ASSESSMENT OF FLOODING ISSUES AND POSSIBLE MITIGATION STRATEGIES FOR THE CITY OF FREDONIA, IOWA

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The City of Fredonia

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1. INTRODUCTION

Since the 1970s, Iowa has experienced increases in annual and seasonal precipitation totals, changes in the frequency of intense rain events, and the seasonality of timing of precipitation (Takle, 2010). An exceptionally wet fall, cold winter, and wet spring contributed to 2019 flooding. Following a series of rainfall events, severe flooding occurred May 30th, affecting many residents of the City of Fredonia, Iowa. The community is interested in reducing basement and surface flooding resulting from runoff originating in an agricultural catchment that drains into the city. This report summarizes an analysis of city's flooding issues and identifies potential flood mitigation alternatives. Representatives from the City of Fredonia, Louisa County Emergency Management, and the Iowa Flood Center contributed to these investigations and discussions.

2. STUDY AREA

The City of Fredonia, Iowa, population 240, is located in the northwest corner of Louisa County in Southeastern Iowa. The city footprint, shown in Figure 2.1, is adjacent to the Cedar River, near Columbus Junction, Iowa. Iowa Highway 92 is located to the south the city. The city lies between an agricultural area to the east, and the Cedar River floodplain to the west.

2.1 Topography

Fredonia is partially located on a relatively flat upland terrace near the Cedar River floodplain. Figure 2.2 depicts LiDAR-derived topographic data collected sometime after 2008. The active Cedar River floodplain is located just to the west of Fredonia at an elevation approximately 20 feet lower than the upland terrace.

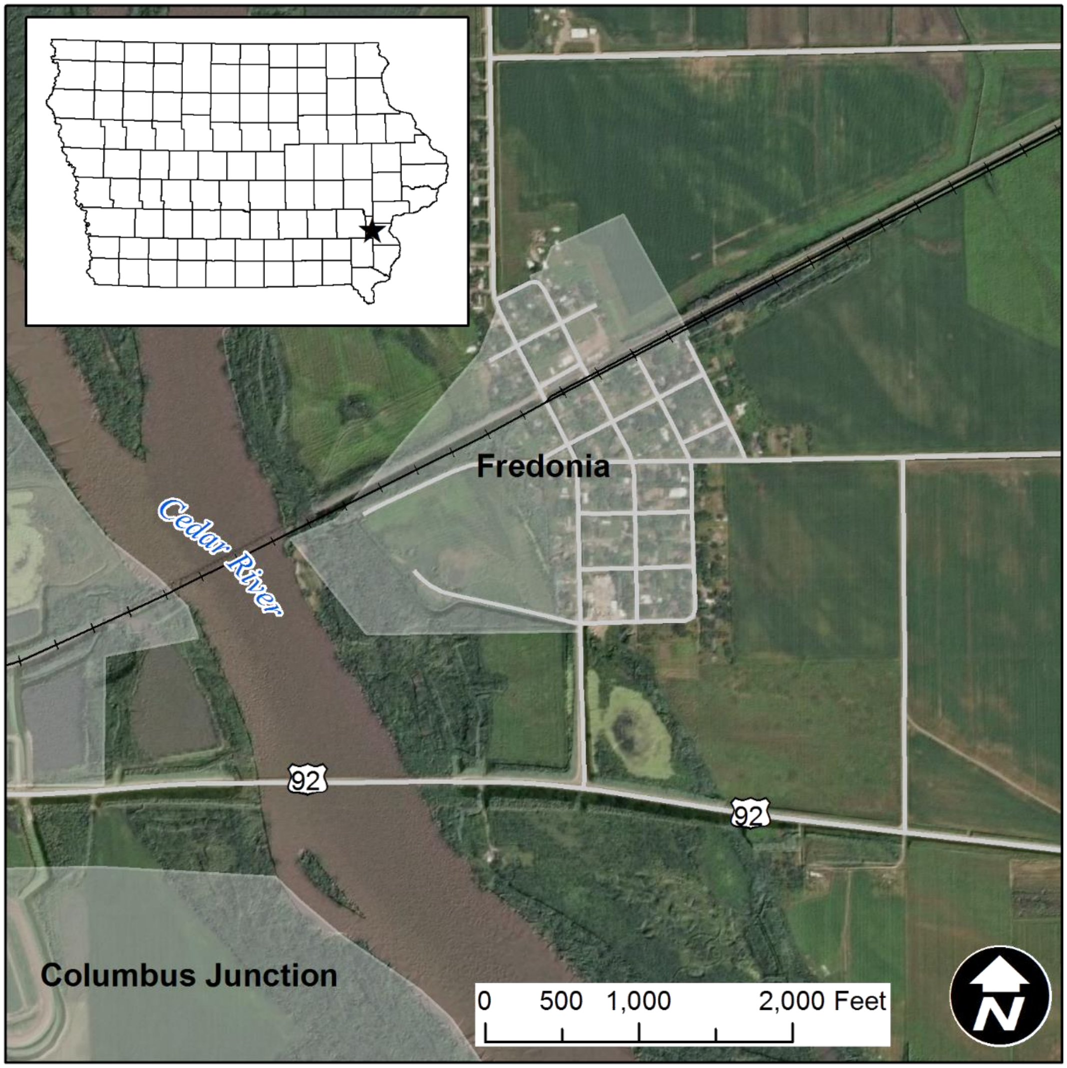

Figure 2.1. The City of Fredonia is located on a floodplain terrace along the Cedar River.

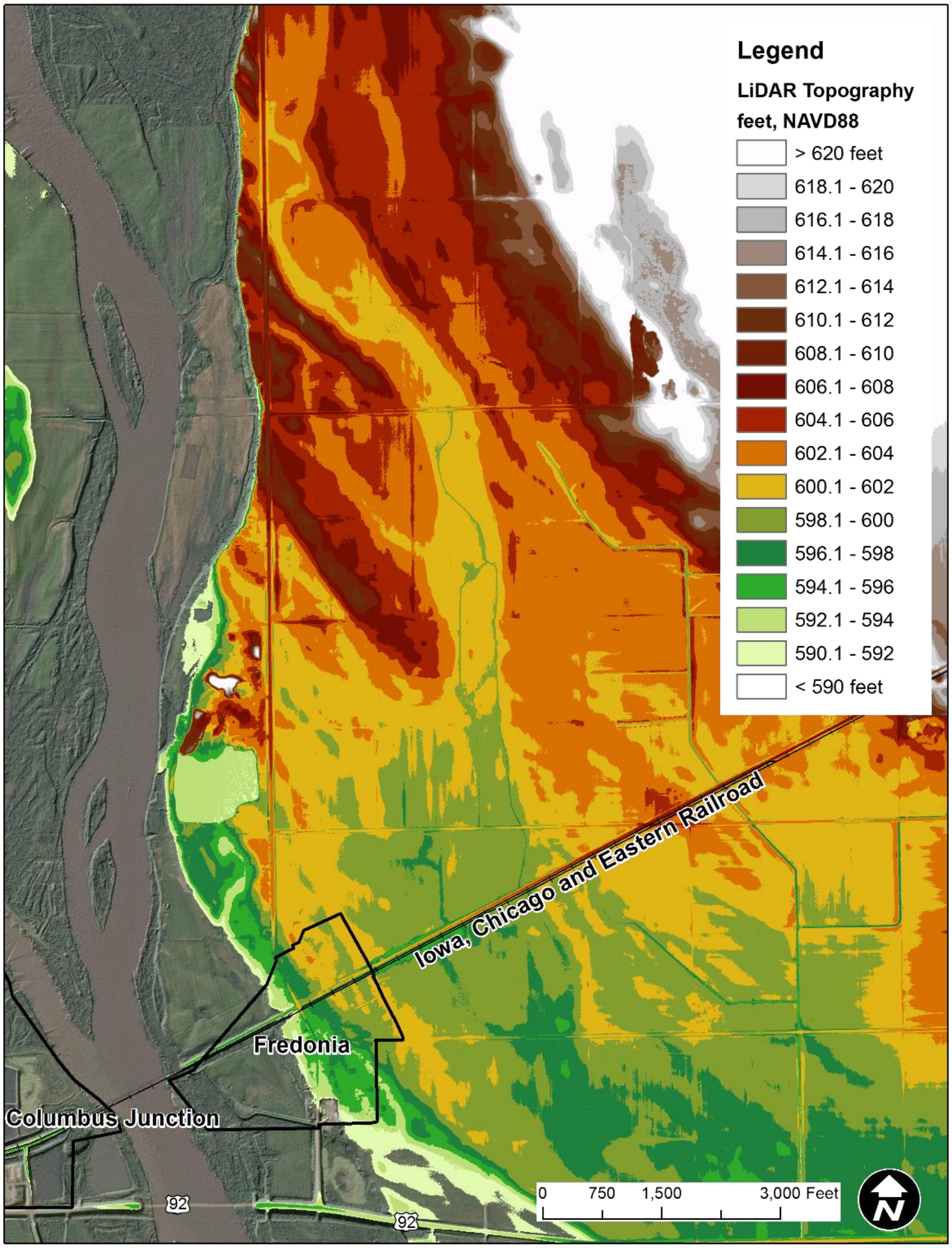

Figure 2.2. Base-earth LiDAR elevations (ft, NAVD88). Fredonia is partially located on the Cedar River floodplain and an upland floodplain terrace.

2.2 Land Use

The existing land use in Fredonia consists of low intensity residential development, with some impervious surface area due to roads, structures and parking lots, as depicted in high resolution land cover data provided by the Iowa DNR, shown in Figure 2.3. Much of the surrounding land use is agricultural, consisting of corn, soybeans and pasture.

2.3 Soil Characteristics

Fredonia is located in the Iowa-Cedar Lowland landform region, which is characterized by deposits of thick alluvium and wide, flat floodplains and upland terraces. These features are evidence of a long geologic history of river flow and movement. Rivers constructed distinctive, flat floored corridors known as alluvial plains, which are underlain by water transported deposits (Prior, 1991).

The NRCS characterizes Hydrologic Soil Groups (HSGs) using the soil layer with the lowest saturated hydraulic conductivity within the profile. HSGs for the study area are shown in Figure 2.4. Corresponding soil characteristics for the HSGs are shown in Table 2.1. In general, groups A, B, C, and D have low, moderately low, moderately high, and high runoff potential, respectively. Much of the agricultural catchment areas contain several HSGs, with the lower lying waterway areas being type C/D, a dual hydrologic soil group, indicating a water table within 24 inches of the surface. Dual classifications (e.g. A/D) describe the runoff potential for drained and undrained conditions. These low-lying areas have historically experienced a high water table, unless some form of artificial drainage has been installed.

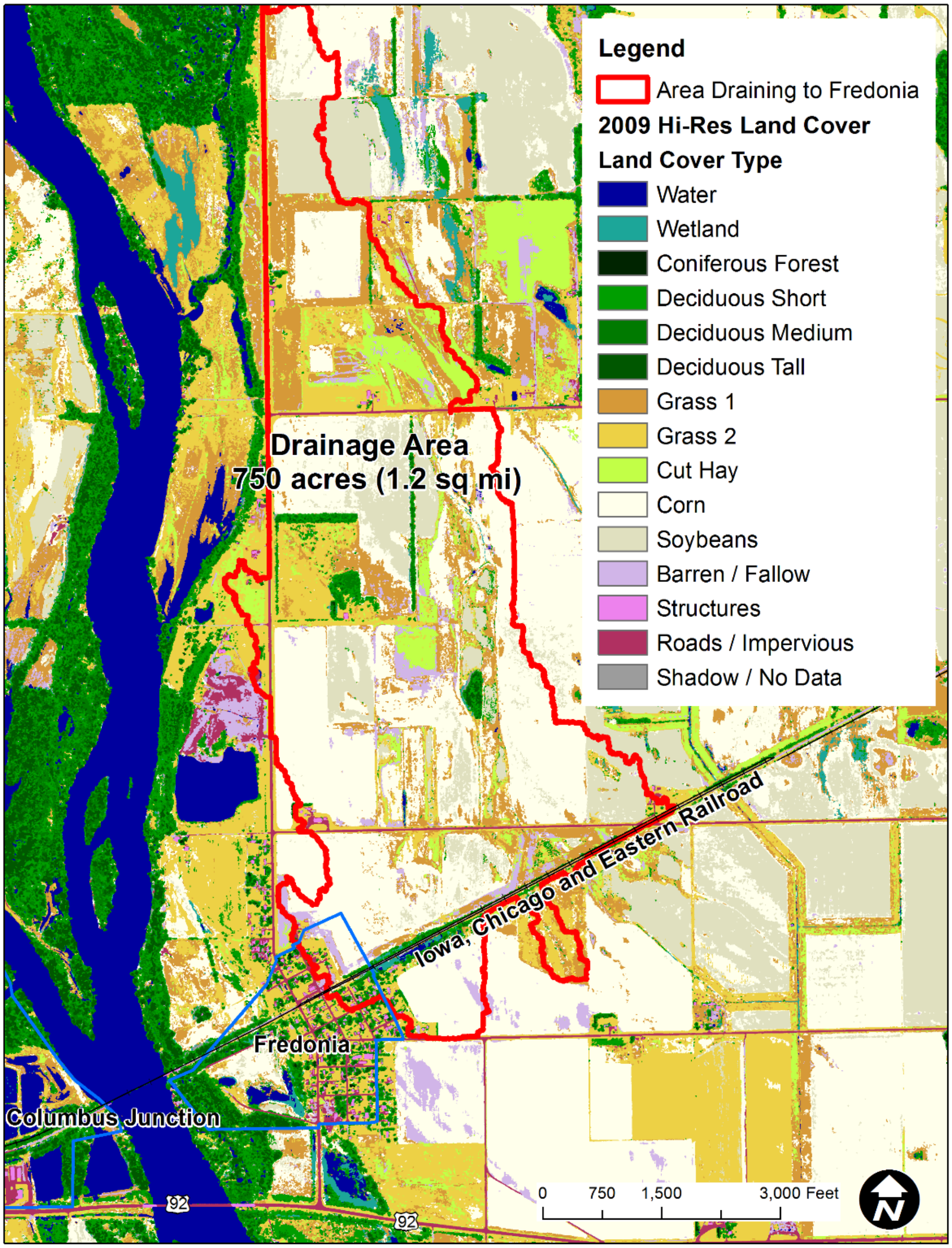

Figure 2.3. Land use in the study area based on High-Resolution Land Cover data provided by the Iowa DNR (2009).

Table 2.1. NRCS Hydrologic Soil Group (HSGs) characteristics (NRCS, 2007) when a water impermeable layer exists at a depth between 20 and 40 inches

Soil property	Hydrologic soil group A	Hydrologic soil group B	Hydrologic soil group C	Hydrologic soil group D
Saturated hydraulic conductivity of the least transmissive layer	>40.0 μm/s (>5.67 in/h)	≤40.0 to >10.0 μm/s (≤5.67 to >1.42 in/h)	≤10.0 to >1.0 μm/s (≤1.42 to >0.14 in/h)	≤1.0 μm/s (≤0.14 in/h)
	and	and	and	and/or
Depth to water impermeable layer	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	<50 cm [<20 in]
	and	and	and	and/or
Depth to high water table	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	<60 cm [<24 in]

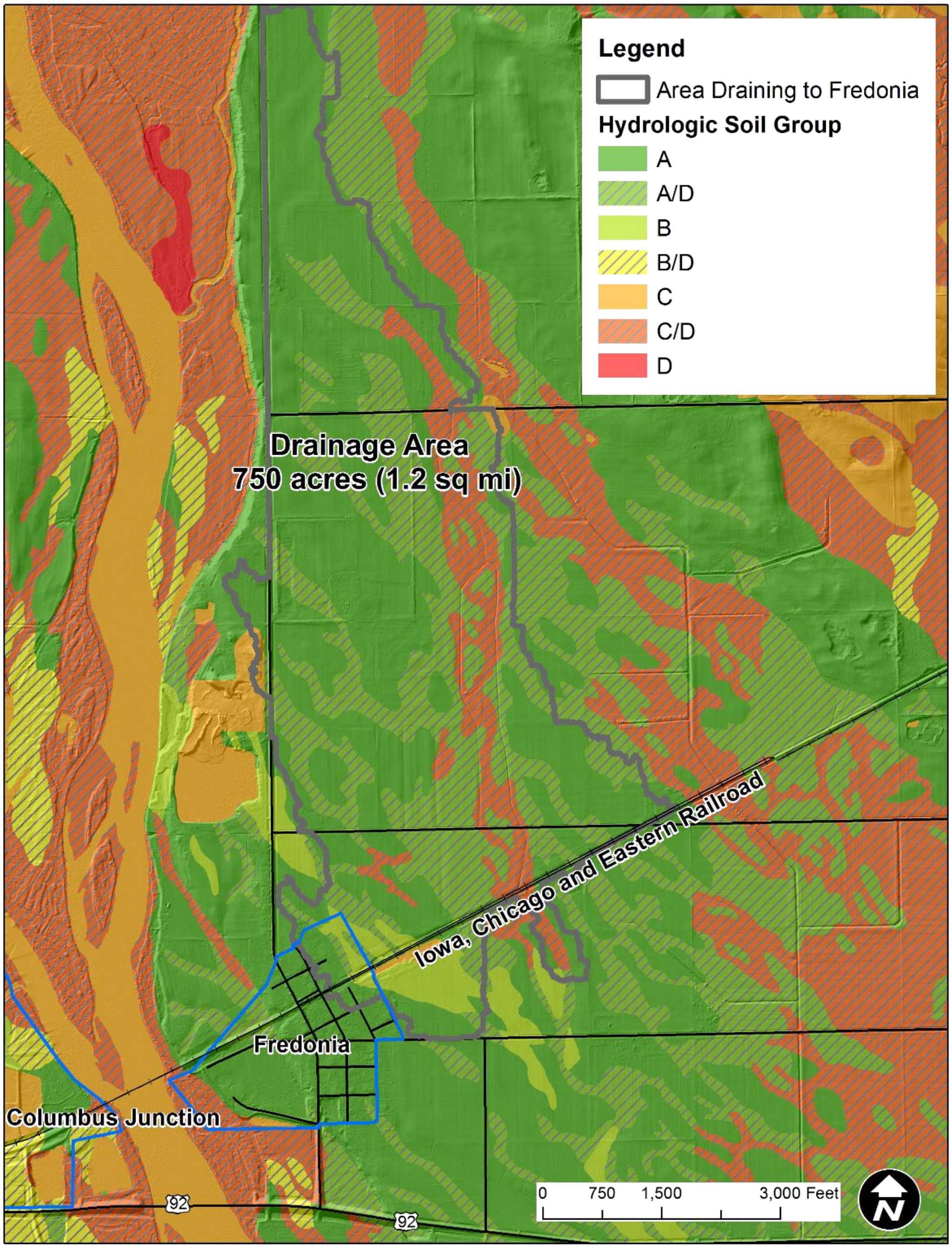

Figure 2.4. Hydrologic soil types based on the USDA/NRCS SSURGO dataset. Dual classifications (e.g., A/D) indicate a seasonal water table within 24 inches of the surface.

2.4 Hydrology

An agricultural catchment, shown in Figure 2.5, contributes runoff that drains into a pond just northeast of the city of Fredonia, shown in Figure 2.6. The pond is located along the Iowa, Chicago and Eastern Railroad. A photograph of the southern portion of the pond is shown in Figure 2.7. The approximate drainage area entering the pond is 750 acres (1.2 square miles). At low flow, the southern portion of the pond discharges via an 18-inch corrugated plastic pipe (R. Bright, Fredonia resident, personal communication, 6/21/2019), eventually reaching the Cedar River. Following heavy rainfall, the pond's low flow outlet can become overwhelmed, once pond storage is exhausted, flood water begins flowing into the city of Fredonia.

Figure 2.8 shows a close-up view of the approximate location of pipes, culverts, and ditches that convey pond discharge through the city of Fredonia, eventually reaching the Cedar River. Figure 2.9 and Figure 2.10 show street views along the drainage way, near the intersection of 3rd Street and the railroad.

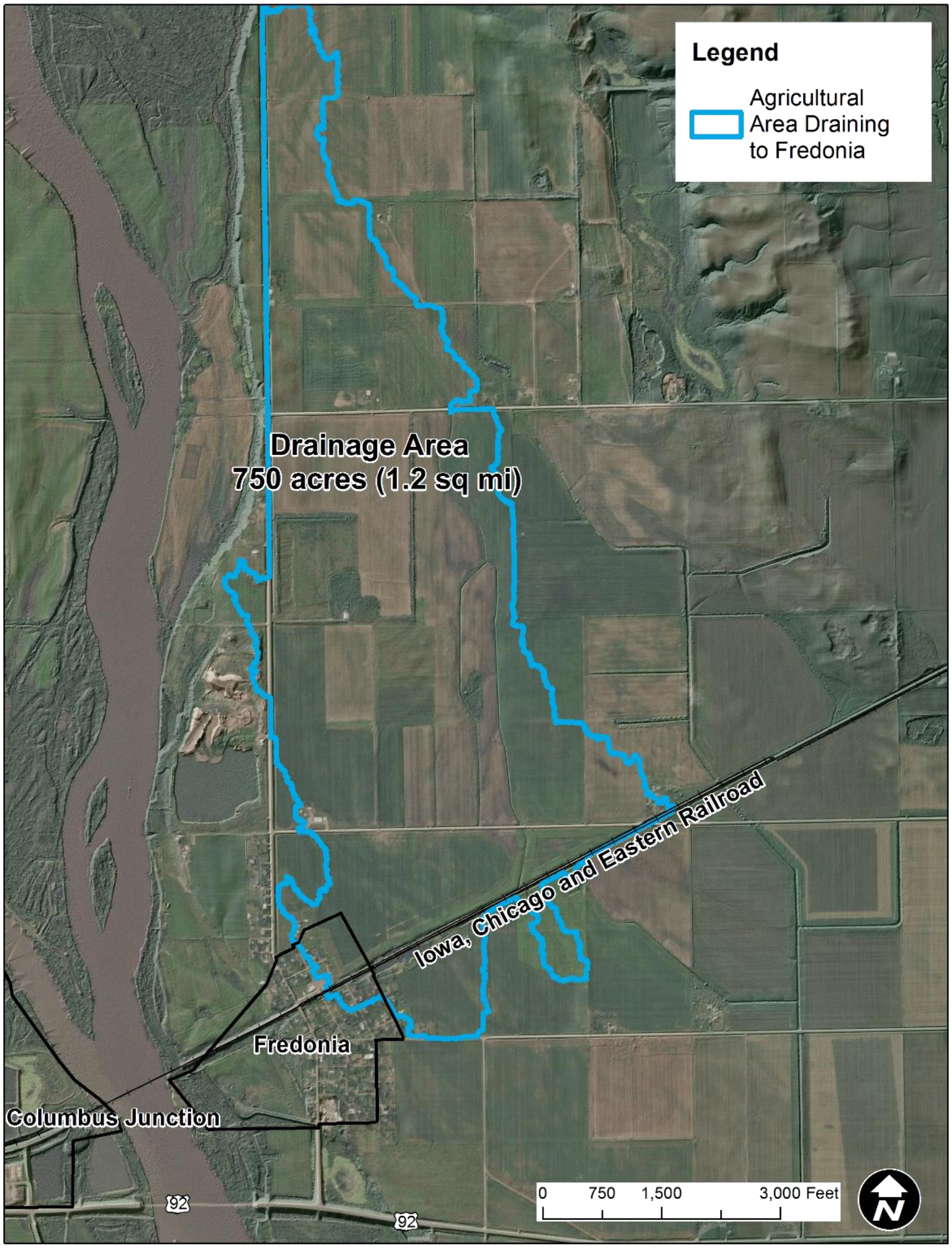

Figure 2.5. Area likely draining into ponds northeast of Fredonia.

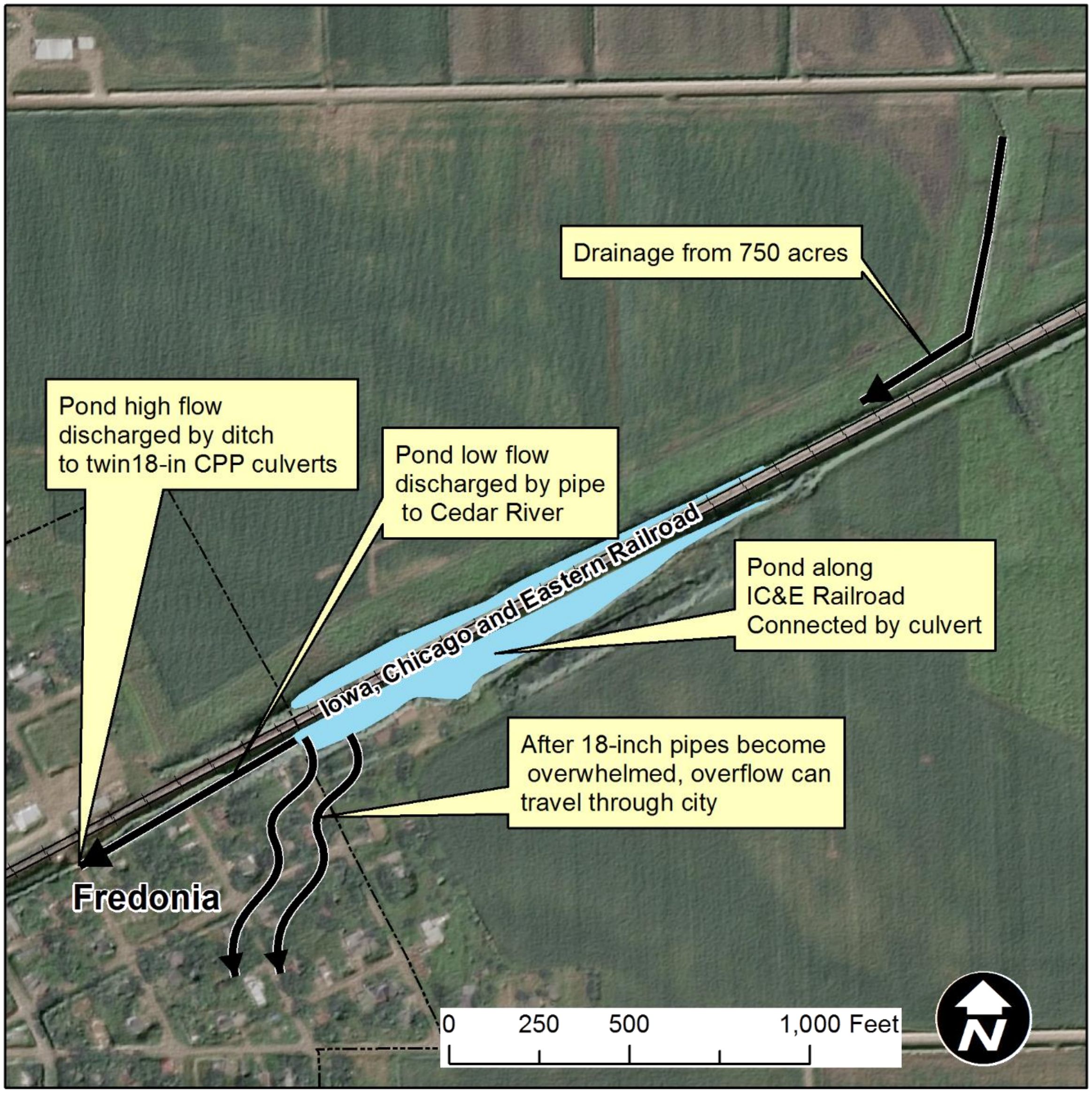

Figure 2.6. Typical pond inflow and outflow characteristics

Figure 2.7. The southern portion of the pond along the IC&E railroad embankment, view is looking northeast.

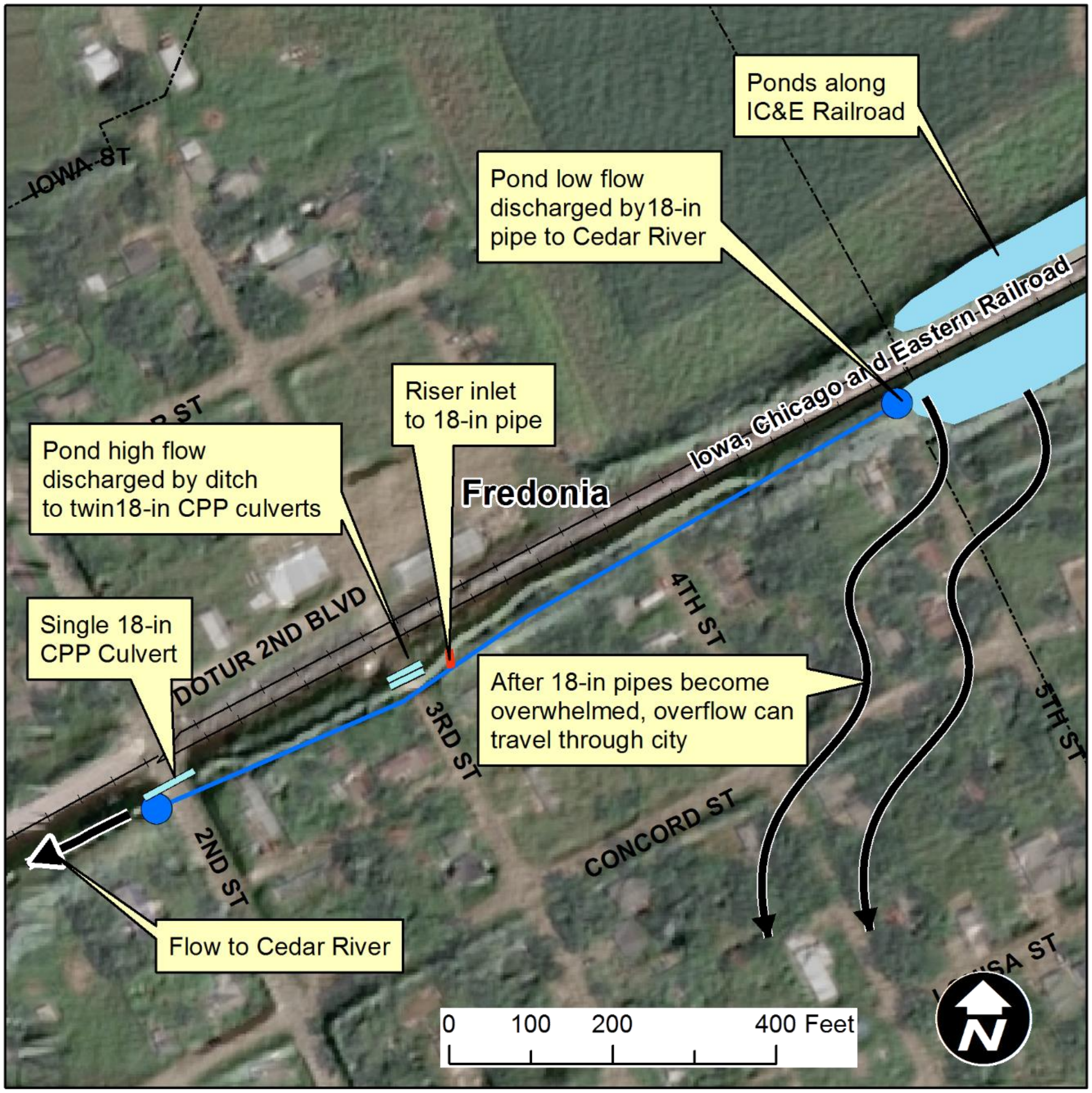

Figure 2.8. Pipes and culverts that convey pond discharge to Cedar River. Locations are approximate.

Figure 2.9. View near the intersection of 3rd Street and the railroad, looking northeast. Twin 18-in corrugated plastic culverts convey ditch flow under 3rd street. An orange riser is connected to the 18-in pipe that drains the pond.

Figure 2.10. View near the intersection of 3rd Street and the railroad, looking southwest. Twin 18-in corrugated plastic culverts convey ditch flow under 3rd street.

The natural flow path of this drainage area appears to have been to the southeast, following the gentle slope of the upland terrace. This is emphasized in **Figure** 2.11 along with the LiDAR topography. The flow path was likely diverted when the railroad embankment was constructed.

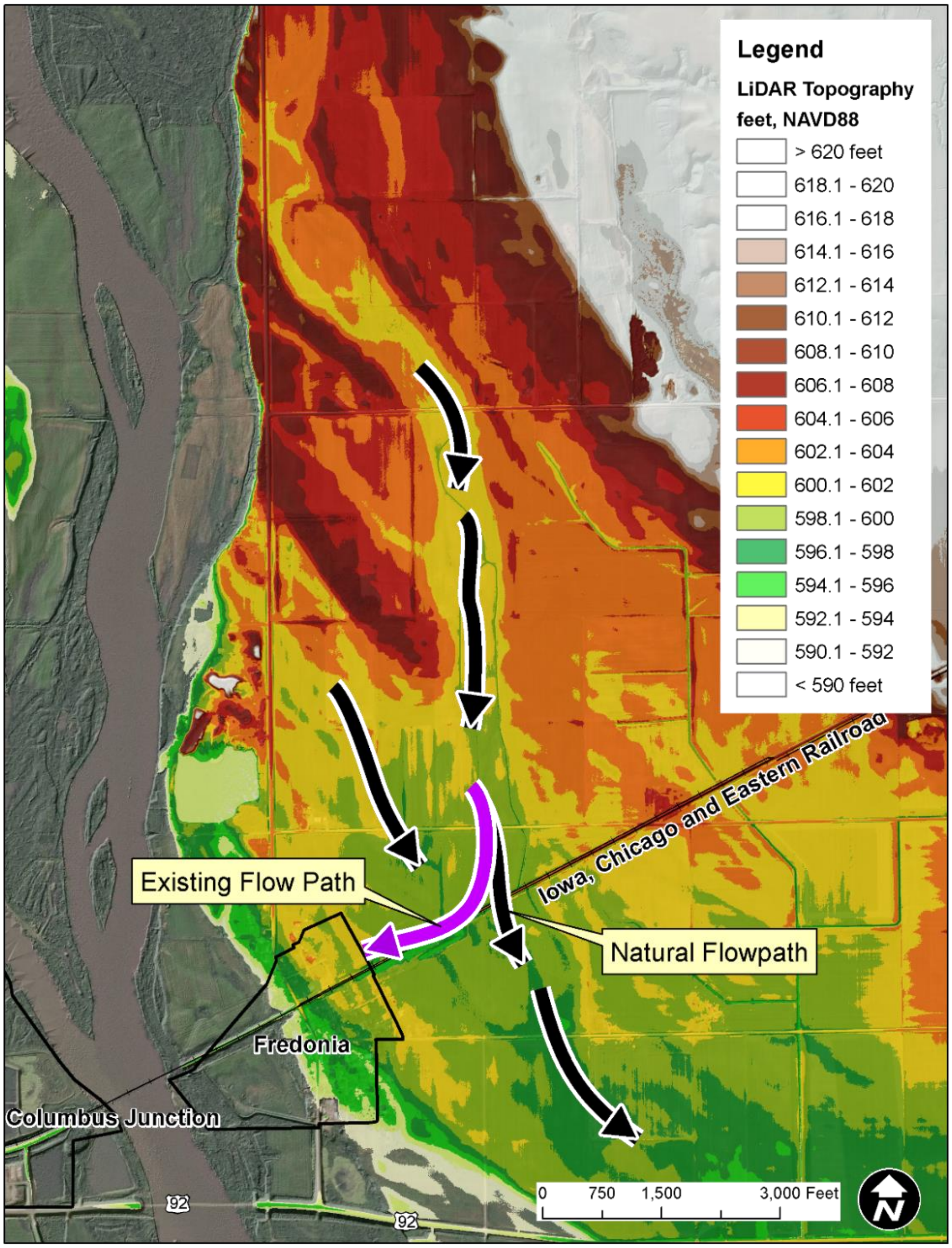

Figure **2.11**. LiDAR terrain indicates the original flow path for this drainage area was likely to the southeast, rather than the existing flow path, which flows along the railroad to the southwest.

3. FLOODING MAY 30TH 2019

A series of rainfall events occurring from May 27 – 30, 2019, overwhelmed the nearby pond and culminated in flash flooding. Many homes experienced basement flooding. Figure 3.1 shows hourly rainfall amounts, along with daily rainfall totals estimated using Multi-Radar/Multi-Sensor System (MRMS) data produced by the National Air and Space Administration (NASA). By May 30th, soils had become nearly saturated and produced significant runoff.

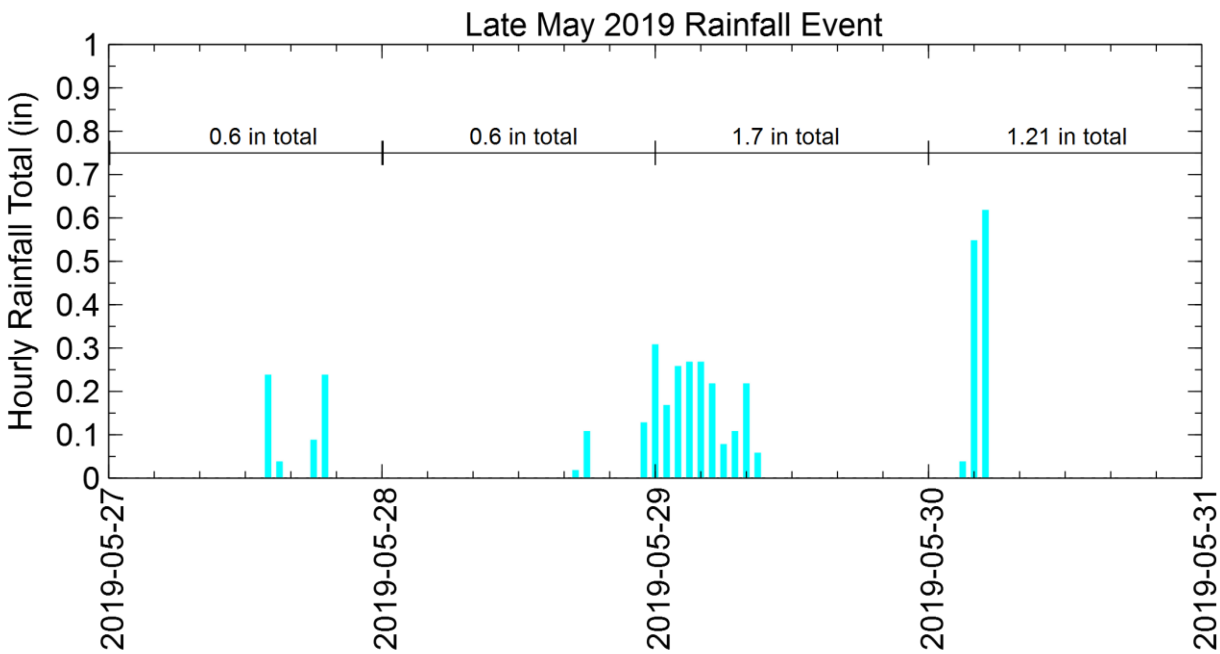

Figure 3.1. Hourly rainfall totals near Fredonia prior to the May 30th 2019 flooding derived from radar rainfall estimates. Daily total rainfall amounts are shown above.

4. MODEL DEVELOPMENT

A computer model was developed to simulate the hydrologic processes occurring in the study area. The model was developed using the U.S. Army Corps of Engineers Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS), a lumped parameter hydrologic modeling software. This model is capable of simulating rainfall-runoff, pond storage and pond outlet behavior. The model was prepared using ESRI's ArcGIS software and the HEC-HMS extension.

The transformation of rainfall to a runoff hydrograph was modeled using the SCS Unit Hydrograph method. The time of concentration (TOC) for each catchment was calculated using the SCS lag method. The partitioning of rainfall into runoff and infiltration was accomplished using the SCS curve number (CN) method. Routing of runoff downstream was accomplished using Muskingum Routing, assuming a flow velocity of 3 feet per second. Assuming average antecedent moisture conditions, CNs ranged from 60 – 72, indicating moderately low runoff potential as a result of HSGs and agricultural land use. A schematic of the HEC-HMS model elements are shown in Figure 4.1.

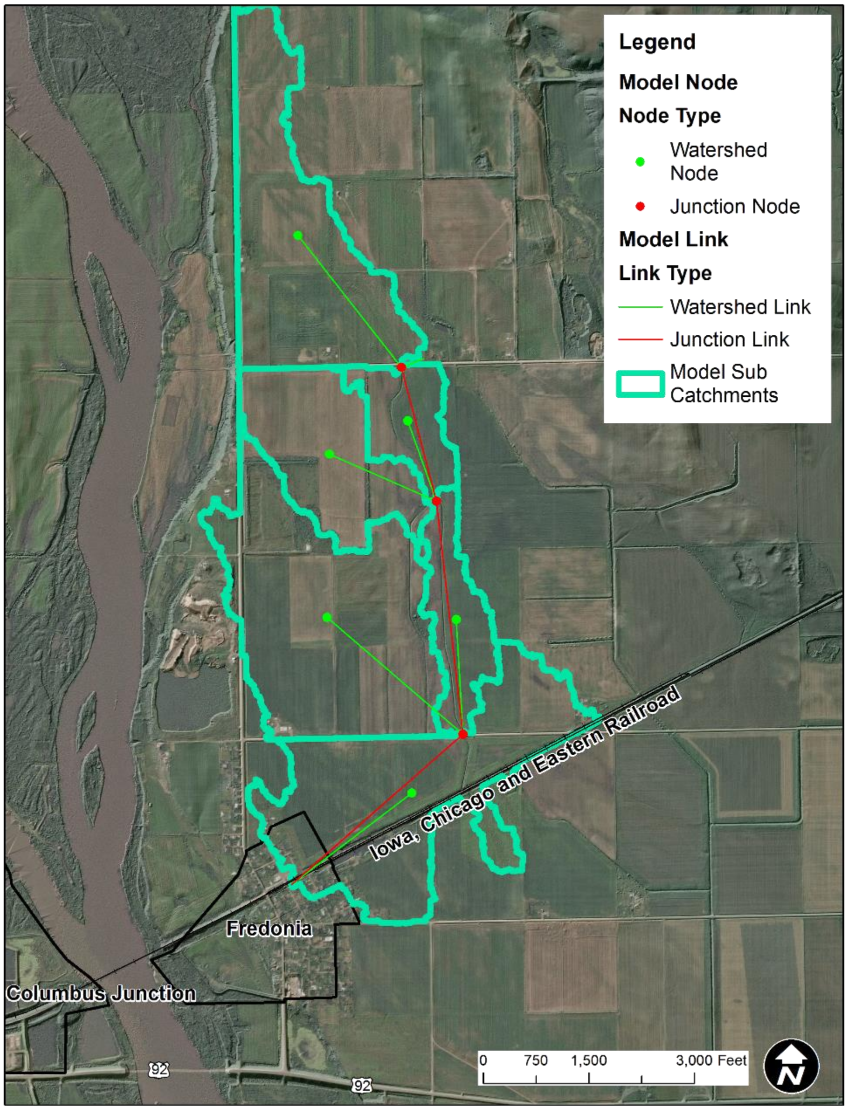

Figure 4.1. HEC-HMS model schematic showing connected elements used to model runoff and convey runoff downstream.

Pond outflow relationships for pipes, culverts, ditches and overflow were modeled using

HydroCAD software. A site visit and conversations with city representatives provided general information about drainage infrastructure, including pipe locations, configurations and dimensions. Pipe invert elevations, lengths, and alignments were estimated using LiDAR topography data and ArcGIS techniques. The inlet of the existing pond outlet was assumed to be the pond water surface elevation present in the LiDAR topography. The relationships of pond water surface elevations, pond outlet discharges, and pond storage for existing conditions and mitigation alternatives were used in the HEC-HMS model.

5. MITIGATION ALTERNATIVES

5.1 Upgrade Outlet Pipe

This alternative replaces the existing 18-inch pipe used as the primary outlet with three 48-inch reinforced concrete pipes. The alignment of the outlet pipe would remain relatively unchanged, and follow the current outlet pipe corridor. The upstream inverts of the pond outlet pipes would be lowered approximately 2 feet to elevation 593 feet (NAVD88), from the estimated existing upstream pipe invert of approximately 595.0 feet (NAVD88)

5.2 Open Ditch Outlet

This alternative replaces the existing 18-inch pipe used as the primary outlet with an open channel ditch. The ditch has a bottom width of 6 feet, a depth of 6 feet, 2:1 (H:V) side slopes, and a top width of 30 feet. The channel slope would be 0.003. The alignment of the ditch would remain relatively unchanged from the current outlet pipe corridor. The upstream invert of the open ditch would be lowered approximately 2 feet to an elevation of 593 feet (NAVD88), from the estimated existing upstream pipe invert of approximately 595.0 feet (NAVD88). The downstream invert would remain approximately unchanged, based on the estimated downstream invert elevation of 530 feet (NAVD88).

6. SIMULATION RESULTS

Three storm events were simulated using the HEC-HMS model: two 24-hour design storms using the 25- and 50-year rainfall amounts taken from NOAA Atlas 14, and the historic rainfall preceding the May 30th 2019 event. Curve numbers for the May 30th 2019 event were modified to account for likely wet antecedent soil moisture conditions, by changing from AMCII to AMCIII. Total rainfall accumulations are shown in Table 6.1. Simulated peak pond inflow and total runoff volume entering the pond for existing conditions are also shown in Table 6.1. While the May 30th, 2019 event appears to have less total rainfall and runoff volume than the 25- and 50-year events, the intensity of the rainfall on May 30th produced a comparable peak pond inflow. This reflects the sensitivity of runoff generation when considering prior rainfall, and rainfall intensity.

Simulated peak pond outlet discharges for each storm event and alternative are shown in Table 6.2. Peak discharges for the 25- and 50-year storm events are similar across all three alternatives. The mitigation alternatives produced lower peak pond outlet discharges than the existing conditions for the May 30th, 2019 event. It is worth noting that the existing alternative includes overflow in this pond outlet discharge.

Table 6.1. Simulated rainfall events along with simulated peak inflow into the pond, and the total runoff volume intercepted by the pond.

Event	Total Rainfall, inches	Peak Discharge into Pond, cubic feet per second	Total Runoff Volume into Pond, acre-feet
25-Year (24-hour Storm)	5.64	126.5	128
50-Year (24-hour Storm)	6.52	190.9	213
May 30, 2019 Event (5/7 - 5/30)	4.1	159.4	25

Table 6.2. Simulated peak pond outlet discharge for each storm event.

	Peak Pond Outlet Discharge, cubic feet per second		
Alternative	25-Year (24-hour Storm)	50-Year (24-hour Storm)	May 30, 2019 Event (5/7 - 5/30)
Existing	124.3 (includes overflow)	188 (includes overflow)	34.1 (includes overflow)
Upgrade Outlet Pipe (Triple 48-in Culverts)	124.3	186.5	126.3
Open Ditch Outlet (30-ft wide, 6-ft deep, 6-ft bottom)	125.1	189.2	131.7

The simulated water surface elevation, and whether the pond is overtopped, is the most meaningful simulation result. The pond appears to begin overflowing into the city of Fredonia when the pond water surface reaches an elevation of approximately 598.8 feet, based on LiDAR topography surrounding the pond. Simulated peak pond water surface elevations for each storm and alternative are shown in Table 6.3. Based on these results, it appears the existing conditions result in the pond being overtopped for each storm event. The mitigation alternatives produced much lower peak pond water surface elevations, on the order of 3 – 4 feet lower, and were never overtopped. This is accomplished through significantly increasing the flow capacity and lowering the upstream invert of the main pond outlet. Both of these factors allow the pond to discharge before it is overtopped.

Table 6.3. Simulated peak pond water surface elevations for each storm event. Pond overtops at approximately 598.8 feet.

	Peak Pond Water Elevation (Overtops at approx. 598.8 feet)		
Alternative	25-Year (24-hour Storm)	50-Year (24-hour Storm)	May 30, 2019 Event (5/7 - 5/30)
Existing	599.6 (Overtopped)	599.9 (Overtopped)	599.0 (Overtopped)
Upgrade Outlet Pipe (Triple 48-in Culverts)	595.6	596.4	595.6
Open Ditch Outlet (30-ft wide, 6-ft deep, 6-ft bottom)	595.4	596.0	595.5

7. Recommendations

Completion of these tasks would improve the city's situation and lead to other opportunities to lower its flood risk:

- Seek grant opportunities to pursue a more detailed study to reduce flood risk through mitigation alternatives that could include providing a higher capacity pond outlet
- Perform maintenance on the pond outlet pipe, culverts, and drainage ditches to remove sediment, vegetation and debris
- Coordinate with Louisa County, any drainage districts, and Iowa, Chicago and Eastern Railroad to explore any opportunities to improve the current drainage situation
- Continue to coordinate with Louisa County Emergency Management and pursue any funding opportunities offered by FEMA and Iowa Department of Homeland Security

This study demonstrates potential flood reduction benefit through improvements to the pond outlet, however, a more detailed evaluation is needed to clearly identify the best course of action. While improvements identified in this study could reduce flood risks, it may not fully mitigate basement flooding issues if related to a high water table during wet periods. Low topographic relief and soil characteristics in this area indicate a seasonal high water table during wet periods.

8. REFERENCES

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