Testing and Refining a Unique Approach for Setting Environmental Flow and Water Level Targets for a Southern Ontario Subwatershed

by

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ABSTRACT

TESTING AND REFINING A UNIQUE APPROACH FOR SETTING ENVIRONMENTAL FLOW AND WATER LEVEL TARGETS FOR A SOUTHERN ONTARIO SUBWATERSHED

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In this study Bradford’s (2008) approach for setting ecological flow and water level targets is tested and refined through application within the Lake Simcoe Region Conservation Authority’s (LSRCA) subwatershed of Lover’s Creek. A method for defining subwatershed objectives and identifying habitat specialists through expert input is proposed and tested. The natural regime of each streamflow and wetland site is characterized along with the hydrological alteration at each site. Potential ecological responses to the hydrologic alterations are then hypothesized for the different types of changes calculated at each site.

Methods for setting overall ecosystem health and specific ecological objective flow targets are proposed and tested. These targets are integrated into a flow regime for each site and a process for using this information for decision making is suggested. Flow magnitude quantification is attempted using hydraulic modelling and sediment transport equations, however the data used were found to be inadequate for this application.

The accuracy of the targets developed using the method presented in this paper is mainly limited by the accuracy of the hydrological model and quantified flow magnitudes. Recommendations for improving these components of the assessment are made.

The unique approach and recommendations presented in this paper provide explicit steps for developing flow targets for subwatersheds within the LSRCA. This research contributes
toward the advancement of EFA within the LSRCA, which provides opportunity for enhanced protection and restoration of ecosystem health across the watershed.
ACKNOWLEDGEMENTS

I would like to thank Dr. Andrea Bradford for providing me the opportunity to perform this research and for her guidance throughout the process. I would also like to thank Dr. Douglas Joy and Dr. John FitzGibbon for their helpful suggestions throughout the preparation of this thesis. A special thanks to Jack Imhof and the members of the Lake Simcoe Hydrology Team who provided constructive feedback. Finally, thanks to my wife, Carly Armstrong for her support over the past couple of years.
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**List of Acronyms**

ANSI - Area of Natural and Scientific Interest

BFI - Baseflow Index

CASIMIR - The Computer Aided Simulation Model for Instream Flow Requirements

CD – Coefficient of Determination

CWT - Central Western Tributary

DEM - Digital Elevation Model

DHRAM – Dundee Hydrologic Regime Alteration Method

DO – Dissolved Oxygen

DRIFT - Downstream Response to Intended Flow Transformations

EFA – Environmental Flow Assessment

EFC – Environmental Flow Component

EFR – Environmental Flow Requirement

ELOHA - Ecological Limits of Hydrologic Alteration

EPAM - Expert Panel Assessment Method

EVHA - Evaluation of Habitat Method

FDC – Flow Duration Curve

GRCA - Grand River Conservation Authority

HA – Hydrologic Alteration
HAM - Habitat Assessment Method

HSC – Habitat Suitability Criteria

IFIM – Instream Flow Incremental Methodology

IHA – Indicators of Hydrologic Alteration

LDC – Level Duration Curve

LSPP – Lake Simcoe Protection Plan

LSRCA – Lake Simcoe Region Conservation Authority

MAF – Mean Annual Flow

MAS – Meters Above Sea Level

OMNR – Ontario Ministry of Natural Resources

OSAP – Ontario Stream Assessment Protocol

POF – Percent of Flow Approach

RCHARC - Riverine Community Habitat Assessment and Restoration Concept

RHYHABSIM - River Hydraulics and Habitat Simulation Program

RSS - River System Simulator

RVA – Range of Variability Approach

SPAM - Scientific Panel Assessment Method

WPCC – Water Pollution Control Centre
Chapter 1: Introduction

It is widely recognized that the maintenance of a river’s natural flow regime is required to sustain its natural structure and function (Bradford 2008; Poff et al., 1997). Naturally-functioning rivers are extremely important as they maintain healthy aquatic environments and promote human wellbeing through the provision of ecosystem services (Acreman and Ferguson, 2010).

In 2008, the Government of Ontario passed The Lake Simcoe Protection Act, which was developed with the intent of protecting and restoring the health of the Lake Simcoe Watershed. The Lake Simcoe Protection Plan (LSPP) was subsequently developed to provide objectives and priorities for restoration and protection. The Lake Simcoe Conservation Authority (LSRCA) is the primary regulatory agency tasked with the implementation of the LSPP to protect and restore the Lake Simcoe Watershed. Chapter 5 of the LSPP discusses water quantity objectives within the watershed, specifically referring to the preservation of water supply to protect aquatic ecosystems through the maintenance of instream flow regimes (LSRCA, 2009).

Instream flows are currently addressed within a variety of Provincial program areas in Ontario, such as Source Water Protection and the Permit to Take Water System (AquaResource, 2011a). Simple, singular flow statistics are often used for environmental flow targets within these programs, which may fail to capture the hydrologic variability that is required to sustain aquatic ecosystems (Poff et al., 1997).

A guidance document titled “Towards a Framework for Determining Ecological Flows and Water Levels in the Lake Simcoe Watershed – A Guidance Document” was developed by LSRCA in collaboration with Dr. A. Bradford to provide a framework for going beyond simple
singular flow statistics and developing target regimes within the Lake Simcoe Watershed (LSRCA and Bradford, 2011). The overall objective of the study described in this dissertation is to advance the practice of EFA and provide better knowledge and tools to support decision making regarding ecological flow regime targets. A pilot Environmental Flow Assessment (EFA) for Lovers Creek Subwatershed in the Barrie/Simcoe area of the Lake Simcoe Watershed was completed using the framework outlined in the guidance document. This paper outlines the challenges that were encountered as well as the decisions made and the tools used throughout the process of implementing the framework. The EFA framework is critically analyzed at all stages of implementation and recommendations are made for future EFA in the LSRCA and other areas choosing to use EFA.
Chapter 2: Literature Review

Ecological Flow and Ecological Functions

Ecological functions are the chemical, biological and physical processes that interact to form an ecosystem. Ecological processes include activities such as nutrient cycling, predator-prey relationships and movement of sediment and water. These processes interact within a system to form unique ecological characteristics such as stream morphology, stream temperature, composition of biological communities as well as sediment size and distribution (Fischenich, 2003). It is imperative to protect ecological functions because biotic communities within a given system rely on the processes and characteristics to carry out different phases of their life history. Neglecting to protect ecological functions threatens the vitality and health of organisms within the biological system. Given that humans are a component of the biological system, protecting ecological functions protects human health and wellbeing (Acreman and Ferguson, 2010; Fischenich, 2003). Protection of ecological functions has proven to provide ecosystem services and the security of social and economic goods and services such as fish, medicines, timber, and protection from natural disasters such as flooding (Acreman and Ferguson, 2010). Finally, the protection of biodiversity for its intrinsic value has been recognized as an important objective of the Province of Ontario and the Government of Canada and the protection of ecological functions is imperative to meet this end (OMNR, 2005).

Environmental flow assessment (EFA) is one technique that can be applied for maintaining critical riverine ecological functions (Poff et al., 1997). EFA or instream flows is the science of determining the flow regime required to maintain specified, valued features of an aquatic ecosystem (King et al., 1999). The natural flow regime consists of flow magnitude,
frequency, timing, duration and rate of change of flows (Poff et al., 1997). To protect ecological functions it is important to maintain a semblance of the natural state of each component of the flow regime as each of these components contributes towards maintaining critical instream ecological functions (Poff et al., 1997). Critical ecological functions required to maintain a healthy aquatic ecosystem will be discussed in detail in the following section.

**Ecological Functions**

Several categories of ecological functions within riverine ecosystems have been identified. (Fischenich, 2003). These include:

1. Hydrological Functions,
2. Groundwater-Surface water Interaction,
3. Geomorphic Functions, and
4. Biogeochemical Functions.

The importance of functions within these categories to aquatic ecosystems is described below. It is important to note that the categories of ecological functions shown above are but one of several groupings that could be used (see Table 1 for an alternative categorization). Ecological functions are strongly interconnected. Depending on the system being studied, certain ecological functions may be more important than other functions (Fischenich, 2003).
Table 1: Summary of some important ecological functions (Bradford, 2008)

<table>
<thead>
<tr>
<th>Flow Need</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Connectivity</strong> (Vannote et al., 1980; Junk et al., 1989; Ward and Stanford, 1993; Jungwirth et al., 2000)</td>
<td><strong>Longitudinal connectivity</strong> Prevent disruption of food web and allow for migration and access to refugia</td>
</tr>
<tr>
<td></td>
<td><strong>Lateral connectivity</strong> Sustain floodplains and riparian wetlands</td>
</tr>
<tr>
<td></td>
<td>Access to complex biophysical floodplain habitats</td>
</tr>
<tr>
<td></td>
<td>Maintain nutrient dynamics</td>
</tr>
<tr>
<td></td>
<td>Recruit woody debris</td>
</tr>
<tr>
<td><strong>Vertical connectivity</strong></td>
<td>Maintain hyporheic interactions</td>
</tr>
<tr>
<td><strong>Water Quality</strong></td>
<td><strong>Stream temperature</strong> Maintain preferred ranges for community of aquatic organisms</td>
</tr>
<tr>
<td></td>
<td>Prevent negative influence on dissolved oxygen</td>
</tr>
<tr>
<td><strong>Meet water quality objectives</strong></td>
<td>Maintain dissolved oxygen concentrations</td>
</tr>
<tr>
<td></td>
<td>Flush away by-products of metabolism</td>
</tr>
<tr>
<td></td>
<td>Achieve nutrient transformation, biodegradation and dilution associated with wastewater effluent discharges</td>
</tr>
<tr>
<td><strong>Sediment Motion</strong> (Church, 2006; Kondolf and Wilcock, 1996; Carling, 1995)</td>
<td><strong>Maintain sediment transport capacity</strong> Maintain balance between deposition and erosion/sustain natural evolution of channel and floodplain morphology</td>
</tr>
<tr>
<td></td>
<td>Replenish substrates for habitats and spawning areas for fish and benthic organisms</td>
</tr>
<tr>
<td><strong>Flushing flows</strong></td>
<td>Maintain quality and character of substrate materials (e.g., prevent suffocation of biota and allow removal of metabolic wastes)</td>
</tr>
<tr>
<td></td>
<td>Source encroaching vegetation</td>
</tr>
<tr>
<td><strong>Channel and Floodplain Morphology</strong> (Whiting, 2002, 1998; Hill et al., 1991; Rosenberg et al., 1996)</td>
<td><strong>Maintain natural meander amplitude and wavelength, sinuosity and branching</strong> Maintain sediment transport capacity</td>
</tr>
<tr>
<td></td>
<td>Maintain aquatic habitat</td>
</tr>
<tr>
<td></td>
<td>Maintain cross-sectional shape of channel</td>
</tr>
<tr>
<td></td>
<td>Maintain capacity of channel</td>
</tr>
<tr>
<td></td>
<td>Maintain thalweg structure for longitudinal connectivity</td>
</tr>
<tr>
<td></td>
<td>Maintain wetted perimeter for food production</td>
</tr>
<tr>
<td></td>
<td>Maintain bank structure for channel stability and habitat provision</td>
</tr>
<tr>
<td><strong>Maintain floodplain morphology</strong></td>
<td>Maintain diversity of floodplain habitats</td>
</tr>
<tr>
<td><strong>Biological Requirements</strong> (Gregory et al., 1991; Imhof et al., 1996)</td>
<td><strong>Maintain stream hydraulics and unique features</strong> Maintain conditions for habitat specialists (e.g., groundwater discharge zones for Brook Trout)</td>
</tr>
<tr>
<td></td>
<td><strong>Maintain stream hydraulics and unique features</strong> Maintain conditions for habitat specialists (e.g., groundwater discharge zones for Brook Trout)</td>
</tr>
<tr>
<td></td>
<td><strong>Moisture levels for riparian vegetation</strong> Riparian vegetation controls bank morphology, controls light and water temperature, provides source of organic matter</td>
</tr>
</tbody>
</table>

**Hydrologic Functions**

Hydrologic processes include surface water storage and hydrodynamic balance processes. Surface water storage processes provide attenuation of high flow events, backwater areas, release of water and maintenance of baseflow during low flow periods (Fischenich, 2003). The attenuation of high flows is important for aquatic ecosystems as it provides relief from the
physical stress that the turbulence and velocity of high flows may cause (Thorpe et al., 2006). Backwater areas are important because they provide low velocity habitat, they can provide refuge areas during high flow periods and they increase contact time for biogeochemical processes. Maintenance of baseflow is important for aquatic ecosystems because it helps to sustain longitudinal connectivity which makes pathways available for organisms to migrate and provides instream habitat during periods when flow may not otherwise be present. In addition baseflow can maintain soil moisture during dry periods (Fischenich, 2003).

The general hydrodynamic balance process recognizes the need for a range of flow conditions required to support the biotic environment. This range of flows includes all five components of the natural flow regime (flow magnitude, frequency, timing, duration and rate of change of flows). The presence of a natural flow regime and the associated variation in flow stage has important implications to the aquatic ecosystem. Variable flow discharge may allow seasonal access to floodplains and wetlands for instream organisms. This seasonal access provides excellent nursery habitat for several species and can significantly alter local biogeochemistry (Junk et al., 1989). In addition, lateral and longitudinal variability is important as it creates heterogeneous physical habitat conditions that lead to habitat complexity and increased biodiversity (Ward et al., 1989). The presence of the natural flow regime is also extremely important as certain organisms rely on aspects of the natural flow regime as a cue to move into the next phase of their life history such as spawning, egg hatching, rearing, reproduction, and migration (Poff et al., 1997).
**Groundwater-Surface Water Interaction Functions**

Groundwater-surface water interactions are important for a variety of reasons. It is important to note that groundwater storage is the dominant source of baseflow for streams in Southern Ontario (Piggot et al., 2005). Groundwater interacts with surface water to regulate stream temperature, moderate low and high flow, increase the processing of nutrients and the exchange of chemicals and provide flow pathways between the channel and subsurface (Fischenich, 2003; USGS, 1998). The maintenance of baseflow has several important implications for the aquatic ecosystem that were mentioned in the “Hydrologic Functions” section above. The regulation of stream temperature is important for several aquatic species that require a specific thermal range for different phases of their life history. For example, brook trout (*Salvelinus fontinalis*) in Canadian Shield waters were found to spawn over groundwater discharge areas to prevent the overwinter freezing of their eggs (Curry et al., 1995). The moderation of low and high flows is important for the aquatic ecosystem as it prevents the stress and potential mortality that these extreme events may cause to organisms. For example, groundwater upwelling may sustain refugial pools that may be critical to the survival of aquatic species during low flow (Boulton and Hancock, 2006). Processing of nutrients and decomposition of organic matter is also dependent on the quantity and quality of the groundwater flux in a stream which can have a significant effect on the aquatic ecosystem. Finally, flow pathways between the channel and subsurface provide a route for movement of organisms and provide habitat for species that have adapted to take advantage of the unique characteristics that the flow pathways provide. Winter stonefly (*Capniidae*) and Water-violet (*Hottonia palustris*)
are two examples of species that depend on groundwater discharge to survive (Curry et al., 1995; Huebner and Vinson, 2004).

**Geomorphic Functions**

Geomorphic functions include the processes of sediment erosion, transport and deposition. These processes are important as they affect the quality of water within the stream and determine the morphological characteristics of the riverine landscape. The quality of water is affected by geomorphic processes since suspended sediment increases turbidity which affects light penetration, photosynthesis and biogeochemical processes. In addition, some nutrients such as phosphorus can bind to sediments and be eroded, transported and deposited (Withers and Jarvie, 2008). The structural characteristics that result from geomorphic processes include the spatial and temporal distribution and size of channel substrate and geomorphic features such as point bars, scour pools, islands, pool-riffle sequences and ox bows (Thorpe et al., 2006).

Geomorphic processes have a significant impact on the aquatic environment. Sediment erosion and deposition are important disturbance processes that contribute to succession of aquatic and riparian habitats. Geomorphic processes are also important because organisms are adapted to tolerate a given suspended sediment regime and if altered, the organisms may suffer stress or mortality. The structural characteristics that result from geomorphic processes are important to aquatic ecosystems since they create habitat complexity. Habitat complexity creates diversity which makes the system more resistant to natural and anthropogenic disturbance (Thorpe et al., 2006). In addition, river systems with natural geomorphic functions are generally
more stable and predictable than systems with disturbed geomorphic functions. This provides important ecosystem services to society such as flood control (Acremen and Ferguson, 2010).

**Biogeochemical Functions**

Biogeochemical functions include the maintenance of biological structure as well as important biogeochemical processes that maintain water chemistry. Maintaining appropriate biological structure includes the presence of diverse communities of native species with appropriate age class and life form distribution as well as genetic diversity. This is extremely important as organisms will interact with each other to create and maintain healthy aquatic ecosystems. For example, organisms interact through predator prey relationships or by providing structural habitat for other organisms, such as that created by downed woody debris or beaver damming (Larson et al., 2001; Thorpe et al., 2006). Biogeochemical processes occur within the soil zone, the groundwater zone and the river channel. The chemical interaction of water with the geologic and biologic components of each zone as well as the length of time within each zone, results in particular characteristics. Important chemical variables include acidity, amount of total dissolved solids, amount of dissolved oxygen, and nutrient levels. Maintenance of appropriate ranges of water quality variables is extremely important as organisms native to a particular environment within the aquatic ecosystem function optimally within a specific range of these variables. In addition, maintenance of appropriate ranges of water chemistry can control the spread of pathogens and viruses within a system (Fischenich, 2003). Biogeochemical
functions can also benefit society by maintaining clean, aesthetically appealing watercourses for recreational enjoyment as well as a potential source of drinking water (Fischenich, 2003).

**Tools and Methods for EFA**

Globally, over 200 instream flow methods have been developed and applied since the inception of EFA. These methods can be subdivided into four main categories; hydrological, hydraulic rating, habitat simulation and holistic methods (King et al., 1999; Tharme, 2003). Depending on the source, additional categories of methods such as “hybrid” and “other” may be present or the classification scheme may be entirely different (Acreman and Dunbar, 2004; Tharme, 2003).

**Hydrologic Methods**

Hydrologic methods use historical flow records or modelled hydrologic flow regimes to attempt to derive ecologically relevant flow statistics. It is imperative that flow data that has not been significantly impacted by anthropogenic disturbance be used for calculation of hydrological statistics. If this flow data does not exist, a simulated natural flow regime can be created with a physically based hydrological model by removing anthropogenic disturbance from the modelled conditions. For example, LPRCA (Unknown) simulated the natural flow regime for Big Creek using the GAWSER model by removing urban and agricultural development from the land use input layer and converting that land to forest. Examples of hydrologic methods include the Tennant Method, the Flow Duration Analysis Method, The Range of Variability Approach (RVA) and the Percent of Flow (POF) Approach (King et al., 1999; Richter et al., 2011; Tharme, 2003).
The Tennant Method (or the Montana Method) has been the most commonly applied environmental flow assessment method globally. This method was developed from field assessments within the state of Montana, Nebraska and Wyoming of relationships between discharge and aquatic habitat, sediment movement and recreation. This method relates seven percentages of mean annual flow (MAF) on a seasonal basis to flows that maintain geomorphic function (flushing flows) and flows that maintain instream habitat condition. (Table 2) (Tennant, 1976). For example, 200% MAF is considered an adequate flushing flow, 60% MAF is considered to provide optimal habitat and 10% is considered ecologically poor or minimum. A common criticism of this method is that the relationships that were developed for streams within Montana, Nebraska and Wyoming should not be applied to other jurisdictions with different stream characteristics without some form of field validation (King et al., 1999; Tharme, 2003).

<table>
<thead>
<tr>
<th>Description of Flow</th>
<th>April to September</th>
<th>October to March</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flushing/maximum flow (from 48-96 hours)</td>
<td>200% Mean Annual Flow (MAF)</td>
<td>N/A</td>
</tr>
<tr>
<td>Optimum range of flow</td>
<td>60 - 100% MAF</td>
<td>60 - 100% MAF</td>
</tr>
<tr>
<td>Outstanding habitat</td>
<td>60% MAF</td>
<td>40% MAF</td>
</tr>
<tr>
<td>Excellent habitat</td>
<td>50% MAF</td>
<td>30% MAF</td>
</tr>
<tr>
<td>Good habitat</td>
<td>40% MAF</td>
<td>20% MAF</td>
</tr>
<tr>
<td>Fair or degrading habitat</td>
<td>30% MAF</td>
<td>10% MAF</td>
</tr>
<tr>
<td>Poor or minimum habitat</td>
<td>10% MAF</td>
<td>10% MAF</td>
</tr>
<tr>
<td>Severe degradation</td>
<td>&lt;10% MAF</td>
<td>&lt;10% MAF</td>
</tr>
</tbody>
</table>

The Flow Duration Analysis Method uses various exceedance percentiles on the flow duration curve as flow indices. A Flow Duration Curve (FDC) displays the percentage of time a given discharge is equaled or exceeded. Commonly applied general indices include \( Q_{90} \), which is the discharge that is equaled or exceeded 90% of the time, \( 7Q_{10} \), which is the low flow event that
occurs for a duration of seven days with a 10 year return period (Tharme, 2003). While 7Q10 is a commonly applied index, it has been demonstrated that it is not sufficient for protecting aquatic habitats (Richter et al., 2011). Flows that make a more explicit link between discharge and ecology have been developed for specific sites. For example, $Q_{17}$ has been used as a flushing flow to remove fine sediments from the channel bed of salmonid spawning grounds and $Q_{40}$ has been used as a flow index to maintain habitat suitable for salmonid spawning (King et al., 1999). The main weakness of flow duration curve analysis is that it does not provide any information about the timing, sequential (single or multiple consecutive storm event) duration of specific flow events or rate of change of the flows, which are all recognized as important components of a complete EFA. This problem can be partially avoided by using monthly or seasonal FDCs but this does not solve the problems of sequential duration and rate of change (Acreman, 2005).

The RVA uses a set of 32 statistics termed Indicators of Hydrologic Alteration (IHA). These IHA’s are categorized into five groups based on the regime characteristic of the IHA. The grouped IHA statistics can be seen in Table 3.
Table 3: Grouped Indicators of Hydrologic Alteration (Richter et al., 1996)

<table>
<thead>
<tr>
<th>IHA statistics group</th>
<th>Regime characteristics</th>
<th>Hydrologic parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1: Magnitude of monthly water conditions</td>
<td>Magnitude, Timing</td>
<td>Mean value for each calendar month</td>
</tr>
<tr>
<td>Group 2: Magnitude and duration of annual extreme water conditions</td>
<td>Magnitude, Duration</td>
<td>Annual minima 1-day means, Annual maxima 1-day means, Annual minima 3-day means, Annual maxima 3-day means, Annual minima 7-day means, Annual maxima 7-day means, Annual minima 30-day means, Annual maxima 30-day means, Annual minima 90-day means, Annual maxima 90-day means</td>
</tr>
<tr>
<td>Group 3: Timing of annual extreme water conditions</td>
<td>Timing</td>
<td>Julian date of each annual 1 day maximum, Julian date of each annual 1 day minimum</td>
</tr>
<tr>
<td>Group 4: Frequency and duration of high and low pulses</td>
<td>Magnitude, Frequency, Duration</td>
<td>No. of high pulses each year, No. of low pulses each year, Mean duration of high pulses within each year, Mean duration of low pulses within each year</td>
</tr>
<tr>
<td>Group 5: Rate and frequency of water condition changes</td>
<td>Frequency, Rate of change</td>
<td>Means of all positive differences between consecutive daily means, Means of all negative differences between consecutive daily values, No. of rises, No. of falls</td>
</tr>
</tbody>
</table>

‘Acceptable’ ranges of variation can be set for each IHA. In the absence of better information, a range of ± 1 Standard Deviation may be used as a preliminary acceptable range. Within the RVA the IHA’s are recalculated on an annual basis using gauged stream data and compared to the determined acceptable range. A key component of the RVA is the ecological monitoring of the given target flow regime. Based on the results of the ecological monitoring program and the recalculation of IHA statistics, the system is adaptively managed and targets are redefined for subsequent years (King et al., 1999, Richter et al., 1997). For example, if it is determined that ecological objectives are not being met but the recalculation of the IHA statistics using the gauged data are within the determined acceptable range, then the acceptable range must be altered and monitored until ecological objectives are being met.

The POF approach sets Environmental Flow Requirements (EFR’s) as allowable deviations from natural conditions expressed as a percent departure from the natural regime. The
POF approach is appealing because it is simple to use and understand. Another benefit of this method is that a semblance of the natural flow regime is maintained while allowing for a degree of flexibility for the water user (Richter et al., 2011). The POF approach can be a strictly hydrological approach by assigning best estimate percent deviations based on expert input or the flow regime can be more explicitly linked to ecological thresholds using scientific studies making the EFR more defensible (Richter et al., 2011).

**Strengths and Weaknesses of Hydrologic Methods**

The Hydrological methods provide simple, rapid, inexpensive, low resolution assessments that are suitable for reconnaissance level EFA. The hydrologic methods can also be used as a component of Holistic Methods (Tharme, 2003). However, these methods are not suitable for high controversy situations where there are multiple stakeholders with opposing interests or where there are important biological values to be protected. Hydrologic methods can be difficult to implement when no data are available to develop a reference regime and can be difficult to defend if the connection between the flow regime and ecology is not explicitly made (King et al., 1999; Tharme, 2003). If hydrological models are used then significant expertise is required to properly set-up and run the model and interpretation of the output requires understanding of the limitations of the model structure and input data (NRCS, 2007).

**Hydraulic Methods**

Hydraulic methods determine the values of hydraulic variables (such as maximum depth, wetted perimeter, velocity or longitudinal connectivity) at a single or multiple river cross-sections as a proxy for the maintenance of specific components of aquatic ecosystem health.
These methods are seen as the precursor for more sophisticated habitat models that assess the combination of several hydraulic variables at multiple cross-sections along with microhabitat and biological information to determine habitat suitability at various river discharges (King et al., 1999). Hydraulic methods are based on the assumption that aquatic ecosystem integrity can be directly related to a specified value of a particular hydraulic variable and that maintenance of a given discharge will ensure preservation of the hydraulic variable and the aquatic ecosystem. The relationship of the hydraulic variable to discharge is usually compared using an arbitrarily defined percent reduction or a breakpoint along the discharge variable graph. For example, the wetted perimeter variable is commonly used as a proxy for fish rearing and benthic invertebrate production within riffle biotopes (Acreman, 2005). Using the hydraulic method one would either seek the discharge that would reduce the wetted perimeter by an arbitrary assigned percent value such as a 50% of optimal habitat or one would use a breakpoint along the discharge, wetted perimeter graph as seen in Figure 1.

![Figure 1: Wetted perimeter discharge relationship with the same data but different breakpoints (Acreman, 2005)](image)
Notice that the two graphs in Figure 1 use the same data but have different breakpoints. Figure 1 thus demonstrates the subjectivity of the breakpoint method. In addition, there may be no evidence to support the assumption that the breakpoint on the figure is a threshold for a healthy aquatic ecosystem (Acreman, 2005). Another example using depth as the hydraulic variable would be the discharge that covers 80% of the gravel available for spawning or a breakpoint on the discharge-depth graph (King et al., 1999). Hydraulic modelling software such as HEC-RAS or R2-cross can be used to assist with developing relationships between hydraulic variables and discharge (Tharme, 2003). Alternatively, relationships between discharge and hydraulic variables can be determined empirically using regression equations (King et al., 1999).

**Strengths and Weaknesses of Hydraulic Methods**

The hydraulic methods provide a relatively simple, cost effective method for determining an EFR. This method also provides a more explicit link between discharge and ecology than the hydrology method by incorporating ecological information related to physical habitat requirements at various discharges (King et al., 1999). In addition, the hydraulic technique can be expanded to encompass habitat requirements of several species with a moderate amount of effort and expense. A major weakness of the hydraulic method is that it relies on the overly simplistic assumption that the health of a given aquatic ecosystem component is dependent on a single hydraulic variable or a small group of hydraulic variables that are measured. The hydraulic method often only results in minimum flows to sustain given habitat variables and does not consider other aspects of a natural flow regime such as timing, duration, rate of change and frequency. Also, it may be difficult to obtain a quality relationship between discharge and the
hydraulic parameters of interest which can significantly impact the effectiveness of the designated EFR. Another disadvantage of the hydraulic method is that the hydraulic relationship is limited in spatial resolution to the cross-sections that were investigated and it can be difficult to expand to out of channel ecosystem components such as riparian vegetation. Finally, another weakness of hydraulic methods is that it can be difficult to link the stage discharge relationship to the actual flow regime (King et al., 1999).

**Habitat Simulation Methods**

The habitat simulation method is an extension of the hydraulic method and involves the use of models to determine quantity and suitability of habitat (such as depth, average column velocity and benthic shear stress) for given target species under various discharges. King *et al* (1999) identified over 25 habitat simulation methods with PHABSIM used within the Instream Flow Incremental Methodology (IFIM) being considered the most advanced. PHABSIM has two main components, a hydraulic simulation component and a habitat simulation component. A collection of five hydraulic simulation programs generate cell-by-cell depths and velocities at various river discharges (USGS, 2001). Habitat simulation programs then use the output from the hydraulic simulation models to link the simulated physical conditions (for example, depth and velocity) to the conditions required by the target species at various stages of the species’ life history called habitat suitability criteria (HSC). HSC are calculated for each cell and at each time step of the model (USGS, 2001) (Figure 2).
These habitat suitability indices are then aggregated to form a weighted usable area curve for each life stage, or combined as seen in Figure 3. Casper *et al.*, (2011) coupled the distributed hydrological model SWAT with PHABSIM for the calculation of EFR’s in Hillsborough River, Florida.
Figure 3: Weighted Usable Area for different discharge values calculated by PHABSIM. A, B and C represent different reaches along the river (Milhous et al., 1989)

Other habitat simulation programs exist such as the River Hydraulics and Habitat Simulation Program (RHYHABSIM) and Riverine Community Habitat Assessment and Restoration Concept (RCHARC) which are both variations of PHABSIM. The Computer Aided Simulation Model for Instream Flow Requirements (CASIMIR) is a newer program that allows for separate calculation of the effects of hydropower fluctuation on instream habitat. Other habitat simulation methods include the Evaluation of Habitat Method (EVHA) and the River System Simulator (RSS) (King et al., 1999).

**Strengths and Weaknesses of Habitat Simulation**

The main advantage of the habitat simulation methods is that it provides a relatively scientific and defensible flow assessment by enabling the evaluation of multiple scenarios for various species and life stages. Windows based software and extensive training is readily available for the PHABSIM model making it accessible to learn and apply. In addition, habitat simulations can readily be incorporated into holistic methodologies. While the software and
training is available for PHABSIM, the models can be data intensive and data collection and model simulation can be time consuming, particularly in developing countries where no data may be present on the riverine biota. Habitat simulation models require significant expertise to run properly and interpretation of the model output requires understanding of the limitations of the input data and the model structure (King et al., 1999; Tharme, 2003). Habitat simulation models can also be spatially restricted to the surveyed cross-sections and may be narrow in scope only focusing on particular species of interest. This method also does not incorporate broader aspects of the riverine landscape such as geomorphic functions and does not account for longer term changes in river morphology. Finally there are several basic assumptions within the models such as the transferability of habitat suitability curves that have been contested. Habitat suitability models require further research, testing and validation to improve confidence in the modelled output which will make them more effective tools for EFA (King et al., 1999; Tharme, 2003).

**Holistic Methods**

The final category is the holistic methods, which build a flow regime based on ecological objectives developed from scratch (termed bottom up) or are derived by deviation away from the natural flow regime (termed top down) or a combination approach which uses both bottom-up and top-down approaches. Holistic methods incorporate a combination of the previously described methods to derive an EFR. Holistic methodologies began to form in the early 1990’s. The South African Building Block Methodology (BBM) and the Australian Holistic Approach were among the first holistic methods developed. Both the BBM and the Holistic Approach are bottom-up methods that require intensive baseline data collection and expert input to build a flow
regime based on identified ecological, geomorphological, water quality or social objectives. The BBM gets its name from the component (building blocks) of the flow regime required to sustain the riverine ecosystem (Acreman and Ferguson, 2010; King and Louw, 1998).

A top-down approach known as the Downstream Response to Intended Flow Transformations (DRIFT) evolved from the BBM method. The DRIFT method involves the identification of important biophysical functions and the flow requirements necessary to maintain the identified biophysical functions. The effect of altering the flow requirement is assessed by a multi-disciplinary team of scientists and thresholds for flow alteration are developed. These thresholds then form the basis of the EFR (King et al., 1999).

Another category of holistic methods are those that rely solely on expert opinion. The Expert Panel Assessment Method (EPAM), the Scientific Panel Assessment Method (SPAM) and the Habitat Assessment Method (HAM) are three examples of expert opinion methods. EPAM was the first holistic expert opinion method to be developed and relies on the interpretation of available data on fish, trees, macrophytes, invertebrates and geomorphology by a team of multidisciplinary scientific experts. SPAM was developed with the intention of improving the effectiveness and transparency of EPAM, and HAM is a combination of both SPAM and EPAM (King et al., 1999).

Another widely applied holistic method is The Instream Flow Incremental Method (IFIM). IFIM was developed in the early 1980’s and is an instream flow decision support system that allows for the assessment of effect of different water management scenarios on river habitat (Bovee, 1982). IFIM has been applied extensively within North America and has been applied in at least 20 countries worldwide (Ban et al., 2009). According to King et al., 1999, it is
considered the most legally and scientifically defensible EFA method available. The IFIM contains a series of procedures and simulation programs such as River2D, GIS and decision support systems, with PHABSIM being the most well known and most commonly used tool within the IFIM (Ban et al., 2009). More recently the IFIM has been extended to assess other components of river health to allow for a more robust EFA (King et al., 1999).

More recently Bradford (2008) developed a holistic framework for EFA in Canada. The framework is designed to be integrated, holistic, hierarchical and adaptive (Figure 4).

Figure 4: Framework for EFA in Canada (LSRCA and Bradford, 2011)
Tools used within the framework are divided into context setting tools and design flow setting tools. Context setting is completed first and involves stream classification, identification of cause-response relationships (with respect to anthropogenic disturbance, the flow regime and ecology), assessment of degree of alteration from the natural flow regime and the identification of the requirement of habitat specialists. The design flow setting phase allows for the choice of one of the three holistic methods; bottom-up, top down or a combination approach. Depending on the objectives, resources and the degree of controversy associated with the particular EFA a level of assessment should be chosen. Three levels are presented within the framework (watershed level, subwatershed level and detailed assessment). Increased importance of the EFA decision warrants increased levels of analysis. Potential tools for defining EFR’s are described for each level of analysis (Bradford, 2008). LSRCA and Bradford (2011) adapted this framework to be used within the LSRCA. The adapted version of this framework is described in “Towards a Framework for Determining Ecological Flows and Water Levels in the Lake Simcoe Watershed – A Guidance Document” (LSRCA and Bradford, 2011)

Poff et al (2010) developed a similar approach called The Ecological Limits of Hydrologic Alteration (ELOHA), but this framework was designed for implementation at the regional scale (province, large basin, country) (Figure 5).
The ELOHA framework involves the development of a hydrological foundation using gauged data and hydrological models. Based on the hydrologic foundation and geomorphic information, rivers are classified at each point of interest, then deviation from the natural flow regime is calculated at each of these points of interest. The ecological response to hydrologic alteration is then determined through expert input and ecological monitoring which is then used to develop the instream flow regime. The ELOHA framework recognizes that social and economic aspects factor into the decision making process, but they are not explicitly discussed within the framework. While the intent of the ELOHA framework was to provide a methodical cost effective EFA framework, it is being found that several regulatory agencies are unable or
unwilling to incur the expense required to implement ELOHA which ranges from $100k to $2M USD (Richter et al., 2011).

**Strengths and Weaknesses of Holistic Methods**

Holistic methods are particularly useful because they allow the ability to construct flows that sustain a wide array of riverine landscape components into the EFR. They also allow flexibility based on time and resources and can have strong ties to the natural flow regime. The main weaknesses of holistic methods are that they can rely heavily on expert opinion (King et al., 1999; Tharme, 2003). Expert opinion is an excellent technique for determining answers to specific questions when data and resources are not available to conduct a more rigorous scientific assessment. However, expert opinion has been criticized as being subjective, non-transparent, and inconsistent and has been perceived as being biased by stakeholders when experts are employed by regulatory authorities or developers (Acreman, 2005).

**Challenges of Determining an EFR**

While it is recognized among the scientific community that EFA is necessary for the effective protection and restoration of riverine landscapes, actual determination of adequate EFR’s in practice has been severely lacking (Richter, 2010). The barriers to determining effective EFR’s have been attributed to several factors that can be broadly grouped into two categories; scientific and policy/legislative challenges.
Scientific Challenges and Potential Solutions

The major scientific barriers to EFR determination include a lack of data, uncertainty in models and flow-ecology response relationships, difficulty extrapolating results across space and time and the challenge of communicating and collaborating across disciplines. The lack of stream gauge data and the resulting difficulty in characterizing the hydrology of a system and establishing a reference regime can be a major challenge. An alternative to using stream gauged data to generate hydrographs is the use of hydrological models. However, there can also be a large degree of uncertainty associated with hydrological models used to establish the basis for flow requirements (Poff et al., 2010).

Another major scientific challenge is the difficulty quantifying the link between flow and ecological response (Poff et al., 1997). Flow-ecological response relationships are particularly difficult to determine when there are multiple factors at play governing the aquatic ecosystem such as climate change and invasive species (Poff et al., 2010). The task of providing information about numerous locations while only having the resources to collect adequate data on a small subset of these locations also presents a significant challenge (Poff et al., 1997). Scientists are required to extrapolate the results from one river segment, reach or watershed to other areas where no data exist. This can be very challenging as rivers and streams are naturally heterogeneous and each geographic area has its own unique characteristics that may require specific EFR’s. Scientists are also required to extrapolate into the future and forecast the results of management strategies which produce inherent uncertainties (Poff et al., 1997).

Another scientific challenge is the difficulty coordinating EFA research between multidisciplinary groups of scientists. The main challenges of having a multidisciplinary team
arise from the different approaches used within the various disciplines as well as the different vocabulary used within each discipline. This creates a communication barrier as well as different opinions as to what is important and how data should be collected (Acreman, 2005).

Some possible solutions to the challenges outlined above are to continue to conduct research that will improve model certainty as well as ensure that adequate stream gauge data are available for hydrological characterization and model calibration. A priori model parameterization and increasingly sophisticated techniques for quantifying model uncertainty provide steps in the right direction (Poff et al., 2010). Conducting research to improve our understanding of the quantitative link between hydrology and ecology will also reduce scientific uncertainty, as will engaging scientists from a variety of disciplines and facilitating productive collaboration between multidisciplinary scientific teams (Acreman, 2005).

**Policy and Legislative Challenges and Potential Solutions**

A major policy challenge that exists within EFA is the transfer of scientific knowledge into effective policy. It is documented within the literature that a communication barrier exists at the scientist-resource manager interface, which leads to tension, indecision and ineffective EFA (Acreman, 2005). This is largely due to the fact that water managers need quick and precise flow requirements to fulfill their responsibilities of being consistent and transparent to multiple stakeholders within a planning cycle, whereas scientists generally need to study a system for multiple years to obtain an answer that contains a large degree of uncertainty (Acreman, 2005; Arthington et al., 2006). To further complicate the incorporation of scientific results into EFR’s, outputs from EFA methods are generally not in a format that supports decision making. For example, scientists often present smoothed curves of flow and ecological response with no
indication of calculated error, and resource managers are tasked with finding suitable thresholds and acceptable levels of ecological degradation (Acreman, 2005).

To facilitate the successful transfer of knowledge between scientists and resource managers within EFA, scientists should make a proper calculation of uncertainty and effectively communicate the results as well as the uncertainty to decision makers. The decision makers should then incorporate this uncertainty into the final EFR’s using ranges of values that represent the calculated uncertainty (Acreman, 2005). Another solution to the communication problems between resource managers and scientists is to define the role of the scientist and resource manager at the onset of the project. Doing this can significantly decrease the chances of conflict between the two parties (Acreman, 2005).

Another major policy and legislative challenge facing EFA is the weak, unclear and conflicting policy and legislation surrounding EFA (LeQuesne et al., 2010). Different levels of government often have overlapping and conflicting objectives since they represent different interests and stakeholder groups. These overlapping and conflicting objectives often lead to confusion and tension between agencies (Le Quesne, et al., 2010). In addition, the policies surrounding EFA are generally not required to be implemented or are unclear to the point that resource managers are uncertain how to implement the given policy. This lack of legislative authority and clarity can be a serious impediment to EFA (LeQuesne et al., 2010). Similar to lack of coordination between government agencies is the problem of a lack of integration between water management activities. For example, the lack of integration between groundwater and surface water management or dam operation. Managing these components separately can lead to ineffective EFA as they may represent different ecological functions which are strongly
interrelated as was described in the “Ecological Flow and Ecological Functions” section above (Richter, 2010).

A proposed solution to the problem of weak, unclear and conflicting policy is to embed EFA into water policy as an objective of sustainable water management similar to water quality policy rather than looking at EFA as a competing interest during water allocation negotiations (Richter, 2010). Another solution that has been found to alleviate some of these problems is to allow for independent oversight of the water management agencies through organizations such as the Great Lakes Compact or the Australian National Water Commission (Le Quesne, et al., 2010).

**Scientific Expert Input for EFA**

When data and resources are not available to complete a full scientific assessment, it is common practice within EFA to use expert opinion to fill data gaps. Experts from a range of disciplines including ecology, hydrology and geomorphology are asked to provide their best estimate based on their knowledge and experience. Expert input is particularly useful for EFA decision making where the understanding of flow-ecology relationships are limited (Cottingham et al., 2001).

There are two main forms of obtaining scientific expert input for EFA; scientific expert panels or independent interviews. The scientific panel approach is conducted in a workshop format that is led by an independent facilitator, government agency staff or is self-regulated. In the scientific panel approach the team of scientist meets several times in the field and the office to discuss the project and make recommendations based on their area of expertise (Acreman, 2005). Scientific panel assessments take approximately 6 months to a year to complete and cost
about $100,000 CND. The main advantage of expert panel assessments is that participants have an opportunity to discuss their perspectives and can generally come to a better understanding of the position of other panel members through dialogue. Some of the disadvantages are that interpersonal conflict can affect the results and there is a high amount of cost and time associated with this technique. In addition, this method requires a significant time commitment from busy scientific experts who may not be able to commit to the project (Cottingham et al., 2001).

In contrast to the scientific expert panel approach, independent interviews are completed in isolation from other panel members. A fast and efficient method for independently surveying experts on a given topic is known as the Delphi Technique (Pill, 1971). The Delphi technique is a method of combining expert opinion on a given subject that is intangible or has a large degree of uncertainty. The method gets its name from the ancient Greek meeting site where Oracles would congregate to make important decisions or provide opinions. The Delphi technique was developed by the RAND Corporation and was first used in military applications in the 1950’s. It is based on the assumption that expert opinion is an acceptable input into decision making when absolute answers cannot be determined and that a group of experts is better than a single expert (Crance, 1986).

This method can be applied to almost any situation requiring ordering or quantification of subjective variables (Pill, 1971). The Delphi technique has been previously applied in environmental flow assessment for the development of habitat suitability indices (Crance, 1986). There are three main steps to this technique. The first step involves asking experts a list of predefined questions. In the second step the questions are organized, analyzed and sent back to
the respondents. Finally, the experts re-answer the questions given the new aggregate information. This process is repeated until a consensus is reached (Crance, 1986).

One of the main advantages of this technique is that it does not require face to face contact (Crance, 1986). Another pro of the Delphi technique is that it is anonymous so overly dominant or opinionated individuals do not have as much influence on the results as in a focus group setting (Pill, 1971). However, a drawback of anonymity is that participants may have a lack of responsibility and accountability for their answers leading to carelessness in their responses (Kennedy, 2003). While this is a widely accepted and applied method across several disciplines caution must be taken as the output of the technique is an opinion and should be treated as such (Pill, 1971). As a result, it is necessary to describe experts fully so that readers have a good idea of their level of expertise and credibility (Kennedy, 2003).
Chapter 3: Research Objectives and Approach

The overall objective of this study is to advance the practice of EFA and provide better knowledge and tools to support decision making. Underlying this main objective are six sub-objectives:

1. Test the proposed functional flow and water level assessment framework and refine the guidance for future applications,
2. Evaluate the utility of existing data and tools for EFA in Lovers Creek subwatershed,
3. Develop target regimes for Lovers Creek subwatershed using existing data and tools,
4. Provide recommendations for improving the developed target regimes,
5. Provide guidance for how target regimes can be applied for decision making, and
6. Build EFA capacity within Ontario and specifically within the Lake Simcoe jurisdiction.

The study objectives were met by following the general steps outlined in the framework for determining ecological flows and water levels (LSRCA and Bradford, 2011). Following the framework, subwatershed objectives were identified and translated into specific functions that have water needs. A functional assessment was then completed, which involved identifying the variables that limit identified functions, the flow and non-flow related processes as well as the important temporal aspects of the flow regime related to each function. The information for identification of the objectives and the functional assessment were primarily derived from expert input using the Delphi Technique (Pill, 1971).

Streamflow study nodes were determined based on a subset of existing LSRCA monitoring points. Wetland study nodes were selected based on wetland location and wetland size. For each wetland and streamflow study node, eco-hydrologic analysis was completed and
hydrologic targets were set based on the hydrologic assessment. The hydrological analysis relied upon output from a MIKE-SHE hydrological model and used Indicators of Hydrologic Alteration (IHA) software (DHI, 2007; Richter et al., 1996). For one streamflow site, functional flows were quantified using a HEC-RAS model and sediment transport equations. The information for each site was integrated into a target regime and recommendations for applying the targets to decision making in the context of Lovers Creek were made.

While applying the framework, the tools and methods for performing specific analysis (which are not provided in the general framework) were determined. The analysis that could be completed at each step was determined by the tools and data that were available. An objective of this research was to test the utility of existing data and models for EFA in the LSRCA and identify the most pertinent data gaps. Given this objective, no new field data were collected for this study. Methods developed from this research can be applied to complete EFA’s in other LSRCA subwatersheds, making best use of resources to fill critical data gaps.

Additional data could not be collected in this study due to limited resources available. A large component of this project was collecting, compiling and synthesizing existing data and determining what analysis could be completed with the existing data as well as determining the limitations of the data and the analysis.

The reluctance to conduct and implement EFA within the LSRCA and within Ontario is partially due to a lack of knowledge of the principles and methods used for EFA. Therefore, one of the objectives of this study was to contribute towards building capacity within the LSRCA and Ontario. To meet the objective of building EFA capacity within the Lake Simcoe jurisdiction the methods outlined in this paper were presented at a number of meetings, workshops and
conferences. The methods described in this paper were presented as a poster presentation at Latornell Conservation Symposium, World Water Day Research Fair, Ontario Wetlands Day Conference and The Grand River Conservation Authority (GRCA) EFA Workshop. The contents in this paper were also presented at a half day EFA workshop that was attended by members of Provincial Government Agencies and Conservation Authorities as well as the interagency Ontario Low Water Response training. In addition, this information was presented at several meetings including those held by the Lake Simcoe Hydrology Team and the GRCA EFA Project Team.
Chapter 4: Description of the Framework for Establishing Requirements for Ecological Flows and Water Levels

The general steps of the framework will be outlined in this Chapter in order to provide a high level understanding of the entire process before the details of the flow assessment are discussed. The steps in the framework can be seen in Table 4. These steps were developed throughout the course of this study and are based on the general framework outline provided in LSRCA and Bradford (2011). There are three phases of the framework, the Context Setting Phase, The Development of a Reference Regime and Hydroecological Analysis Phase and the Development of the Target Regime Phase.

The Context Setting Phase is comprised of five steps that serve the purpose of developing the foundational knowledge required for the flow assessment. Most of the information required to complete these steps is available within current documentation such as the subwatershed plans. Scientific Expert Input was used to confirm the information or to fill data gaps where information was not available in existing documentation.

The Development of a Reference Regime and Hydro-ecological Analysis Phase consists of three steps that must be completed for each analysis node. The main purpose of this phase is to establish an understanding of the historic and current hydrological regime at each node and assess the potential ecological responses to the calculated hydrologic alteration.

The final phase in the framework is the Development of the Target Regime Phase which also consists of three steps. The purpose of Phase III is to generate a target regime that will be used to restore or protect general ecosystem health as well as specific ecological functions. This phase is also completed at each study node. The targets for overall ecosystem health are
developed from the hydrologic statistics while targets for ecological objectives are developed from hydrologic statistics and quantified functional flows. The targets for overall ecosystem health and the targets for the ecological objectives are then combined to create a target regime at each study node.

Table 4: Steps of framework for ecological flows and water levels

<table>
<thead>
<tr>
<th>PHASE I</th>
<th>(Context Setting)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Define Subwatershed Characteristics</td>
</tr>
<tr>
<td>b)</td>
<td>Define Subwatershed Goals</td>
</tr>
<tr>
<td>c)</td>
<td>Identify the Habitat Specialists</td>
</tr>
<tr>
<td>d)</td>
<td>Complete the Functional Analysis</td>
</tr>
<tr>
<td>e)</td>
<td>Complete Geomorphic/Hydrologic Classification and Select Analysis Nodes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE II</th>
<th>(Development of a Reference Regime and Hydro-ecological Analysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Characterize the Natural Regime</td>
</tr>
<tr>
<td>b)</td>
<td>Assess the Hydrologic Alteration</td>
</tr>
<tr>
<td>c)</td>
<td>Hypothesize Ecological Responses to Hydrologic Alteration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE III</th>
<th>(Development of a Target Regime)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Set Targets for Overall Ecosystem Health</td>
</tr>
<tr>
<td>b)</td>
<td>Set Targets for Ecological Objectives</td>
</tr>
<tr>
<td>c)</td>
<td>Integration into a Target Regime</td>
</tr>
</tbody>
</table>
Chapter 5: Models and Tools

This chapter will describe the models and tools used for the flow assessment. The models used in the EFA will be described to provide an understanding of their structure and limitations. The tools will be described to facilitate understanding the results and discussion of the tool output. Understanding the model and tool limitations is important as they will affect the certainty of the results of the flow assessment.

MIKE-SHE Hydrological Model

A hydrological model was developed by AquaResource Incorporated for the City of Barrie Tier Three study. This model completely covers the Lovers Creek subwatershed as can be seen in the map of the model extent shown in Figure 6 (AquaResource Incorporated, 2011b). The results of the hydrological model created by AquaResource Incorporated were used throughout this study.
Figure 6: Barrie Tier Three Model Domain (Adapted from AquaResource Incorporated., 2011b)
The Danish Hydraulic Institute’s fully integrated groundwater surface water model MIKE-SHE was used to model the area. MIKE-SHE is a physically-based, distributed hydrological model. The model is flexible and allows the modeler to use different levels of spatial resolution and model complexity depending on the application. The model simulates all of the major processes of the hydrological cycle illustrated in Figure 7, including groundwater flow, unsaturated flow, overland flow, evapotranspiration and channel flow, which is modeled using the MIKE 11 hydraulic model (DHI, 2007).

![Figure 7: Modelled processes using MIKE-SHE (DHI, 2007)](image)

Within MIKE-SHE, precipitation reaches the ground surface and is separated into surface runoff or infiltration if it is not intercepted by the canopy or if it melts from the snow. Surface runoff commences when net precipitation exceeds the infiltration rate. Once surface runoff is
generated, it is routed overland on a cell-by-cell basis using a 2-D diffusive wave approximation of the St. Venant equations. Overland flow can evaporate or infiltrate at each cell as it moves along the surface towards the channel. Channel flow is represented using the kinematic routing method by linking to MIKE-11. Groundwater surface water interaction within the channel is calculated based on groundwater head, surface water elevation and the hydraulic conductivity of the river bed.

Infiltration within the Barrie Tier Three model is simulated using the 2-layer water balance with the Green and Ampt infiltration routine. Water will move from the soil surface, vertically through the unsaturated zone and into the saturated zone. The depth of the saturated zone will depend on groundwater heads. Saturated flow is modelled using an iterative, implicit finite difference solution of the 3-D Darcy equation. This component of the model provides a more complex representation of saturated flow than most other hydrologic models such as GAWSER and HEC-HMS.

Within this model, evapotranspiration can remove water from the storage on the canopy, the soil surface or from soil water through plant uptake. Different land covers are given different rooting depths, which determines the depth at which the water can be removed from the soil for that specific location within the model. Potential evapotranspiration is calculated outside of MIKE-SHE and is inputted into the model. Water can be removed from either of the 2 layers of the unsaturated zone and the amount of water removed by evaporation will depend on the potential evaporation rate and the amount of available water within the unsaturated zone. Sublimation may also occur from the snowpack.
The primary purpose of the model was to simulate groundwater recharge for input into the FEFLOW groundwater model. The model has a grid resolution of 200 m and discharge along the stream network can be modeled at intervals of approximately 500 m. Urbanized hydrology (channelized streams, storm sewers, storm water ponds) was not included in the model but it is possible to incorporate this by linking MIKE-SHE with MOUSE, which is a DHI program that simulates pipe flow (DHI, 2007).

Data from two climate stations were used within the model. The Cookstown Station was used for the southern portion of the subwatershed and the Barrie Water Pollution Control Centre (WPCC) Station for the northern section of the subwatershed. A 5 m resolution digital elevation model (DEM) was used to determine the topography across the subwatershed. This DEM was also used to develop approximately 100 m wide cross sections every 500 to 1000 m along the river network. These cross sections are used by MIKE-11 for hydraulic routing simulation. For the channel routing calculation, a roughness coefficient of 0.05 was used for both the channel and the floodplain. Land use and land cover data were based on LSRCA maps from 2008. The unsaturated zone in the model was classified into four soil classes, gravel, sand, sandy till and clay based on Quaternary geology. These soil classes were then assigned hydrologic properties such as infiltration rate and suction head based on calibration and past experience modelling in the area. The saturated zone is a simplification of the geologic structure of the nine layered FEFLOW model. The MIKE-SHE model is simplified to three layers, an upper surficial aquifer, a middle confining layer and a lower confined aquifer. Water withdrawal is simulated in the model using pump rates and location, and well screen depths supplied by the Ministry of Environment’s Permit to Take Water program. The pump rate is adjusted by a consumption
factor which accounts for water that is consumed and not returned to its source (Figure 8) (AquaResource Incorporated, 2011b).

Figure 8: Modelled pumping wells (AquaResource Incorporated, 2011b)
Metrics used for calibration include annual streamflow, mean monthly streamflow, daily hydrograph comparisons, ranked duration daily streamflow, $R^2$ coefficient and log Nash-Sutcliffe coefficients. Calibration of the model focused on low flows and not on matching peak flows. While streamflow data for Lovers Creek at Tollendale exists from 2001 to 2009, only four years of streamflow data were used (2001-2004) for calibration because data beyond 2004 are thought to be incorrect. Mean annual precipitation for the subwatershed is measured at about 900 mm/y and evapotranspiration is approximately 500-550 mm/y which makes the streamflow measurements beyond 2004 of greater than 700 mm/y unrealistic. It is thought that this discrepancy is a result of the stage discharge relationship changing after urbanization or because the gauged data has not been corrected for ice. Spot flow measurements were not used for calibration by AquaResource Incorporated to calibrate the model because the measurements were only taken on one day and, according to AquaResource Incorporated, may not be representative of baseflow conditions. Other spot flow measurements were taken by the LSRCA over several dates at three locations but were also not used for calibration since it is uncertain whether or not these measurements were taken at baseflow conditions (AquaResource Incorporated, 2011b).

The calibrated model matches annual and monthly gauged flows well up to 2004 (Figure 9). The higher monthly simulated flow in August is thought to be a result of the use of the unrepresentative rain amounts during periods of aerially sporadic thunderstorms. From daily hydrograph comparison it was seen that August low flows match well but August peak flows do not (Figure 10). The ranked daily duration curves also show a good match with the observed data showing slightly lower low flows beyond about 90% exceedance (Figure 10). The log
Nash-Sutcliff coefficient for the Lovers Creek model is 0.53 and the $R^2$ coefficient is 0.57. According to Chiew and McMahon (1993) a Nash-Sutcliffe coefficient greater than or equal to 0.60 is considered satisfactory. According to this standard, the Lovers Creek model's performance is slightly below satisfactory. Due to lack of accurate data beyond 2004, the model was not validated for Lovers Creek (AquaResource Incorporated, 2011b).

In addition, modelled snow depths were compared to snow course measurements and it was found that there was good agreement between simulated and observed snow depths.
Groundwater levels were used as a secondary confirmation of model performance. Groundwater level error is shown in Table 5, where Layer 1 is the surficial aquifer and layer 3 is the confined aquifer (AquaResource Incorporated, 2011b). The general patterns of the simulated groundwater contours match well with the observed contours but the mean error and mean absolute error are fairly high.

Table 5: Groundwater level error (AquaResource Incorporated, 2011b)

<table>
<thead>
<tr>
<th>Metric</th>
<th>MIKE SHE Layer 1</th>
<th>MIKE SHE Layer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Wells</td>
<td>1698</td>
<td>330</td>
</tr>
<tr>
<td>Mean Error</td>
<td>-7.3 m</td>
<td>-4.0 m</td>
</tr>
<tr>
<td>Mean Absolute Error</td>
<td>9.0 m</td>
<td>6.9 m</td>
</tr>
<tr>
<td>Root Mean Square Error (RMSE)</td>
<td>13.4 m</td>
<td>9.3 m</td>
</tr>
<tr>
<td>Normalized RMS</td>
<td>9.3 %</td>
<td>8.5%</td>
</tr>
<tr>
<td>Min Head</td>
<td>186.8 masl</td>
<td>181.4 masl</td>
</tr>
<tr>
<td>Max Head</td>
<td>331.0 masl</td>
<td>290.4 masl</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.82</td>
<td>0.63</td>
</tr>
</tbody>
</table>

**HEC-RAS Model Development**

During this study, a HEC-RAS model was developed for the purpose of quantifying functional flows. The modelled site (called site LOV1-01) is located near the mouth of Lovers Creek subwatershed and is a LSRCA monitoring station (Figure 21). Site LOV1-01 was surveyed on June 22nd 2005 by LSRCA staff according to the Ontario Stream Assessment Protocol (OSAP) (Stanfield, 2010). The site was surveyed with 10 transects spaced at an equal interval of 4.89 m totaling a longitudinal distance of 44 m. It is important to note that 44m is a small reach to be modelling with a 1-D hydraulic model. The inability for a 1-D model to capture the micro-differences in velocity and depth at this scale should be considered when interpreting the model output. To overcome the limitations of 1-D hydraulic modelling a longer reach should be modelled in 1-D or more advanced 2-D or 3-D hydraulic models should be used.
The first upstream transect (transect 10) is located at the outlet of a large culvert (Figure 12). Water depths were measured at 6 approximately equal intervals along each transect. The maximum wetted width at this site is 16.6 m at transect 9 and the minimum wetted width is 4.5 m at transect 1. A hydraulic model was constructed by the author of this paper from the OSAP data from this site. It is recognized that this is not the optimal dataset for hydraulic modelling, but due to the limited resources available for conducting fieldwork, these data were deemed adequate to meet the main study objective of testing the framework for EFA. The primary objective of constructing the hydraulic model using the OSAP data was to have a model that could be used to test and demonstrate EFA techniques for quantifying functional flows. A secondary objective was to test the utility of the OSAP data for creating a hydraulic model for the purpose of EFA.

The U.S. Army Corps of Engineers HEC-RAS 4.1.0 software was used for the hydraulic modelling. HEC-RAS 4.1.0 requires cross-sectional channel geometry as well as Manning’s roughness values as input. OSAP cross sections are collected independently of each other so the difference in channel bed elevation between cross-sections is unknown. For this model, slope was estimated from the DEM at the location of site LOV1-01. Given that the site is only 44 m long and the resolution of the DEM is 5 m, the slope derived from the DEM is a very rough estimate. A slope value of 0.7% was derived from the DEM. Stream profiles of creeks surrounding Lovers Creek have an average gradient that ranges from 0.93% (Dyment Creek) to 2.32% for (Bunkers Creek) which is slightly higher than the slope estimated for site LOV1-01. The stream profile data for Lovers is not available but the gradient from the headwaters to the mouth is 0.08% (LSRCA, 2011a). It is expected that the slope at site LOV1-01 should be steeper.
than the overall gradient of the main channel of Lovers because it is a pool-riffle sequence which would have a steeper slope than the wetland areas that are present along the majority of the main channel.

Since elevation expressed as meters above sea level (MAS) is unknown, an arbitrary elevation of 10 m was chosen for the water level at the first downstream transect (transect 1) and each of the remaining transects were shifted up in elevation to conform to a constant slope of 0.7%. In OSAP, water depths are measured to the water’s edge, and then a different protocol is used to measure bank elevations. Banks are measured at 4 points that are within 1.5 m of the water’s edge on the date of measurement. The bank elevations are measured from the ground surface to a tape that runs perpendicular to the stream (Figure 11). To mesh the bank elevations with the water depths it was assumed that the first bank elevation is measured to the water surface level as in Figure 11. Undercut banks are recorded in the OSAP database and occur on the right bank at transect 5 and on the right bank at transect 6. At these locations the increase in elevation from the water level to the ground surface is unknown and the transition of elevation from the water level to the bank may be slightly inaccurate in the model. In addition, the measured banks will be dependent on the flow and water level at the time of measurement. If the measurements were at a low flow, then the bank measurements may not be representative of the true bank but may be the non-wetted channel at the time of measurement.
Manning’s roughness for the channel bed was estimated using the Strickler formula (Equation 1)

\[ n = 0.019\left(D_{50}\right)^{1/6} \]

Equation 1: Calculating Manning’s n from median particle size (Sturm, 2001)

where \( n \) is Manning’s n and \( D_{50} \) is the median particle size in cm for the transect. The bank Manning’s roughness was estimated based on the recorded dominant vegetation and the values given by Sturm (2001) where meadow is given a Manning’s n of 0.035 and forest is given a value of 0.15. Where no vegetation is present on the bank the Manning’s roughness was set at the value used for the channel at that transect.

HEC-RAS also requires upstream and downstream boundary conditions. The most stable boundary conditions for modelling subcritical steady flow in HEC-RAS are an upstream discharge boundary condition and a downstream depth condition. Based on the Tollendale gauge, the recorded discharge at this site on the day it was surveyed by the LSRCA was 0.4 m³/s. The OSAP database contains hydraulic head measurements at each transect point, which can be converted to velocity using Equation 2. This equation was adapted for the OSAP manual from Rantz (1982) and is a basic application of the Bernoulli equation. Discharge was estimated using
hydraulic head data to determine the utility of this data for estimating discharge at sites where no gauge exists. To estimate discharge at site LOV1-01, velocity was converted from hydraulic head using the equation provided in the OSAP manual (Equation 2).

\[ v = 0.625\sqrt{0.02(HH)} \]

*Equation 2: Estimating velocity from hydraulic head (Stanfield, 2010)*

where \( v \) is velocity in m/s and \( HH \) is hydraulic head in mm. As outlined in the OSAP manual, average discharge was then calculated at each cross-section by multiplying the velocity by the wetted width and the average depth (Table 6).

<table>
<thead>
<tr>
<th>Cross-Section</th>
<th>Downstream</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Transect Discharge (m³/s)</td>
<td></td>
<td>0.34</td>
<td>0.35</td>
<td>0.46</td>
<td>0.45</td>
<td>0.36</td>
<td>0.24</td>
<td>0.50</td>
<td>0.68</td>
<td>0.74</td>
<td>0</td>
</tr>
</tbody>
</table>

The calculated discharges from the hydraulic head range from 0 m³/s to 0.74 m³/s with an average of 0.41 m³/s and a standard deviation of 0.21 m³/s. The calculated average discharge of 0.41 m³/s corresponds very well with the gauged record of 0.4 m³/s. This suggests that this method may be suitable for calculation of discharge at ungauged sites, but comparisons at several more sites are required to confirm that the method is valid.

The recorded discharge of 0.4 m³/s was set for the upstream boundary condition and the downstream boundary condition was set at an average water elevation of 10m based on the chosen water level for the model. The model was run in HEC-RAS using steady flow analysis assuming a subcritical flow regime.
Data required for model calibrations (such as measured water levels at different flows) are not available but other information exists that can be used to verify the accuracy of various aspects of the model. The geometry of the model suggests that the site is comprised of an upstream pool followed by a riffle, which is what is to be expected within one channel cross-over (Stanfield, 2010). The geometry in the model also indicates that a meandering thalweg is present within the channel (Figure 12). Based on the photograph in Figure 12 it appears as though a pool is present at the outlet of the culvert and a side channel is present in the approximate location of the meandering thalweg indicating that the model geometry extracted from the OSAP database is a reasonably accurate representation of reality.

Figure 12: Comparison of model geometry to site photo

Riffle Crest

Flow Direction

Pool

Side

Flow Direction
The major limitation of this model is that the channel slope is unknown. Tying in cross-sections with known slope would greatly improve the accuracy of the model. In addition, measuring water surface elevation at various discharges and using this information for calibration would greatly improve the model. There is a culvert just upstream of the model boundary. This culvert may have an effect on the modelled water depths, but this was not considered in this analysis.

In summary the model created from the OSAP data produced a channel with logical geometry and water levels that are suitable for testing the EFA framework and demonstrating the tools and models that can be used for EFA. However, the values produced by the model are highly uncertain due to lack of channel slope information and water level data for calibration. Accurate surveying of the longitudinal channel slope and water surface profiles for calibrating the model would greatly enhance the models ability to predict water levels at different flows. During the quantification of functional flows this model will be used to test and demonstrate EFA tools and methods. Throughout this process the model will continue to be evaluated.

**Indicators of Hydrologic Alteration (IHA)**

Numerous ecologically relevant hydrologic metrics can be calculated within the IHA software. IHA is used extensively in this research, therefore a description of the program’s functions and output is provided to facilitate understanding the results and discussion in this paper. A brief description of IHA and its components is given below.

There are a total of 33 IHA parameters that are grouped into five categories. An annual or seasonal mean or median statistic is calculated for each parameter. The first category contains
12 parameters which indicate the median or mean magnitude of each monthly flow. The second parameter group is extreme water conditions and consists of the 1, 3, 7, 30 and 90 day minimum and maximum flow calculated from a moving average. Parameter group 2 also contains the number of zero flow days and the base flow index which is calculated as the ratio of the 7 day minimum to mean annual flow (MAF). The third parameter group describes the timing of the 1 day minimum and maximum. The fourth parameter group is comprised of the count and duration of high and low pulse counts. High and low pulses are flows that exceed user defined thresholds. The default threshold for high and low pulses are set at the median plus and minus 25% respectively. The fifth parameter group consists of the rise and fall rate of peaks and the number of times flow changes from increasing to decreasing and vice versa, which is known as the number of reversals (The Nature Conservancy, 2009).

Another group of parameters available in more recent versions of IHA are the Environmental Flow Components (EFCs). There are five types of EFCs: extreme low flows, low flows, high flows, small floods and large floods (Figure 13). Thresholds based on user defined flows, flow duration curve percentiles and/or return intervals are set to assign ranges of EFC magnitudes. The default thresholds are set to represent flow ranges that have general ecological functions, however, thresholds are meant to be refined based on the users’ knowledge of the flow-ecology relationship at their study site. For example, the default threshold for small floods is a return interval of 2 years which is generally accepted as bankfull flow. Flows greater than this threshold may have important ecological relevance related to floodplain inundation, such as the use of the floodplain as a nursery area for fish. Additional evidence through geomorphic studies may suggest that bankfull occurs at a different flow than the 2 year return interval. The
flow rate determined from the studies should be used for the EFC small flood threshold. The frequency, duration, peak flow, timing and rise and fall rates are calculated on an annual or user defined seasonal basis for each EFC (The Nature Conservancy, 2009).

![Figure 13: Example of EFCs calculated at site LOV1-01 located at the mouth of Lovers Creek](image)

The program allows for the calculation of parametric or non-parametric statistics. Non-parametric statistics are recommended because of the skewed nature of most hydrometric data. IHA can be used for characterization of the hydrologic regime. The median and the coefficient of dispersion (CD) (an estimate of variation in the data) are calculated for each IHA and EFC parameter. The CD is calculated using Equation 3. For annual parameters, CD’s are useful for determining inter-annual variability.
Hydrologic alteration can be calculated within IHA by comparing pre and post impact hydrologic regimes. For two period analysis the EFC, high and low pulse thresholds are derived from the pre impact data. Various statistics are calculated to estimate hydrologic alteration. The deviation factor is calculated for the median and CD of each IHA and EFC parameter using Equation 4 and is analogous to a percent change from the pre impact to post impact scenario.

\[
\text{Deviation Factor} = \frac{|\text{Post impact value} - \text{Pre impact value}|}{\text{Pre impact value}}
\]

Equation 4: Calculation of deviation factor (The Nature Conservancy, 2009)

A statistic called the significance count can be generated within IHA. This statistic helps explain the validity of the deviation factor. To calculate the significance count IHA randomly mixes all the pre and post impact years together 1000 times and calculates the deviation factor for the medians and CD for each random shuffle. The significance count is the fraction of times that the median or CD was above the calculated deviation factor when years are not mixed. A low significance count (closer to 0) means that the deviation factor is significant and a high significance count (closer to 1) means that the deviation factor is not significant.

Another set of statistics that are generated to help explain the degree of alteration are the range of variability statistics (RVA). When RVA was first incorporated into IHA, users were setting flow targets that maintained parameter values within RVA ranges such as the 25th and 75th percentile. It was recognized that this method can prevent extreme events that may have ecological relevance. To combat this issue a new method was developed where the 33rd and 66th percentile of each statistic are computed for the natural regime. Three bins are created based on
these percentiles; (0-33%, 34-66% and 67-100%). IHA calculates the number of annual values that fall within each bin for the natural regime (which will be roughly equal for each bin) and compares that to the number of annual values that fall within each bin for the altered regime. The degree of alteration is calculated for each bin as the percent difference between the observed number of values based on the natural regime and expected number of values based on the altered regime. IHA variables should be maintained such that annual values for parameters are equally distributed into the three statistical divisions, which accounts for the entire range of variability (Mathews and Richter, 2007; Peters et al., 2011; The Nature Conservancy 2009). An example of the RVA approach and the calculation of hydrologic alteration is shown for a period of record of 6 years in Figure 14.
### Figure 14: RVA approach and calculation of hydrologic alteration

<table>
<thead>
<tr>
<th>Percentile of Statistic</th>
<th>Pre-Impact</th>
<th>Post-Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>66th %</td>
<td>High RVA Category</td>
<td>High RVA Category</td>
</tr>
<tr>
<td>33rd %</td>
<td>Mid RVA Category</td>
<td>Mid RVA Category</td>
</tr>
<tr>
<td>2 4 6</td>
<td>Low RVA Category</td>
<td>Low RVA Category</td>
</tr>
</tbody>
</table>

**Hydrologic Alteration (HA)**

\[
HA = \frac{\text{Observed # of Occurrences} - \text{Expected # of Occurrences}}{\text{Expected # of Occurrences}}
\]

- **High RVA HA**
  \[
  = \frac{4-2}{2} = 1
  \]

- **Mid RVA HA**
  \[
  = \frac{2-2}{2} = 0
  \]

- **Low RVA HA**
  \[
  = \frac{0-2}{2} = -1
  \]
Chapter 6: Results and Discussion (Application of the Framework)

Phase I: Context Setting

a) Define Subwatershed Characteristics

*Topography and Landuse*

Lovers Creek subwatershed is 59.5 km², accounting for approximately 2% of Lake Simcoe Watershed’s total area. The subwatershed has a gentle gradient with 70% of the area having slopes less than 5%. Steeper slopes of greater than 5% are mostly located in the west central area of the watershed (Figure 15).
Landuse is illustrated in Figure 16 and consists of urban and built-up areas (31%), agriculture (34%) and natural heritage areas (35%). Note that Figure 16 shows the land use for Lovers Creek as well as Hewitt’s Creek and Barrie Creeks. The subwatershed is partially located in the City of Barrie (26%) and the County of Simcoe (74%) (LSRCA, Unknown). The lower end of the watershed is primarily within the City of Barrie whereas the middle and upper sections of the subwatershed are within the county of Simcoe. A major highway within the subwatershed is Highway 400 which passes through the subwatershed in a north-south direction very near its western boundary. The smaller roads within the subwatershed generally do not interfere with the streams with the exception of the local roads in the lower end of the subwatershed (LSRCA, Unknown). The agricultural areas mostly consist of row crops and pastures and the wetlands are woody wetlands often surrounded by coniferous woodlands (LSRCA, 2011a). Lovers Creek has a well vegetated riparian area with 70% natural heritage cover within a 30m buffer from the creek (Figure 16).
Surficial Geology and Geomorphology

The creek runs through till plain with some surficial deposits of kame or sand and gravel outwash in the areas of higher elevation which are mostly in the western section of the subwatershed. The eastern section of the subwatershed is primarily sand overlaying fine-grained soils (Appendix 1a-c)(LSRCAa, 2011). Lovers Creek has moderate to high infiltration areas across most of the subwatershed and contains a hydrogeologically significant groundwater recharge area called Lovers Creek Infiltration Area (Appendix 1 and Figure 17).
Figure 17: Significant wetlands and ANSI’s around Lovers Creek subwatershed (Adapted from (LSRCA, 2011b))
Sections of Lovers Creek are deeply incised with valley walls approximately 8-10 m high while other sections show little to no incision. Bank stability has been measured at various locations along the creek (Figure 18). It can be seen that most of the measured banks within the subwatershed are relatively stable. The banks along the main channel with the least stability are all clustered in the central section of the main channel, with sites LOV1G, LOV1H, LOV1I and LOV1J having the highest instability (Figure 18).

Climate

The climate of Lovers Creek subwatershed is typical of Southern Ontario with warm summers where the precipitation consists mainly of rain and cold winters where precipitation is mostly in the form of snow. There are no climate gauges within Lovers Creek subwatershed, but there is a station about 4 km to the North West of the creek’s outlet Barrie WPCC and another station (Cookstown) about 5 km south-west of the headwater boundary. The Barrie WPCC station has an average annual temperature of 6.7 °C and an average annual precipitation of 921 mm.
mm over a 29 year period of record from 1971-2000. The Cookstown station has an average annual temperature of 6.3 °C and an average annual precipitation of 818 mm over the same period of record. The difference in precipitation occurs mostly during the winter months and is due to the lake effect on the Barrie WPCC gauge (LSRCA, 2011b).

**Hydrology**

Lovers Creek runs a length of about 92 km and flows from Innisfil Heights down to a long bay that extends off the south-west side of Lake Simcoe called Kempenfelt Bay. The subwatershed has a drainage density of 1.6 km/km² which is slightly higher than the Lake Simcoe Watershed average of 1.46 km/km² (LSRCA, 2011a). Lovers Creek has a stream gauge located 100 m upstream of the mouth of the creek (Figure 19). This gauge is owned and operated by LSRCA and has a period of record of 2001-2012. According to LSRCA (2012b), and based on the gauge data, Lovers Creek at Tollendale has a mean annual flow of 0.76 m³/s, a high estimated mean annual baseflow of 0.44 m³/s and a low estimated mean annual baseflow of 0.29 m³/s corresponding to a baseflow index of 57% and 38%, respectively. Baseflow was determined by LSRCA (2012b) using the BFLOW program which is an algorithm that is meant to replicate graphical baseflow separation techniques. The high estimate is the first pass output and the low estimate is the third pass estimate. According to the gauge, Lovers Creek experiences its highest mean monthly flow and peakiness ratio in April at 1.65 m³/s and 21.2 respectively. The peakiness ratio is an indication of the variability of the streamflow and is calculated as the ratio of the 10th percentile to the 90th percentile. The lowest mean monthly flow occurs in August and is 0.31 m³/s. Lovers Creek has an extended low flow (7Q5) of 0.06 m³/s (LSRCA, 2011b).
Several spot flow measurements have also been collected at various points along Lovers Creek for low flow studies. One example is a spot flow measurement taken by Golder Associates as part of the South Simcoe Municipal Groundwater Study (LSRCA, 2011b). The measurement was taken near the mouth of the creek during a dry period and a baseflow of 0.14 m³/s was recorded. The sand and gravel outwash surficial geology and the steep slopes in the western portion of the subwatershed leads to significant groundwater upwelling whereas the gentle slope and fine grained soils in the eastern section of the subwatershed leads to little upwelling and little baseflow contribution.
Results from the source water protection Tier 2 water budget model indicates that Lovers Creek and the adjacent Hewitt’s Creek lose groundwater through inter-basin transfers with the majority of the water draining south and less water draining to adjacent subwatersheds to the east and west (LSRCA, 2010). Two municipal wells for Innisfil are located in the headwaters of the subwatershed with a reported average pump rate of 170 m$^3$/d in 2008. Additional water takings associated with golf courses and aggregate extraction can be found across the subwatershed (Figure 8).

Ecology

Lovers Creek subwatershed is considered unimpaired based on the conditions of the aquatic ecology and the water quality (LSRCA, Unknown). The groundwater upwellings in the western tributaries of Lovers Creek result in the river’s coldwater stream classification and provide locations for Trout spawning within the subwatershed (Figure 20). There are two biologically significant areas in the subwatershed; one area is the tenth concession tributary to Lovers Creek and the other is the south headwaters of Lovers Creeks. The Lovers Creek subwatershed also contains an Area of Natural and Scientific Interest (ANSI) located along one of the western tributaries (Figure 17). An ANSI is an area that has been identified by the Ministry of Natural Resources as having natural heritage or scientific value that should be protected. Private landowners are given tax incentives to protect ANSIs that occur within their property (CLTIP, 2011).
Lovers Creek Swamp is a Provincially Significant Wetland located within the subwatershed that consists of 99% swamp and 1% marsh. The wetland runs from Innisfil Creek all the way north to Kempenfelt Bay and covers an area of 6.8 km² (Figure 17) (LSRCA, 2010). The Lovers Creek wetland evaluation indicates that the wetland is predominantly palustrine with a small percentage of isolated wetland. However, the wetland surrounds Lovers Creek, which would suggest a classification of riverine. According to the wetland evaluation file, the swamp has a moderate to high amount of groundwater discharge and a high amount of groundwater recharge. The swamp has known ephemeral (less than 2 weeks inundation), temporal (temporal
2 weeks- 1 month) and seasonal (1-3 months) areas but no permanently or semi-permanently (>3 months) inundated areas (OMNR, 2011).

Lovers Creek Swamp has a high level of interspersion with over 277 intersecting vegetation communities. Based on the wetland evaluation file, the swamp is highly biologically significant and very important for flood attenuation and trapping nutrients as well as an important carbon sink. The wetland is moderately important for short-term water quality improvement but does not protect shoreline erosion. Lovers Swamp contains the provincially significant snapping turtle (*Chelydra serpentina*) as well at the provincially significant plant species Yellow-Monkey flower (*Mimulus moschata*). In addition, Lover Creek Swamp holds a number of locally significant plant species such as Nodding Trillium (*Trillium cernuum*) and Showy Lady’s-slipper (*Cypripedium reginae*) as well as locally significant winter cover, staging and moulting habitat for waterfowl and fish staging, migration, spawning and nursery habitat (OMNR, 2011; OMNR, 1994).

**b)-d) Definition of Subwatershed Goals, Habitat Specialists and Functional Analysis Assessment through Expert Input**

**Methodology Developed**

The Delphi technique was used for obtaining expert input to provide information required to complete steps within the Context Setting phase of the flow assessment. Experts from different disciplines with local knowledge of the study area were chosen to answer the questions. Through discussion with various staff at different agencies it became apparent that the experts at LSRCA would have the most local scientific expert knowledge of the subwatershed. The members of the Scientific Expert Team were decided upon with the help of the LSRCA
Subwatershed Planning Specialist, Warren Yerex. Chosen members were then contacted to see if they were interested in participating in the process. As recommended by Acreman and Dunbar (2004) the scientific expert team chosen was multidisciplinary and consisted of experts with a good knowledge of the study area. These experts included a Senior Environmental Monitoring Scientist, Senior Fisheries Biologist, Natural Heritage Ecologist, Aquatic Ecologist and a Conservation Lands Planner from the LSRCA as well as a Fish and Wildlife Technician from the Midhurst District Ministry of Natural Resources. A series of questions from general to specific were addressed within the questionnaire to determine how much information could be gleaned from the expert input process. A list of questions can be seen in Appendix 2.

Responses to the questions were summarized and similar answers were grouped together. Answers that occurred more frequently and answers that the respondent explicitly expressed as important were given greater weight. The aggregated survey responses as well as a summary of the responses and a plan for how the survey results were going to be used within the study were sent to the participants. The participants then responded to the aggregated survey results and commented on the aggregated survey analysis. The participant responses were considered with respect to the original survey and the original conclusions were adjusted accordingly. To assist with interpretation and analysis of survey results, responses to the questions were organized into a series of tables that are an adaptation of Table 1 presented in the framework document.

Results of Application of Developed Methodology

b) Identify Goals and Objectives

Although a range of goals and objectives were identified, the majority of the responses were related to cold water fish, wetland protection and maintenance of natural geomorphic
functions. It was identified that frequency of erosive flows has likely increased in more heavily developed areas and as a result, there may be local problems with incision. The human value of maintaining agricultural drainage in upstream fields was identified as being an important constraint that should be considered when implementing flow and water level targets (Table 7). The number of objectives chosen for this study was dependent on the amount of importance that the objectives were given during the interviews. These primary goals and objectives for the subwatershed were fairly evident prior to conducting the surveys through review of the various documents (primarily the subwatershed plan) but it was helpful to have this confirmed by the experts. As described in Figure 4, the framework is adaptive and if it is found through monitoring that additional functions are required to be integrated into the flow assessment, then this can be done when the flow assessment is revisited. Various specific quantifiable objectives were identified (such as the index of biotic integrity) but there was no consensus as to which measures are preferable.

c) Identify Habitat Specialists

The main habitat specialists identified include cold water fish (primarily brook trout but also mottled sculpin) as well as wetland amphibians and wetland vegetation (Table 7). Small mouth bass and riparian vegetation were also identified as important habitat specialists but they were rarely mentioned and not emphasized by the participants, so they were not included in the flow assessment.

d) Complete Functional Flow Assessment

Following the functional flow assessment method outlined in the framework for setting ecological flows and water levels, required functions were identified for each goal and the
important variables that limit functions were also identified. The flow and non-flow related processes that govern these variables were summarized as well as the temporal aspects of the flow regime.

Subwatershed goals were characterized as biotic, geomorphic or human goals. For the biotic goal of maintaining coldwater fish the most important functions identified were to maintain refugia from warm water and spawning habitat, as well as connectivity to warm water refugia and spawning habitat. For the biotic goal of wetland protection, it was identified that the most important function for maintaining wetland amphibians is maintaining breeding habitat and for wetland vegetation, soil saturation was identified as the most important function. To prevent excessive erosion is was suggested by the experts that erosive flows should be minimized, and to achieve the human need of agricultural drain use, it was identified that adequate drainage of upstream agricultural fields is required (Table 7).

<table>
<thead>
<tr>
<th>Goals</th>
<th>Habitat Specialist</th>
<th>Required Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic</td>
<td>maintain coldwater fish</td>
<td>refugia from warm water</td>
</tr>
<tr>
<td></td>
<td>brook trout</td>
<td>connectivity to refugia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>spawning habitat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>connectivity to spawning habitat</td>
</tr>
<tr>
<td>Geomorphic</td>
<td>prevent excessive channel erosion</td>
<td>minimal erosive flows</td>
</tr>
<tr>
<td>Human</td>
<td>allow for agricultural drain use</td>
<td>adequate field drainage</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

The variables that limit functions were identified for each required function (Table 7). For example, it was identified that pool depth and pool temperature are the most important
variables for maintaining summer refugia from warm water. Flow related processes were then identified for each variable that limits a required function. For example, the identified flow related processes governing the variable of pool depth are the flows capable of mobilizing accumulated superficial sediment to scour pools as well as flows required to maintain water depth. The timing of the flow related process that governs the variable required for the identified function was then defined for each flow related process. For example, flows capable of mobilizing accumulated superficial sediment required to scour pools should occur during the spring freshet so that the pools have the required depth in the summer. Finally non-flow related processes that may also affect the variable are identified because it may be possible to meet flow objectives by managing these processes in combination with flow (LSRCA and Bradford, 2011). For example, sediment yield was identified as a non-flow related process relating to pool depth since changes in sediment supply may cause increased or decreased pool depth as a result of a change in sediment accumulation within the pools. Variables that limit functions, flow and non-flow related processes and temporal aspects of each required function are shown in Tables 8 and 9 for streamflow sites and wetland points respectively. Targets were not set for the required function of maintaining adequate field drainage or for preventing excessive channel erosion, but these functions should be viewed as a constraint when implementing flow and water level targets and should be explored in future analysis.
<table>
<thead>
<tr>
<th>Goal Type</th>
<th>Required Functions</th>
<th>Variable(s) that Limit the Function</th>
<th>Flow-related Process(es) Governing Variable</th>
<th>Flow Regime (Temporal Aspects)</th>
<th>Non-flow Related Processes Affecting Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biotic</td>
<td>maintain summer refugia from warm water</td>
<td>pool depth</td>
<td>flows capable of mobilizing accumulated superficial sediment to scour pools</td>
<td>spring</td>
<td>sediment yield</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>adequate flows to maintain pool depth</td>
<td>summer</td>
<td>riparian cover, climate change, thermal discharges</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pool temperature</td>
<td>adequate flow depth to maintain temperature</td>
<td>summer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>maintain connectivity to thermal refuge areas</td>
<td>depth at riffle crest</td>
<td>adequate flows to maintain depth and velocity suitable for fish passage</td>
<td>summer</td>
<td>dams and barriers</td>
</tr>
<tr>
<td></td>
<td>maintain spawning habitat</td>
<td>spawning substrate</td>
<td>flows that will flush fine sediment from spawning beds</td>
<td>Fall - Winter; brook trout spawn October-December (Scott and Crossman, 1973)</td>
<td>sediment yield</td>
</tr>
<tr>
<td></td>
<td>groundwater upwelling</td>
<td></td>
<td>adequate groundwater discharge to attract spawning brook trout</td>
<td>fall/winter</td>
<td>channel bed sediment blocking discharge pathways</td>
</tr>
<tr>
<td></td>
<td>maintain connectivity to spawning habitat</td>
<td>depth at riffle crest</td>
<td>adequate flows to maintain depth and velocity suitable for fish passage</td>
<td>fall/winter</td>
<td>dams and barriers</td>
</tr>
<tr>
<td>Geomorphic</td>
<td>minimize erosive flows</td>
<td>bed and bank erosion</td>
<td>frequency and duration of erosive flows</td>
<td>all year</td>
<td>channel and bank stability</td>
</tr>
</tbody>
</table>
Table 9: Functional flow assessment for Lovers Creek subwatershed water level points

<table>
<thead>
<tr>
<th>Required Functions</th>
<th>Variable(s) that Limit the Function</th>
<th>Flow-related Process(es) Governing Variable</th>
<th>Flow Regime (Temporal Aspects)</th>
<th>Non-flow Related Processes Affecting Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>maintain amphibian breeding habitat (vernal pools)</td>
<td>duration, area and depth of pool inundation</td>
<td>high water levels of a significant duration</td>
<td>spring</td>
<td>climate - drying of vernal pools</td>
</tr>
<tr>
<td>soil saturation</td>
<td>depth of saturation</td>
<td>natural seasonal variation in water level regime</td>
<td>all year</td>
<td>climate - drying of vernal pools</td>
</tr>
</tbody>
</table>

Other Information from Surveys

It was generally not known how much flow can deviate from its natural regime before the species of interest is affected to the point where the objectives are no longer being met. However, it was estimated that as little as 0.5 m difference in depth to water table may distinguish areas of wetland and non-wetland plant species and changes of much less than 0.5 m may result in shifts in wetland vegetation communities. Most respondents recommended the identified variables be measured at the stream reach scale.

When asked about other specific biological values, Ephemoptera, Plectoptera and Trichoptera were cited as important macroinvertebrates. Setting flow requirements for macroinvertebrates is outside the scope of this study. However, it is recommended that targets for macroinvertebrates be explored in the future as data for macroinvertebrates within the LSRCA exist. It was uncertain what important molluscs exist in the subwatershed and no specific molluscs were identified. Since these values were not identified in the goals and objectives and because no specific molluscs were identified, these were not considered as main flow objectives for this study.
It was anticipated that specific locations such as important spawning sites of brook trout or important reproduction areas for wetland amphibians were going to be identified in the points of interest section of the survey. These areas were then going to be used for measuring flow ecological response. Participants in the survey identified that the ecological functions are located in headwater areas, all wetlands (particularly headwater wetlands), gaining reaches and lower western tributaries. These areas are much more general than was anticipated, but the information can still be used to narrow down some locations for measuring hydrologic alteration and flow ecological response.

Key stressors and threats were identified for the subwatershed with the majority of the responses focusing on intensive development in the middle to lower portion of the subwatershed. This information will be important when considering site selection and management scenarios. Additional data that may be useful for the project was identified through the survey and some advice was offered by the participants as to how the surveys could be more effectively conducted. The suggested refinements to the surveys will be discussed in “Chapter 7: Study Limitations and Recommendations”.

e) Geomorphic/Hydrologic Classification and Selection of Study Nodes

Identifying study nodes is an important step in the EFA process. Study nodes should capture the variability of the landscape. In order to do this, a hydrologic and/or geomorphic classification of the landscape should be completed. Once the classification is completed, study nodes should be distributed across the different classes.

The LSRCA completed a valley segment based geomorphic classification in Lovers Creek based on slope and surficial geology. Slope was divided into high, moderate and low
categories and surficial geology was divided into high, moderate and low permeability. Combined, these categories create nine possible groupings. Of the nine possible designations, six of the groups are present in Lovers Creek subwatershed. LSRCA established stream monitoring stations at random locations within each of the six designations. Data such as stream temperature, fish and benthic invertebrate presence has been collected and will continue to be collected for various ecological monitoring programs at these locations. Additional study nodes were located to detect changes associated with specific landscape attributes such as inline storm water ponds, instream barriers and the effect of the lake (Table 10 and Figure 21). Interestingly, there are no sites along any of the eastern tributaries. It is suspected that this is because the eastern tributaries are mostly warm water habitat which is of less interest to the LSRCA.

<table>
<thead>
<tr>
<th>Site Code</th>
<th>Randomly Selected?</th>
<th>Site Features and Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOV1A</td>
<td>No</td>
<td>Detect Population Influence of Lake Simcoe</td>
</tr>
<tr>
<td>LOV1B</td>
<td>Yes</td>
<td>Moderate Slope, Low Porosity</td>
</tr>
<tr>
<td>LOV1C</td>
<td>No</td>
<td>Above an On-Line SWM Pond</td>
</tr>
<tr>
<td>LOV1D</td>
<td>No</td>
<td>Above a Series of Four Barriers</td>
</tr>
<tr>
<td>LOV1E</td>
<td>Yes</td>
<td>High Slope, Moderate Porosity</td>
</tr>
<tr>
<td>LOV1F</td>
<td>No</td>
<td>Above a Barrier</td>
</tr>
<tr>
<td>LOV1G</td>
<td>Yes</td>
<td>Low Slope, Low Porosity</td>
</tr>
<tr>
<td>LOV1H</td>
<td>No</td>
<td>Above a Barrier</td>
</tr>
<tr>
<td>LOV1I</td>
<td>No</td>
<td>Above a Barrier</td>
</tr>
<tr>
<td>LOV1J</td>
<td>Yes</td>
<td>Moderate Slope, Moderate Porosity</td>
</tr>
<tr>
<td>LOV1K</td>
<td>Yes</td>
<td>Moderate Slope, Low Porosity</td>
</tr>
<tr>
<td>LOV1L</td>
<td>Yes</td>
<td>Low Slope, Moderate Porosity</td>
</tr>
<tr>
<td>LOV1M</td>
<td>No</td>
<td>Above a Barrier</td>
</tr>
<tr>
<td>LOV1N</td>
<td>No</td>
<td>Above a Barrier</td>
</tr>
</tbody>
</table>
A subset of the LSRCA monitoring sites were used for this study. Analysis was completed at four streamflow points shown in Figure 22. Three of the streamflow points run along the main channel of Lovers Creek from the mouth up to the headwaters and were chosen to gain an understanding of the difference in hydrology at different locations along the main channel. The fourth streamflow point is located at the upstream end of one of the western tributaries. This location is not an LSRCA monitoring station but was chosen as it has been identified as an ANSI.

In addition to streamflow study nodes, wetland study nodes were identified (Figure 22). The wetland locations were selected in order to gain an understanding of the hydrology of
wetlands with different attributes such as size, subwatershed position and surrounding land cover. One wetland point is located on a small section of Lovers Creek Swamp wetland in the lower end of the subwatershed along a small tributary and the other three points are located in a large section of Lovers Creek Swamp near the upstream end, off the main channel. The points in the upstream section of Lovers Creek Swamp are located at the center of the wetland as well as the east and west edge to gain an understanding of the spatial variability of the hydrological regime and hydrologic alteration of the swamp.

Figure 22: Lovers Creek analysis nodes
Streamflow Analysis

Phase II: Development of a Reference Regime and Hydro-Ecological Analysis

MIKE-SHE modelled, daily streamflow and water level data for the pre-settlement and current flow regimes were obtained from AquaResource Incorporated. In this study, modelled hydrographs and hydroperiods were compared for the same 59 (1951-2009) year period so human impact on the flow regime could be separated from climatic influences. The first year of the modelled streamflow and water level were used as a warm-up period for the model and was not included in the analysis.

For the purpose of this study, “pre-settlement” condition was considered to be before the majority of European settlement took place in the study area. The pre-settlement scenario was created by removing urban and agricultural land cover from the model. Hard copy land surveys from the early 1800’s were obtained from the Natural Heritage Information Centre of the Ministry of Natural Resources to determine the previous extent of the wetland and forest. Based on a visual comparison of both the early 1800’s survey maps and the current land cover maps, the spatial extent of the wetland in the past appears similar to the present day wetland extent for Lovers Creek Subwatershed, so the current wetland extent was used as the pre-settlement scenario and the remainder of the land was converted to forest.

To verify the assumption that the spatial extent of the wetland in the past was similar to the present day wetland extent in Lovers Creek, some wetland extent values for the Town of Innisfil were examined. The boundaries of the Town of Innisfil and Lovers Creek subwatershed are not exactly the same; however, there is significant overlap between these boundaries so statistics for the Town of Innisfil can be used to approximate values for Lovers Creek.
subwatershed. Ducks Unlimited (2010) estimated the Town of Innisfil had a pre-settlement wetland cover of 11.2%. The calculated current wetland coverage in Lovers Creek subwatershed based on data used in this study from the ecological lands classification is 9.2%, which is close to the 11.2% pre-settlement coverage estimated by Ducks Unlimited (2010).

Streamflow and water level data from the MIKE-SHE model were reformatted by the author of this paper for input into the IHA software, where the option of comparing 2 datasets was chosen. Non-parametric statistics were generated because of the skewed nature of most hydrometric data (The Nature Conservancy, 2009).

a) Characterize the Natural Regime

**EFC Parameter Calibration**

Prior to calculating the IHA and EFC statistics it was necessary to define appropriate thresholds for separating the EFC parameters. The term “calibration” will be used throughout this section to mean manually adjusting threshold values until the EFC’s are representative of their respective flow range based on visual inspection of the hydrograph. Thresholds for separating EFC parameters can either be set as a user defined flow percentile, a return interval or a flow value (The Nature Conservancy, 2009). The default IHA thresholds can be seen in Table 11.

<table>
<thead>
<tr>
<th>Environmental Flow Component (EFC)</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>separation of high flow pulse and low flow</td>
<td>75th Percentile</td>
</tr>
<tr>
<td>extreme low flow</td>
<td>10th Percentile of low flows</td>
</tr>
<tr>
<td>small flood minimum peak flow</td>
<td>2 year return interval</td>
</tr>
<tr>
<td>large flood minimum peak flow</td>
<td>10 year return interval</td>
</tr>
</tbody>
</table>
The Nature Conservancy (2009) recommends beginning EFC parameter calibration by examining the separation of high flow from low flow. Once this is properly calibrated, they recommend calibrating the other parameters. There are two options for the separation of high flow from low flow; regular calibration and advanced calibration. Regular calibration separates high flow from low flow using one high flow threshold (default 75\textsuperscript{th} percentile), where flows that exceed the high flow threshold are considered high flows and flows that do not are considered low flows. Advanced calibration uses a high flow threshold (default 75\textsuperscript{th} percentile) and a low flow threshold (default 50\textsuperscript{th} percentile). Flows that are above the high flow threshold are considered high flows and flows that are below the low flow threshold are considered low flows. Flows that are in between the high and low flow threshold are assigned to either high or low flow based on the rate of increase or decrease in flow from the previous day. The high flow start rate parameter (default value = increased flow of 25\% or more from the previous day) and the high flow end rate threshold (default value = decreased flow of 25\% or more from the previous day) are used to determine the transition between high and low flow classification when flows are between the high and low flow thresholds.

Based on visual analysis of separation of the daily hydrographs for both the regular and advanced calibration at the different sites it was determined that advanced calibration provided the best separation, so it was used for the hydrological analysis.

After assigning thresholds for the separation of high and low flow, The Nature Conservancy (2009) recommends calibrating the remainder of the parameters based on ecologically relevant flow thresholds. For calibration of the small flood threshold, The Nature Conservancy (2009) recommends using the bankfull flow. Bankfull depth can be estimated as
the minimum width to depth ratio at the channel cross over or can be estimated based on a return interval (Stanfield, 2010). Channel geometry data are available for site LOV1-01, so width to depth ratios were calculated for several flow depths at the upstream crossover (transect 10). It was found that the width to depth ratio decreased until the maximum elevation of the surveyed cross-section. This may be because the survey was not wide enough to reach bankfull width. Since bankfull width could not be determined from the surveyed cross-sections, the estimated average return interval for bankfull flow in Southern Ontario streams of 1.6 years was used for site LOV1-01 and for the remainder of the sites where channel geometry data were not analyzed (Annable, 1995).

The calibrated EFC values for the streamflow sites can be seen in Table 12. The advanced calibration parameters, high flow start rate threshold, and high flow end rate threshold were set to defaults of 25% and 10% respectively. High and low pulse default values are set to default values of the median plus and minus 25% for all sites. Note that the high flow, low flow and extreme low flow threshold values are 0 m³/s for the CWT site since it is an ephemeral stream. The characteristics of the streamflow at each site will be explored in more detail in the next section.

<table>
<thead>
<tr>
<th>EFC</th>
<th>Threshold</th>
<th>Flow (m³/s)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LOV1-01</td>
<td>LOV1-G</td>
<td>LOV1-03</td>
<td>CWT</td>
<td></td>
</tr>
<tr>
<td>high flow</td>
<td>75th Percentile</td>
<td>0.22</td>
<td>0.17</td>
<td>0.047</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>low flow</td>
<td>50th Percentile</td>
<td>0.13</td>
<td>0.11</td>
<td>0.027</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>extreme low flow</td>
<td>10th Percentile of low flows</td>
<td>0.08</td>
<td>0.06</td>
<td>0.004</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>small flood minimum peak flow</td>
<td>1.6 year return interval</td>
<td>7.50</td>
<td>4.65</td>
<td>1.18</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>large flood minimum peak flow</td>
<td>10 year return interval</td>
<td>15.32</td>
<td>9.35</td>
<td>2.13</td>
<td>0.66</td>
<td></td>
</tr>
</tbody>
</table>
A summary of the general characteristics of the natural regime for each study site as well as a comparison of the hydrology between the sites is provided in this section. Potential reasons for differences between hydrological regimes are explored in this section at a high level. A more complete understanding of the causes for differences between the hydrological regimes would require a quantification of the characteristics of each contributing area as well as more intimate knowledge of how each hydrological component was modelled. This in depth analysis is out of the scope of this report. The landscape characteristics of the contributing areas of all OSAP sites have been characterized and would be useful for this type of analysis (November 17 2011 conversation with L. Stanfield (OMNR Senior Research Biologist), unreferenced). Unfortunately these data were not available for this study. Understanding the natural regime is important as it defines the physical constraints of the system. Targets that are set should be guided by the natural regime and should be within the natural range of variability of the pre-settlement system (LSRCA and Bradford, 2011).

As would be expected, flow magnitudes are smaller for the sites further upstream along the main channel with LOV1-01 having a MAF of 0.31 m³/s, followed by site LOV1-G then LOV1-03 with MAF’s of 0.22 and 0.06 m³/s respectively. The POR highs range from greater than 35 m³/s for LOV1-01 to 21.6 m³/s for LOV1-G and 5.6 m³/s for LOV1-03. The POR lows range from 0.03 m³/s for LOV1-01 to 0.024 and 0.002 m³/s for LOV1-G and LOV1-03 respectively. The Central Western Tributary (CWT) site has a significantly different flow pattern than the sites along the main channel. The CWT is an ephemeral stream with a POR maximum of 1.39 m³/s and a POR minimum of 0 m³/s (Figure 13). The modelled flow is 0 m³/s for over 92% of the time at the CWT site and there is a median value of 340 zero flow days
(Figure 23). This is consistent with field observations from June 23rd 2011 of the CWT site which revealed little evidence of an active channel and well-established terrestrial vegetation. Only selected statistics will be discussed throughout this section for the CWT site since several of the statistics are not relevant due to the ephemeral nature of this site.

Table 13: Basic streamflow statistics for all streamflow sites

<table>
<thead>
<tr>
<th></th>
<th>LOV1-01</th>
<th>LOV1-G</th>
<th>LOV1-03</th>
<th>CWT</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAF (m³/s)</td>
<td>0.31</td>
<td>0.22</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td>POR Maximum (m³/s)</td>
<td>36.2</td>
<td>21.6</td>
<td>5.6</td>
<td>1.4</td>
</tr>
<tr>
<td>POR Minimum (m³/s)</td>
<td>0.03</td>
<td>0.024</td>
<td>0.002</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 23: FDCs for all streamflow sites

The sites along the main channel have an annual flow pattern that is typical of permanent streams in Southern Ontario with high spring flows, low summer baseflows and a small fall freshet (Figure 24). The CD and thus inter-annual variability is the highest in the spring for sites LOV1-01 and LOV1-G and lowest in the summer whereas the opposite is true for site LOV1-03,
where the lowest inter-annual variability is seen in the spring and the highest is in the summer (Figure 24). The higher inter-annual variability of summer flows at LOV1-03 may be a result of the less reliable baseflows from the smaller contributing area of this site versus the other two sites further downstream. The higher inter-annual variability of the spring flows at sites LOV1-01 and LOV1G further downstream may be a result of the variability in delivery of the spring melt and precipitation caused by the variability in landscape characteristics, (such as slope, surficial geology and land cover) precipitation and snowpack across the larger contributing area of these sites (Maidment, 1993). The mean monthly flow and CD for the CWT site is 0 for all months (Figure 24).

Figure 24: Median monthly flow and median monthly flow CD for all streamflow sites
As would be expected, the flow peaks for each EFC decrease with decreasing drainage area (Figure 25). The extreme low flow frequency and high flow frequency are fairly similar for all of the main channel sites. However, for the CWT site, the extreme low flow frequency is significantly higher than the main channel sites and the CWT high flow frequency is lower than the main channel sites (Figure 26). This may be explained by the smaller catchment area and ephemeral nature of the CWT site (Maidment, 1993).

![Figure 25: Flow peak EFCs and flood peak CD for all streamflow sites](image-url)
The duration of the different EFCs is fairly similar for all of the sites with the exception of the significantly higher small and large flood duration for site LOV1-01 and the significantly higher extreme low flow duration at the CWT site (Figure 27). The higher small and large flood duration at site LOV1-01 may partially be the result of larger drainage area of site LOV1-01 but there are many other factors that may influence flood duration such as catchment drainage density and land cover (Dingman, 1993). There are high CD’s and thus high inter-annual variability for most of the EFCs, with exceptionally high inter-annual variability in high flow peak at the CWT site, extreme low flow frequency at site LOV1-01, and large flood duration for all sites except for the CWT site (Figure 25, Figure 26 and Figure 27).
The 1, 3, 7, 30 and 90-day minimum and maximum flows are the highest for site LOV1-01 and decrease with decreasing drainage area. Inter-annual variability is fairly low for both minimum and maximum flows with the exception of the 30 day minimum flow at site LOV1-03 and the 7 and 30 day maximum flows for site LOV1-01 (Figure 28, Figure 29). These variabilities may be related to the summer monthly median variability for site LOV1-03 and the spring monthly inter-annual variabilities for site LOV1-01 described above (Figure 24). The median date of the minimum flow for LOV1-01, LOV1-G, LOV1-03 sites are August 23rd, August 13th and July 13th respectively and the median date of the maximum flow for LOV1-01, LOV1-G, LOV1-03 are April 17th, April 19th and June 14th respectively. The inter-annual variability for the date of minimum and maximum are low for all sites (Figure 28, Figure 29).
Figure 28: Minimum flow statistics and minimum flow CD for all streamflow sites

Figure 29: Maximum flow statistics and maximum flow CD for all streamflow sites
The baseflow index (BFI = 7 day minimum/MAF) is similar for both LOV1-01 and LOV1-G at 0.23 and 0.25 but much less at 0.06 for LOV1-03. The significantly lower BFI for site LOV1-03 is consistent with the previous observation of high inter-annual variability in monthly median flows for the summer. The rise and fall rates are highest at LOV1-01, and decrease as the sites move upstream. This may be due to the higher percentage of wetland area in the upper end of the subwatershed that may attenuate the flow and reduce rise and fall rates (Black, 1996). The rise rate of the CWT is higher than LOV1-03 but lower than LOV1-01 and LOV1-G while the fall rate for the CWT is the highest of all sites (Figure 30). The CD (inter-annual variability) of baseflow index, rise and fall rate and number of reversals are fairly low compared to the CD’s of other statistics for all sites.

Figure 30: Rise and fall rates and rise and fall CD for all streamflow sites
b) Assessment of Hydrologic Alteration

**Impacts of Anthropogenic Disturbances on Streamflow**

The major disturbance in the contributing area for all of the sites that likely has the largest effect on the modelled hydrology is the conversion of the forested land cover to urban and agricultural land use. The expected effects of this change in land cover on a system’s hydrology include reduced evapotranspiration and loss of storage from the loss of forest vegetation and the reduction of infiltration from the increased impervious surfaces. These changes generally result in increased high and flood flow peaks, magnitudes and frequencies but decreased high and flood flow durations as well as reduced baseflow and increased rise and fall rates (Leopold, 1968). The current land cover within the contributing area of each site can be seen in Figure 31 and 32. It can be seen that the majority of urbanization is located near the mouth of the subwatershed and is within the contributing area of LOV1-01 but not LOV1-G, LOV1-03 or the CWT site. LOV1-G consists of wetland, agriculture and a small amount of urban development, while LOV1-03 is predominantly wetland mixed with some agriculture. The CWT is a small catchment area that appears to be predominantly agricultural fields with a small amount of development (Figure 31 and Figure 32).

Groundwater and surface water takings may also have an impact on the streamflow at the different sites. Groundwater takings were included in both the pre-settlement regime and the current regime so it is difficult to discern the impact of this disturbance. The majority of the water takings in Lovers Creek subwatershed are less than 100 m³/day and probably do not have a large effect on the hydrology of the system. It is recommended that future studies remove
groundwater takings from the pre-settlement scenario in order to better understand the impact of this disturbance across the subwatershed.

Additional anthropogenic disturbances that may affect streamflow at the site but were not incorporated into the model include a municipal drain, dams and barriers, stormwater management and channel hardening structures (Appendix 1 d-f). The purpose of the municipal drain is to speed up the removal of surface water from upstream agricultural lands which could have an effect on the streamflow and the ecological functions throughout the river. The drain is included in the model where the additional channels exist as can be seen in the upper portion of the subwatershed where the channels appear unnaturally straight. The channel drains are periodically dredged to increase movement of water from the fields. This may cause inaccuracies in the hydraulic routing component of the model if adjustments to the model are not made to account for the channel dredging (Dingman, 1993).

Several dams and barriers and channel hardening structures are scattered across the subwatershed. These structures are not included in the MIKE-SHE model but may have a cumulative impact on the hydrology of the system (FISRWG, 1998).

Stormwater management can impact the hydrologic regime in urban areas where surface runoff may be collected and routed through constructed channels and detained in stormwater ponds. This will obviously impact the hydrological regime as the precipitation will move across the landscape at different rates and to different locations than it would under natural conditions (Leopold, 1968).
Figure 31: Contributing area of LOV1-01 and LOV1-G streamflow sites
Figure 32: Contributing area of LOV1-03 and CWT streamflow sites
**Hydrological Analysis**

Pre-settlement and current modelled streamflows were compared to determine the degree of hydrologic alteration at all of the streamflow sites. The FDC in Figure 33 indicates that flows of all exceedance probabilities at site LOV1-G have increased. Figure 33 shows that median flow (50\textsuperscript{th} percentile) increases by 19\% from pre-settlement to the current regime at site LOV1-G. The FDCs for all other sites are very similar to Figure 33 indicating that both the low and high flows increase at all of the sites from the pre-settlement to the current condition. These observations are mostly consistent with the expected effects of replacing forests with urban and agricultural land, with the exception of the increase in baseflow (Leopold, 1968). The increase in baseflow may be the result of the increased water volume from the reduced evapotranspiration having a larger effect than the decrease in infiltration caused by the increased imperviousness from urban infrastructure and agricultural soil compaction. Analysis of various components of the modelled water budget as well as the model parameterization may help determine if this hypothesis is valid. It is recommended that model output for a variety of the water budget components beyond streamflow be used for the assessment of the hydrologic alteration in future EFA’s.
All median monthly flows increase for each site with the exception of median March and April flows at site LOV1-01 (which show a slight decrease) and the CWT site (which shows no change). Site LOV1-03 has the highest increase in monthly median flows for most months followed by LOV1-G then LOV1-01. For most sites, the inter-annual variability of monthly flow increases anywhere from 0-45% as indicated by the CD in Figure 34. The inter-annual variability decreases for April and March median flows at site LOV1-01 (Figure 34).
Figure 34: Change in monthly median flow and CD for all streamflow sites

At most sites, the changes in extreme low duration and frequency are consistent with the observation of increased magnitude of low flows. Extreme low flow frequency and durations decrease at all sites except for LOV1-G, which experiences a slight increase in extreme low flow duration and the CWT site which experiences an increase in extreme low frequency (Figure 35). The extreme low flow at site CWT is 0 m³/s, so the increase in low flow frequency is likely due to the increase in high flow pulses that result in a flow of 0 m³/s occurring more frequently but for a shorter duration.
High flow and small flood frequencies either do not change or increase at all sites, which is consistent with the expected effects of the modelled land cover changes (Figure 35) (Leopold, 1968). Large flood frequencies are not shown in Figure 35 because there is no change in this statistic at any of the sites. High flow, small flood and large flood durations either do not change or decrease at most sites, which is also consistent with the expected effects of the modelled land cover changes (Leopold, 1968). The exception to this trend is the increase in high flow, small flood and large flood durations at site LOV1-03. There is a very large increase in small flood frequency inter-annual variability at the CWT site and substantial decreases in inter-annual variability for extreme low flow duration at all sites along the main channel (Figure 35).

![Figure 35: Change of EFCs and EFC CDs for all streamflow sites](image-url)
The minimum and maximum flows for all sites increase by at least 10% and by as much as 50%. The statistics for the date of the minimum for LOV1-01 and LOV1-G slightly decrease indicating that the minimum flows occur earlier in the year and the date of maximum flows for all sites shifts to occur later in the year. The significance count of the change in date of minimum flows is high indicating that the change is not likely significant. The inter-annual variability increases for all statistics with exceptionally high increases in inter-annual variability for the 3 and 7 day minimum flows at site LOV1-03 and the date of the maximum flow at site LOV1-01 (Figure 36).

Figure 36: Change of minimum and maximum flows and minimum and maximum flow CDs for all streamflow sites
There are no zero flow days in either the pre-settlement or current scenario for the main channel sites and a slight decrease in zero flow days for the CWT site. The BFI slightly decreases for LOV1-01 and LOV1-G and slightly increases for LOV1-03. The decrease in BFI results from the larger increase in MAF relative to the 7 day minimum flow given that the BFI is the ratio of the two statistics. The rise and fall rate as well as the number of reversals either increase or do not change at all sites except for the CWT site where the rise rate decreases. The rise rate increases substantially more at site LOV1-01 than LOV1-G and LOV1-03 (Figure 37).

As described above, the majority of urbanization that is located near the mouth of the subwatershed is within the contributing area of LOV1-01 but not LOV1-G and LOV1-03, which may explain the higher increase in LOV1-01 rise rate. It would be expected that the conversion from forested land cover to urban and agricultural land cover would increase the rise and fall rate due to reduced interception from the forest cover and increased surface runoff from increased impervious surface area (Leopold, 1968). It is uncertain why the rise rate decreases at the CWT site. The number of reversals increase at all sites with the CWT site increasing substantially more. The increase in the number of reversals may be because water from a single event that would not have reached the stream as rapidly in the pre-settlement scenario as a result of evapotranspiration or infiltration may now enter the stream more rapidly causing a flow pulse. The CWT may be affected the most by this phenomenon because it is a naturally flashy system according to the characterization of the natural regime (Leopold, 1968). There is an exceptionally high increase in inter-annual variability in fall rate at site LOV1-03 and a high
decrease in inter-annual variability for the number of reversals and number of zero flow days at the CWT site (Figure 37).

![Figure 37: Change of BFI, zero flow days and rise and fall statistics and CDs for all streamflow points](image)

**Modified Dundee Hydrological Regime Alteration Method (DHRAM) Index**

The modified DHRAM index is an aggregate of the IHA statistics that provides a useful summary of hydrological alteration at each site. The DHRAM index can also provide an effective format for communicating a simplified hydrologic index to non-technical audiences. It is however important to realize that this should serve as a summary index only and should not replace more detailed analysis of each IHA statistic.
The modified DHRAM index is a modification of the DHRAM index developed by Black et al. (2005), and is calculated by averaging the absolute value of the percent change from the pre-settlement to the current scenario for each of the five IHA parameter groups. The averages of the IHA parameter groups are then summed to produce the modified DHRAM index. The index value is a relative number for assessing the alteration within a subwatershed where higher modified DHRAM indices suggest that more hydrologic alteration has occurred. The original DHRAM index is very similar to the modified DHRAM index but in the original DHRAM index parameter group averages are divided into percentile ranges, the different percentile categories are assigned incremental scores, then the scores are summed to produce an index value (Black et al., 2005). The modified DHRAM scores for the streamflow points are 2.84, 2.06, 1.57 and 2.13 for site LOV1-01, LOV1-03, LOV1-G and the CWT site respectively. The modified DHRAM indices for all streamflow sites can be seen in Figure 38.
Figure 38 shows that according to the DHARM index, the highest amount of hydrologic alteration occurs at site LOV1-01 located at the mouth of the river. The second highest hydrologic alteration occurs at the CWT site followed by site LOV1-03 and then site LOV1-G. Site LOV1-01 has the highest amount of urbanization in its contributing area so it makes sense
that it would have the highest alteration. There are no obvious reasons as to what may be causing the different degrees of hydrological alteration at the remainder of the sites.

c) Hypothesized Ecological Responses to Hydrologic Alteration

The purpose of this next section is to hypothesize potential ecological responses to the hydrologic alterations that have been identified in the previous section. First, the ecological characteristics of each site will be described based on the data that are currently available (Table 15). Next, the ecological functions (from the functional flow assessment) that are relevant at each site will be identified based on the characteristics of each site. An ecological model will be developed for each site based on the identified ecological functions and their temporal aspects, and finally, potential ecological responses to hydrological alteration will be discussed based on the type of hydrological alteration and the ecological characteristics of each site. It is important to note that the ecological functions that were chosen for each site in this study were based on the current condition of the subwatershed and were thus chosen to protect existing conditions. If the objective of the flow assessment was to restore sites to a given condition then the attributes of the restored condition should be used to define the ecological model.

Ecological Characteristics of Streamflow Sites

Site LOV1-01

Over the past decade ecological data have been collected at site LOV1-01 by the LSRCA. According to this data, this site has a “very good” benthic invertebrate score based on the Hilsenhoff index. A “very good” benthic invertebrate score within the Hilsenhoff index indicates that there is a high composition of arthropods that are sensitive to low concentrations of
dissolved oxygen and that there is possibly only slight organic pollution at the site (LSRCA, 2011a; Hilsenhoff, 1988). The site has recorded warm water temperatures but cold water fish. Water temperature classification was determined by the LSRCA using the method developed by Stoneman and Jones (1996). This method classifies stream temperature as cold, cool or warm using a nomogram, the water temperature at 16:00 hours and the maximum air temperature from that day. Both brook trout and mottled sculpin have been caught at this site. The occurrence of cold water fish in warm water habitats is likely due to the presence of cold water temperature microhabitats such as areas with deep pools, coldwater upwelling, undercut banks and riparian or instream cover. The occurrence of cold water fish in warm water habitats may also be due to cold water fish passing through the study site during sampling but this is less likely (LSRCA, 2011a). The site has a fair index of biotic integrity, meaning that there is low to average diversity and abundance of fish at the site (LSRCA, 2011a).

The banks along a 40 m transect at the site were surveyed and it was found that 60% of the sample points were stable, 30% were moderate and 10% of the sample points were unstable. These classifications are based on bank angle, soil/substrate and other bank characteristics (Stanfield, 2010). Filamentous algae and non-filamentous algae are found throughout the reach but there is no moss, aquatic macrophytes, watercress and terrestrial vegetation, although grass is found under the water at some points near both banks (Stanfield, 2010).

Following the method described in Mathews and Richter (2007), an ecological model was developed based on information from the functional flow assessment and the site attributes outlined above (Figure 39). The ecological functions that were identified through the functional flow assessment within this study include maintaining thermal refuge pools in the summer,
maintaining spawning habitat and maintaining connectivity to thermal refuge areas and spawning habitat.

According to the scientific experts interviewed for this study, the functions of maintaining summer thermal refuge pools, as well as connectivity to summer pools are particularly important as warm water temperatures are recorded but cold water fish are observed at this site. Connectivity to spawning habitat will also be important since brook trout are present at this site and will need to migrate upstream to spawning habitat. The function of maintaining spawning habitat for coldwater fish is not relevant at this site since, according to the scientific experts, spawning occurs in the headwaters where groundwater upwelling is present. Further evidence suggesting that groundwater upwelling (and trout spawning) does not occur at site LOV1-01 is the absence of watercress as recorded in the OSAP database.

<table>
<thead>
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<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
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<tbody>
<tr>
<td><strong>HIGH FLOWS</strong></td>
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<tr>
<td>• Scour pools to maintain pool depth for summer thermal refuge</td>
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</tr>
</tbody>
</table>

| **LOW FLOWS** |     |     |     |     |     |     |     |     |     |     |     |     |
|               |     |     |     |     |     |     |     |     |     |     |     |     |
| • Maintain connectivity to thermal refuge areas |
| • Maintain temperature and depth of summer pools |
| • Maintain connectivity to spawning habitat |

Figure 39: Ecological model for site LOV1-01
Site LOV1-G

According to the data collected at site LOV1-G by the LSRCA, LOV1-G has a fair benthic invertebrate score based on the Hilsenhoff index which means that the site likely has fairly significant organic pollution (LSRCA, 2011a; Hilsenhoff, 1988). Similar to site LOV1-01, warm water temperatures are recorded at the site but cold water fish are present. Mottled sculpin have been captured at this site but brook trout have not. This likely indicates that cold water refuge areas are present near this site (LSRCA, 2011a). This site has a poor fish index of biological integrity which means that there is low fish abundance and diversity and there are no top predators or trout (LSRCA, 2011a). The site has filamentous algae, aquatic macrophytes, grass and terrestrial plants present but no recorded presence of moss, watercress or non-filamentous algae (Stanfield, 2010). The banks along the 40 m reach length of the site are recorded as being 25% unstable, 65% moderately stable and 10% stable based on bank angle, soil/substrate and other bank characteristics (Stanfield, 2010).

An ecological model was created for site LOV1-G based on the information from the functional flow assessment and the attributes at this site. Given that cold water fish are found at this site, but warm water temperatures are recorded, thermal refugia for cold water fish has been identified as a limiting need at this site. Coldwater fish spawning habitat does not likely occur at this site because the spawning habitat was identified to occur in the headwaters and this site is midway along the main channel. In addition, watercress is not present at this site which is an indication of coldwater upwelling and potential brook trout spawning. However, connectivity to spawning areas will likely be important at this site since brook trout occur at this site and will
need to migrate to spawning habitat. The ecological model for site LOV1-G is the same as site LOV1-01 (Figure 39).

Site LOV1-03

According to the ecological data collected at site LOV1-03 by the LSRCA, LOV1-03 has a fairly poor benthic invertebrate score, which means that substantial organic pollution is likely (LSRCA, 2011a; Hilsenhoff, 1988). The site has warm water fish present and neither brook trout nor mottled sculpin have been caught at this site. No temperature measurements have been taken at this site. Site LOV1-03 has a poor fish index of biotic integrity which means that there is low fish abundance and diversity and there are no top predators or trout (LSRCA, 2011a). Bank stability and the presence of algae and aquatic plants were not recorded at this site. It is uncertain why temperature, bank stability, algae and aquatic plants were not measured at this site but it is hypothesized that more data are collected at sites that are perceived to have greater ecological value and sites that are more affected by development and are at the most risk.

An ecological model was created based on information in the functional flow assessment and the site attributes described above (Figure 40). Since cold water fish are not found in this reach, the functions associated with thermal refugia will not be included. The reach is located near several headwater tributaries that have potential brook trout spawning habitat, so connection to coldwater fish spawning habitat will be included as an important function.
CWT Site

The central western tributary site is not a LSRCA monitoring location. This site was chosen because it has been identified as an ANSI by the Ontario Ministry of Natural Resources (OMNR). The OMNR was contacted for additional information regarding this site but no information was provided. Site LOV1-H, which is located along the same tributary as the CWT site, but is closer to the main channel of Lovers Creek, has coldwater temperatures but no fish caught at the site (Figure 21). Site LOV1-H has an excellent benthic rating which means that it is likely that there is no organic pollution at the site. According to the OSAP database, site LOV1-H has no filamentous or non-filamentous algae, moss, aquatic macrophytes, but has an abundance of watercress and grass within the channel as well as some terrestrial vegetation.

The CWT site is likely inhospitable for most aquatic species given that the natural regime model output indicates that no flow is present in the stream at this site for the majority of the year (a median of 340 days). The decrease of zero flow days and general increase in low and high flows from pre-settlement to the current scenario is not likely large enough to provide habitat to aquatic species.

Based on an assessment of the site attributes and the functional flow assessment, none of the functions that were identified by the scientific experts are relevant at this site and therefore no ecological model or targets based on ecosystem objectives were developed.
Table 14: Summary of ecological characteristics for each site (Note: Data are not available for the CWT site)

<table>
<thead>
<tr>
<th></th>
<th>LOV1-01</th>
<th>LOV1-G</th>
<th>LOV1-03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benthic Invertebrate Score</td>
<td>Very Good</td>
<td>Fair</td>
<td>Fairly Poor</td>
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<tr>
<td>Stream Temperature Classification</td>
<td>Warm</td>
<td>Warm</td>
<td>N/A</td>
</tr>
<tr>
<td>Fish Type Present</td>
<td>Cold</td>
<td>Cold</td>
<td>Warm</td>
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<tr>
<td>Index of Biotic Integrity</td>
<td>Fair</td>
<td>Poor</td>
<td>Low</td>
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<tr>
<td>Bank Stability</td>
<td>Stable</td>
<td>60%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>30%</td>
<td>65%</td>
</tr>
<tr>
<td></td>
<td>Unstable</td>
<td>10%</td>
<td>25%</td>
</tr>
<tr>
<td>Algae Present</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
</tr>
<tr>
<td>Stream Vegetation</td>
<td>Some Grass</td>
<td>Aquatic macrophytes, grass and terrestrial plants</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Flow-Ecological Response Linkages**

This next section will discuss the hypothesized ecological response to the hydrological alteration that has been described above. The hypotheses described below are based on scientifically derived, general relationships that have been compiled from decades of environmental flow studies (Poff et al., 1997). These hypothesized responses occur at different temporal scales and may have already occurred within the system as a result of the alteration, may be in the process of occurring or may occur in the future as a result of the hydrological alteration. These relationships can be used to identify monitoring opportunities and guide scientific studies that test the hypothesized flow-ecological response relationships. These relationships can also be used to guide restoration activities within the subwatershed. The general hypothesized flow-ecological response relationships described below were derived from the literature and knowledge of the study area from existing reports. This information could possibly be improved and better tailored to the specific study site if the relationships were derived from experts with knowledge of the local area (Poff et al., 2009). Expert input was not
used at this phase of the EFA because the structured expert interviews were conducted before the hydrologic alteration was calculated for each site. It is recommended that expert input be incorporated into this phase of future EFA’s.

Change in Annual Minimum and Extreme Low Flows

Annual minimum flows increase from the pre-settlement to the current scenario at all sites, extreme low flow frequency decreases at all sites but the CWT site and extreme low flow duration decreases at all sites but LOV1-G. The increase in minimum flows and decrease in extreme low flow duration and frequency both result in an overall increase in low flows. The increase in low flows may have a positive effect on the ecosystem by providing an overall increase in habitat availability (The Nature Conservancy, 2009). The increased low flows may also decrease soil moisture stress which may lead to changes in riparian vegetation. The increased depth from the increase in low flows may lead to reduced temperatures and increases in dissolved oxygen (DO), which is beneficial for certain cold water species such as brook trout (Imhof et al., 1996). However, the increase in low flow may lead to decreased riffle habitat reducing aeration and DO. The increase in low flows may have other negative effects such as invasion by habitat generalists who are less tolerant to lower flows. Finally, the increase in low flows may cause changes to the food web by decreasing the number of isolated pools where predators would normally feed on vulnerable prey (The Nature Conservancy, 2009).

The increased duration of extreme low flows at site LOV1-G and the increased frequency of extreme low flows at the CWT site may cause desiccation induced stress or mortality to the flora and fauna at these sites (The Nature Conservancy, 2009).
Change in Annual Maximum Flows

It was identified through the assessment of hydrological alteration that there is an increase in annual maximum flows from the pre-settlement scenario to the current scenario at all of the streamflow sites. The increase in maximum flows may affect the aquatic ecosystem in several ways. There may be an effect on channel morphology and subsequently on sediment balance and physical habitat as a result of this change. The increase in annual maximum flows may also alter the physical habitat of the floodplain by forming new habitats such as secondary channels and oxbows. In addition, organic material (food) and woody debris (habitat) may wash into the channel from the floodplain as a result of an increase in annual maximum flows. The additional woody debris may provide additional habitat for cold water fish seeking thermal refuge at sites where this is relevant. Field investigation of the geometry and land cover of the floodplain at all sites may help elucidate whether or not these hypothesized effects have occurred or may occur in the future. The median timing of maximum flow shifts to later in the year for all sites. This shift may interrupt species that have entered phases of their life cycle that are not adapted to cope with high flows at that time of the year.

Change in Annual High Flows

An increase in annual high flow frequency was identified at all sites except for LOV1-03. An increase in high flow frequency may lead to increased erosion which may disrupt physical habitat features such as pools and riffles. This may then have an effect on the summer pool habitat available for thermal refuge at sites where refugia is relevant (The Nature Conservancy, 2009). Increased frequency of high flows may also change the size of streambed substrates which will have subsequent effects on the use of the space by fish and benthics that prefer a
given substrate type for certain phases of their life cycle (Poff et al., 2009). More frequent high flows may lead to increased bed scouring which may interfere with the establishment and survival of benthic invertebrates with poor re-colonization ability, shifting the community towards “weedy” invertebrate species (Poff et al., 2009). Young of year abundance may be reduced due to the increased stress from high flow pulses. It is unknown whether or not these sites are used as nursery areas for young of the year fish.

Riparian vegetation may be affected by the increased frequency of scour caused by the increased frequency of high pulses. The nutrient balance also may be affected as there may be an increase in flushing of nutrients down the channel (The Nature Conservancy, 2009). This could affect nutrient quantity and timing which may affect nutrient bioavailability at the site and downstream (Withers and Jarvie, 2008). Finally, an increase in summer high flow frequency at site LOV1-01 may lead to increased temperature spikes within the river. Temperature spikes may occur as a result of the surface runoff coming in contact with hot pavement in the summer before entering the stream. These temperature spikes may cause stress or mortality to cold water species in the area (Jones and Hunt, 2009).

A small increase in high flow duration is observed at site LOV1-G and a small decrease in high flow duration is apparent at the CWT site. The increase in high flow duration may amplify the effects of the increase in high flow frequency described above.

Change in Annual Small and Large Floods

A decrease in small flood duration was observed at site LOV1-01 and the CWT site and a decrease in large flood duration was observed at site LOV1-01 and LOV1-03. This reduced duration of small and large floods may lead to a reduction in time for floodplain spawning and
reduction in the time the floodplain can be used as a nursery area resulting in reduced invertebrate and fish production and biomass. It may also lead to a reduction in time for fish to feed in the floodplain and for waterfowl to utilize the floodplain habitat. Reduced duration of small and large floods may affect the riparian area reducing the time for the floodplain water table to recharge. This may result in a change of floodplain forest types, to types that are tolerant to drier conditions. In addition, shorter durations of large and small floods may allow for less time for sediments and nutrients to settle from water and be deposited on to the floodplain, disrupting the sediment and nutrient balance within the system (The Nature Conservancy, 2009).

Increased duration of small and large floods occurs at site LOV1-G while site LOV1-03 experiences a slight increase in large flood duration. An increase in duration of small and large floods may have the opposite effect of reducing the flows as described above such as an increase in the amount of time available for floodplain use as spawning, nursery, and foraging habitat, increased floodplain water table recharge, and changes in riparian vegetation and nutrient balance. In addition, in areas where refuge from high velocities that are associated with small and large floods are not available, increased durations of these flows may lead to stress or mortality.

The frequency of small floods increases for site LOV1-G and the CWT site. The ecological response to the increased frequency of small floods will be similar the ecological response to increased durations described above (The Nature Conservancy, 2009).

**Change in Rise Rate, Fall Rate and Number of Reversals**

An increase in rise rate, fall rate and number of reversals is observed at most sites. The increase in rise rate may lead to entrapment of terrestrial organisms on islands or in the
floodplain and may increase stress to mobile organisms as they will have less time to move to high flow refugia (The Nature Conservancy, 2009). An increase in fall rate may have the opposite effect and may entrap aquatic species in isolated habitats or in extreme cases may cause stranding. The increase in number of reversals may force species to become more mobile resulting in the increased expenditure of energy and a decrease in overall health (The Nature Conservancy, 2009).

Change in Inter-annual Variability of Flow Statistics

Increases in inter-annual variability for the different statistics may lead to stress to organisms that have adapted to rely on the natural predictability of a given flow for various stages of their life history. Decreased inter-annual variability will result in more predictable habitat disturbance which may favour habitat generalists and lead to less ecosystem complexity. The natural flow regime consists of the optimal balance between inter-annual variability and inter-annual predictability.

In summary, the natural hydrological regime and the degree of hydrologic alteration was characterized for each site within this section. An ecological model was developed for each site based on the functional analysis completed in the context setting phase and the ecological characteristics for each site were described. Finally, flow ecological response hypothesis were made based on scientifically accepted general relationships between flow alteration and potential ecological responses. In the next section, targets will be developed to protect or restore overall ecosystem health and also to specifically protect the important ecological functions that were identified in the context setting phase.
Phase III: Development of a Target Regime

In order to avoid or reverse the potential ecological effects of the hydrologic alteration described above, it is necessary to restore or maintain the natural hydrological regime as much as possible. This will allow for the maintenance of natural physical, chemical and biological conditions at the site. In order to do this, hydrologic targets can be set to inform decision making. Two types of hydrological targets are set in this flow assessment. The first targets are set based on all IHA hydrological statistics. These targets are important for overall ecosystem health and help to identify issues that may not be apparent from the second set of hydrological targets. The second set of hydrological targets relates to the specific ecological objectives and is important for maintaining those specific functions.

a) Targets for Overall Ecosystem Health

Targets for each IHA statistic were set based on the range of variability of each hydrologic statistic. The range of variability (RVA) bounds (33rd and 66th percentile) for each IHA statistic for each site can be seen in Table 15. As described in the “Indicators of Hydrologic Alteration” section, median annual values of the statistic are divided into categories based on the percentile of the value. Three RVA categories are created; Low = 0th -33rd percentile, Mid = 33rd-66th percentile and High = 66th-100th percentile. Under the natural condition, an equal number of values fall into each category. The hydrologic alteration factor is a measure of the change in the number of values that fall into each category from the pre-settlement to the current condition. The flow target is to maintain an equal distribution of the median annual values across the three RVA categories (The Nature Conservancy, 2009).
It is suggested that the hydrologic model be run for various development (e.g. low impact development vs. regular development) or restoration scenarios (e.g. low impact development retrofits). Each scenario should then be compared to the pre-development condition within IHA to produce a series of hydrologic alteration factors. The hydrologic alteration of the different scenarios can then be compared to determine which scenario has the highest hydrologic alteration factors and thus the highest impact on the hydrological regime. The potential benefits of restoration or impacts of development of the different scenarios on the overall health of the system can be evaluated by inferring potential flow ecological responses to the hydrological alteration. The assessment of these potential benefits and impacts will provide information to decision makers that will lead to more effective restoration and more ecologically sustainable development.

The targets could also be applied post-construction to monitor the actual effect of the restoration or development on the system. This could be accomplished by comparing gauged data at the site to the natural regime and the pre-construction regime.
### Table 15: RVA bounds for IHA at all streamflow sites

<table>
<thead>
<tr>
<th></th>
<th>LOV1-01</th>
<th>LOV1G</th>
<th>LOV1-03</th>
<th>CWT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 33%</td>
<td>High 66%</td>
<td>Low 33%</td>
<td>High 66%</td>
</tr>
<tr>
<td>January Median Flow (m³/s)</td>
<td>0.12</td>
<td>0.18</td>
<td>0.09</td>
<td>0.13</td>
</tr>
<tr>
<td>February Median Flow (m³/s)</td>
<td>0.13</td>
<td>0.19</td>
<td>0.09</td>
<td>0.14</td>
</tr>
<tr>
<td>March Median Flow (m³/s)</td>
<td>0.19</td>
<td>0.33</td>
<td>0.14</td>
<td>0.19</td>
</tr>
<tr>
<td>April Median Flow (m³/s)</td>
<td>0.25</td>
<td>0.49</td>
<td>0.15</td>
<td>0.23</td>
</tr>
<tr>
<td>May Median Flow (m³/s)</td>
<td>0.17</td>
<td>0.21</td>
<td>0.11</td>
<td>0.14</td>
</tr>
<tr>
<td>June Median Flow (m³/s)</td>
<td>0.12</td>
<td>0.15</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>July Median Flow (m³/s)</td>
<td>0.09</td>
<td>0.11</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>August Median Flow (m³/s)</td>
<td>0.09</td>
<td>0.11</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>September Median Flow (m³/s)</td>
<td>0.10</td>
<td>0.13</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>October Median Flow (m³/s)</td>
<td>0.12</td>
<td>0.15</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>November Median Flow (m³/s)</td>
<td>0.14</td>
<td>0.18</td>
<td>0.11</td>
<td>0.14</td>
</tr>
<tr>
<td>December Median Flow (m³/s)</td>
<td>0.14</td>
<td>0.18</td>
<td>0.11</td>
<td>0.13</td>
</tr>
<tr>
<td>1-day minimum Median Flow (m³/s)</td>
<td>0.07</td>
<td>0.08</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>3-day minimum Median Flow (m³/s)</td>
<td>0.07</td>
<td>0.09</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>7-day minimum Median Flow (m³/s)</td>
<td>0.07</td>
<td>0.09</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>30-day minimum Median Flow (m³/s)</td>
<td>0.09</td>
<td>0.11</td>
<td>0.06</td>
<td>0.07</td>
</tr>
<tr>
<td>90-day minimum Median Flow (m³/s)</td>
<td>0.12</td>
<td>0.15</td>
<td>0.08</td>
<td>0.12</td>
</tr>
<tr>
<td>1-day maximum Median Flow (m³/s)</td>
<td>7.77</td>
<td>11.12</td>
<td>3.82</td>
<td>5.90</td>
</tr>
</tbody>
</table>
### Table 15 Continued

<table>
<thead>
<tr>
<th></th>
<th>LOV1-01</th>
<th>LOV1G</th>
<th>LOV1-03</th>
<th>CWT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 33\textsuperscript{rd} %</td>
<td>High 66\textsuperscript{th} %</td>
<td>Low 33\textsuperscript{rd} %</td>
<td>High 66\textsuperscript{th} %</td>
</tr>
<tr>
<td>3-day maximum Median Flow (m³/s)</td>
<td>4.49</td>
<td>7.13</td>
<td>2.33</td>
<td>3.45</td>
</tr>
<tr>
<td>7-day maximum Median Flow (m³/s)</td>
<td>2.25</td>
<td>4.73</td>
<td>1.20</td>
<td>2.11</td>
</tr>
<tr>
<td>30-day maximum Median Flow (m³/s)</td>
<td>0.96</td>
<td>1.88</td>
<td>0.51</td>
<td>0.86</td>
</tr>
<tr>
<td>90-day maximum Median Flow (m³/s)</td>
<td>0.55</td>
<td>0.84</td>
<td>0.31</td>
<td>0.43</td>
</tr>
<tr>
<td>Number of zero days (#)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Base flow index</td>
<td>0.20</td>
<td>0.26</td>
<td>0.23</td>
<td>0.27</td>
</tr>
<tr>
<td>Date of minimum (Julian date)</td>
<td>221</td>
<td>248</td>
<td>217</td>
<td>239</td>
</tr>
<tr>
<td>Date of maximum (Julian date)</td>
<td>95</td>
<td>162</td>
<td>97</td>
<td>163</td>
</tr>
<tr>
<td>Rise rate ((m³/s)/day)</td>
<td>0.03</td>
<td>0.05</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Fall rate ((m³/s)/day)</td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>Number of reversals (#)</td>
<td>124.80</td>
<td>134.20</td>
<td>125.50</td>
<td>135.10</td>
</tr>
<tr>
<td>Low pulse count (#)</td>
<td>7.80</td>
<td>14.20</td>
<td>7.00</td>
<td>14.06</td>
</tr>
<tr>
<td>Low pulse duration (days)</td>
<td>3.50</td>
<td>5.77</td>
<td>3.57</td>
<td>5.43</td>
</tr>
<tr>
<td>High pulse count (#)</td>
<td>19.00</td>
<td>23.20</td>
<td>22.00</td>
<td>26.00</td>
</tr>
<tr>
<td>High pulse duration (days)</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

**b) Targets Based on Ecological Objectives**

The second set of targets is based on the specific objectives defined through the expert input process. Flow magnitudes required for each function can be determined from expert input, hydrological thresholds or from quantification of the functional flows. Quantification of flow...
magnitudes using quantification tools and methods shown in Table 16 was only attempted for the LOV1-01 site. The main purpose of attempting to quantify the functional flows was to demonstrate the methods that can be used and to identify the most pertinent data gaps that are currently inhibiting the accurate quantification of functional flows.

Quantifying Functional Flows for Site LOV1-01

Quantification of flow magnitudes required for ecological objectives was attempted using the assessment tools and methods shown in Table 16. A description of the quantification of each function identified from the functional flow assessment that is relevant at this site will be described below.
Table 16: Table relating flow objectives to information required for quantification of flows

<table>
<thead>
<tr>
<th>Required Functions</th>
<th>Important Variable(s) that Limit Need</th>
<th>Flow-related Process(es) Governing Variable</th>
<th>Flow Regime (Temporal Aspects)</th>
<th>Flow Quantification Tool/Method</th>
<th>Data Source</th>
<th>Threshold Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>maintain summer refugia from warm water</td>
<td>pool depth</td>
<td>flows capable of mobilizing accumulated superficial sediment to scour pools</td>
<td>spring</td>
<td>sediment entrainment equations</td>
<td>OSAP</td>
<td>calculate flows capable of mobilizing accumulated superficial sediment in pools</td>
</tr>
<tr>
<td></td>
<td>pool depth</td>
<td>adequate flows to maintain water depth</td>
<td>summer</td>
<td>HEC-RAS</td>
<td>OSAP</td>
<td>calculate flow to equal 30cm pool depth</td>
</tr>
<tr>
<td></td>
<td>pool temperature</td>
<td>adequate flow depth to maintain temperature</td>
<td>summer</td>
<td>HEC-RAS</td>
<td>Unknown</td>
<td>calculate the flows to maintain a cold water temperature class</td>
</tr>
<tr>
<td></td>
<td>pool temperature</td>
<td>adequate amount of localized cool groundwater discharge to maintain pool temperature</td>
<td>summer</td>
<td>MIKE-SHE/FEFLOW</td>
<td>AquaResource</td>
<td>groundwater discharge regime</td>
</tr>
<tr>
<td>maintain connectivity to thermal refuge areas</td>
<td>depth at riffle crest</td>
<td>adequate flows to maintain depth and velocity suitable for fish passage</td>
<td>summer</td>
<td>HEC-RAS</td>
<td>OSAP</td>
<td>calculate flow to maintain 20cm depth at riffle crest</td>
</tr>
</tbody>
</table>
Flows Capable of Mobilizing Accumulated Superficial Sediment to Scour Pools:

Flows capable of mobilizing accumulated superficial sediment to scour pools were calculated following the methods outlined by Al Zaghal (2010). This method is based on sediment entrainment thresholds and is calculated by comparing boundary shear stress to critical boundary shear stress. Boundary shear stress ($\tau_o$) is calculated using Du Boyes equation (Equation 5).

$$\tau_o = \rho_w g d S$$

*Equation 5: Calculation of boundary shear stress*

where $\rho_w$ is the density of water (998 kg/m$^3$), $g$ is acceleration due to gravity (9.81 m/s$^2$), $d$ is flow depth in meters, and $S$ is the reach slope. Du Boyes equation in the form shown in Equation 5 relies on the assumption of approximately uniform flow so that the energy slope can be approximated as the reach slope. This form of the equation also relies on the assumption that channel width is much greater than the channel depth so the hydraulic radius can be approximated by the average depth. Water surface slope is different at a given discharge on the rising limb than the falling limb. For this application, water surface slope is assumed to be equal on the rising limb and the falling limb. Critical boundary shear stress is calculated using Equation 6.

$$\tau_c = \theta_c (\rho_s - \rho_w) g D_{50}$$

*Equation 6: Calculation of critical boundary shear stress*

where $\theta_c$ is the critical dimensionless shear stress, also known as the Shields Parameter, $\rho_s$ is the density of sediment (taken to be 2650 kg/m$^3$), $\rho_w$ is the density of water (998 kg/m$^3$), $g$ is the acceleration due to gravity (9.81 m/s$^2$), and $D_{50}$ is the median particle size in meters. Following Al Zaghal (2010), a Shields Parameter of 0.06 was used for the loose unconsolidated material.
found on the pool surface. The sediment entrainment potential can be calculated as the amount by which boundary stress exceeds critical shear stress.

This method requires pool particle size data, energy slope (which is approximated as the reach slope by assuming uniform flow), and a rating curve relating pool depth to discharge. Reach slope was estimated from the DEM, the rating curve equation for Lovers Creek at Tollendale gauge was obtained from the LSRCA and the particle size information was extracted from the OSAP database. In OSAP, median axis of particles immediately below each point in the transect, as well as the maximum particle size in a 30cm ring around the point are measured. There are three axes to any particle, the longest axis, the narrowest axis and the axis that is in between the longest and narrowest axis, which is called the median axis. The median axis of a particle is measured if the particle is between 2 and 1000mm, otherwise the recorded size is dictated by the material and description shown in Table 17. Ideally, the particle size of the superficial sediment is determined from scoop samples that have been taken from the pool, but these data do not exist so the OSAP data were used.

Table 17: OSAP recorded particle size protocol (Stanfield, 2010)

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>Size to be Recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Unconsolidated Clay’</td>
<td>Very hard packed when dry and sticky when wet</td>
<td>‘0.01’</td>
</tr>
<tr>
<td>‘Consolidated Clay’</td>
<td>Hard even when wet, slippery, gray in colour, often laminated</td>
<td>‘0.011’</td>
</tr>
<tr>
<td>‘Silt’</td>
<td>Feels soft like a powder or flour</td>
<td>‘0.05’</td>
</tr>
<tr>
<td>‘Sand’</td>
<td>Gritty, sizes &gt;0.05 and &lt; 2 mm</td>
<td>‘0.10’</td>
</tr>
<tr>
<td>‘Bedrock’</td>
<td>Exposed bedrock</td>
<td>‘1111’</td>
</tr>
<tr>
<td>Measured particles</td>
<td>Between 2 mm and 1000 mm.</td>
<td>Median axis</td>
</tr>
<tr>
<td>‘Large Boulders’</td>
<td>&gt; 1000 mm but not attached to bedrock</td>
<td>‘1001’</td>
</tr>
</tbody>
</table>
The methods outlined by Al Zaghal (2010) can be applied to gravel bed rivers with a high percentage of sand in the pool. The reach particle distribution for LOV1-01 can be seen in Table 18.

| Count (#) | 60 |
| Mean (mm) | 47.16 |
| Standard Deviation (mm) | 74.61 |
| D16 (mm) | 0.10 |
| D50 (mm) | 15.00 |
| D84 (mm) | 78.00 |

Table 18: LOV1-01 particle size distribution

Based on the classification system outlined in Bain et al. (1985) where 2-16 mm is classified as gravel, 17-64 mm as pebble and 65-256 mm as cobble, the reach at LOV1-01 is predominantly a gravel/pebble bed river. The number of points that were recorded as sand were compared to the total number of recorded points to get an estimate of the sand content in the pool. There were 14 points recorded as sand and 30 total points measured in the pool for a 46.7% sand coverage in the pool. Based on this analysis, site LOV1-01 is a gravel bed reach with a high percentage of sand in the pool, which meets the requirements for applying the methods in Al Zaghal (2010) for calculating sediment entrainment.

Given that the relationship between stage and depth is unknown, it is assumed that the relationship between stage and depth is such that discharge is 0 m³/s at a depth of 0 m.

Combining this assumption with the rating curve supplied by LSRCA at site LOV1-01 produces the depth-discharge relationship shown in Figure 41. Boundary shear stress calculated using Equation 5 versus discharge is shown in Figure 42. Boundary shear stress was calculated at each
point along transect 9, which is the assumed location of the gauge. The average boundary shear stress was then calculated by averaging the boundary shear stress for each point along the transect. The critical shear stress was calculated using Equation 6 and a $D_{50}$ of 0.005 m, which was calculated from the pool particle size distribution. Using these parameters and Equation 6, critical shear stress was calculated to be 4.86 N/m². According to the calculations, the discharge required to obtain a critical shear stress of 4.86 N/m² is approximately 0.07 m³/s, which is roughly the 7th percentile of annual flows. Based on these calculations, the critical shear stress is almost always exceeded so the bed is almost always mobile.

These results suggesting that the bed is almost always mobile at all flows does not seem logical since nearly half of the pool is covered in sand and there are no zero flow days at this site based on modelled and measured streamflow. If the calculations are correct then no flow threshold for mobilizing the bed sediments is required since the desired function of pool scouring is occurring at almost all flows experienced within the river.

Error in the calculation of pool scouring flows may be due to a few factors. The assumption linking the stage to the depth may be incorrect which could cause error in the calculation. The estimated slope may be too high leading to an overestimate of boundary shear stress. Following the depth-slope method, the energy grade line was approximated by the reach slope of the entire pool-riffle sequence. The energy grade line of the pool is likely more gentle then the overall gradient of the pool-riffle sequence, which could explain the over-estimated slope used in the calculation. The assumption that the hydraulic radius can be approximated by the depth will lead to an over-estimate of boundary shear stress particularly for deeper narrow channels. To estimate the error that this assumption may create, the hydraulic radius was
compared to the average depth for a few selected discharges. The differences between the hydraulic radius and average depth were less than 7.0% suggesting that this assumption does not significantly contribute towards the boundary shear stress error. Another possibility is that the rating curve may be inaccurate at the low end causing error in the stage discharge relationship, subsequently effecting the calculation of the boundary shear stress. Error in the calculation of critical shear stress may be due to the measurement of $D_{50}$ where the sample strategy did not produce an accurate representation of the pool substrate. In addition, the method of assuming that all sand particles are 0.1mm may lead to inaccuracies in estimating $D_{50}$, leading to potential error in the calculation of critical shear stress.

![Figure 41: Rating curve for site LOV1-01](image-url)
It is important to note that in addition to flow, sediment supply management may also be an important aspect of maintaining geomorphic functions such as pool scouring flows. It is possible that the flow required to scour the pool exists but that sediment supply is so high that sediment accumulates in the pools. (Al Zaghal, 2010) High sediment yield may be a result of upstream agricultural practices however Lovers Creek has a high amount of riparian cover which likely reduces the amount of fine sediment entering the river. Additional analysis would be required to determine the sediment balance within Lovers Creek.

Similar methods to those described above can be applied to calculate the flushing of fines from spawning riffles and are proposed in Al Zaghal (2010). Cold water spawning habitat does not likely exist at this site so these flows were not calculated, but it is recommended that these
methods be explored in future iterations of this EFA in headwater areas that may be used for spawning.

**Flows to Maintain Depth Suitable for Fish Passage:**

At low flows the riffle crest is considered the hydraulic control point and is generally used as the location to measure fish passage for a pool-riffle sequence (GRCA, Unknown). Based on the geometry of the LOV1-01 reach, transect 5 appears to be the riffle crest (Figure 12). GRCA (Unknown) uses a recommended 20 cm minimum depth at the riffle crest for brook trout passage. A value of 20 cm was also used for this study.

A variety of flows were modelled using the HEC-RAS model to determine which flow provided 20 cm depth at the riffle crest. The model was set-up with a downstream boundary condition of critical depth and an upstream condition of the tested flow. The results of selected model runs can be seen in Table 19. Based on the model output, a flow of 0.4 m³/s is required to produce a depth of 20 cm at the riffle crest. The HEC-RAS output for a flow of 0.4 m³/s is shown in Figure 43.

| Flow (m³/s) | 0.07 | 0.14 | 0.3 | **0.4** | 0.8 |
| Flow (m³/s) | | | | | |
| Maximum Depth (m) | 0.08 | 0.15 | 0.16 | **0.2** | 0.27 |

**Table 19: Riffle crest maximum depth at different flows**
To test the effect of the use of critical depth as a downstream boundary condition on the depth at the riffle crest, deviations from critical depth were modelled and the depth at the riffle crests for the different downstream boundary conditions were compared (Table 20 and Figure 44). No change in water surface elevation is observed for up to a 50% change in water depth and only a 33.33% change in water depth at the riffle crest is observed for a 100% increase in downstream water level boundary condition. Given that the water surface elevation at the riffle crest changes very little with large changes in downstream boundary condition, the use of critical depth as the boundary condition is reasonable.
Table 20: Comparing water surface elevations at the riffle crest using different downstream boundary conditions

<table>
<thead>
<tr>
<th>Deviation (%)</th>
<th>Downstream Boundary Condition Depth (m)</th>
<th>Downstream Boundary Condition Elevation (m)</th>
<th>Modelled Elevation at Riffle Crest (m)</th>
<th>Water Depth at Riffle Crest (m)</th>
<th>% Change at Riffle Crest</th>
</tr>
</thead>
<tbody>
<tr>
<td>+100</td>
<td>0.44</td>
<td>10.08</td>
<td>10.09</td>
<td>0.24</td>
<td>33.33</td>
</tr>
<tr>
<td>+50</td>
<td>0.33</td>
<td>9.97</td>
<td>10.04</td>
<td>0.18</td>
<td>0</td>
</tr>
<tr>
<td>+20</td>
<td>0.26</td>
<td>9.90</td>
<td>10.04</td>
<td>0.18</td>
<td>0</td>
</tr>
<tr>
<td>+15</td>
<td>0.25</td>
<td>9.89</td>
<td>10.04</td>
<td>0.18</td>
<td>0</td>
</tr>
<tr>
<td>+10</td>
<td>0.24</td>
<td>9.88</td>
<td>10.04</td>
<td>0.18</td>
<td>0</td>
</tr>
<tr>
<td>+5</td>
<td>0.23</td>
<td>9.87</td>
<td>10.04</td>
<td>0.18</td>
<td>0</td>
</tr>
<tr>
<td>critical water depth</td>
<td>0.22</td>
<td>9.86</td>
<td>10.04</td>
<td>0.18</td>
<td>-</td>
</tr>
</tbody>
</table>

Figure 44: Longitudinal water surface profiles for a flow of 0.4 m³/s and different boundary conditions. Downstream boundary conditions are as follows; PF1 = 10.08m, PF2 = 9.97m, PF3 = 9.90m, PF4 = 9.89m, PF5 = 9.88m, PF6 = 9.87m, PF7 = 9.86m.

According to hydrological analysis a flow of 0.4 m³/s corresponds to an 85\textsuperscript{th} percentile flow. This would mean that fish would be prevented from moving at the mouth of the stream for the vast majority of the flows in the system. The stream is fairly small, so it is possible that a 20
cm depth at the riffle crest occurs this rarely. The value of 20 cm at the riffle crest is a conservative value and it is possible that fish are able to migrate at lower depths.

There are a few possible reasons why the modelled flow for fish passage at the riffle crest may be inaccurate. Inaccurate estimates of model input such as the slope, Manning’s n or cross-sectional geometry could have an effect on the accuracy of the modelled fish passage flow. An overestimation of slope and an underestimation in Manning’s n would likely result in the overestimation of the flow for fish passage. A more accurate measure of the reach slope and water surface elevations at different flows that could be used to calibrate Manning’s n would improve the model. In addition, the modelled reach is only 44 m, which as described above, is a short reach for 1-D flow modelling.

The method of surveying the riffle crest in OSAP is not ideal because the riffle crest may be missed with the technique that was used. It should be noted that the method of surveying in OSAP is not likely the main problem in this model because missing the riffle crest would likely result in an underestimate of flows for longitudinal connectivity as opposed to an overestimate as seen in this study.

Future surveying for the purposes for EFA should be modified based on the following information. The transects for LOV1-01 was surveyed at longitudinally equal intervals that were set perpendicular to the stream for all transects. Several sources indicate that it is better to survey pool-riffle attributes (such as the riffle crest, head and foot) as opposed to equally spacing the transects along the reach. In addition, the literature indicates that the transect along the riffle crest should follow the crest as opposed to moving perpendicular to the river (GRCA, Unknown; Parish Geomorphic Limited, 2005; U.S Fish and Wildlife Service, 1978).
It is recommended that future site surveying protocols require transects be taken at the riffle crest and that the survey should run along the riffle crest as opposed to perpendicular to the bank. In addition to the evaluation of longitudinal connectivity at riffle crests, it may also be beneficial to assess the connectivity for fish at barriers such as culverts and dams within the system.

**Flows to Maintain Pool Water Depth:**

The flow required to maintain pools of an adequate depth to provide thermal refuge for cold water fish (primarily brook trout) was explored. A threshold depth of greater of than 15 cm for adult brook trout was used based on the brook trout habitat index (Raleigh, 1982). The minimum pool depth required for fish refugia can be dependent on several factors including stream size, order, form and type. The value of 15 cm as suggested by Raleigh (1982) may not be appropriate for all streams and caution should be taken when deciding on a threshold depth for pool refugia. It is recommended that expert input be used to determine threshold depths for different sites in future flow assessments.

Pool depth at different flows was determined using a combination of HEC-RAS and ArcGIS. After georeferencing the geometry in HEC-RAS, the model was run at different flows using critical depth as the downstream boundary condition to produce water surface elevations at different flows. To test the assumption of critical flow as a boundary condition, similar analysis to that completed to test the assumption for fish passage flow was completed (Figure 44). Deviations from the critical flow value were modelled for various upstream flow boundary conditions and the changes from critical flow had little effect on the water surface profile of the pool indicating that the assumption of critical flow is valid. The water surface elevations were
imported into ArcGIS using the ArcGIS extension, HEC-GeoRAS. The 3D line feature of the HEC-RAS cross-sectional geometry was processed in ArcGIS to produce an interpolated channel bed elevation grid (Figure 45).

Figure 45: Relative channel bed elevations at site LOV1-01 created in ArcGIS

Water surface profiles imported from HEC-RAS using HEC-GeoRas were processed and converted to grid format. The water depths were calculated by subtracting the water elevation grid from the channel bed elevation grid. The water depths were then reclassified into 2 groups, less than 15 cm and greater than 15 cm deep. The area of the polygons corresponding to the 2 groups were then calculated. An ArcGIS model was created using Model Builder to run the
analysis automatically so that the depths could be rapidly calculated for various flows. The results of the processing outlined above can be seen in Figure 46 and Table 21.

Figure 46: Calculated flow area for different discharge at site LOV1-01

Table 21: Calculated area of pools >15cm deep at various discharges for site LOV1-01

<table>
<thead>
<tr>
<th>Flow (m³/s)</th>
<th>Pool Area (m²)</th>
<th>Pool Area % of Total Wetted Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>158</td>
<td>63.15%</td>
</tr>
<tr>
<td>0.06</td>
<td>164</td>
<td>62.48%</td>
</tr>
<tr>
<td>0.08</td>
<td>170</td>
<td>61.76%</td>
</tr>
<tr>
<td>0.10</td>
<td>174</td>
<td>61.65%</td>
</tr>
<tr>
<td>0.12</td>
<td>180</td>
<td>62.48%</td>
</tr>
</tbody>
</table>
The period of record minimum in the current regime of 0.04 m³/s produces 158 m² of pool area. Based on visual analysis of Figure 46 this comprises a large percentage of the total pool area (where the pool area is defined as the channel area above the riffle crest). Figure 46 and Table 21 show that pool area with depths greater than 15cm change very little with increasing flow. A 200% increase in flow to 0.12 m³/s results in only a 14.4% increase in pool area of greater than 15cm depth. Raleigh (1982) recommend that the pool area percent of total wetted area be between 40% and 60% to allow for a mix of both trout food production and rearing areas. All modelled flows have pool area with approximately 60% of the portion of total wetted area and therefore meet this requirement (Table 21). Pool area was plotted against flow to determine if a breakpoint exists in the relationship that might be suitable for a threshold. The relationship is approximately linear so no apparent breakpoints or thresholds that would be appropriate for a flow threshold. Since the lowest flows experienced at site LOV1-01 produce a large percentage of the total pool area with adequate depth for cold water fish, the amount of pool area increases marginally with increasing flows and no break point appears to be present; no flow threshold for the pool area objective can be derived from this analysis.

In addition to pool depth, cover for fish was identified as being important. Cover is measured in OSAP and is defined as any object that comes into contact with the water that has a minimum median axis of 100mm and blocks at least 75% of the sunlight from the stream bottom. The cover quality in OSAP is grouped into 1 of 3 categories. The categories are (1) no cover present, (2) only embedded cover present and (3) at least some unembedded cover present. Unembedded cover has at least 4cm overhang and provides overhead and velocity protection.
while embedded cover has less than 4 cm overhang and only provides velocity protection. Cover type is recorded as flat rock, round rock, wood, macrophytes, bank, or other. Site LOV1-01 has recorded cover at 55% of the points with 25% embedded and 30% unembedded. These values exceed the recommended minimum of 25% stream cover (Raleigh, 1982).

Since the cover is defined as any object that comes into contact with the water, the technique for measuring cover in OSAP does not account for shading by riparian vegetation and other structures not touching the water that can also contribute to cover. So, the actual amount of cover may be higher than what is recorded in OSAP (Raleigh, 1982). Based on the site visit on June 23rd 2011, it appears as though shading by riparian vegetation that does not come into contact with the water is present. A photo of the site from the site visit can be seen in Figure 12.

This analysis could be improved by dividing the pools into different classes of suitability based on different depths and cover quality. In addition to depth with cover, other variables of importance to the success of cold water fish, such as velocity, could be modelled and the ranges of the variables could be specific to the requirements at different phases of particular cold water fish’s life cycle. This would require much more complex habitat modelling that is out of the scope of this project but may be appropriate in future iterations of the EFA.

The same model limitations that were outlined for the calculation of fish passage flow such as the unknown channel slope, potential errors in channel geometry and estimation of Manning’s n could also have an impact on the accuracy of the pool depth results.
Flows to Maintain Pool Temperature

Two flow related processes were identified for flows to maintain pool temperature; flows to maintain adequate pool depth to sustain temperature and localized groundwater discharges. The flows required to maintain adequate pool depth to sustain temperature could be determined using the temperature modelling component of HEC-RAS or by using other temperature modelling software. Point estimates of groundwater discharge are modelled in both MIKE-SHE and FEFLOW tier three models (Figure 47) (AquaResource Incorporated and Golder Associates, 2010). Given that stream temperature can be influenced by groundwater upwelling, it is suggested that the output from these models be explored for determining flows required to maintain pool temperature. This analysis is out of the scope of this research.

Figure 47: Modelled groundwater discharge using FEFLOW model (Adapted from AquaResource Incorporated and Golder Associates, 2010)
Setting Targets for Ecosystem Objectives

Unfortunately due to limitations of the data used to complete the calculations, the flow quantifications at site LOV1-01 are highly uncertain and were therefore not used for the target setting. As discussed above, the evaluation of the flow magnitudes required for the specific objectives above are however useful as they provide detailed methods that can be used to quantify flows in future EFA’s. In addition, the most pertinent data gaps preventing accurate quantification of functional flows were determined throughout the process. Since the quantification of the flows did not produce suitable flow magnitudes for setting targets related to specific needs, the magnitudes for the specific ecological functions at site LOV1-01 were defined by the EFC thresholds based on FDC percentiles and return intervals. This method was also used for the other streamflow sites.

Targets were developed for the ecological functions that were identified as being important for each site according to the ecological models developed in the “Ecological Characteristics of Streamflow Sites” section above (Figure 39 and Figure 40). Ecological functions were associated with an appropriate EFC parameter according to the functional associations of the EFCs presented in The Nature Conservancy (2009). For example, The Nature Conservancy (2009) associates the high flow EFC with the function of shaping the physical character of the river including the formation and maintenance of pools and riffles. So, for target setting in this study, the high flow EFC was associated with the desired function of scouring pools to maintain pool depth for summer refugia. Similarly, The Nature Conservancy (2009) associates the low flow EFC with maintaining suitable habitat space and temperature as well as enabling fish to move between different habitat areas. So, the low flow EFC was associated with
the required functions of maintaining depth, temperature and connectivity to thermal refuge and spawning areas. To keep the interpretation of the results simple, single parameter calibration was used for the separation of high and low flows. The association of EFC parameters to the ecological functions for each site can be seen in Table 22.

Flow targets were then categorized into 1 of 4 possible target types. Identified functions were categorized as having either a minimum magnitude threshold or a maximum magnitude threshold. A minimum magnitude threshold type is applicable to functions where it is hypothesized that a decrease in flow magnitude below a minimum threshold will have a negative impact on the ecological function. For example, maintaining summer pool depth is a minimum threshold because decreasing depth below the minimum threshold would negatively impact the function whereas increasing depth beyond the minimum threshold will not likely have a negative impact on this specific function. Maximum thresholds are the opposite of minimum thresholds where an increase in flow magnitude above a maximum threshold may have a negative impact on the function but flow magnitudes below the maximum threshold will probably not have a negative impact on the given function. Identified functions are also categorized based on whether or not increasing above or decreasing below a flow threshold is desired or not desired. Flows to scour pools and maintain flow depth is an example of a function where increasing above of a minimum flow threshold is desired, whereas the function of maintaining pool depth is an example of a function where increasing above a minimum flow requirement is not desired because the function will be negatively impacted (Figure 48). The assigned target types for each ecological function at each site can be seen in Table 22.
Frequency and duration targets were set for each of the identified ecological functions at each site. The frequency and duration targets are based on the natural frequency and duration of flows within the range of magnitudes defined by the EFC thresholds. The targets are defined by the 25th or 75th percentile of the natural range of the frequency and duration of flows. For targets where increasing above or decreasing below the threshold is desired, the 25th percentile of median annual frequency and duration was set as a minimum target and for functions where increasing above or decreasing below the threshold is not desired, the 75th percentile was set as a
maximum target. These targets can be refined if additional research indicates that different frequencies and durations are suitable for performing the given functions. The targets for all of the streamflow sites can be seen in Table 22. This table indicates that flows of less than 0.13 m³/s should not have a median occurrence of more than 8 times per summer and should not have a median duration of more than 10 days or there may be negative impacts to the functions of maintaining pools for summer refugia and connectivity to thermal refuge areas at site LOV1-01.

<table>
<thead>
<tr>
<th>EFC Parameter</th>
<th>Flow Regime (Temporal Aspects)</th>
<th>Ecological Function(s)</th>
<th>Target Type</th>
<th>Flow Magnitude Range (from EFC thresholds) (m³/s)</th>
<th>Flow requirement</th>
<th>Target Based on Natural Hydrology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Percentile</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25th</td>
</tr>
<tr>
<td>SITE LOV1-01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>high flow</td>
<td>spring (75th percentile of annual - 1.6y return interval)</td>
<td>• Scour pools to maintain pool depth for summer thermal refuge</td>
<td>minimum threshold, increasing above desired</td>
<td>0.22 - 7.5</td>
<td>median frequency (times/year)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>median duration (days)</td>
</tr>
<tr>
<td></td>
<td>summer</td>
<td>• Maintain temperature and depth of summer pools</td>
<td>minimum threshold, decreasing below not desired</td>
<td>0.13-0.03</td>
<td>median frequency (times/year)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maintain connectivity to thermal refuge areas</td>
<td></td>
<td></td>
<td>median duration (days)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>fall/winter</td>
<td>• Maintain connectivity to spawning habitat</td>
<td>minimum threshold, decreasing below not desired</td>
<td>0.13-0.03</td>
<td>median frequency (times/year)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>median duration (days)</td>
</tr>
<tr>
<td>SITE LOV1-G</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>high flow</strong> (75th percentile of annual - 1.6y return interval)</td>
<td><strong>spring</strong></td>
<td>• Scour pools to maintain pool depth for summer thermal refuge</td>
<td>minimum threshold, increasing above desired</td>
<td>0.17 - 4.65</td>
<td>median frequency (times/year)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>median duration (days)</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td><strong>summer</strong></td>
<td>• Maintain temperature and depth of summer pools</td>
<td>minimum threshold, decreasing below not desired</td>
<td>0.11-0.024</td>
<td>median frequency (times/year)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maintain connectivity to thermal refuge areas</td>
<td></td>
<td></td>
<td>median duration (days)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td><strong>fall/winter</strong></td>
<td>• Maintain connectivity to spawning habitat</td>
<td>minimum threshold, decreasing below not desired</td>
<td>0.11-0.024</td>
<td>median frequency (times/year)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>median duration (days)</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SITE LOV1-03</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>low flow</strong> (50th -0th percentile of annual)</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

*None of the ecological objectives were applicable at the CWT therefore no objective based targets were set*

It is recognized that the assigned target magnitudes for the given functions are uncertain.

The EFA framework is viewed as an ongoing process that can be iteratively reassessed and refined to produce targets that have a higher degree of certainty. It is recommended that the target magnitudes be refined in subsequent EFA iterations by quantifying functional flows, or estimated magnitudes, frequencies and durations required for specific functions could be refined using expert input. If more refined flow magnitudes are calculated or decided through expert
input then updated values can easily be integrated into an improved flow assessment using the techniques demonstrated above.

It is recommended that these targets be applied to aid decision making in a similar manner as the targets for overall ecosystem health. This can be accomplished by modelling various development or restoration scenarios (ex. low impact development vs. regular development), calculating the ecosystem objective statistics and comparing the statistics of the different scenarios to determine the impact or benefit of a given scenario versus the other development scenarios.

c) Integration into a Target Regime

The combination of values derived for the overall ecosystem health targets and the specific ecological objective targets were integrated into one target regime for each site (Figure 49, Figure 50 and Figure 51, Figure 52). Land and water resource development should be managed in a manner that maintains the hydrologic statistics within the target ranges. Where this is not possible, management should attempt to direct the existing flow regime in the trajectory of the natural regime. In situations where managers are restricted from making management changes that will maintain or direct the flow regime towards the natural regime, then acceptable percent deviation from the natural regime statistics should be evaluated based on an acceptable level of degradation of ecological objectives as determined by water managers. Estimates of changes to the ecological objectives at different percent changes in flow can be accomplished using techniques to quantify functional flows described above.
Figure 49: LOV1-01 target regime
Overall Ecosystem Targets

Minimize the hydrologic alteration factor of the
32 Indicators of Hydrologic Alteration statistics

Figure 50: LOV1-G target regime
Overall Ecosystem Targets

Minimize the hydrologic alteration factor of the 32 Indicators of Hydrologic Alteration statistics

Figure 51: LOV1-03 target regime
Figure 5.2: CWT site target regime (Note: median monthly flow for all months is 0 m³/s and there are no Ecological Objective targets for this site)
Water Level Analysis

This section will examine the natural hydrologic fluctuations of wetland water levels and the hydrologic alteration from the pre-settlement water level regime to the current regime. Targets will be set based on the natural range of pre-settlement conditions and recommendations will be made for improving the certainty of the set targets. It is important to note that the MIKE-SHE model has a mean absolute error of 9.0 m and 6.9 m in subsurface water layer 1 and 3 respectively (AquaResource Incorporated, 2011b). Given the high degree of error, the results can be used to infer general changes but the absolute values of the changes cannot be determined with much certainty. Site specific model calibration and validation is required in order to refine the model to the point where absolute changes can be resolved with any certainty.

MIKE-SHE modelled water level and distance to water table data were obtained from AquaResource Incorporated. The water levels and distance to water table were modelled at a time step of every other day. Water level data were processed in IHA and used for the majority of the analysis. The distance to water table data was only examined to provide additional insight into the hydrological characteristics of the different wetland points. Exploration of distance to water table data for target setting is recommended for future assessments.

The bi-daily water level time series data were imported into IHA and were linearly interpolated to produce a modelled pre-settlement and current daily water level regime from 1950-2009. IHA statistics and the degree of alteration were calculated for each wetland point as will be described in the following sections. EFCs were not calculated for water level data because the ecological foundations of the thresholds when applied to hydroperiod analysis are
not known. If relationships between EFC thresholds and ecological functions of wetlands were known then the EFC component of IHA would be valuable to water level target setting.

Figure 53: Wetland points

Phase II: Development of a Reference Regime and Hydro-Ecological Analysis

a) Characterize the Natural Regime

Modelled distance to water table data suggests that wetland point 1 and 2 are recharge areas wetland point 3 is a discharge area and wetland point 4 fluctuates between groundwater discharge and recharge (Figure 54). This is inferred from the depth to water table data by
assuming that a hydraulic head above the ground surface is a discharge area and hydraulic heads below the ground surface are recharge areas.

As would be expected, the monthly water levels for the sites that are further upstream and at higher elevations have higher water levels (Figure 55) (Mitsch and Gooslink, 2000). Of the wetland points that are upstream, wetland point 2 has the highest water level, while wetland points 3 and 4 have similar levels with wetland point 3 being slightly higher in the summer and winter months. The water levels at wetland point 2 are likely higher because the ground surface is at a higher elevation further away from the main channel. The higher summer and winter water levels at wetland point 3 may be due to wetland point 3 receiving floodwaters from the main channel during high flows and storing and releasing these floodwaters to the channel at periods of lower flow (Figure 56) (Mitsch and Gooslink, 2000).
In order to better analyze the difference in water level fluctuations at each site, the water levels were converted to relative water levels by setting the minimum MAS value at each site to
zero and adjusting the remainder of the water levels according to the relative minimum value. This was done by subtracting the minimum water level in MAS from the bi-daily water level at each site before processing in IHA. The relative monthly median water levels can be seen in Figure 57. Wetland point 1 has the highest relative water levels followed by point 2, 3 then 4. The higher relative water level indicates that there is a greater difference between the minimum and maximum level (a wider range of fluctuation) at that point. From Figure 57 it can be seen that the highest water levels are experienced in the spring and the lowest water levels in the summer at all wetland points. Wetland point 1 appears to have a smoother curve suggesting less variability in median monthly water level between months while wetland point 4 appears to have much greater variability in median monthly water level between months.

Figure 57: Pre-settlement condition relative median monthly water levels for all wetland points
The water level duration curve (LDC) in Figure 58 shows that wetland point 1 has the largest range of water levels while wetland point 4 has the smallest range. The LDC’s have similar shapes indicating a similar distribution of high, mid and low levels however, wetland point 2 appears to have more high levels and wetland point 3 appears to have fewer high levels and more low levels.

Wetland point 1 has the highest median rise rate, followed by wetland point 2, 4 then 3. Wetland points 1 and 2 have the highest median fall rates followed by wetland point 4 (Figure 59). Wetland point 3 has the highest median number of reversals with 64 followed by wetland point 4 with 62 then wetland point 2 and 1 with 36 and 40 reversals respectively.
b) Assessment of Hydrologic Alteration

**Impacts of Anthropogenic Disturbance on Water Levels**

In this section, the hydrological alteration from the current regime will be described and the difference between the hydrological alterations at the different wetland sites will be discussed. Hypothesis for differences in hydrological alteration between the different sites will be posited based on the information that are available. Testing of these hypotheses is beyond the scope of this research.

As with the streamflow sites, the dominant anthropogenic disturbance likely to affect the modelled water levels is the replacement of forested land cover with urban and agricultural land cover. The expected effects of this change in land cover on a systems hydrology include reduced evapotranspiration and loss of storage from the loss of forest vegetation and the reduction of infiltration from the disturbance of soils and increased impervious surfaces (Leopold, 1968).
The expected effect of the land conversion on wetland hydrology will depend on the dominant hydrological processes of the impacted wetland. If the wetland is predominantly fed by surface water, the increased imperviousness caused by the land cover change will likely result in an increased peak in water levels following storm events (similar to the response of streamflow to the land cover change). This will particularly be true in an urban setting if storm water is directly routed to urban wetland areas.

For groundwater fed wetlands, increased impervious surface from urbanization is likely to result in decreased water levels due to reduced infiltration and recharge. However, if water from an impacted area is routed to a high infiltration zone, then water levels may increase (Mitsch and Gooslink, 2000).

Delineation of the contributing areas of the wetland points based on ground surface topography was attempted but the contributing areas were only 1 or 2 cells large due to the lack of accuracy (± 10m horizontal accuracy and ± 5m vertical accuracy) and resolution (10m) of the digital elevation (OMNR, 2002). Since these delineations did not provide any useful results, visual analysis of the surrounding land cover was used to infer the potential effects of land cover change on the wetland points (Figure 60). It is important to recall that the cell resolution of the MIKE-SHE model is 200m. This resolution will have a large effect on the ability of the model to capture finer scale hydrological processes occurring around the wetland points (AquaResource Incorporated, 2011b). To put this into perspective, wetland point 3 is approximately 350m (less than 2 cell sizes) from wetland point 4 and 820m (approximately 4 cell sizes) from wetland point 2.
Hydrologic Analysis

An increase in monthly median water levels is seen at all sites except for wetland point 1, with the highest increase occurring at wetland point 2, then point 4 and then point 3 (Figure 61). The CD’s and thus inter-annual variability of median monthly water level follow a similar pattern with the inter-annual variability decreasing at all points except for wetland point 1. There is an exceptionally large increase in spring monthly median water level inter-annual variability at wetland point 1 (Figure 61).
The decrease in water levels at wetland point 1 and increase at other sites may be due to the increased imperviousness at this site due to urbanization versus the other sites that have less urban land cover and more agriculture, wetland and forest. Wetland point 1 is a recharge site with a maximum and average depth from the ground surface to the water table in the current modelled scenario of 9.4 m and 10.2 m respectively suggesting little surface water interaction and that the water levels at this site are driven by groundwater processes. This would suggest that reduction of infiltration caused by urbanization may lead to a reduction in groundwater levels at this site. The areas surrounding the other wetland points are predominantly forest and agriculture which are generally more pervious than urban areas. The increase in water level at the other wetland points may be due to the increased water volume from decreased evapotranspiration (Mitsch and Gooslink, 2000).

It is interesting to note that while water levels are reduced at wetland point 1, baseflows are not reduced at site LOV1-01 (which is located near the mouth of the subwatershed within the urbanized area). This may be because the proportion of its contributing area that is urbanized is relative low (Black, 1996). It would be interesting to see modeled streamflow output along the tributary near wetland point 1 to see if baseflows are reduced at this location.
Following the same trend as the monthly medians, minimum and maximum water levels increase at all sites except for wetland point 1. The median minimum and maximum date show little change for all sites. The inter-annual variability of maximum and minimum statistics increases at wetland point 1 while the inter-annual variability of the maximum and minimum statistics decreases for the majority of the other sites. Exceptionally high inter-annual variability increases are seen for the 30 and 90 day maximum at wetland point 1.
Figure 62: Hydrologic alteration of minimum and maximum water level statistics for all sites

The rise rates and rise rate inter-annual variability for wetland points 2, 3 and 4 increases or do not change, while the rise rate and rise rate inter-annual variability for wetland point 1 decreases. The fall rate and fall rate inter-annual variability for wetland point 1 both increase, while there is no change in fall rate statistics for the other sites. Finally, the number of reversals decreases for wetland point 2, while the number of reversals increases for wetland point 2 and 4 and wetland point 4 shows no change in this statistic. There is an exceptionally high increase in inter-annual variability in number of reversals at wetland point 1 (Figure 63).
The DHRAM index that was described in the Streamflow “Modified Dundee Hydrological Regime Alteration Method (DHRAM) Index” section was calculated for the wetland points (Figure 64) (Black et al., 2005).
Figure 64 indicates that wetland point 1, in the lower end of the watershed has the highest degree of alteration followed by wetland point 2 then 4 then 3. The modified DHRAM scores for wetland point 1-4 are 3.20, 1.58, 0.94 and 1.55 respectively. Higher alteration at wetland point 1
may be explained by the high amount of urbanization surrounding the point. It is difficult to speculate the reasons for the difference in the degree of alteration for the remaining points.

c) **Hypothesized Ecological Responses to Hydrologic Alteration**

**Decrease in Water Level**

The general decrease in water levels at all times of the year at wetland point 1 may have several impacts on the hydrologic functions of the wetland which may subsequently affect the wetland ecology. The decrease may result in an increased capacity to store floodwaters which may also lead to a decrease in erosion due to a potential reduction of high flows. The decreased water levels may also lead to decreased recharge to groundwater due to decreased inundation depth and lower hydraulic head. Reduced water level may also alter how sediments, nutrients and contaminants are transported and processed within the wetland (Sheldon et al., 2005).

The decrease in water levels may also have a direct effect on the flora and fauna within the wetland. The composition and richness of plant community will depend on the amount of water in the root zone of the plants. Decreased water level may lead to prolonged drought which may affect the ability of native species to disperse and germinate seeds, avoid herbivores and compete with other plant species resulting in invasion of non-native plant species (Sheldon et al., 2005). Reduced water levels may decrease the number of aquatic species such as benthic invertebrates, fish and amphibians as vertical and horizontal habitat area may be reduced. As described above, the reductions in water level may lead to changes in plant community which will alter major food sources, shelter and egg or individual attachment area for different aquatic species (Tarr and Babbitt, Unknown). The reductions in water level may also change the access
and composition of predators which may lead to changes in community richness at various levels of the food web.

Reductions in water levels may cause desiccation induced mortality such as stranding and can impact thermal regimes leading to thermal stress such as overheating in summer and freezing in the winter. Unnatural dry periods in the spring can be particularly harmful to wetland amphibians as reduced water levels and drying can have a large impact on the success of amphibian breeding. However, it has been shown that populations that are spatially distributed across a connected landscape in areas of different depth and water permanence will be more resilient to localized droughts. Wetland point 1 is fairly well connected to other habitat within Lovers Creek Swamp, which may make it more resilient to decreased water levels (Figure 65) (OMNR, 2011). Decreased water levels may also impact waterfowl by allowing increased wetland access to terrestrial animals exposing nests to predation. Finally, the decrease in water level may also impact the availability of waterfowl brood-rearing areas affecting waterfowl success (Sheldon et al., 2005)

Increase in Water Level

An increase in water level as experienced at wetland points 2, 3 and 4 may have the opposite effect of the hypothesized ecological response to decreased water levels described above. For example, increases in water level may result in a decreased capacity to store floodwaters resulting in increased flooding and erosion. The increase may also result in increased recharge due to the higher hydraulic depth. Wetland flora and fauna may be affected by increases in water level since the habitat availability for fish, invertebrates and amphibians will likely increase. The increase in habitat availability may favour wetland plants and animals
that are more tolerant to increased inundation which may alter wetland community composition and predator prey relationships.

**Water Level Reversals and Inter-annual Variability**

A change in the number of water level reversals as well as a change in inter-annual variability can have negative impacts on the wetland ecology as wetland species have different water level requirements at different times of the year that might not be met if the number and timing of water level fluctuations are changing (Sheldon et al., 2005).

**Phase III: Development of a Target Regime**

**a) Targets for Overall Ecosystem Health**

As with the streamflow targets, wetland targets for overall ecosystem health were set based on the range of variability of each IHA statistic. The RVA bounds (33rd and 66th percentile) for each IHA statistic for each site can be seen in Table 23. Results of modelling the hydrological regime with various restoration or development scenarios can be compared to targets. The hydrologic alteration of the different scenarios can be compared within IHA and the potential benefits and impacts of different scenarios on the overall health of the system can be evaluated through inferring potential flow ecological responses to the hydrological alteration. The assessment of these potential benefits and impacts will provide information to decision makers and will lead to more effective restoration and more ecologically sustainable development. The targets could also be applied post construction to monitor the actual effect of the restoration or development on the system by evaluating monitored water level data at the site.
over time and comparing the trajectory of the water level regime to the natural regime and the pre-construction regime.

Table 23: Hydrologic targets for overall ecosystem health at all wetland sites

<table>
<thead>
<tr>
<th>Wetland Point 1</th>
<th>Wetland Point 2</th>
<th>Wetland Point 3</th>
<th>Wetland Point 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 33rd%</td>
<td>High 66th%</td>
<td>Low 33rd%</td>
</tr>
<tr>
<td>January</td>
<td>1.30</td>
<td>1.56</td>
<td>0.65</td>
</tr>
<tr>
<td>February</td>
<td>1.33</td>
<td>1.61</td>
<td>0.69</td>
</tr>
<tr>
<td>March</td>
<td>1.54</td>
<td>1.76</td>
<td>0.78</td>
</tr>
<tr>
<td>April</td>
<td>1.76</td>
<td>1.78</td>
<td>1.04</td>
</tr>
<tr>
<td>May</td>
<td>1.71</td>
<td>1.74</td>
<td>0.99</td>
</tr>
<tr>
<td>June</td>
<td>1.61</td>
<td>1.68</td>
<td>0.84</td>
</tr>
<tr>
<td>July</td>
<td>1.50</td>
<td>1.59</td>
<td>0.69</td>
</tr>
<tr>
<td>August</td>
<td>1.39</td>
<td>1.47</td>
<td>0.61</td>
</tr>
<tr>
<td>September</td>
<td>1.32</td>
<td>1.45</td>
<td>0.57</td>
</tr>
<tr>
<td>October</td>
<td>1.28</td>
<td>1.43</td>
<td>0.62</td>
</tr>
<tr>
<td>November</td>
<td>1.28</td>
<td>1.45</td>
<td>0.64</td>
</tr>
<tr>
<td>December</td>
<td>1.29</td>
<td>1.52</td>
<td>0.68</td>
</tr>
<tr>
<td>1-day minimum</td>
<td>1.08</td>
<td>1.25</td>
<td>0.49</td>
</tr>
<tr>
<td>3-day minimum</td>
<td>1.09</td>
<td>1.25</td>
<td>0.49</td>
</tr>
<tr>
<td>7-day minimum</td>
<td>1.09</td>
<td>1.26</td>
<td>0.50</td>
</tr>
<tr>
<td>30-day minimum</td>
<td>1.12</td>
<td>1.28</td>
<td>0.52</td>
</tr>
<tr>
<td>90-day minimum</td>
<td>1.21</td>
<td>1.37</td>
<td>0.56</td>
</tr>
<tr>
<td>1-day maximum</td>
<td>1.91</td>
<td>2.10</td>
<td>1.15</td>
</tr>
<tr>
<td>3-day maximum</td>
<td>1.90</td>
<td>2.04</td>
<td>1.13</td>
</tr>
<tr>
<td>7-day maximum</td>
<td>1.85</td>
<td>1.97</td>
<td>1.12</td>
</tr>
<tr>
<td>30-day maximum</td>
<td>1.79</td>
<td>1.85</td>
<td>1.08</td>
</tr>
<tr>
<td>90-day maximum</td>
<td>1.74</td>
<td>1.77</td>
<td>0.99</td>
</tr>
<tr>
<td>Date of minimum</td>
<td>55.80</td>
<td>309.40</td>
<td>231.80</td>
</tr>
<tr>
<td>Date of maximum</td>
<td>93.80</td>
<td>109.40</td>
<td>103.00</td>
</tr>
<tr>
<td>Rise rate</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Fall rate</td>
<td>-0.0045</td>
<td>-</td>
<td>0.0045</td>
</tr>
<tr>
<td>Number of reversals</td>
<td>33.00</td>
<td>39.00</td>
<td>38.00</td>
</tr>
</tbody>
</table>
b) Hydrologic Targets Based on Ecological Objectives

The two objectives that were identified through scientific expert input for wetland protection are maintaining wetland amphibian habitat and maintaining wetland vegetation. The limiting needs that were identified for wetland habitat specialists were to maintain breeding habitat for wetland amphibians and to maintain required levels of soil saturation for wetland plants. Water levels were not quantified to identify specific thresholds for wetland objectives due to time restrictions and lack of data for this analysis. Instead, IHA variables relating to the specific objectives were identified and targets were set for the appropriate season.

Amphibian Habitat

Information on the amphibian species present at the different sites does not exist. Information on amphibians that are potentially present in Lovers Creek however do exist so the general amphibian breeding requirements for species that are potentially present in Lovers Creek were applied to all wetland points. A list of amphibian species potentially present in the subwatershed was generated based on the maps from Ontario’s Nature Reptile and Amphibian Atlas and the Wetland Evaluation File (OMNR, 2011; Ontario’s Reptile and Amphibian Atlas, 2011)(Table 24). Only recently recorded (after 1991) amphibian observations were counted for this analysis. The important variable required to maintain amphibian breeding habitat is to maintain vernal pools for the duration required for breeding. Total larval time and breeding season were compiled to help inform the selection of appropriate IHA statistics for maintaining amphibian breeding habitat (Table 24).
According to Ontario’s Nature Reptile and Amphibian Atlas and the Wetland Evaluation File, amphibians present in Lovers Creek subwatershed breed in the spring and have a total larval time of about 70-90 days. The exception to this trend is the green frog (*Lithobates clamitans*) which

### Table 24: Wetland amphibians present in Lovers Creek Subwatershed

<table>
<thead>
<tr>
<th>Species</th>
<th>Habitat</th>
<th>Breeding Date</th>
<th>Breeding Season</th>
<th>Egg Hatching Time</th>
<th>Tadpole Stage Time</th>
<th>Total Larval Time</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Toad</td>
<td>wide variety of terrestrial habitats</td>
<td>late March to early June</td>
<td>spring</td>
<td>a few days to a few weeks</td>
<td>50-65 days</td>
<td>90 days</td>
<td>Ontario Nature/Wetland Evaluation</td>
</tr>
<tr>
<td>Gray Treefrog</td>
<td>tree/shrub community</td>
<td>N/A</td>
<td>late spring/early summer</td>
<td>5-7 days</td>
<td>40-60</td>
<td>70 days</td>
<td>Ontario Nature/Wetland Evaluation</td>
</tr>
<tr>
<td>Green Frog</td>
<td>shallow permanent waterbodies</td>
<td>late spring to August</td>
<td>late spring - late summer</td>
<td>N/A</td>
<td>overwinter</td>
<td>1 year</td>
<td>Ontario Nature/Wetland Evaluation</td>
</tr>
<tr>
<td>Northern Leopard Frog</td>
<td>wide variety of habitats</td>
<td>N/A</td>
<td>mid-late spring</td>
<td>1-3 weeks</td>
<td>30-60 days</td>
<td>90 days</td>
<td>Ontario Nature/Wetland Evaluation</td>
</tr>
<tr>
<td>Spring Peeper</td>
<td>wide variety of habitats - breed mostly in temporary woodland ponds</td>
<td>N/A</td>
<td>early spring</td>
<td>1-2 weeks</td>
<td>30-60 days</td>
<td>90 days</td>
<td>Ontario Nature/Wetland Evaluation</td>
</tr>
<tr>
<td>Western Chorus Frog</td>
<td>wide variety of habitats - breeds in any fishless pond with &gt;10cm of water</td>
<td>N/A</td>
<td>very early spring</td>
<td>within a few weeks</td>
<td>Metamorphosis occurs by early-midsummer</td>
<td>90 days</td>
<td>Ontario Nature</td>
</tr>
<tr>
<td>Wood Frog</td>
<td>moist woodlands and vernal woodland pools</td>
<td>early spring</td>
<td>very early spring</td>
<td>N/A</td>
<td>45-85 days</td>
<td>N/A</td>
<td>Wetland Evaluation</td>
</tr>
</tbody>
</table>
has a breeding date of late spring to early August and a total larval time of about 1 year (OMNR, 2011; Ontario’s Reptile and Amphibian Atlas, 2011). Chin (1996) found maximum spring water level to be one of the most important variables for wetland amphibian protection as it supports embryo development. In addition, it has been found that water level fluctuation was the most significant factor affecting amphibian species richness when compared to wetland size, presence of predators, distance to breeding habitat and other factors (Richter and Azous, 2001).

For this assessment, it is suggested that the 7, 30, and 90 day maximum spring water level should be maintained in order to maintain natural inundation and protect wetland amphibian breeding habitat for the majority of amphibian species found in the subwatershed.

**Wetland Vegetation**

As part of the wetland evaluation for Lover Creek Swamp, the swamp was divided into sections and surveyed for wetland type, soil and vegetation type. Wetland point 1 falls into unit 18-7, which is a palustrine wetland with inflow and sandy loam soils. Based on air photo interpretation and observations from the edge of the property, three of a possible 12 vegetation types are found at wetland point 1. The three that are present are conifer, deciduous and tall shrubs with conifers dominating (OMNR, 2011). The surveyed unit for wetland point 2 can be seen in Figure 65.
Wetland point 2 is in a surveyed unit that was found to be a palustrine wetland with organic muck soil and deciduous, tall shrubs, narrow leaved emergents, herbaceous groundcover and conifer vegetation with deciduous trees dominating. Wetland point 3 is in a unit that is classified as riverine, with organic muck soils and robust emergent, narrow leaved emergent, and tall shrub vegetation with narrow leaved emergent plants dominating. For the wetland evaluation, wetland points 1-3 were surveyed from the edge of the property but wetland point 4 was surveyed onsite. The field investigation found that wetland point 4 is a palustrine wetland with sandy clay soil and tall shrub, deciduous trees, herbaceous groundcover and narrow leaved emergents with narrow
leaved emergents dominating. Information from soil cores and a list of the different species present at the site was also produced from the survey at wetland point 4 (OMNR, 2011). Since the expert interviews did not identify any specific wetland plant species to focus on, targets will be set based on the general hydrological requirements of swamp vegetation. In the future, it is recommended that the surveyed field sites with the most information be considered for the flow assessment and targets for specific wetland plants or plant guilds be explored.

Swamp soils are usually saturated for most of the growing season with inundation occurring seasonally during the spring freshet and occasionally by seasonal storms. Maintaining a natural range of summer low levels is important as the summer low water level needs to be long enough to allow for seed dispersal but should not be so long that it allows for the colonization of non-native wetland vegetation (Michigan DNR, Unknown).

Given that soil is saturated for most of the year, natural monthly median water levels should be maintained to sustain saturation. The 90 day maximum in the spring will be important to maintain seasonal inundation and the natural range for the 7 and 30 day summer low will be important to allow for seed dispersal but prevent invasion of non-native species.

**Target Setting for Wetland Objectives**

An ecological model for all of the wetland points was created based on the defined objectives and the associated IHA statistics (Figure 66). RVA boundaries for each of the identified statistics were calculated for the appropriate season. The calculated targets can be seen in Table 25. Although there is overlap in some of the overall ecosystem health target statistics, most of the actual targets are different because the targets for ecosystem health are set
based on annual statistics and most of the targets for ecosystem objectives are set based on seasonal statistics.

<table>
<thead>
<tr>
<th>7 day max, 30 day max, 90 day max</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Maintain seasonal inundation for wetland vegetation</td>
</tr>
<tr>
<td>• Maintain amphibian breeding habitat</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Median monthly level</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Maintain soil saturation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7 day min, 30 day min, 90 day min</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Prevent prolonged drought and invasion of non-natives</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.30</td>
<td>1.56</td>
<td>0.65</td>
<td>0.90</td>
<td>0.73</td>
<td>0.81</td>
<td>0.61</td>
<td>0.73</td>
<td>0.66</td>
<td>0.82</td>
<td>0.70</td>
<td>0.84</td>
</tr>
<tr>
<td>1.33</td>
<td>1.61</td>
<td>0.69</td>
<td>0.92</td>
<td>0.72</td>
<td>0.82</td>
<td>0.60</td>
<td>0.73</td>
<td>0.66</td>
<td>0.82</td>
<td>0.70</td>
<td>0.84</td>
</tr>
<tr>
<td>1.54</td>
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<td>0.78</td>
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<td>0.90</td>
<td>0.66</td>
<td>0.82</td>
<td>0.70</td>
<td>0.84</td>
<td>0.70</td>
<td>0.84</td>
</tr>
<tr>
<td>1.76</td>
<td>1.78</td>
<td>1.04</td>
<td>1.28</td>
<td>0.89</td>
<td>0.97</td>
<td>0.83</td>
<td>0.91</td>
<td>0.70</td>
<td>0.84</td>
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<tr>
<td>1.71</td>
<td>1.74</td>
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<td>1.22</td>
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<td>0.91</td>
<td>0.70</td>
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<td>1.05</td>
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<td>0.41</td>
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<td>1.50</td>
<td>1.59</td>
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<td>0.90</td>
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<td>0.30</td>
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<td>0.65</td>
</tr>
<tr>
<td>1.28</td>
<td>1.45</td>
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<td>0.81</td>
<td>0.71</td>
<td>0.79</td>
<td>0.61</td>
<td>0.71</td>
<td>0.61</td>
<td>0.71</td>
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Table 25: Targets based on ecological objectives for all wetland points

Figure 66: Ecological model for all wetland points

169
Table 25 Continued

<table>
<thead>
<tr>
<th></th>
<th>WP1 Level (m)</th>
<th>WP2 Level 2 (m)</th>
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<td>90-day minimum</td>
<td>1.41</td>
<td>1.50</td>
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c) Integration into a Target Regime

The overall ecosystem health and ecosystem objective targets in the previous section were integrated into target regimes for each wetland point (Table 26). Land and water resources should be managed such that the statistics identified below remain within their target ranges. Where this is not possible management decisions should attempt to project the hydrological regime in the trajectory of the target regime.
Table 26: Integrated targets for all wetland points

<table>
<thead>
<tr>
<th></th>
<th>WP1 Level (m)</th>
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<th>WP3 Level (m)</th>
<th>WP4 Level (m)</th>
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<td>0.01</td>
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<td>-0.0045</td>
<td>-0.0045</td>
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**Spring**

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<td>7-day maximum</td>
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**Summer**

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Chapter 7: Study Limitations and Recommendations for Future Flow Assessments

This next section summarizes the study limitations and collates the recommendations for future flow assessments that were made throughout the paper and provides additional recommendations. Recommendations are sequentially provided for the different steps of the framework.

Phase I: Context Setting

a) Define Subwatershed Characteristics

Subwatershed plans are being developed for each subwatershed within the LSRCA. These subwatershed plans are based on a summary of the existing data, studies and models for each subwatershed. The LSRCA subwatershed plan for Lovers Creek was being developed concurrently with this study so some draft sections of the subwatershed plan were available. For future EFA’s within the LSRCA the subwatershed plans should be the basis for the definition of subwatershed characteristics.

- Use subwatershed plans as the primary source of information for the identification of subwatershed characteristics

b)-d) Definition of Subwatershed Goals, Habitat Specialists and Functional Analysis

The definition of subwatershed goals, habitat specialist and information for the functional analysis was mostly derived from scientific expert interviews. It was found that it is best to conduct interviews in person if possible although telephone and emailed responses to questions are better than no response if potential participants are extremely busy. Planning to conduct
interviews in a time when participants may not be as busy (for example, in the winter when there is less field work) may increase the chance of obtaining face to face meetings.

It is recommended, as suggested by survey participants, that scientific experts from municipalities be included in future flow assessment teams, that interview questions and some background on ecological flows be provided in advance of the surveys and that the surveys be tailored to a participant’s expertise (ex. a hydrogeologist should be asked more questions related to hydrogeology than aquatic biology). If the survey questions are tailored to scientist’s expertise, there should be some more general questions with the goal of obtaining any cross-disciplinary knowledge that may be available.

Macroinvertebrates were identified as being important but were not emphasized during the expert interviews and were therefore not included in the EFA. Flows to prevent excessive erosion and to maintain adequate field drainage were also identified but targets were not set for these functions. Data for macroinvertebrates within the LSRCA exist and it is recommended that targets for macroinvertebrates be explored in the future assessments as well as targets for preventing excessive erosion and maintaining field drainage.

Identified functions in this study were examined separately. It is recommended that functional guilds (categories of species with similar patterns of resources use) be explored which may allow for the inclusion of additional functions with minimal additional effort (Noble et al., 2007). The method for including or excluding goals, habitat specialist and ecological functions that were suggested in the expert interviews into the flow assessment was somewhat subjective. More quantitative and defensible methods of determining inclusion or exclusion of content from the expert interviews should be explored.
• Provide interview questions and background on EFA in advance of the interviews

• Conduct expert interviews during non-field season

• Conduct interviews face to face when possible, then by telephone interviews, finally written responses can be useful as a last resort

• Consider including experts from municipalities in scientific interviews

• Consider tailoring survey questions to specific participant’s expertise

• Explore target setting for macroinvertebrates, preventing excessive erosion and maintaining field drainage

• Explore the incorporation of functional guilds into the functional flow assessment

• Explore more quantitative and defensible methods for determining the inclusion or exclusion of information from the expert interviews into the flow assessment

e) Geomorphic/Hydrologic Classification and Selection of Study Nodes

Geomorphic classification of the landscape was completed by the LSRCA based on subwatershed size, surficial geology and slope. It is recommended that the geomorphic classification be improved by including additional variables or exploring different methods of geomorphic classification. In addition, hydrologic classification has not been completed within the LSRCA. It is recommended that hydrologic classification be completed to segment Lovers Creek subwatershed or the LSRCA into relatively homogeneous hydrological units. The USGS HIP software offers hydrological classification functionality through principal components analysis and may be a good method for hydrological classification within the LSRCA (Henriksen et al., 2006). Once a good landscape classification has been established, the transfer of flow targets to different locations with similar classifications can be explored.
For this study, flow targets were set at a subset of the monitoring locations within Lovers Creek subwatershed. It is recommended that analysis be completed at other LSRCA monitoring stations particularly some of the western tributaries that are known to have brook trout and groundwater upwelling.

Only one of the wetland points used for this study had site specific survey data from the Wetland Evaluation File. It is recommended that future wetland points be selected in locations where the site specific information has been collected so that that the wetland evaluation information can be used to inform the flow assessment.

- Consider improving existing geomorphic classification
- Complete a hydrologic classification within Lovers Creek or the LSRCA using software such as the USGS HIP
- Set flow targets for additional monitoring locations within Lovers Creek subwatershed
- Select wetland points that correspond with locations where detailed wetland evaluation survey data exist

**Phase II: Development of a Reference Regime and Hydro-Ecological Analysis**

a) **Characterize the Natural Regime**

*Determining Pre-settlement Wetland Extent*

The pre-settlement land cover for this study was determined using visual analysis of hard copy historic survey maps. These hard copy maps were being digitized at the time of this study and digital copies of the maps may be available for future flow assessments. This is particularly useful as digital land cover data are required for the hydrologic model. If the digital OMNR NHIC maps are not available, Ducks Unlimited produced historic wetland maps and digital copies of these maps may be available. In addition, a GIS tool called the SAGA wetland index is
available and can be used to predict historic wetland coverage. The SAGA wetland index may be a useful tool for estimating pre-settlement land cover where historic maps do not exist.

- Use digitized versions of the OMNR Natural Heritage Information Centre historic land cover maps or Ducks Unlimited historic wetland maps to determine the pre-settlement land cover

- Explore the use of the SAGA wetland index tool for determining pre-settlement wetland cover where historic maps do not exist

**Improvements to Hydrological Model Calibration and Analysis**

The MIKE-SHE hydrologic model was only calibrated for 4 years (2001-2004) and was not validated. Streamflow data are available at the Tollendale gauge from 2001 to present, but the data from 2004-present has inaccuracies that are thought to be due to problems with the rating curve and complications with ice. Techniques for correcting the existing streamflow data should be explored so that the data can be used for model calibration and validation. Several spot flow measurements are available at various locations that could be used to calibrate the model and improve model accuracy. In addition, a spot flow monitoring program is planned as part of the LSRCA environmental flows program which will produce new data that can be used for model calibration. It is recommended that the spot flow measurements be used to calibrate the model which will improve model accuracy. The MIKE-SHE model calibration was primarily focused on low flows. For the purpose of EFA, it is recommended that the model be calibrated to various flows including peak flows and low flows. The MIKE-SHE model used for this study was run with land use data from 2008. It is important that the most up to date land use data be used for the EFA particularity when the hydrology of different land use scenarios are being compared.
Improvement of model accuracy is particularly important for the modelling of water levels where the current model error is far too high for accurate water level assessment. Monitoring of water levels and the use of the monitored data to calibrate the modelled water levels is recommended. In addition, the current spatial model resolution of 200 m is too large for the assessment of land cover change on water levels as hydrological processes in wetlands that are important to EFA occur at a finer scale. In this study, depth to water table data were used to supplement interpretation of the wetland hydrology. It is recommended that IHA or other EFA statistics using depth to water table be explored.

Hydrologic model and input parameter uncertainty are not currently calculated. It is recommended that this be calculated to provide insight into the true difference between baseline and altered flow regime and difference due to model error (Acreman et al., 2009). This additional information will help elucidate the amount of confidence that can be put in the modelled results. It is important to note however, that the model will make similar errors in the different scenarios that are run. This means that the model error will be less important when assessing relative changes between modelled scenarios.

For this study, groundwater takings were included in the pre-settlement scenario. It is recommended that groundwater takings be removed from the pre-settlement scenario in future EFA’s. Additional anthropogenic disturbance that may impact the hydrology of the subwatersheds such as stormwater management, dredging of the agricultural drain, dams and barriers and bank hardening were not included in the model. The impact of these disturbances should be explored and the incorporation of these disturbances into the model should be considered.
• Attempt to correct 2004-present Tollendale gauge data so it can be used for model calibration and validation

• Use spot flow measurements for model calibration

• Calibrate model to different flow ranges as opposed to focusing on low flows as in the calibration by AquaResource Inc.

• Ensure up to date land use data are used within the model

• Collect water level data and use this data to calibrate the modelled water levels

• Increase spatial resolution of the modelled water level grid

• Explore IHA and other EFR statistics using the depth to water table data

• Calculate model and input parameter uncertainty

• Remove groundwater takings from the pre-settlement condition

• Explore the impact of anthropogenic disturbances that are not included in the model on hydrology and consider incorporation of these disturbances into the model

**IHA Parameter Calibration**

For this study default parameter and threshold calibration values were used for the majority of the IHA and EFC parameters. The exception to this was the 1.6 year return interval used for bankfull flow. The values used for IHA and EFC parameter calibration for the characterization of the natural regime could potentially be improved through further analysis.

• Explore improvement of IHA and EFC parameter calibration and threshold values

**b) Assess Hydrologic Alteration**

In this study, connections between the hydrologic regime and landscape characteristics were made based on limited knowledge of the hydrologic model output (beyond water level and
streamflow) and parameterization and a visual analysis of the landscape characteristics of each sites contributing area. A more in depth knowledge of model parameterization and quantitative characterizations of the contributing area characteristics would improve the understanding of the natural and altered hydrology. Attributes of the contributing areas of each OSAP point have been characterized and it is recommended that the information from these characterizations be used in future LSRCA flow assessments (November 17 2011 conversation with L. Stanfield, unreferenced).

Qualitative linkages between flow statistics and landscape characteristics were made in this study. If more contributing area attributes where characterized, then quantitative relationships between flow statistics (such as rise rate) and point or contributing area statistics (such as percent contributing area) could be made.

It is recommended that summary indices such as the modified DHRAM index be used for communication of results to the public and to facilitate the communication of the comparison of different modelled scenarios to decision makers.

- Obtain a more in depth knowledge of modelled water budget components and model parameterization
- Obtain characterized contributing areas of OSAP data
- Explore quantitative relationships between flow statistics and contributing area characteristics
- Use summary indices such as the modified DHRAM index for communicating hydrologic alteration results to the public and decision makers
c) Hypothesize Ecological Responses to Hydrologic Alteration

The flow ecological-response linkages in this study were inferred based on generalized relationships. These flow-ecological response relationships could be improved if they were developed with experts who have site specific knowledge. As more flow assessments occur and more specific flow-ecology relationships are developed, less work will be required to develop and confirm these relationships. It is recommended that a database be created that contains information on flow-ecological responses that can be referred to when conducting a flow assessment. Scientific evidence that supports the flow-ecological response hypothesis will be extremely valuable in cases where the flow assessment is contentious and the results require higher certainty. It is recommended that studies be conducted to test contentious flow-ecological response relationships that have been hypothesized. If hydrological alteration was calculated at several points, statistical relationships could possibly be developed between flow statistics (such as the rise rate) and biological indices (such as the Hilsenhoff index or Index of Biological Integrity)

- Develop flow-ecological response relationships with scientific experts with local knowledge
- Develop a database that contains flow-ecological response relationships
- Conduct studies to test contentious hypothesized flow-ecological response relationships
- Explore statistical relationships between flow statistics and biological indices

Phase III: Development of a Target Regime

a) Targets for Overall Ecosystem Health

The targets for overall ecosystem health were primarily displayed in tabular format. It would be beneficial to incorporate these statistics into the targets regime figure.
• Explore techniques for graphically displaying overall ecosystem health targets

b) Targets for Ecological Objectives

Quantifying Functional Flows

Improvements to the Hydraulic Model Data Collection Procedures and Calculations

The data that are available for the hydraulic modelling did not produce results that could be used for the flow assessment. The main reason for the problems with the hydraulic model was the techniques used for the collection of the cross-sections. It is recommended that the cross-sections be surveyed in a manner that is consistent with Parish Geomorphic Limited (2005). This would require some simple modifications to the existing data collection protocols. First, the measured wetted channel points and the points along the bank should be collected along a single transect. The transects should also be tied in to each other by measuring the longitudinal channel gradient along the length of the model reach. The transects in OSAP are surveyed at equal intervals along river reach. It is recommended that pool-riffle attributes be explicitly surveyed such as the riffle head, crest and foot. The transects should run perpendicular to the bank (as in the existing protocol) with the exception of the riffle, which should be followed regardless of its orientation with respect to the bank (GRCA, Unknown; Parish Geomorphic Limited, 2005; U.S Fish and Wildlife Service, 1978). In addition, water surface elevations should be measured at different flows to provide information for model calibration. Discharge was calculated using hydraulic head and channel dimensions and the methods from the OSAP manual. This method produced an average reach discharge that is within 0.01 m³/s of the gauged discharge. It is recommended that this method be tested at other sites to determine the accuracy of the calculated discharge. The hydraulic modelling for this study was completed in HEC-RAS.
MIKE-SHE hydrologic model is coupled with the hydraulic model, MIKE-11. There may be benefits to housing the hydrologic and hydraulic model in one program and this possibility should be explored. A 1-D hydraulic model was used for this study due to data availability. It is recommended that more advanced 2-D or 3-D hydraulic models be explored for future EFA’s. However, it should be noted that 2-D or 3-D hydraulic models are much more data intensive than a more simple 1-D model.

The technique of target setting using geomorphic and hydraulic variables relies on the assumption that a change in these variables can be used as a proxy for a given ecological response. While this is an accepted method and the purpose of the functional flow assessment is to identify the most relevant variables that may influence ecological response, the assumption that the response is directly related to these variables may not be valid (Poff et al., 2010). Where contentious decisions must be made, it may be necessary to study the assumed link between the variables and the given ecological response.

A threshold depth of 15 cm for summer pool refugia was used in this study based on the habitat suitability index by Raleigh (1982). Minimum depth for pool refugia is dependent on several factors that differ between sites so it is recommended that expert input be used to determine threshold depths for different sites in future flow assessments. A single depth threshold was used for this study. The analysis could be improved by using categories of depths and cover with varying suitability.

- Measure wetted channel points and banks along the same transect
- Measure longitudinal gradient to tie in surveyed cross-sections
- Survey pool-riffle attributes such the riffle head, crest and foot as opposed to equally spacing transects

- At the riffle crest, survey along the crest as opposed to perpendicular to the bank

- Measure water surface elevations at different flows to provide data for model calibration

- Compare discharge calculated from hydraulic head to gauged discharge at multiple sites to determine the accuracy of the method

- Explore the benefits of using MIKE-11 for hydraulic modelling

- Explore the use of 2-D or 3-D hydraulic models

- In situations where flow decisions are contentious, conduct studies to better understand the assumed connection between functional variables and ecological response

- Use expert input for the definition of thresholds (such as pool depth) for quantifying functional flows

- Use categories of thresholds with different suitability as opposed to one threshold

**Improvements to Sediment Transport Calculations**

The data that were available for the sediment transport calculations did not produce results that could be used for the flow assessment. As with the hydraulic modelling, changes to the data collection techniques may solve the issues that were encountered in this study. The energy slope (which can be approximated by reach slope) is required for the calculation of the boundary shear stress. The water surface or the reach slope was not available so slope was estimated from the DEM. A field measurement of the water surface or the reach slope would improve the calculation of the boundary shear stress. In this study the stage was assumed to be
equal to the stream depth. This assumption may not be valid and future EFA’s should establish a proper relationship between stage and depth.

The calculation of critical shear stress requires the $D_{50}$ of the accumulated surficial sediment. The data that was used was from a pebble count style survey with an assumed size of 0.1 mm for sand. In OSAP, sand was defined as particles that feel “gritty”. Ideally, the $D_{50}$ of the accumulated surficial sediment would come from scoop samples taken within the pool. It is recommended that scoop samples be taken for the estimation of the superficial sediment $D_{50}$.

If data were available, the sediment transport equations could also be applied to calculate the flows required to flush fines from spawning riffles. It is recommended that this be calculated in future assessments where applicable (Al Zaghal, 2010).

- Measure water surface slope or reach slope for a more accurate calculation of boundary shear stress
- Take scoop samples within pools for a more accurate estimation of superficial sediment $D_{50}$
- Where applicable, apply sediment transport equations to calculate flushing flows
- Establish a relationship between stage and depth

Additional Methods for Quantifying Functional Flows

Additional methods for quantifying functional flows were suggested in this study but were not explored in depth. The use of groundwater discharge from MIKE-SHE or FEFLOW and temperature modelling software such as HEC-RAS or SSTEMP could be used for quantifying flows for maintaining groundwater discharge and stream temperature.

- Explore the use of FEFLOW or MIKE-SHE modelled groundwater discharge for quantifying groundwater discharge requirements
• Explore the use of temperature modelling software for quantifying stream temperature requirements

c) Integration into a Target Regime

Streamflow EFC thresholds used for target setting for this study were based on flow percentiles that have generally accepted ecological functions. It is recommended that the target magnitudes be refined using quantified functional flows or scientific expert input. Targets for wetland vegetation could be refined for specific species or vegetation types that are present based on the wetland evaluation information.

The EFC functionality of the IHA software was not used for the wetland component of this study. If specific water level thresholds for wetland functions could be developed, the EFCs would be very useful. The EFCs may be more applicable to wetland target setting if depth to water table data were used. If depth to water table data were used, then the ground surface could be set as a threshold and the duration and frequency of inundation could be calculated. Similarly, different rooting depth requirements for wetland vegetation could be set as thresholds.

MIKE-SHE has other model outputs such as soil moisture which may also be useful to explore.

• Refine streamflow EFC thresholds used for target setting based on quantified functional flows or scientific expert input

• Explore the development of EFC thresholds for wetland target setting, potentially using depth to water table data

• Explore the use of other hydrological model output for wetland target setting, such as soil moisture
General Recommendations

It was difficult to obtain the required data in a timely fashion which has the potential to cause unnecessary delays and extra cost in future flow assessments within the LSRCA. Timely acquisition of data has been cited as a problem within other flow assessments where the delays were cited to be the potential cause of loss of project momentum, loss of team members, revisiting activities that have already been completed and loss of stakeholder and team member interest (Dickens, 2011). Dickens (2011) suggests breaking the EFA down into smaller subprojects with well-defined goals and end-points as a possible solution to these delays. In addition, having a clear understanding of the data requirements at the onset of the project (which has been identified within this study) and requesting data early on in the process will aid in the timely acquisition of necessary data. Having key contacts at Ministries and Conservation Authorities where data is to be requested and acknowledgement of the importance and relevance of the flow assessments will aid in the acquisition of the data (Dickens, 2011).

It is recommended that a multi-disciplinary Provincial EFA experts group be developed. These experts could liaise with local experts within their same discipline to acquire the necessary information to conduct a flow assessment. Forming a Provincial EFA expert group would alleviate the need to train each local jurisdiction in EFA making the process of target setting across Ontario more efficient.

Stakeholder participation is a component of the guidance document that should be considered for inclusion into future flow assessments. It is recommended that the participants consist of dominant stakeholders who have an influence on and an interest in water flows within the subwatershed. It is also recommended that the stakeholder group participate and contribute
at various stages throughout the process but that they do not actually make the final decisions (Acreman and Ferguson, 2010).

Monitoring of prescribed flow and water level targets is a key component of any EFA. Monitoring flow and water levels at locations across the watershed is recommended to ensure that the flow and water level regimes are progressing in accordance with the set target regimes.

Climate change was not assessed in this study but this could be incorporated by altering the climatic parameters within the hydrologic model and examining the impact of climate change on streamflow and water levels along with the identified anthropogenic disturbances. It is recommended that future simulations include climate change scenarios.

It is recommended that modelled groundwater discharge from MIKE-SHE or FEFLOW be explored for the purpose of target setting. Similar to streamflow or water levels, the natural regime and hydrologic alteration could be calculated and targets for maintaining a groundwater upwelling regime could be set.

- Ensure that the flow assessment has well defined goals and endpoints
- Ensure a clear understanding of the data requirements before the onset of the project
- Establish key contacts within Provincial Ministries and Conservation Authorities that will aid in the acquisition of required data
- Establish a Provincial EFA expert group
- Include stakeholder participation throughout the EFA process
- Monitor streamflow and water level targets at locations across the subwatershed
- Include climate change scenarios in future hydrological simulations for EFA
• Explore the development of groundwater discharge regime targets
Chapter 8: Conclusions

Throughout this study the framework for ecological flows and water levels was tested and refined and preliminary targets for four streamflow and four water level locations were set. A method for defining objectives and identifying habitat specialists as well as completing the functional flow assessment through expert input was proposed and tested. The developed method proved useful for determining the information that was required for the flow assessment; however it was found that the expert interviews could have been extended to derive input at other points in the process such as developing flow ecological response relationships and threshold setting.

The natural regime of each streamflow and wetland site was successfully characterized along with the hydrological alteration at each site. These characterizations allow for an improved understanding of the natural hydrologic system as well as the potential hydrologic alterations at each site. The characterizations are however, limited by a lack of certainty in the hydrologic model output, which can be refined with additional calibration. Potential ecological responses to the hydrologic alterations were then hypothesized for the different types of alterations experienced at the different sites. It was difficult to develop specific ecological response to hydrologic alteration hypotheses without more site specific knowledge but general relationships were hypothesized based on existing data and general relationships. The hypothesized relationships are useful for understanding the potential ecological impacts from the calculated hydrologic alteration at each site and they may also be useful in guiding future studies that test flow ecological response hypotheses.
Methods for setting two types of flow targets were proposed and tested. The two target types are targets for overall ecosystem health and targets for specific ecological objectives. Targets for overall ecosystem health were set for all IHA statistics with the purpose of protecting or restoring ecological functions that were not accounted for in the targets for ecological objectives. The accuracy of the overall ecosystem health targets is limited by the accuracy of the hydrological model output that the targets are derived from. The proposed targets provide a solid foundation for overall ecosystem protection and can easily be improved as the accuracy of the hydrological model is improved.

The targets for ecosystem objectives were set for the identified ecological functions that are applicable to each specific site. Functional flow quantification for the purpose of setting thresholds was attempted using OSAP data, but it was found that the data were not adequate for this application. Several recommendations for improving the data collection techniques for the purpose of EFA were made. The streamflow ecosystem objective targets were set using generalized relationships between ecological functions and hydrological thresholds, such as flow percentiles and return intervals. The streamflow targets are based on EFC magnitudes, frequencies and durations, while wetland ecosystem objective targets were set based on annual and seasonal IHA statistics. The targets set for ecological functions are limited by the accuracy of the hydrological magnitude threshold and the hydrological model output.

The overall ecosystem health targets and the ecosystem objective targets were integrated into a flow regime for each site. A method for applying the targets to support decision making that impacts flow and water levels was then proposed. The developed target regimes go well beyond the current singular statistics that have been commonly used for environmental flow
targets in Ontario to date. The tools and methods for developing the target regimes are provided in this paper in a logical manner along with recommendations for improving targets so that the method can be iteratively applied to improve upon existing targets or the method can be applied to develop target regimes for other subwatersheds in the LSRCA. Given that tools and methods for developing flow regime targets have been methodically laid out in this paper, and that the targets are a substantial improvement from existing singular flow statistics, the overall objective of advancing the practice of EFA and providing better knowledge and tools to support decision making has been met.

This paper provides explicit steps for developing flow targets for subwatersheds within the LSRCA using data that are currently available. Recommendations for how the flow assessments can be improved through collection of additional data or through additional analysis have also been made. Setting environmental flow targets is viewed as an iterative process where targets should continually be revisited and improved based on new information and methods. As the methods described in this paper are continually applied and the targets are continually refined, more informed, sustainable decisions will be made that will lead to the enhanced protection and restoration of ecosystem health across the LSRCA.
References


Arthington A. H., Bunn, S. E., Poff, N. L., Naiman, R. J. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications, 16(4), 1311-1318.


Appendix 1: Additional Subwatershed Maps

a) Surficial Geology Map
b) Soils Map
c) Historic and current mottled sculpin capture locations
d) Bank Hardening and Channelization Map
e) Municipal Drains Map
f) Barriers to fish Movement Map
g) Intake and Wellhead Protection Zone Maps
h) Ecological Integrity Index based on fish catch
i) Ecological Integrity based on benthic invertebrates
j) Fish communities and instream temperature
k) Wetland Types in Lovers Creek
1) Current and historic presence of brook trout
Appendix 2: Aggregated Survey Responses

Goals and Objectives:

1. What do you think are all of the values that should be restored or protected within Lovers Creek subwatershed? (Ex. protect cold water habitat, wetlands, geomorphic functions, human uses, biogeochemical functions etc.)
   - Cold water fish
   - Cold water fish/temperature
   - Cold water habitat that supports brook trout
   - Cold water habitat
   - Existing cold water habitats should be protected
   - Barriers to fish passage should also be removed
   - Wetland protection
   - All wetlands (especially provincially significant wetlands (PSW))
   - Wetlands
   - Maintain meander (natural geomorphic processes)
   - all watercourses & meanderbelts
   - re-instating meandering channels where they have been straightened
   - areas of floodplain
   - Human Use
   - Agricultural drains – note several straight sections within the stream network
   - significant valleylands
   - all woodlands
   - Prevent fragmentation of valley land
   - Endangered species according to the Endangered Species Act (2007)
   - Migratory birds according to the Migratory Birds Convention Act
   - Biological form and function of the creek should be restored
   - creating vegetative buffers

2. Can you prioritize this list in order of importance?
3. Can you identify more specific and quantifiable objectives associated with the protection or restoration of these values – possibly identified through other policy such as a fisheries management plan? (Ex. maintain 70% of known and existing brook trout spawning habitat during spawning period)

- Fish density based on an index
- No wetland loss except for the following 2 exceptions:
  - In areas designated as “settlement areas” only PSW’s are protected
  - Wetlands are also NOT protected from municipal drains
- Look at the “Integrated Watershed Management Plan” for specific objectives
- No loss of Riparian Cover

- Achieve feature area percentages as per the Recommendations provided by Environment Canada's How Much Habitat is Enough. We publish Watershed Report Cards as way to illustrate current states.

- Simply trying to keep the water cold

- A fisheries management plan would help to protect this creek and highlight areas for rehabilitation.

- > 6% imperviousness will lose BT

4. What species do you think are habitat specialist

- Cold water fish
- Cold water species
- Brook Trout (Salvelinus fontinalis) and Mottled Sculpin (Cottus bairdi) both require cold water.
- Brook Trout and Mottled Sculpin

- Small mouth bass

- Wetlands – frogs/amphibians (tree frogs, wood frogs, newts etc.)
- Amphibians would be habitat specialists
5. Which stages of this/these species life history that are related to flow require maintenance vs. species that are habitat generalists and do not require specific flow requirements

- Coldwater Habitat: Refugia from warm water
- Coldwater Habitat: Spawning
- Brook Trout require groundwater upwelling for spawning
- Brook Trout and Mottled Sculpin – summer temperature and flow is most important

- Wetland amphibians: breeding
- Wetland vegetation: general
- Vernal pools that have correct hydroperiods are critical to successful breeding.
- As vernal pools are not always considered as wetlands, they are not always afforded protection.

6. What are the main flow related variables that are required to be maintained within a specific range to meet the habitat specialists life history requirement (Ex: temperature, living space, substrate character etc.)

- Coldwater Habitat: Refugia pools with adequate depth and temperature
- Coldwater Habitat: Groundwater upwelling for spawning
- Coldwater Habitat: Connectivity to groundwater upwelling locations (gaining reaches) for spawning
- Temperature and groundwater upwelling
- Brook Trout require groundwater upwellings & gravel substrates for spawning
- BT require cold water, undercut banks, overhanging vegetation, cold deep pools for all other life stages
- BT need streams free of barriers so that they can move between spawning areas and feeding/cover areas
- Brook Trout and Mottled Sculpin – temperature and imperviousness

- Wetland amphibians: Inundated duration of vernal pools
- Thinks the swamp is groundwater fed based on air photos (there is not a lot of open water)
  - Wetland Vegetation: maintenance of a depth of saturation (min soil moisture) to prevent invasion of none wetland plants - wetland plants (yellow birch, hemlock)
    - Shallow water vs deeper water rooting plants
  - Riparian vegetation: flow to disperse riparian vegetation seed
  - Small mouth bass – need clean, cool water
    - Sediments from increased sediment load cover spawning bed on shores of kempenfelt bay

7. Do you have insight into what scale these variables operate and can be measured at?
  - Currently determine cold water locations at the reach scale through spot flow measurements
  - Scale is stream reaches
  - Reaches can be measured using the geomorphic modules of the Ontario Stream Assessment Protocol
  - Wetland vegetation: Thinks that fluctuation of ½ of a meter will determine a shift from wetland to non-wetland plant species.

8. If there are multiple functions (ex. for a single species) do you have a sense of what the “critical” or “limiting” function is?
  - Coldwater Habitat: Temperature
  - Brook Trout and Mottled Sculpin – temperature and imperviousness (upwelling)
  - Brook Trout require groundwater upwelling & gravel substrates for spawning
  - BT require cold water, undercut banks, overhanging vegetation, cold deep pools for all other life stages
  - BT need streams free of barriers so that they can move between spawning areas and feeding/cover areas

9. If this critical or limiting function was removed, do you know what the next critical or limiting function might be?
  - All functions are important
10. Do you have any idea what non-flow related processes affect these functions?

- Removal of riparian vegetation
- Riparian removal
- Lack of riparian cover
- Climate change
- Nutrient inputs
- Warming water inputs from ponds
- Harding and straightening of channels

11. Do you have any insight into how much the flow can deviate from its natural regime before the species is affected to the point where the objectives are no longer being met?

- Wetland vegetation: Thinks that fluctuation of ½ of a meter will determine a shift from wetland to non-wetland plant species.
- No, but there may be studies into this. If not a good study idea.
- Does not know – does not think anybody knows but may be some insight in the literature

Other Specific Potential Biological Values?

12. What are the specific or important macroinvertebrates in the subwatershed?

- Stoneflies, mayflies and caddisflies are generally the most important and sensitive
- EPT – mostly because that is what BT eat
- Protecting flow for EPT is probably sufficient for protecting flow for other bugs
- Food for fish & birds

13. Are there any important mussels within the subwatershed?

- They have not studied molluscs- the expertise does not exist in house
- He recommends maintaining representative habitat
- Specifics are generally only recorded on a SAR basis
- Unknown
- Not sure but can check with the DFO

14. What are the important amphibians?
15. What are the important wetland plants, invertebrates, fish, amphibians, other?

- To obtain a list of wetland plants, please contact the OMNR to obtain a copy of the Lovers Creek Provincially Significant Wetland evaluation.

Other Values or Functions?

16. Do you think channel incision is a problem within Lovers Creek subwatershed as identified in the Draft Tier 3 report?

- Thinks the channel is naturally incised
- A lot of material in the system
- Highly erosive
- Large (meter diameter) boulders moving through
- Thinks there is a problem in developed areas and channelized areas
- The sites that I have visited haven’t had a problem with incision

17. Are there any human uses (recreational/aesthetic values/sewage assimilation) related to flow or biogeochemical functions that should be protected?

- I don’t think Lovers Creek is large enough for sewage assimilation or recreation
- The aesthetic value of having a creek running through a city should be protected
- Recreational pond in the NW of shed
- Golf course – riparian destruction (generally designed OK but when altered, they have a cumulative impact on the system)
- Marina at the mouth that needs to be dredged

Points of Interest:

18. Do you know any specific locations of the identified ecological functions

- Wetlands: headwater wetlands, Lovers Creek Swamp, the mid-channel, narrow wetland
- Edges of the wetland (seems to be a change in IBI
  - Coldwater habitat: coldwater fish in warm water locations
    - Good for looking at coldwater refugia in warm water areas
  - Each gaining reach as defined by the gaining reach layer
- Headwater areas
- Headwater wetlands and lower western tributaries
- Locations of all natural heritage features, watercourses, and our identified natural heritage system.

19. More specifically → Do you know of specific locations that habitat specialist undergo critical phases of their life history? (Ex. brook trout spawning)
  - Headwater areas of the watershed…nothing specific

20. Do you know how variable these locations are within the system? (Ex. brook trout spawning location may be based on short term changes in the channel bed, movement of substrate and changes in locations of upwelling based on groundwater and river head)
  - These locations would not be variable.

21. Do you have a sense of how far a specific species will travel to find conditions that meet the identified critical or limiting functions?
  - Brook Trout will travel long distances to find groundwater upwelling for spawning.
  - Brook Trout mostly stay in the creek (will not often travel out to the lake)

22. Do you know what the future flow and biological monitoring locations and plans are? It would be good to have our points of interest correspond with past, current and future monitoring locations.
  - Yes we have set long term monitoring sites within the watershed, headwater, mid channel and outlet.

**Current/future state of the watershed:**
23. Are you aware of the key threats and stresses that currently affect the hydrologic regime or ecological processes within Lovers Creek and those that are anticipated to in the future?

- Bottom of the watershed is turning into urban landscape
- City of Barrie's recently annexed lands, they will be the focus of intense development pressures
- Residential and commercial development is currently the biggest stressors on the system and this will only increase in the future.
- Industrial development (has already gone in the wrong place)
- Barriers to fish migration
- Online storm water ponds
- Municipal drains (channel dredging in the headwaters)

**Data:**

24. Is there a geomorphic assessment completed for Lovers Creek similar to the York Region Geomorphological study for the Mask, East and West Holland?

- Not that he knows of
- Unknown

25. Is there additional information available about the ESA’s within the creek identified in the draft tier 3 report

- Unknown

**Other:**

- Can provide information as to how the cold water designation was determined
- Something like the 4:00pm temperature on the hottest day of the year
- Gaining and losing reach layer from the spot flows – he thinks gaining and losing reaches are related to the Laurentian feature
- Can provide a list of specific inverts that were caught at the monitoring locations (thinks there are upwards of 600 species)
Trent is doing some flow monitoring in LSRCA – may be doing some in Lovers – who to talk to about this? – Information will be included in the comprehensive monitoring program?

Mentioned OSAP

Aquatic Resource Management Plans developed by Jeff Andersen

He will send me a layer of fish catch from OMNR and consultant surveys

May have information about SAR (amphibians and molluscs in Lovers Creek)

Questions about the Process of Identifying Goals, Objectives and Points of Interest:

26. What do you think worked well about our expert consultation?

Questions are straight forward and easy to answer

Good that it was done in person

27. How we can improve this component of the environmental flow assessment process?

Send questions to interviewee before the interview

Make the survey more specific to different biologist, terrestrial biologist, hydrogeologist, aquatic biologist

28. Can you recommend anybody else that we can speak to?

Chandler Eves – Did the BMP’s for riparian cover and has walked the entire creek

Andrea Gynan – Stewardship coordinator; may have some local knowledge of the subwatershed

Rob Wilson and Jeff Andersen should have specific information about the system

Christine Wilson – Created a report about the Economic Value of Important Features

I think you have gotten everyone in our office.

Aurora Ministry of Natural Resources?