November 2014

CYNERGY CONSULTING INC.

Final Report of Stream Daylighting: Yorklands Green Hub

Yorklands Green Hub, photograph by Emily Nickerson (September 2014)

Prepared for

Trout Unlimited Canada

With cooperation from

YORKLANDS GREEN HUB

Citizens Supporting Ontario's Prosperous and Sustainable Future

Ontario STREAMS

HELPING PEOPLE AND THEIR RIVERS

Executive Summary

Trout Unlimited Canada has proposed a project to daylight a stream reach that is located on the northeast corner of the Yorklands Green Hub property in Guelph, ON. The Yorklands Green Hub is located on the former Guelph Correctional Centre property; the land was heavily engineered while the facility was in operation. Before, Clythe Creek used to be a coldwater trout stream with smaller headwater streams feeding into it (O'Flanagan, 2014). Human interference is likely the main cause for the changes in the characteristics of the creek, including the loss of riparian vegetation, disconnection of headwater streams and addition of manmade waterfalls (O'Flanagan, 2014). Currently, the buried stream is conveyed in a culvert with no opportunity for aquatic species, like Brook Trout, and minimal habitat. Brook Trout are native to eastern North America and are commonly used as an indicator species for coldwater habitats. This species is sensitive to temperature changes, decreased dissolved oxygen levels and high flow rates during juvenile development (Ficke et al, 2009). To address these challenges, daylighting, a practice of uncovering buried waterways to restore the natural channel, is used. This design must meet all regulations and guidelines for natural channel design outlined by the Ministry of Natural Resources.

Various designs have been explored based on available information set out by the Ministry of the Environment, Grand River Conservation Authority, and City of Guelph. A feasibility and cost-benefit analysis was performed on all possible designs that meet the outlined constraints. The final design was modelled in EPA SWMM and HEC-RAS and all technical drawings were done in AutoCAD. The objective when daylighting a stream is to restore the stream to its natural state, enhancing hydrologic and hydraulic features based on outlined constraints and criteria. The design will provide environmental, social, economic, and health and safety benefits. The ideal solution creates a safe and aesthetically pleasing system that allows an opportunity for habitat growth in the area. Four design options were evaluated and it was determined that rerouting the creek to Clythe Creek is the best option. This will allow Clythe Creek to receive the benefits of the cold headwaters as well as allow for the possibility for Brook Trout to return to the creek. The final stream design is expected to cost approximately $295,000.00. Additionally, recommendations for integration of the design into the broader site conservation plan of Trout Unlimited Canada will be made.

This final report outlines the responsibilities of Cynergy Consulting Inc. including the scope, key milestones and deliverables for this project. A detailed cost estimate and final design recommendations is provided. Cynergy Consulting Inc. is committed to high quality design work to meet the needs of Trout Unlimited Canada, as detailed in this final report.

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1 Problem Description

1.1 Overview

The United Nations expects that 66% of the world's population will be urban by 2050 (United Nations, 2014). Today, 82% of North Americans live in urbanized regions – this number is expected to continue to increase in coming decades (United Nations, 2014). The pace and projected intensification of urban development is and will increasingly place significant pressures on global resources. To balance these demands, sustainable development techniques will be required.

Urban watershed management goals and strategies are surfacing in response to these pressures, including non-site specific and site specific approaches. Streams are an integral component of watersheds, contributing to groundwater recharge, supplying conveyance and flood control, influencing downstream quantity and quality, and providing aquatic habitat. Stream daylighting is being implemented as a site-specific watershed management strategy (Platt, 2006). Providing social, environmental, economic, and health and safety benefits, stream daylighting is becoming an increasing trend in urban renewal projects (Platt, 2006).

1.2 Current Problem

Trout Unlimited Canada has a mission to conserve, protect and restore Canada's freshwater ecosystems and their coldwater resources. In Guelph, Trout Unlimited has partnered with the Yorklands Green Hub, a non-partisan citizens group that is promoting the repurposing of the former Guelph Correctional Centre into a public "Ontario Environmental Centre". This site has numerous hydrologic and hydraulic features (Figure 25). In particular, Trout Unlimited Canada has identified a buried stream onsite which used to feed Clythe Creek. In the current condition of the buried stream, there is limited opportunity for aquatic habitat and the culvert is in a state of disrepair, it is partially collapsed at the inlet headwall (Appendix A). Culverts are noted to include an increased risk of flooding, the prevention of fish passage and lower water quality (American Rivers, N.D.). As part of a restoration plan to bring Brook Trout back to Clythe Creek, Trout Unlimited Canada has retained Cynergy Consulting Inc. to complete the daylighting of a stream reach located on the northeast corner of the Yorklands Green Hub property.

The Guelph Correctional Centre focused on productive work and training rather than incarceration (Yorklands Green Hub, 2014). As a result, the natural features, land and water, were heavily engineered over the 63 years the facility was in use (O'Flanagan, 2014). Before, the Clythe Creek used to be a cold water trout stream with smaller headwater streams feeding into it (O'Flanagan, 2014). Human interference is likely the main cause for the changes in the creek's characteristics, including the loss of riparian vegetation, disconnection of headwater streams and addition of manmade waterfalls (O'Flanagan, 2014).

1.3 Site History and Existing Features

1.3.1 Site History

The Guelph Correctional Centre was designed in a period of optimism for the rehabilitative capabilities of a reformatory (Infrastructure Ontario, 2009). The land, acquired in 1910, was constructed on a large plot of land next to the Ontario Agricultural College, who had a hand in the planning of the grounds. It was designed based on the theory that outdoor labour and industrial work had the potential of improving prisoner behavior while saving the province money.

The initial intent of the 800 acre property was for agricultural production, which required significant land transformations, all done through prison labour starting in the 1920's (Infrastructure Ontario, 2009). At its most productive the inmates were employed on site at the abattoir, wood-working, woolen mill, tailor shop, mattress factory, farming, as well as the institutions laundry. The reformatory in fact had the highest agricultural output of a government farm as early as 1912 .To develop the agricultural capacity of the land the prisoners drained wetland area on site. It is speculated by planners (April Nix, Environmental Planner and Steve Robinson, Senior Heritage Planner) at the City of Guelph that soil from the two large man made ponds on site was used to fill in wetland area to make land create acceptable cropland (Campbell, Robinson & Nix, 2014). With the province's correctional focus shifting away from rehabilitation in the 1990's the site was scheduled for disposal in 1999 and fully decommissioned in 2001. Infrastructure Ontario currently owns the site and it is planned to be incorporated into the City's Guelph Innovation District project as of May 2014 (City of Guelph, 2014).

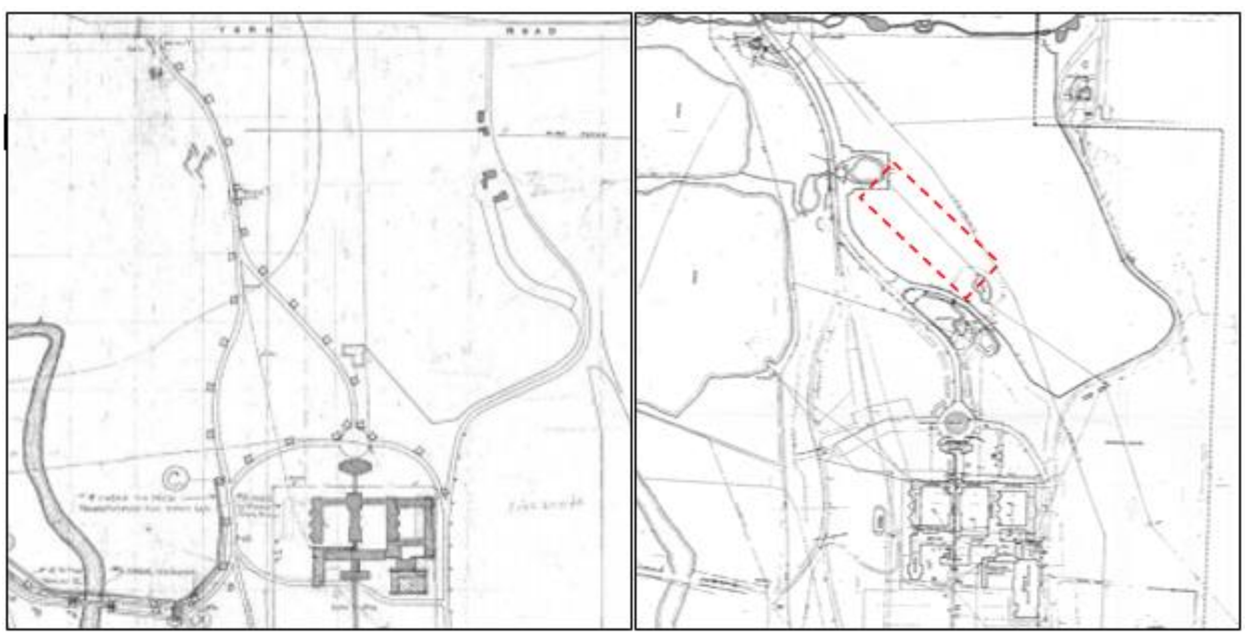


Figure 1: Excerpt's from Guelph Correctional Center – Left: 1921 Right: No date (Assumed post-1921)

Figure 1 shows the City plans of the Guelph Correctional Center, the left dated 1921 and the right an unknown date. The map from 1921 outlines the site characteristics before or during much of the sites land transformations (Infrastructure Ontario, 2009). It is assumed that the undated map is from after 1921, as developments such as the North and South ponds and additional infrastructure and buildings are present. Changes significant to the daylighting project from the 1921 map and the undated map include; open water features, additional roads, and the burying of the reach in question, on the north portion of the site. Some hydrologic features, specifically the Clythe Creek Provincially Significant Wetland (PSW) complex, are not included in either map, but are assumed to have existed. The daylighting project is attempting to restore the reach to the earliest known conditions, in this case the 1921 site map. Based on the site topography there is a drainage path through the reach (Figure 25). The buried culvert (outlined in red) will be removed and the natural drainage path will be restored. The above figures are excerpts of full maps of the Correctional Center, which may be found in Appendix B.

1.3.2 Cultural and Natural Heritage Features

The site has significant cultural and natural heritage amenities which will be taken into consideration during the design process. Man-made features constructed during the reformatory's operation have cultural heritage value and must remain intact (Campbell, Robinson & Nix, 2014). The primary concern with regards to this daylighting project is the stonework surrounding the buried stream.

The North and South ponds are considered the largest open water sources within the City of Guelph, as Guelph Lake does not lie within the City boundaries (Campbell, Robinson & Nix, 2014). A daylighting project should not negatively impact the ponds, specifically in regard to quantity. The small pond which the current stream is directly connected to may be habitat to local fish species, if that is the case the disconnection of the current stream should not negatively impact the ponds water quantity.

Significant changes in site grading occurred with the land transformations done to the site (Infrastructure Ontario, 2009). The site grading is not considered to have cultural or natural heritage value and may be manipulated for the purpose of this project (Campbell, Robinson & Nix, 2014).

Clythe Creek has problems with warming primarily attributed to runoff from York Road as well as sources upstream (Campbell, Robinson & Nix, 2014). To enhance the significance of this stream daylighting project vegetation surrounding the stream is crucial to maintaining the temperature of the streams water flowing into Clythe Creek. With a direct connection from a daylighted stream to Clythe Creek could provide the most significant cooling effects (see Design Options – Option 2.3). Careful consideration needs to be taken when the stream is reintroduced. A natural reference point for reintroduction similar to other introductions to the creek will need to be found. Clythe Creek's flow has been significantly altered throughout Guelph's development and finding a natural point of reintroduction may not be possible, if that is the case a similar reference point may be found at nearby stream, sub watersheds or tributaries.

Table 1: Summary of natural and cultural heritage features

Feature	Type	Significant Considerations
Stonework and surrounding walls	Cultural	No alterations to features constructed by Guelph Reformatory inmates.
North and South Ponds	Natural	No reduction in water quantity
Smaller Ponds	Natural	No significant reduction in water quantity
Clythe Creek	Natural	Naturally introduce new surface water source to mitigate negative effects to stream morphology
Site Grading	Natural	None

Table 1 summarizes the natural and cultural heritage features, indicating considerations that will need to be addressed in the final daylighting design.

1.4 Restoring Natural Features

1.4.1 Overview

In North America, urban streams are one of the most disturbed and degraded aquatic systems (Brown, 2000). Urban development has not prioritized protecting fisheries and stream habitat, placing streams in culverts and destroying ecological and human connections (Brown, 2000). As streams and rivers degrade, we are realizing the importance of the ecological functions these buried systems once provided. Interest in restoring urban streams is growing both nationally and internationally as part of increased emphasis on the liveability of urban communities (Brown, 2000). Natural habitat is used as a common criterion to assess sustainability of the urban environment (Brown, 2000).

1.4.2 Daylighting: A Watercourse Restoration Initiative

Daylighting is a process of returning waterways to the landscape (France, 2012). France notes that daylighting is not a process to bring waterways to the surface, rather it is about re-allowing the stream to make its profile on the landscape (2012). Natural channel design attempts to reconstruct channels to self-sustaining ecological and geomorphic functions of natural waterways (TRCA, 2009). Today, this practice is frequently used in watercourse restoration and realignment projects, gaining popularity over the last 10-15 years in Ontario (TRCA, 2009).

1.4.3 Daylighting Case Studies

1.4.3.1 Baxter Creek, location not provided

Baxter Creek flowed through a pipe which was underneath green space between two streets (France, 2000). Initially, the engineering firm put large blocks in a longitudinal straight line (France, 2000). After the first rainstorm, the project failed and the firm had to re-design the stream to reflect appropriate hydrology and geomorphology (France, 2000). This case study highlights the importance of understanding site ecology, hydrology, and geomorphology – the power of water cannot be underestimated.

1.4.3.2 Restoration of Jenkins Creek, Maple Valley, Washington

The Jenkins Creek restoration was part of the Soos Creek Basin Plan, prepared in 1990 by the King County Surface Water Management Division (Pinkham, 2000). The project was completed in three phases. The first phase involved installing corrugated arch pipes with gravel bottoms, creating a passage more conducive to fish then ordinary pipes under roadways (Pinkham, 2000). The second phase involved addressing erosion caused by degradation of vegetation by the public. The county choose a public-information approach instead of acquiring rights-way for structural interventions (Pinkham, 2000). Finally, the third phase involved daylighting the stream channel and recreation of the floodplain. Vegetated bioinfiltration swales were used to intercept pollutants and sediments as they followed off nearby roads and parking areas towards the stream (Pinkham, 2000). As the primary objective was to improve fisheries, attention was given to optimum channel depth, velocity of spawning areas and other habitat needs. Three years following the implementation of the design, the stream structures were still in place (Pinkham, 2000). Overall survival of vegetation was good with the exception of one species that did not survive. Additionally, some noxious species were beginning to invade (Pinkham, 2000). Salmonids were noted to be passing through and using the channel in November, however, the channel was dry except for three pools in June. The temperature of these pools exceeded appropriate levels for salmonid survival but it is noted that, hopefully, once vegetation is fully grown, these pools will remain cool (Pinkham, 2000). The low-density of land uses and single ownership of the land facilitated right-of-way negotiations. This case study highlights the importance of engaging the public and landowner on the aesthetic properties and function superiority of native species. Additionally, it shows the time lag for the natural features to mature before thermal benefits are noted. France notes that most species take approximately five year to mature (2012).

1.4.3.3 Restoration planning for China Creek, Vancouver, BC

China Creek was flowing underground for 50 years in highly impervious urban system. It used to be one of the largest drainage basins with an area of approximately 12km^2, flow of 2.5m^3/s and width of 7m (Brown, 2000). Trout Creek was a headwater tributary to China Creek. It once had three streams flowing into it, Gladstone Creek was the largest tributary. The area around Trout Lake used to be a peat bog that was surrounded by a hemlock forest (Brown, 2000). This case study by Brown identifies that the social and economic complexities of restoring such as a heavily urbanized stream but that it could be a catalyst for capacity building and community activism (2000). This case study reviewed four design options including daylighting the creek to support fish populations, daylighting the creek to convey stormwater as primary purpose while supporting fish populations was not necessary, flooding Trout Lake to store water and restore the wetland, and daylight Gladstone Creek. A matrix of constraints and opportunities identifies daylighting Gladstone Creek or flooding Trout Lake to have the fewest constraints since they have smaller scopes and require less land (Brown, 2000). The major constraints include biophysical and socio-economic. This paper emphasizes the need to gain public and political support to daylight the China Creek (Brown, 2000). It notes that action-oriented initiatives should be taken to maintain participation and interest in the restoration effort. Given the scale of this restoration, it is suggested that small-scale demonstration projects are used as phases of the broader restoration plan (Brown, 2000). For example, Brown indicates that the Gladstone Creek could be daylighted to attract credibility, demonstrate benefits, attract funding, raise awareness and contribute to design and implementation of future phases (2000). Although, not yet implemented, this stream restoration case study illustrates the various components and considerations when phasing in a much larger restoration project.

1.4.4 Effectiveness of 'Natural' Channel Design

Conservation authorities have the mandate to conserve, restore and manage natural resources on a watershed basis (Conservation Ontario, 2013). With limited comprehensive monitoring programs for installed designs in place, Toronto and Region Conservation Authority indicate that evaluation of natural channel design project performance is sparse (2009).

Existing monitoring protocols do not consider the following (TRCA, 2009):

- Monitoring newly constructed channels
- Construction impact to vegetation and time needed to re-establish riparian vegetation
- Mechanisms for natural channel design failure

Objectives of natural channel design are usually specific to features and functions of aquatic systems (TRCA, 2009). Themes for natural channel design success include (TRCA, 2009):

- Measures of dynamic stability and habitat value
- Channel stability can be measured by pass through of sediment, assuming the channel is in equilibrium (in = out). Although, guidelines exist in Regional Monitoring Network (Regional Monitoring Network – TRCA, 2001) to understand sediment dynamics using cross-sections, long-profiles, erosion pins and other geomorphic measures, they do not allow for determination of sediment deposition.
- Quantify systematic adjustments and characterize the factors that impact future channel stability including channel geometry, type and strength of bank materials, bank and floodplain vegetation, and composition of surficial and sub-pavement sediments
- Assessing habitats and collecting and analyzing benthic invertebrate and fish assemblages

- Water quality is usually more influenced by watershed characteristics upstream of natural channel design rather than the design itself

Numerous studies suggest that performance should be evaluated based on habitat enhancement and not natural channel design functions as a design isolated from a broader ecological system (TRCA, 2009). Performance assessment for this design should incorporate a habitat enhancement lens.

Natural channel design is finite. Post-construction monitoring is less relevant as channel becomes established and natural processes are maintained (TRCA, 2009). TRCA recommends that, instead, watershed-scale indicators should be used to monitor the on-going function of channels (2009). Monitoring the performance the natural channel design as part of an integrated natural system is crucial.

2 Design Parameters

2.1 Scope

This project reviews current stream daylighting techniques in order to understand opportunities for contextual optimization of practices. The design considers impacts of daylighting a reach of a buried Yorklands Green Hub stream on restoring the Brook Trout fish species in Clythe Creek. This stream is a headwater feeder into Clythe Creek.

The primary concern of the project is to develop a natural channel design that could allow for passage of Brook Trout and restoration of aquatic species and habitat. Additionally, the project addresses how this design will be integrated into the existing site plans of Trout Unlimited Canada. The design focuses on a specific reach of the buried stream on the northeast corner of the Yorklands Green Hub property (Figure 1). This reach is the nearest reach to Clythe Creek, the creek within the Brook Trout restoration plan for Trout Unlimited. This design is site specific, but key design components and considerations may be adapted to other sites within the Yorklands Green Hub or other daylighting projects.

It is recognized that daylighting this stream reach is part of a much larger water management plan for the Yorklands Green Hub, a collaboration of a variety of stakeholders including University of Guelph researchers. Additionally, Trout Unlimited has a broader conservation plan for the site and Clythe Creek, beyond daylighting this stream segment. The design does not consider these aspects, as they are not yet developed. However, recommendations for how the design can be integrated into these plans are made.

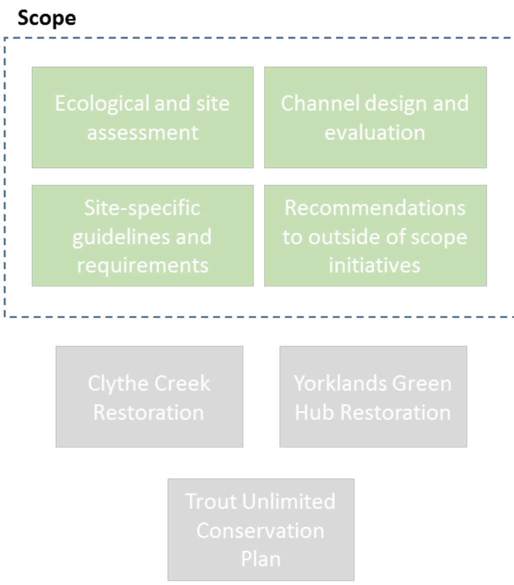


Figure 2 : Project Scope

Design ideas have been developed and evaluated using the following software programs:

- ArcGIS – a geographical information systems software used to create maps specifically for the drainage area and the land use of the surrounding area
- United States Environmental Protection Agency's Stormwater Management Modelling (EPA SWMM) - a dynamic rainfall-runoff simulation program to model single storm events and find the peak flows of the stream
- HEC-RAS - computer modelling software that is used to simulate flow through natural channels

To test potential design ideas, streamflow was determined using EPA SWMM and flow measurements were taken at the inlet and outlet of the culvert to verify modelling. Flood lines and sediment control was determined using HEC-RAS. ArcGIS was used to create maps specifically for the drainage area and the land use for the surrounding area. All design drawings were completed using the computer aided design software, AutoCAD. The final report of this design includes a detailed design for construction purposes; no blueprints for building structure, plumbing or mechanical is provided. Further, construction and implementation of the design will need to be contracted out and will not be completed by Cynergy Consulting Inc.

2.2 Constraints and Criteria

2.2.1 Design Constraints

- The Grand River Conservation Authority (GRCA) outlines water quality targets to maintain cold water aquatic life. The document outlines that there is to be >6 mg/L DO (Dissolved Oxygen), water temperatures from 15 - 20°C, total phosphorus and nitrogen concentrations of less than 0.024 mg/L and 1.07 mg/L, respectively. According to the GRCA targets, the increases to suspended solids may not exceed 25 mg/L during short term exposure and less than 5 mg/L during long term inputs. Increases to stream turbidity may not exceed 8 NTUs during short term exposures and less than 2 NTUs during long term inputs (Grand River Conservation Authority, 2013).
- As the stream reach is a headwater feeder to Clythe Creek, water quality targets must additionally meet those of Brook Trout. The dissolved oxygen concentration must be greater than 7 mg/L (Ficke et al, 2009). The temperature regime must remain between 10 - 14°C (Ficke et al, 2009). A channel gradient less than 7% is recommended. Additionally, high flow rates have the potential to hinder juvenile development or displace fish.
- Under the Clean Water Act of Ontario Source Protection Plan, the health of the drinking water cannot be adversely affected by construction or placement of the stream (Clean Water Act, 2006).
- Construction must follow the In-Water Work Timing Window Guidelines produced but the Ministry of Natural resources (Ontario Ministry of Natural Resources (OMNR), 2013).
- Design and management strategies are outlined in the Natural Channel Systems: An Approach to Management and Design. The stream design must meet these guidelines and are a requirement of the Ministry of Natural Resources (MNR, 2001).
- The Yorklands Green Hub includes the Clythe Creek Provincially Significant Wetland (PSW) Complex which under the GRCA Policies for the Administration of Ontario Regulation 150/06 Section 8.4 are protected from development unless it can be demonstrated that the hydrological and ecological functions will be created, restored, and/or enhanced (GRCA, 2013).
- Grand River Conservation Authority Watershed Management Plan outlines the threshold for healthy flow regimes to be: bed mobilizing flow on a yearly basis, semi-annual scouring to re-suspend and move superficial fines, floodplain inundation (>bankfull +30 cm), nutrient management (>bankfull) and biological functions, and low flows that allow fish movement between pools along with maintaining a littoral zone of 10 cm depth (GRCA, 2014).
- To control erosion forces, identifying the local soil types and analyzing their cohesion and providing evidence to support the stream flow will not rapidly erode the stream bed and cause outflanking or total bank failure (OMNR, 2001).

- Department of Fisheries and Oceans (DFO) land development guidelines are in place to "...ensure that the quality and quantity of fish habitat are preserved and maintained..." this design will have to be planned in accordance with these guidelines (DFO, 1993).
- The City of Guelph requires that no site heritage or natural features are destroyed (Cambell, Robinson and Nix, 2014).

Cynergy Consulting Inc. commits that our designs addresses all outlined constraints.

2.2.2 Design Criteria

- The intended site plan includes public use and wildlife use, safety of these groups is necessity during planning, construction, and final stages of the project.
- Minimizing the need for offsite materials would benefit both economic and ecological factors related to the project.
- Aesthetics are an important factor as the Yorklands Green Hub site is purposed for public use and a source for educational activity, the final design should be visually appealing.
- Reduce the cost of daylighting by producing an economical and sustainable design to minimize cost; excess funds can be allocated to other beneficial projects.
- The design should agree with the Yorklands Green Hub Mission statement along with the Mission statement of Trout Unlimited Canada.
- The design should minimize maintenance to help reduce cost.

Cynergy Consulting Inc. commits that our designs addresses all outlined criteria.

3 Site Characteristics

Figure 3 shows the site of the proposed daylighting project. The location is scaled down from a provincial level of reference to better identify the location of the site using Scholars Geoportal. The site is in the east-end of Guelph, at the corner of York Road and Watson Parkway, in Southern Ontario. Site characteristics are determined using ArcGIS (Table 2). These parameters are used to develop and assess the design.

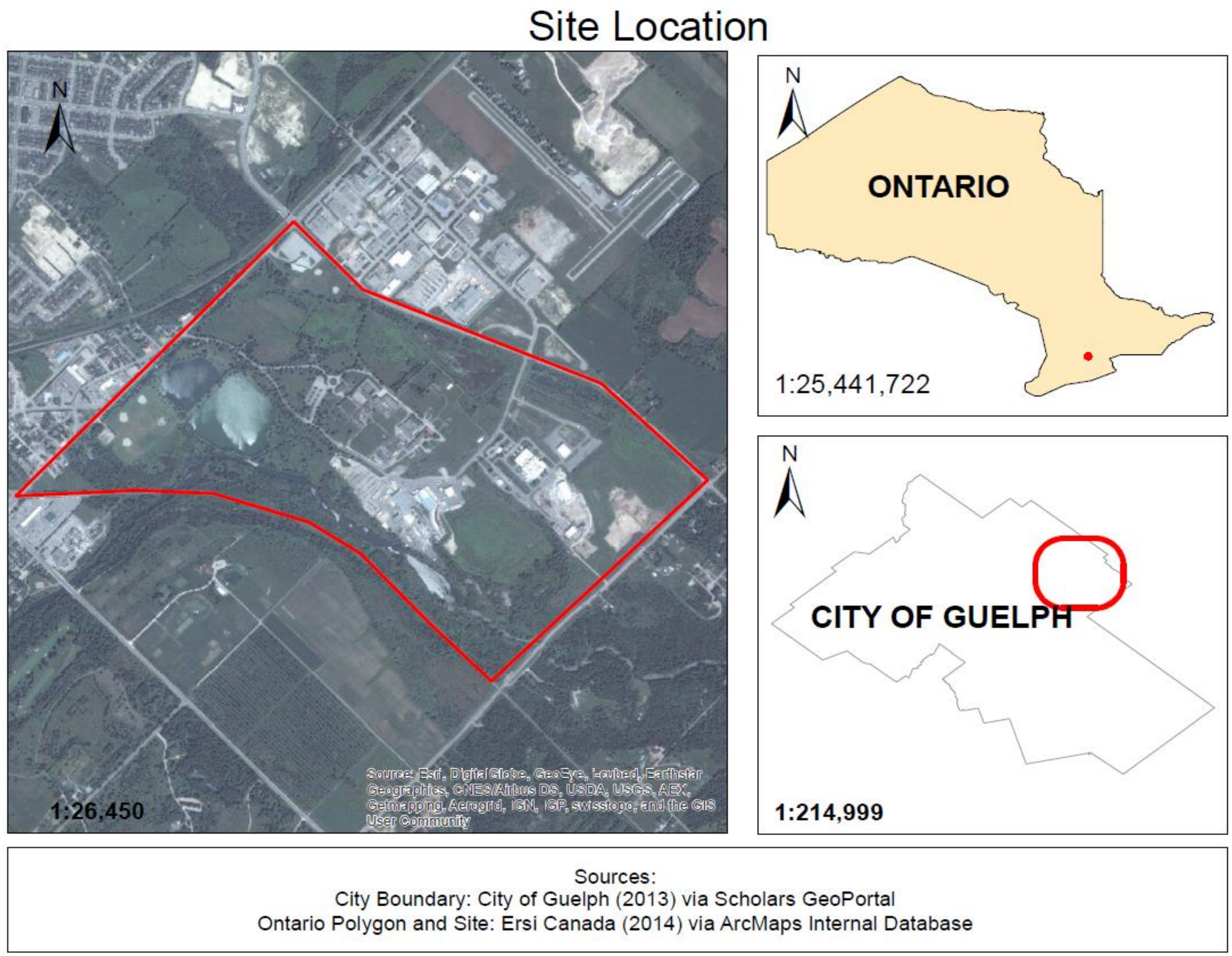


Figure 3: Site Location

Table 2 summarizes the relevant maps that were used to develop and assess the design. Notable characteristics and importance to the design are described.

Table 2: Map Summary (Appendix D)

Map	Characteristic	Importance to Design
Land Use	Measurable area and type of land use	Inputs for the EPA SWMM modeling for runoff coefficients
Soil Type	Burford Loam	Soil composition for erosion and infiltration inputs for both HEC-RAS and EPA SWMM. *Soil Characteristics:* Well sorted with stratified gravel layers, with rapid internal, slow external drainage, slopes ranging from 1 to 20 percent (Hoffman *et al*, 1963). Soil cohesion is estimated to be in the mid-range, with shear stress values in the 25-50 kPa (OMNR, 2002). *Composition:* 30-40 % Sand, 40-50% Silt, 15-20% Clay, with 3-5% Organic matter (Hoffman *et al*, 1963).
Contour	Slope grades and Elevation	Outlining the drainage area for measurement and land type/use characteristics involved for modeling
Surface Hydrology	Hydrologic features on the side and Drainage paths	Location of wetlands and their significance, location of large water bodies for routing options
Digital Elevation Model	Slope grades and elevation, drainage path	Visual representation of the characteristic site drainage
Water Table and Contours	Water bodies gaining from groundwater source	To approximate that the water bodies are gaining water from a secondary source (we cannot adversely affect the water levels in the North and South ponds).

4 Proposed Designs

4.1 Open Channel Design

Daylighting projects are done in order to expose some or all of previously covered waterways (American Rivers, N.D.). A stream is daylighted through the design of an open channel. There are three main types of open channel design – vegetative, flexible and rigid lining. Vegetative lining is the most desirable type of open channel design. This type of channel has many benefits including erosion control, new potential for habitats and water quality benefits (Knox County Stormwater Management Manual, 2008). Riprap is typically used for the flexible lining as it provides a rough surface that can dissipate energy. These channels are used when the flow velocity is too high for a vegetative liner. A rigid liner is usually constructed of concrete and would be used when extreme flow capacity is needed (Knox County Stormwater Management Manual, 2008).

The objective when daylighting a stream is to restore the stream to its natural state, enhancing hydrologic and hydraulic features based on the outlined constraints and criteria. A vegetative liner is the best solution to daylight the Yorklands Green Hub stream reach, based on outlined criteria and objectives.

4.2 Natural Channel Design Features

4.2.1 Environmental Benefits

Stream daylighting can provide several environmental benefits. Exposure of the stream will potentially provide a habitat for local species, particularly but not exclusively aquatic species. Part of the restoration would involve the re-establishment of a riparian zone, this would promote the growth of foliage in proximity to the stream. Increasing the growth of trees and brush will aid in mitigating warming, as well as the potential to raise the local air quality. As groundwater is generally colder and has little dissolved oxygen, maintaining temperature is a key parameter to maximize the cooling effect from the stream. The temperature maintenance and increasing the dissolved oxygen is beneficial to local species downstream. Brook Trout is a non-invasive species that requires clean, cold water habitats, survival of this species has been noted to be a good indicator of ecosystem health (Waco & Taylor, 2010). Additionally, Guelph drinking water is fed by the local groundwater, with developments proceeding at excitable rates, the need to maintain recharge areas is important. Without recharge areas the groundwater supply will be negatively affected, the supply will no longer be able to meet the demand both in quality and quantity. Planning and development needs to be carefully considered to protect and maintain areas of recharge to replenish the groundwater supply (GRCA, 2014).

4.2.2 Social Benefits

The site is located in an industrial area of Guelph. Development of recreational amenities have the capacity to provide a positive impact on the newly developing community. Daylighting the buried stream would have the potential to enhance the aquatic habitat in Clythe Creek while providing aesthetic value. The uncovering of a stream will create a public amenity for children as well as a resource schools can use for education. Development of natural amenities has the potential to increase quality of life in a growing community (Sinclair, 2012).

4.2.3 Economic Benefits

The recently approved plans for the Guelph Innovation District, a 1,000 acre site which encompasses Yorklands Green Hub and the buried stream, is expected to bring 7,000 new residents and 9,000 new jobs to the area (City of Guelph, 2014). The project highlights the importance of cultural and natural heritage sites, in particular the Eramosa Valley and Clythe Creek as well as trails and cycling paths. This daylighting project will restore natural features which has, in past projects, correlated with increased property value in the community (Sinclair, 2012).

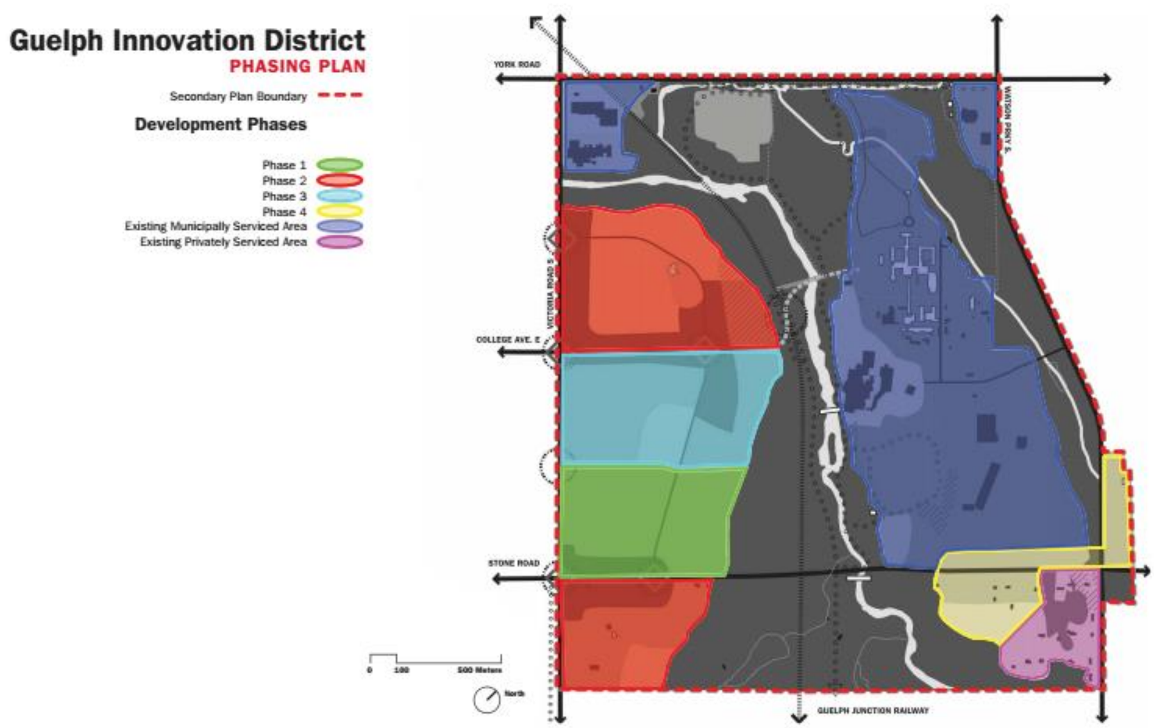


Figure 4: Guelph Innovation District Phasing Plan (Planning Alliance, 2014)

4.2.4 Health and Safety Benefits

As the site is intended for educational and public use, safety of the visitors is a priority. Daylighting can reopen deteriorating culverts that impose unnecessary risk to the public and reopen the natural pathways for drainage; reducing the local runoff velocities and volumes to better manage the effects of urbanization related to flood risks (Pinkham, 2000). Removing the culvert may reduce sharp or protruding edges and will be cost-effective to manage safety in regards to visual walk through inspections. Maintaining the safety of the culvert may be more technically involved then a natural channel design, requiring more costly measures.

4.3 Natural Channel Design Options

There are many things to consider while designing the daylighting of a creek and natural channel design. The first major component while designing a stream is the bankfull discharge. The bankfull discharge is the flow rate that defines the channel dimensions. It transports most of the streams sediment there by forming the channel (North Carolina Stream Restoration Institute, ND). This flow rate is the basis for many other parts of the channel design including the geometry and erosion control measures. Of the four options outlined below three of them involve the daylighting of the stream. In order to determine the bankfull discharge modelling of the surrounding area will be needed. This will be done using the EPA's SWMM software. Table 3 summarizes the parameters needed to model the drainage plan in EPA SWMM.

Table 3: EPA SWMM Properties

Property	Unit	Description
Area	m	Area of Subcatchment
Width	m	width of Overland Flow
Slope	%	Average Surface Slope
Imperviousness	%	Percent of Impervious Area
N-Imperv	N/A	Manning's N for Impervious Area
N-Perv	N/A	Manning's N for Pervious Area
Curve Number	N/A	SCS Runoff curve number
Rain Gage	N/A	Design Storms for Guelph, ON

There are a couple of characteristics of the Yorklands Green Hub that may cause some obstacles during the design process. There are many historic features on the site, specifically the stone walls. These features are protected heritage features and must be left intact. Another obstacle on the site is the PSW complex located on the site. These obstacles must be taken into consideration when choosing the appropriate design for the site.

4.4 Option 1 – Do Nothing

The first option would be to leave the culvert as is. This is the cheapest option however it also provides no benefits to the site. Also the current culvert is beginning to show signs of deterioration specifically at the inlet (refer to Appendix A). The failure of this culvert could result in uncontrolled flooding to the lands of Yorklands Green Hub.

4.5 Option 2 – Daylight the Stream

Figure 5 summarizes three design options for the daylighted stream path, each has specific considerations for the reroute. The routes presented in Figure 5 are not designed stream channels; this is simply a representation of possible paths, highlighting different options for the stream outlet.

Figure 5: Design Daylighting Options

4.5.1 Option 2.1 – Reroute along current path of Culvert

This is the shortest of the three proposed daylighting routes at an approximate length of 190m and is expected to be the cheapest of the rerouting options because it is the shortest reach (Appendix F). If the creek were to be rerouted along the current creek Clythe Creek would receive no benefit from the daylighting specifically when it comes to the temperature benefits the stream could provide to Brooke Trout. The stream would benefit by allowing the wetland to return through the controlled of the creek flooding of the creek. One problem with this design is that is must pass through a stone fence which is considered a cultural heritage feature. A culvert would be needed for the creek to travel under the fence as to not disturb it.

4.5.2 Option 2.2 Reroute to Clythe Creek

The second rerouting option is to design the creek so it goes directly to Clythe Creek (Appendix F). This creek would have an approximate length of 498m and would allow Clythe Creek to experience the benefits of the cold headwaters of the newly designed creek. One potential problem with this design is that the stream will no longer be feeding the ponds. This should not be a problem as the ponds are also groundwater fed. This is due to the fact that the groundwater table is at a higher elevation then the creek themselves. Further investigation will need to be completed in order to find out if the ponds would stay at their current water level without the input of the stream. One benefit of routing the creek to Clythe would be it would not have to pass through any heritage features or roadways. This would cut the cost as there would be no need for culverts. This route would also benefit by allowing the wetland to return through controlled flooding of the creek during major storm events and the spring thaw. One potential drawback of this design is that Clythe Creek will have to be re-evaluated to ensure it can handle the increased flow rate that it would receive. This should not be a problem as there are already plans in place to widen York Road and Clythe Creek must be redesigned anyways.

4.5.3 Option 2.3 Reroute to North Pond

The third rerouting option is to design a creek that travels directly to the north pond (Appendix F). This creek would have an approximate length of 444m. This creek would bypass the smaller pond to the north where the current creek would travel. This route would cause a couple of additional problems as it crosses the entrance way to Yorklands Green Hub. A culvert would be needed to cross the road which will add additional costs to the stream. The stream may cause potential flooding problems along the entrance to the Yorklands Green Hub during major storms. Even though this stream is not the longest of the three daylighting options it would be the most expensive to the additional culvert under the road and stone fences.

Table 4: Summary of design options

Design option	Cost	Length	Number of heritage features	Number of culverts required	Risk of uncontrolled flooding
1	N/A	N/A	0	0	High
2.1	Moderate	190	1	1	Low
2.2	Moderate	498	0	0	Low
2.3	High	448	2	2	Moderate

5 Design Evaluation

5.1 Evaluation Criteria

5.1.1 Environmental Impact

Environmental impact includes numerous aspects including the degradation of existing habitat through the construction process to the potential of environmental damage through flooding. This also includes the loss of heritage features through construction of the channel. The best option is the one that damages the least amount of habitat as well as heritage features through construction of the channel.

5.1.2 Flood Damage Control

The ability of the channel to reduce flooding to the Yorklands Green Hub property.

5.1.3 Opportunity for Habitat Growth

Opportunity for habitat growth is the ability of the channel to sustain new habitats. These new habitats would include fish, birds, plants and several other species. Typically the greater the size of the channel the greater the available habitat.

5.1.4 Cost of Construction

The cost of construction includes all cost associated with the construction of the channel. This includes excavation, grading, landscaping as well as additional costs such as culverts.

5.1.5 Aesthetics

The best design option should be able to blend into the surrounding landscape as if the design was always there.

5.2 Evaluation Procedure

A decision matrix and sensitivity analysis was completed to evaluate the design options and select the preferred option.

5.2.1 Design Matrix

In order to evaluate each design option, each evaluation criteria is given a value. The sum of these values equals 1. The values are as follows:

- Impact on Environment: 0.25
- Flood Damage Control: 0.2
- Cost of Construction: 0.2
- Opportunity for Habitat Growth: 0.25
- Aesthetics: 0.1

Criterion were ranked based on client priorities, prioritizing environmental impact and habitat growth. Using these values each design option was ranked from the best option to the worst for each evaluation criteria. The summation of the product between the ranking and the value is used to determine the best possible design option for Yorklands Green Hub.

Table 5: Decision matrix

Selection Criteria		1	2.1	2.2	2.3
Impact on Environment	Value	0.25	0.25	0.25	0.25
	Rank	1	2	3	4
Flood Damage Control	Value	0.2	0.2	0.2	0.2
	Rank	4	1	2	3
Cost of Construction	Value	0.2	0.2	0.2	0.2
	Rank	1	2	3	4
Opportunity for Habitat Enhancement	Value	0.25	0.25	0.25	0.25
	Rank	4	3	1	2
Aesthetics	Value	0.1	0.1	0.1	0.1
	Rank	4	3	1	2
Total Weighted Score		2.65	2.15	2.1	3.1
Overall Rank		3	2	1	4

Based on the results from the decision matrix the best option is 2.2 (reroute to Clythe Creek) followed closely by option 2.1 (reroute along current path of culvert). Option 2.2 is the best option since it will provide cool water to Clythe Creek, provide the largest amount of new habitat and avoid all heritage features on the Yorklands Green Hub site. Based on the results from the decision matrix the best option is 2.2 (reroute to Clythe Creek) followed closely by option 2.1 (reroute along current path of culvert). Option 2.2 is the best option due the facts that it will provide cool water to Clythe Creek, provide the largest amount of new habitat and avoid all heritage features on the Yorklands Green Hub site. From GIS mapping and feedback from Trout Unlimited, it is determined that the ponds will stay at their current levels once the culvert is removed. Due to time constraints, site investigation was not completed to verify this assumption. Before construction of this design begins and flow is removed, the flow into the pond should be temporarily cut off to verify this assumption. In addition, the Clythe Creek redesign will have to be re-evaluated to ensure it can handle the additional flow of the daylighted stream reach.

5.2.1 Sensitivity Analysis

A sensitivity analysis was completed understand the effects of changing weightings of different criteria on the optimal decision strategy, prioritizing environmental, human and cost benefits. Option 2.2 is still the best option when environmental and human benefits are prioritized. However, when cost is prioritized, Option 1: Do Nothing is preferable.

Priority: Environmental Benefits

Table 6 summarizes the adjusted decision matrix which prioritizes environmental benefits, cost and aesthetics are not prioritized. The weighting of the criterion are adjusted as follows:

- Impact on Environment: 0.4
- Flood Damage Control: 0.1
- Cost of Construction: 0.05
- Opportunity for Habitat Growth: 0.4
- Aesthetics: 0.05

Table 6: Decision matrix prioritizing environmental benefits

Selection Criteria		1	2.1	2.2	2.3
Impact on Environment	Value	0.4	0.4	0.4	0.4
	Rank	1	2	3	4
Flood Damage Control	Value	0.1	0.1	0.1	0.1
	Rank	4	1	2	3
Cost of Construction	Value	0.05	0.05	0.05	0.05
	Rank	1	2	3	4
Opportunity for Habitat Enhancement	Value	0.4	0.4	0.4	0.4
	Rank	4	3	1	2
Aesthetics	Value	0.05	0.05	0.05	0.05
	Rank	4	3	1	2
Total Weighted Score		2.65	2.35	2	3
Overall Rank		3	2	1	4

When environmental benefits are prioritized, Option 2.2 is the best option. This is the same result as obtained with the decision matrix (Table 5).

Priority: Human Benefits

Table 7: Decision matrix prioritizing human benefitsTable 7 summarizes the adjusted decision matrix which prioritizes anthropogenic benefits, flood damage control and aesthetics are prioritized.

- Impact on Environment: 0.05
- Flood Damage Control: 0.4
- Cost of Construction: 0.1
- Opportunity for Habitat Growth: 0.05
- Aesthetics: 0.4

Table 7: Decision matrix prioritizing human benefits

Selection Criteria		1	2.1	2.2	2.3
Impact on Environment	Value	0.05	0.05	0.05	0.05
	Rank	1	2	3	4
Flood Damage Control	Value	0.4	0.4	0.4	0.4
	Rank	4	1	2	3
Cost of Construction	Value	0.1	0.1	0.1	0.1
	Rank	1	2	3	4
Opportunity for Habitat Enhancement	Value	0.05	0.05	0.05	0.05
	Rank	4	3	1	2
Aesthetics	Value	0.4	0.4	0.4	0.4
	Rank	4	3	1	2
Total Weighted Score		3.55	2.05	1.7	2.7
Overall Rank		4	2	1	3

When human benefits are prioritized, Option 2.2 is the best option. This is the same result as obtained with the decision matrix (Table 5).

Priority: Cost Benefits

Table 8 summarizes the adjusted decision matrix which prioritizes cost benefits, cost is prioritized.

- Impact on Environment: 0.05
- Flood Damage Control: 0.1
- Cost of Construction: 0.7
- Opportunity for Habitat Growth: 0.05
- Aesthetics: 0.1

Table 8: Decision matrix prioritizing cost benefits

Selection Criteria		1	2.1	2.2	2.3
Impact on Environment	Value	0.05	0.05	0.05	0.05
	Rank	1	2	3	4
Flood Damage Control	Value	0.1	0.1	0.1	0.1
	Rank	4	1	2	3
Cost of Construction	Value	0.7	0.7	0.7	0.7
	Rank	1	2	3	4
Opportunity for Habitat Enhancement	Value	0.05	0.05	0.05	0.05
	Rank	4	3	1	2
Aesthetics	Value	0.1	0.1	0.1	0.1
	Rank	4	3	1	2
Total Weighted Score		1.75	2.05	2.6	3.6
Overall Rank		1	2	3	4

When cost is prioritized, Option 1: Do Nothing, is ranked the highest. This finding does not agree with the results determined in the decision matrix (Table 5).

6 Design

Based on the design matrix and sensitivity analyses, Option 2.2 was selected for design. This design prioritizes environmental and social benefits, aligning with Trout Unlimited's objective to enhance habitat and to work to restore Brook Trout to Clythe Creek. Using the Rosgen classification method, healthy flow regime requirements and Brook Trout habitat requirements, channel meander pattern, geometry, and riffle-pool structures were designed. These components were then consolidated into HEC-RAS and tested under the 1.5 and 2 year flow and under the instantaneous flow obtained from stream gauging.

6.1 Determining drainage area

In order to determine the flow rates a drainage area was determined. This was done by delineating the area using topographic maps of the site and verifying results through site visits. It was determined that the stream had a drainage area of 78.06 ha. Other methods were used to attempt to find the drainage area including OFAT and GIS; these methods provided significantly higher findings for the reach drainage area, estimating it to be greater than 400ha. Based on the size of the reach and site visits, it was determined that the manual delineation was the most appropriate method.

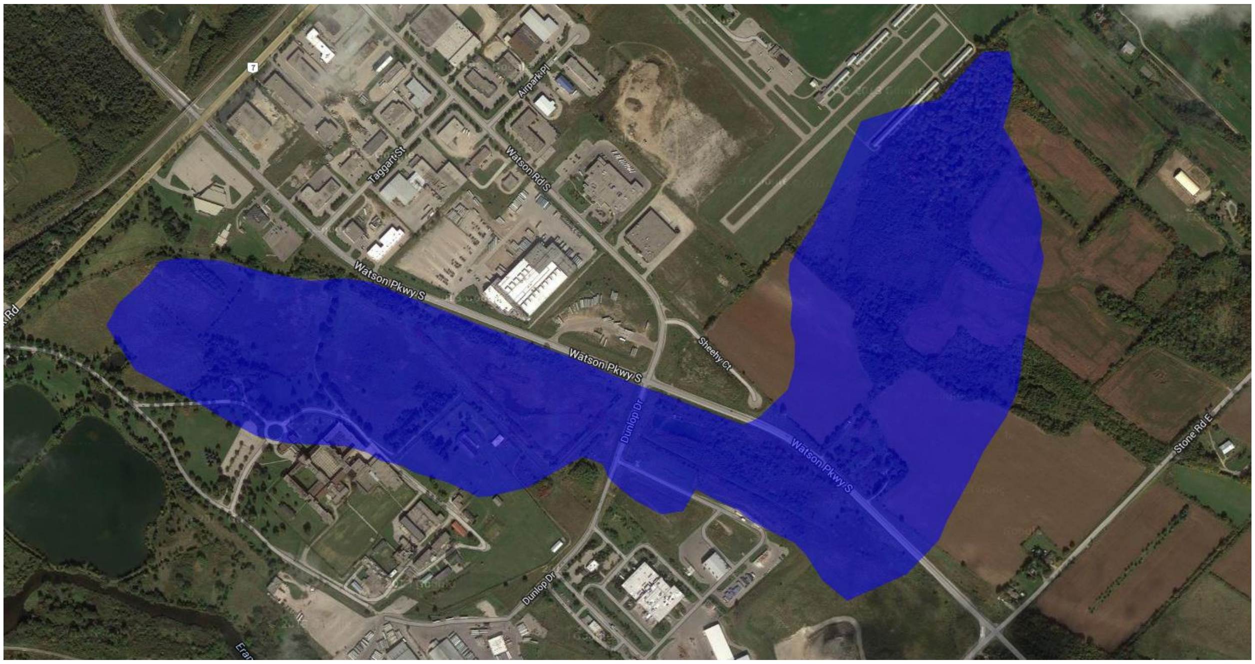


Figure 6: Estimate of Drainage Area (77 ha) with Google Earth

6.2 Hydrologic assessment using EPA SWMM

Using the estimated drainage area, a flow rate was calculated using EPA SWMM. The first step to design a natural channel is to determine the flow rates for which the channel will be designed. Ideally, the flow in the stream would be measured over a period of time to determine the most appropriate design flows; the longer the period, the more accurate the estimation. Due to time constraints, this method was not possible and the flow rates were determined using EPA SWMM.The design storms entered into the model were calculated from the Guelph Turf Grass Station using a 6hr SCS storm distribution. The SCS method was selected because it is appropriate for rural or small urban watersheds (*Stormwater Management*, ND). Once the design storms were determined, the land use parameters had to be found for the subcatchment using GIS (Table 2). The developed maps are provided in Appendix D. The results are summarized below in Table 9.

Table 9: Land Use Parameters

Land use	Area (ha)	% Area	% Perv Area	Mannings n	N -Perv Weighted Avg	SCS CN	CN Weighted Avg
Improved Pasture	29.5	37.8%	40.43%	0.17	0.069	39	14.7
Non-Productive Woodland	4.3	5.51%	5.89%	0.8	0.047	25	1.38
Productive Woodland	4.7	6.02%	6.44%	0.4	0.026	45	2.71
Unimproved Pasture and Range Land	33.5	42.9%	45.92%	0.13	0.060	68	29.2
Urban Built Up Area (Imperv)	5.1	6.53%	N/A	0.011	N/A	98	6.40
Total	78.06	100%	100%	N/A	0.201	N/A	54.4

From the land use results the directly connected impervious area was determined to be less than 5%. This is the minimum value that should be entered into the model, according to the EPA SWMM User Manual. Table 10 outlines the catchment parameters that were entered into EPA SWMM and Table 11 shows the peak flow rates for various return periods that were determined from the model.

Table 10: EPA SWMM Parameters

EPA SWMM Parameters	
Total Area (ha)	78.06
Area (m^2)	780570
Flow Path (m)	152.4
Width (m)	5121.85
High Point	342
Low Point	310.5
% Slope	0.57%
Building Area (m^2)	2034
Road Area (m^2)	16221
Parking Areas (m^2)	29314
Urban Built up Area (m^2)	91200
% Imperv	5%
N - Imperv	0.201
N - Perv	0.011
D - Store Imperv	0.011
D-Store Perv	0.05
% Zero Imperv	25

Table 11: EPA SWMM Results

Return Period	Peak Flow (CMS)
1	0.26
2	0.57
5	0.83
10	1.08
25	1.46
50	1.91
100	2.53

6.3 Stream Design Requirements

For this design, the type of stream to be designed, flow regime characteristics and requirements for Brook Trout habitat need to be determined. Stream type was classified using the Rosgen Stream Classification method, using site characteristics as the primary input. Characteristics of a healthy flow regime are provided by the Grand River Conservation Authority (GRCA) Watershed Manual (2014).

6.3.1 Rosgen Stream Classification Method

There are many techniques used to classify streams with varying degrees of success depending on available information and regional applicability. The Rosgen Stream Classification Method uses site and channel characteristics to classify a channel (Appendix G). Rosgen Stream Classification is the most popular method in natural channel design due to its broad geographic applicability (Annabel, 1996). This method is useful for easily identifying stream characteristics and determining physical parameters (Annabel, 1996). Considering there is currently a culvert on site, instead of a channel, the classification was derived from site characteristics, common stream classifications in Southern Ontario and desired channel attributes suitable for Brook Trout habitat.

In Southern Ontario, types B, C, and E are most common (Figure 7). These streams have been most frequently studied types in Southern Ontario, suggesting there is more background information on which to base the design. Type B streams are riffle-dominated with “rapids” and infrequently spaced scour-pools at constrictions or bends. Types C and E are gentle-gradient, riffle-pool type streams. A type B stream design is not appropriate as Brook Trout require velocities of <15cm/s. While type E and C have comparable attributes, type E allows for a greater meander length, reducing the channel slope, and as a result slowing the flows. It also

Figure 7: Type B, C, E Rosgen Stream Classification (Left to Right) (USDA NACS, 2007)

promotes a narrower, deeper channel. This is an important factor as the depth required for Brook Trout is 15cm. Type E channel are commonly found in agricultural areas and rely on vegetation for stability (Montana Department of Natural Resources and Conservation, ND). A type E channel will provide the thermal mitigation through shading through well vegetated banks and narrow channel width. These vegetation requirements also will also provide greater channel stability. The selection of a type E stream determined the various parameters for the design (Table 12).

Table 12: Design Parameter for Type E Stream

Parameter	Unit	Value
Width/Depth Ratio	-	<12
Sinuosity	-	>1.5
Slope	%	<2
Entrenchment Ratio	-	>2.2

6.3.2 Flow Regime Requirements

For the stream design to be self-maintaining, it has to satisfy the requirements of a healthy flow regime in order to provide sufficient sediment and nutrients to parts of the stream. The GRCA describes a healthy flow regime as “flows that support ecological health and healthy river processes” (GRCA, 2014).

Table 13 outlines the flow regime types and their functions, along with the specific flow requirements for the stream design.

The design satisfies most of these requirements for healthy flow regimes based on the design flow for the channel. The bankfull flow was determined to be at the 1.5 year return period; the frequency of the storm that causes the stream to flow full occurs at a return period of 1.5 years. For the bed mobilizing flow, the occurrence of the flow is near to the necessary annual mark. The function of this flow is to “refresh” the bed material and move bed material downstream.

To deliver nutrients that are contained in the bed material to other areas, a scouring flow is required. The flow to accomplish scouring conditions has to provide enough shear stress to disturb the particles. This shear stress was calculated and reported in the section of erosion control (Section 6.5).

For the floodplain to flourish and provide an adequate habitat for terrestrial wildlife, the floodplain requires inundation every two to five years. As the bankfull flow was designed using a return period of 1.5 years, there is high likelihood that this will occur within the time period.

In order to determine the low flows that are part of the flow regime, daily flow data is recommended to be collected as design flows do not allow for determination of low flows. This data allow determination of the low flows and respective water levels. Adjustments can then be made to improve the availability of trout habitat or the feasibility of the design can be reassessed.

Table 13: Healthy flow regime requirements (adapted from GRCA Watershed Management Plan Draft 5 Version 2 (2014))

Flow type	Flow Regime	Description	Frequency	Duration	Design Specific Requirements
Channel Maintenance	Bed Mobilizing	A maintenance flow to loosen the top layer of the bed material and mobilize finer sediments	Annually	A day	Bankfull (Particle size larger than D_{50})
	Scour/ Deposition	A maintenance flow to suspend and move superficial fines and organic material, prevent homogeneity in the channel	Twice a year	A day	Maximum Daily flow (Particle size D_{50})
Nutrient Management And Biological Function	Floodplain Inundation	A flow depth of 30 cm over low-lying spawning areas in the lower order streams suitable for spring spawning	Once every 2 to 5 years in the spring spawning season	2 consecutive weeks, slowly receding	Flow greater than Bankfull
	Floodplain Nutrient Cycling	Inundation of the floodplain allows for nutrients to be delivered to floodplain vegetation	Annually	At least a few hours of the day to few days	Bankfull flow
	Macrophyte Flushing	Remove excess and nuisance Vegetation	Twice annually Summer Fall	Daily	Daily Average Flow values
Low Flows	Littoral Zone Maintenance	Maintains a depth of 10 cm	May to Nov Dec to March	7 day average flow conditions	Depth > 10cm (Minimum) Depth > 15cm (for Brook Trout) Minimum Daily flow
	Longitudinal Connectivity	Depth allows fish Movement	Year-round	A day	

6.3.3 Brook Trout Habitat Requirements

Enhancing the habitat for Brook Trout in Clythe Creek is a primary concern for this design. Table 14 highlights design considerations for Brook Trout habitat. When developing the channel geometry, the key variables pertaining to Brook Trout include providing a channel depth of at least 15 cm and velocity of less than 15 cm/s.

Table 14: Brook Trout Design Considerations

Design Component	Consideration
Channel Geometry	Channel velocity <15cm/s
	Channel depth > 15cm
	Channel gradient <7%
	Baseflow ≥ 55 % of average annual daily flow

6.4 Stream Design

The flow rates that were found using EPA SWMM were used in HEC-RAS to design the natural channel. HEC-RAS is a computer modelling software that models the hydraulics of water effects through natural channels. Once the channel is designed in AutoCAD, the geometry and channel elevations can be entered into HEC-RAS.

6.4.1 Channel Geometry

The geometry of the channel was found by using empirical formulas outlined in *Morphological Relationships of Rural water Courses in Southern Ontario and Selected Field Methods in Fluvial Geomorphology* by WK Annable. Using the equations outlined for a Rosgen Type E Stream, the channel wavelength was determined to be 34m and the radius of the curve was found to be 8.5m.

6.4.2 Determining Elevation Profiles using ARC-GIS

The elevations for the channel were found using ArcGIS since surveying was not possible due to time constraints. The digital elevation model (DEM) profile had a range of 306.87 to 347.99m and an average elevation of 320.16m within the study area. A raster file was created using the DEM to Raster conversion tool in ArcGIS to create a 10 x 10m grid of elevations across the study area (Figure 8). Using this grid an elevation at any point along the reach was approximated using the closest grid point, which was accurate to the sixth decimal place. HEC-RAS cross-section (highlighted in red on Figure 8) elevations were selected using the closest elevation point to the center of the cross-section.

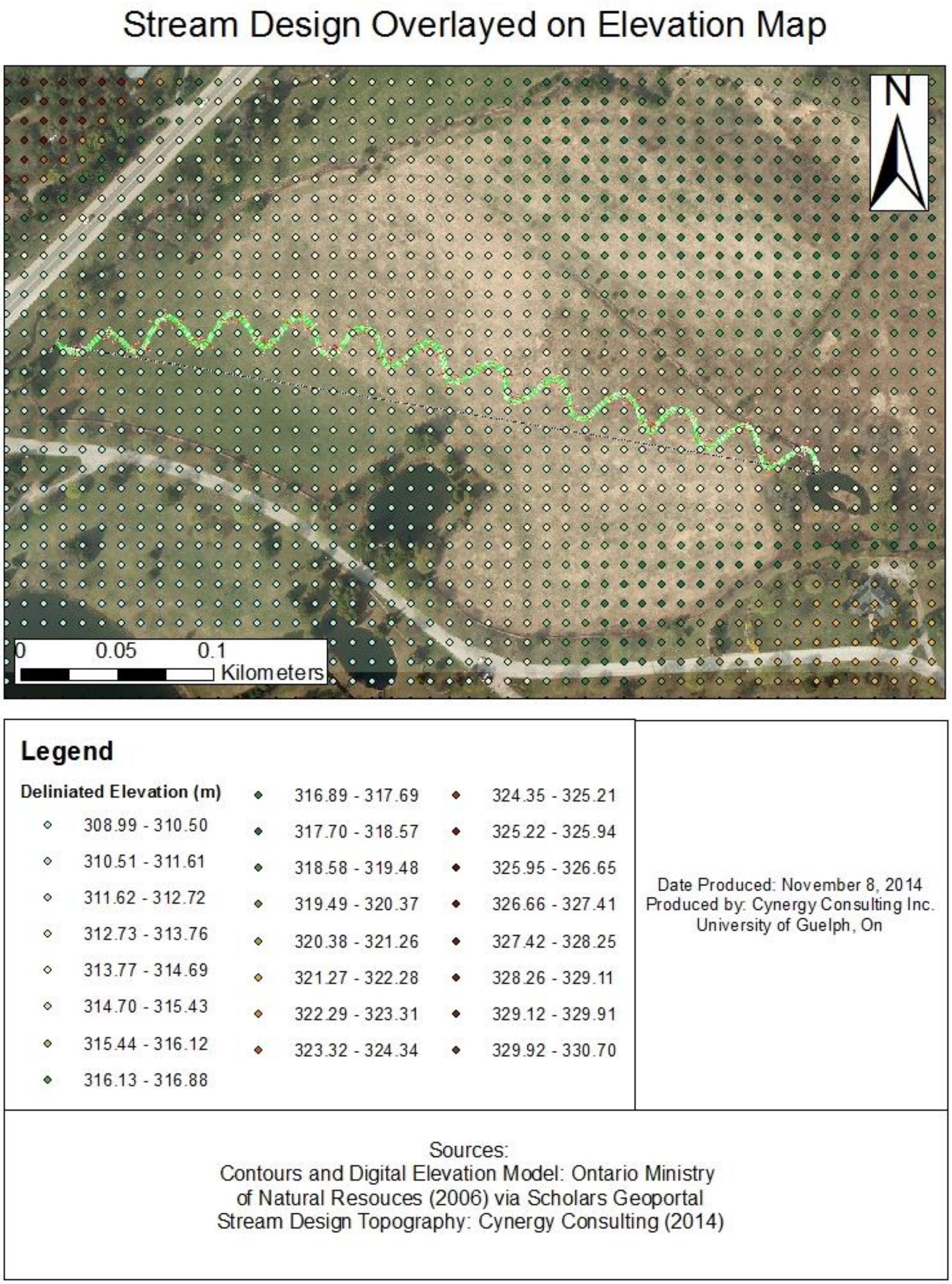


Figure 8: Determining elevation profile

Figure 9 illustrates the current elevations of the channel and the proposed elevations for the channel. Using the proposed elevations, a slope of 0.68% was determined.

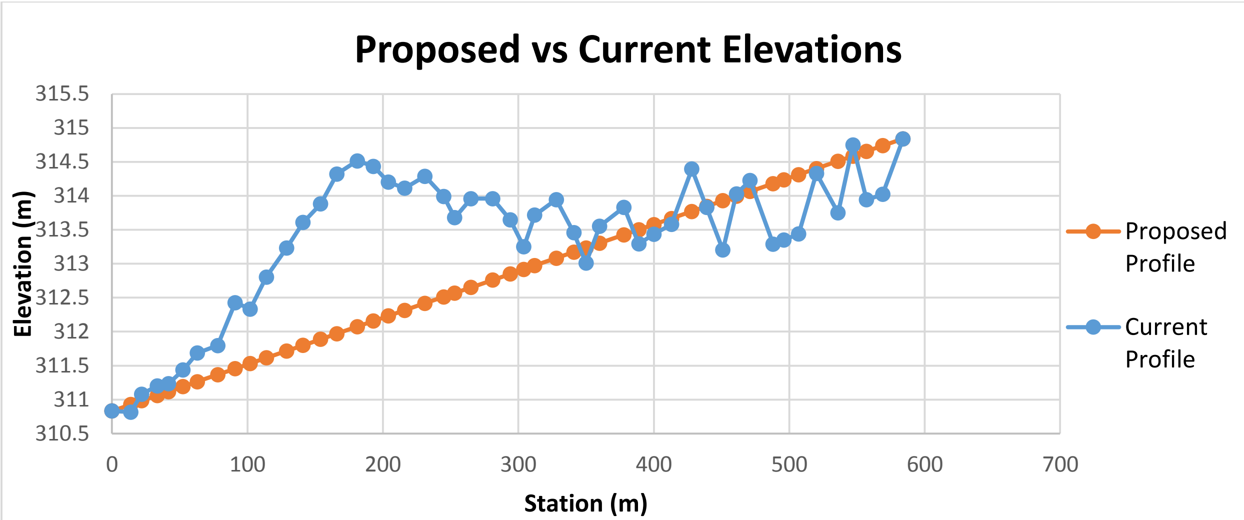


Figure 9: Proposed vs Current Elevations

6.4.3 Hydraulic Model using HEC-RAS

Hydraulics of water effects through the stream were modelled in HEC-RAS, evaluating the riffle-pool, floodplain and channel design.

6.4.3.1 Riffle-Pool Design

A riffle-pool design provides natural stability to the stream. The pools and riffles of a stream are, respectively, the deep and shallower portions of a stream. The pools are found along the meandering part of the stream and riffles form naturally in-between the pools, forming a shallower portion to the stream (Encyclopaedia Britannica, 2014). The riffles and pools provide the stream with changing hydraulic conditions during different discharges. During low flows, water is stored in the pools and smaller flows passing over the riffles will create small hydraulic jumps, which allows the water to be re-aerated (BC Stream Restoration Technical Bulletin, ND). During large flow events the riffles provide protection to the pools by creating dead zones behind boulders and other obstacles (BC Stream Restoration Technical Bulletin, ND).

6.4.3.2 Floodplain Design

In order to provide protection against storms greater than the 1.5 year return period, a flood plain is designed in order to convey these larger flows. The floodplain of the channel was designed to convey up to the 100yr storm. From HEC-RAS modelling, it was determined that the 100yr flow of 2.5CMS requires a flood plain of 0.25 m high and a width of 5m on either side of the channel. The roughness coefficient of the floodplain is 0.05, which is typical for scattered brush and heavy weeds. Figure 10 shows a detailed drawing of the floodplain and water surface elevations.

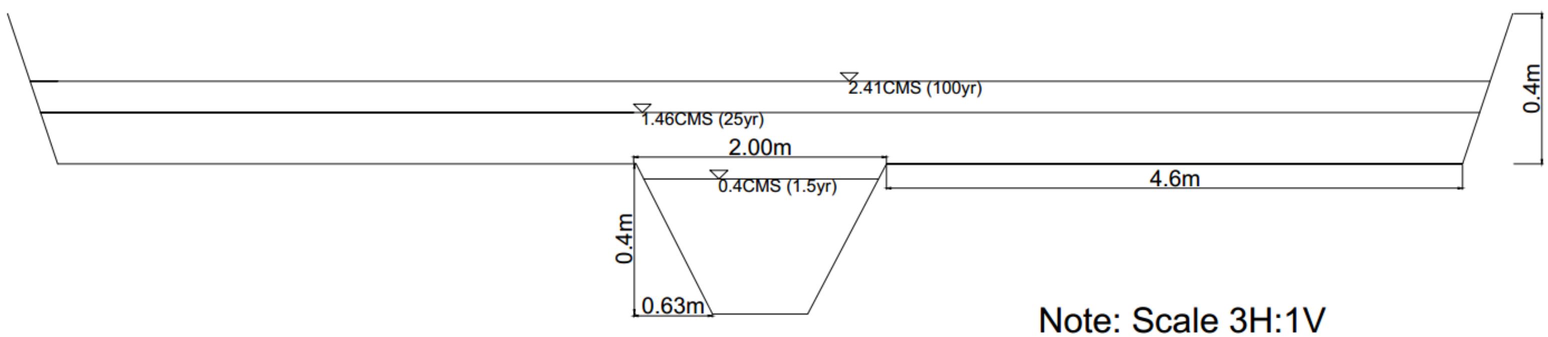


Figure 10: Cross Section View

6.4.3.3 Channel Design

Table 15 outlines the channel characteristics. In order to determine the size of the channel, a bankfull discharge is required. Bankfull discharge can range in return interval from 1.5 to 1.7 years (Annabel, 1996). The corresponding discharge for the 1.5 year return period is 0.4CMS, as determined in EPA SWMM. The channel geometry is presented in Figure 11.

*Table 15: Summary of Channel Properties (*found from empirical formulas in Annabel, 1996)*

Channel Properties	
Valley Length (m)	402
Reach Length (m)	586
Sinuosity	1.5
Top Width (m)	2
Depth (m) - Riffle	0.4
Depth (m) - Pool	0.5
W/D	5
Wave Length* (m)	34
Curve Radius* (m)	8.5

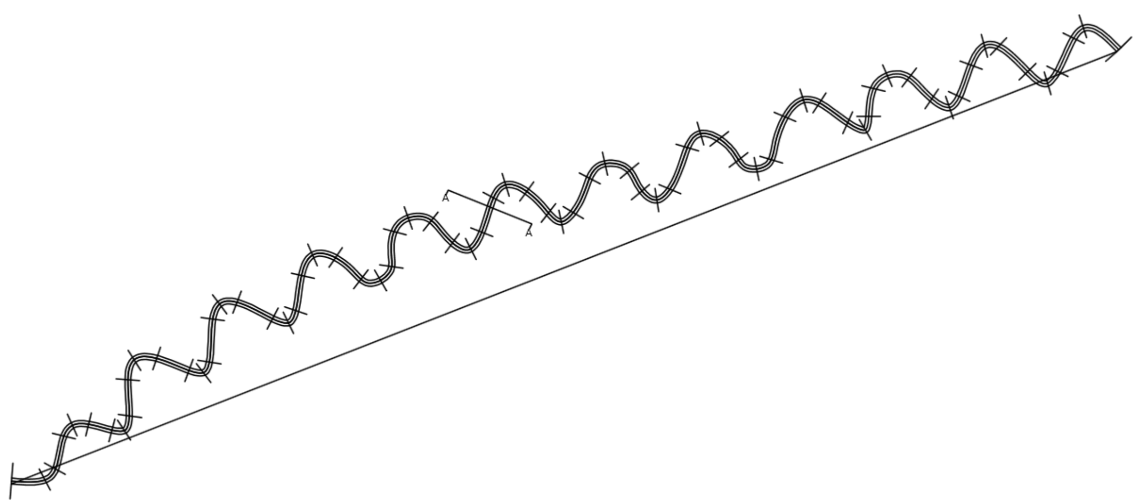


Figure 11: Channel geometry

Cross-sections were entered into HEC-RAS, totalling 71 sections. A detailed summary of these cross sections can be found in Appendix K. From HEC-RAS, water surface elevations were determined along with the velocities throughout the stream. A diagram of the water surface elevations can be found in Appendix K, along with the full HEC-RAS results. The average velocity for the bankfull (1.5yr storm) is 0.8m/s for a riffle and 0.6m/s for a pool. Both of these values are acceptable for a Type E stream.

6.5 Erosion Control

In order to maintain proper function of the stream design, the potential sediment loading factors need to be considered. These factors have controls that range from man-made geotextiles to natural vegetation control strategies. Man-made and natural vegetation are recommended to control erosion factors.

The factors that cause erosion include flow regimes and higher flow velocities that put more shear stress on the soil. If the shear stress is great enough, the soil particles will become suspended and move downstream. This can cause sediment to build up in undesirable areas and suspended sediment can cause adverse effects on aquatic life. Vegetation can be used as an effective tool to mitigate these effects. Figure 12 presents the basic plan for the stream bank vegetation.

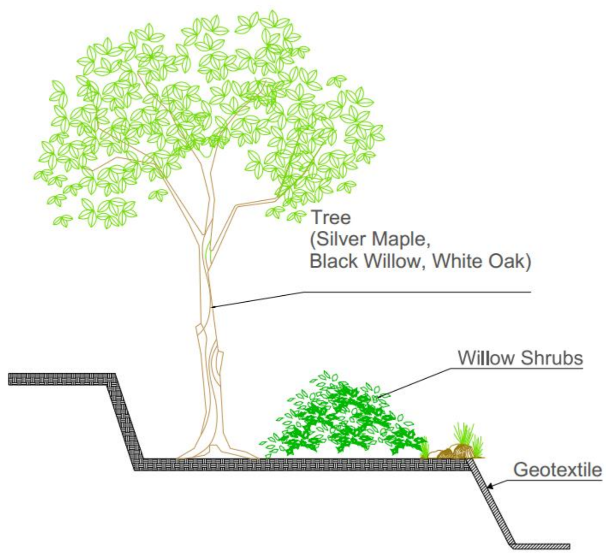


Figure 12: Stream vegetation

Erosion controls are not only important in the life of the stream but during the construction phase as well. A detailed plan to control sediment loading is required prior to construction; erosion control techniques must be in place for cut and fill, routing, and planting phases. Typical effective controls can be found in the appendix of the *Erosion and Sediment Control Guideline for Urban Construction* produced by the Toronto and Region Conservation Authority (2008). A detailed plan outlining these controls should be developed to meet the constraints listed in the project. Increases in suspended solids in the region’s waterways should be minimized to negate short and short term repercussions.

Geotextiles will be used to control the erosion for this design. These geotextiles will be woven, degradable textiles that will help the seeding of vegetation. The selected textiles are biodegradable erosion control mats (Terrafix Synthetics, 2014). These will act as a temporary liner the stream, providing a barrier between the flow and any possible lose soil that would otherwise be moved through erosion forces (Harman & Starr, 2011). Coir mats are another biodegradable erosion control that have a life span of 36-72 months which would allow for natural vegetation to mature (Terrafix Synthetics, 2014). These types of mechanisms are primarily used for bank stability and channel sediment loading, providing immediate benefits while vegetation has a chance to mature to a state of providing bank stability.

For a successful stream design, the sediment loading factors will have to be considered. The tractive force for a 1.5 year design storm stream depth is at the higher end of known values (Ministry of Transportation, n.d.). Please refer to Appendix L for the sediment related calculations and model results. In order to maintain a healthy stream equilibrium, the bed mobilizing flows should be able to move mean particle sizes (D_{50}) up to the 90^{th} percentile (Ness & Joy, 2002). Table 16 contains the parameters needed for sediment loading model developed by the Ohio Department of Natural Resources.

Table 16: Parameters for Sediment Loading Calculations

Parameter	Value	Units
Depth	0.36	m
Slope	0.0069	m/m
Density of Water	999.7	kg/m^3
Density of Soil	2650	kg/m^3
Gravity Constant	9.81	m/s^2
Mean Particle size (D_{50})	0.0025	m

Table 17 highlights the results for the model; variability in the different methods is noted. In order to be conservative, the lowest sediment loading is considered. The selected geotextiles should not inhibit the ability of the flow to move particles as the stream matures. The selection of biodegrading textiles allows the channel time to mature. The results were determined at bankfull discharge; bankfull discharge represents the bed mobilizing flow under healthy flow regime requirements. The shear stress is the force required to move a mean particle size. The shields number is the point at which a particle becomes suspended and is a dimensionless parameter. The sediment loading rates are found per unit width of the channel during bankfull.

Table 17: Sediment loading calculation results

Property	Variable	Value	Units
Threshold of Motion			
Shear Stress	τ	24.36	N/m^2
Shields parameter	τ^*c	0.61	dimensionless
Particle at threshold of motion	D_{cr}	0.025	m
Bedloading/Unit Width			
Bed-load transport (Meyer-Peter)	ϕ	3.41	dimensionless
	q_s	0.0017	m^2/s
Bed-load transport (Einstein 42)	ϕ	1.14	dimensionless
	q_s	0.00056	m^2/s
Bed-load transport (Einstein 50)	ϕ	4.07	dimensionless
	q_s	0.002	m^2/s
Ackers and White	n	0.019	dimensionless
	U	2.23	m/s
	q_b	0.0006	m^2/s

The data from modeling of the stream shows that the velocity of the stream during a 1.5 year event is much greater than normal vegetation would be able to withstand (Tyminski & Kahuza, 2011).

In the flood plain, trees and shrubs will be planted to provide adequate shading for the stream to mitigate the thermal effects from daylighting the stream. The root systems of these plants will also help reinforce the soil, improving its resistance to erosion. The vegetation will provide other benefits such as rainfall interception, increased infiltration capacity through root systems, and transpiration of soil water (Donat, 1994). The use of vegetation that is indigenous will promote the return or rehabilitation of eco-zones that are located in the buffer zone around the stream. The goal is to restore the stream aquatic life; terrestrial wildlife can benefit from stream restoration as well.

Table 18 presents recommended short and long-term control types, their benefits, their limitations, and recommended vegetation. This table summarizes the main ideas and purposes that the vegetation will provide. It has been adapted using Michael Donat's *Bioengineering Stream Banks* a publication by the government of British Columbia and other supporting technical documents (1995).

Table 18: Vegetation Summary

Control	Benefits	Limitations	Recommended Vegetation
Trees	• Thermal Mitigation • Bank stabilization • Species Dependent	• Flood plain planting • Time needed reach maturity	• Silver Maple • Black Willow • White Oak • Sycamore
Live Stakes	• Soil erosion • Low maintenance • Low Initial Costs	• Bank slopes • Can be inundated often • 3:1 slopes preferred	• Spike rush • Swamp-milkweed
Cordon Construction	• Improved hydrologic retention • Machinery installed lower cost • High sliding resistance	• Wet, steep slopes are preferred • Flood plain	• Sandbar willow • Shinning willow • Meadowsweet • Dwarf Raspberry
Hedge	• Bank shading • Typically Willow shrubs • Closer proximity to stream than trees • Density can be high	• Growth time • Frequency of inundation	• Sandbar willow • Shinning willow • Meadowsweet • Dwarf Raspberry
Reed Roll Construction	• No maintenance • Water quality improvements • Immediate benefits	• Bank/stream interface • Riprap combination	• Narrow/Broad-leaved cattail • Common Bur-reed • River bulrush
Geotextiles	• Provide base to growth • Combined with vegetation	• Stream bed • Stream bank • Areas of high erosion	• Erosion Control blankets • Coir mats

6.6 Design Integration into Clythe Creek

In order to successfully integrate the channel into Clythe Creek, the stream should enter Clythe Creek at an appropriate angle (Figure 13). From a meeting with the City of Guelph it was stated that the angle should be equivalent to similar tributaries that enter into Clythe. However, since Clythe Creek is being redesigned in the near future to allow for the widening of York Road, this angle is currently unknown. According to *Rehabilitation of Clythe Creek*, the velocity of Clythe Creek at a bankfull discharge of 2CMS is 0.65m/s (2008). The exit velocity of the newly designed stream reach is currently 0.54 m/s according to the HEC-RAS results. Erosion of Clythe Creek should not occur as it enters Clythe Creek, assuming it were to enter the creek at an appropriate angle. Once the project is completed, this site should be closely monitored in order to ensure the designed channel is not dumping too much sediment into Clythe Creek. It should also be noted that Clythe Creek redesign models should be evaluated in order to ensure that it can withstand the additional flows that the new stream will provide.

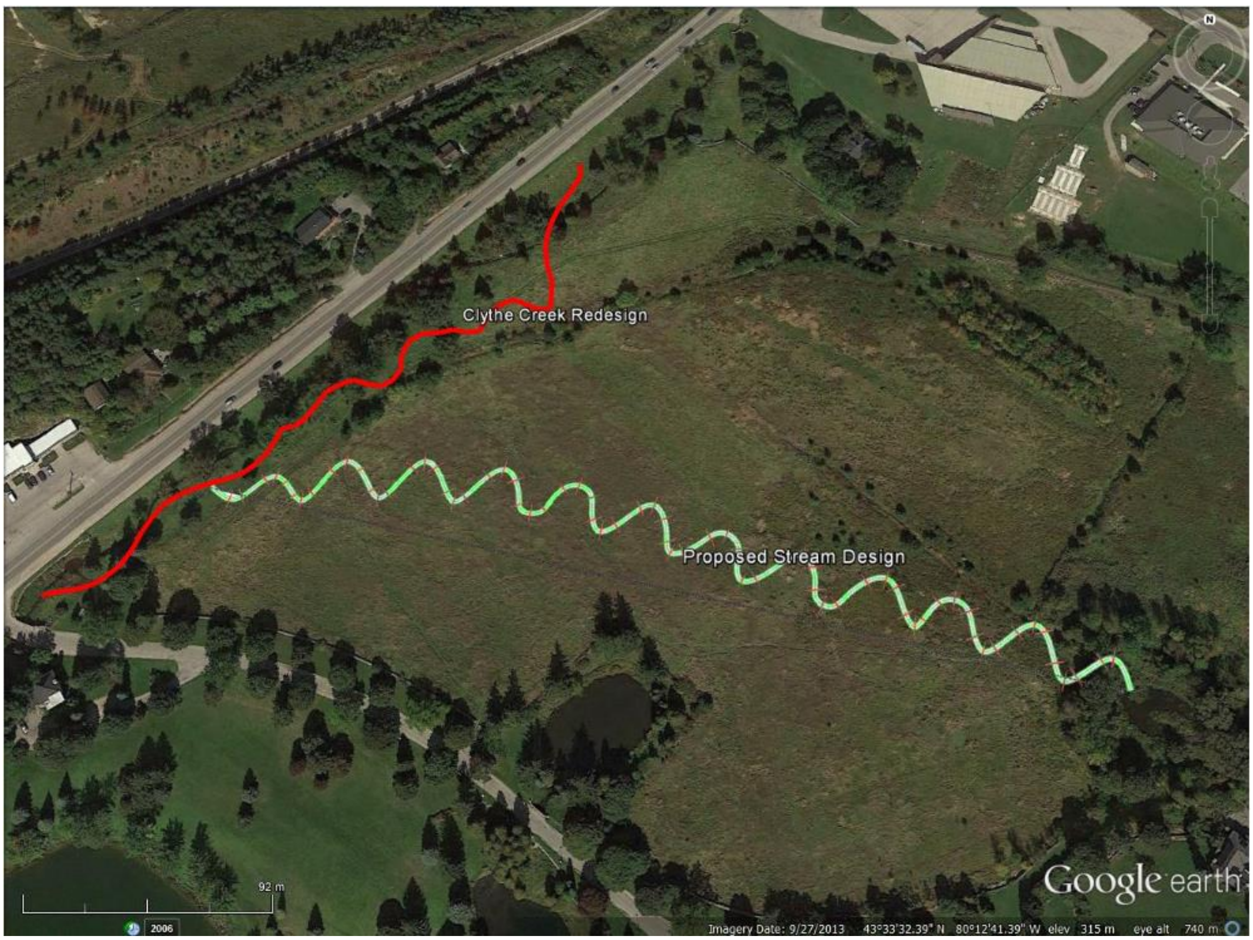


Figure 13: Integration of stream design into Clythe Creek redesign

6.7 Monitoring

Success criteria for the design are outlined, as recommended by TRCA (2009).

- *Constructed riffles*: considered functional if >50% individual riffles are functioning (TRCA, 2009).
- *Bioengineering elements*: successful if >50% bioengineered structures need to be stable; limited evidence of imminent failure exists (TRCA, 2009). For this design, these structures include geotextiles.
- *Habitat structures*: evaluated based on survival and function (TRCA, 2009).

TRCA notes that obstruction to fish passage was a reoccurring issues, indicating vegetation encroachment and riffles disconnecting pools at low flows (2009). For this design, it is recommended that flow monitoring be used to determine the low flows for this reach in order to assess the viability of the design at low flows for fish passage. This design still provides significant opportunity to improve the water quality for the restoration of Brook Trout in Clythe Creek, providing cold water to the stream. In addition, TRCA notes that individual bioengineering element failure should not be interpreted as design failure; it could be a natural adjustment process (2009). Most common failures include: partial riffle structure failure, low survival rates of live staking, excessive bank erosion (> 50% of channel length) and extensive areas of exposed parent material (TRCA, 2009). It is recommended that monitoring be conducted before, immediately after and periodically 5-10 years afterward, conducting periodic evaluation of channel adjustments after large food events should occur (TRCA, 2009).

6.8 Cost Analysis

Cost analysis includes total outright cost, estimates of phasing, and replacement cost.

6.8.1 Total Daylighting Cost

The assumptions for the costing of the design include:

- A ground crew of four workers plus two operators for the equipment
- Each worker and operator is billed at $50/hr
- That the work day is 8 hours in duration
- Work week is 6 days

Table 19 outlines the cost for the construction phases. Mobilization is the cost of getting the necessary equipment to complete the project to the site and to take it away again at the end of the project. The decommissioning of the existing culvert will have to take place as well, as the potential for failure increases the risk to the safety of site visitors and flooding risk. The bulk of the cost is a result of channel routing and landscaping operations. Costs can be reduced by using vegetation on site. To make sure the stream follows the correct grading, a cut and fill operation is required. As this is a site contained operation, cost of this operation is reasonable.

Table 19: Daylighting Costs

Phase		Unit Cost	Units	Total
Mobilization	Float	$150.00	4	$600.00
Removal of Culvert	Labour	$300.00	32	$9,600.00
	Equipment	$6,500.00	1	$6,500.00
Routing of Channel	Labour	$300.00	96	$28,800.00
	Equipment	$6,500.00	2	$13,000.00
	Materials	See Materials Section		$6,410.00
Landscaping/ Vegetation	Labour	$250.00	288	$72,000.00
	Equipment	$2,000.00	6	$12,000.00
	Materials	See Materials Section		$94,620.00
Cut/fill	On-site (per m^3)	$3.00	3488	$10,464.00
Total cost without materials				$152,964.00

Material cost for the project is high but there is opportunity for this price to be cut depending on the site-assessment for vegetation (Table 20). These prices are based recent market costs for these materials and a delivery charge for the materials is included in the totals.

Table 20: Material Cost

Material	Unit Price	Units	Delivery	Total
Trees	$700.00	40	$11,600.00	$39,600.00
Top Soil and Seed	$2.50	6000	$290.00	$15,290.00
Sod/Grass	$4.50	5940	$1,450.00	$28,180.00
Shrubs and shoreline	$12.00	600	$4,350.00	$11,550.00
Geotextiles	$3.00	2040	$290.00	$6,410.00
Total material cost				$101,030.00

Table 21 includes the costing totals for this particular project and is subject to change due to market price fluctuation, inflation, and changing circumstances. For a safety factor in the estimation of the cost, a 15% overhead is included in the total. It will provide funds for incidentals, which is industrial standard in the construction sector.

Table 21: Total Costs

	Totals
Sub Total	$253,994.00
Overhead	$38,099.10
Total	$292,093.10

6.8.2 Order of Phases to Reduce Costs

A more cost effective way to phase in the design would be to do the construction phases in an order that makes the cost more economical. The routing of the channel and planting of vegetation could occur before the removal of the existing culvert, allowing the vegetation time to mature. Once vegetation has matured to a state that will provide the necessary functions, the culvert can be removed and flow diverted to the channel. This would allow the tree cost to be reduced along with the cost of the geotextiles as well. This method would reduce the total cost to $256,201.10, making this a favourable costing option.

6.8.3 Replacing the Culvert

The most economical option is to simply replacing the existing culvert; environmental and aesthetic benefits are not noted. Table 22 shows the per meter cost of the culvert both for the installation and the culvert itself. The total cost for the replacement is $160,756. This cost is assumed to cover all costs associated with the replacement operation.

Table 22: Culvert Costing (Vemax Management, 2009)

Costing rate		
Culvert	$229.65	/m
Installation	$574.13	/m
Total	$160,756.00	

6.8.4 Monitoring Cost

After the completion of the stream, a monitoring plan is important until the channel is established. This is plan is assumed to be completed by someone with appropriate technical experience and would be billed out at rate appropriate to that title. Table 23 includes the monitoring components and their respective costs. The total cost for the monitoring program, as suggested by the TRCA, is $136,960.00. This is based on a 3 year monitoring program for a 100-300m reach; parameters were doubled for this design since the stream is 590m in length. The necessity is recommended to be reassessed at the end of this term (TRCA, 2009). These costs are classified under maintenance, as these costs would be incurred once the project is completed.

Table 23: Monitoring costs after construction (TRCA, 2009)

Monitoring Component	# of Staff	Days	Hourly Rate /person	Hours /day	Cost/day	Total Cost
Fluvial Geomorphology	2	28	80	8	$1,280.00	$35,840.00
Aquatic Habitat	2	20	80	8	$1,280.00	$25,600.00
Fish Community	2	16	80	8	$1,280.00	$20,480.00
Water Quality	2	28	80	8	$1,280.00	$35,840.00
Riparian Conditions	1	16	80	8	$640.00	$10,240.00
Engineered/ Bioengineering Elements	1	5	80	8	$640.00	$3,200.00
Social & Cultural Elements	1	9	80	8	$640.00	$5,760.00
Total	--	122	--	--	--	$136,960.00

6.9 Life Cycle Analysis

Life cycle analysis is the assessment of the environmental impacts of a product throughout its manufacturing and ultimate disposal. Within the scope of this project, the product is defined as the final restoration project. The stream is designed to re-establish natural form and function, resulting in the life of the stream becoming immeasurable once it is established. Therefore, life cycle analysis methods are not appropriate since they rely on a finite life of products. The environmental benefits provided by the restored stream throughout its life would mitigate the effects of the construction and manufacturing processes.

However, some suggested design techniques have a finite lifespan. In the case that geotextiles are used to help with erosion control, Figure 14 shows the carbon dioxide in kilograms for the production and transportation. These are designed to last 36 to 72 months, as they degrade the vegetation is assume to take over the erosion control functions. There is no disposal as these products are biodegradable and any waste will be converted into organic matter as it decomposes. Most of the carbon based emissions come from the manufacturing process. This was calculated using the online Life Cycle Analysis tool (Industrial Design Consultancy, 2014).

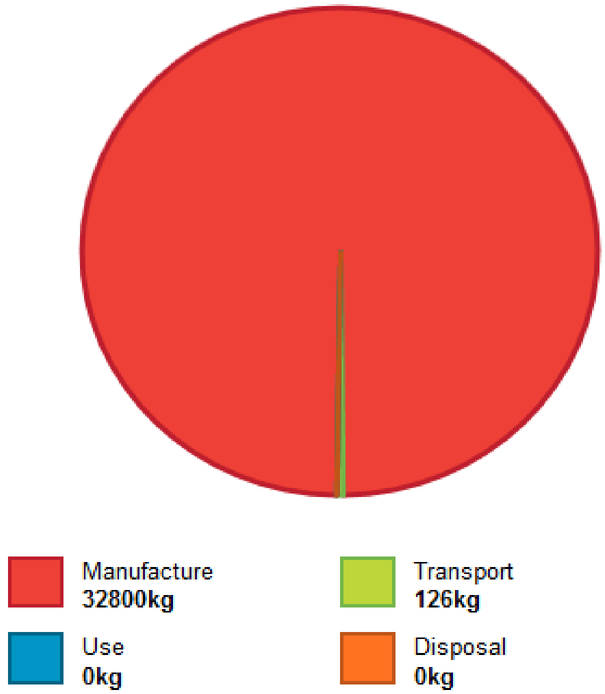


Figure 14: Carbon production for geotextiles

As the other materials for the construction of the site are either contained on site or vegetation, a life cycle analysis methods are not the appropriate to measure the benefits of the materials for this project. Scenarios are important considerations in the discourse of life cycle analysis. In Guelph, the Yorklands Green Hub is located within Innovation District development plans. Although these plans are not implemented, if the city moves forward with plans, it will require increased flood control. This is important as impervious cover increases with development. Increased flood control provides significant design benefits of the design, in particular as the channel becomes more established. Life cycle analysis of natural design interventions should consider scenarios since life lengths are indefinite and a variety of factors affect their benefits and potential for adjustments or disposal.

6.10 Water Quality Analysis

The water quality data in Table 24 was measured at the site on November 6, 2014 at 12pm. Using GRCA guidelines for water quality, the measurements taken were within the requirements for dissolved oxygen, temperature, and turbidity. These measurements were completed to understand the current water quality. The goal of the design is to maintain these water quality parameters. The assumption is that once the stream has established itself, these constraints will be met and the quality of the water will not be degraded.

Table 24: Water quality data, measured November 6, 2014

Parameter	Inlet			Small Outlet			Large Outlet		
DO (mg/L)	8.77	8.77	8.7	9.04	9.03	9.01	8.82	8.95	8.96
Temperature (°C)	8.8	8.8	8.8	8.7	8.8	8.8	9.6	9	8.9
Turbidity (NTU)	1.67	1.71	1.7	1.37	2.03	1.5	1.75	1.73	1.82

The quality between the inlet and the outlet does not vary, the water in the culvert is not currently affected by flowing through the culvert. The expectation is that by daylighting, the quality will be maintained once the channel has established and vegetation has matured, providing necessary shading.

6.11 Design Benefits

Daylighting the buried stream will provide habitat enhancement in the surrounding area and water quality benefits in Clythe Creek. The planting of riparian vegetation creates habitat potential for terrestrial wildlife. The groundwater fed headwater stream contributes cool water to Clythe Creek, a creek with thermal regime issues. The cooling of Clythe Creek attempts to mitigate some thermal regime issues, creating better conditions for cold water species including Brook Trout. Daylighting the buried stream would have the potential to enhance the aquatic habitat in Clythe Creek while providing aesthetic value.

The increased flow path through the meandering stream as well as the developed floodplain contribute to reducing the local runoff velocities and volumes to better manage the effects of urbanization related to flood risks. These benefits have the potential to become more significant with the development of the Guelph Innovation District. The recently approved plans for the Guelph Innovation District, a 1,000 acre site which encompasses Yorklands Green Hub and the buried stream, is expected to bring 7,000 new residents and 9,000 new jobs to the area (City of Guelph, 2014). This daylighting project will restore natural features which has, in past projects, correlated with increased property value in the community (Sinclair, 2012).

7 Detailed Work Plan

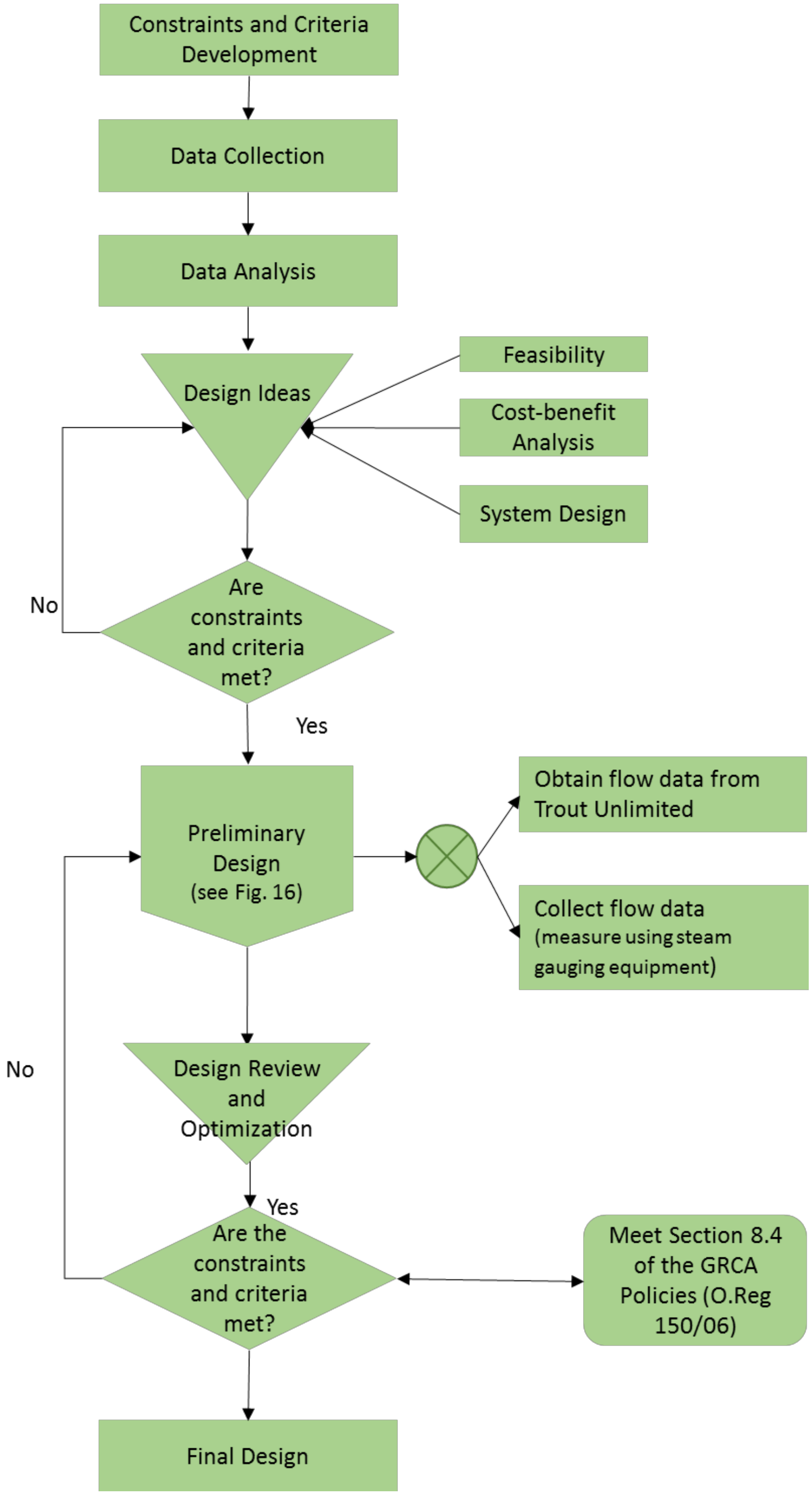


Figure 15: Detailed work plan overview

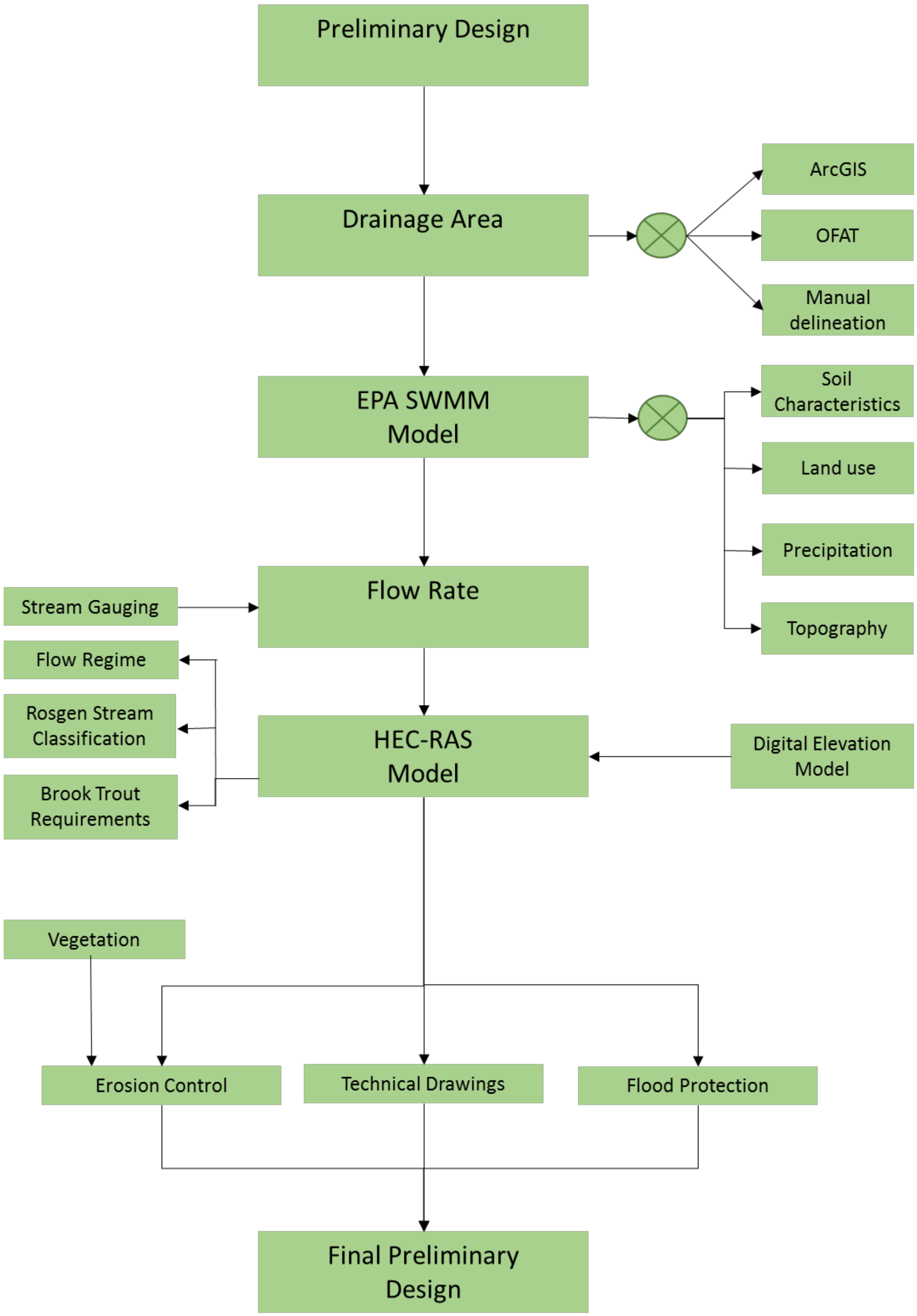


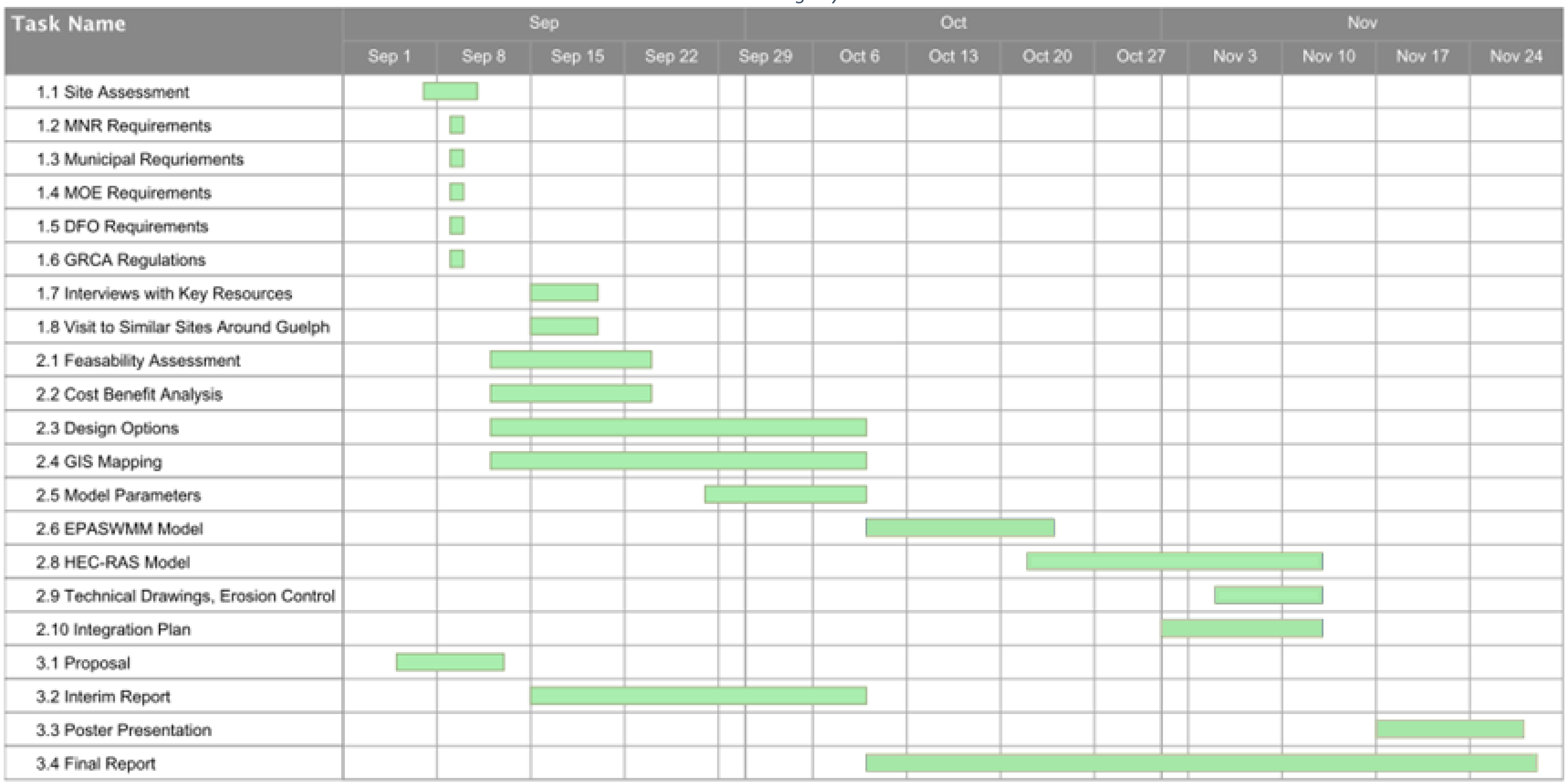
Figure 16: Detailed work plan - preliminary design

Figure 15 and Figure 16 highlight the design process that Cynergy Consulting Inc. implemented. Key decisions and required information are noted.

8 Timelines

Table 25 shows that the project was completed on time.

Table 25: GANTT chart outlining key tasks and deliverables



9 Budget

Table 26: Proposed Budget

Task Description	Nickerson, E	Jewson, G	Campbell, D	Reid, D	Total Hours	Total Cost	Due Date
Billable Rate	$80/hr	$80/hr	$80/hr	$80/hr			
1 - Research and Data Collection							
Site Assessment	3	2	2	2	9	$720	09-Sep-14
MNR Requirements	0	2	0	2	4	$320	09-Sep-14
Municipal Requirements	2	0	2	0	4	$320	09-Sep-14
MOE Requirements	1	1	0	0	2	$160	09-Sep-14
DFO Requirements	1	0	3	1	5	$400	09-Sep-14
GRCA Policies and Regulations	0	2	0	2	4	$320	09-Sep-14
Interviews with Key Resources	6	6	6	6	24	$1920	15-Sept-14 to 19-Sept-14
Reference Site Visits	4	4	4	4	16	$1280	15-Sept-14 to 19-Sept-15
2 - Data Analysis and Engineering Design							
Feasibility Assessment	6	8	6	4	24	$1920	24-Sep-14
Cost-Benefit Analysis	5	2	4	4	15	$1200	24-Sep-14
System Design	4	10	10	12	36	$2880	07-Nov-14
Integration Recommendations	6	3	1	2	12	$960	12-Nov-14
3 - Deliverables							
Proposal	30	30	30	30	120	$9600	12-Sep-14
Interim Report	40	40	40	40	160	$12800	06-Oct-14
Poster Presentation	10	10	10	10	40	$3200	27-Nov-14
Final Report	40	40	40	40	160	$12800	01-Dec-14
4 - Weekly Meetings and Project Management							
Initial Project Evaluation	5	5	5	5	20	$1600	07-Sep-14
Team Meeting	60	60	60	60	240	$19200	Weekly
Meeting With Advisor	12	12	12	12	48	$3840	Weekly
Check-In meeting with Client	6	6	6	6	24	$1920	Biweekly
Total Labour Hours	241	243	241	242	967		
Total Cost Estimate	$19280	$19440	$19280	$19360	$77360	$77360	

10 Risks and Uncertainties

There are numerous risks and uncertainties related the project design. It is uncertain whether Brook Trout will populate this daylighted stream once the design in implemented. The segment is a tributary to Clythe Creek, a creek which currently has blockages to fish passage (O'Flanagan, 2014). If Brook Trout do not return, this stream would still provide important habitat for aquatic species. Monitoring will be required to assess how this design is performing from an ecological, hydrological and geomorphic perspective. Secondly, it is speculated base on ArcGIS modelling that the receiving pond of the design segment is a gaining pond. This indicates that the removal of the stream flow should not affect water levels in the downstream ponds. However, due to the scale of the DEM files, it is unsure how the water table varies locally and temporally with precision. Also, Trout Unlimited believes that there is potential soil contamination on site. The extent and spatial distribution of contamination is unknown and relevant government documents is not being released. The design considers that there is no site contamination, proper controls would need to be implemented if this is the case. Daylighting should be re-evaluated if serious contamination is noted throughout the site. Another uncertainty is that there was no flow data available for the stream. The stream was then designed using flow rates determined using EPA SWMM and design storms for the city of Guelph. Finally, in order to model the stream using HEC-RAS the current elevations of the site were required. Due to time constraints for this project the elevations for the site were found using ArcGIS instead of surveying the site.

11 Recommendations

It is recommended that a geotechnical investigation be performed on the site. A geotechnical investigation would determine if there is any contamination on the site and if the daylighting project should move forward. A geotechnical investigation would also be useful in order to ensure the correct soil types were used in determining the flow rates for the stream. It is also recommended that the flow rates of the stream be measured for at least one year. In order to get proper flow rates for the stream a data logger should be used in order to measure continuous flows of the stream. The channel would then be designed based on actual flow rates instead of flows determined from modeling. The flow rates at the inlet and outlet of the north pond should also be measured. In order to confirm that the pond is gaining water, the flow exiting the pond should be greater than the flow entering it. Finally it recommended that that the site be surveyed in order to ensure that the proper elevations were used while designing the new channel.

12 Summary

The main goal of this project was for Cynergy Consulting Inc. to develop a natural channel design that would enhance the habitat of Clythe Creek and restore Brook Trout to Clythe Creek. The design team reviewed possible solutions from a variety of sources to determine the current design limitations and opportunities. The design is tailored towards the specified site in determining the best practice for the area. Four possible design options were evaluated with best option being to reroute the creek directly to Clythe Creek. This allowed Clythe Creek to receive the benefits of the cold headwaters as well as the possibility for Brook Trout to return to the creek.

The Cynergy Consulting Inc. team used current data and state-of-the-art solutions to create a suitable natural channel design solution for the client. Above all, the Cynergy Consulting Inc. design team kept the client’s needs in firm focus when determining the best solutions to stream daylighting.

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14 Appendices

14.1 Appendix A: Relevant Images

Figure 17: Degradation of Inlet of Culvert from site visit on October 30, 2014

Figure 18: Culvert Outlet from site visit on September 9, 2014

Figure 19: Culvert Interior from site visit on October 30, 2014(view inlet to outlet)

14.2 Appendix B: Historical Photos

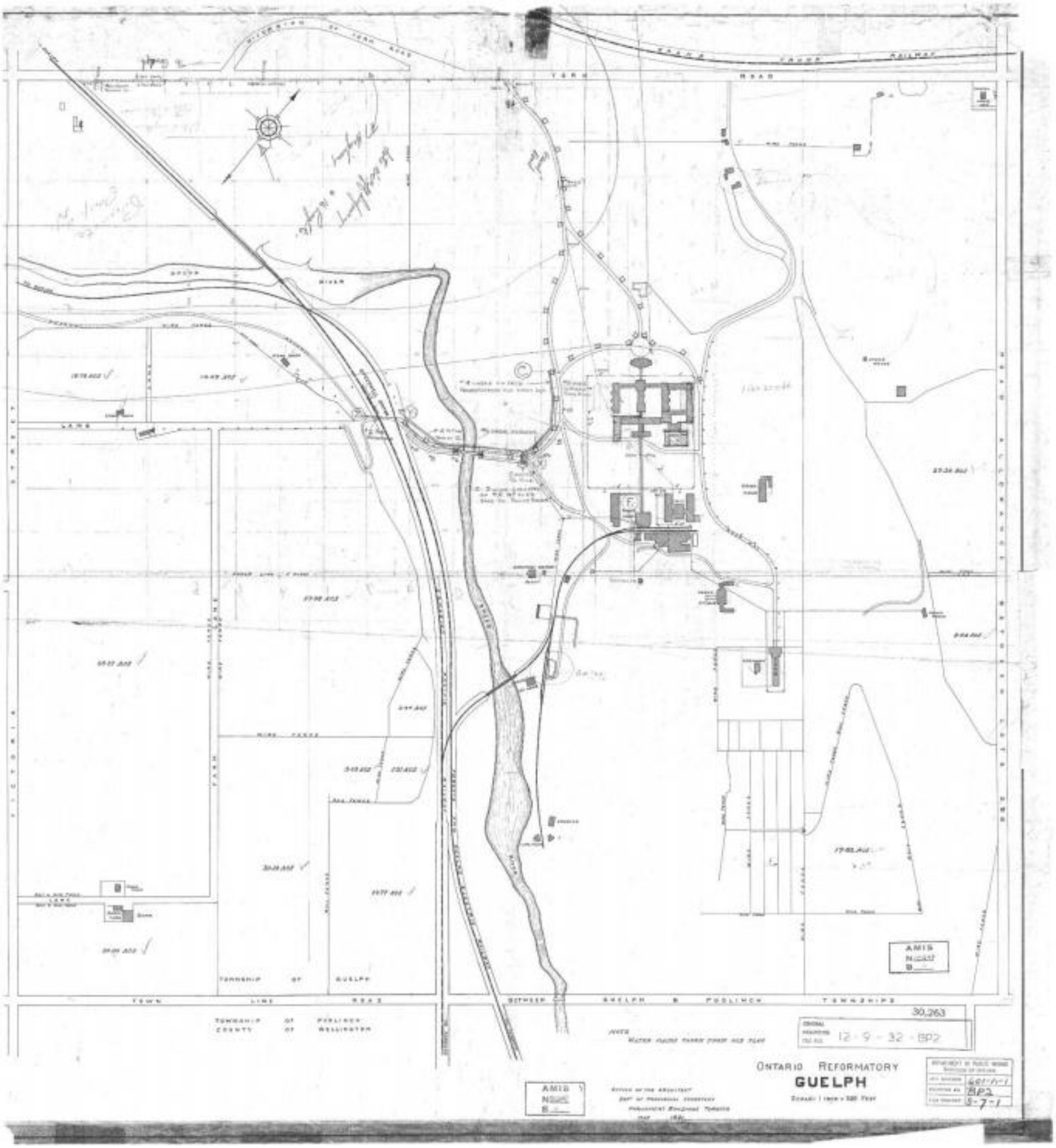

Figure 20: Guelph Reformatory Site Plan (1921)

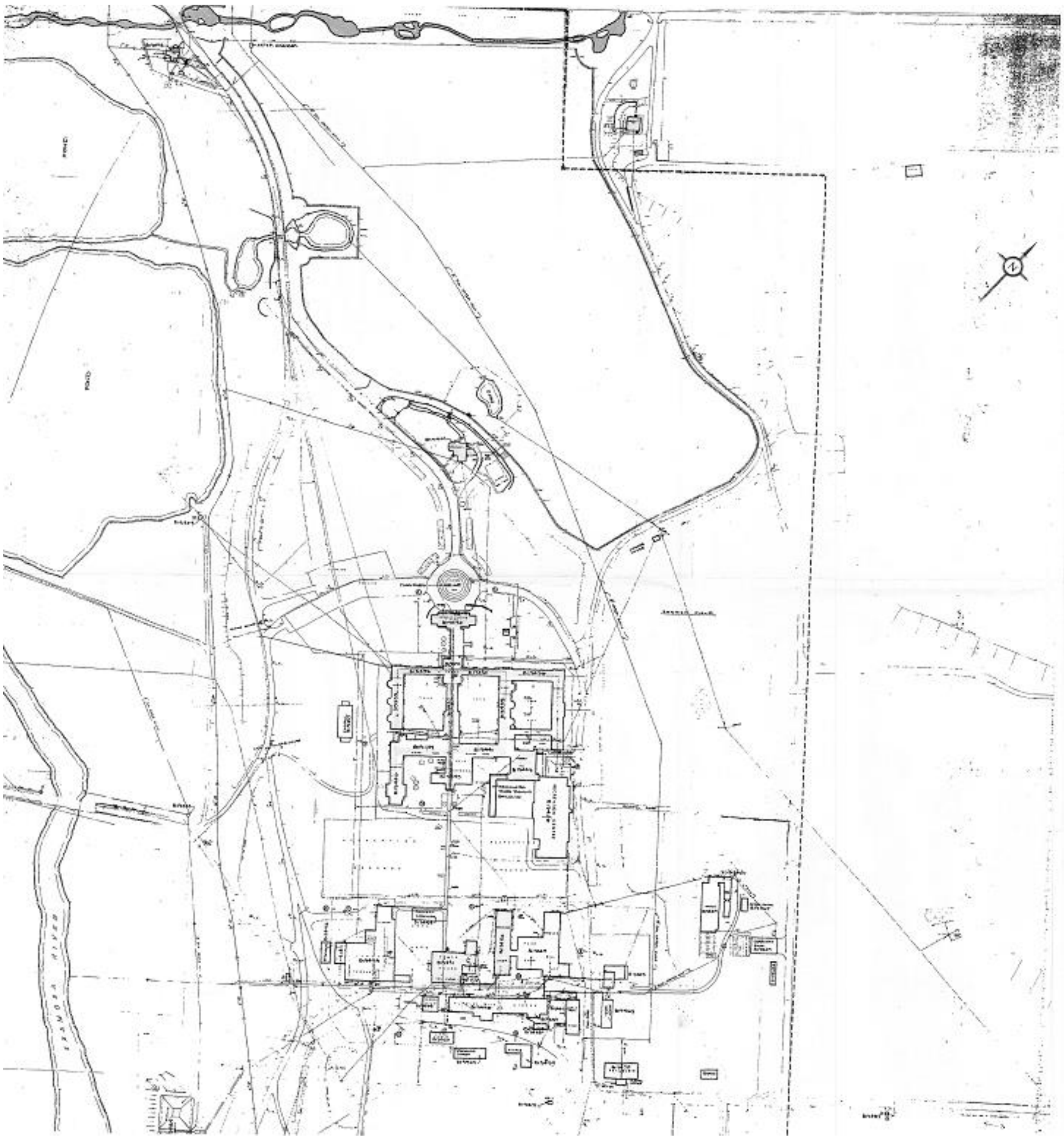

Figure 21: Guelph Reformatory Site Plan (n.d.)

14.3 Appendix C: Meeting with City of Guelph Planning Department Minutes

Meeting with City of Guelph Planning Department

October 2 2014 3:30 PM

Present: Doug Campbell, Stephen Robinson, April Nix

- Majority of features presently have heritage value
- North and South ponds are largest open water features within the City's boundaries – giving it natural heritage value.
- Clythe Creek currently has warming problems
    - Most likely due to York road and factors upstream
    - How wide the meander pattern and stream morphology a big consideration
    - Natural vegetation very important for heating
    - Stream topography challenges grading issues due to the work the laborers did
    - "Puddle" or wetland area draining to creek on east side of site could be utilized
- Since Clythe Creek has been altered so much it will be challenging to find a natural reference point for reintroduction if we want to reconnect directly to the creek
    - Best idea is to check out similar stream/subwatersheds/ tributaries
- Fill from ponds likely added to hypothetically wetland area near daylighting site to remove the wetland
    - Study area likely was part of the PSW before land transformations
    - Don't want to negatively affect the wetland due to the water balance
- Small pond may be currently fish habitat

Natural heritage

- City's Appendicles/ Natural Heritage Site can further isolate locally/ county wide significant biodiversity
- Design Storm
    - Use 25yr ideally
    - Use rainfall information from Arboretum
- For any on site testing permission from Infrastructure Ontario will be required

14.4 Appendix D: Site Characteristics

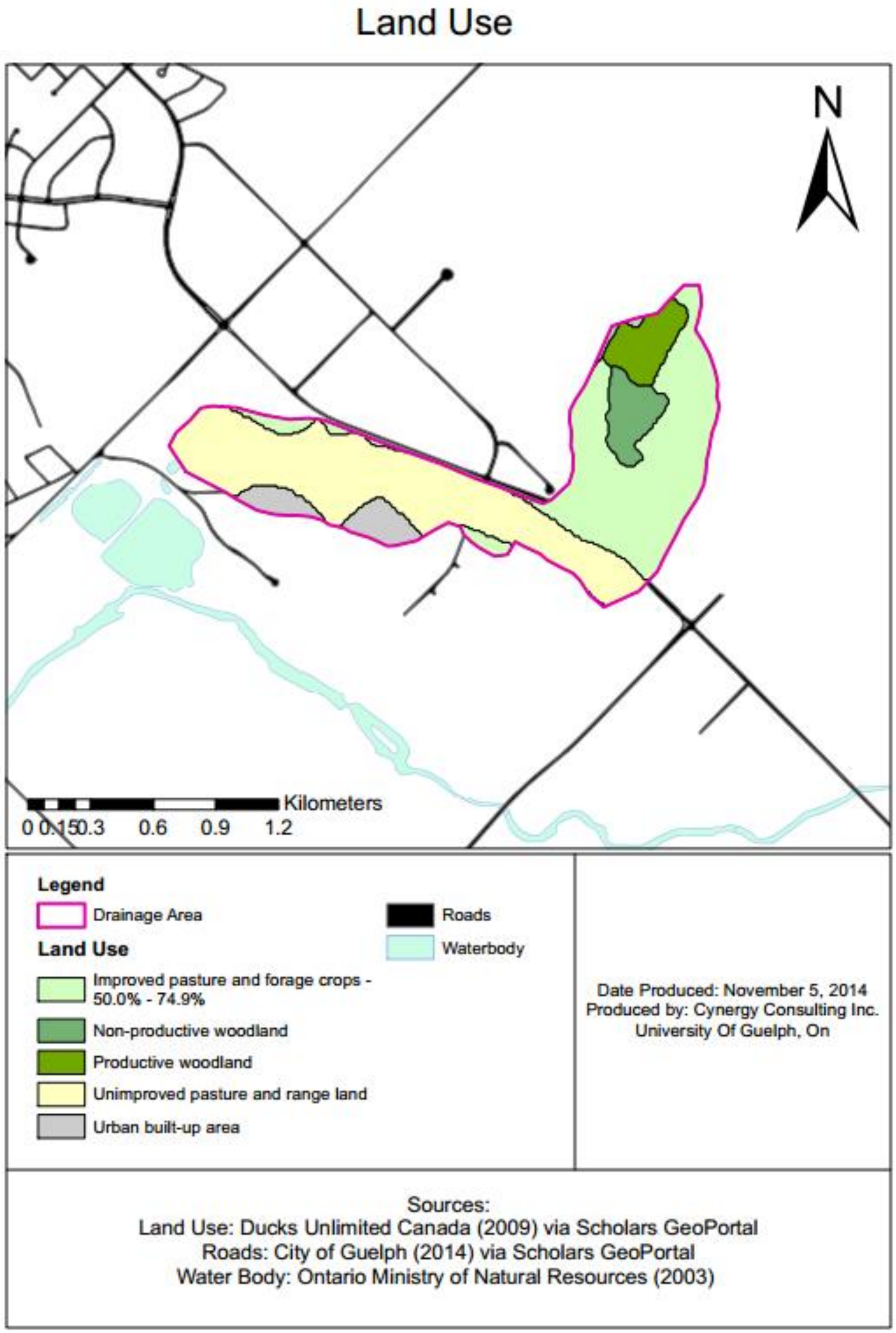

Figure 22: Land Use

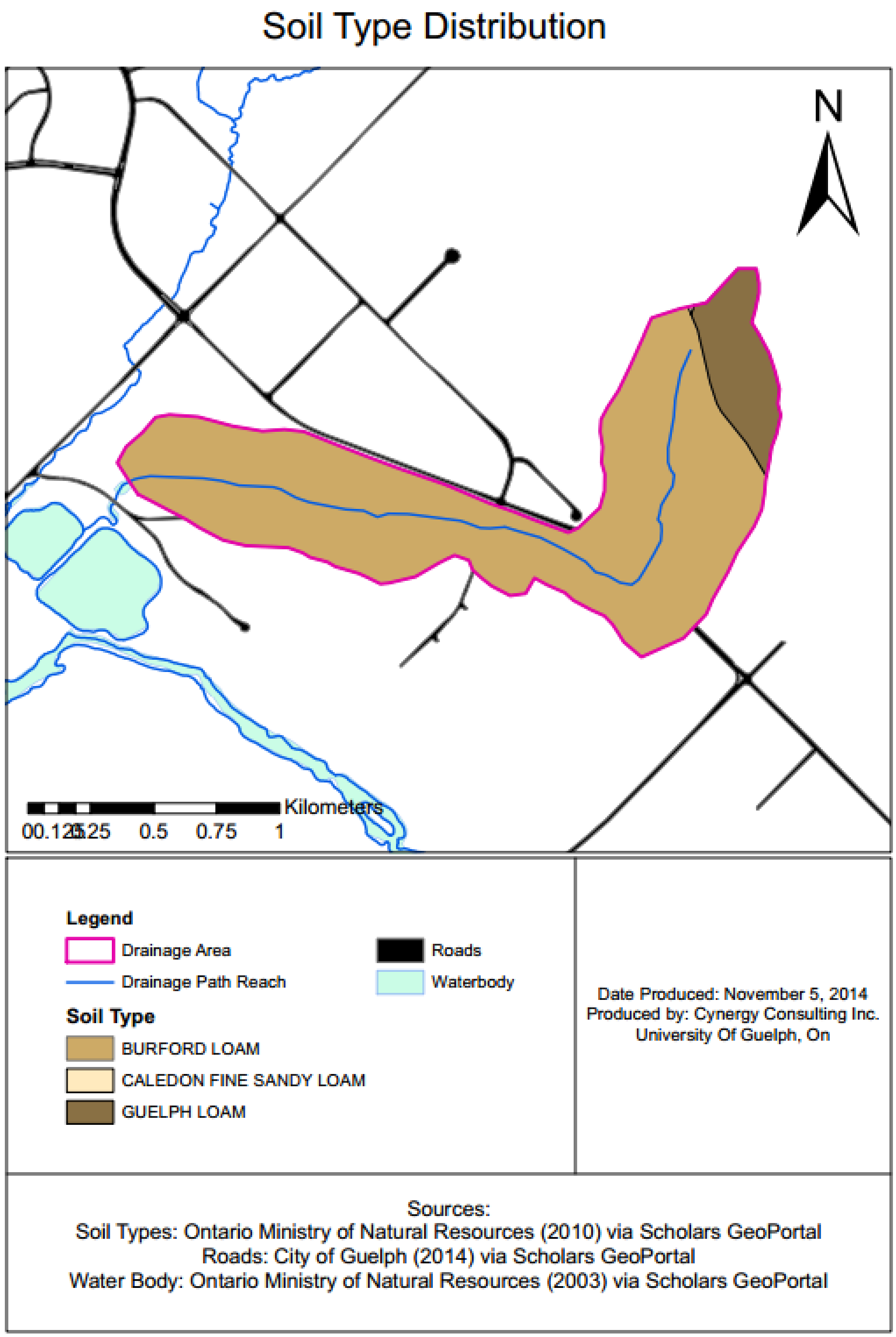

Figure 23: Soil Type Distribution

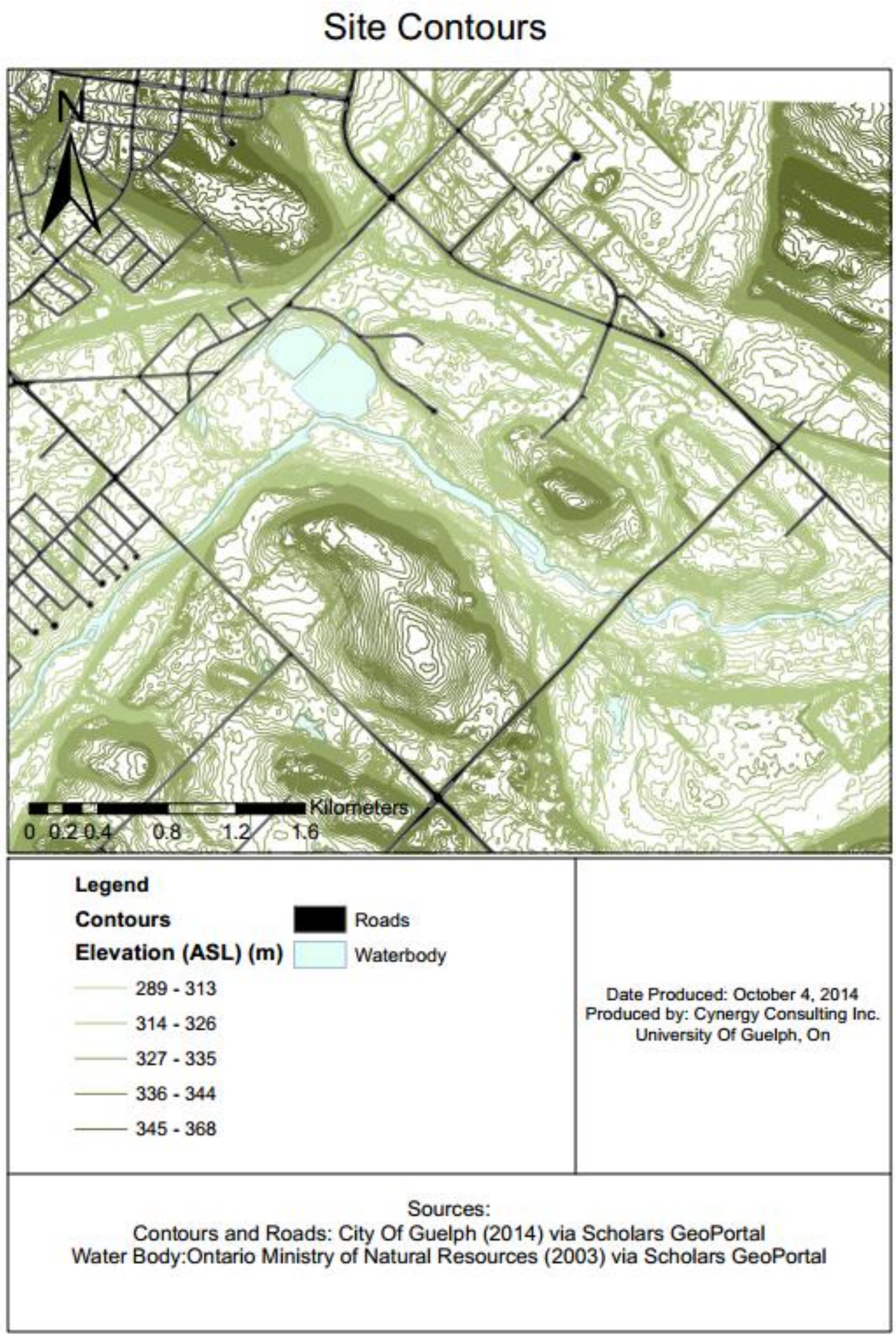

Figure 24: Site Contours

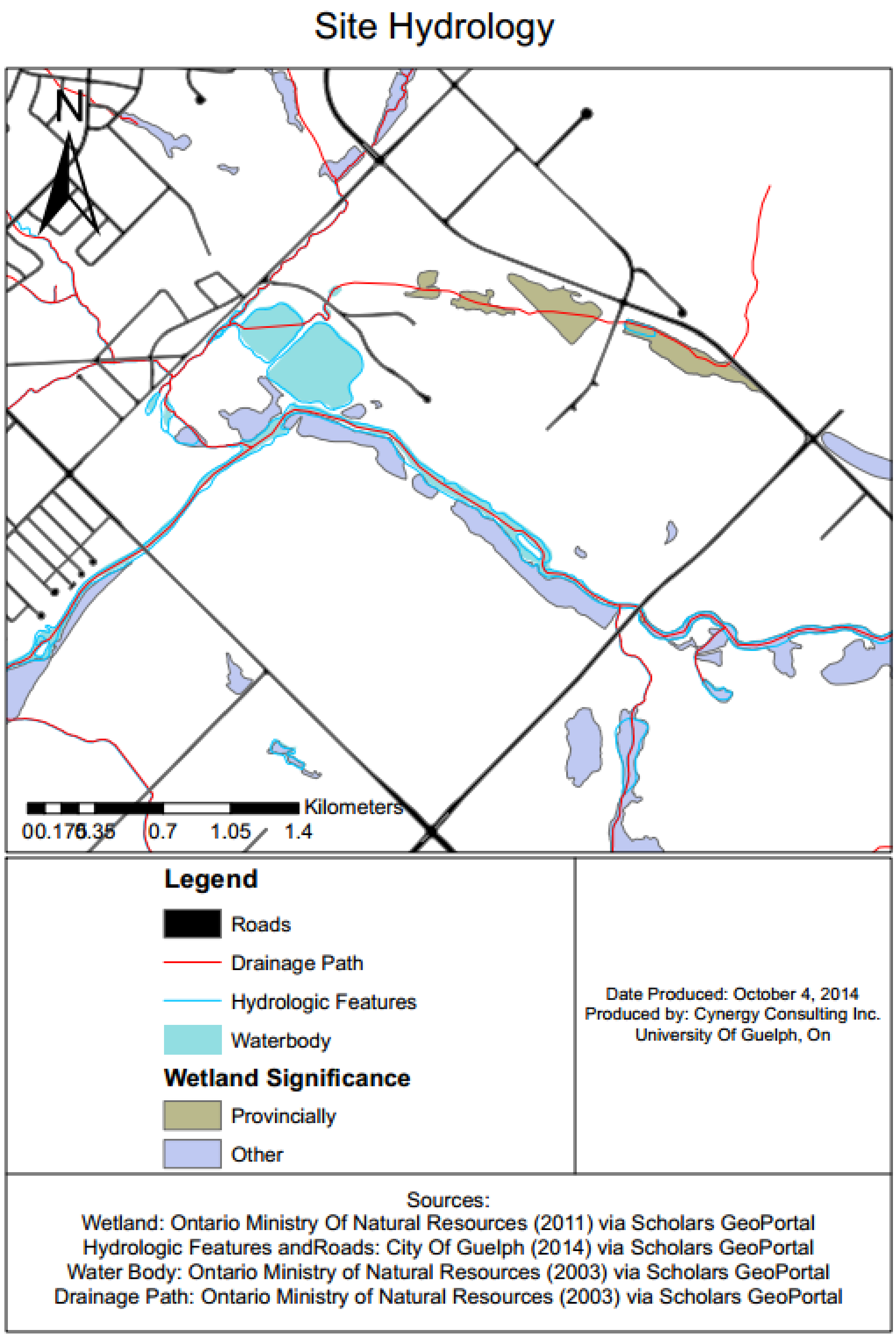

Figure 25: Site Hydrology

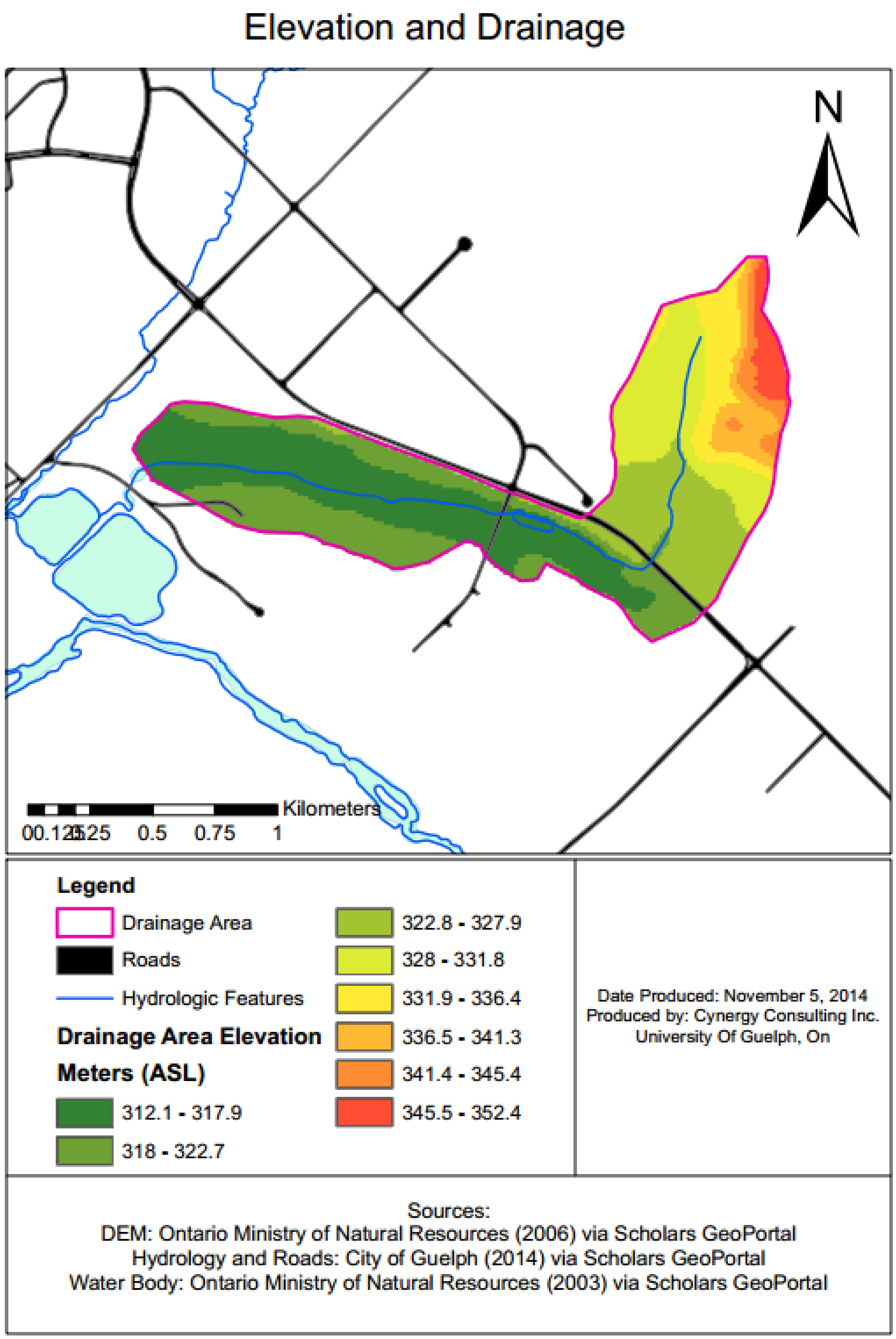

Figure 26: Elevation and Drainage

Water Table and Contours

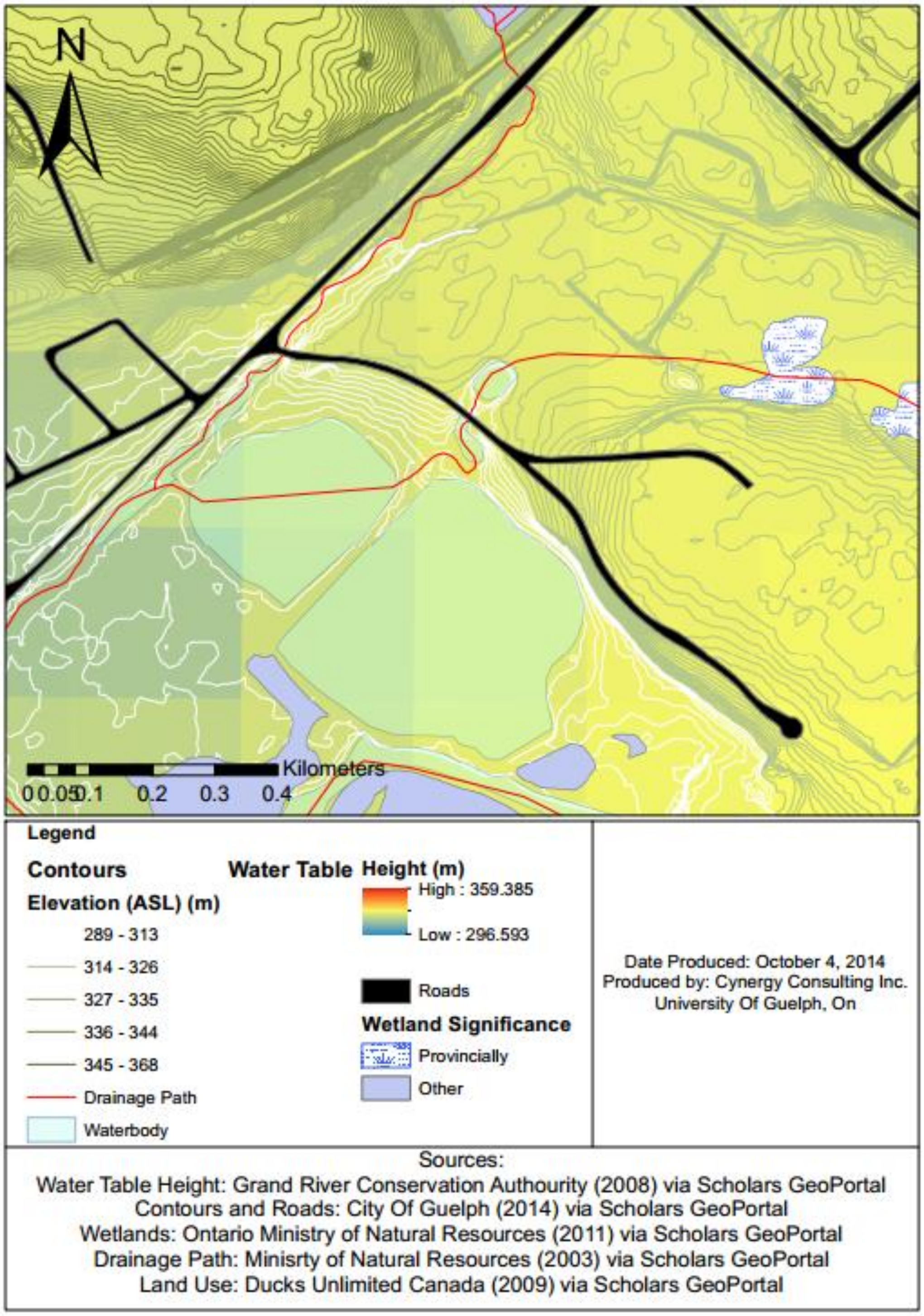

Figure 27: Water Table and Contours

14.5 Appendix E: Site Parameters

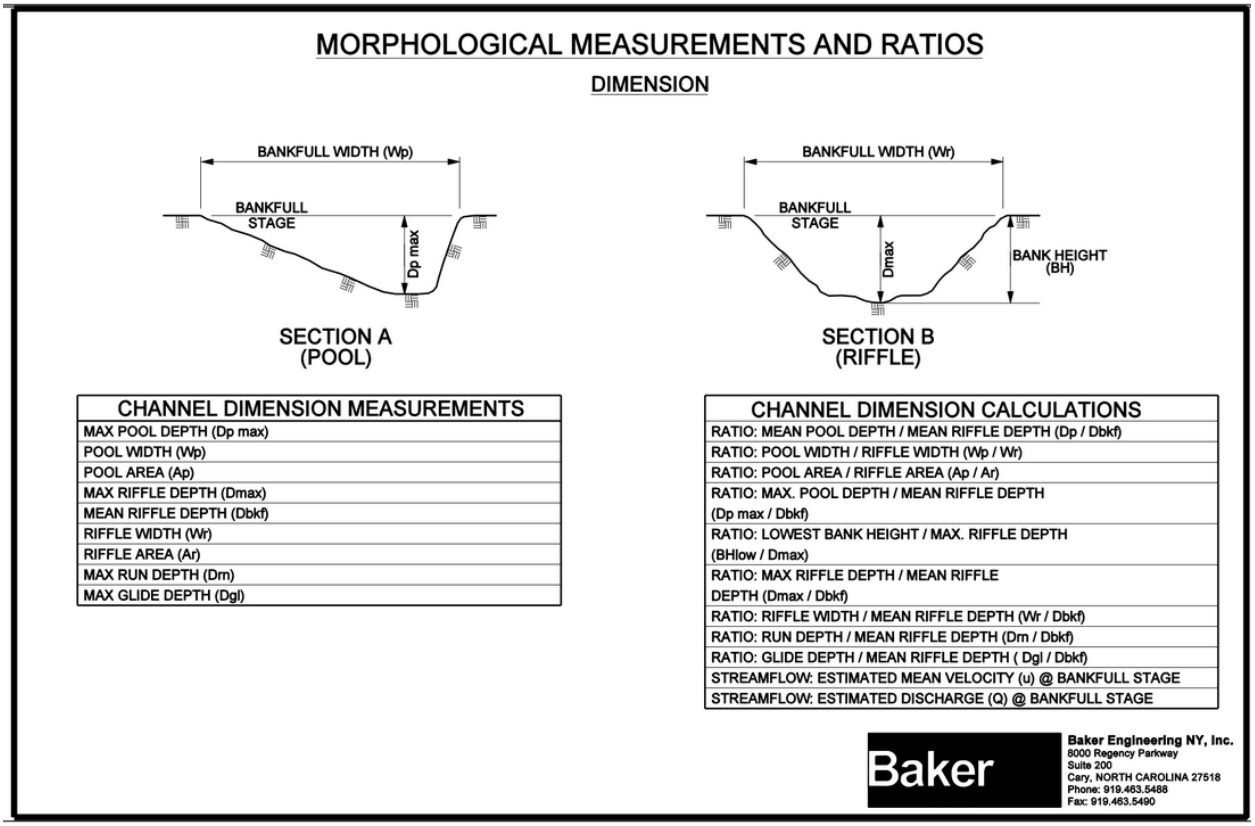

Figure 28: Channel Dimensions (Harmen and Starr, 2008)

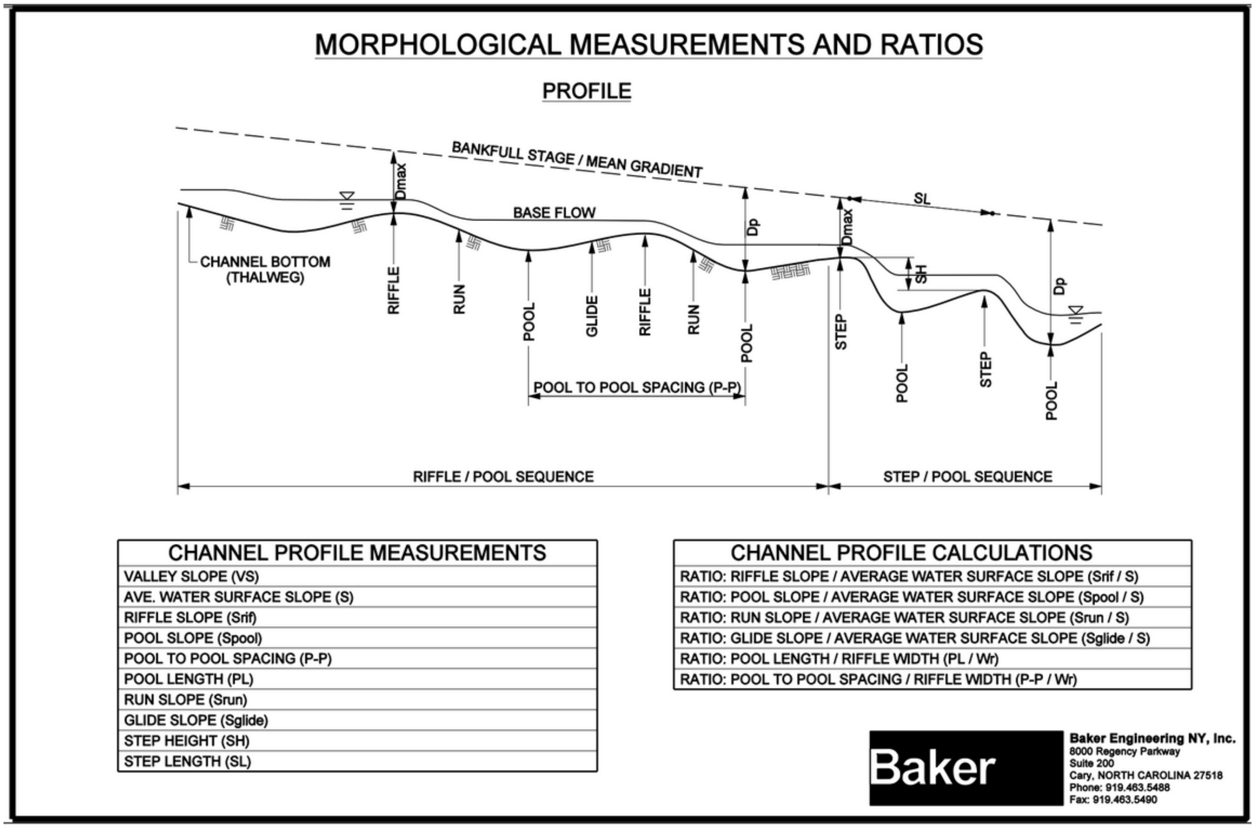

Figure 29: Channel Profile Measurements (Harmen and Starr, 2008)

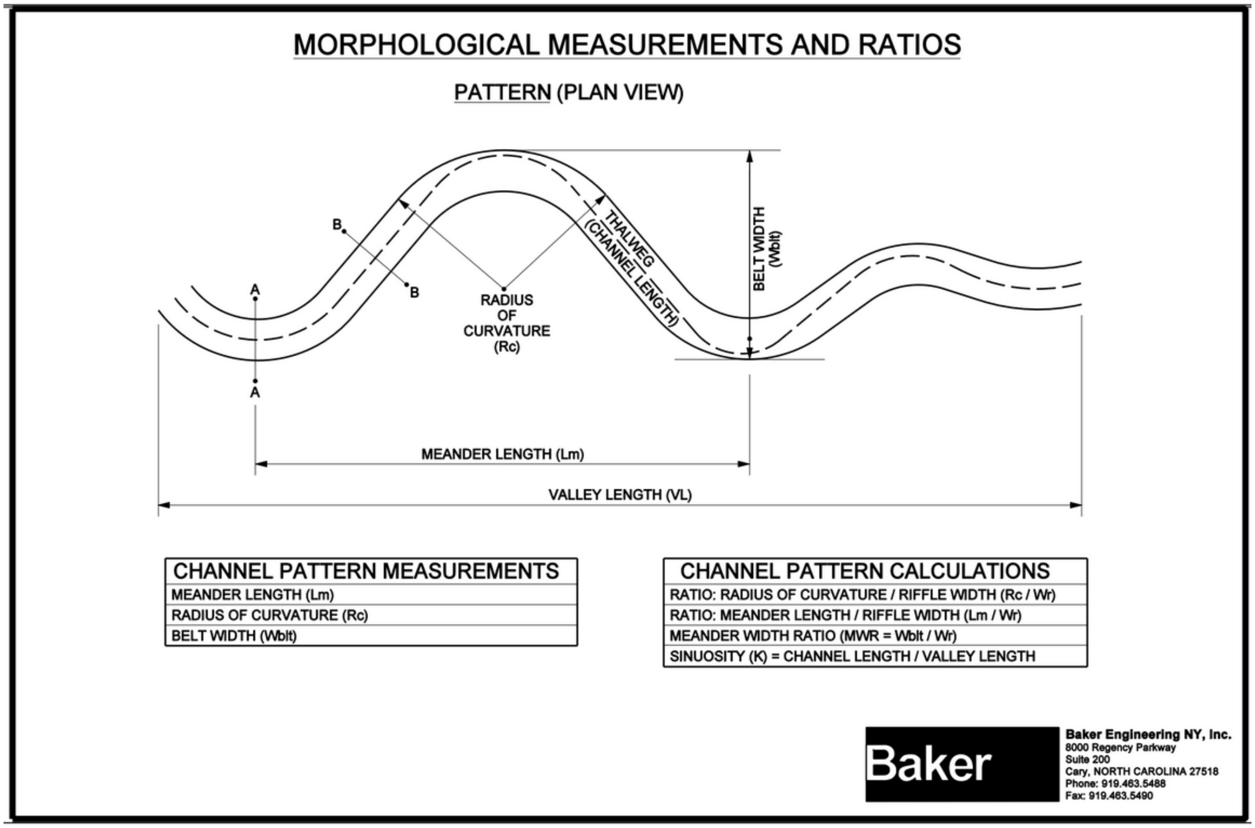

Figure 30: Morphological measurement and ratios (Harmen and Starr, 2008)

14.6 Appendix F: Design Options

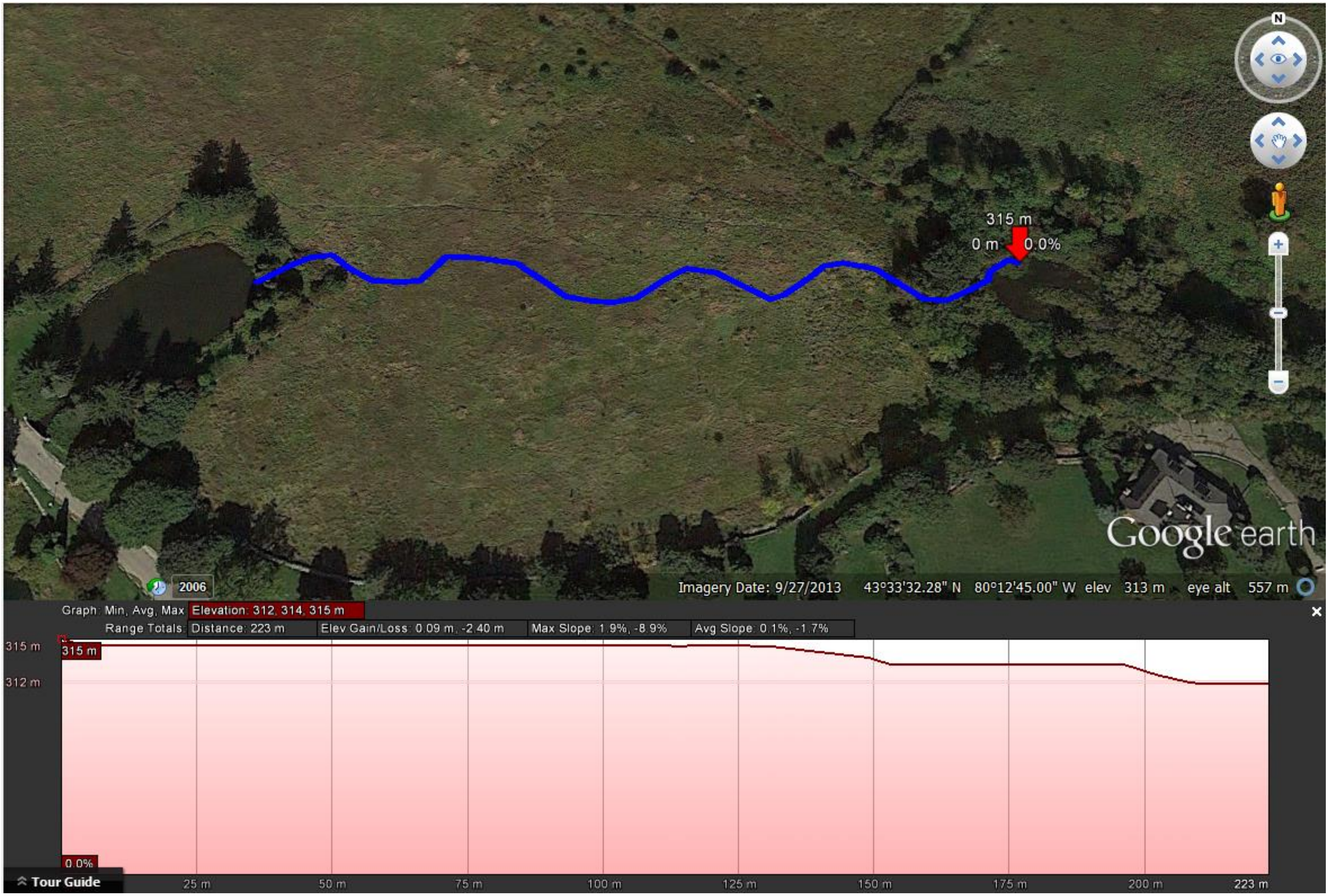

Figure 31: Option 2.1 and Elevation Profile

Figure 32: Option 2.2 Elevation Profile

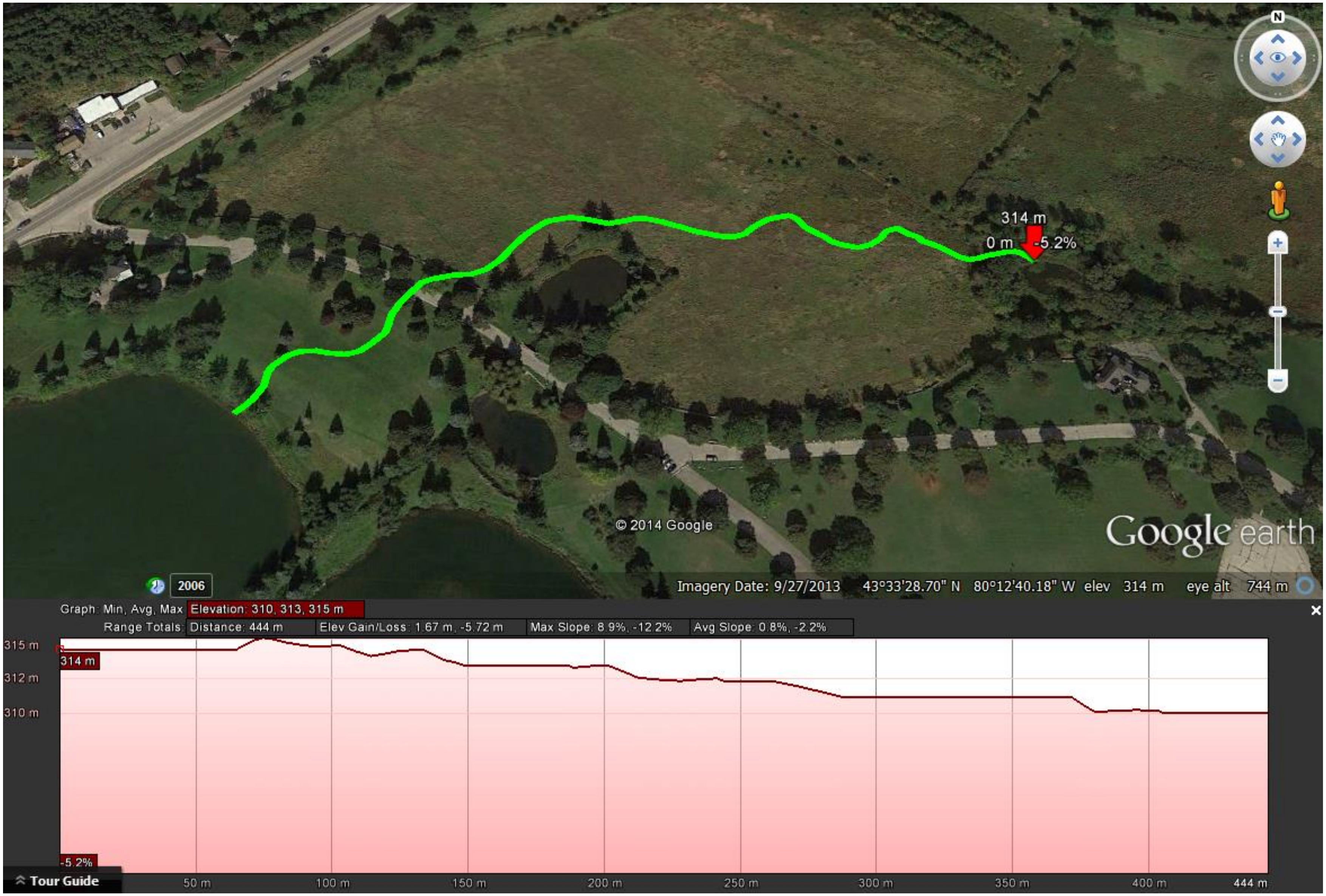

Figure 33: Option 2.3 Elevation Profile

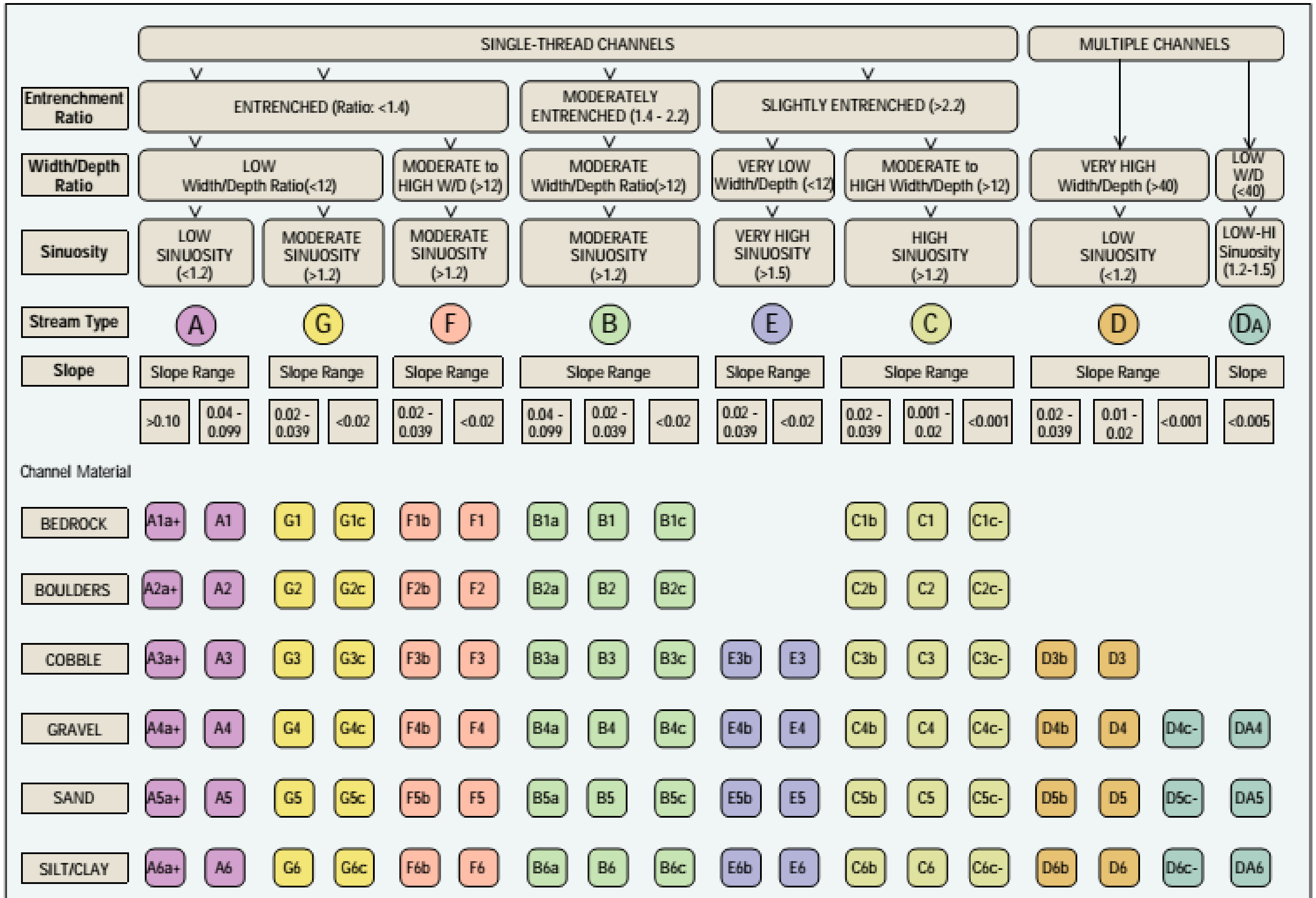

Figure 3. Key to the Rosgen Classification of Natural Rivers. As a function of the "continuum of physical variables" within stream reaches, values of *entrenchment* and *sinuosity* ratios can vary by +/– 0.2 units; while values for width/depth ratios can vary by +/– 2.0 units.

Figure 34: Rosgen Stream Classification

14.8 Appendix H: City of Guelph IDF Curves

The following IDF curves were developed using the "City of Guelph - Frequency Analysis of Maximum Rainfall and IDF Curve Update".

Table 27: City of Guelph Data for IDF Curve Development

Return Period	1	2	5	10	25	50	100
a	316.91	509.17	835.7	1129.9	1710.72	2499.69	3811.79
b	6.18	2.15	3.84	5.61	9.09	13.33	19.09
c	0.756	0.764	0.799	0.818	0.851	0.883	0.925

$i=a/(td+b)^c$

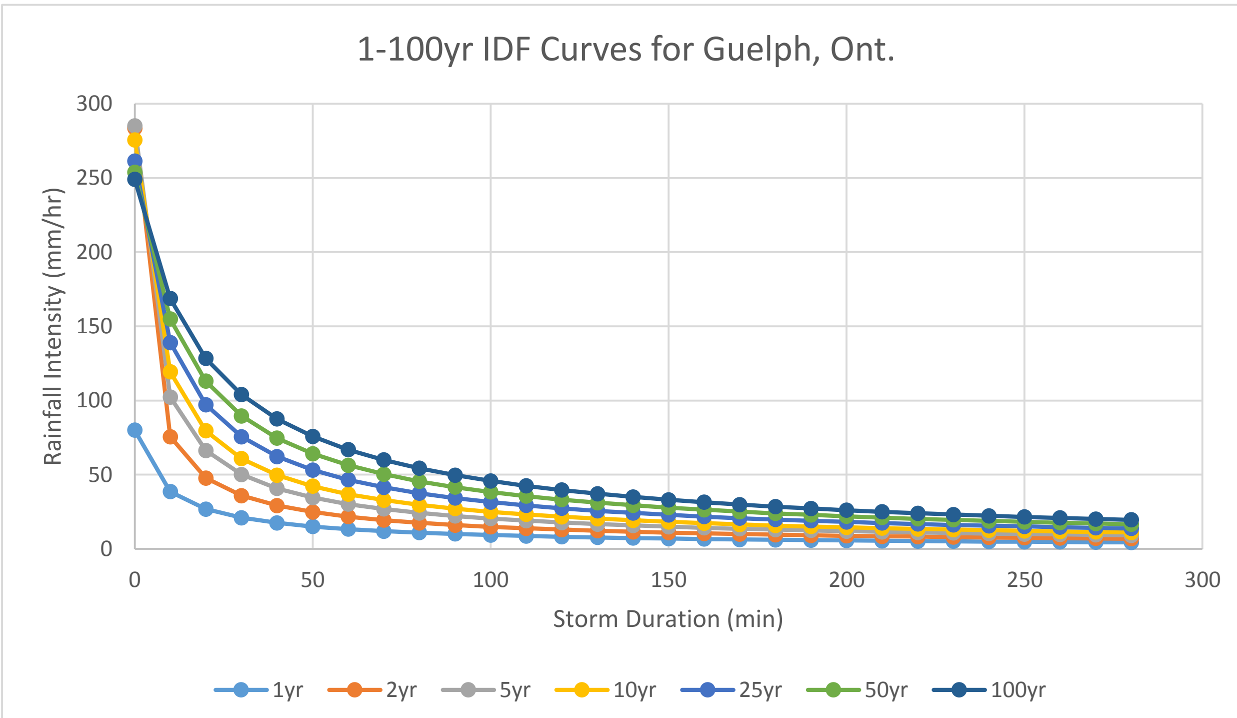

Figure 35: Design Storms - Developed using City of Guelph IDF Curve Data

14.9 Appendix I: Stream Gauging Data (October 30, 2014)

14.9.1 Stream Gauging Raw Data

Table 28: Stream gauging raw data

Source	Distance (m)	Section Length (m)	Depth (cm)	Depth (m)	Velocity (m/s)	Discharge (m3/s)
Small Outlet (1.55m)	0	0.25	5	0.05	0	0
	0.25	0.25	7.3	0.073	0.06	0.001095
	0.5	0.25	2.6	0.026	0	0
	1	0.5	6.5	0.065	0.38	0.01235
	1.5	0.5	2.3	0.023	0	0
	1.55	0.05	0	0	0	0
Large Outlet (1.35m)	-0.0001	-	0	0	-	-
	0	0.1	26.6	0.266	0	0.002016
	0.1	0.1	28.8	0.288	0.07	0.000268
	0.2	0.1	26.8	0.268	0.01	0.000285
	0.3	0.1	28.5	0.285	0.01	0.003516
	0.4	0.1	29.3	0.293	0.12	0.00812
	0.5	0.1	29	0.29	0.28	0.004505
	0.6	0.1	26.5	0.265	0.17	0.00243
	0.7	0.1	27	0.27	0.09	0.00182
	0.8	0.1	26	0.26	0.07	0.00225
	0.9	0.1	25	0.25	0.09	0
	1	0.1	22	0.22	0	0.0023
	1.1	0.1	23	0.23	0.1	0.00345
	1.2	0.1	23	0.23	0.15	0.00391
	1.3	0.1	23	0.23	0.17	0
	1.35	0.05	23	0.23	0	0.000176
	1.35001	-	0	0	-	-
Inlet (1.1m)	-0.0001	-	0	0	-	-
	0	0.1	17.6	0.176	0.01	0.0014
	0.1	0.1	17.5	0.175	0.08	0.0024
	0.2	0.1	15	0.15	0.16	0.00279
	0.3	0.1	15.5	0.155	0.18	0.0027
	0.4	0.1	15	0.15	0.18	0.00484
	0.5	0.1	22	0.22	0.22	0.0036
	0.6	0.1	20	0.2	0.18	0.00258
	0.7	0.1	21.5	0.215	0.12	0.00301
	0.8	0.1	21.5	0.215	0.14	0.00084
	0.9	0.1	14	0.14	0.06	0
	1	0.1	19.5	0.195	0	0
	1.1	0.1	20	0.2	0	0
	1.1001	-	0	0	-	-

14.9.2 Current Channel Profiles

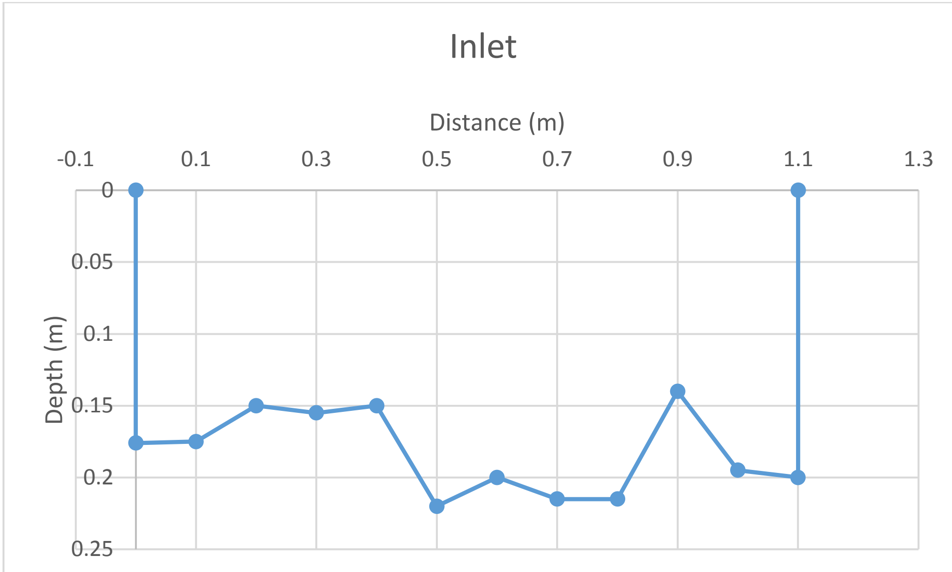

Figure 36: Culvert Inlet Profile

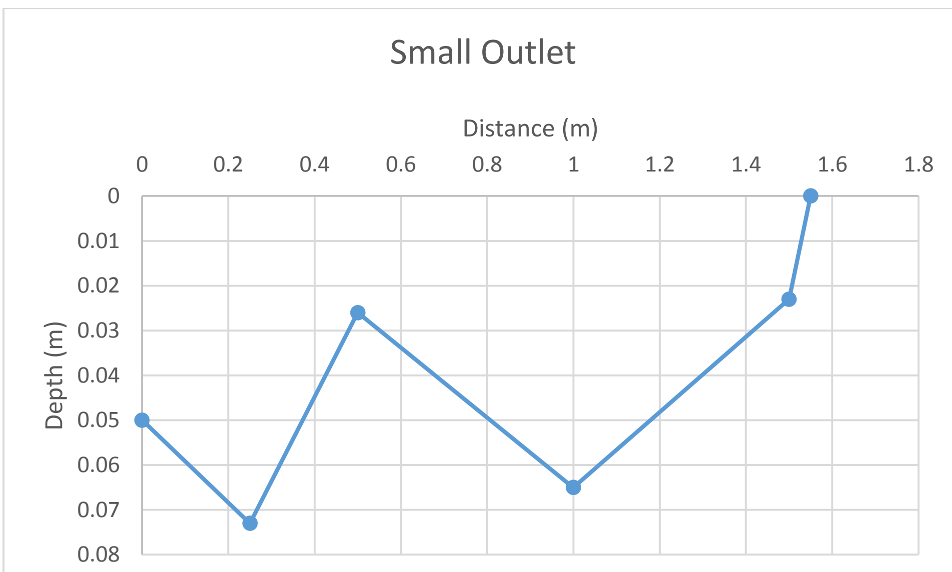

Figure 37: Small Culvert Outlet Profile

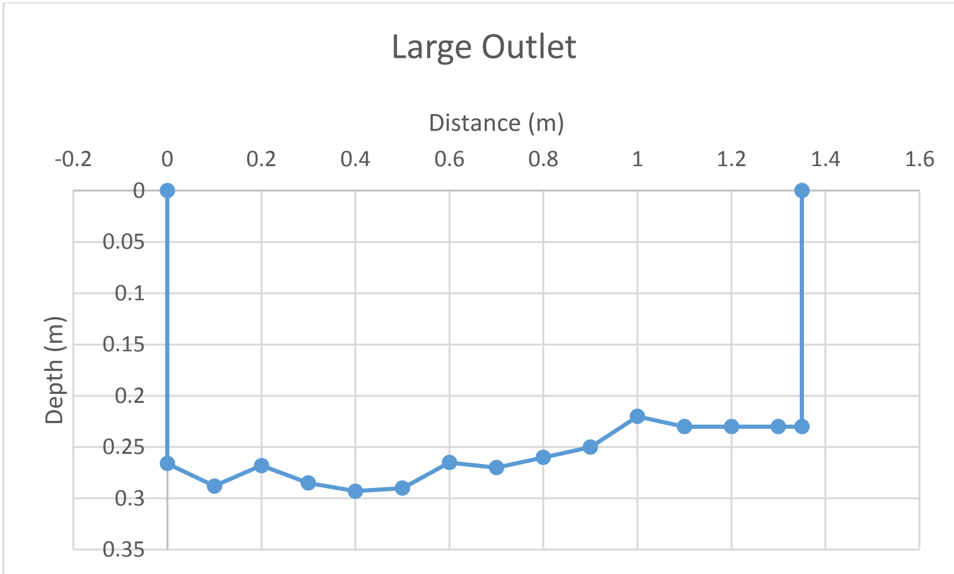

Figure 38: Large Culvert Outlet Profile

14.9 Appendix I: EPA SWMM Model

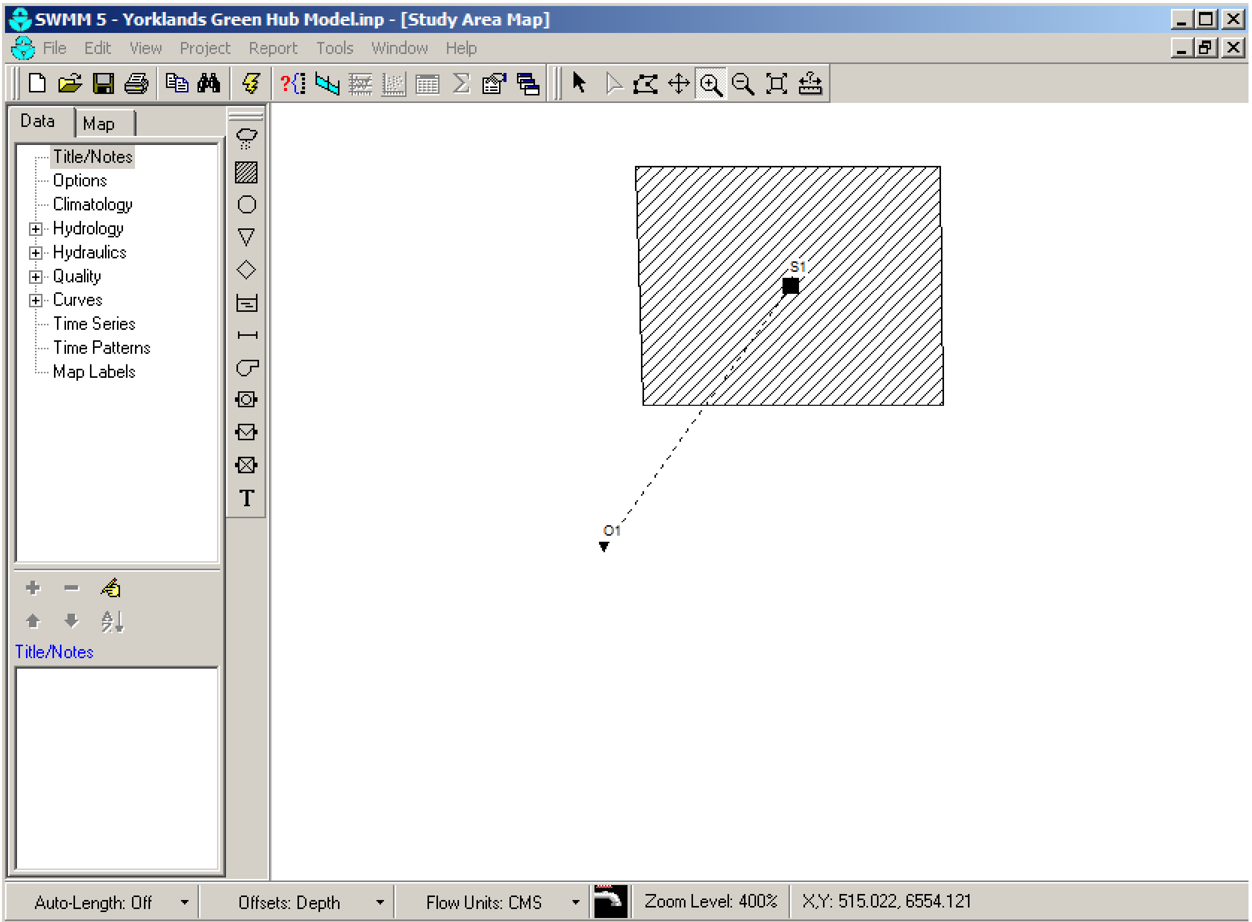

Figure 39: EPA SWMM Model

14.10 Appendix J: Geometry Calculations

Empirical formulas for meander relationships from *Morphological Relationships of Rural water Courses in Southern Ontario and Selected Field Methods in Fluvial Geomorphology* (1996).

Meander Wavelength for Type E Stream:

λ = wavelength
W_b = Width of bank

$$\lambda = 21.66{W_b}^{0.63}$$

$$\lambda = 21.66 * 2^{0.63} = 34m$$

Radius of Curve for Type E Stream:

r_c = radius of curve
W_b = Width of bank

$$r_c = 5.26{W_b}^{0.62}$$

$$r_c = 5.26 * 2^{0.62} \approx 8.5m$$

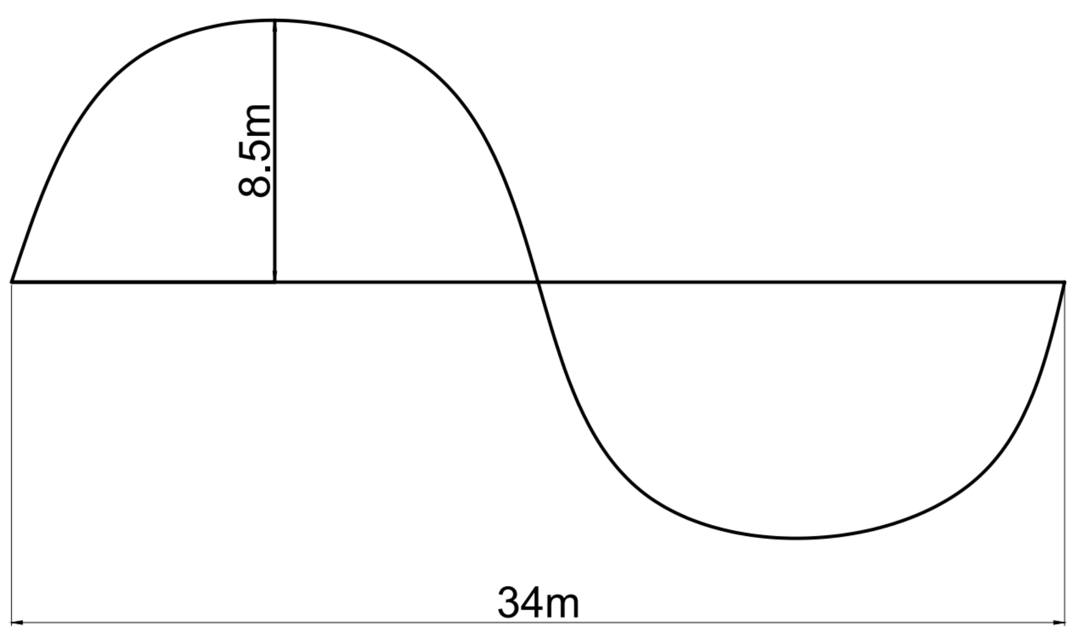

Figure 40: Wavelength and radius of curvature

14.11 Appendix K: HEC-RAS

Table 29: Input Parameters for HEC-RAS

Cross Section	Riffle Pool	Distanc From Clythe (m)	Current Elv (m)	Bank Elv (m)	Bottom Elv (m)	Change in Elevation	Station (m)								A	B	C	D	Area	Volume of Cut
							0.00	A	5.00	B	C	7.00	D	12.00						
0.00	Riffle	0.00	310.83	310.83	310.43	0.00	310.83	310.83	310.83	310.43	310.43	310.83	310.83	310.83	0.00	5.63	6.37	12.00	0.55	N/A
1.00	Right Pool	11.00	310.95	310.91	310.55	0.04	310.95	310.91	310.91	310.41	310.41	310.91	310.91	310.95	0.04	5.80	6.60	11.96	1.12	9.19
2.00	Riffle	18.00	310.95	310.96	310.55	-0.01	310.96	310.96	310.96	310.56	310.56	310.96	310.96	310.95	0.00	5.63	6.37	12.00	0.55	5.85
3.00	Riffle	27.00	311.20	311.02	310.80	0.19	311.20	311.02	311.02	310.62	310.62	311.02	311.02	311.20	0.19	5.63	6.37	11.81	1.97	11.34
4.00	Left pool	32.00	311.20	311.05	310.80	0.15	311.20	311.05	311.05	310.55	310.55	311.05	311.05	311.20	0.15	5.40	6.20	11.85	1.73	9.25
5.00	Riffle	37.00	311.36	311.09	310.96	0.27	311.36	311.09	311.09	310.69	310.69	311.09	311.09	311.36	0.27	5.63	6.37	11.73	2.64	10.91
6.00	Riffle	45.00	311.24	311.14	310.84	0.10	311.24	311.14	311.14	310.74	310.74	311.14	311.14	311.24	0.10	5.63	6.37	11.90	1.28	15.66
7.00	Right Pool	50.00	311.44	311.17	311.04	0.26	311.44	311.17	311.17	310.67	310.67	311.17	311.17	311.44	0.26	5.80	6.60	11.74	2.83	10.28
8.00	Riffle	57.00	311.44	311.22	311.04	0.21	311.44	311.22	311.22	310.82	310.82	311.22	311.22	311.44	0.21	5.63	6.37	11.79	2.17	17.51
9.00	Riffle	67.00	311.80	311.29	311.40	0.50	311.80	311.29	311.29	310.89	310.89	311.29	311.29	311.80	0.50	5.63	6.37	11.50	4.40	32.85
10.00	Left pool	73.00	311.88	311.33	311.48	0.55	311.88	311.33	311.33	310.83	310.83	311.33	311.33	311.88	0.55	5.40	6.20	11.45	4.66	27.19
11.00	Riffle	82.00	312.17	311.39	311.77	0.77	312.17	311.39	311.39	310.99	310.99	311.39	311.39	312.17	0.77	5.63	6.37	11.23	6.43	49.92
12.00	Riffle	93.80	312.43	311.48	312.03	0.95	312.43	311.48	311.48	311.08	311.08	311.48	311.48	312.43	0.95	5.63	6.37	11.05	7.82	84.05
13.00	Right Pool	98.00	312.33	311.50	311.93	0.83	312.33	311.50	311.50	311.00	311.00	311.50	311.50	312.33	0.83	5.80	6.60	11.17	7.26	31.67
14.00	Riffle	103.00	312.71	311.54	312.31	1.18	312.71	311.54	311.54	311.14	311.14	311.54	311.54	312.71	1.18	5.63	6.37	10.82	9.51	41.95
15.00	Riffle	115.00	312.85	311.62	312.45	1.23	312.85	311.62	311.62	311.22	311.22	311.62	311.62	312.85	1.23	5.63	6.37	10.77	9.93	116.67
16.00	Left pool	121.00	313.23	311.66	312.83	1.57	313.23	311.66	311.66	311.16	311.16	311.66	311.66	313.23	1.57	5.40	6.20	10.43	12.23	66.49
17.00	Riffle	128.00	313.23	311.71	312.83	1.52	313.23	311.71	311.71	311.31	311.31	311.71	311.71	313.23	1.52	5.63	6.37	10.48	12.17	85.42
18.00	Riffle	141.00	313.61	311.80	313.21	1.81	313.61	311.80	311.80	311.40	311.40	311.80	311.80	313.61	1.81	5.63	6.37	10.19	14.35	172.42
19.00	Right Pool	145.00	313.51	311.83	313.11	1.68	313.51	311.83	311.83	311.33	311.33	311.83	311.83	313.51	1.68	5.80	6.60	10.32	13.91	56.53
20.00	Riffle	152.00	313.88	311.87	313.48	2.01	313.88	311.87	311.87	311.47	311.47	311.87	311.87	313.88	2.01	5.63	6.37	9.99	15.85	104.17
21.00	Riffle	163.00	314.32	311.95	313.92	2.37	314.32	311.95	311.95	311.55	311.55	311.95	311.95	314.32	2.37	5.63	6.37	9.63	18.64	189.71
22.00	Left pool	170.00	314.29	312.00	313.89	2.29	314.29	312.00	312.00	311.50	311.50	312.00	312.00	314.29	2.29	5.40	6.20	9.71	17.57	126.74
23.00	Riffle	179.00	314.51	312.06	314.11	2.45	314.51	312.06	312.06	311.66	311.66	312.06	312.06	314.51	2.45	5.63	6.37	9.55	19.28	165.81
24.00	Riffle	191.00	314.43	312.14	314.03	2.29	314.43	312.14	312.14	311.74	311.74	312.14	312.14	314.43	2.29	5.63	6.37	9.71	18.03	223.83
25.00	Right Pool	196.00	314.20	312.18	313.80	2.03	314.20	312.18	312.18	311.68	311.68	312.18	312.18	314.20	2.03	5.80	6.60	9.97	16.61	86.59
26.00	Riffle	202.00	314.20	312.22	313.80	1.99	314.20	312.22	312.22	311.82	311.82	312.22	312.22	314.20	1.99	5.63	6.37	10.01	15.69	96.90
27.00	Riffle	213.00	314.35	312.29	313.95	2.06	314.35	312.29	312.29	311.89	311.89	312.29	312.29	314.35	2.06	5.63	6.37	9.94	16.25	175.71
28.00	Left pool	221.00	314.29	312.35	313.89	1.94	314.29	312.35	312.35	311.85	311.85	312.35	312.35	314.29	1.94	5.40	6.20	10.06	14.95	124.81
29.00	Riffle	230.00	314.29	312.41	313.89	1.88	314.29	312.41	312.41	312.01	312.01	312.41	312.41	314.29	1.88	5.63	6.37	10.12	14.87	134.22

30.00	Riffle	239.00	314.04	312.47	313.64	1.57	314.04	312.47	312.47	312.07	312.07	312.47	312.47	314.04	1.57	5.63	6.37	10.43	12.54	123.35
31.00	Right Pool	245.00	313.68	312.51	313.28	1.16	313.68	312.51	312.51	312.01	312.01	312.51	312.51	313.68	1.16	5.80	6.60	10.84	9.88	67.26
32.00	Riffle	251.00	313.99	312.55	313.59	1.44	313.99	312.55	312.55	312.15	312.15	312.55	312.55	313.99	1.44	5.63	6.37	10.56	11.50	64.15
33.00	Riffle	263.00	313.96	312.64	313.56	1.32	313.96	312.64	312.64	312.24	312.24	312.64	312.64	313.96	1.32	5.63	6.37	10.68	10.63	132.79
34.00	Left pool	270.00	313.96	312.68	313.56	1.27	313.96	312.68	312.68	312.18	312.18	312.68	312.68	313.96	1.27	5.40	6.20	10.73	10.03	72.33
35.00	Riffle	280.00	313.96	312.75	313.56	1.21	313.96	312.75	312.75	312.35	312.35	312.75	312.75	313.96	1.21	5.63	6.37	10.79	9.75	98.92
36.00	Riffle	290.00	313.65	312.82	313.25	0.83	313.65	312.82	312.82	312.42	312.42	312.82	312.82	313.65	0.83	5.63	6.37	11.17	6.84	82.97
37.00	Right Pool	294.00	313.25	312.85	312.85	0.40	313.25	312.85	312.85	312.35	312.35	312.85	312.85	313.25	0.40	5.80	6.60	11.60	3.93	21.54
38.00	Riffle	299.00	313.25	312.88	312.85	0.37	313.25	312.88	312.88	312.48	312.48	312.88	312.88	313.25	0.37	5.63	6.37	11.63	3.34	18.18
39.00	Riffle	312.00	313.72	312.97	313.32	0.74	313.72	312.97	312.97	312.57	312.57	312.97	312.97	313.72	0.74	5.63	6.37	11.26	6.21	62.14
40.00	Left pool	320.00	313.82	313.03	313.42	0.79	313.82	313.03	313.03	312.53	312.53	313.03	313.03	313.82	0.79	5.40	6.20	11.21	6.47	50.72
41.00	Riffle	328.00	313.82	313.08	313.42	0.74	313.82	313.08	313.08	312.68	312.68	313.08	313.08	313.82	0.74	5.63	6.37	11.26	6.18	50.57
42.00	Riffle	337.00	313.95	313.14	313.55	0.80	313.95	313.14	313.14	312.74	312.74	313.14	313.14	313.95	0.80	5.63	6.37	11.20	6.66	57.75
43.00	Right Pool	342.00	313.46	313.18	313.06	0.28	313.46	313.18	313.18	312.68	312.68	313.18	313.18	313.46	0.28	5.80	6.60	11.72	2.97	24.07
44.00	Riffle	348.00	313.08	313.22	312.68	-0.14	313.22	313.22	313.22	312.82	312.82	313.22	313.22	313.08	0.00	5.63	6.37	12.00	0.55	10.56
45.00	Riffle	363.00	313.67	313.32	313.27	0.35	313.67	313.32	313.32	312.92	312.92	313.32	313.32	313.67	0.35	5.63	6.37	11.65	3.20	28.09
46.00	Left pool	370.00	314.36	313.37	313.96	0.99	314.36	313.37	313.37	312.87	312.87	313.37	313.37	314.36	0.99	5.40	6.20	11.01	7.89	38.82
47.00	Riffle	376.00	313.83	313.41	313.43	0.42	313.83	313.41	313.41	313.01	313.01	313.41	313.41	313.83	0.42	5.63	6.37	11.58	3.75	34.93
48.00	Riffle	386.00	313.29	313.48	312.89	-0.19	313.48	313.48	313.48	313.08	313.08	313.48	313.48	313.29	0.00	5.63	6.37	12.00	0.55	21.50
49.00	Right Pool	394.00	312.97	313.54	312.57	-0.56	313.54	313.54	313.54	313.04	313.04	313.54	313.54	312.97	0.00	5.80	6.60	12.00	0.80	5.39
50.00	Riffle	400.00	313.44	313.58	313.04	-0.14	313.58	313.58	313.58	313.18	313.18	313.58	313.58	313.44	0.00	5.63	6.37	12.00	0.55	0.00
51.00	Riffle	415.00	313.58	313.68	313.18	-0.10	313.68	313.68	313.68	313.28	313.28	313.68	313.68	313.58	0.00	5.63	6.37	12.00	0.55	8.22
52.00	Left Pool	422.00	314.39	313.73	313.99	0.67	314.39	313.73	313.73	313.23	313.23	313.73	313.73	314.39	0.67	5.40	6.20	11.33	5.52	21.25
53.00	Riffle	428.00	313.69	313.77	313.29	-0.08	313.77	313.77	313.77	313.37	313.37	313.77	313.77	313.69	0.00	5.63	6.37	12.00	0.55	18.21
54.00	Riffle	440.00	313.16	313.85	312.76	-0.69	313.85	313.85	313.85	313.35	313.35	313.85	313.85	313.16	0.00	5.63	6.37	12.00	0.69	7.40
55.00	Right Pool	446.00	313.16	313.89	312.76	-0.74	313.89	313.89	313.89	313.39	313.39	313.89	313.89	313.16	0.00	5.80	6.60	12.00	0.80	0.00
56.00	Riffle	451.00	313.20	313.93	312.80	-0.72	313.93	313.93	313.93	313.53	313.53	313.93	313.93	313.20	0.00	5.63	6.37	12.00	0.55	0.00
57.00	Riffle	460.00	314.03	313.99	313.63	0.04	314.03	313.99	313.99	313.59	313.59	313.99	313.99	314.03	0.04	5.63	6.37	11.96	0.86	0.00
58.00	Left Pool	467.00	314.22	314.04	313.82	0.19	314.22	314.04	314.04	313.54	313.54	314.04	314.04	314.22	0.19	5.40	6.20	11.81	1.99	9.95
59.00	Riffle	473.00	314.52	314.08	314.12	0.45	314.52	314.08	314.08	313.68	313.68	314.08	314.08	314.52	0.45	5.63	6.37	11.55	3.95	17.82
60.00	Riffle	485.00	313.29	314.16	312.89	-0.87	314.16	314.16	314.16	313.76	313.76	314.16	314.16	313.29	0.00	5.63	6.37	12.00	0.55	27.01
61.00	Right Pool	496.00	313.29	314.24	312.89	-0.95	314.24	314.24	314.24	313.74	313.74	314.24	314.24	313.29	0.00	5.80	6.60	12.00	0.80	0.00
62.00	Riffle	499.00	313.35	314.26	312.95	-0.91	314.26	314.26	314.26	313.86	313.86	314.26	314.26	313.35	0.00	5.63	6.37	12.00	0.55	0.00
63.00	Riffle	511.00	313.44	314.34	313.04	-0.90	314.34	314.34	314.34	313.94	313.94	314.34	314.34	313.44	0.00	5.63	6.37	12.00	0.55	0.00
64.00	Left Pool	520.00	314.35	314.40	313.95	-0.05	314.40	314.40	314.40	313.90	313.90	314.40	314.40	314.35	0.00	5.40	6.20	12.00	0.60	0.00
65.00	Riffle	524.00	314.33	314.43	313.93	-0.10	314.43	314.43	314.43	314.03	314.03	314.43	314.43	314.33	0.00	5.63	6.37	12.00	0.55	2.30
66.00	Riffle	538.00	313.75	314.52	313.35	-0.78	314.52	314.52	314.52	314.12	314.12	314.52	314.52	313.75	0.00	5.63	6.37	12.00	0.55	7.67
67.00	Right Pool	547.00	314.29	314.59	313.89	-0.30	314.59	314.59	314.59	314.09	314.09	314.59	314.59	314.29	0.00	5.80	6.60	12.00	0.80	0.00
68.00	Riffle	550.00	314.75	314.61	314.35	0.14	314.75	314.61	314.61	314.21	314.21	314.61	314.61	314.75	0.14	5.63	6.37	11.86	1.63	3.64
69.00	Riffle	564.00	313.94	314.70	313.54	-0.76	314.70	314.70	314.70	314.30	314.30	314.70	314.70	313.94	0.00	5.63	6.37	12.00	0.55	15.24
70.00	Left Pool	569.00	313.94	314.74	313.54	-0.79	314.74	314.74	314.74	314.24	314.24	314.74	314.74	313.94	0.00	5.40	6.20	12.00	0.60	0.00
71.00	Riffle	584.00	314.84	314.84	314.44	0.00	314.84	314.84	314.84	314.44	314.44	314.84	314.84	314.84	0.00	5.63	6.37	12.00	0.55	0.00

Table 30: Sample Results from HEC-RAS (Station 291.3 –Riffle, Station 294 – Pool)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
final	291.333*	Stream Gauging	0.02	312.4	312.5	312.51	0.002075	0.22	0.1	1.07	0.23
final	291.333*	1.5-yr	0.42	312.4	312.81	312.84	0.005697	0.75	0.55	1.93	0.45
final	291.333*	5-yr	0.83	312.4	312.91	312.94	0.00534	0.87	1.42	10.86	0.45
final	291.333*	25-yr	1.46	312.4	312.98	313.02	0.005628	1.01	2.24	11.31	0.48
final	291.333*	100 yr	2.53	312.4	313.08	313.12	0.005689	1.16	3.35	11.89	0.5
final	294	Stream Gauging	0.02	312.35	312.51	312.51	0.00049	0.14	0.16	1.19	0.12
final	294	1.5-yr	0.42	312.35	312.83	312.85	0.003256	0.62	0.67	1.97	0.34
final	294	5-yr	0.83	312.35	312.93	312.96	0.003755	0.78	1.55	10.56	0.38
final	294	25-yr	1.46	312.35	313.01	313.04	0.004481	0.95	2.34	10.71	0.42
final	294	100 yr	2.53	312.35	313.1	313.14	0.005028	1.12	3.37	10.91	0.46

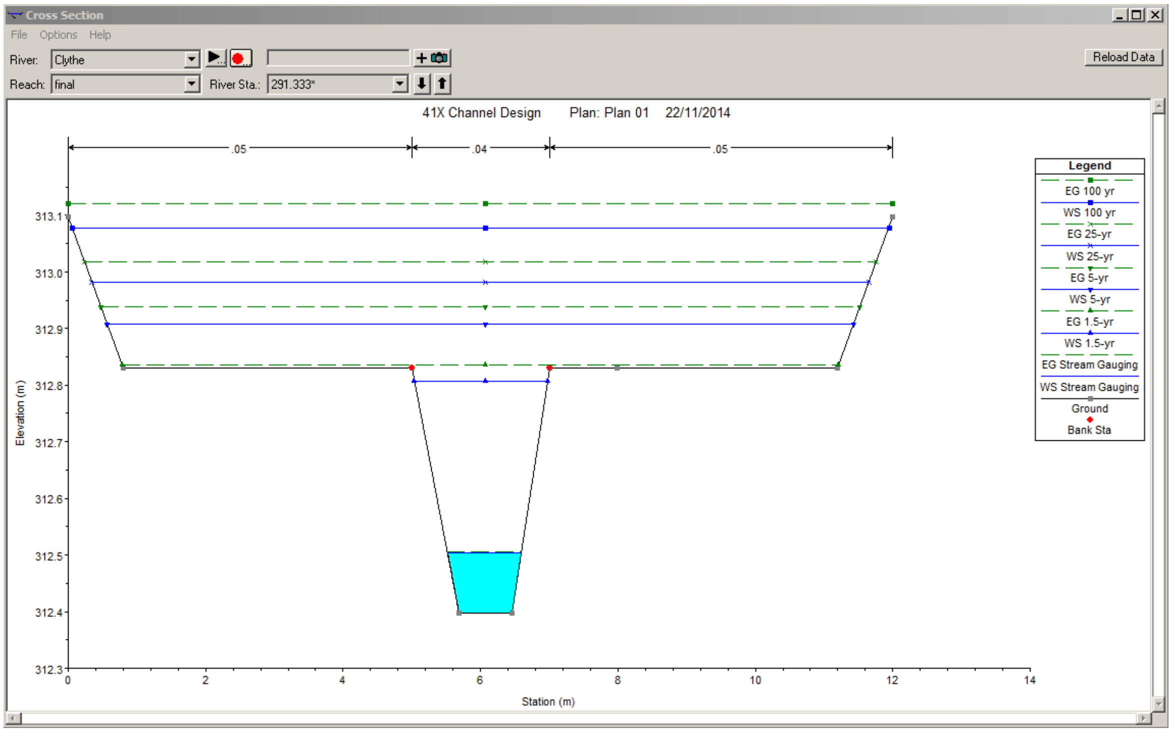

Figure 41: HEC-RAS Cross Section

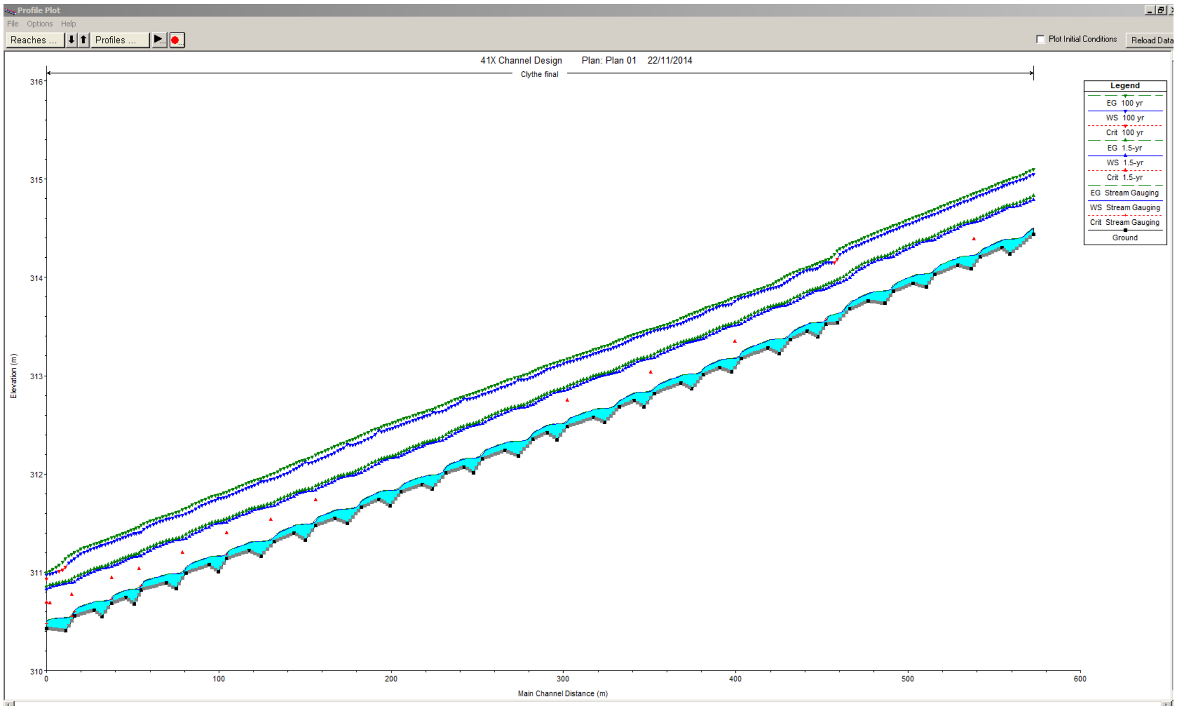

Figure 42: HEC-RAS Profile View

14.12 Appendix L: Soil Erosion Calculations

For Appendix: (soil calculations)

Tractive force Calculation

Alberta Ministry of Transportation Appendix F

$$R_h = \frac{Area}{Wetted\ Perimeter} = \frac{h(b+T)/2}{b + 2(((T-b)/2)^2 + h^2)^{1/2}}$$

$$R_h = \frac{0.36(0.75+2)/2}{0.75 + 2(((2-0.75)/2)^2 + 0.36^2)^{1/2}}$$

$$R_h = 0.2258\ m$$

$$\tau = \delta \times R_h \times s$$

$$\tau = 9.804 \frac{kN}{m^3} \times 0.2258\ m \times 0.0069 \frac{m}{m}$$

$$\tau = 0.01527\ \frac{kN}{m^3} = 15\ Pa$$

Maximum Tractive Force

$$\tau_{max} = \delta \times depth \times s$$

$$\tau_{max} = 9.804 \frac{kN}{m^3} \times 0.36\ m \times 0.0069 \frac{m}{m}$$

$$\tau_{max} = 0.0244\ \frac{kN}{m^3} = 24\ Pa$$

Mean Particle size (Two Stage Channel Design Document)

$$D_{50} = 1000 \times d \times s$$

$$D_{50} = 1000 \times 0.36m \times 0.0069\ m/m$$

$$D_{50} = 0.0025\ m = 2.5\ mm$$

For the Sediment Loading Calculations

Used the Ohio department of Natural Resources module “Sediment Equations 4-0”. Retrieved from http://www2.ohiodnr.com/soilwater/water-conservation/stream-restoration#SPR

Threshold of Motion		metric units		conversion	English units with grain size in mm	
depth	d	**0.36**	m	3.28	1.2	ft
slope	S	**0.0069**	m/m	1	0.0069	ft/ft
diameter sediment	d_s	**0.002484**	m	1000	2	mm
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
density fluid	ρ_f	999.7	kg/m^3	0.00194	1.94	slugs/ft^3
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	slugs/ft^3
specific weight of water	γ	9807.057	N/m^3		62.5	lb/ft^3
		999.7	kg$_f$/m^3			
shear stress	τ	24.4	N/m^2		0.509	lb/ft^2
		2.5	kg$_f$/m^2			
Shields parameter	τ_{*c}	0.606	dimensionless		0.606	dimensionless
Particle at threshold of motion	D_{cr}	0.02508	m		0.08	ft

Figure 43: Threshold of Motion

Bedload per unit channel width		metric units		conversion	English units with grain size in mm		check back to SI	
depth	d	**0.36**	m	3.28	1.2	ft		
slope	S	**0.0069**	m/m		0.0069	ft/ft		
diameter sediment	d_s	**0.002454**	m		2	mm		
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2		
density fluid	ρ_f	999.7	kg/m^3	0.00194	1.94	$slugs/ft^3$		
density sediment	ρ_s	2650	kg/m^3	0.00194	5.15	$slugs/ft^3$		
relative density	s	2.650795239	dimensionless		2.65079524	dimensionless		
shear stress	τ	24.4	N/m^2		0.509	lb_f/ft^2		
dimensionless parameter	Ψ	1.63			1.63			
bed-load transport (Meyer-Peter)	Φ	3.408			3.407			
	q_s	**0.0017**	m^2/s		**0.0179**	ft^2/s	0.00167	m^2/s
bed-load transport ($Einstein_{42}$)	Φ	1.136			1.136			
	q_s	**0.00056**	m^2/s		**0.00598**	ft^2/s	0.00056	m^2/s
bed-load transport ($Einstein_{50}$)	Φ	4.069			4.068			
	q_s	**0.00199**	m^2/s		**0.02142**	ft^2/s	0.00199	m^2/s
Ackers and White	n	0.019			0.019			
	U	2.23	m/s		7.32	ft/s		
	q_b	**0.00060**	m^2/s		**0.00638**	ft^2/s	0.00059	m^2/s

Figure 44: Bedload per unit channel width

Resistance Manning's and D'Arcy-Weisbach		metric units		conversion	English units with grain size in mm	
depth	d	**0.36**	m	3.28	1.2	ft
slope	S	**0.0069**	m/m	1	0.0069	ft/ft
diameter sediment	d_s	**0.002484**	m	1000	2	mm
max depth	d_{max}	**0.46**	m	3.28	1.5	
gravitational acceleration	g	9.81	m/sec^2	3.28	32.2	ft/sec^2
Resistance factor = sqrt(8/f)						
Colebrook-White Eq (Hey 1979) for D_{84}	u/u^*	15.5			15.5	
Leopold, Wolman & Miller (1964) for D_{84}	u/u^*	15.7			15.7	
Griffiths (1981) for D_{50}	u/u^*	14.3			14.3	
Manning's roughness coefficient (n):						
Colebrook-White Eq (Hey 1979) for D_{84}	n	0.0174			0.0174	
Leopold, Wolman & Miller (1964) for D_{84}	n	0.0171			0.0172	
Griffiths (1981) for D_{50}	n	0.0189			0.0189	
D'Arcy-Weisbach friction factor:						
Colebrook-White Eq (Hey 1979) for D_{84}	f	0.0333			0.0333	
Leopold, Wolman & Miller (1964) for D_{84}	f	0.0324			0.0324	
Griffiths (1981) for D_{50}	f	0.0394			0.0394	

Figure 45: Resistance Manning's and D'Arcy-Weishbach

14.13 Appendix M: Water Quality Data

Site Visit

Nov 6/2014

Turbidity

Turbidity @ outlet large
~~29.66 NTU (Reading 1)~~
~~61.46 NTU (Reading 2)~~
1.75 NTU (R3)
1.73 NTU (R4)
1.82 NTU (R5)

Turbidity @ Small outlet
(R1) 1.37 NTU
(R2) 2.03 NTU
(R3) 1.50 NTU

Turbidity @ inlet
(R1) 1.67 NTU
1.71 NTU
1.70 NTU

DO & Temperature

DO @ Large outlet
R1 8.02 mg/L @ 9.6°C
R2 8.75 mg/L @ 9.0°C
R3 8.96 mg/L @ 8.9°C

DO @ Small outlet
R1 9.04 @ 8.7°C
R2 9.03 @ 8.8°C
R3 9.01 @ 8.8°C

DO @ Large Inlet
R1 8.77 @ 8.8°C
R2 8.77 @ 8.8°C
R3 8.7 @ 8.8°C

Figure 46: Raw water quality data, November 6, 2014

14.14 Appendix N: Design Team Biographies

Emily Nickerson will complete her undergraduate program in Water Resources at the University of Guelph December 2014. She has diverse experience including two summer research positions with the School of Engineering, University of Guelph, overseas work experience with Engineers Without Borders Canada and internship with Purpose Capital in social finance. Through these experiences and applied university courses, Emily has developed experience with water quantity and quality designs, community-driven approaches and project management. Relevant courses that she has completed include: Water Management (ENGG*2550), Geomorphology (GEOG*2000), Water Quality (ENGG*3590), Hydrology (ENGG*3650), Soil Mechanics (ENGG*3670), Groundwater (GEOL*3060), Geographic Information Systems in Environmental Engineering (ENGG*3340), Soil-Water Conservation Systems Design (ENGG*4340), Urban Water Systems Design (ENGG*4370) and Watershed Systems Design (ENGG*4250). Emily has course-based experience using Excel, GIS, EPA-SWMM, HEC-RAS and CAD.

Graham Jewson will complete his undergraduate program in Environmental Engineering at the University of Guelph December 2014. He has diverse experience including a summer position at West-Can Sealcoating Inc. working in management mainly working with clients. Through this summer position and applied University coursework Graham has developed experience with project implementation and project management. Relevant courses that he has completed include: Water Quality (ENGG*3590), Hydrology (ENGG*3650), Soil Mechanics (ENGG*3670), GIS in Environmental Engineering (ENGG*3340), Groundwater (GEOL*3060), Urban Water Systems Design (ENGG*4370), and Watershed Systems Design (ENGG*4250). Graham has work and course-based experience using Excel, EPA-SWMM, HEC-RAS, MatLAB, ArcGIS, and AutoCAD.

David Reid will complete his undergraduate program in Environmental Engineering at the University of Guelph December 2014. He has diverse experience including a summer position at CC Tatham and Associates in Barrie, Ont working mainly with stormwater management. Through this summer position and applied University coursework David has developed experience with water quality and quantity design and project management. Relevant courses that he has completed include: Water Quality (ENGG*3590), Hydrology (ENGG*3650), Soil Mechanics (ENGG*3670), Groundwater (GEOL*3060), Urban Water Systems Design (ENGG*4370) and Watershed Systems Design (ENGG*4250). David has work and course-based experience using Excel, EPA-SWMM, HEC-RAS, MatLAB, Visual Otthymo, Culvert Master and AutoCAD.

Doug Campbell will complete his undergraduate program in Environmental Engineering at the University of Guelph December 2014. He has diverse experience including two summer positions with the City of St. Catharines as a Student Environmental Technician and a summer position working as an engineering assistant with LaFramboise Group. Through these summer experiences and applied University coursework Doug has developed experience with water quality and quantity design and project management. Relevant courses that he has completed include: Water Quality (ENGG*3590), Hydrology (ENGG*3650), Soil Mechanics (ENGG*3670), Groundwater (GEOL*3060), Geographic Information Systems in Environmental Engineering (ENGG*3340), Urban Water Systems Design (ENGG*4370) and Watershed Systems Design (ENGG*4250). Doug has course-based experience using Excel, GIS, EPA-SWMM, HEC-RAS, MatLAB and CAD.