Appendix B - Hydrology and Hydraulics Technical Memorandum

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Project Name	Aldershot Stream Rehabilitation		
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Subject:	Hydrologic and Hydraulics		

TECHNICAL MEMORANDUM

1 INTRODUCTION

As part of this work, a hydraulic and hydrologic assessment of the West Aldershot Creek watershed and outfall contributors to the creek was completed, as well as hydraulic assessment of all culvert crossings along the creek. The assessment included: catchment delineation using (GIS) tools, characterization of design runoff/flows, climate change sensitivity analysis using the MTO IDF forecast tool, hydraulic evaluation of existing structures and hydraulic grade line during the various design storm scenarios for the culvert crossings. The following documents were considered in the analysis:

- River & Stream Systems: Flooding Hazard Limit: Technical Guide (2002), Ministry of Natural Resources

2 STUDY AREA

The study area is located within the North Shore Watershed, West Aldershot Creek subwatershed, under the jurisdiction of Conservation Halton (CH). The study area occurs within high density residential and low density residential land uses (City of Burlington Official Plan Schedule B). The West Aldershot Creek corridor is designated as a key feature of Halton's Regional Natural Heritage System. The study area contains Aldershot Creek, a portion of the Lake Ontario Shoreline and significant valleyland. No provincially or locally significant wetlands, Areas of Natural and Scientific Interest (ANSI) or Environmentally Significant Areas (ESA) have been identified within or immediately adjacent to the study area.

Aldershot Creek exhibits the effects of an urbanized hydrologic regime, largely without the benefit of stormwater management controls. Its watershed is relatively small and covered by a high proportion of impervious surfaces, so it is predisposed to rapid routing of surface runoff and floodwater during even modest rainstorms. The unnaturally rapid, or 'flashy', hydrologic response has accelerated erosion along the bed and banks of the creek. Particularly along the upstream half of the study corridor, the channel is confined along the bottom of a nearly V-shaped ravine, with little to no floodplain to attenuate flow energy. As a result, flows during all floods greater in magnitude than a 2-year event are disproportionately deep. Deeper flows translate into higher velocities and shear stresses exerted along the bed and banks, ultimately exceeding the channel boundary's ability to resist erosion. Significant degradation (down-cutting) along the bed paired with continuous scour along the banks has led to the development of severe undercuts (up to 2 m) along the base of the confining valley walls themselves. Many mass movement failures have occurred recently along the lower valley walls in response to the fluvial erosion. Residents of neighbouring condominiums have reported trees falling into the channel once their root masses are sufficiently undermined, which, in turn, has exacerbated erosion by forcing flows over, under and around the woody debris jams that form. Without intervention, the channel will continue to deepen and widen its cross-section through incremental fluvial scour and mass wastage until it re-equilibrates with its new hydrologic regime – a process that would

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take decades. The downstream half of the study corridor exhibits fewer and less severe bed and bank erosion given the widening of the valley and accessibility of a floodplain. The City has prioritized the assessment and management of erosional processes along the creek valley, through the development of erosion control solutions, to mitigate further risk to infrastructure (such as sanitary infrastructure, stormwater outfalls, roadways and pumping station facility) and local and downstream aquatic and riparian habitats.

For the purposes of this assessment and planning erosion control solutions, Aldershot Creek can be described according to three reaches that pose risks to stormwater and/or sanitary sewer infrastructure (Figure 2-1):



Figure 2-1: Overview of existing reaches and at-risk infrastructure in Aldershot Creek

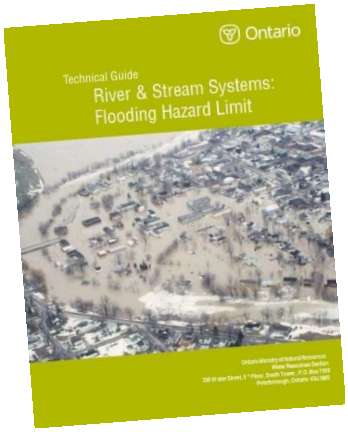
2.1 Reach Characterization

Reach 1 extends from the main outfall south of Fairwood Place downstream to a valley widening adjacent to the southern limit of the access road along the west side of Aldershot School. This reach, which is confined along the bottom of a deep, narrow valley, exhibits the most extensive and continuous erosion, and will require the greatest amount of mitigative and restorative work.

Reach 2 extends from the valley widening downstream to the crossing of North Shore Boulevard. The valley is broader and shallower along this reach, with the channel abutted by low terraces and eventually a contemporary, active floodplain. The channel is wider and gentler, so erosion is less continuous and severe. Erosion control measures can be mostly designed and implemented without geotechnical concerns or significant earthworks.

Reach 3 extends from North Shore Boulevard to the culvert outlet into Lake Ontario beneath Oaklands Park Court. The channel is entrenched within fill-mantled ground, which is readily eroded. A large, scallop-shaped hollow has formed along the east bank where flows have been deflected around a series of woody debris jams.

3 MODELING APPROACH



To appropriately model the creek and generate reliable velocities and floodplain mapping results, the guidelines presented in MNR's *River & Stream Systems: Flooding Hazard Limit: Technical Guide (2002) Chapter C Hydrologic and Hydraulic Procedures* were followed. Table 3-1 provides a breakdown of the general guideline sections, a description of the guideline, and details as to how they were addressed in the Aldershot Creek model. Sections 4 and 5 describe the hydrologic and hydraulic modeling approaches and results in more detail.

Table 3-1: Considerations as per applicable sections of the MNR Flooding Hazard Limit Technical Guideline, 2002

Chapter C Hydrologic and Hydraulic Procedures			
Section	Title	Description	Consideration
2.8	Data Required: Cross Sections	- obtain information on the geometry of the channel and its flood plain	- The topographic data used to create the RAS model was derived from a combination of LiDAR drone survey and on-ground bathymetric survey (for in-river values) completed by Groma. The point cloud was post-processed, the traditional bathymetric survey was merged with the topographic survey, and a 3D surface was created. From there, AE cut cross sections from the surface which include the channel and floodplain.
2.10	Data Required: Meteorologic and Physiographic Data	- drainage area, area of lakes and swamps, basin slope, channel slope, channel length, mean annual runoff, precipitation, snowfall, soil types, forest cover, groundwater, land use, infiltration rates and soil moisture conditions	- This data was collected using various GIS techniques, data from Environment Canada, and MNR's OFAT III tool
2.11	Data Required: Lake Levels	- For a given flood flow in the stream, there is a wide range of possible lake levels (Lake Ontario) that could be coincident and therefore it is necessary to obtain lake level data in such cases to enable a reasonable judgement or assumption to be made	- We used two (2) scenarios (water level low and high) to model the boundary conditions at Lake Ontario to represent conservative design conditions for velocities and floodplain extent, respectively
Chapter E Methods of Computing Flood Flows			
Section	Title	Description	Consideration
2.3	Hydrologic Models: Recommended Model Selection	- Framework for model selection including a list of recommended models	- We used PCSWMM to estimate hydrologic response in urban catchments considering storage within the storm network (SWMM is one of the recommended hydrologic programs for Single Event, Urban Area models)
2.4	Hydrologic Models: Model Calibration	- General guidelines for calibrating and validating hydrologic modelling parameters	- Hydrologic parameters such as drainage area, subcatchments, and impervious areas were estimated using GIS. Channel parameters were estimated based on data collected during multiple site visits and survey. We

			had no observed events available for calibration or validation of the hydrologic model so engineering judgement was used to adjust parameters
Chapter F Water Level Computations: Open Water (Hydraulics)			
Section	Title	Description	Consideration
2.0	Backwater Profiles	- usually, steady flow conditions can be assumed along a particular length of watercourse or river and the water surface profile computations may be based on the solution of the 1-D energy equations for gradually varied flow (the Bernoulli equation)	- our analysis is a 1-D steady flow model
3.0	Flood Routing	- the problem cannot be reduced to a steady flow assumption because of rapidly varying inflows or tributary flows, the effects of significant channel storage, or complex interactions between channel flow and adjacent flood plain areas	- N/A; model was run in steady state
4.0	Choosing a Hydraulic Modelling Technique	- the selection of the appropriate model is left to the judgement of the individual professional - ultimately, any model based upon the principles in this chapter, and which can be calibrated and verified by the user, is an acceptable choice	- HEC-RAS program (maintained by the US Army Corps of Engineers) is listed as one of the options in the hydraulic model selection matrix and is well accepted in the hydraulic modeling community; this software was selected for use
6.0	Effect of Lakes and Reservoirs	- they act to attenuate flood flows in a watershed, therefore, the storage and outflow characteristics of major lakes and reservoirs must be considered in the hydrologic analysis	- Because Aldershot Creek discharges into a large lake (Lake Ontario) it is necessary to obtain lake level data to enable reasonable judgement and assumptions to be made; level data was based on DFO water level gauge for Lake Ontario (Station ID: 02HB017; Station Name: Lake Ontario at Burlington)
5.0	Reservoir Routing	- Reservoirs, lakes and onstream storage facilities affect flows and water levels along a river system - In addition, where streams are subject to artificial regulation by dams or diversions it is necessary to estimate the effects of regulation to enable a	- N/A; Aldershot Creek has no upstream storage facilities and is not a part of a regulated watercourse; upstream routing was completed per the existing storm network to route overland and in-pipe flows as they outlet to the watercourse

		conversion of streamflows to natural conditions prior to undertaking a flood frequency analysis	
7.0	Waterway Crossings and Encroachments	- Bridges, culverts, weirs, and embankments create local head losses and rapidly varied flow conditions and represent discontinuities in the flood profile and need to be considered - computer model such as HEC-RAS can be applied for backwater analysis - it is a current policy of MNR to base flood profile computations, for flood hazard mapping purposes on existing conditions along the river	- Culverts on North Shore Blvd. W. and Oaklands Park Ct. have been considered as part of the HEC-RAS model. Backwater effects are taken into consideration in the model and impacts upstream of the culverts can be assessed
8.0	Model Calibration	- suitable for calibration: streamflow and water level measurements	- Insufficient data was available for a proper model calibration, therefore in lieu of reliable model calibration and validation, testing and sensitivity was completed for model parameters
9.0	Testing and Sensitivity	- changing one variable, within prescribed limits, and conducting simulations with all other variables held constant; oftentimes peak discharge and roughness factors are found to be the most sensitive parameters	- Sensitivity performed for peak discharges and roughness coefficients only

4 HYDROLOGICAL ANALYSES

Hydrology was estimated using a combination of GIS and modeling tools. Data was mapped in Manifold GIS and area classifications and percent impervious were assumed based on aerial imagery and zoning map data. CN values were then estimated based on land use classification and hydrologic soil group C (sandy clay loams; poor drainage) in the US Department of Agriculture's TR-55. Storm catchments were delineated in GIS based on a combination of topographic survey, contours, and stormwater infrastructure data. Using the aforementioned data, a composite CN number was generated for each of the storm catchments. These parameters were then used in a PCSWMM model to estimate runoff (considering a 4-hour synthetic Chicago storm) and routed inflows into each reach. All flows within the hydrologic model were accounted for within the system by creating synthetic curb and gutter overland flow paths to the downstream junctions. It was determined that considering basic routing in the analysis (as opposed to no routing) reduced flows upwards of 45%; therefore, the PCSWMM model provides a simplified 1D-1D model of overland and storm network flows with assumed hydraulic parameters (including slope and pipe diameters) to provide an estimate of pipe-routed flows. The result is flows into each of the three (3) study reaches. A summary of the resultant flows into each creek reach is presented in Table 4-1, below.

Table 4-1: Estimated flows into the three (3) reaches of the creek

Reach	Estimated Flows (m^3/s)						
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	Hazel
1	5.6	6.5	7.1	7.6	8.0	8.3	6.7
2	8.4	10.1	10.9	11.6	12.0	12.4	10.6
3	10.4	12.9	14.5	16.2	17.2	18.0	12.8

4.1 Climate Change

Understanding risks of climate changes on projects and potential adaptation and mitigation strategies helps our clients to make informed decisions and plan long-term climate change strategies. Therefore, as part of the base scope of work for the hydraulic and hydrology assessments, AE conducted a Climate Change Sensitivity analysis using the MTO IDF forecast tool to look at the potential implications that climate change may have on precipitation in Aldershot. Flows were forecasted using PCSWMM model considering a design life of 50 years, using a 6-hour duration (since a comparable 4-hour storm duration was not available). A comparison between the current and future projected design flows is presented in Table 4-2. Based on the results from hydrologic modeling, future rainfall intensities and depths are estimated to be approximately 5 % higher than current (2010) design values. This increase has been assumed to translate directly into an increase of 5% in peak design flow.

Table 4-2: Comparison between current and future climate change influenced design flows according to MTO IDF Lookup Tool

Current (2010)		Approximate future (2070)		Difference	
Rainfall intensity (100-Yr, 6hr) (mm/hr)	Rainfall depth (100-Yr, 6hr) (mm)	Rainfall intensity (100-Yr, 6hr) (mm/hr)	Rainfall Depth (100-Yr, 6hr) (mm)	Rainfall intensity (100-Yr, 6hr) (mm/hr)	Rainfall depth (100-Yr, 6hr) (mm)
13.3	80.1	14.0	84.0	~ 5 %	~ 5%

This comparison assumes that the projected increase in rainfall would translate directly to an equivalent increase in streamflow. Furthermore, there is a range of uncertainty not accounted for in this analysis. Climate change analysis was not considered in the prospective hydraulic analysis, however this can be changed if the City wishes to further consider the potential impacts of climate change.

5 HYDRAULIC ANALYSES: EXISTING CONDITIONS

The hydraulics of the existing structures was analyzed in two stages:

1) Capacity of the existing culverts, and
2) Level of the hydraulic grade line during the various design storm scenarios for the culverts.

Streamflows and water levels were simulated using a survey-generated surface in HEC-RAS 5.0.5 with flow contributions as described in Section 2: Hydrology. Mannings values were assumed for naturalized channel and floodplain with heavy brush. A figure of the model in plan is presented in Appendix A. Details pertaining to the hydraulic model build are provided in Appendix B.

The culvert crossing Oaklands Park Court leads out to the Hamilton Harbour, and therefore the hydraulic model accounts for the downstream boundary conditions. The culvert crossing Oaklands Park Court will experience the backwater effects of the lake, and under high lake levels, its hydraulic capacity will be reduced. Therefore, lake elevations formed the downstream boundary conditions in the hydraulic model and backwater effects were explored as part of the assignment. The model was run under two (2) different downstream boundary conditions as follows:

1) High lake levels: this scenario represents the critical boundary condition for determining flooding depths, extents, and backwater effects
2) Low lake levels: this scenario represents the critical boundary condition when determining velocities and associated erosion and scour (within the limit of backwater effect).

Upstream boundary conditions assumed a Normal Depth, due to the supercritical flow conditions in the upper reach. Flows for the 2-, 5-, 10-, 25-, 50-, 100-Year and Hazel storm were run in the hydraulic model to estimate flooding extent, water depth, and velocities for both downstream scenarios mentioned, above.

5.1 Existing Conditions: Results

Error! Reference source not found. in Appendix D provides a summary of the resultant velocities at selected cross sections for all modelled return periods under Scenario 2 (low lake levels). In summary, velocities ranged for each of the reach of the three (3) Reach sections as follows:

Table 5-1: Existing Conditions Summary Range of Resultant Velocities

Existing Conditions Hydraulic Modeling Scenario 2: Low Lake Levels							
Reach	Range of in-Channel Velocities (m/s)						
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	Hazel
1	0.6 - 4.0	0.7 – 4.1	0.7 – 4.2	0.7 – 4.3	0.6 – 4.4	0.6 – 4.5	0.5 – 4.4
2	0.3 – 2.1	0.2 – 1.9	0.2 – 1.3	0.2 – 0.8	0.2 – 0.6	0.2 – 0.6	0.2 – 0.7
3	0.5 – 2.3	0.5 – 2.5	0.6 – 2.6	0.6 – 2.7	0.6 – 2.8	0.6 – 2.8	0.6 – 2.8

What's most interesting to note is that the most conservative (highest) velocities in Reach 2 actually occurs under the 2-Year scenario. It's suspected that this is happening because the culvert at the downstream end of Reach 2 is unable to convey flows during most of the higher storm events, thus creating significant backwater, high water levels, and low velocities.

Floodlines were calculated using HEC-RAS to estimate the extent and depth of flooding within each of the three (3) reaches. These floodlines were produced by combining the resultant water surface profiles generated by HEC-RAS combined with surveyed topography. HEC-RAS's built-in GIS platform, RAS Mapper, was used to display the floodplains over aerial imagery to provide a visual representation of potential impacts to nearby properties and infrastructure. ***It is important to note that these floodplain lines were generated under a set of assumptions appropriate to the erosion study and are not suitable for regulatory purposes.*** Figures C1 thru C-3 in Appendix C shows the approximate existing floodplain extents and depth under each of the modelled return periods (2-, 5-, 10-, 25-, 50-, 100-Year and Hazel) under downstream boundary conditions of Scenario 1 (high lake levels), since this is the scenario most significant to establishing floodplain extents and depths near the outlet to Lake Ontario.

6 CONCLUSIONS

This technical memo summarized the hydrologic and hydraulic analysis for the existing conditions. The memo will be updated during detailed design to include a hydraulics analysis for the preferred rehabilitation alternative in each reach.

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APPENDIX A – HYDRAULIC MODEL PLAN VIEW

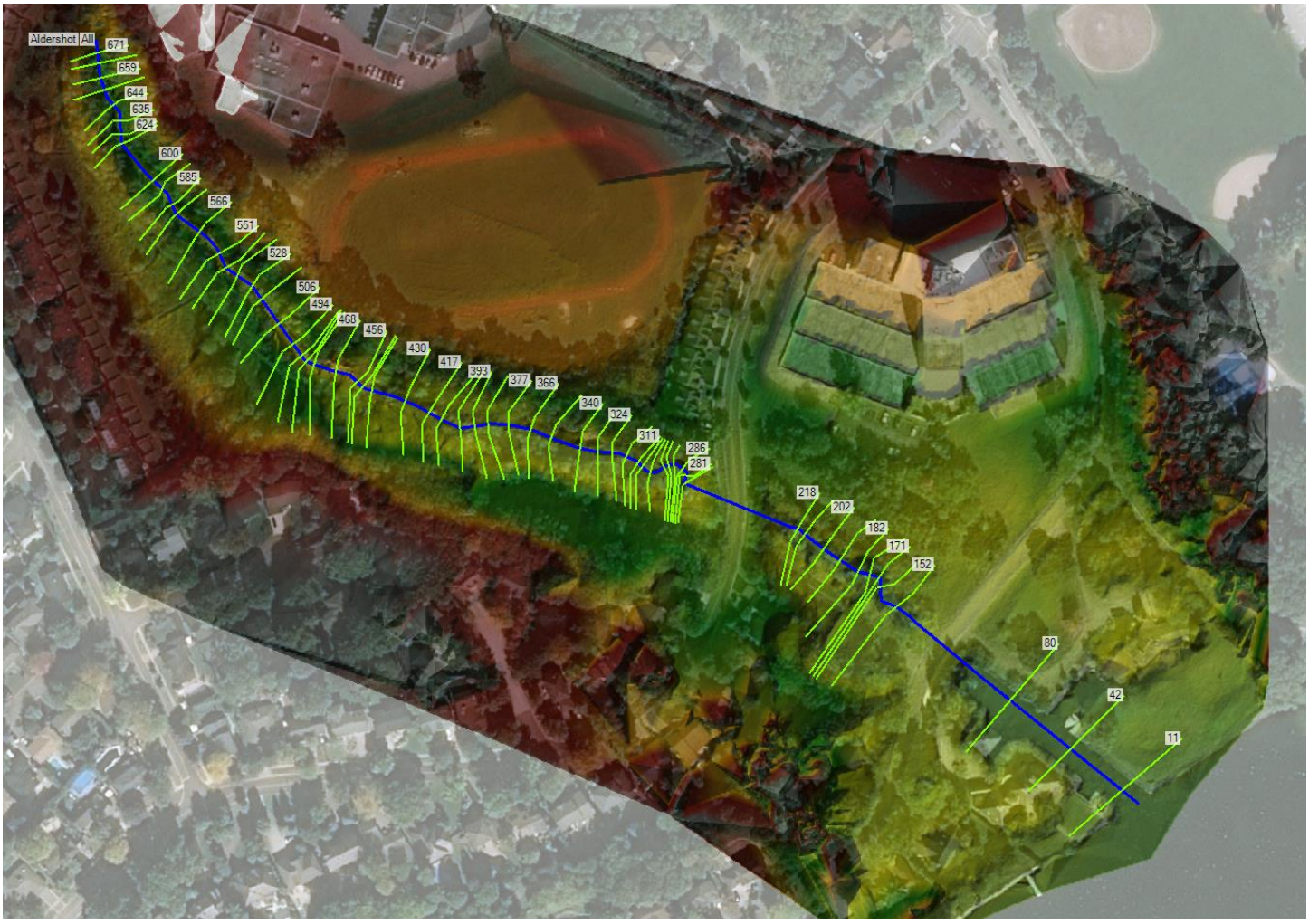


Figure A-1: Plan view of the hydraulic model in RAS Mapper

APPENDIX B – HYDRAULIC MODEL DETAILS

Model	Element	Method	Notes
Geometries	Projection	NAD 83 CSRS UTM 17	- Projection as per the Canadian Geodetic Survey, Canadian Spatial Reference System, Natural Resources Canada
	Terrain	LiDAR survey (topography) + field survey (bathymetry)	- Drone-collected LiDAR survey of the topographical features; since drone LiDAR does not penetrate the water surface, it needed to be supplemented with field measurements to capture creek bathymetry
	River Centreline	RAS-Mapper	- Estimated based on bathymetric survey
	Cross Sections	RAS-Mapper	- Estimated based on combined topographic and bathymetric survey
	Banks	RAS-Mapper	- Estimated based on bathymetric survey
	Channel Roughness	Reach 1 Manning's n Channel (0.030) LOB/ROB (0.075)	- For main channels, clean, straight, no rifts or deep pools - For overbanks (floodplains) with trees and brush
		Reach 2 & 3 Manning's n Channel (0.035) LOB/ROB (0.075)	- For main channels, clean, straight, no rifts or deep pools with some stones and weeds - For overbanks (floodplains) with trees and brush
Structure(s)	Culvert Properties (diameter, length, road deck)	As-builts, field measurements, and survey	- Culvert diameters and materials from field measurements and compared with as-builts - Culvert road deck elevation estimated as per survey - Culvert inverts estimated as per bathymetric survey

	Culvert Roughness Coefficient	Manning's n (0.025)	- Roughness coefficients consistent with CSP material
Flows	Profiles	2, 5, 10, 25, 50, 100-Yr + Hazel	- To model multiple storms pertinent to design including 2-Yr (fish-passage); 10-Yr (culvert design for North Shore Blvd. W); and 100-Yr (culvert design check flow for scour); and Hazel (regional). The Regulatory Storm is the greater of the 100 year or the Regional storm.
	Flow Locations	Three (3)	- There are three (3) flow change locations corresponding to the upper end of each reach at the approximate location of inlets from the storm system; one (1) at the top end of Reach 1, one (1) at the top end of Reach 2, and one (1) at the top end of Reach 3 at the outlet of the North Shore Blvd. W culvert
	Flows	PCSWMM	- The storm flows (overland and basic STM system routing) was completed in PCSWMM considering Chicago synthetic storm to approximate inflows at three (3) locations along the creek; some assumptions and approximations were made modeling the storm system
Model Boundary Conditions	Upstream	Normal Depth (0.013)	- Model required both u/s and d/s BC since Mixed flow regime was being modeled - Normal depth estimated from bathymetric survey
	Downstream	Known WS (75.2 m)	- Model required both u/s and d/s BC since Mixed flow regime was being modeled - Downstream water surface elevation based on Maximum Great Lakes (Ontario) Water Surface elevation as reported by USACE (in cooperation with NOAA and Canadian Hydrographic Service)
Simulation Control Specs	Simulation Type	Steady State	- To capture peak flows and volumes
	Flow Regime	Mixed	- Due to high variability in the local terrain, the model is run in Mixed flow regime to capture both the supercritical flows (characteristic of the regime in Reach 1 at the upper end of the creek) and subcritical flows (characteristic of the regime in

			Reaches 2 and 3 at the middle and bottom end of the creek)
	Units	Metric or Imperial	- Units set to metric (mm, m, km, …)
	Optional Programs	Floodplain Mapping	- To visualize the extent and depths of the floodplain and check that proposed design alternatives meet floodplain criteria (not to increase the extent of the floodplain) - Based on topographical drone LiDAR survey (i.e. model “Terrain” file)

APPENDIX C – HYDRAULIC MODEL RESULTS



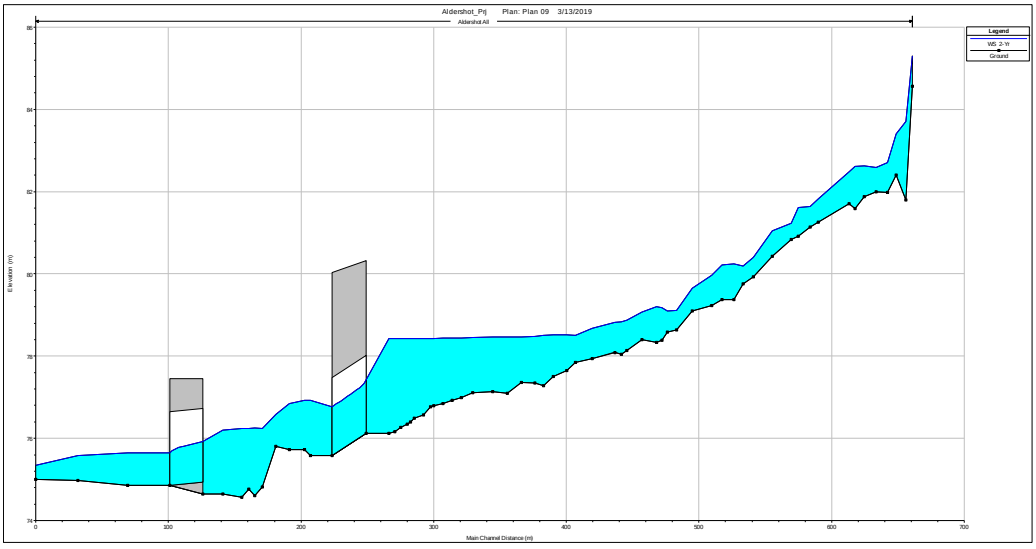


Figure C-1: 2-Year hydraulic results (existing)



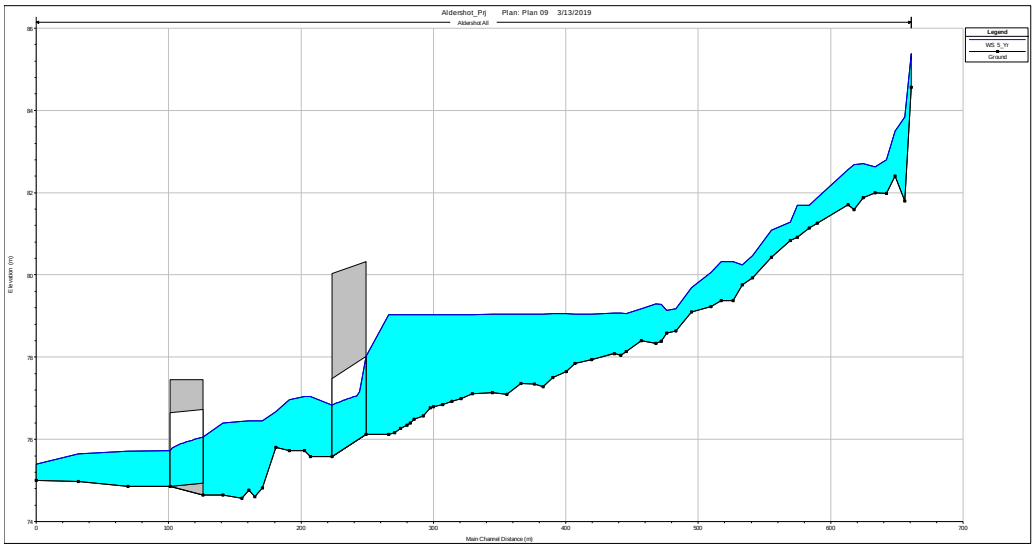


Figure C-2: 5-Year hydraulic results (existing)



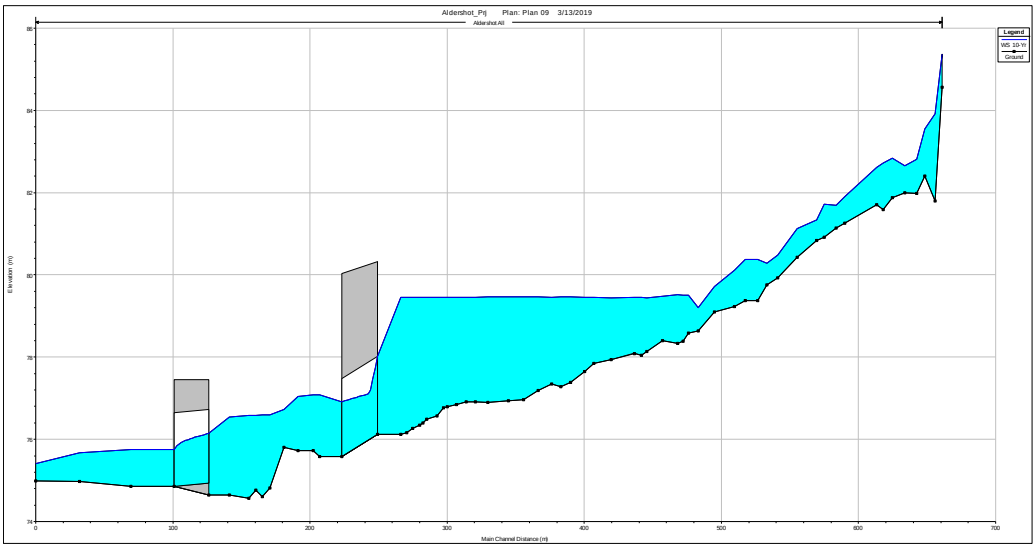
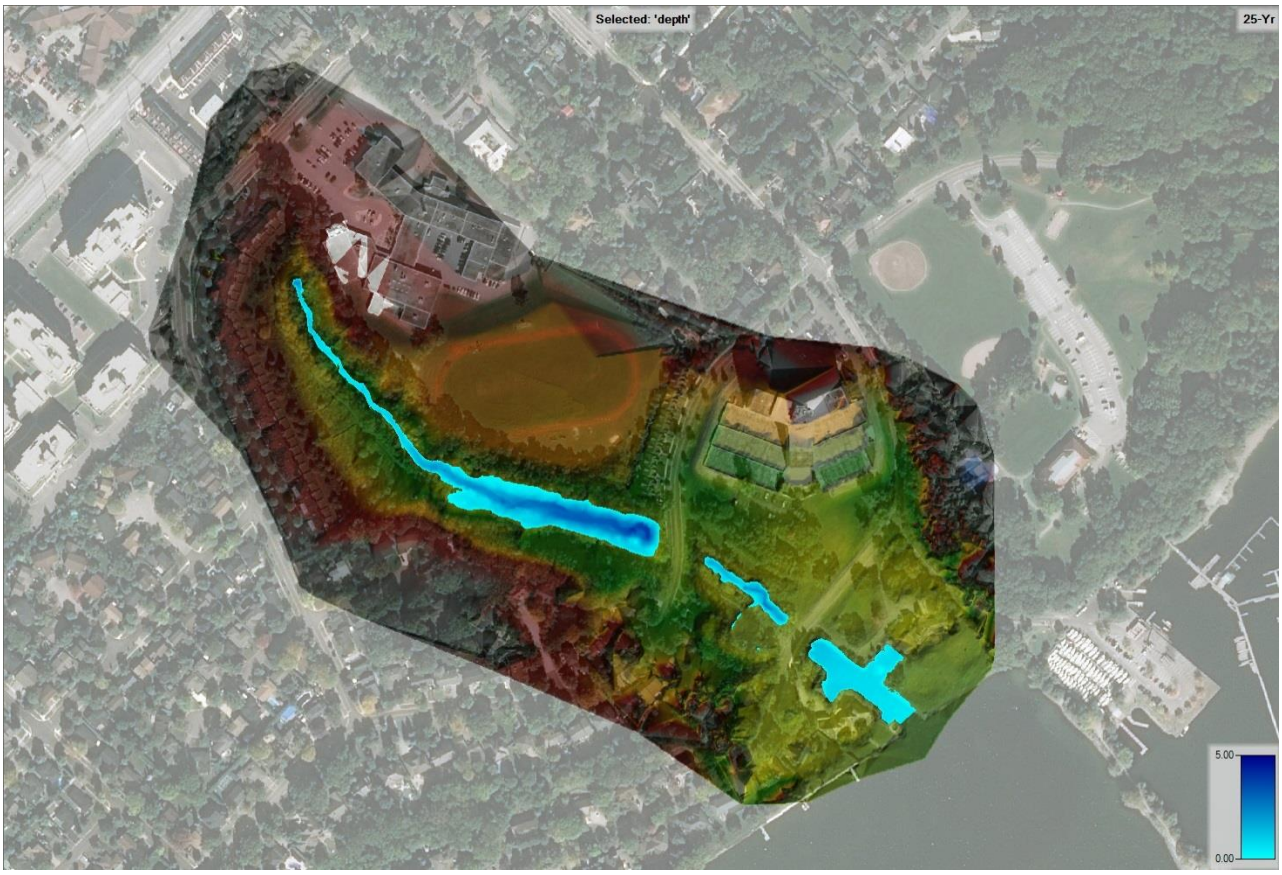


Figure C-3: 10-Year hydraulic results (existing)



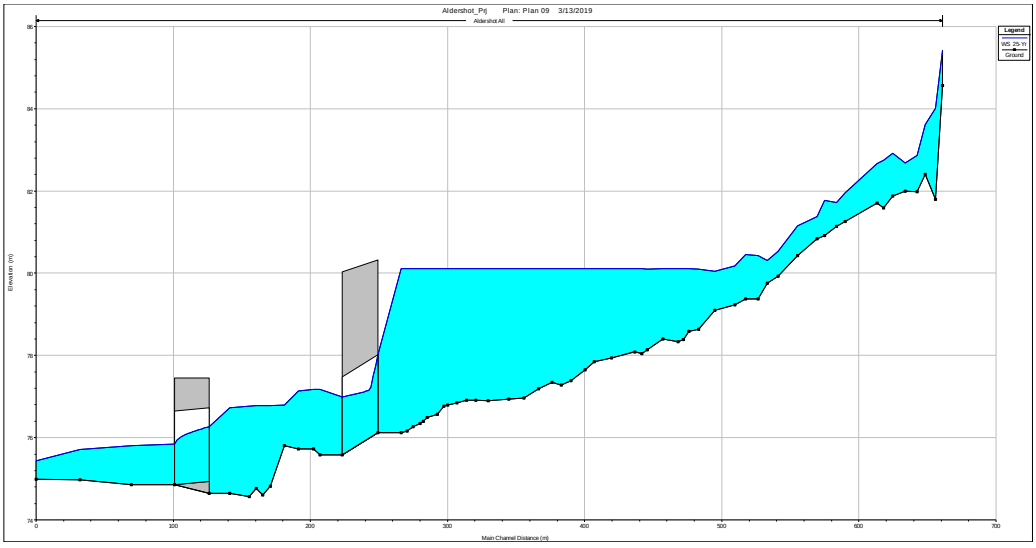
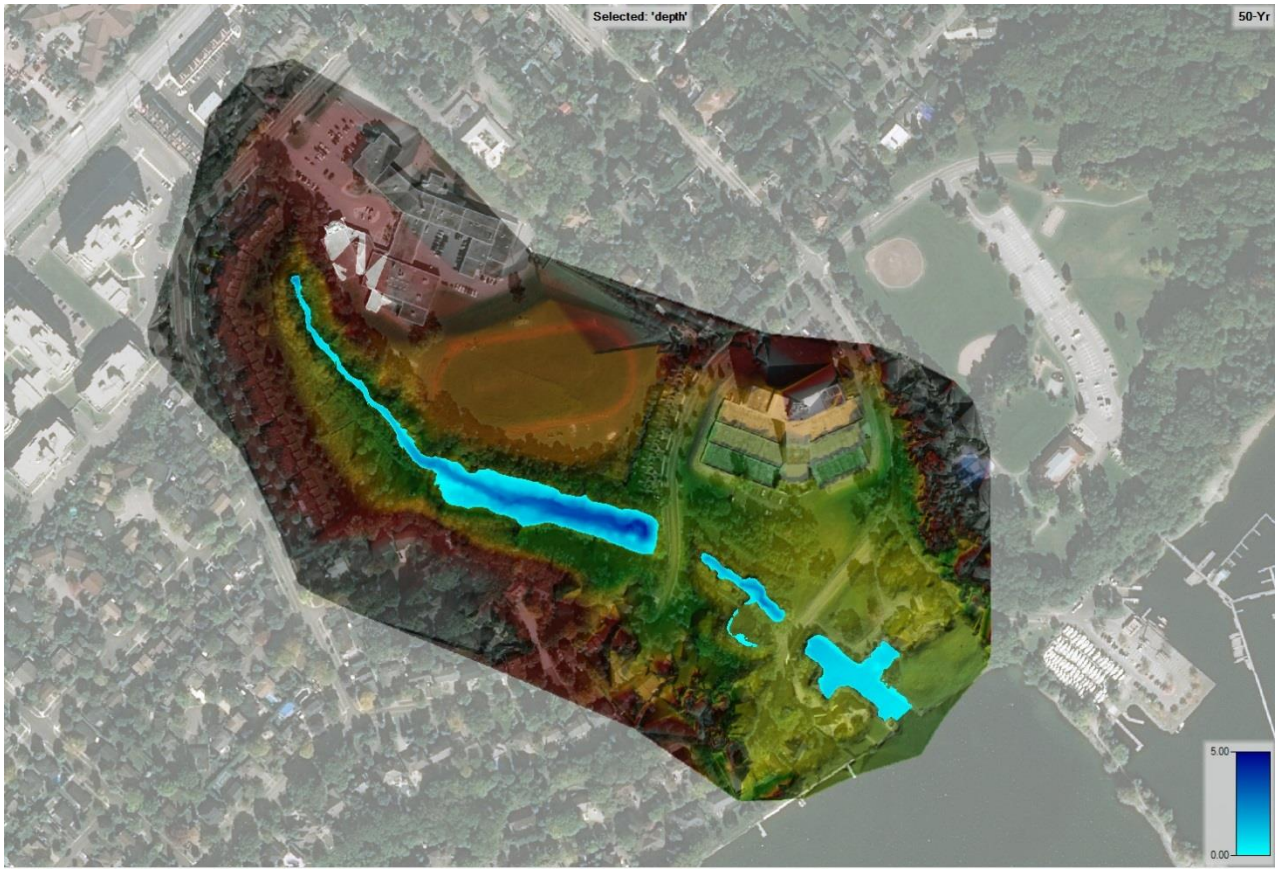


Figure C-4: 25-Year hydraulic results (existing)



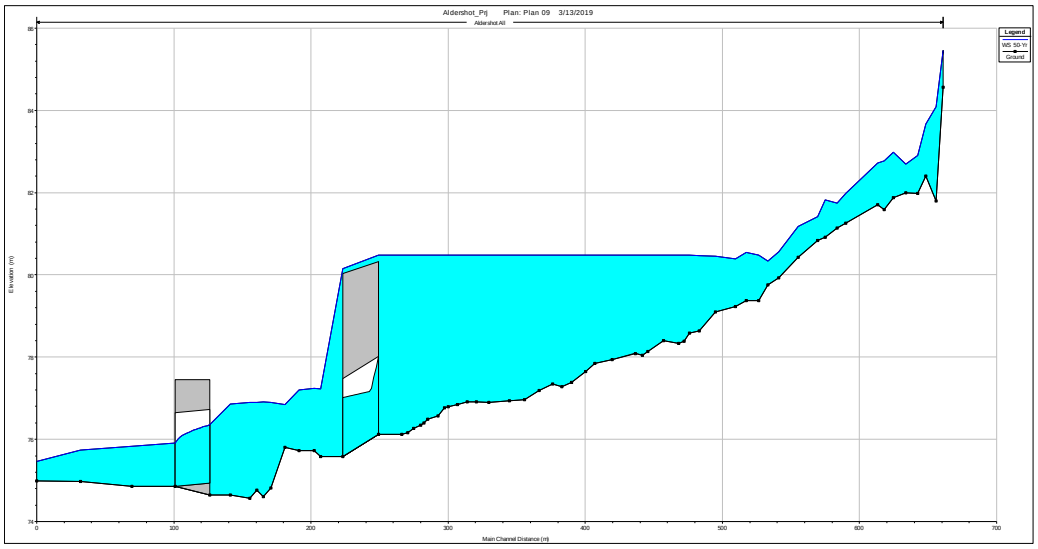


Figure C-5: 50-Year hydraulic results (existing)



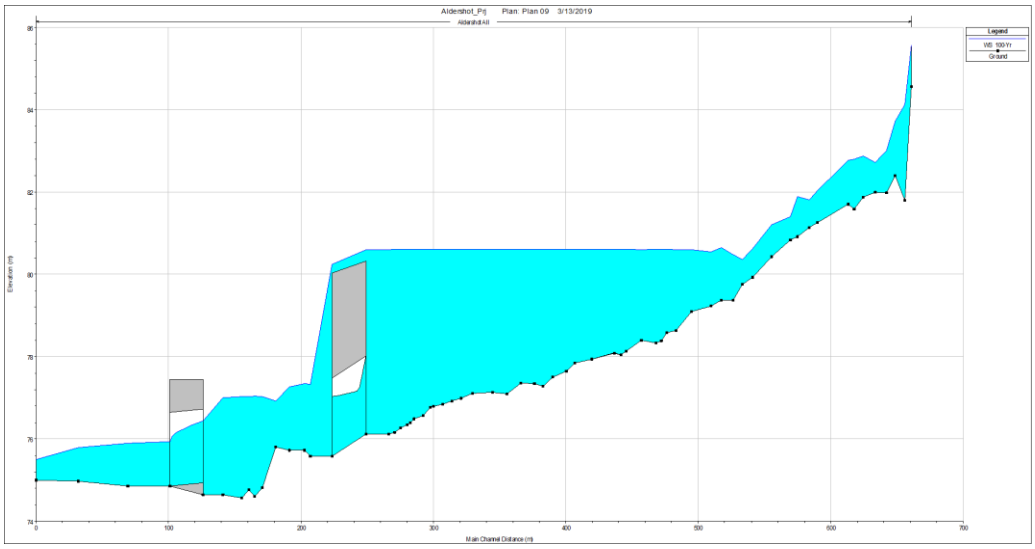
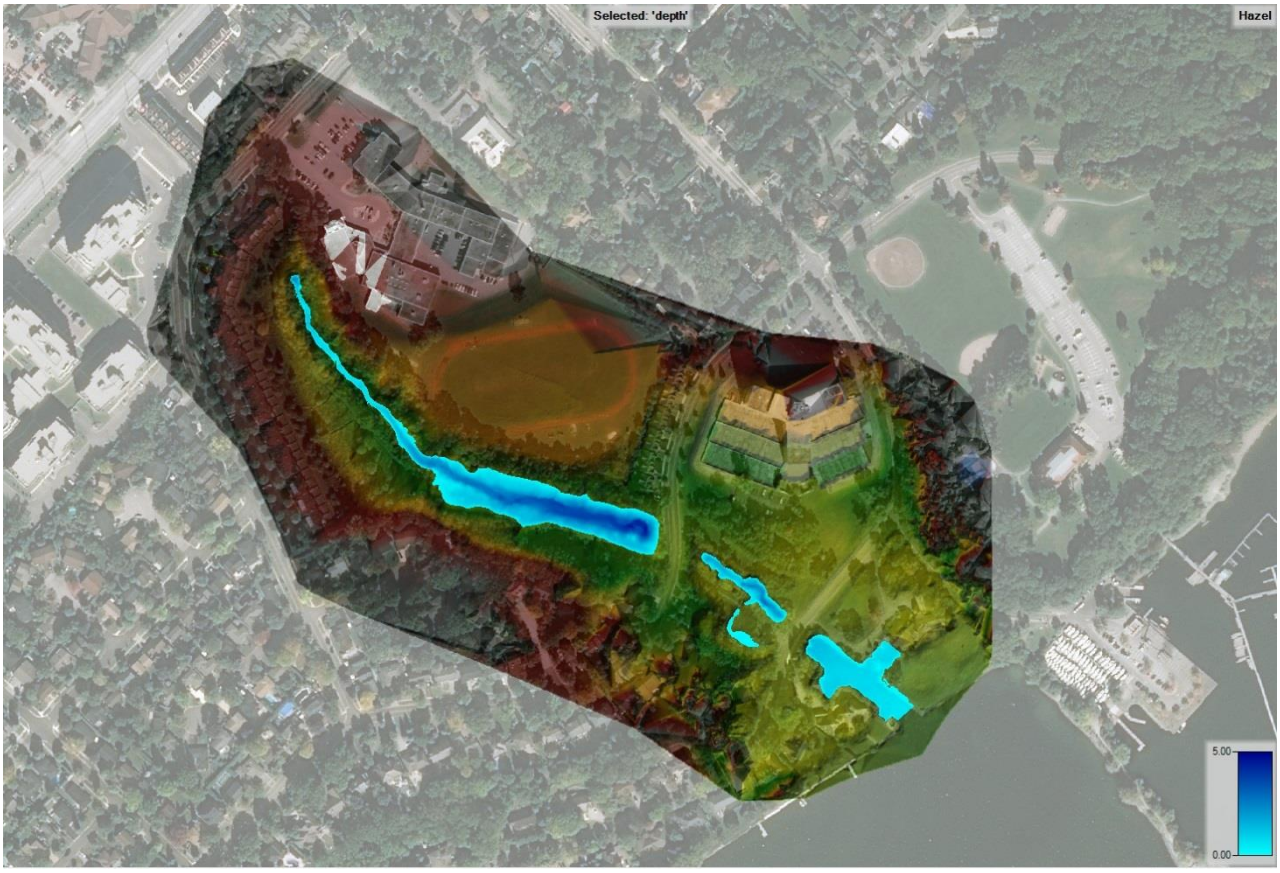


Figure C-6: 100-Year hydraulic results (existing)



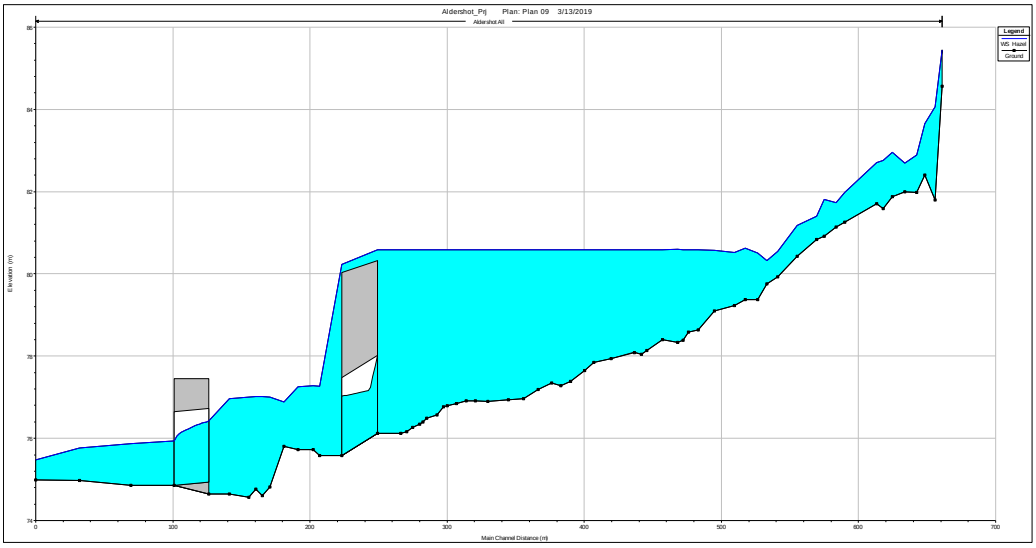


Figure C-7: Hazel hydraulic modeling results (existing)