETJ

Transportation Network

- US Highway
- State Highway
- Local Road
- Railroad

Drainage System

- Rivers/Streams
- Creeks/Wash

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Figure 46: Future Land Use

Comprehensive Plan
City of Norfolk

Future Land Uses

- Agricultural
- Rural Residential
- Single Family Residential
- Townhomes
- Multi Family Residential
- Mixed Use
- Commercial
- Offices/Services
- Mixed Commerce
- Industrial
- Public
- Parks & Recreation
- Elkhorn River Corridor
- Surface Water
- Residential Reserve
- Commercial Reserve
- Mixed Commerce Reserve
- Industrial Reserve
- City Wellhead
- Water
- North Fork Elkhorn River Corridor

1 inch = 4,000 feet

0 2,250 4,500 9,000 Feet

0 0.375 0.75 1.5 Miles

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5.2 Hydraulics

The hydraulic analysis was conducted utilizing a 2D HEC-RAS model for the drainage area, given that a significant portion of the area experiences overland flow. The model used best available LiDAR data from the NRCS for the terrain, alongside supplemental field collected survey data for the various culvert crossings on critical roadways. Runoff hydrographs that were calculated from the HEC-HMS hydrological component of the model were routed directly to the 2D computational mesh, using internal boundary conditions. These boundary conditions accounted for the combined hydrograph data of each subbasin, that were determined during the hydrological portion of the analysis. In total, 8 HEC-RAS scenarios were created and run to evaluate the depth for the existing and future conditions. This includes 4 scenarios that evaluated the ponding depths of 10-Year and 100-Year storms under existing and future conditions, with the assumption that the outlets that flow through the levee into the North Fork Elkhorn River were open. Another 4 scenarios ran the same storm conditions and land use, but with the levee outlets assumed to be closed in order to see the impact on the flooding extents.

5.3 Results

Through the hydrologic and hydraulic analyses, the peak flows, flooding locations, and the WSE's for the existing and future conditions were determined. The inundation boundaries for the flooding extents of the existing conditions, with both the 10- and 100-year storms, are shown on Figure 6 and Figure 9 below, for open outlets and closed outlets along the levee, respectively. For comparisons between the existing and future conditions flooding extents with the assumed open levee outlets, the results are shown on Figure 7 and Figure 8 for the 10-year and 100-year storm events, respectively. The resulting extents with the levee outlets closed, using the same storm and land use scenarios as above, are located within Figure 10 and Figure 11. The computed maximum flow rate for the 100-year storm events, compared to the previous analysis conducted by Mainelli and Wagner Associates (MWA) are reported in Table 5.

Table 5: 100-Year Flow Rate Result Comparisons

Source	*100-year Flow Rate (cfs)*
JEO - Existing Conditions	1974
JEO - Future Conditions	2082
NDNR	1650
HWS (TR20)	2100
MWA (TR55)	2000
MWA (CiA)	2090

The findings from the current evaluation appear consistent with the previously determined flows and show the extents of potential flooding in the area. Findings indicate that the region north of State Highway 35 and along Victory Rd. experiences significant volume of flooding during 100-year events, with Victory Rd. itself overtopping a maximum of 1.65 and 1.74 feet for existing and future conditions, respectively. During more frequent flooding events of 10-year storms, Victory Rd. still sees some level of overtopping with 0.65 and 0.82 feet during existing and future conditions, respectively. Another significant area of flooding is just north and south of the intersection of US Highway 275 and State Highway 35. The areas just alongside the roadways, during 100-year future conditions, experience ponded depths ranging from 0-5 feet, with Highway 275 overtopping at a maximum of 1.0 foot depth. During 10-year storms, the ponded depths of the surrounding area range from 0-4 feet for future conditions. In comparison, the 4 subsequent scenarios that were run under the assumption that the levee outlets were closed, and their flows moved east, there was minimal change on the overtopping/flooding along Victory Rd. The roadway saw a slight increase in overtopping depths at a maximum of 0.16 feet higher, and an increase of around 0-1 feet in the surrounding locations. The most significant impact that can be seen is additional ponding occurring just west of Victory Rd. and north of Highway 35, extending all the way up towards East Benjamin Ave. Given that these areas, specifically north of Highway 35 and along Victory Rd., are experiencing future development it is clear that some actions should be taken to limit the potential flooding in the region. While the culverts overall are generally sufficiently sized, in many places the channels themselves are undersized and result

in uncontrolled flows throughout the area. Recommendations to achieve these action objectives are provided within the following section 6.

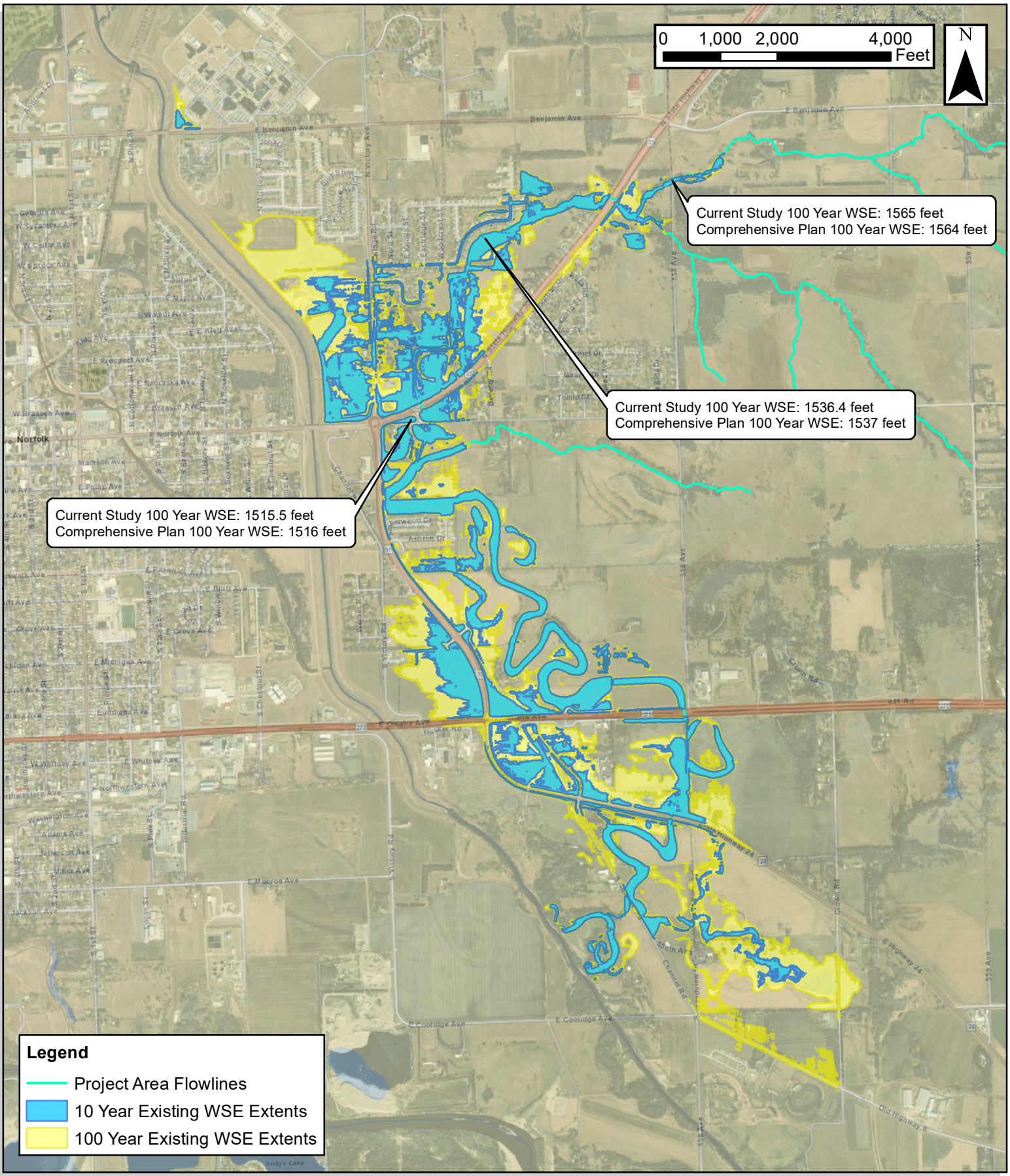

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Figure 6:
Existing Conditions WSE Extents - Open Outlets

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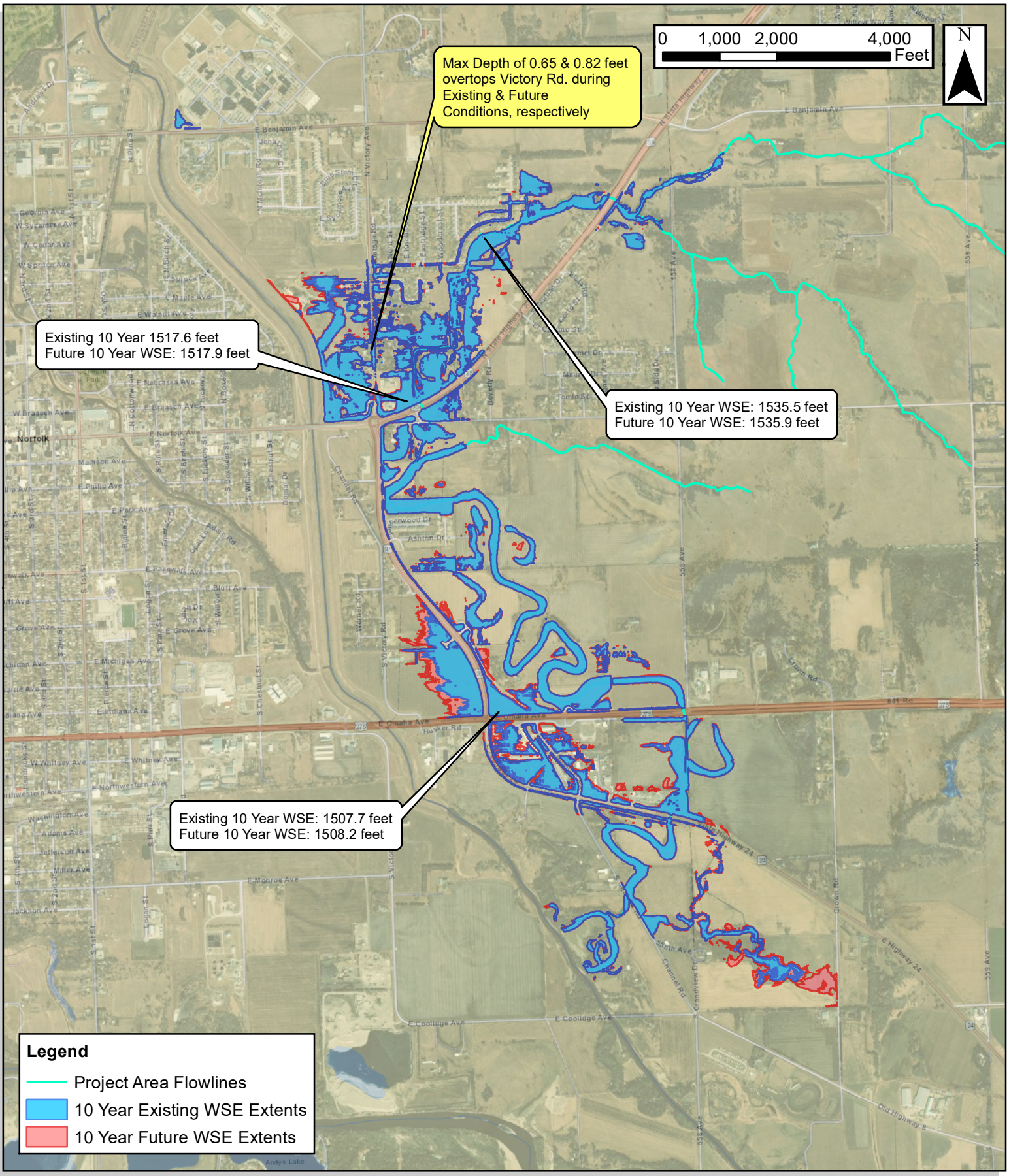

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Figure 7:
10-Year Existing vs. Future WSE Extents - Open Outlets

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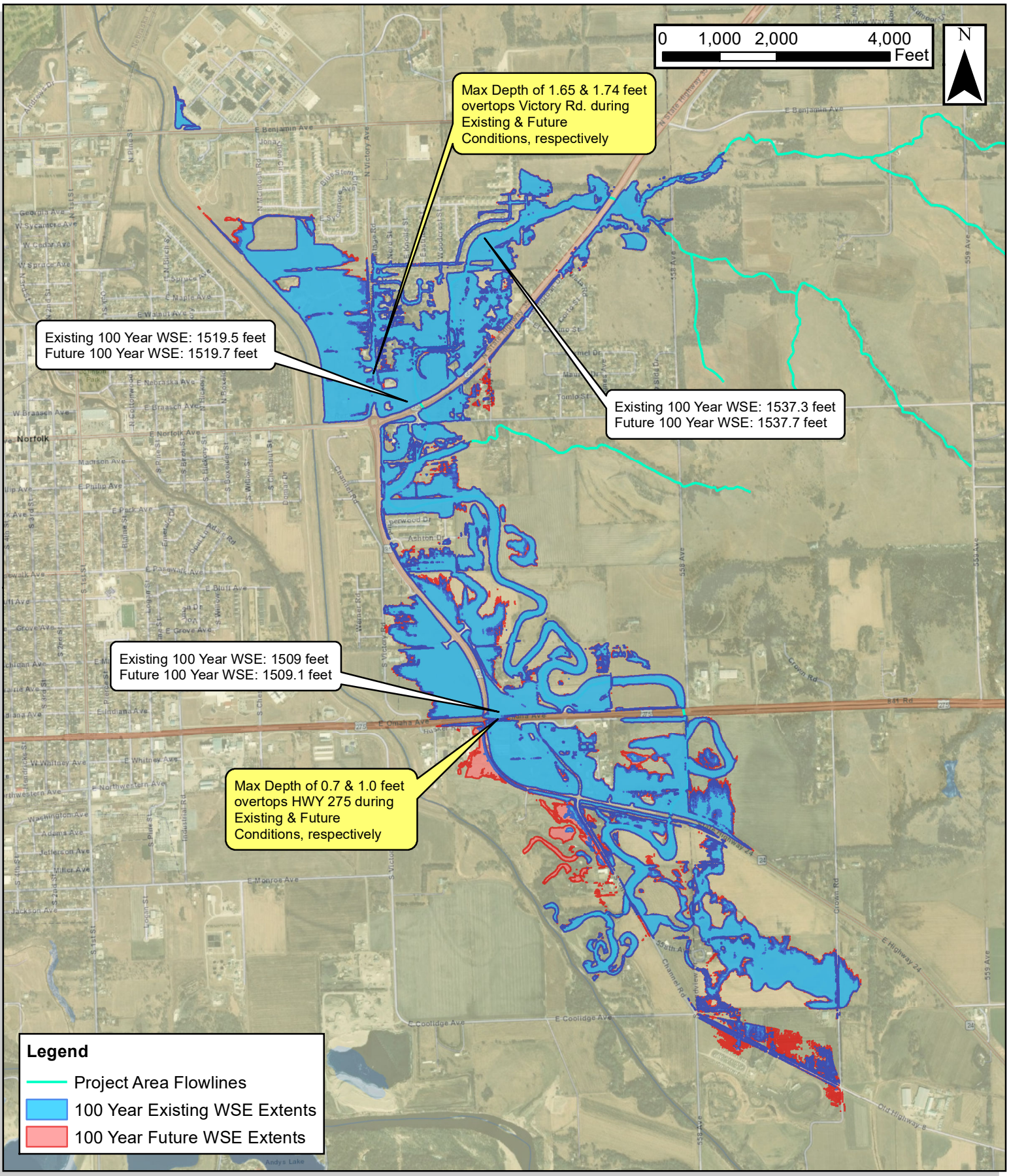

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Figure 8:
100-Year Existing vs. Future WSE Extents - Open Outlets

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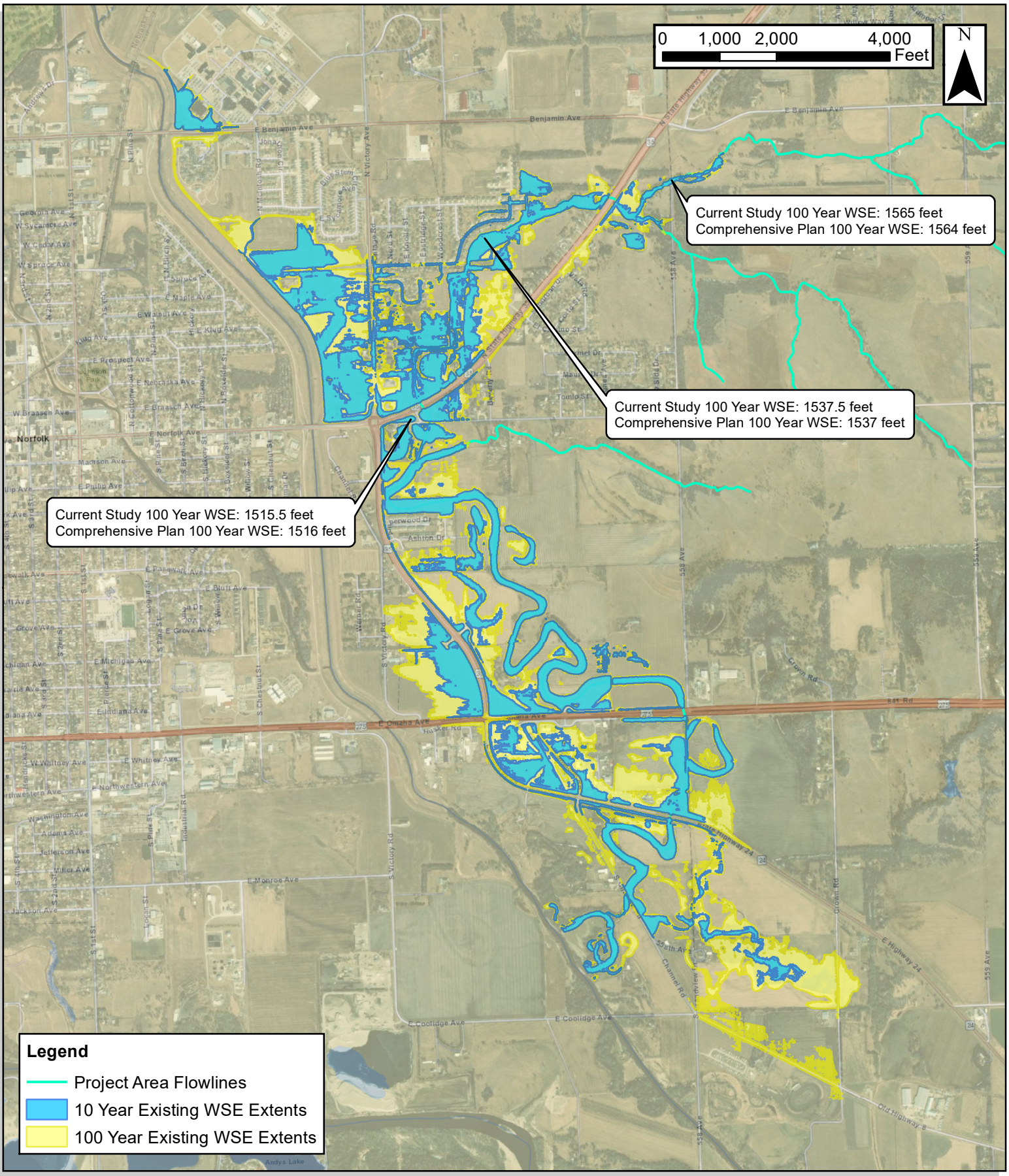

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Figure 9:
Existing Conditions WSE Extents - Closed Outlets

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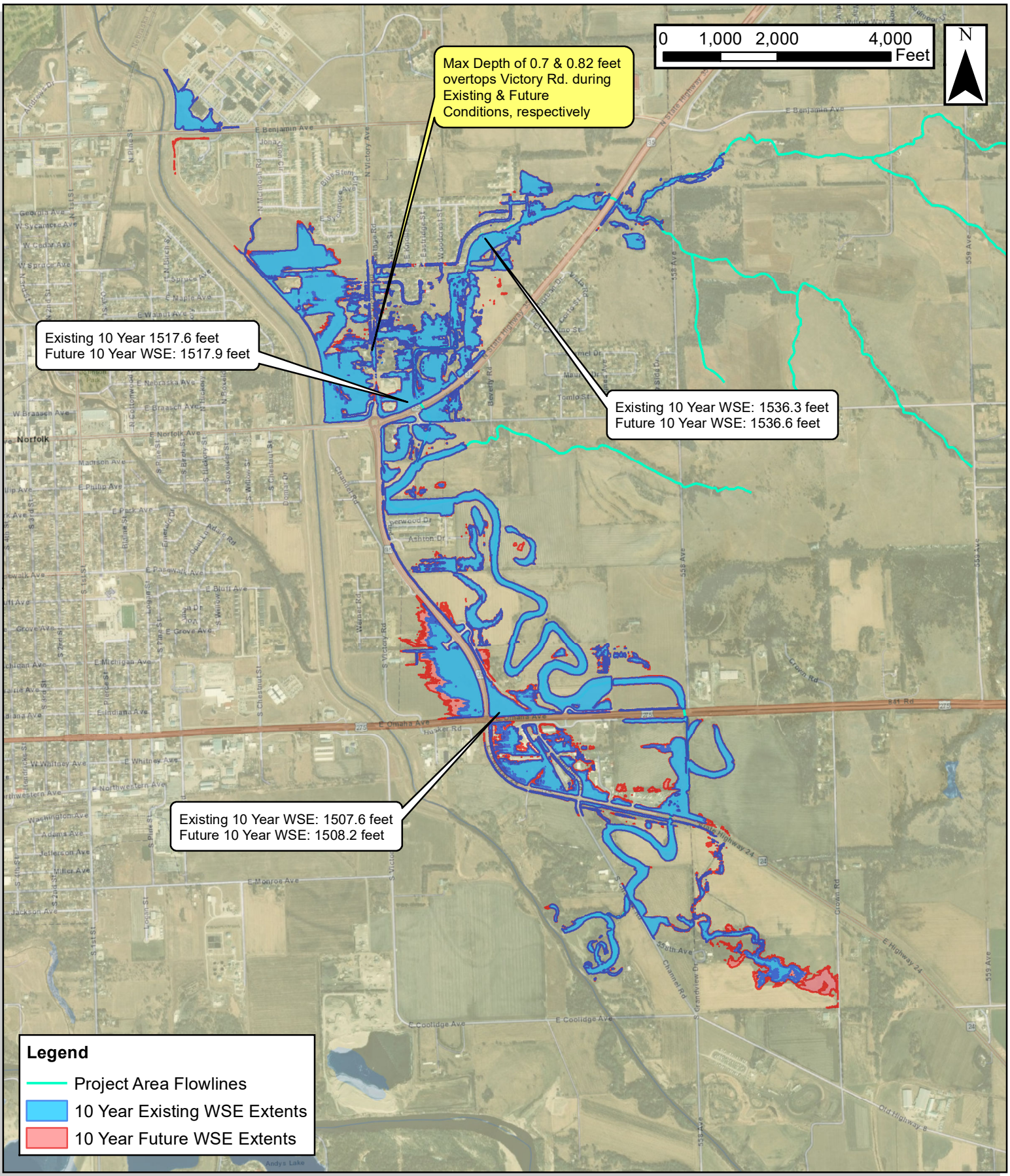

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Figure 10:
10-Year Existing vs. Future WSE Extents - Closed Outlets

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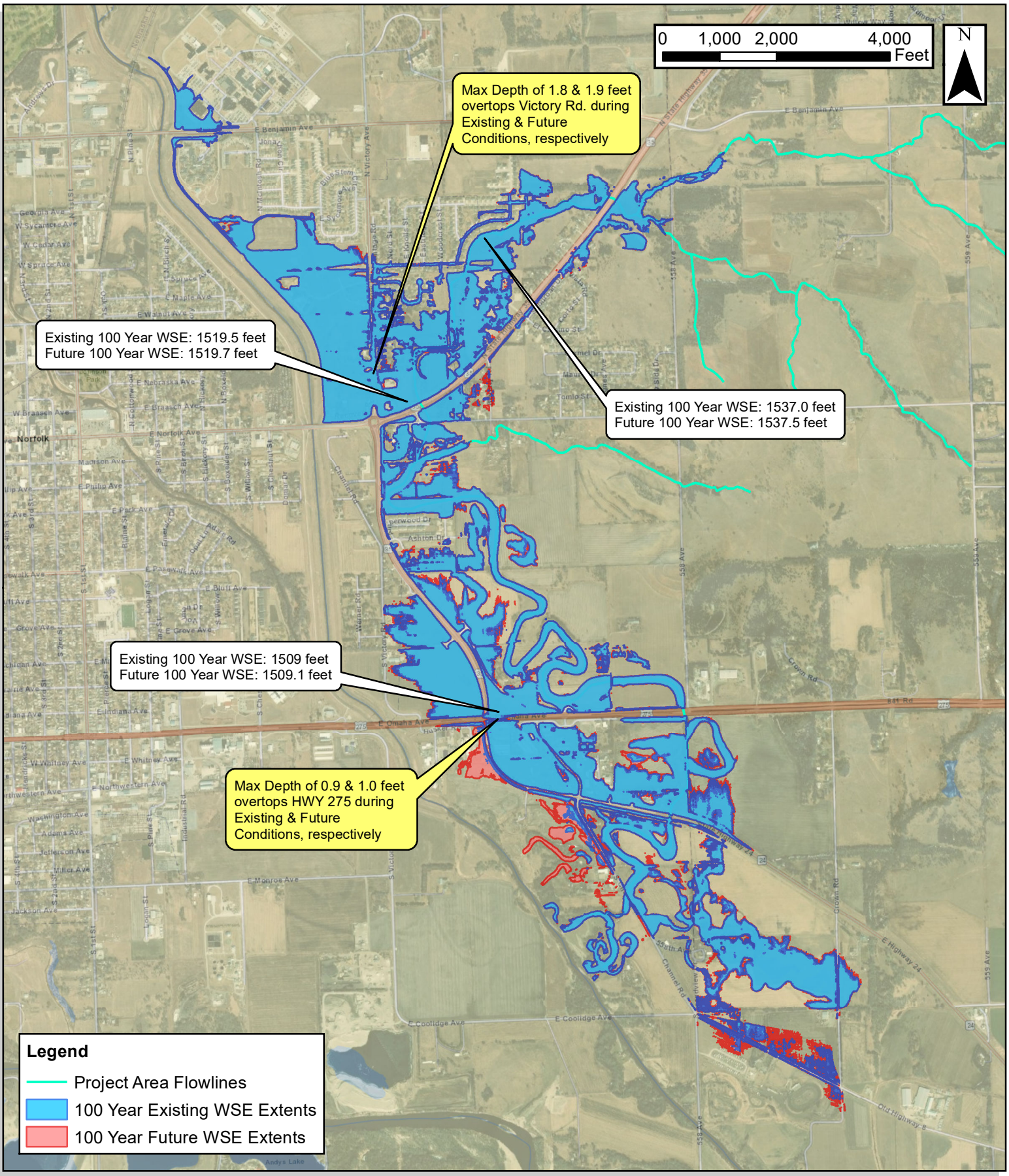

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Figure 11:
100-Year Existing vs. Future WSE Extents - Closed Outlets

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6. RECOMMENDATIONS

Given the extent and location of the flooding in the region, there are a few recommendations on how to mitigate the risk. For the 10-year storm event, channel improvements in key areas could be used to handle the flows more adequately. However, with the 100-year scenario a detention pond would be necessary to manage the increased flows in addition to the channel improvements. These determinations were based upon the flooding extents/WSEL as well as the culvert capacity along the main tributary. The storm event capacities for these culverts can be seen below, with ID's referenced in Figure 2 and Figure 12.

Table 6: Main Tributary Culvert Capacities

Culvert ID	Storm Event Capacity*
1	Greater than 100-Year
5	Greater than 100-Year
6	10-Year
8	Less than 10-Year
9	Greater than 100-Year
23	25-Year
25-26	Less than 10-Year
*These capacities are based on existing conditions	

While most of these culverts are sufficiently sized, there are a few exceptions. Culvert #8 is sized below a 10-year event, however, this constriction is currently serving to create a de-facto detention pond just upstream and effectively reduces the flows downstream. This culvert appears to be a private field access and all ponding associated with this undersized culvert is limited to the same agricultural field. Increasing the size and conveyance of this culvert without adding additional, or at least compensatory detention, may worsen conditions downstream. This undersized culvert has little impact for larger storms as it will be overtopped and larger storm event flows will not be impeded.

Culvert #25-26 are both on the southernmost end of the project area and are currently insufficiently sized for 10-year events. Due to this being further downstream of the critical concern area, it does not affect the future construction space but should be noted as a potential opportunity for increasing the culvert size to adequately handle greater storm events as development occurs in the area. The analysis concludes that the roadway (S. Channel Rd.) may frequently overtop. This overtopping does not currently have any significant impact to upstream water surface elevations or flood risk as the flows from larger events overtop the roadway and are conveyed. If development pressure continues in this area, then modifications to these culverts and to S. Channel Rd. may be warranted. The two proposed improvements are discussed below.

6.1 Administrative Measures

The City of Norfolk has recently adopted (August 2020) a Drainage Criteria Manual. This document outlines design criteria for future development within the planning and zoning jurisdiction. There are two sections of this criteria that are critical as this area continues to develop.

Section 1.4.4 Detention contains requirements for future development to include detention/retention facilities for both water quality and quantity. Post-project peak flow rates shall not exceed existing peak flow rates for the 2-year, 10-year and 100-year discharges. (Refer to the Drainage Criteria Manual for specific language).

Section 1.4.5 Flood Corridor Management contains requirements for the preservation of a minimum flood corridor of the greater of either the 100-year floodplain or the channel bottom width, plus 60 feet, plus six times the channel depth. (Refer to the Drainage Criteria Manual for specific language).

As this area continues to develop, it is recommended that at a minimum strict compliance with the Drainage Criteria Manual is maintained.

6.2 Channel Improvements

A potential option in order to properly maintain the necessary flows for the 10-year storm events and reduce the flood risk along the main project tributary is to excavate out additonal channel segments. These proposed improvements would be along areas of the tributary with the least defined existing channel beds and overbanks, particulary in the region just north and south of State Highway 35. The analysis indicates that the existing channel configurations and sizes are more of an obstruction to conveyance than the existing culverts in many locations.

These locations of concern are noted below in Figure 12 as well as the recommended sizing of the channel and proposed berm structure. Within these locations, the modeled improvements were run using the bottom channel widths identified in Figure 12, 5 to 1 channel slopes, and a mannings along the channel of 0.03. The proposed berm on the west side of the channel, just north of State Highway 35 would be used to contain the additional flooding along that region. Proposed channel cross sections for this reach are quite wide varying from 60' to 80' wide (Refer to Figure 12). In reality the final design of these channels should consider a multi-stage channel configuration or other methods to manage the long term maintenance concerns. Given the minimal slope in this reach, the final design of these channels should consider the impacts of siltation and/or vegetation. Additional considerations for addressing larger events with a regional detention facility are included in the following section. The final design of channel improvements in this area should also be coordinated with any detention to provide a holistic solution.

For the model, the berm was sized with a 3 foot width and 3 to 1 side slopes. In order to continue to allow flow along the ditch just north of Highway 35, a culvert would need to be added through the berm as well as a flap gate to prevent backflow from the main channel. The results of the model for the 10-year event compared to the existing conditions can be seen below in Figure 13. The flooding areas north of Highway 275 become significantly more confined to the channel throughout, particulary in the reach north of State Highway 35. This reduction in water elevation also prevents the overtopping of the roadway on Victory Rd. that is seen in the current existing model.

6.3 Regional Detention Facility

This analysis reviewed the existing conditions of the entire watershed and very few locations for adequate upstream detention large enough to provide a significant reduction in flows were located. Most of the areas do not provide adequate topography or open/undeveloped areas.

The analysis did identify one potential location for a regional detention pond along the northern portion of the tributary north of State Highway 35 that would reduce peak flows for up to the 100-year event. This area is currently undeveloped with a residential area to the north. (Refer to Figure 12) This area given the tributary running through it is critical to the watershed. Any future development of will be very critical to the flow conveyance. This area, with adequate sizing, would be able to detain much of the flows between the 10-year and 100-year events. For the calculations, it assumed the 60-foot-wide channel improvement north of State Highway 35 (presented above) would be implemented alongside it in order to convey the flow. With this, the channel capacity would be 1160 cfs for the 60-foot section. For the 100-year storm event, the channel has a maximum flow of 1675 cfs. In order to accommodate the volume beyond the proposed channel capacity, a detention pond sized at approximately 32.5 acre-feet would need to be constructed to maintain the channel up to the 100-year storm condition.

As this area is considered for development, it is strongly recommended that adequate open space is maintained to provide this detention. Potential uses such as parks, athletic fields or other uses compatible with occasional flood storage are recommended. A final design that includes a minimum storage of 32.5 acre-feet is recommended.

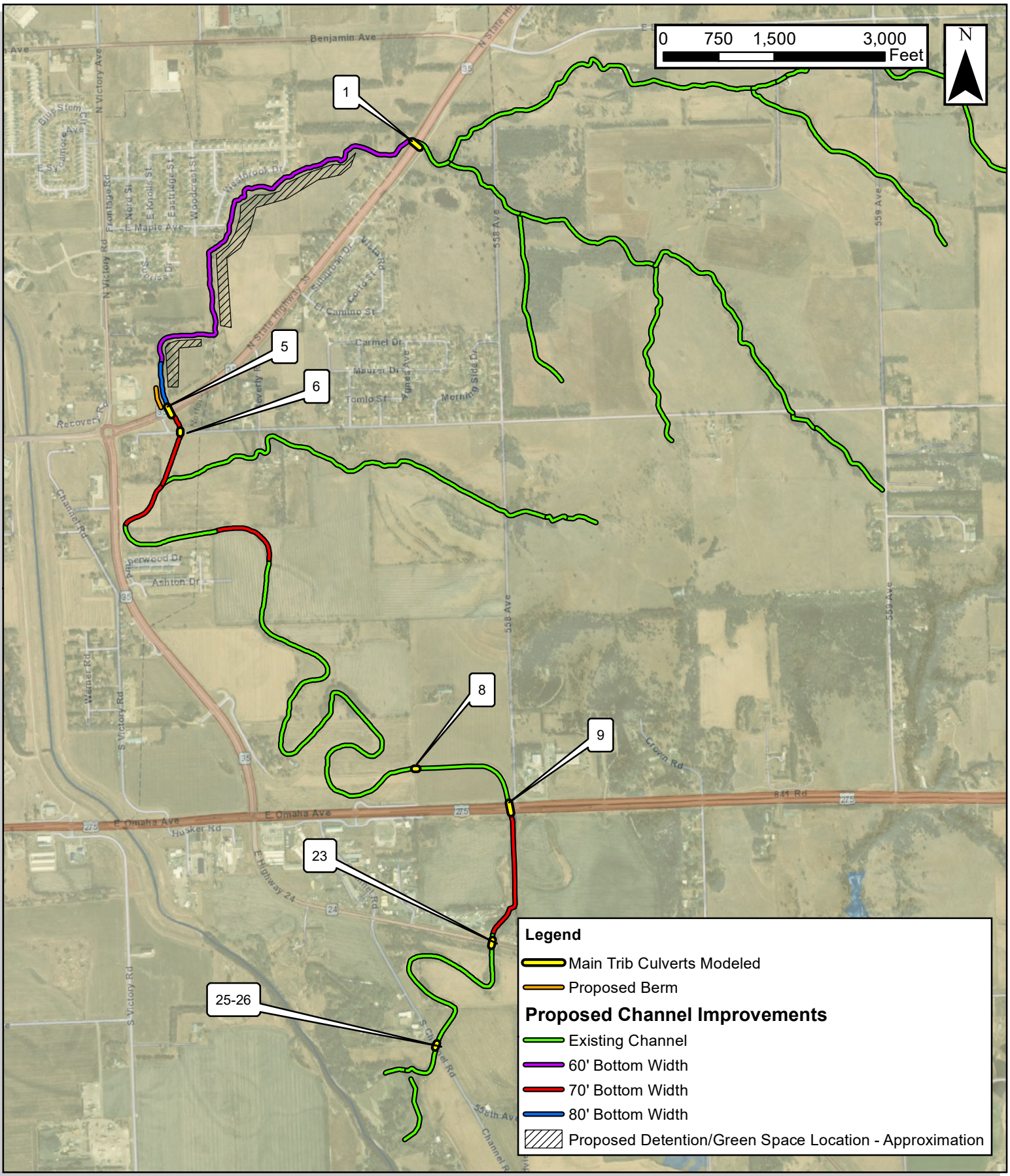

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Figure 12:
Proposed Structural Improvement Location and Sizing

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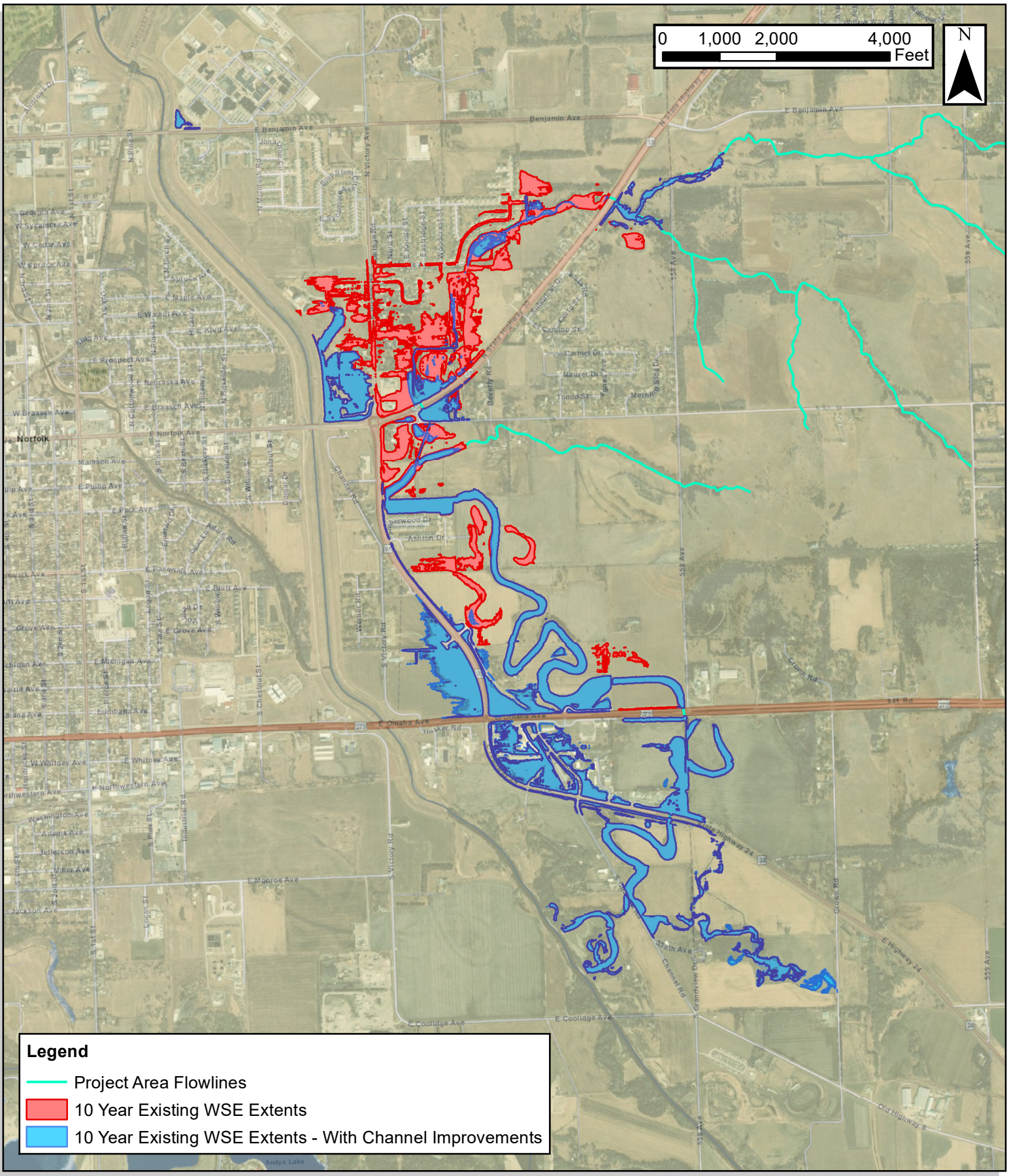

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Figure 13:
Existing Conditions with Channel Improvement - Open Outlets

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