OFFICE COPY

North Area Drainage Study

Wahoo, Nebraska

JEO
Consulting Group, Inc.

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OVERVIEW

The purpose of this study is to evaluate the flooding conditions for an area immediately northwest of the City of Wahoo. Flooding along the primary drainage way in this area has been of substantial concern to area residents. In addition, residential/commercial development of agricultural land is anticipated in the upper portions of the watershed which could potentially exacerbate the problem. As part of the study, drainage deficiencies and potential for flooding were identified through hydrologic and hydraulic (H & H) analysis. The analysis considered existing conditions, as well as future conditions based on expected further development. Based on this analysis, conceptual improvements were developed and are provided along with probable opinion of cost. Conceptual improvements were developed to: reduce existing flood risks; and mitigate increased flood risks due to future development. Also provided are watershed management recommendations. Though not actual projects, these recommendations could be implemented by the City to further assist in mitigating flood risks. This drainage study and the projects identified herein are supplement to the effective 2007 Wahoo Hazard Mitigation Plan.

The City of Wahoo is located approximately 25 miles north of Lincoln, in Saunders County, Nebraska. The drainage area (watershed) for the analysis is located in the northern portion of the City. The watershed encompasses approximately 375 acres of both residential and agricultural land. The primary drainage way within the study area begins northwest of the intersection of County Road M (CoRd M) and County Road 17. It continues south along CoRd 17, crossing Chestnut Street north of 16th Street. This drainage way discharges into Sand Creek approximately one-half mile east of Chestnut Street.

STUDY PROCEDURES

To evaluate the flooding conditions within the study area, an H & H analysis was conducted. The objectives were:

1) to determine how much runoff is generated and where it is flowing (Hydrology)

2) to determine the capability of the drainage system to convey such runoff (Hydraulics)

HYDROLOGY

Future development within the study area can have substantial impacts on stormwater drainage. Changes in land use (i.e. from agricultural land to commercial development) can alter the stormwater runoff characteristics. As such, this analysis investigated two scenarios based upon the development of the watershed. The first scenario considered existing land use conditions. The second scenario considered full development conditions within the watershed. Full development is defined as: all current undeveloped land will be of residential land use, except where zoned for commercial land use as identified in the unofficial Wahoo Zoning Map. A copy of the unofficial Zoning Map is included in the Appendix.

The SCS Method (also called TR-55 Method) was used to estimate peak runoff (Q) at several critical locations throughout the study area. This method relates peak runoff rates to precipitation depths, land use and topography. A curve number (CN) is used to represent the proportion of precipitation that contributes to runoff, based on land use types, hydrologic soil groups and management practices. A time of concentration is also used to represent the amount of time elapsed after the beginning of a storm event to the point at which runoff rates peak. The peak runoff rate is determined by an empirical equation that relates the quantity of runoff from a given area to a total rainfall that is falling at a uniform rate on the same area. The 50-year storm event is the storm that has a two percent (2%) chance of occurring in a given year. The 10-year, 50-year and 100-year storm event were considered for this analysis. The 24-hour rainfall depths for the 10-year, 50-year and 100-year storm event are 4.5, 5.9 and 6.5 inches, respectively.

Using information provided by field surveys and USGS topographic maps, drainage areas within the study area were delineated for the hydrologic analysis. Determination of the drainage basins was done in such manner as to focus on critical locations in the system (culverts and ditches). The delineated drainage basins for are shown in Figure 1 and are labeled according to the designated stream reach. Table 1 describes the primary land use for each sub-basin and each development condition. For the purposes of this study, the primary drainage way was divided into three stream reaches. The 'Upper Reach' (UR) is approximately 3,700 feet in length and is located north of 23rd Street. The 'Middle Reach' (MR) is approximately 2,000 feet in length and is located south of 23rd Street and west of Chestnut Street. The 'Lower Reach' (LR) is approximately 3,000 feet in length and is located between Chestnut Street and the confluence with Sand Creek. The stream reach designations are illustrated in Figure 2.

Table 1: Sub-basins for Hydrologic Analysis

Sub-basin ID	*Existing Conditions Primary Land Use*	*Fully Developed Conditions Primary Land Use*
LR01	Agricultural	Residential
LR02	Residential	Residential
MR01	Commercial	Commercial
MR02	Residential	Residential
MR03	Agricultural	Commercial
MR04	Agricultural	Residential
UR01	Agricultural	Commercial
UR02	Agricultural	Residential
UR03	Agricultural	Commercial
UR04	Agricultural	Commercial
UR05	Agricultural	Residential
UR06	Agricultural	Commercial
UR07	Agricultural	Residential

HYDRAULICS

Field surveys were conducted to obtain topographic cross-sections of stream reaches at several locations within the study area. The cross-sections were obtained at sufficient intervals to accurately represent the channel and overbank geometry for the hydraulic model. The configuration and location of each cross-section is illustrated in Figure 2. Cross-section labels approximate the stationing (distance) along the reach, upstream of the confluence with Sand Creek.

Also obtained during the field data collection, were first-floor elevations (FFE) for several structures along the Middle Reach, in the area of primary flooding concern. Digital photographs of streams and drainage structures are included the Appendix, as well as photographs of flooding from recent storm events.

The Manning's equation was used to evaluate the hydraulic characteristics of stream reaches and culverts within the study area. The capacity of a stream to convey stormwater is dependent upon channel geometry, slope and surface roughness (also called Manning's coefficient). Typical Manning's coefficients for natural ditches can range from 0.030 (grass) to 0.060 (dense vegetation). The Manning's coefficient for concrete-lined channels can be as low as 0.013 which contributes significantly to conveyance capacity. Runoff rates, as determined from the hydrologic analysis, were input into the hydraulic model at key locations to determine the flooding elevations.

STUDY FINDINGS

Through the H & H analysis, peak runoff rates and flood elevations at specific locations were determined. The resulting peak discharges (cubic feet per second, cfs) for each scenario for the 100-year storm event are shown in Table 2 and are the basis for the drainage improvement recommendations. Analysis results for the 10- and 50-year storm events are included in the Appendix.

Table 2: Analysis Results for 100-year Storm Event

Location	*Cross-Section ID*	*Existing Conditions*		*Fully Developed Conditions*	
		Q (cfs)	*Elevation (ft)*	*Q (cfs)*	*Elevation (ft)*
North of CoRd M	8231	292	1265.16	368	1265.26
At CoRd M (60-inch RCP)	7755	292	1262.39	368	1262.57
South of CoRd M	6508	625	1245.86	829	1246.17
Adjacent to 23rd St.	4945	838	1231.66	1157	1232.12
Northeast of Walnut St.	3633	906	1223.53	1272	1224.02
East of Walnut St.	3271	906	1220.87	1272	1221.22
At Chestnut St. (6-ft x 6-ft RC Box)	2897	928	1218.34	1325	1218.83
East of Chestnut St.	2052	928	1200.21	1325	1201.09
West of Sand Creek Confluence	848	1055	1184.80	1466	1185.43

As evident from the H & H analysis, anticipated land development within the study area may contribute to increased flooding risks. Flood elevations determined from the analysis do suggest the potential for flooding to structures along the Middle Reach during a 100-year storm event. The channel along the Middle Reach is very shallow, not well defined. Though many factors contribute to channel conveyance and flood elevations (i.e. downstream impacts), the geometry or size of the channel along this reach was specifically identified as the overriding cause. It was determined that overtopping of the Chestnut Street culvert (6-foot by 6-foot concrete box) does occur during major storm events. However, it does not appear that backwater effects due to the culvert deficiency contribute significantly to flooding elevations upstream. The deficiency does result in increased flood elevations locally, potentially encroaching upon structures immediately east of Chestnut Street. To further illustrate the results of the analysis, the 100-year 'flood corridor' was delineated for fully developed conditions, in Figure 3. The flood corridor

approximates the maximum flooding limits during the 100-year storm event. Also included at several locations is the 100-year flood elevation under these conditions.

The delineated flood corridor is based upon available 10-foot vertical contour data and is for guidance only and should not be used for FEMA floodplain regulation or flood insurance purposes.

Field observations identified dense vegetation and potential bank instability along the Lower Reach, east of Chestnut Street. Obstructions along the channel banks can negatively impact conveyance capacity, which was reflected in the hydraulic results through increased flood elevations relative to a clean, uniform channel. However, the potential for flooding in the Lower Reach appeared substantially less than within the Middle Reach. Continued maintenance and monitoring of the channel condition by City staff would aid in identifying further degradation in the early stages.

STUDY RECOMMENDATIONS

Several recommendations have been developed, and provided as part of this study. Drainage improvement recommendations provided include channel improvements to increase conveyance and detention to reduce peak runoff rates, each resulting in reduced flooding elevations. Watershed management recommendations are also provided, serving to assist the City manage future development as it pertains to stormwater runoff.

DRAINAGE IMPROVEMENT RECOMMENDATIONS

As indicated previously, drainage improvement recommendations were developed to not only address flooding concerns along the Middle Reach, but to mitigate adverse flooding impacts due to future development. Proposed projects include open channel improvements to improve overall drainage system efficiency, thereby reducing flood elevations. Projects also include a detention structure, providing a means to store excess runoff and control the rate of release. By reducing peak runoff rates, this type of project also contributes to reduced flood elevations. These recommendations are preliminary in nature and shall not be used for construction purposes. Continued maintenance, while not included in the proposed projects, will enhance the drainage system's effectiveness and can be performed by City maintenance staff.

Project MR-01: Concrete-lined Open Channel Improvements Upstream of Chestnut Street

The existing open channel within the Middle Reach, adjacent to Walnut Street does not provide sufficient capacity to convey peak flows during a 100-year storm event. The proposed channel should have a trapezoidal cross-section with a bottom width of twenty feet, side slopes of 2:1 (H:V), and depth of 3.5 feet. The channel lining will be made of concrete to maximize conveyance and minimize maintenance needs. The channel side slopes will be natural grass. The flowline elevation at the upstream limit should be dropped by 0.5 feet, and the length of the proposed channel should be re-graded to achieve a constant slope. The existing channel immediately upstream of the proposed channel should be re-graded locally to sufficiently transition to the new flowline elevation. Crushed rock rip rap is also recommended at the upstream and downstream limits of channel improvements to ensure proper performance and prevent erosion. Refer to Figure 4 for the configuration of proposed improvements for Project MR-01.

Project MR-02: Natural-lined Open Channel Improvements Upstream of Chestnut Street

As an alternative to a concrete-lined channel, a natural grass-lined channel is proposed. The grass-lining, though less efficient at stormwater conveyance, can provide additional aesthetic benefits and can potentially be more cost-effective. This channel should have the same shape and geometry of the proposed concrete-lined channel: a trapezoidal cross-section with a bottom width of twenty feet; side slopes of 2:1 (H:V); and depth of 3.5 feet. The channel lining and side slopes will be of natural grass. As with Project MR-01, the flowline elevation at the upstream limit should be dropped by 0.5 feet, and the length of the proposed channel should be re-graded to achieve a constant slope. The existing channel immediately upstream of the proposed channel should be re-graded locally to sufficiently transition to the new flowline elevation. Crushed rock rip rap is also recommended at the upstream and downstream limits of channel improvements to ensure proper performance and prevent erosion. Refer to Figure 4 for the configuration of proposed improvements for Project MR-02.

Flood elevations for this proposed channel will be greater than those for the proposed concrete channel. For this reason, this project is recommended in conjunction with regional detention upstream, as proposed for Project UR-01 or UR-02.

Project MR-03: Culvert Improvements at Chestnut Street

According to the analysis, the existing culvert at Chestnut Street is deficient, without sufficient capacity to prevent roadway overtopping during a 50-year storm event. An additional 6-foot by 6-foot concrete box culvert is proposed, parallel to the existing culvert. This improvement is not intended to provide conveyance for 50-year peak flows. Improvements to achieve such conveyance were not deemed cost-effective. Instead, the addition of the parallel barrel will reduce local 100-year flood elevations, protecting nearby structures. Refer to Figure 4 for the configuration of proposed improvements for Project MR-03.

Project UR-01: Regional Detention Basin East of 23rd Street

Stormwater detention is another method for managing runoff to mitigate flooding. A regional detention structure is proposed at the downstream portion of the Upper Reach, adjacent to the existing 23rd St. The concept design for the structure evaluated at this site is based upon coincident improvements along the Middle Reach, as identified for Project MR-02. The attenuation of peak flows provided by the detention basin will offset the increased flood elevations for the grass-lined channel improvements along

the Middle Reach as compared to the concrete-lined channel. The proposed detention (dry) pond will provide approximately 19 acre-feet of storage volume at a maximum depth of 5 feet. The top of bank surface area of the pond should be approximately 5 acres. The proposed outlet structure should be a concrete weir, 20 feet wide by 5 feet tall with sufficient rock rip rap and overflow protection to prevent erosion. Refer to Figure 5 for the configuration of proposed improvements for Project UR-01.

Project UR-02: Regional Detention Basin at Proposed 23rd Street Extension

The Transportation Plan within the 2006 Wahoo Comprehensive Plan identifies a proposed extension of 23rd Street, east to connect with Chestnut Street. The outlet structure proposed for project UR-01 would require substantial modification to function properly if a roadway were to be constructed at this location. Therefore, a second conceptual alternative has been developed for this outlet structure to accommodate a future roadway crossing. The proposed detention basin would remain the same, at the downstream portion of the Upper Reach, providing approximately 19 acre-feet of storage volume at a maximum depth of 5 feet. The top of bank surface area of the pond should be approximately 5 acres. The proposed roadway crossing should be a concrete structure with a total 24-foot span, 5 feet from flowline to roadway centerline. Roadway overtopping would be anticipated during 100-year storm events and sufficient rock rip rap and overflow protection to prevent erosion are recommended. Once again, the concept design for these structures is based upon coincident improvements along the Middle Reach, identified for Project MR-02. Refer to Figure 5 for the configuration of proposed improvements for Project UR-02.

WATERSHED MANAGEMENT RECOMMENDATIONS

Additional recommendations are provided as potential regulatory measures for the City in regards to new development within the study area. These watershed management recommendations are examples of typical municipal regulations and may not be applicable for the City of Wahoo. If adopted by the City, enforcement of similar regulations would be at the discretion of City staff.

Stormwater Requirements for New Development

Changes in runoff characteristics should be regulated to include measures to mitigate changes incurred due to new development. Detention and retention facilities are ways to mitigate changes in runoff such as amount and volume. Detention and retention facilities can be included within a site design or can be incorporated into a larger facility that mitigates for development over a larger area and span of time. On-site storage facilities are required unless the master planning process or regional analysis as shown that the detention requirements can be transferred to a regional facility, which is determined to be of regional benefit to the drainage system by the City. On-site detention facilities shall have release rates that do not exceed the pre-development peak discharge rates for the 2-year, 10-year, and 100-year storms. New development shall entail either on-site stormwater mitigation measures, or contribution to regional stormwater facilities if available.

A candidate could be the Sycamore Hills Subdivision. This site is located west of the Middle Reach, north of Walnut St. and south of 23rd St. New development at this site, as with many new developments, likely will increase stormwater runoff due to increased impervious surfaces. As part of the site plan, a detention pond was proposed to

regulate post-development runoff. Though it does appear adequate to handle on-site drainage, it is unlikely to provide appreciable flood benefits downstream. As an alternative to building on-site storage for local drainage, the owner may contribute funding to a regional stormwater management structure which will provide significant flood benefit to local residents.

Detention Pond Maintenance

Storage facilities proposed in a development, along with all inlet and outlet structures and/or channels, are to be owned and maintained by the developer or a property-owners' association unless a different ownership/maintenance arrangement has been approved by the City. Facilities shall be designed to minimize maintenance problems typical of urban detention facilities such as; weed growth, grass and vegetation maintenance, sedimentation control, bank deterioration, standing water or soggy surfaces, mosquito control, blockage of outlet structures, litter accumulation, and maintenance of fences and perimeter plantings. Proper design focuses on elimination or reduction of maintenance requirements by addressing the potential for problems to develop. The bottom area of storage facilities shall be graded toward the outlet to prevent standing water conditions.

100-year Flood Corridor

Proposed development shall not encroach upon the minimum 100-year flood corridor where possible. New development shall be designed so the lowest opening of adjacent new buildings is a minimum of one foot above the calculated 100-year flood elevation. The sequencing process shall include an evaluation of alternative approaches in the order listed below:

Avoidance: Encroachment of riparian vegetation and the existing grade should be avoided if there is a practicable alternative that does not cause encroachment.

Minimization: If it is determined that avoidance is not practicable then steps must be taken to minimize impacts to the riparian vegetation and/or the existing grade.

Mitigation: Impacts to the riparian vegetation or to the existing grade must be mitigated after an appropriate and feasible alternative has been chosen through minimization.

If avoidance is deemed not feasible, sufficient evidence shall be provided demonstrating a 'no-net rise' in the 100-year flood elevation. Additionally, the elevations of any building or structure along open channels must be provided indicating that no opening in the building or structure is subject to flooding at the proposed 100-year elevations.

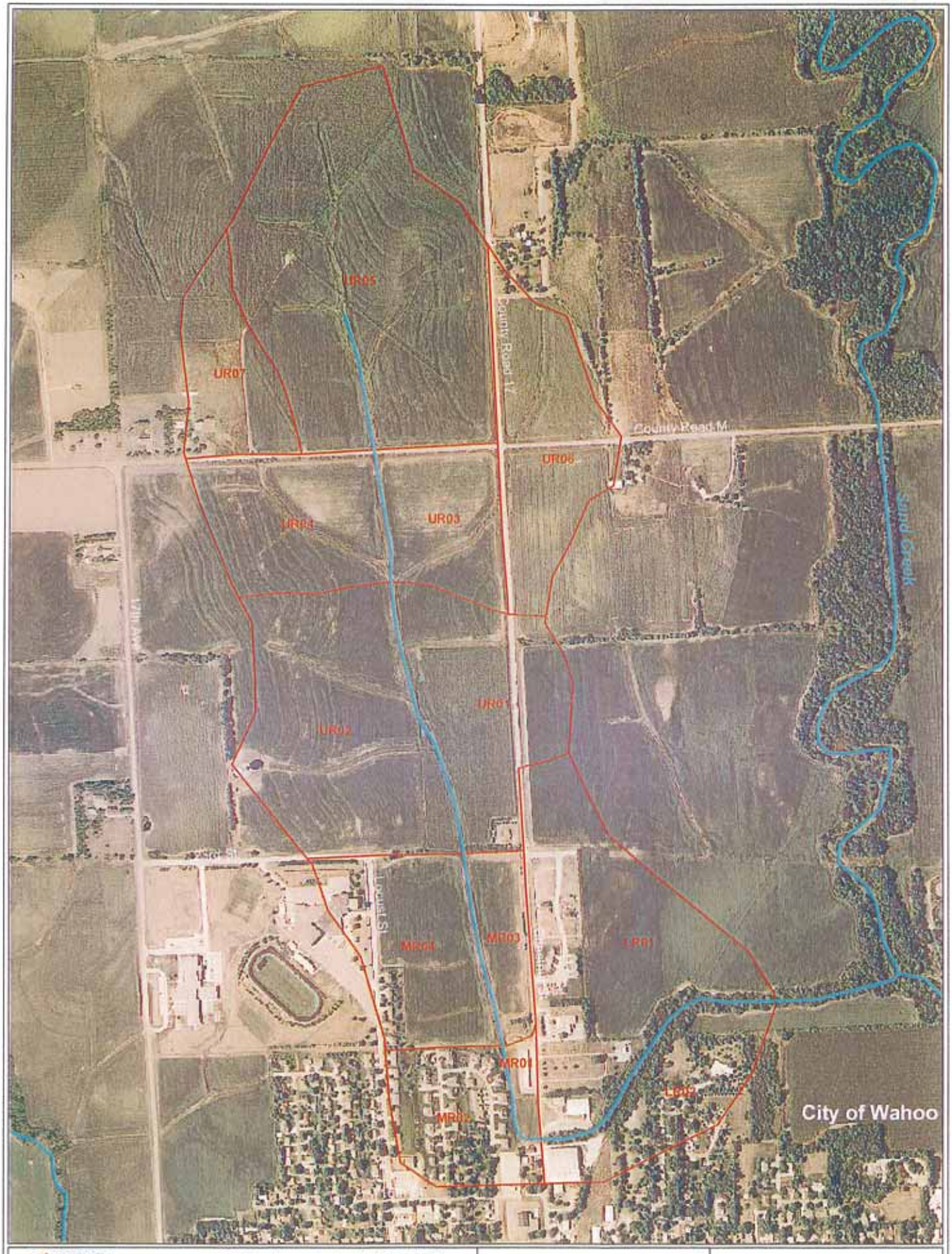
PROBABLE OPINION OF COST

Preliminary cost opinions are provided in Table 3 for the proposed drainage improvements. The probable cost opinions are based on cost information from the Nebraska Department of Roads and recent similar project experience. Engineering costs were estimated at 30% of total construction costs and include field survey, project design and bidding services. Contingencies (i.e. unplanned field modifications) were also included in the cost opinions and were estimated at 20% of total construction costs. No detailed topographic survey has been performed to locate existing utilities. Potential conflicts with these utilities may have an effect on final design. For this reason, actual project costs may vary due to changes during final design. The City maintenance staff may be able to complete some of the work in-house, reducing the work needed from an outside contractor. This also may cause actual project costs to vary from this preliminary cost opinion.

Table 3: Probable Opinion of Cost

Project ID	*Description*	*Opinion of Cost*
MR-01	Concrete-lined Open Channel Improvements Upstream of Chestnut Street	$270,000
MR-02	Natural-lined Open Channel Improvements Upstream of Chestnut Street	$70,000
MR-03	Culvert Improvements at Chestnut Street	$85,000
UR-01	Regional Detention Basin East of 23rd Street	$105,000
UR-02	*Regional Detention Basin at Proposed 23rd Street Extension	N / A

** Project UR-02 may be completed in coordination with proposed 23rd Street improvements and costs may vary.*



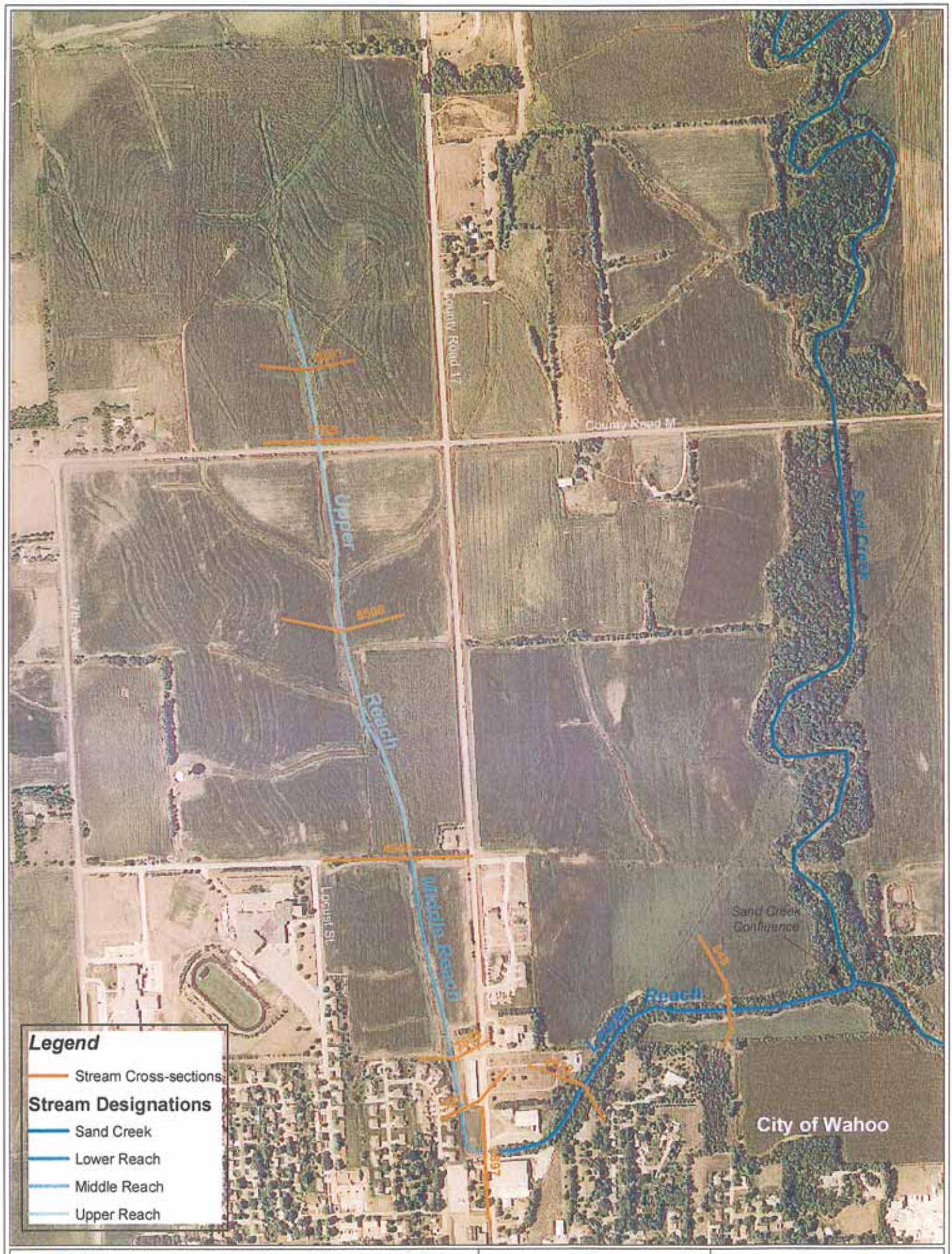
JEO Consulting Group, Inc.
Aug. 08, 2008

2008 Drainage Study - North Study Area
City of Wahoo, Nebraska
JEO Project # 607D19

0 212.5 425 850 Feet

N

FIGURE 1:
Hydrologic Sub-Basin Map



JEO Consulting Group, Inc.
Aug. 08, 2008

2008 Drainage Study - North Study Area
City of Wahoo, Nebraska
JEO Project # 607D19

0 250 500 1,000 Feet

N

FIGURE 2:
Hydraulic Cross-Section Map

JEO Consulting Group, Inc.
Aug. 08, 2008

2008 Drainage Study - North Study Area
City of Wahoo, Nebraska
JEO Project # 607D19

0 187.5 375 750 Feet

N

FIGURE 3:
100-year Flood Corridor Map
Fully Developed Conditions

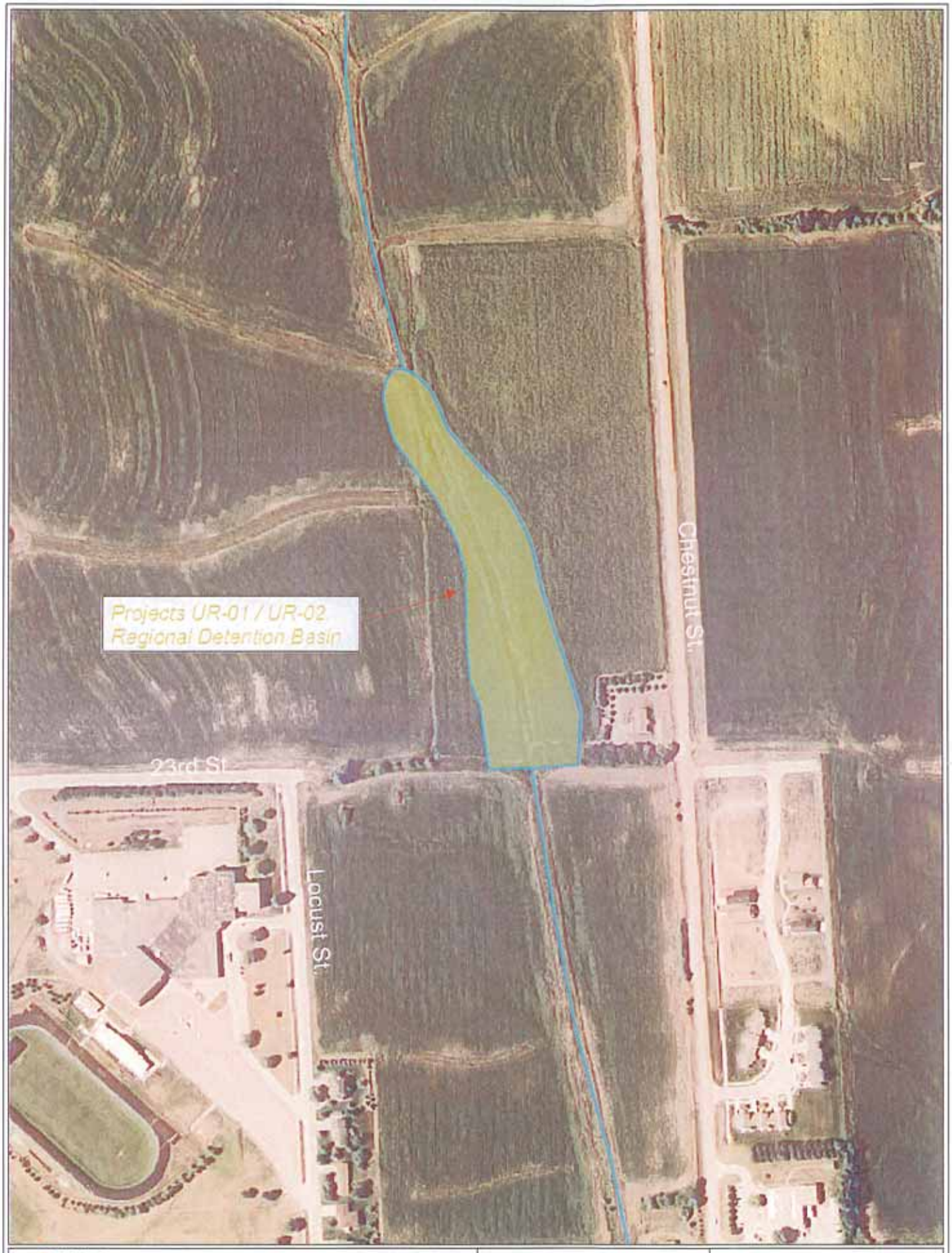
JEO Consulting Group, Inc.
Aug. 08, 2008

2008 Drainage Study - North Study Area
City of Wahoo, Nebraska
JEO Project # 607D19

0 50 100 200 Feet

N

FIGURE 4:
Proposed Projects Map 1
MR-01, MR-02, MR-03



JEO Consulting Group, Inc.
Aug. 08, 2008

2008 Drainage Study - North Study Area
City of Wahoo, Nebraska
JEO Project # 607D19

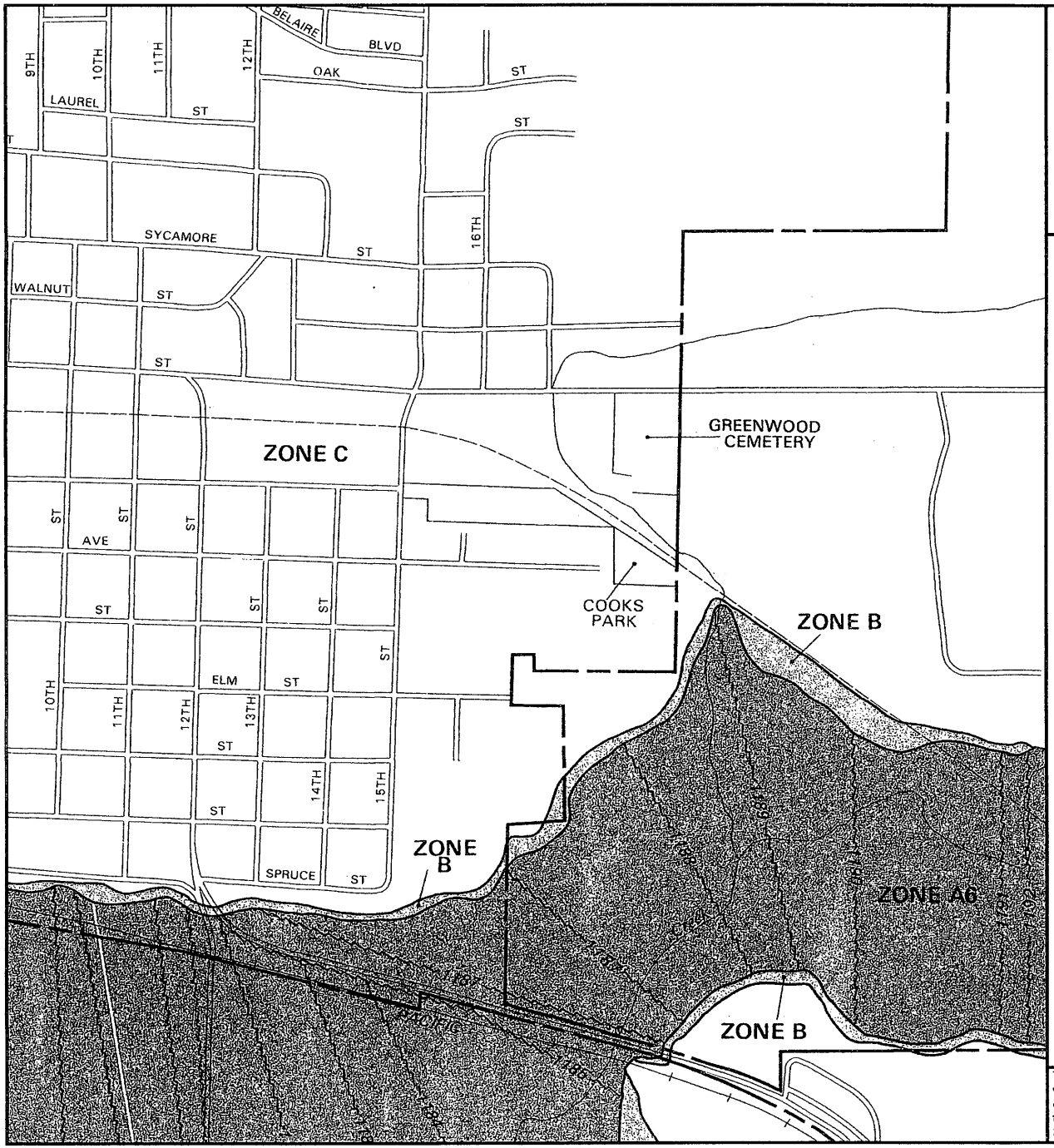
0 100 200 400 Feet

N

FIGURE 5:
Proposed Projects Map 2
UR-01, UR-02

APPENDIX 1

WAHOO FLOODPLAIN MAP - PANEL 310204 0005 C



APPROXIMATE SCALE

800 0 800 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM

FLOOD INSURANCE RATE MAP

CITY OF
WAHOO,
NEBRASKA
SAUNDERS COUNTY

(ONLY PANEL PRINTED)

COMMUNITY-PANEL NUMBER
310204 0005 C

MAP REVISED:
JANUARY 3, 1986

Federal Emergency Management Agency

APPENDIX 2

LOCATION MAP FROM HMGP PROJECT GRANT APPLICATION

*100-Year Flood Boundary is in the revision process by FEMA and is considered "Draft". The FEMA MapMod database, as of Jan. 17, 2008, indicates the floodplain is in the "Technical Review" stage. Floodplain data provided by the Nebraska Department of Natural Resources. Last FIRM panel adopted by FEMA January 3, 1986. Community-Panel Number - 310204 0005 C

*Wetlands data obtained from U.S. Fish & Wildlife Service website. Wetlands are from "Lower 48 USGS 24K Quads". Data was downloaded on Thursday, May 22, 2008.

JEO
May 22, 2008

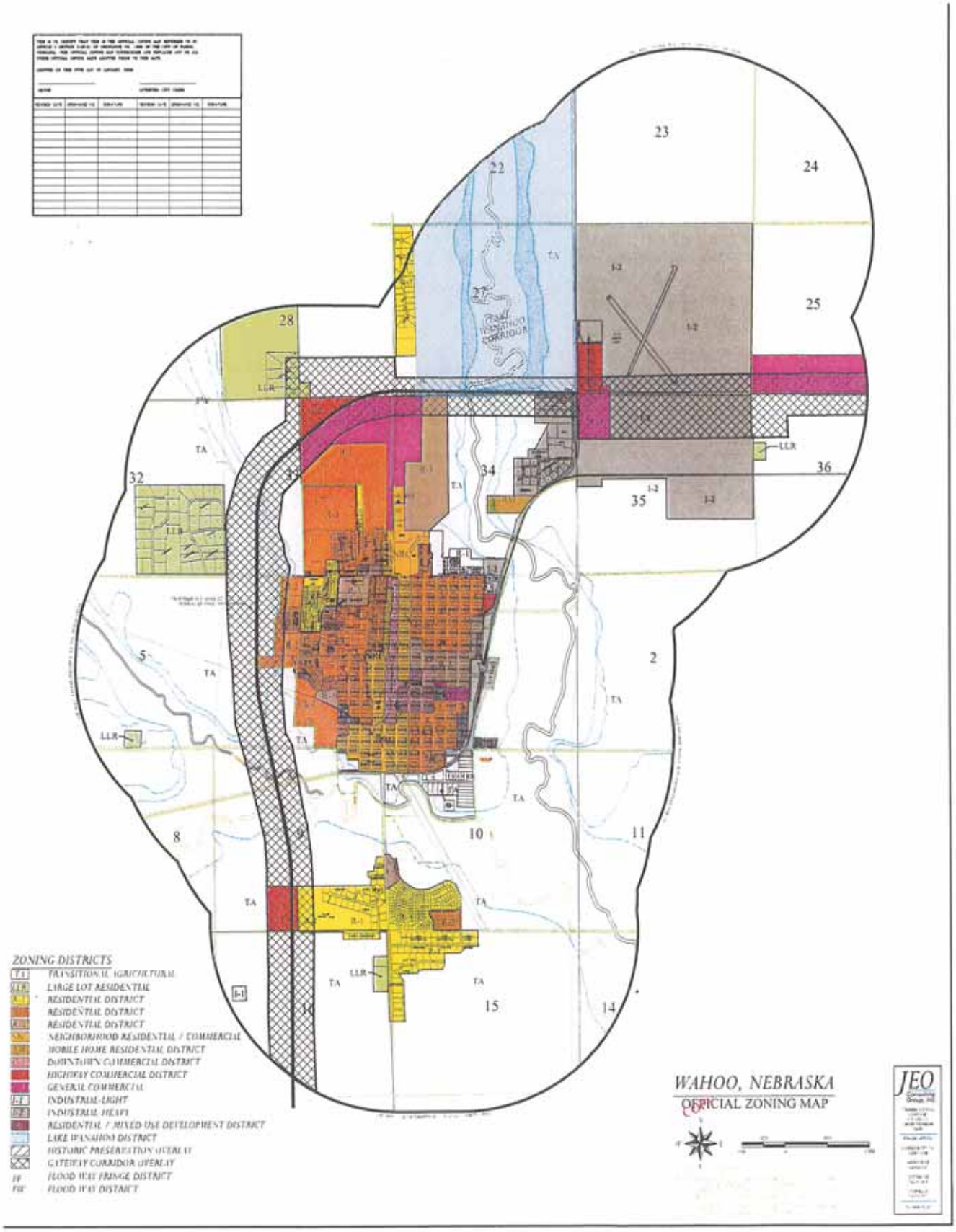
Project Grant Application
City of Wahoo, Nebraska

0 187.5 375 750 Feet

Proposed Project Location
Open Channel Improvements
Upstream of Chestnut

APPENDIX 3

UNOFFICIAL WAHOO ZONING MAP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14
TA
LLR
I-1
I-2
ZONING DISTRICTS
TA TRANSITIONAL AGRICULTURAL
LLR LARGE LOT RESIDENTIAL
R-1 RESIDENTIAL DISTRICT
R-2 RESIDENTIAL DISTRICT
R-3 RESIDENTIAL DISTRICT
NC NEIGHBORHOOD RESIDENTIAL / COMMERCIAL
MH MOBILE HOME RESIDENTIAL DISTRICT
C-1 DOWNTOWN COMMERCIAL DISTRICT
C-2 HIGHWAY COMMERCIAL DISTRICT
C-3 GENERAL COMMERCIAL
I-1 INDUSTRIAL-LIGHT
I-2 INDUSTRIAL-HEAVY
MU RESIDENTIAL / MIXED USE DEVELOPMENT DISTRICT
LW LAKE WAHOO DISTRICT
HISTORIC PRESERVATION OVERLAY
GATEWAY CORRIDOR OVERLAY
FF FLOOD WAY FRINGE DISTRICT
FW FLOOD WAY DISTRICT
WAHOO, NEBRASKA
OFFICIAL ZONING MAP
JEO

APPENDIX 4

HYDROLOGY AND HYDRAULICS RESULTS FOR EXISTING CONDITIONS

Hydrograph Summary Report

Hydraflow Hydrographs by Intelisolve v9.22

Hyd. No.	Hydrograph type (origin)	Peak flow (cfs)	Time interval (min)	Time to peak (min)	Hyd. volume (cuft)	Inflow hyd(s)	Maximum elevation (ft)	Total strge used (cuft)	Hydrograph description
1	SCS Runoff	158.92	3	726	566,033	----	------	------	UR05 (XS 8231)
2	Reach	156.36	3	732	566,031	1	------	------	Route UR05
3	SCS Runoff	59.08	3	726	210,448	----	------	------	UR06
4	Reach	58.24	3	732	210,447	3	------	------	Route UR06
5	SCS Runoff	40.35	3	723	130,483	----	------	------	UR07
6	Reach	37.22	3	729	130,481	5	------	------	Route UR07
7	SCS Runoff	42.72	3	723	138,159	----	------	------	UR03
8	SCS Runoff	59.33	3	723	191,887	----	------	------	UR04
9	Combine	337.85	3	729	1,237,005	2, 4, 6, 7, 8	------	------	Combine UR03/UR04 (XS 6508)
10	Reach	309.84	3	735	1,237,001	9	------	------	Route Combine UR03/UR04
11	SCS Runoff	65.20	3	726	232,219	----	------	------	UR01
12	SCS Runoff	95.76	3	726	341,071	----	------	------	UR02
13	Combine	442.33	3	732	1,810,292	10, 11, 12	------	------	Combine Upper Reach (XS 4945)
16	Reach	430.56	3	738	1,810,291	13	------	------	Route Combine Upper Reach
17	SCS Runoff	27.26	3	720	74,429	----	------	------	MR03
18	SCS Runoff	55.24	3	726	195,986	----	------	------	MR04
19	Combine	473.42	3	738	2,080,704	16, 17, 18	------	------	Combine MR03/MR04 (XS 3633)
20	Reach	473.34	3	741	2,080,704	19	------	------	Route Combine MR03/MR04
21	SCS Runoff	8.913	3	720	24,154	----	------	------	MR01
22	SCS Runoff	55.22	3	720	149,813	----	------	------	MR02
23	Combine	484.16	3	741	2,254,672	20, 21, 22	------	------	Combine Middle Reach (XS 2897)
25	Reach	475.17	3	744	2,254,670	23	------	------	Route Combine Middle Reach
26	SCS Runoff	95.31	3	732	386,559	----	------	------	LR01
27	SCS Runoff	44.74	3	723	124,551	----	------	------	LR02
28	Combine	547.36	3	744	2,765,781	25, 26, 27	------	------	Combine Lower Reach (XS 848)

Hydrograph Summary Report

Hydraflow Hydrographs by Intelisolve v9.22

Hyd. No.	Hydrograph type (origin)	Peak flow (cfs)	Time interval (min)	Time to peak (min)	Hyd. volume (cuft)	Inflow hyd(s)	Maximum elevation (ft)	Total strge used (cuft)	Hydrograph description
1	SCS Runoff	251.00	3	726	882,573	----	------	------	UR05 (XS 8231)
2	Reach	246.61	3	732	882,570	1	------	------	Route UR05
3	SCS Runoff	93.32	3	726	328,136	----	------	------	UR06
4	Reach	91.78	3	732	328,135	3	------	------	Route UR06
5	SCS Runoff	63.68	3	723	203,453	----	------	------	UR07
6	Reach	59.79	3	729	203,450	5	------	------	Route UR07
7	SCS Runoff	67.43	3	723	215,421	----	------	------	UR03
8	SCS Runoff	93.65	3	723	299,196	----	------	------	UR04
9	Combine	536.70	3	729	1,928,772	2, 4, 6, 7, 8	------	------	Combine UR03/UR04 (XS 6508)
10	Reach	500.71	3	735	1,928,768	9	------	------	Route Combine UR03/UR04
11	SCS Runoff	102.97	3	726	362,081	----	------	------	UR01
12	SCS Runoff	151.24	3	726	531,807	----	------	------	UR02
13	Combine	715.72	3	732	2,822,656	10, 11, 12	------	------	Combine Upper Reach (XS 4945)
16	Reach	696.52	3	738	2,822,654	13	------	------	Route Combine Upper Reach
17	SCS Runoff	42.84	3	720	116,052	----	------	------	MR03
18	SCS Runoff	86.29	3	726	303,115	----	------	------	MR04
19	Combine	772.02	3	735	3,241,822	16, 17, 18	------	------	Combine MR03/MR04 (XS 3633)
20	Reach	772.57	3	738	3,241,824	19	------	------	Route Combine MR03/MR04
21	SCS Runoff	13.44	3	720	36,494	----	------	------	MR01
22	SCS Runoff	84.10	3	720	228,084	----	------	------	MR02
23	Combine	791.12	3	738	3,506,398	20, 21, 22	------	------	Combine Middle Reach (XS 2897)
25	Reach	775.16	3	744	3,506,397	23	------	------	Route Combine Middle Reach
26	SCS Runoff	149.10	3	729	597,861	----	------	------	LR01
27	SCS Runoff	74.38	3	720	202,861	----	------	------	LR02
28	Combine	897.20	3	741	4,307,121	25, 26, 27	------	------	Combine Lower Reach (XS 848)

HEC-RAS Plan: Scen1 River: river1 Reach: CHAN

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
CHAN	8231.49	10-yr	159.00	1263.94	1264.97	1264.97	1265.17	0.080281	3.58	44.37	121.41	1.04
CHAN	8231.49	50-yr	251.00	1263.94	1265.11	1265.11	1265.37	0.070230	4.10	61.16	123.46	1.03
CHAN	7755.99	10-yr	159.00	1253.43	1260.34	1256.98	1260.35	0.000458	0.88	192.79	123.04	0.10
CHAN	7755.99	50-yr	251.00	1253.43	1262.19	1257.84	1262.19	0.000106	0.64	527.52	242.15	0.06
CHAN	7719		Culvert									
CHAN	7681.00	10-yr	159.00	1252.43	1256.31	1256.31	1257.28	0.056881	7.91	20.10	10.37	1.00
CHAN	7681.00	50-yr	251.00	1252.43	1257.07	1257.07	1258.25	0.054056	8.70	28.85	12.43	1.01
CHAN	6508.51	10-yr	338.00	1242.71	1245.35		1245.40	0.003260	2.08	206.13	172.03	0.27
CHAN	6508.51	50-yr	537.00	1242.71	1245.72		1245.80	0.003869	2.57	274.36	193.97	0.31
CHAN	4945.95	10-yr	442.00	1227.72	1230.81		1231.26	0.034026	7.95	112.29	116.51	0.89
CHAN	4945.95	50-yr	716.00	1227.72	1231.44		1231.77	0.022218	7.47	197.85	156.26	0.75
CHAN	3633.58	10-yr	473.00	1218.56	1222.63	1221.28	1222.75	0.002788	2.70	175.15	90.48	0.34
CHAN	3633.58	50-yr	772.00	1218.56	1223.30	1221.83	1223.46	0.003125	3.21	240.94	109.89	0.37
CHAN	3271.27	10-yr	473.00	1216.59	1220.28	1220.28	1220.77	0.012589	6.68	109.24	112.35	0.74
CHAN	3271.27	50-yr	772.00	1216.59	1220.71	1220.71	1221.29	0.013499	7.69	159.04	148.26	0.79
CHAN	2897.24	10-yr	484.00	1210.01	1217.56	1214.41	1217.70	0.001502	3.20	199.48	207.24	0.27
CHAN	2897.24	50-yr	791.00	1210.01	1218.15	1215.60	1218.37	0.002166	4.17	263.94	336.85	0.32
CHAN	2860		Culvert									
CHAN	2822.00	10-yr	484.00	1209.93	1214.36	1214.36	1215.72	0.025697	9.33	51.88	19.04	1.00
CHAN	2822.00	50-yr	791.00	1209.93	1215.56	1215.56	1217.18	0.024153	10.21	77.44	23.70	1.00
CHAN	2052.24	10-yr	484.00	1193.19	1198.82	1197.83	1199.28	0.010481	5.44	88.94	34.31	0.60
CHAN	2052.24	50-yr	791.00	1193.19	1199.85	1198.77	1200.44	0.010690	6.18	127.94	41.67	0.62
CHAN	848.43	10-yr	547.00	1178.08	1183.53	1182.68	1184.04	0.015029	5.74	95.27	45.51	0.70
CHAN	848.43	50-yr	897.00	1178.08	1184.49	1183.83	1185.04	0.015021	5.96	150.54	69.21	0.71

APPENDIX 5

HYDROLOGY AND HYDRAULICS RESULTS FOR FULLY DEVELOPED CONDITIONS

Hydrograph Summary Report

Hydraflow Hydrographs by Intelisolve v9.22

Hyd. No.	Hydrograph type (origin)	Peak flow (cfs)	Time interval (min)	Time to peak (min)	Hyd. volume (cuft)	Inflow hyd(s)	Maximum elevation (ft)	Total strge used (cuft)	Hydrograph description
1	SCS Runoff	208.93	3	723	669,479	----	------	------	UR05 (XS 8231)
2	Reach	206.59	3	729	669,478	1	------	------	Route UR05
3	SCS Runoff	98.68	3	723	315,814	----	------	------	UR06
4	Reach	97.58	3	726	315,813	3	------	------	Route UR06
5	SCS Runoff	45.54	3	723	145,912	----	------	------	UR07
6	Reach	43.50	3	729	145,909	5	------	------	Route UR07
7	SCS Runoff	83.06	3	720	235,358	----	------	------	UR03
8	SCS Runoff	115.37	3	720	326,886	----	------	------	UR04
9	Combine	497.22	3	726	1,693,445	2, 4, 6, 7, 8	------	------	Combine UR03/UR04 (XS 6508)
10	Reach	470.75	3	729	1,693,442	9	------	------	Route Combine UR03/UR04
11	SCS Runoff	112.16	3	723	359,758	----	------	------	UR01
12	SCS Runoff	135.60	3	723	433,087	----	------	------	UR02
13	Combine	686.43	3	729	2,486,288	10, 11, 12	------	------	Combine Upper Reach (XS 4945)
15	Reach	678.34	3	732	2,486,286	13	------	------	Route Combine Upper Reach
16	SCS Runoff	42.08	3	720	116,023	----	------	------	MR03
17	SCS Runoff	69.64	3	723	223,160	----	------	------	MR04
18	Combine	747.03	3	732	2,825,468	15, 16, 17	------	------	Combine MR03/MR04 (XS 3633)
19	Reach	747.10	3	735	2,825,468	18	------	------	Route Combine MR03/MR04
20	SCS Runoff	8.913	3	720	24,154	----	------	------	MR01
21	SCS Runoff	55.22	3	720	149,813	----	------	------	MR02
22	Combine	770.96	3	732	2,999,435	19, 20, 21	------	------	Combine Middle Reach (XS 2897)
24	Reach	752.72	3	738	2,999,434	22	------	------	Route Combine Middle Reach
25	SCS Runoff	115.02	3	726	405,745	----	------	------	LR01
26	SCS Runoff	44.74	3	723	124,551	----	------	------	LR02
27	Combine	839.17	3	738	3,529,730	24, 25, 26	------	------	Combine Lower Reach (XS 848)

Hydrograph Summary Report

Hydraflow Hydrographs by Intelisolve v9.22

Hyd. No.	Hydrograph type (origin)	Peak flow (cfs)	Time interval (min)	Time to peak (min)	Hyd. volume (cuft)	Inflow hyd(s)	Maximum elevation (ft)	Total strge used (cuft)	Hydrograph description
1	SCS Runoff	319.41	3	723	1,019,250	----	------	------	UR05 (XS 8231)
2	Reach	315.73	3	726	1,019,250	1	------	------	Route UR05
3	SCS Runoff	141.41	3	723	456,848	----	------	------	UR06
4	Reach	140.61	3	726	456,848	3	------	------	Route UR06
5	SCS Runoff	69.62	3	723	222,144	----	------	------	UR07
6	Reach	66.99	3	729	222,142	5	------	------	Route UR07
7	SCS Runoff	112.60	3	720	324,816	----	------	------	UR03
8	SCS Runoff	156.38	3	720	451,133	----	------	------	UR04
9	Combine	728.39	3	726	2,474,188	2, 4, 6, 7, 8	------	------	Combine UR03/UR04 (XS 6508)
10	Reach	699.16	3	729	2,474,186	9	------	------	Route Combine UR03/UR04
11	SCS Runoff	159.38	3	723	516,829	----	------	------	UR01
12	SCS Runoff	203.26	3	723	649,425	----	------	------	UR02
13	Combine	1012.71	3	726	3,640,440	10, 11, 12	------	------	Combine Upper Reach (XS 4945)
15	Reach	1005.41	3	732	3,640,437	13	------	------	Route Combine Upper Reach
16	SCS Runoff	58.70	3	720	164,425	----	------	------	MR03
17	SCS Runoff	106.47	3	723	339,750	----	------	------	MR04
18	Combine	1110.92	3	729	4,144,613	15, 16, 17	------	------	Combine MR03/MR04 (XS 3633)
19	Reach	1115.50	3	732	4,144,613	18	------	------	Route Combine MR03/MR04
20	SCS Runoff	13.44	3	720	36,494	----	------	------	MR01
21	SCS Runoff	84.10	3	720	228,084	----	------	------	MR02
22	Combine	1156.00	3	732	4,409,190	19, 20, 21	------	------	Combine Middle Reach (XS 2897)
24	Reach	1126.92	3	738	4,409,189	22	------	------	Route Combine Middle Reach
25	SCS Runoff	175.96	3	726	617,728	----	------	------	LR01
26	SCS Runoff	74.38	3	720	202,861	----	------	------	LR02
27	Combine	1273.65	3	735	5,229,776	24, 25, 26	------	------	Combine Lower Reach (XS 848)

HEC-RAS Plan: Scen2 River: river1 Reach: CHAN

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
CHAN	8231.49	10-yr	209.00	1263.94	1265.05	1265.05	1265.28	0.072665	3.86	54.08	122.60	1.03
CHAN	8231.49	50-yr	319.00	1263.94	1265.20	1265.20	1265.50	0.066396	4.42	72.13	124.79	1.03
CHAN	7755.99	10-yr	209.00	1253.43	1261.96	1257.39	1261.96	0.000094	0.58	473.89	226.44	0.05
CHAN	7755.99	50-yr	319.00	1253.43	1262.45	1258.45	1262.46	0.000131	0.74	593.37	260.14	0.06
CHAN	7719		Culvert									
CHAN	7681.00	10-yr	209.00	1252.43	1256.74	1256.74	1257.84	0.055802	8.41	24.85	11.54	1.01
CHAN	7681.00	50-yr	319.00	1252.43	1257.70	1257.70	1258.82	0.051849	8.50	37.51	16.80	1.00
CHAN	6508.51	10-yr	497.00	1242.71	1245.66		1245.74	0.003679	2.46	263.67	190.70	0.30
CHAN	6508.51	50-yr	728.00	1242.71	1246.03		1246.13	0.004122	2.90	337.87	212.36	0.33
CHAN	4945.95	10-yr	686.00	1227.72	1231.37		1231.72	0.023303	7.54	187.56	152.03	0.76
CHAN	4945.95	50-yr	1013.00	1227.72	1231.92		1232.23	0.018508	7.50	280.21	186.68	0.70
CHAN	3633.58	10-yr	747.00	1218.56	1223.26	1221.78	1223.41	0.003083	3.16	236.51	108.10	0.37
CHAN	3633.58	50-yr	1111.00	1218.56	1223.82	1222.30	1224.04	0.003326	3.72	306.28	145.26	0.40
CHAN	3271.27	10-yr	747.00	1216.59	1220.67	1220.67	1221.25	0.013676	7.67	154.06	144.42	0.80
CHAN	3271.27	50-yr	1111.00	1216.59	1221.07	1221.07	1221.75	0.014318	8.57	207.45	206.75	0.83
CHAN	2897.24	10-yr	771.00	1210.01	1218.15	1215.53	1218.35	0.002072	4.08	263.16	335.79	0.32
CHAN	2897.24	50-yr	1156.00	1210.01	1218.66	1217.28	1218.97	0.002846	5.10	325.86	407.89	0.38
CHAN	2860		Culvert									
CHAN	2822.00	10-yr	771.00	1209.93	1215.50	1215.50	1217.10	0.024141	10.15	75.95	23.46	0.99
CHAN	2822.00	50-yr	1156.00	1209.93	1217.26	1217.26	1218.31	0.011794	8.59	170.13	134.06	0.73
CHAN	2052.24	10-yr	771.00	1193.19	1199.77	1198.72	1200.37	0.010837	6.18	124.84	41.14	0.62
CHAN	2052.24	50-yr	1156.00	1193.19	1200.73	1199.62	1201.47	0.011126	6.89	167.69	48.03	0.65
CHAN	848.43	10-yr	839.00	1178.08	1184.37	1183.68	1184.91	0.015022	5.90	142.11	66.15	0.71
CHAN	848.43	50-yr	1274.00	1178.08	1185.16	1184.52	1185.77	0.015011	6.32	201.70	85.48	0.72

APPENDIX 6

DIGITAL PHOTOGRAPHS

607D19 - Wahoo Drainage Study North
Digital Photograph Index

Photo ID	Direction	Description
LR 001.jpg	East	Open Channel East of Chestnut St.
LR 002.jpg	South	Rip rap at Chestnut St. Culvert Outlet (south bank)
LR 003.jpg	East	Rip rap at Chestnut St. Culvert Outlet (south bank)
LR 004.jpg	East	Open Channel East of Chestnut St.
LR 005.jpg	West	Rip rap at Chestnut St. Culvert Outlet
LR 006.jpg	West	6-ft x 6-ft Box Culvert Outlet at Chestnut St.
LR 007.jpg	West	6-ft x 6-ft Box Culvert Outlet at Chestnut St.
LR 008.jpg	North	6-ft x 6-ft Box Culvert Outlet at Chestnut St.
LR 009.jpg	East	Open Channel East of Chestnut St.
LR 010.jpg	West	6-ft x 6-ft Box Culvert Inlet at Chestnut St.
MR 001.jpg	West	Open Channel West of Chestnut St.
MR 002.jpg	Wet	Open Channel West of Chestnut St. (south bank)
MR 003.jpg	West	Open Channel West of Chestnut St.
MR 004.jpg	Southwest	Structure Southwest of Chestnut St. Culvert
MR 005.jpg	West	Open Channel West of Chestnut St.
MR 006.jpg	Northwest	Structure Northwest of Chestnut St. Culvert
MR 007.jpg	Southwest	Structures Near Open Channel West of Chestnut St.
MR 008.jpg	Southwest	Structures Near Open Channel West of Chestnut St.
MR 009.jpg	South	Open Channel West of Chestnut St.
MR 010.jpg	North	Open Channel West of Chestnut St.
MR 011.jpg	West	Storm Pipe Outlet to Open Channel West of Chestnut St.
MR 012.jpg	North	Structures Near Open Channel West of Chestnut St.
MR 013.jpg	West	Open Channel West of Chestnut St.
MR 014.jpg	South	Open Channel West of Chestnut St.
MR 015.jpg	South	Structure Northwest of Chestnut St. Culvert
MR 016.jpg	South	Structures Near Open Channel West of Chestnut St.
MR 017.jpg	West	Structures Near Open Channel West of Chestnut St.
MR 018.jpg	South	Open Channel West of Chestnut St.
MR 019.jpg	North	Open Channel West of Chestnut St. North of Walnut St.
MR 020.jpg	North	Open Channel West of Chestnut St. North of Walnut St.
MR 021.jpg	North	Open Channel West of Chestnut St. North of Walnut St.
MR 022.jpg	Northwest	Proposed Development North of Walnut St. East of Locust St.
MR 023.jpg	Northwest	Proposed Development North of Walnut St. East of Locust St.
MR 024.jpg	North	Open Channel West of Chestnut St. North of Walnut St.
MR 025.jpg	North	Open Channel West of Chestnut St. North of Walnut St.
MR 026.jpg	South	Open Channel West of Chestnut St. North of Walnut St.
MR 027.jpg	Southeast	Proposed Development North of Walnut St. East of Locust St.
UR 001.jpg	East	Open Channel West of Chestnut St. North of 23rd St.
UR 002.jpg	East	Open Channel West of Chestnut St. North of 23rd St.
UR 003.jpg	North	Open Channel West of Chestnut St. North of 23rd St.
UR 004.jpg	North	Open Channel West of Chestnut St. North of 23rd St.
UR 005.jpg	Southwest	Open Channel West of Chestnut St. North of 23rd St.
UR 006.jpg	West	Open Channel West of Chestnut St. North of 23rd St.
UR 007.jpg	South	Open Channel South of County Road M
UR 008.jpg	South	Open Channel South of County Road M
UR 009.jpg	North	60-inch RCP Culvert Outlet at County Road M
UR 010.jpg	North	Open Channel North of County Road M

LR = Lower Reach, defined as the open channel east of Chestnut St.
MR = Middle Reach, delined as the open channel west of Chestnut St. and South of 23rd St.
UR = Upper Reach, defined as the open channels north of 23rd St.

***Several other photographs are provided of miscellaneous flooding observed in the area.*

LR 003.JPG

LR 008.JPG

MR 001.JPG

MR 002.JPG

LR 010.JPG

MR 019.JPG

MR 018.JPG

MR 014.JPG

MR 021.JPG

LR 001.jpg

LR 002.jpg

LR 005.jpg

LR 004.jpg

LR 006.jpg

LR 007.jpg

MR 003.jpg

MR 004.jpg

MR 005.jpg

MR 006.jpg

LR 009.jpg

MR 007.jpg

MR 008.jpg

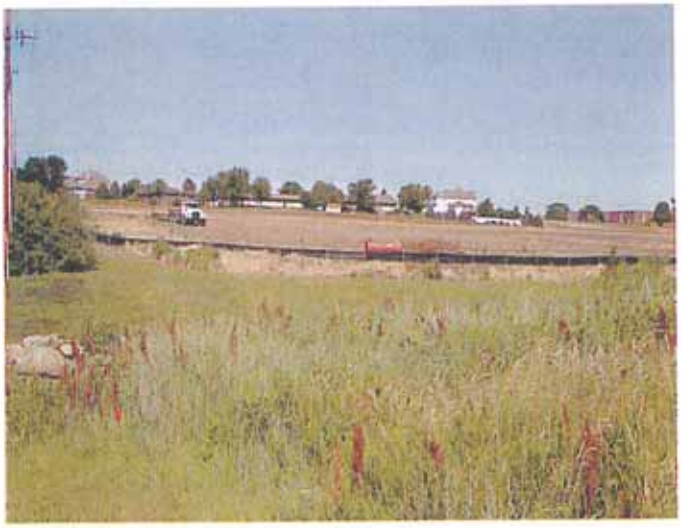
MR 009.jpg

MR 010.jpg

MR 011.jpg

MR 012.jpg

MR 013.jpg



MR 022.jpg

MR 023.jpg

MR 020.jpg

MR 016.jpg

MR 017.jpg

MR 024.jpg

MR 025.jpg

MR 015.jpg

UR 001.jpg

MR 026.jpg

UR 004.jpg

UR 003.jpg

MR 027.jpg

UR 002.jpg

UR 008.jpg

UR 010.jpg

UR 009.jpg

UR 007.jpg

UR 006.jpg

UR 005.jpg

misc flooding 003.jpg

misc flooding 002.bmp

misc flooding 004.bmp

misc flooding 001.bmp