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FLOOD INUNDATION MAPPING FOR HURON CREEK, HOUGHTON COUNTY, MICHIGAN

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HOUGHTON COUNTY, MICHIGAN

By

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A REPORT

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To the Montana Conservation Corps, Big Sky Watershed Corps, for inspiring a love of Water Resources

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Abstract

The 2018 Father's Day Flood rattled the Houghton County, MI community. Thousands of dollars in damage to public and private property were incurred due to slope failure, scour and stagnant water. Though the flood was billed as a once-in-a-lifetime event, hazard mitigation planning has become essential, as extreme weather events are expected to become more frequent with a changing climate. While Federal Emergency Management Agency funding will provide detailed flood hazard maps in the future, mapping is expected to be several years out. To aid the City of Houghton community with immediate flood hazard mitigation planning, a hydraulic-based flood depth map was created for the Huron Creek Watershed. Utilizing the HEC-GeoRAS extension within the ArcGIS software, channel cross sections were drawn from a pre-flood 2018 digital elevation model. The cross sections were then imported to HEC-RAS software, where flow structures were added and channel geometry edited to match surveyed elevations. A steady-state mixed flow analysis was performed for the 1% annual exceedance event (100-year flood). The water surface profile and flood depth map produced reveal that areas at high risk of flooding mainly lie downstream, at Lakeshore Drive. Areas of high velocity and potential scour risk were also identified at the Canal Road and Calverley Road culverts. Suggestions for mitigating the risk of flooding along Lakeshore Drive include increasing the culvert size, widening the upstream channel, removing the outlet weir, and making structural or nonstructural changes to adjacent property to reduce the impact of flooding. In addition, scour reduction may be achieved through the emplacement of inline weirs/vanes.

1 Introduction

On the morning of June 17th, 2018, Houghton, Michigan experienced extensive flooding due to a 1000-year storm event (NWS, 2018). The flash flooding caused infrastructure damage to both residential and public structures throughout Houghton County. Slope failure and deep channel incision have also altered the landscape, in some cases redirecting flow paths and creating groundwater springs. Both local and federal agencies responded rapidly to the event with aid, starting a remediation and mitigation process that will continue for years to come.

To aid in hazard prevention and mitigation planning, the purpose of this study is to provide a visual assessment of flood risk in the Houghton community, specifically for the Huron Creek drainage area. Identifying potential impacts of future large storm events is essential for flood hazard resiliency. Furthermore, with climate change, large storm events are predicted to become more frequent. Preparing for a shift in climate is essential for communities to thrive. Hazard mitigation is the key to success in communities experiencing urban development along with the effects of climate change. Flood inundation maps may also serve as a tool for continued research and as an educational resource for both the general public and planning agencies.

Currently, the extent of flood hazard mapping within Houghton county is limited. While floodplains are assessed on a permit-by-permit basis (Occhipinti, 2019) there is not an extensive map delineating the floodplain based upon the FEMA recommended 100- year for the county. At present, only the township of Chassell has a FEMA flood hazard map. The current FEMA map was finalized in 1990, where flooding was principally caused by high lake stages in Chassell Township. Historical flooding in this area is marked by several occurrences of the 50-year and 100-year stage events. In contrast to Chassell Township, the Houghton and Hancock areas are subject to flooding from overland flow. Thus, the need for new flood maps is imperative.

To address the need for local flood maps, the Huron Creek drainage area was selected as a case study to create a flood depth map. The Huron Creek watershed is of particular interest because significant infrastructure and floodplain damage occurred all along the main channel of Huron Creek during the Father's Day Flood. Flooding occurred at both upstream sections of the creek, near the outlet of Huron Lake, and near the outlet, along Lakeshore Drive. While many culverts along the channel display evidence of scour, where concrete has been eroded to rebar, only one location suffered from failure. The culvert on Sharon Avenue was overtopped, and significant scour and incision occurred, causing pavement failure. Less immediately damaging scour changed the landscape of Huron Creek by rerouting channel beds, displacing bed load material, and scouring vegetation. Repairs by the City of Houghton have consisted of rebuilding failed pavement and the replacement of the Sharon Avenue culvert. Given the new repairs, it is essential that a flood map be produced in the area to provide an up-to-date assessment of flood hazard risk.

Section 1 of this report introduces the context of flood hazard mapping in the US, as well as the social and geomorphic context for Huron Creek. Section 2 addresses the methodology used to produce the flood depth map using both geographic information systems (GIS) and the US Army Corps of Engineers HEC-RAS software (Brunner, 2016)). Section 3 offers interpretation and recommendations based upon the produced flood maps. Section 4 concludes with limitations and suggestions for further work.

1.1   Flood Hazard Mapping Methods and Extent

Because of the ever-present threat of floods, many methods have been developed to map flood hazard risk, by both governmental agencies and researchers. Two principal methods exist: those that are hydraulic-based and those that are geographically based. Hydraulic-based models generally rely on channel geometry and hydraulic principles to produce flood-depth maps (Merwade, 2008). Uncertainties therefore exist based on the quality and resolution of channel properties, along with mathematical modeling assumptions. In contrast, geographically based models utilize a variety of land-based physical parameters to produce zones of high and low flood hazard (Merwade, 2008). Uncertainties in these empirically based models are therefore a function of weighting techniques and imagery resolution. While hydraulically based mapping is the most commonly used by governing agencies, interest in geographically based flood hazard mapping has been renewed due to the increased quality and decreased cost of remotely sensed data.

Largely, hydraulic methods dominate in the United States, as the methods created by US Geologic Survey and the Federal Emergency Management Agency are tightly woven into legislation (Merwade, 2008). In particular, disaster recovery funding is dependent on FEMA delineated maps or Flood Insurance Rate Maps (FIRMs), and FEMA requires use of hydraulic methods. Two commonly used software programs for computing flood depths are the US Army Corps of Engineers HEC-RAS (Brunner, 2016) and HEC-GeoRAS (Ackerman, 2011). Typically, a 100-year return flow is mapped, based on an established flood frequency curve or the application of a statistical or physically based hydrologic model to generate discharges corresponding to a design storm event. Flood depth grids, water surface elevation grids, and velocity grids can then be generated so as to aid planners in risk assessment.

State and local planners can use this flood risk information to update zoning codes, identify low risk areas for evacuation and shelter, as well as identify high hazard areas for first responders to avoid. Moreover, flood risk maps can be used to communicate flood risk to local citizens and business owners. Because land use change affects the accuracy of FIRMs, regular updates to flood maps are recommended. Beyond flood-depth mapping, the FEMA-based HAZUS model is widely used for estimating potential damage costs. The HAZUS model estimates physical, economic, and social impacts of disasters. These asset losses can then be used to prioritize areas for mitigation.

Outside of the US, more focus has been given to modeling flood hazard areas, utilizing GIS for remote areas, where field surveying is either too dangerous or expensive, or the

period of record is short. For example, a study carried out by Kourgialas and Karatzas (2011) investigated the use of overlaying geographic features such as geology, slope, rainfall intensity, land use, flow accumulation and elevation to pinpoint areas of high flood hazard. The final weighted map was found to compare well with the previous large flood record. Similar geographically based flood hazard mapping has been carried out in the Netherlands (e.g., De Bruijn, 2009). Development and application of similar approaches for rural areas and small communities in the U.S. may be beneficial.

1.2   Huron Creek Watershed Characteristics

Huron Creek watershed is located in Houghton County in the Upper Peninsula of Michigan. Characterized as a small basin (3.4 square miles), the Huron Creek watershed consists of four smaller subbasins, which can be seen in Figure 1.
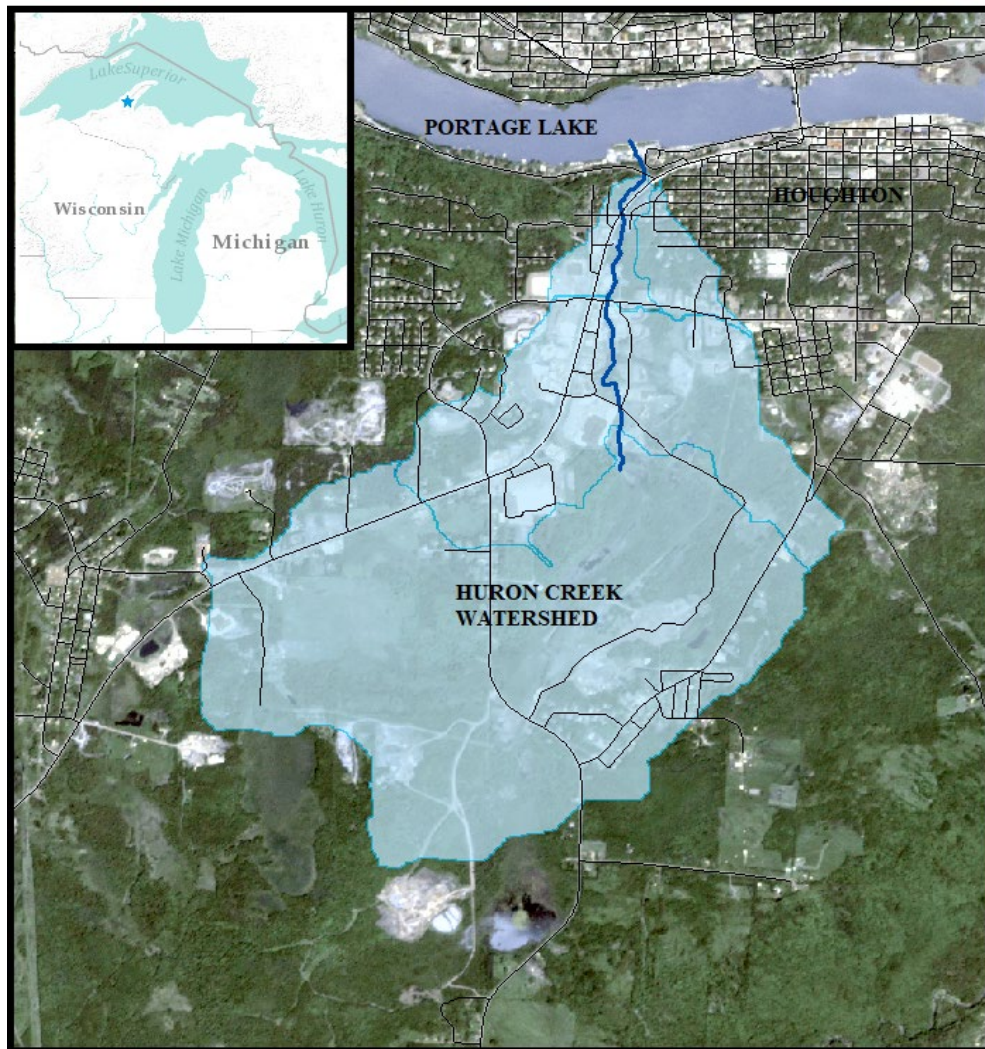
Figure 1. Huron Creek Watershed Location

The focus of this study begins at Huron Lake, near the center of the watershed, from which Huron Creek winds north through Houghton's business district, finally discharging into Portage lake. The main stem of Huron Creek extends 1.34 miles, or 7080 ft. The channel soil consists of fine-grained sand (Blink, 2007). Largely, land use within the watershed is urban and residential. From a period of 1978-2005 land development in the watershed increased by 15.4% (Blink 2007). During this time, several sections of the Huron Creek were relocated. Notably, segments of creek were moved at two distinct points, Walmart and Chutes and Ladders Park (Blink, 2007). Such changes make the watershed particularly vulnerable to flooding, as the channel's natural ability to slow down and spread out water has been significantly reduced. The Father's Day Flood illustrated several such places were land use change likely increased runoff and reduced flood storage and conveyance capacity along Huron Creek. In particular, the Sharon Avenue culvert was overtopped, and the area downstream of the Lakeshore Drive culvert flooded.

2   Methodology

To determine the extent of flooding for the Huron Creek watershed, the following general method was followed. Geospatial information was first collected in ArcGIS 10.6 and channel geometry drawn using the HEC-GeoRAS tool. Channel geometry data was then extracted and exported into HEC-RAS, where flow structures, boundary conditions and discharges were specified. A mixed regime, steady-state flow analysis was run in HEC-RAS, and then a flood depth map was produced in RAS Mapper. A visual overview of the process and the software programs employed can be found in Figure 2.
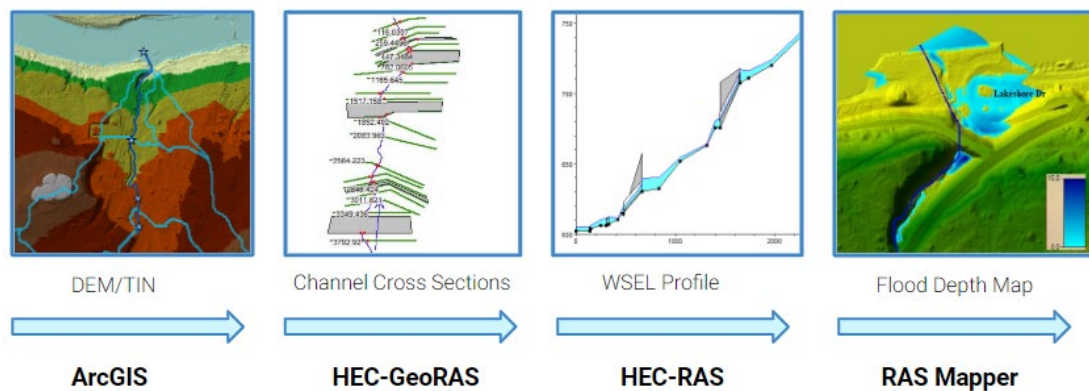
Figure 2. Overview of the software and associated outputs used to create a flood depth map.

A more detailed process for creation of a flood depth map in HEC-GeoRAS and HEC-RAS can be seen in Figure 3, borrowed from the HEC-GeoRAS manual (Ackerman, 2011).
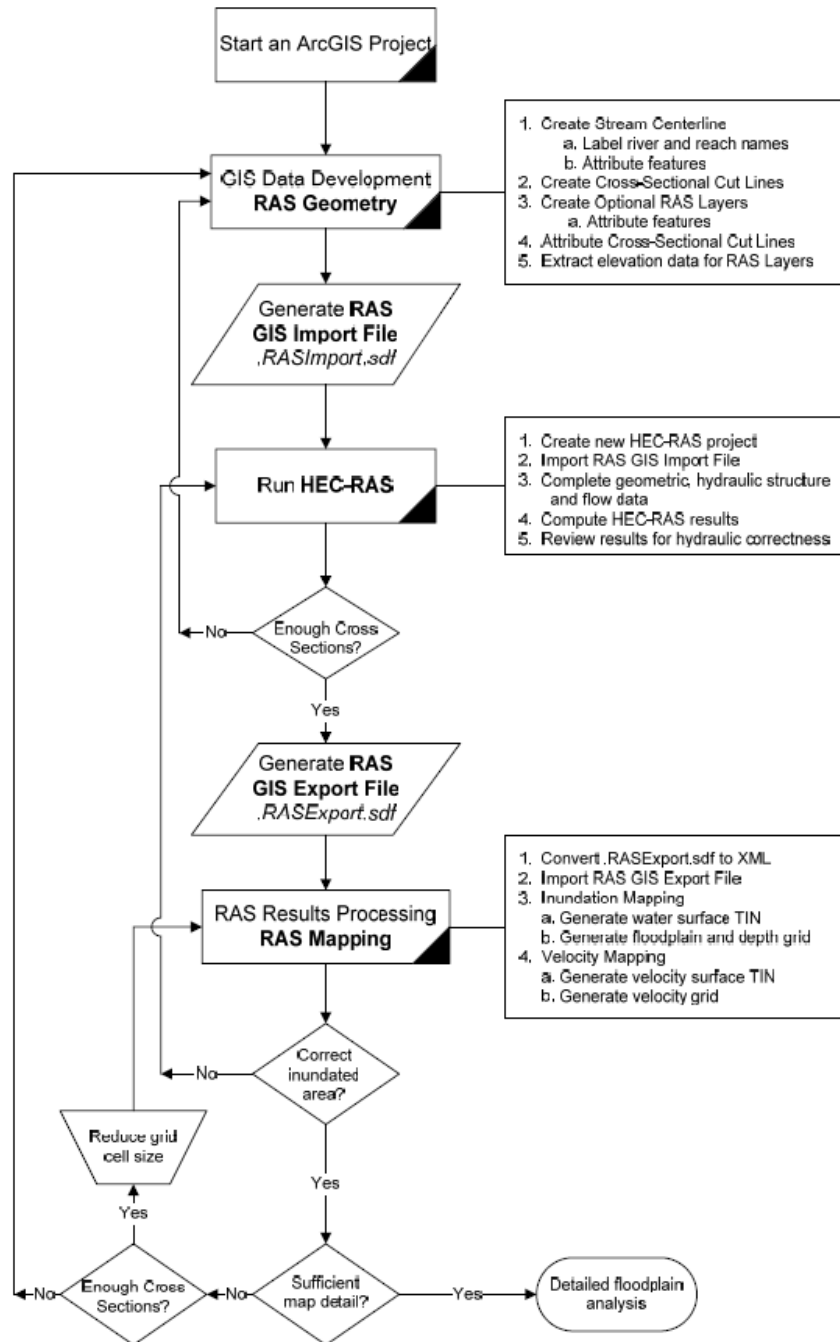
Figure 3. Flood depth mapping process flow chart reproduced from Figure 3-1 from HEC-GeoRAS User's Manual v10 (Ackerman, 2011)

2.1 Geodatabase Development

To begin creating the model geometry and to understand the physical properties of the watershed, a geodatabase containing the watershed basins, hydrography and digital elevation model (DEM) was assembled. Table 1 displays the data layers used within the geodatabase and their source. Note that the DEM and associated calculations are based on 3-inch ground pixel resolution.

Table 1. Huron Creek Geodatabase Data layers

Data Layer	Information Type	Resolution	Source
DEM (HHELEV2018)	Raster (.img)	3 inches	Michigan Statewide Authoritative Imagery & LiDAR Program MiSAIL, 2018
Satellite	Raster (.TIF)	5 meters	Planet Team, 2017
Subwatersheds	Polygon	N/A	Derived by Rudiger Escobar Wolf, Geological and Mining Engineering and Sciences, using a 10-meter DEM provided by United States Geological Survey, The National Map, 2019
Discharge	Point	N/A	MDEQ - WRD Flood Discharge Database, 2019
Roads	Polyline	N/A	United States Geological Survey The National Map, 2019
Drainages	Polyline	N/A	United States Geological Survey The National Map, 2019
Culverts	Point	N/A	Local Survey

The data frame coordinate system was set to NAD 1983 State Plane Michigan North FIPS 2111 (US feet), and all layers were projected in turn so that vertical and horizontal units were measured in feet. Once layers were assembled, pre-processing of the data began so that HEC-GeoRAS cross section geometry could be developed.

2.2   Input Data Processing

Once the geographic information was assembled, a triangular irregular network (TIN) layer representing surface topography was created based on the three-foot contour interval layer delineated from the DEM. A stream centerline and flowlines were then specified using the drainage layer of Huron Creek in the HEC-GeoRAS toolbox. Left and right banks were then drawn parallel to the channel utilizing the TIN and satellite images. River reaches and flow line directions were then specified so as to relate with cross sectional data. With the centerline and banks specified, cross sections were cut perpendicular to the flow line of the stream centerline. The cross sections were also dog-legged to accurately capture left overbank (LOB) and right overbank (ROB) flow areas.

Cross sections were drawn at distinct bends in the main channel (ranging from 2 ft to 30 ft apart), as well as directly on, above and below upstream and downstream flow structures. The cross sections were then checked for quality by utilizing the Plot Cross Section Tool in HEC-RAS. Specifically, both left and right bank locations were placed at points acting a natural levee, so as to prevent water accumulation in lower elevation areas not connected to the channel. Cross sections were redrawn or edited until the desired channel geometry was achieved. Note that in this study, the cross-section data is dependent on the DEM, so cross section data was limited to a 3-inch pixel resolution.

2.3   Hydraulic Model

Once all the geospatial data layers were completed, they were specified using the Layer Setup function in HEC-GeoRAS to reference the layers according to their functional use. Next, the stream centerline and cross section topology, elevation, lengths and stations were related using the attributes function. This geometric data was then exported from HEC-GeoRAS and subsequently imported into HEC-RAS. In HEC-RAS, cross sections were edited manually so that the left and right banks were positioned logically. With the channel and overbank areas specified, Manning's roughness values were then input for LOB, ROB and the main channel for each cross section. Table 2 displays the values for the Manning's roughness values input into each cross section, based on Sturm (2010, pp. 129-132)

Table 2. Manning's Roughness Values for Huron Creek

Manning's n	Description	Source
Banks		
0.033	**Lined or Built up Channels B-2:** Nonmetal, Dry Rubble and Riprap	Table 4.1 Values of Manning's Roughness, pg 129-132, Sturm, 2010
0.07	**Natural Streams D-2:** Flood Plains c. Brush-Medium/dense brush	Table 4.1 Values of Manning's Roughness, pg 129-132, Sturm, 2010
.030	**Natural Streams D-2:** Flood Plains a. Pasture, brush, Short grass	Table 4.1 Values of Manning's Roughness, pg 129-132, Sturm, 2010
Channel		
0.035	**Natural Streams D-1:** Minor streams 2.0 clean straight no deep pools, stones and weeds	Table 4.1 Values of Manning's Roughness, pg 129-132, Sturm, 2010

Next, flow structures were added to the geometric data by utilizing the Bridge/Culvert Data toolset in HEC-RAS. A total of 11 flow structures were accounted for in the hydraulic model. Seven culverts were identified along Huron Creek, as well as four weirs. In addition, during field survey, two additional inline bridge structures were identified at the Chutes and Ladders Park. These pedestrian bridges were not included in the model because their support structures did not encroach on the channel at bankfull elevation. Figure 4 displays culvert crossings as well as locations where flood discharges have been estimated by the MDEQ.
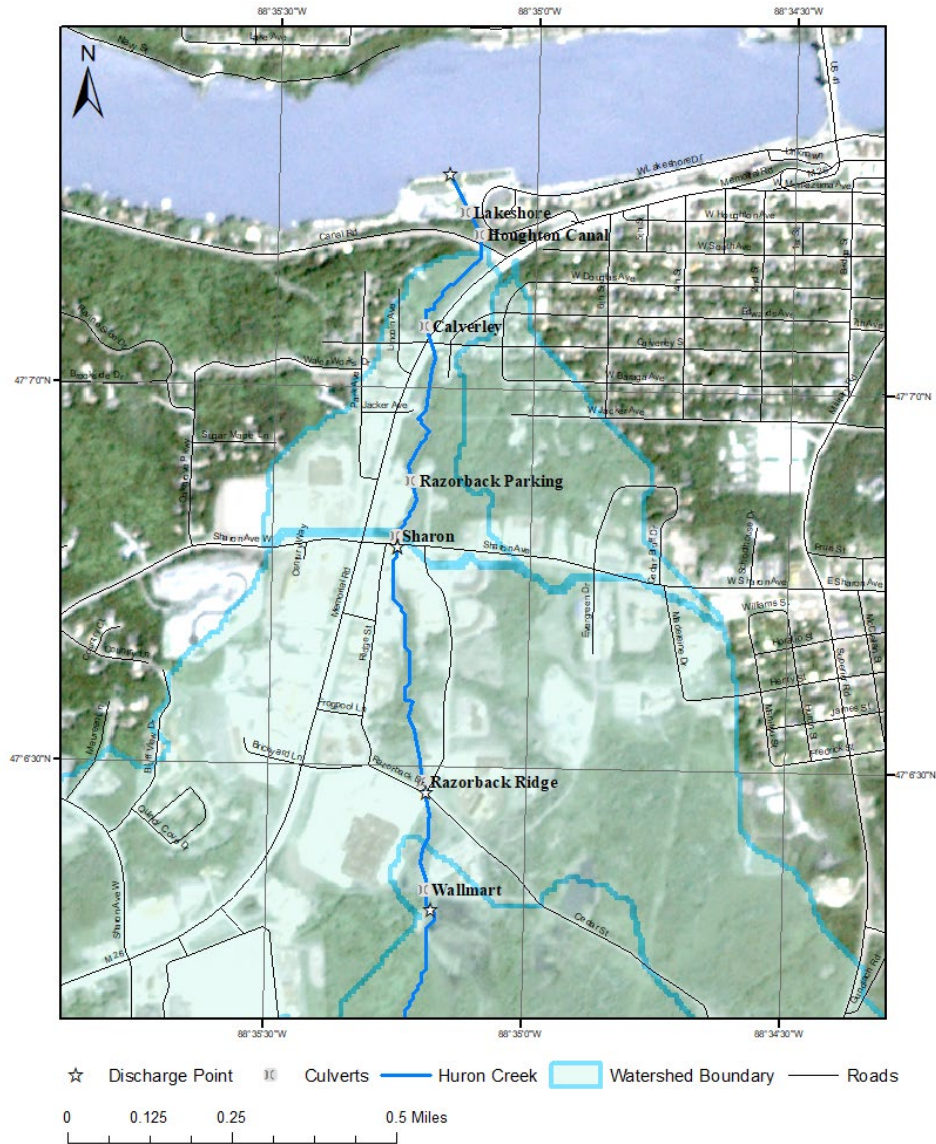
Figure 4. Huron Creek culvert crossings overlaid with discharge points.

Flow structures were modeled in HEC-RAS using four distinct cross sections—two upstream and two downstream of each structure-- to account for flow contraction and expansion ineffective flow areas. Both culvert and weir information was collected using a combination of field survey and the analysis of permits and design plans provided by the City of Houghton. In the absence of elevation survey data, road heights were estimated using the DEM (to be consistent with cross sections), and structure invert elevations were estimated from scaled photographs. Table 3 describes culvert properties and inputs into

HEC-RAS. Note that entrance loss coefficients were estimated using the Michigan Department of Transportation Drainage Manual, Appendix 5-B. Finally, ineffective flow areas were added to account for flow contraction upstream and expansion downstream of culverts, as well as to prevent flow in low areas not connected to the channel. Figure 5 displays an example of the Lakeshore culvert input into HEC-RAS as well as the corresponding field photograph.

Table 3. Huron Creek culvert data.

Name	Diameter (or W/H) (ft)	Barrel Count	Culvert Type	Ke Loss Coefficients	Manning's Roughness	Length (ft)	Slope
Lakeshore Drive	6.83/4	2	Pipe-Corrugated Steel/ projecting	0.9	0.026	14	0.0714
Houghton Canal	6.50	2	Concrete Culvert	0.5	0.013	188.5	0.0796
Calverley/ Memorial	6.00	2	Concrete Culvert	0.5	0.013	200	0.138
Razorback Parking lot	6/8	1	Pipe-Corrugated Steel/ projecting	0.9	0.026	42.6	0.0235
Sharon	8.00	1	Pipe-Corrugated Steel/ projecting	0.9	0.024	260	0.0076
Razorback/ Ridge Rd	6.83/9.67	1	Concrete Box Bridge	0.4	0.013	168	0.0059
Walmart	12.17/9.67	1	Concrete Box Bridge	0.4	0.013	50	0.04
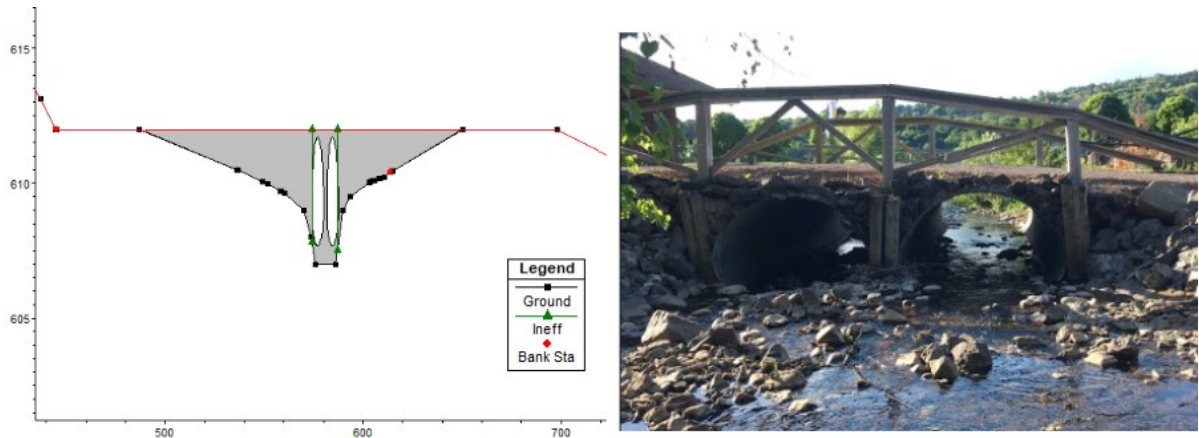
Figure 5. HEC-RAS input and corresponding field photograph for the Lakeshore Culvert, near the outlet of Huron Creek. Note image is facing downstream.

Next, weir information was input using the Inline Structure tool. Input information for weir structures can be found in the table in Appendix A.1. All weirs were modeled as broad-crested weirs, with one continuous horizontal line representing the weir crest. This represents a simplification of some of the weir structures; for example, in Figure 6 it can be seen that the Old Dam weir has an uneven crest, but it was modeled as a level crest at the waterline. It should also be noted that the outlet structure, which consists of four submerged and suppressed pipe culverts, was modeled as a weir. The outlet was modeled as a weir because the structure remains submerged year-round, slowly leaking water through small openings between the culverts and the bounding portage piers. The system therefore functions like a large broad-crested weir, especially during high flow events, where water is backed up in the channel until it is released over the culverts' concrete headwall.
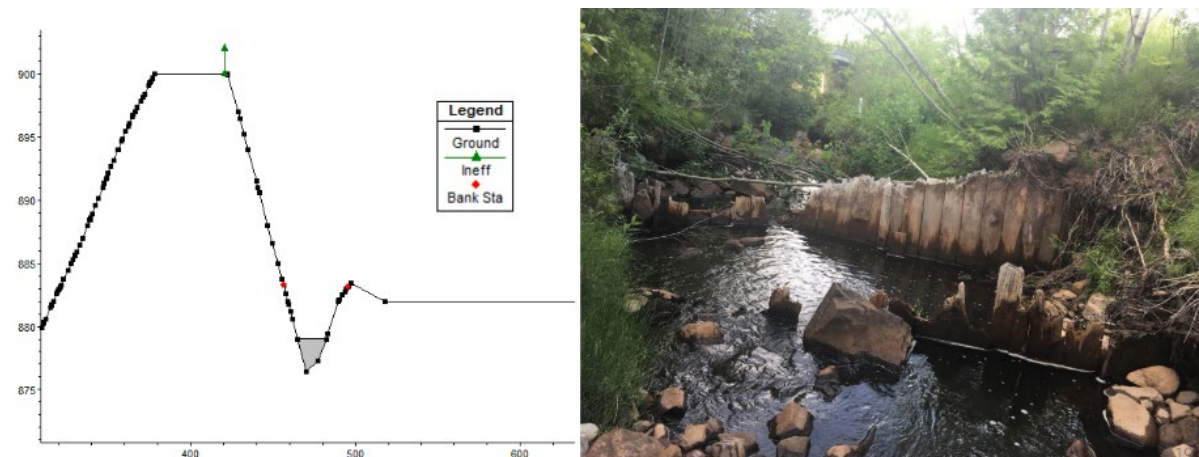
Figure 6. HEC-RAS input and corresponding field photograph for the Old Dam weir near the mouth of Huron Lake. Note image is facing downstream.

With the weir and culvert information specified, channel properties were input and the channel geometry was adjusted to match the flow structure data. At this stage it was

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essential to adjust channel geometry because initial cross sections delineated from the DEM do not display channel bottom data (bathymetry), but instead plot the water surface elevation at the time the image was captured. To reconcile this difference, the DEM-based cross sections were adjusted so that the channel bottom matched culvert elevations. Figure 7 illustrates the adjusted channel geometry in comparison to the original DEM.
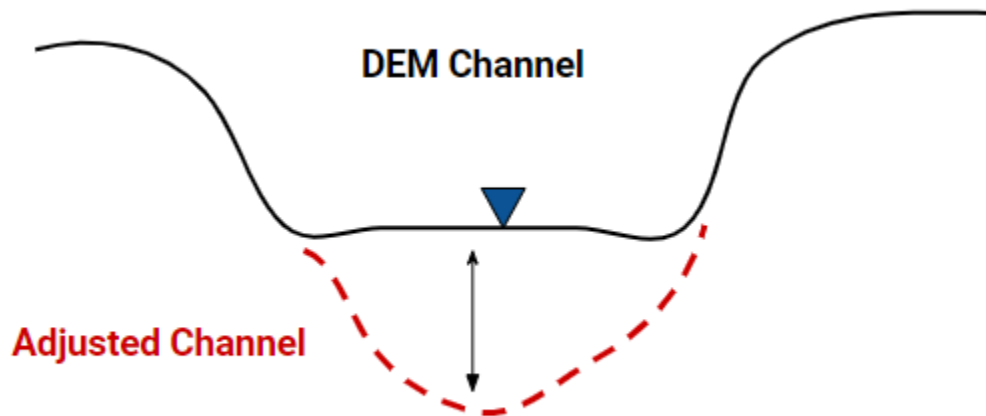
Figure 7. DEM channel geometry adjustment

For cross sections that did not have an associated culvert, the culvert elevation immediately upstream or downstream of the section was used to estimate channel thalweg elevation and adjust the channel bottom. Cross sections sufficiently far away from a culvert were estimated by linearly interpolating the difference in thalweg elevation between the bounding culverts. This process can be seen in seen in Figure 8.
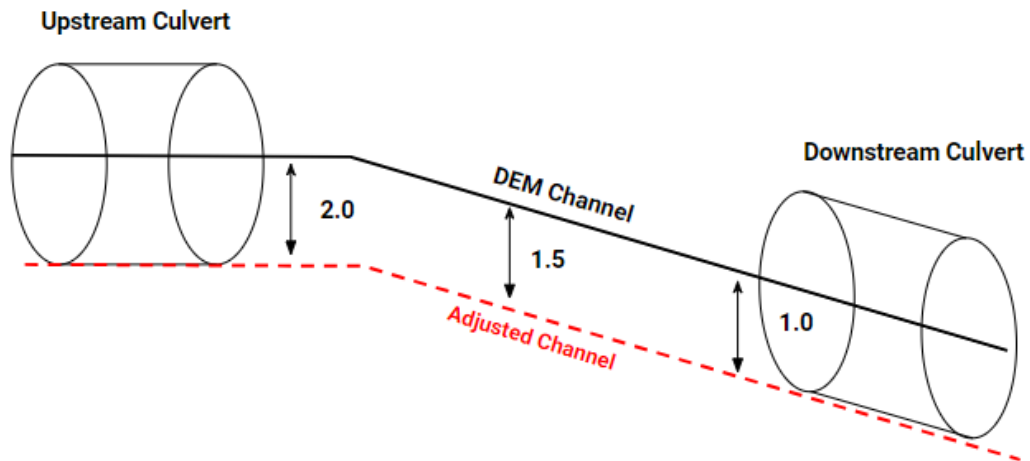
Figure 8. Channel geometry adjustment for cross sections between bounding culverts.

Downstream reach lengths for the left and right bank were assumed to be the same as the main channel. Because channel depth was based on post-flood measurements, it can be seen that channel bed geometry is deeper than pre-flood existing DEM ground surface elevations, and therefore it is expected that the simulated water surface elevations will be conservative. Before running the steady flow analysis, cross section points were filtered so that each section had less than 500 points.

Using the Steady Flow data tool, upstream and downstream boundary conditions were specified. The upstream boundary at the outlet of Huron Lake was specified as critical depth, while the downstream boundary used the lake water surface elevation of 602.0 ft. Using discharge data acquired from the Michigan Department of Environmental Quality Flood Discharge Database, a 1% annual exceedance design flood was modeled (MDEQ 2019). Discharges and associated cross section stations can be seen in Table 4. It should be noted that because only discharge change locations are specified in the model, the final outlet value of 800 cfs was not input into the model, because it represented the same discharge as the West Sharon station. While the outlet lies 3000 ft downstream, and thus it is expected that the discharge value would exceed 800 cfs, a separate hydrologic analysis was beyond the scope of this study.

Table 4. Michigan DEQ Discharge for Return Period, Huron Creek

Location	Station	100 year (cfs)
Huron Dam	6840.229	410
Copper Country Mall Driveway	5737.15	600
West Sharon	3349.436	800
Outlet	116.030	800

Finally, because culvert slopes ranged from .006 - 0.13 ft/ft, with the average slope of 0.05 ft/ft, a mixed flow regime was specified, assuming both supercritical and subcritical flow would occur at different points along the channel.

2.4 Flood Mapping

Once HEC-RAS produced a steady flow result, RAS Mapper was opened and the Floodplain Mapping Tool was executed to generate a bounded polygon of the flooding extent. To create a flood depth map, the DEM was imported into RAS Mapper and the ESRI projection specified. The Floodplain Mapping Tool also produced velocity and water surface elevations maps. Note that for the flood depth map, positive flood depths indicate that the water surface is higher than the terrain surface, and flooding occurs when the top of the channel is exceeded.

3 Results

3.1 Hydraulic Model

Results for the 1% annual exceedance flood can be seen in both the profile and 3D perspective plot in Figures 9 and 10, respectively. It can be seen in Figure 9 that two culverts within the system are overtopped. Both the Lakeshore and Razor lot culverts are overtopped, but display different flooding effects. While the Razor lot culvert is overtopped, the surrounding channel is very deep and wide, causing flooding to be contained in the channel upstream of the culvert. However, downstream of the culvert flooding extends out into the right bank and into the road. Any overtopping places culverts and roadways at risk of failure from scour. For an illustration of the overtopped Razor lot culvert, see Appendix A.3.

In contrast, the cross section in Figure 11 shows the extent to which the Lakeshore Dr. culvert is overtopped, where flooding occurs both upstream and downstream of the culvert. From the 3D plot in Figure 10 flooding outside the left and right channel banks occurs mainly near the outlet, or Lakeshore Drive. The downstream section is particularly vulnerable, where flooding occurs several hundred feet outside the right bank and presumably continues beyond the drawn cross section until the land surface begins to rise. This result is consistent with the Father's Day Flood, when much of Lakeshore Drive was flooded.
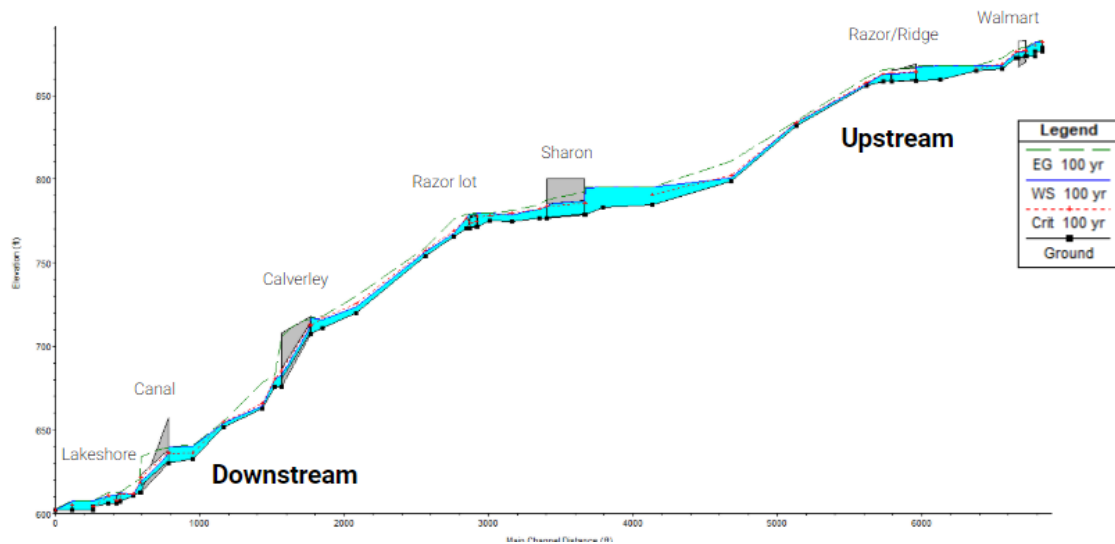
Figure 9. Modeled water surface profile of Huron Creek during the 100 yr flood
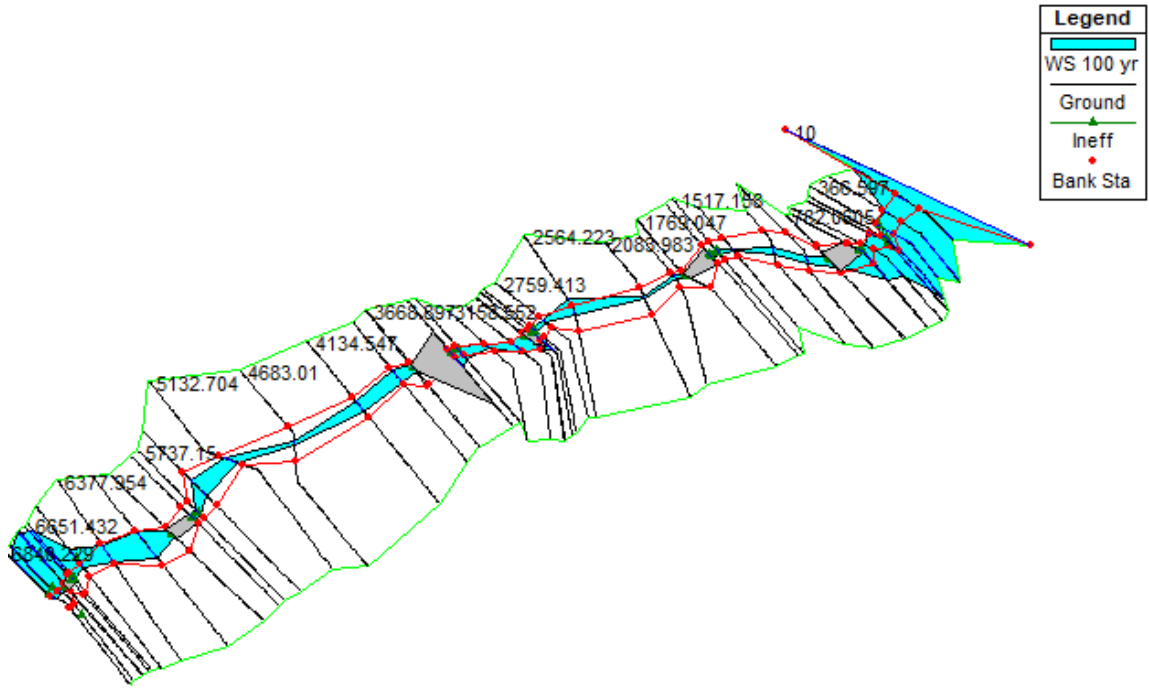
Figure 10. Modeled 3D plot of Huron Creek during the 100 yr flood. Note that station 10 is the most downstream section, where upstream to downstream is oriented left to right.
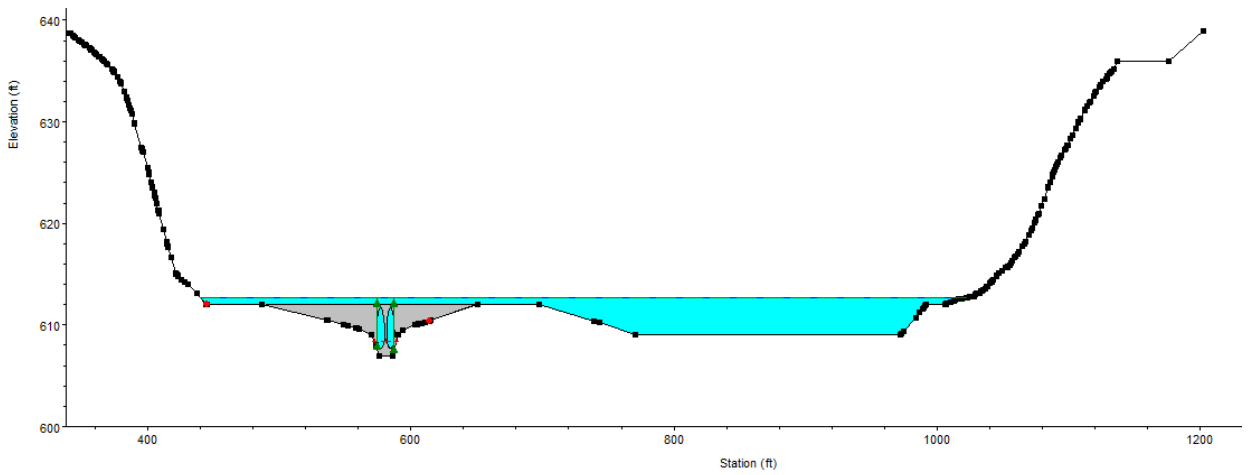
Figure 11. Lakeshore Drive culvert upstream (top) and downstream (bottom) cross sections for the 100-yr flood.

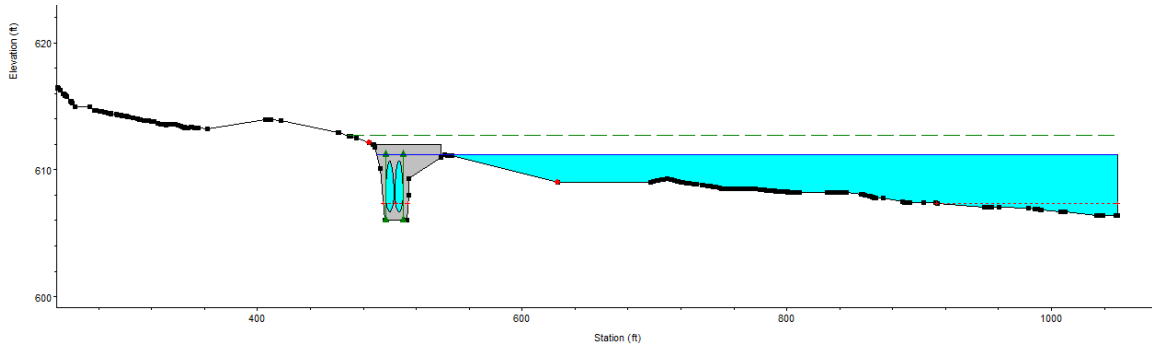Other areas of interest include the Calverley and Houghton Canal culverts. Both culverts, though not overtopped, display unusually high downstream velocities--38.4 ft/s at Calverley Rd. and 30.5 ft/s and Canal Rd. These velocities are 200% larger than any of the other velocities displayed within the system. This disparity can be seen in the table of upstream and downstream velocities included in Appendix A. Both culverts have steep slopes (0.08-0.13 ft/ft) and low roughness coefficients (0.013). They are both relatively long culverts, at around 200 ft, and characterized as concrete pipe culverts with grooved end entrance and headwalls. Because of the steep slopes and smooth concrete surface, these areas are prone to high-velocity flow. These areas should therefore be considered for additional scour protection. Houghton County may also consider using inline vanes/weirs or riffle and pool structures to reduce flow to protect these areas from erosion. Furthermore, the use of riffles and pools may provide the ecological benefit of cold and slow velocity refugia for the native fish population (Radspinner 2010).

Additionally, because these culverts display graffiti and other signs of human use, protective screens may be considered to protect against high velocity drownings or injuries. However, adding screens will increase maintenance requires as well as the risk of blockage by debris.

Besides managing risk at particular locations within the system, a watershed scale approach is also recommended. In particular, by utilizing low impact development solutions to manage runoff, the same type of flood risk reduction, as a targeted structure improvement, can be achieved. For instance, with the strategic placement the of detention basins, swales and raingardens, the amount of runoff from the watershed could be greatly reduced. With a reduction of runoff, the timing and quantity of peak flows are reduced, therefore reducing flood risk. Given that the Huron Creek Watershed maintains a significant portion of the urban landuse, reducing the impact of urban impervious surfaces could have a great potential to increase local flood resiliency.

3.2 Flood Depth Hazard Map

The flood depth map can be used to assess flood risk and identify vulnerable areas, similar to the use of a FEMA FIRM Map. The flood depth map is consistent with the 3D plot produced in HEC-RAS, showing that the primary area of concern is the Lakeshore Drive culvert and adjacent floodplain. Similar to Figure 10, results in Figure 12 show that flooding has the potential to extend beyond the defined channel cross sections.
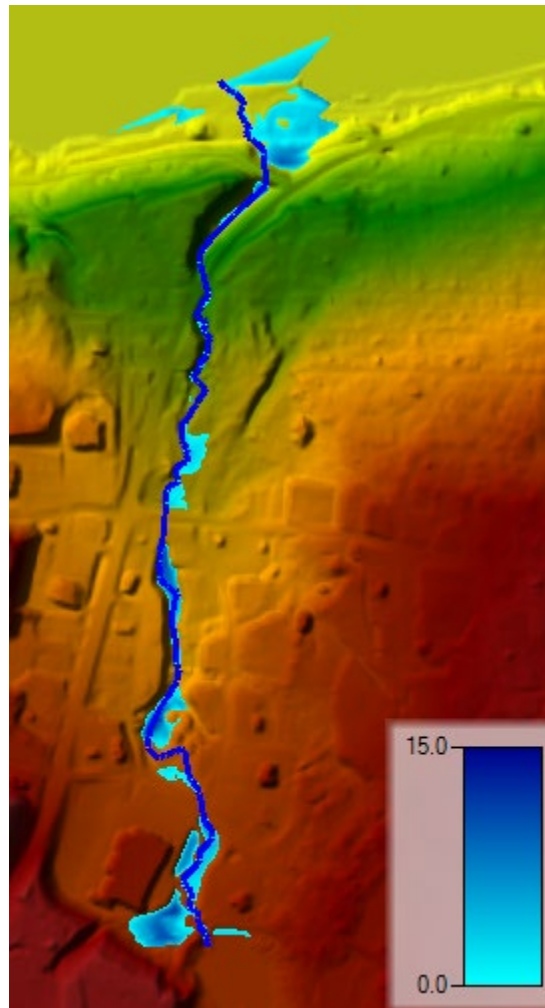

Figure 12. Flood Depth Map of Huron Creek for 100-year return period
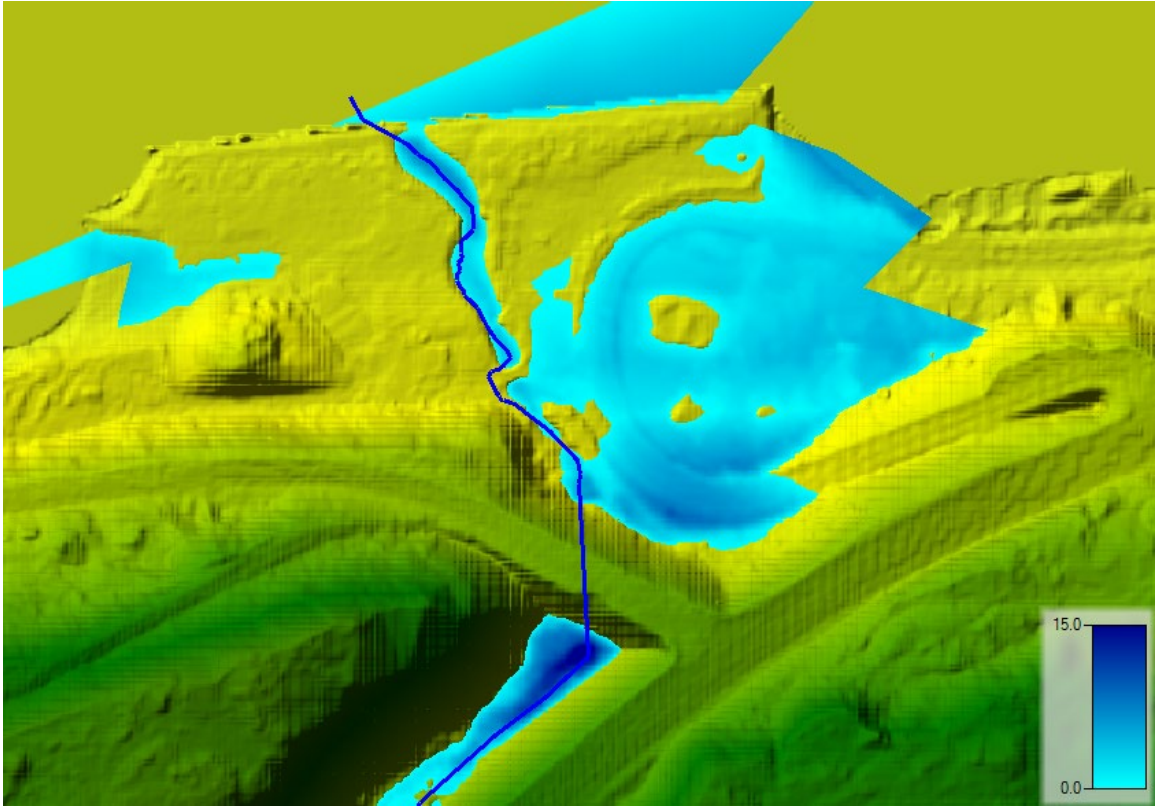
Figure 13. Lakeshore Flood Depth Map for the 100-yr flood

In particular, as can be seen in Figure 13, the results from the flood depth map suggest that current residents of Lakeshore Drive should apply for flood insurance if they do not already have policies. Residents that are at particular risk, should also consider structural changes to their homes, such as stilts, or nonstructural measures, such as berms or sandbags. The City of Houghton may also consider the expanding the Lakeshore Drive culvert, widening the channel upstream of the Lakeshore culvert, or removing the outlet weir structure, all of which may help reduce the amount of water backing up in the area.

In addition to the horizontal extent of flooding, the flood depth grid provides a clear picture of areas of deep water. Sharon Avenue displays the greatest water depths at 15 ft. Figure 14 displays the stark contrast of the deep water in the incised and urban upstream section of the Sharon Avenue culvert and the significantly shallower riparian area just downstream. This contrast between riparian and urban channel section provides an unmistakable visual about the impact that land use has on flooding.
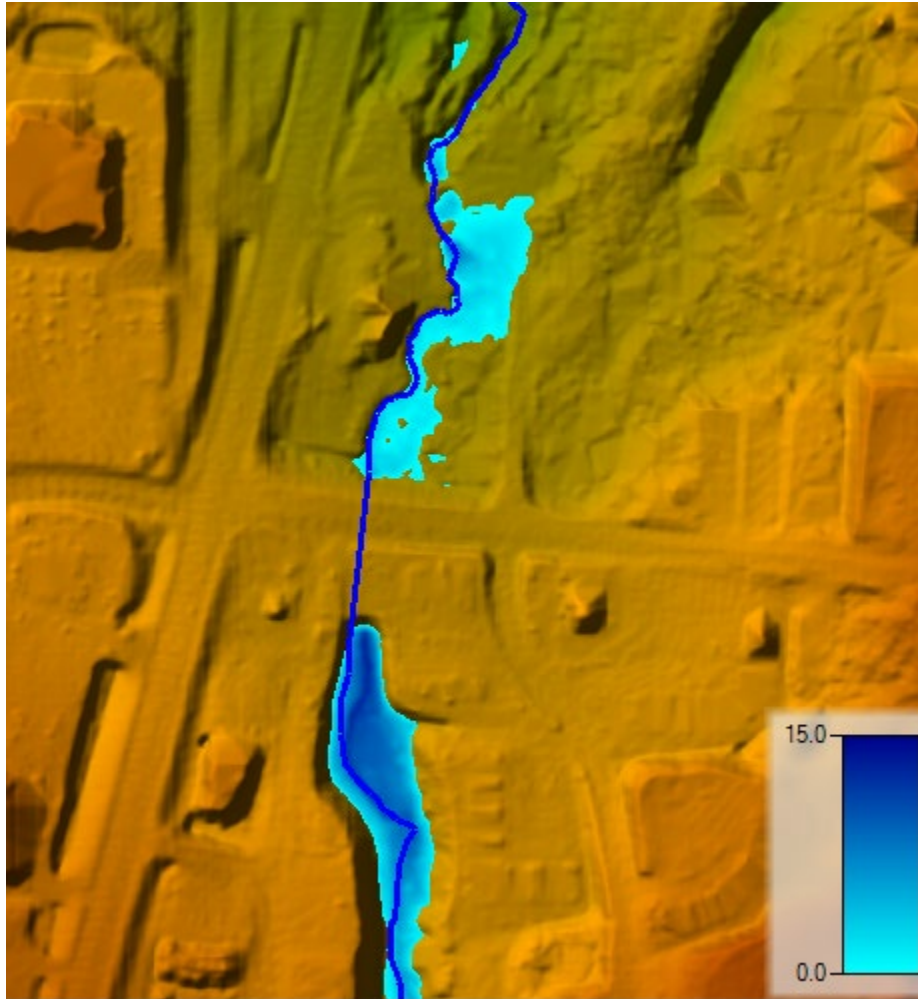
Figure 14. Sharon Avenue Flood Depth Map for the 100-yr flood

Finally, while the preliminary map produced results that were consistent with recent flood events, there were several areas within the map that lacked plotted flood depths. As can be seen in Figure 15, for the downstream section of the Walmart culvert, the map does not display continuous flood depths.
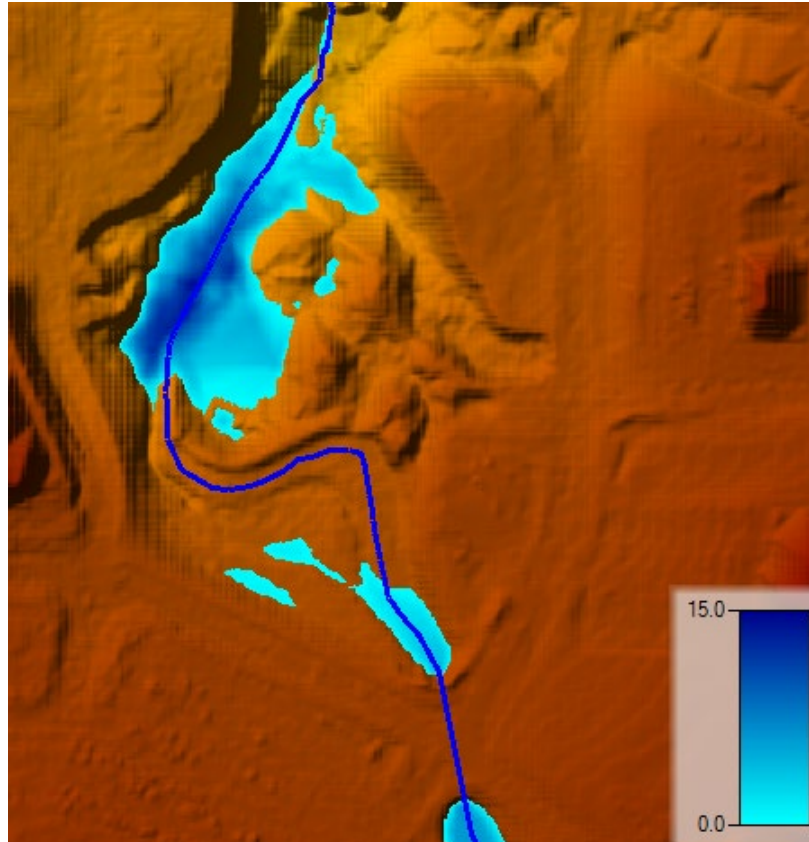
Figure 15. Missing flood depths just downstream of the Walmart culvert.

These gaps within the map are caused by the disparity between the adjusted channel geometry and the original DEM, which was used in Ras Mapper. Because the original DEM was not adjusted to reflect bathymetry, when imported into Ras Mapper, the channel bed is represented by the water surface elevation at the time the imagery was taken. This means that in some locations the water surface elevation generated by the hydraulic model in HEC-RAS (with the adjusted channel bottom geometry) lies below DEM water surface, and thus appears as a gap within the map. An illustration of the disparity is shown in Figure 16.
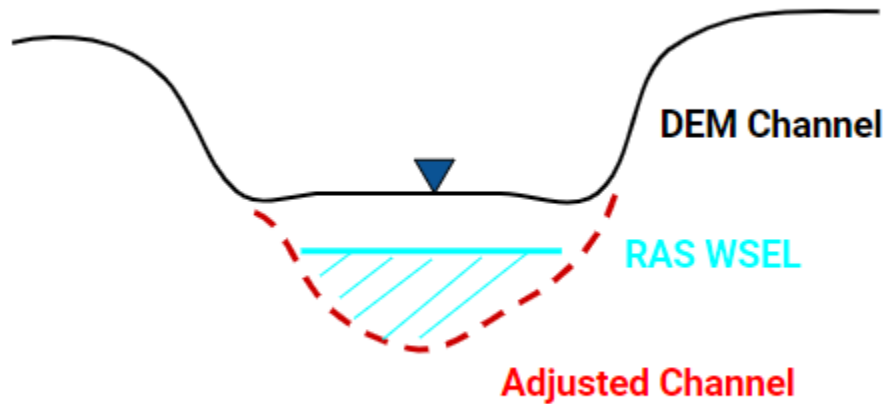
Figure 16. Illustration of missing flood depths in Ras Mapper, as the HEC-RAS generated water surface elevation (WSEL) lies below the DEM elevation.

To correct for this difference, the original DEM should be modified using raster subtraction to carve the channel within ArcGIS (Scott, 2018). It is recommended that future work concentrate on adjusting the DEM to reflect ground-truth bathymetry geometry. Other DEM complications such as canopy cover should also be considered. A brief visual analysis of the orthographic imagery associated with the DEM revealed that canopy obstruction is limited to coniferous vegetation. In particular, the area bounded by the Sharon and Razor lot culverts is characterized by cedar swamp, where foliage is moderately dense and has the potential to smooth the DEM surface, introducing error into the flood depths produced. While snow cover and deciduous canopy cover effects were also considered, no apparent obstruction was found from these effects.

4 Conclusion

In utilizing a digital elevation model (DEM), as well as the HEC-RAS and HEC-GeoRAS software tools, a preliminary flood depth map was produced for the 100-year return period. The 100-year floodplain surface revealed that along the Huron Creek drainage, Lakeshore Road is particularly prone to flooding. Largely, this is due to the low-lying area adjacent to the stream banks near the outlet. Structural changes including the expansion of the Lakeshore culvert, deepening or widening the upstream channel, and the removal of the outlet structure are recommended to reduce flood risk at Lakeshore Drive. The model also highlighted areas of high velocity such as the Canal and Calverley Road culverts, along with locations of significant depth, which planners may note as secondary flood hazards. Utilizing river restoration techniques, such as inline vanes and weirs to reduce scour, is recommended for the stream sections adjacent to the Calverley and Canal culverts. Additionally, a holistic watershed management approach is encouraged, to reduce runoff by employing low impact development solutions that may help to increase flood resiliency. However, because these results were based mostly upon remotely sensed inputs, before implementing changes based upon these results, it is recommended that the planners perform a more robust analysis, using the following recommendations.

First and foremost, because cross sectional data was dependent on an aerial-image DEM cross section elevation data should be adjusted to ground survey data to improve the accuracy of the channel geometry. Manual channel surveys should also be used to generate a DEM corrected for bathymetry for the entire channel, so that no gaps appear in aflood depth map generated with Ras Mapper.

Further work should also consider hydraulic assumptions stated in section 2.1. In particular, the Manning's *n* values for the overbank areas, as well as the channel bottom and banks, were estimated from descriptions in Table 4.1 of Sturm's "Open Channel Hydraulics" text. Alternatively, land use data may be input as a polygon feature class into ArcGIS and related to Manning's roughness values using relational tables. HEC-GeoRAS may then be used to define roughness continuously along a cross-section, thus improving the spatial resolution of the model. For even greater reliability, roughness can be determined per each cross section through manual survey. Other hydraulic assumptions should be studied as well, especially upstream and downstream boundary condition assumptions.

Other input improvements to enhance accuracy include adding bridge structures and modeling some of the culverts as with partially embedded. Future consideration should also be given to inline structures. In particular, the outlet into Portage Lake should be considered. Because surveying was inaccessible, and records absent, the four-culvert outlet was modeled based upon recent behavior and was assumed to be acting like a weir. This assumption may have exaggerated the ponding of water in the lakeshore area.] Additionally, this model was limited to culvert and weir crossings and did not include

two bridge structures at Chutes and Ladders Park. For a more robust analysis, these bridges should be included in the hydraulic model.

Finally, while the baseline 100-year flood was assessed, other return periods and study emphases should be explored. In particular, it is recommended that the 200-year event be investigated, since estimated discharges are available from the MDEQ. Further research may also investigate larger events, such as the Father's Day Flood or a scaled event exceeding the 200-yr flood, so as to help prepare a hazard mitigation plan for all possible contingencies. Additionally, the system should also be modeled utilizing a hydrograph under unsteady-state conditions in order to investigate storage changes through time.

While many precision and accuracy improvements would enhance the detail and usability of this preliminary model, the study demonstrates that with minimal expense and surveying time, the combination of ArcGIS, Hec-GeoRAS, Hec-RAS, RAS Mapper and remotely sensed data, a preliminary Flood Depth Map can be created. Moreover, because of its simplicity, the map may be used for preliminary hazard mitigation planning as well as to guide future hazard mitigation studies.

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A   HEC-RAS Inputs and Results

A.1   Weir Inputs

Name	Width (ft)	Weir Type	Crest Elevation (ft)
Outlet	2	Concrete/submerged culverts	607
Lakeshore Weir	2	Concrete broad crested	606.9
Old Dam	0.5	Wooden Panels	879.01
Mouth of Huron Lake	1	Wood Log	879.01

A.2   Culvert Velocities

Location	US Velocity (ft/s)	DS Velocity (ft/s)	Flow Type
Lakeshore	0.67	0.67	Subcritical
Canal Rd	12.73	30.5	Supercritical
Calverley	13.74	38.38	Supercritical
Razorback Parking lot	4.74	4.74	Subcritical
Sharon	13.93	15.60	Subcritical
Razorback/Ridge	12.65	14.56	Supercritical
Walmart	10.27	12.38	Supercritical

A.3   Razor Lot Culvert Cross Sections
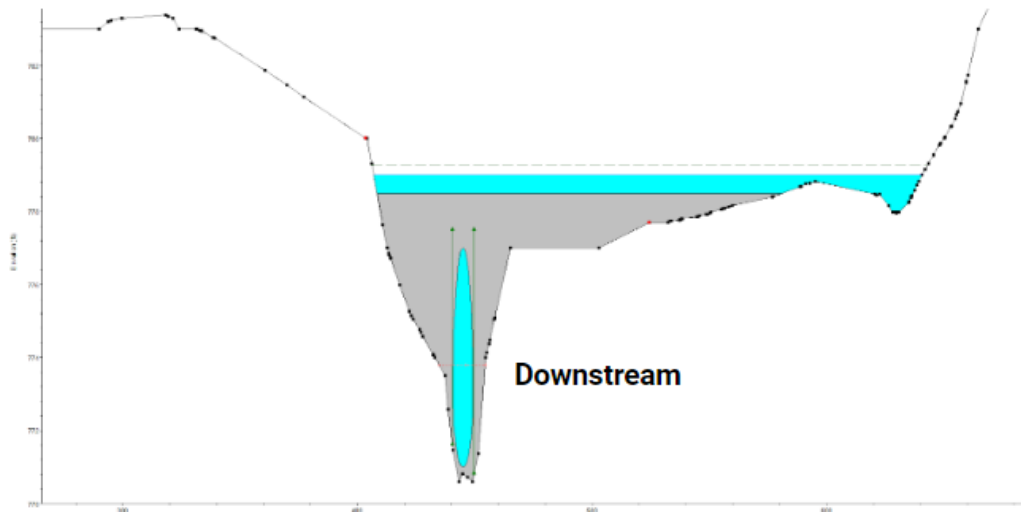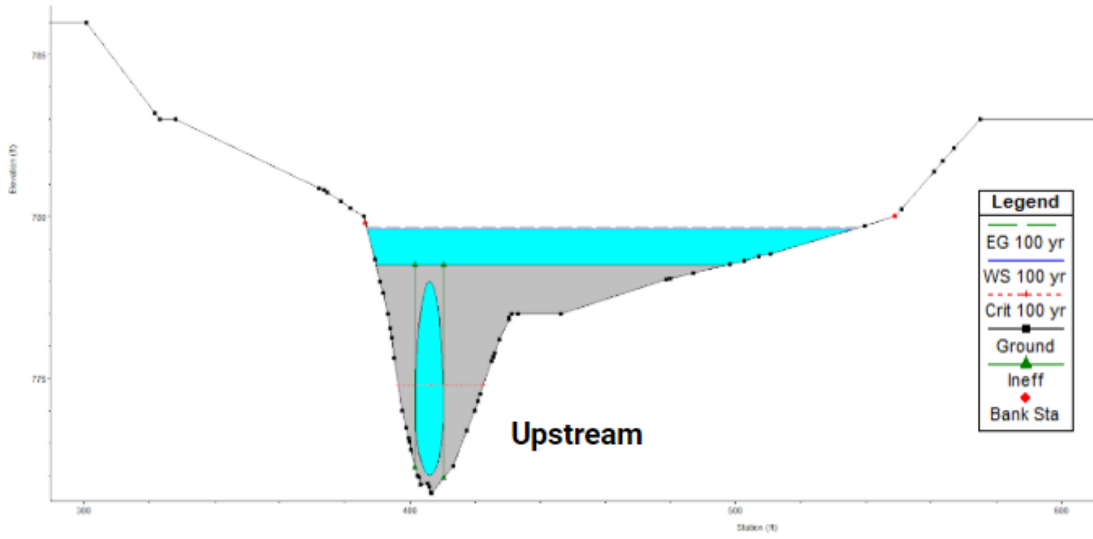
B   Field Photographs

The Razor parking lot culvert, with cedar swamp habitat, looking downstream.

Washko, Sarah. "Razor Lot US". 2019.

The Calverley Ave. culvert a, two barrel concrete culvert, looking downsream.

Washko, Sarah. "Calverley DS". 2019.

The Walmart culvert, a concrete arch with wingwalls, looking upstream.

Washko, Sarah. "Walmart US". 2019.

The Lakeshore weir, a 2.5ft high concrete broad crested weir, looking upstream.

Washko, Sarah. "Lakeshore Weir US". 2019.