GIS APPLICATION FOR AQUATIC BARRIER MITIGATION

IN THE UPPER THAMES RIVER WATERSHED

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this Research Paper.

I authorize Ryerson University to lend this Research Paper to other institutions or individuals for purposes of scholarly research.

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ABSTRACT

The Upper Thames River watershed, like most watersheds in Southern Ontario, has many dams and barriers within its boundaries that can have adverse effects on the aquatic ecosystem. In many cases, the dams and barriers are in poor condition and no longer serve the purpose for which they were originally constructed. Removal or mitigation of such structures is an effective tool for the restoration of river systems. Significant resources are required to mitigate the ecological impacts, limiting the amount of rehabilitation work that can be undertaken. Targeting mitigation efforts for the greatest improvements in aquatic ecosystem health is necessary. Characteristics of the dams/barriers alone are not sufficient to identify their impact. Spatial variation in the type and quality of aquatic ecosystems in their proximity must also be considered.

In this research the impacts of aquatic dams and barriers have been quantified using watershed analysis tools available within Geographic Information Systems (GIS). An ecological approach is employed to consider the cumulative impacts of barriers adapting a watershed concept to more localized barrier catchments. Analysis that utilized fourteen criteria to prioritize dams and barriers for mitigation efforts was undertaken. Working with a hydrologically conditioned DEM, a watershed model was developed and used in combination with a dam and barrier inventory for the Upper Thames River Watershed to develop catchment areas for each dam and barrier.

With spatial refinements to the inventory data, the watershed model was successfully used to define catchments for 128 barrier sites in the watershed. These catchments

provide the first step in the analysis conducted to consider the full spatial extent of the ecological impacts associated with the dams/barriers. Using existing watercourse data, GIS overlay analysis was used to summarize conditions in each barrier catchment. These characteristics are considered in combination with other criteria specific to each dam or barrier to develop a priority list of structures to consider for mitigation efforts.

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COLDCOOL – Cold or Cool Water

CPR – Canadian Pacific Railroad

CRWR - Centre for Research in Water Resources (University of Texas at Austin)

CULTURAL - Cultural Significance

DEM - Digital Elevation Model

DFO - Fisheries and Oceans Canada

EA - Environmental Assessment

ESRI - Environmental Systems Research Institute

FCS - Flood Control Structure

Fish_COM - Fish Community

GIS - Geographic Information Systems

GPS – Global Positioning System

HEC-HMS - Hydrologic Engineering Centre – Hydrologic Modeling System

HEC-RAS - Hydrologic Engineering Centre – River Analysis System

HSPF - Hydrological Simulation Program – FORTRAN

I_P - Intermittent/Permanent

INVASION - Risk of Invasion

KI – Known Impediment

LENGTH - Additional Watercourse Length Available

MIT – Mitigated

MIT_REQ - Mitigation Required

MNR - Ontario Ministry of Natural Resources

MNR-LEMU - Ministry of Natural Resources – Lake Erie Management Unit

MOE - Ontario Ministry of the Environment

MSL - mean sea level

OGDE - Ontario Geospatial Data Exchange

OMAFRA - Ontario Ministry of Agriculture Food and Rural Affairs

PUC – Public Utilities Commission

SAR - Species at Risk

SO - Stream Order

STR_HAZ - Structural Hazard

SWM - Stanford Watershed Model (SWM)

SWMM - Storm Water Management Model

TAC - Technical Advisory Committee

TFCS - True Flood Control Structure

TRIBTHMS - Tributary to Thames

UT – Upper Thames

UTRCA – Upper Thames River Conservation Authority

Chapter 1: Introduction

1.1 GIS Application in Water Resource Management

Water is a concern for all citizens. A healthy water system is necessary to support both human life and the functions of the natural environment. Significant pressures exist that affect both the quality and quantity of Ontario’s water resources. These pressures stem from extensive urban and agricultural development that alter the natural water cycle and degrade the quality of the water and aquatic ecosystems it supports. In addition, recent shifts in weather patterns and increases in “extreme” weather (i.e. droughts and storms) attributed to climate change exacerbate many of these pressures. Scientific research indicates that global warming will increase the frequency and magnitude of extreme hydrologic events and have implications for water resources (Cunderlik, 2005). Stressors to the water system are reflected in water quality degradation from point and non-point pollution sources, severe flooding and conversely reduced flow in many watercourses for long periods of time. Such stressors and the devastating results to our water system highlight the need for water management that assess how land development will affect water and aquatic ecosystems (Maidment, 2002).

Hydrologists have grappled with many of the problems affecting our water system by developing hydrologic models. Well understood hydrologic models have existed for many years. Various models, such as the Stanford Watershed Model (SWM), Hydrological Simulation Program – FORTRAN (HSPF) and Storm Water Management Model (SWMM), have been developed to simulate watershed behaviours based on known inputs in an attempt to reflect natural processes such as, precipitation-runoff and flooding. Integration of hydrology models with Geographic Information Systems (GIS) has brought forth the concept of spatial hydrology models. They are designed to simulate water flow and transport processes on a geographic region (typically a watershed) using the data structures provided by a GIS (Maidment and Djokic, 2000). These models benefit from the manipulation, visualization and data storage power of GIS. Two examples of spatial hydrology models are the Hydrologic Engineering Centre – River Analysis System (HEC-RAS) for use in floodplain management and Hydrologic Engineering Centre – Hydrologic Modeling System (HEC-HMS) used to simulate precipitation-runoff processes in a watershed.

In addition, GIS has provided a consistent method to delineate watersheds and stream networks using Digital Elevation Model (DEM) data of land surfaces (Maidment, 2002). GIS has been accepted as a useful tool for assembling and managing water resource information and for developing input parameters used in hydrologic models. In recent years this has advanced through the development of GIS data models to facilitate exchange of data between hydrologic simulation models and GIS. The ArcHydro data model has been developed jointly by Environmental Systems Research Institute (ESRI) and the Centre for Research in Water Resources (CRWR) at the University of Texas at Austin. The data model creates and populates a data framework and provides tools that can be used in independent hydrologic models. These watershed management tools and data model concepts have been employed in this research to help address the impacts of dams and barriers on water quality and aquatic ecosystems in the Upper Thames River watershed.

1.2 Watersheds, Conservation Authorities and the Upper Thames River

1.2.1 Watershed Management

Watershed based management has been identified as the best approach to monitor and manage surface water based issues (O'Connor, 2002). The watershed is recognized as an appropriate unit for managing water resources. The boundaries of a watershed are based on biophysical boundaries defined by the hydrologic cycle and are capable of demonstrating the cumulative effects of environmental stressors. A watershed is made up of the land area that is drained by a river and its tributaries (MOE, 1993; MNR, 1993). Human activity is governed according to political boundaries that often intersect watersheds making it difficult to cumulatively manage human and environmental interaction. Watershed management plans are aimed at protecting water resources and ecosystem health in relation to ongoing land use changes. Watershed management is necessary due to development and agricultural pressure or for rehabilitation needs (Conservation Ontario, 2003). In Ontario, watershed plans have historically been broad based plans including all aspects of the health of the watershed including protection of the quality and quantity of water.

1.2.2 Ontario Conservation Authorities

By the late 1920s, deforestation and drought were causing extensive soil loss and flooding in the province, which led to a call for a broad new initiative to deal with conservation, flood control and reforestation. The widespread concern over a range of environmental issues led to the passage of the Conservation Authorities Act in 1946. The Act fostered the creation of Conservation Authorities that are watershed based agencies responsible for the protection and management of natural resources (Conservation Ontario, 2003). Conservation Authorities are local, community-based and are dedicated to conserving and managing natural resources on a watershed basis. Thirty-six authorities have formed since the 1946 passing of the Conservation Authority Act that operate in watersheds where 90% of the provincial population resides (Conservation Ontario, 2003). Today, Ontario's Conservation Authorities are a model of watershed based conservation and resource management for other provinces and countries. The objectives of Ontario's Conservation Authorities are:

- to ensure that Ontario's rivers, lakes and streams are properly safeguarded, managed and restored;
- to protect, manage and restore Ontario's woodlands, wetlands and natural habitat;
- to develop and maintain programs that will protect life and property from natural hazards such as flooding and erosion;
- and to provide opportunities for the public to enjoy, learn from and respect Ontario's natural environment (Conservation Ontario, 2006).

Conservation Authorities were developed as a partnership between the municipalities of the watershed and the province. This partnership is reflected by municipal representation on the boards of the Conservation Authorities as well as through the funding provided by municipalities. Much of the work undertaken by Conservation Authorities has been conducted with technical guidance provided by the province. Conservation Authorities employ a number of technical staff including: biologists, ecologists, engineers, hydrogeologists, planners, and communications and GIS professionals. The wide range of staff focuses their expertise on watershed planning and on integrating their fields together on a watershed basis.

1.2.3 Upper Thames River Conservation Authority

In May 1947, representatives from municipalities throughout the entire Thames River watershed met to vote on a resolution to form a conservation authority for the entire Thames River watershed. The proposal was defeated because it did not have the required two-thirds support of the delegates. The results showed that most of the delegates from the upper Thames watershed had voted in favour, while those in the lower Thames watershed had voted against. A second vote was held in August 1947, attended by the 27 municipalities in the upper Thames River watershed. The proposal received the required support, and the Province was asked to establish a conservation authority that would include the City of London and the watershed upstream of the city. (Department of Planning and Development, 1952) As a result, the Upper Thames River Conservation Authority (UTRCA) was established on September 18, 1947 by Order in Council.

The UTRCA represents an approximate area of 3430 square km. and is home to approximately 422000 people (Figure 1.1). Watershed management, flood protection, surface and ground water quantity and quality programs are important aspects of the UTRCA's mandate. Today, the UTRCA's area of jurisdiction includes all or portions of the municipalities listed in Table 1.1.

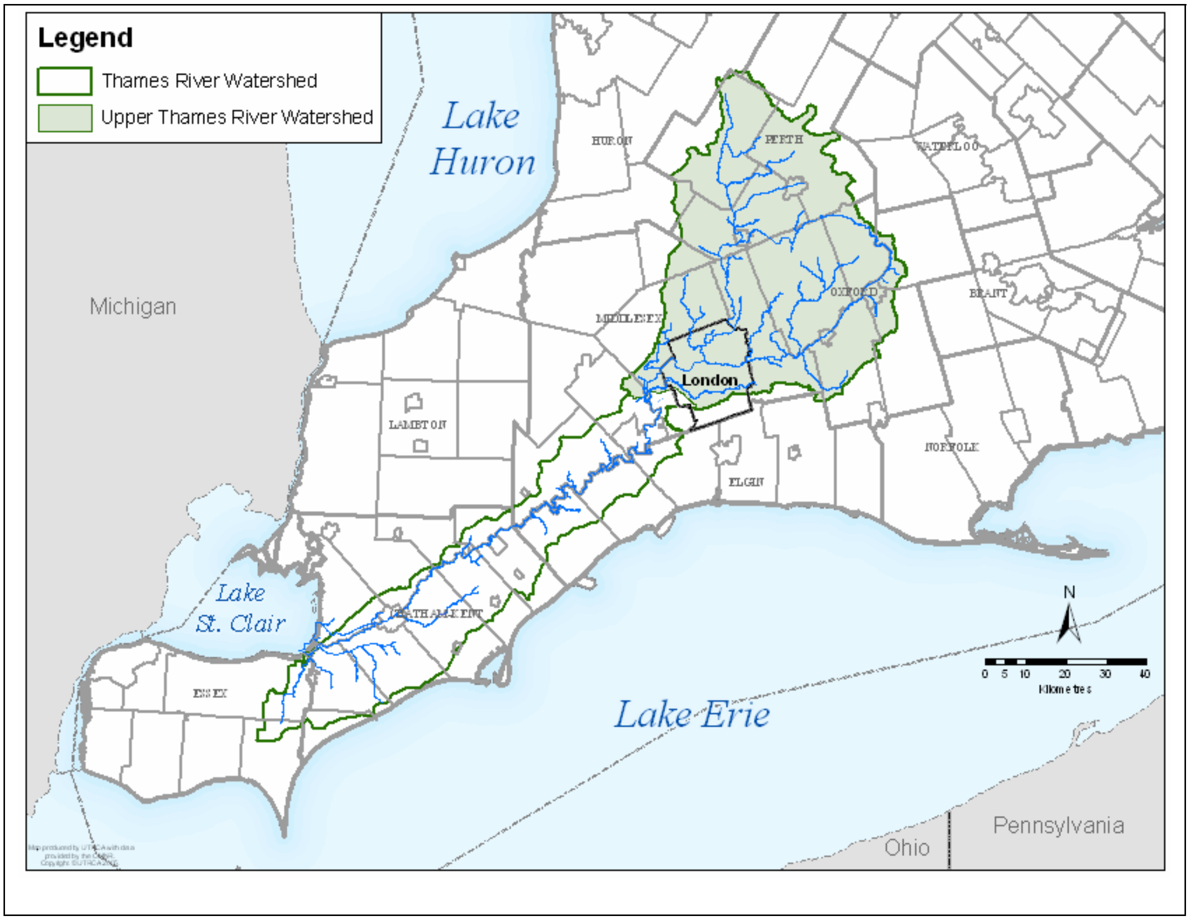


Figure 1.1: Thames River Watershed

The UTRCA has shifted from its initial focus on flood control and prevention through structural engineering solutions and land acquisition, to a more holistic, ecosystem approach. Programs and services today include:

- Flood control and dams
- Land use planning and regulations
- Watershed research and planning
- Environmental monitoring
- Conservation services / stewardship
- Natural areas, parks and recreation
- Community partnerships (UTRCA, 2006).

Table 1.1: UTRCA Member Municipalities

Upper and Single Tier Municipalities	Lower Tier Municipalities
City of London City of Stratford Middlesex County Oxford County Perth County Town of St. Marys	City of Woodstock Municipality of South Huron Town of Ingersoll Township of Blandford-Blenheim Township of East Zorra-Tavistock Township of Lucan-Biddulph Township of Middlesex Centre Township of Norwich Township of Perth East Township of Perth South Township of South-West Oxford Township of Thames Centre Township of West Perth Zorra Township (UTRCA, 2006)

Dam and barrier mitigation is integral to many of the identified UTRCA program areas. These include flood control and dams, watershed research and planning, environmental monitoring, conservation services / stewardship and community partnerships. Flood control and dams are considered a core mandate of the UTRCA. Many dams exist in the watershed that perform flood control functions and require significant management, including operation and maintenance. UTRCA owns or operates many of these that perform water control and stream flow augmentation functions. In addition, UTRCA dams exist that were created for other purposes such as recreation. Given the broad mandate of the conservation authority it is important to consider options to mitigate impacts of some structures as part of their management. Watershed research has identified that dams and barriers act as physical barriers isolating populations of aquatic species (Thames River Recovery Team, 2004). The 2001 UTRCA Watershed Report

Cards highlighting watershed conditions identified a need to explore mitigation of the impacts of barriers in the watershed (UTRCA, 2001).

Environmental monitoring programs of the UTRCA include surface water quality monitoring, reservoir monitoring, benthic invertebrate monitoring, fish sampling and habitat assessment. Significant water quality problems have been identified in various impoundments throughout the watershed. These include potentially toxic blue-green algae bloom problems, eutrophication, nutrient loading, reduced dissolved oxygen content and elevated bacteria levels (Figure 1.2). In addition some barriers in the watershed have been identified to limit the migration of fish and wildlife. The conservation services / stewardship program explores design options for individual dams or barriers to best mitigate the impacts on the watercourse. These options include removal plans, fish way passage design and rock and riffle design to overcome elevation changes associated with drop structures or perched culverts. Past efforts have included the development of a range of mitigation options to be considered as part of an environmental assessment process associated with barrier projects.

(Photos by Karla Young – UTRCA 2005)

Figure 1.2: Blue-Green Algae Bloom – Fanshawe Reservoir August 2005

Community partnership is considered a key program area at the UTRCA. Significant consultation and partnership with stakeholders has fostered conservation efforts. Involving the local community stakeholders in the early stages of any environmental project increases community "buy-in" and can harness the motivation of various local stakeholders. For example, the "Friends of Dingman Creek" environmental club and staff from the City of London were instrumental in the process to remove a significant barrier (Dingman Weir) located on Dingman Creek in London, Ontario. Recognizing the cultural significance that barriers or impoundments can have with local communities highlights the need to develop community partnerships that educate and involve stakeholders in barrier mitigation. Working to mitigate impacts associated with dams and barriers represents only one portion of implementing watershed management efforts but involves a multi-disciplinary team from various program areas operating within the UTRCA.

1.3 Research Objectives

Dams and other aquatic barriers can have major negative impacts on aquatic ecosystems. The adverse effects include barring migration of fish and wildlife, increasing soil deposition and erosion, altering water quantity and quality, eutrophication (excess nutrients that cause excessive algae growth and a resulting lack of oxygen), and increasing wildlife mortality (World Commission on Dams, 2000). The overall research objective is to employ GIS functionality and the applicable watershed analysis tools to support decision making when identifying and prioritizing barriers for mitigation efforts.

Stream rehabilitation work by the UTRCA in the watershed has resulted in the removal of two barriers, the most significant of which was the Dingman Weir located in London, Ontario. Dingman Weir provided a case study that highlighted the significant amount of resources needed to proceed with removal of a dam or barrier. The process to remove the weir in 2005 took approximately three years and included study of mitigation options through application of the Municipal Class Environmental Assessment process. Given the number of barriers in the watershed coupled with limited resources for mitigation work it is necessary to develop a methodology for targeting efforts to achieve the best results. This methodology together with a priority listing of "best bets" for barrier mitigation or removal will be useful for securing funding, approaching municipal partners and landowners that own structures and for involving and educating the general public on the impacts of barriers.

The use of GIS as a tool in the assessment of dams and barriers for mitigation is intended to serve two main purposes. Firstly, for data storage and management as significant primary data have been collected in the field using GPS for location coordinates, and data sheets for gathering various attributes of each structure. These data are stored as a GIS point layer that locates the dam or barrier and documents a series of attributes that can be used in analysis. Secondly, GIS was employed to derive and associate data contained in other GIS data layers with each of the barriers located in the watershed. The objective is to use watershed delineation tools available in GIS software to create catchment polygons for each of the barriers and integrate the various sources of data using the GIS analysis tool overlay. Both the primary and derived data were then stored in a GIS database that can be updated as necessary. Data will be discussed in greater detail in Section 1.4.

The analyses and results are intended to serve as a decision support tool for the remediation of negative impacts associated with dams and barriers in the watershed. Many variables are included in the analysis and some of the data are subjective based on the observations of technicians that collected data in the field. For example, cultural value is one of the variables that is considered but could be misinterpreted during the site visit. This variable considers activities taking place around the barrier and the impoundment that was created in many cases, such as trails, cultural heritage, recreation etc. While some cultural characteristics will be obvious others will not surface until mitigation or removal options are developed and public consultation occurs. The results of this research are considered a starting point for barrier mitigation efforts. The priority order of barriers developed in this research is not intended to dictate when rehabilitation efforts occur. For example, if funding for barrier mitigation is available specifically for work at a given barrier it will be implemented regardless of its priority ranking here. This may occur if action is required to repair a structure prompting consideration of removal or mitigation options. Furthermore, in some cases mitigation work on structures that are identified to have significant rehabilitation potential may never occur.

Mitigating the impacts of barriers in the Thames River watershed has been identified in various watershed planning initiatives, such as the Thames River Recovery Strategy for Aquatic Species at Risk (Thames River Recovery Team, 2004) ant the UTRCA

Watershed Report Cards (UTRCA, 2001). Some of the work outlined in this research has been ongoing over the last five years in an effort to implement the recommendations of these planning efforts. The objectives of this research include:

- Creating a geo-referenced dam and barrier inventory database,
- Establishing criteria for assessing and prioritizing barriers,
- Evaluation and prioritization of dams and barriers against the criteria developed,
- Development of a generalized guide for the assessment and mitigation of barriers to guide future actions.

Consultation with applicable agency representatives is another objective of this work in an effort to gain early input from applicable stakeholders. A technical advisory group was formed and consulted in the development of the criteria for assessing barriers. The professional opinion of various agency staff was sought in development of this project, including representatives from agencies that will be responsible for reviewing mitigation plans and potentially issuing work permits in future barrier projects. The aim was to review and refine the criteria and its weighting based on input from the technical advisory group. The overall objective is supported using current data and by developing a process that considers all watershed barriers cumulatively to achieve the greatest rehabilitation results.

1.4 Data

Significant data have been collected in the Upper Thames (UT) watershed as part of ongoing monitoring programs undertaken collaboratively by agencies including the UTRCA, Ontario Ministry of Natural Resources (MNR), Ontario Ministry of the Environment (MOE) and Fisheries and Oceans Canada (DFO). Data includes water quality information, benthic invertebrate sampling, fish sampling and habitat assessment. These background data are used to characterize aquatic ecosystem health of the watercourses and are useful for targeting remediation, best management practices and conservation efforts. In addition a detailed database of watershed barriers has been developed using historic documentation and mapping, recent orthoimagery and extensive field work to collect and verify barrier attribute data and location with GPS. In combination with these primary data sets significant spatial data holdings are available that characterize the UT watershed. These include such information as a hydrologically corrected DEM, stream order and flow direction data and various other base data available through membership in the Ontario Geospatial Data Exchange (OGDE). The key GIS datasets that are used in this project are described in more detail in Table 1.2 below.

Data exist in various ESRI compatible file formats (shapefile, geodatabases, GRID, etc). Primary barrier data collected by UTRCA are stored in tabular databases and linked to GIS point data.

Table 1.2: GIS Data

Layer Name	Data Description and Use
Watercourse	• GIS line layer. • Includes all river, stream and municipal drain features plus virtual line segments to maintain watercourse connectivity through water polygon features (lakes, ponds and reservoirs), under road crossings and through woodlots where watercourses are not visible for air photo interpretation. • Data are jointly owned and managed by the Ontario Ministry of Natural Resources and the Upper Thames River Conservation Authority. • Available to members of the Ontario Geospatial Data Exchange (OGDE) • Includes attribute information for stream order and stream flow direction. Stream order algorithm used is according to the Strahler stream order system (stream order system that classifies stream segments based on the number of tributaries upstream i.e. a stream with no tributaries is considered first order) • Additional watercourse classification data attributes are included in this data set including information on fish community (species present), temperature regime and watercourse permanence. This information is extended to watercourse reaches based on UTRCA sampling sites throughout the watershed. • Information from this data is cross referenced with catchments created for each barrier in the watershed.
Digital Elevation Model (DEM)	• Raster GIS layer, 10 metre grid cell resolution. • Hydrologically conditioned using digital watercourse data to enforce the continuous down slope of flow direction for drainage networks. Ensures watercourses represent local minimum elevations in the DEM. • Data are owned by the Ontario Ministry of Natural Resources, created in collaboration with the Upper Thames River Conservation Authority. • Available to member of the Ontario Geospatial Data Exchange (OGDE). • Provides elevation at each raster cell in metres above sea level. • Used for watershed analysis tools including the development of a flow accumulation layer and catchment areas for each barrier.
Barriers	• GIS point layer. • Includes all barrier sites inventoried by field staff in 2002. • Data are owned and managed the Upper Thames River Conservation Authority. • Locates all barriers inventoried in the watershed and includes attribute information for flood control status, impediment classification and mitigation status, structural conditions, tributary status – i.e. is it a direct tributary of the Thames River, cultural value and risk of invasion by non-native species. • Point locations will be used in combination with DEM to determine boundary for barrier catchments on a watercourses. • Attribute information is ranked and used in weighted classification of barrier priority for mitigation.

1.5 Summary

The introduction sets the context for this report demonstrating the concept of watershed management, the GIS tools and data that support them and how conservation authorities have evolved to take on such a role as part of watershed management. The geographic study area is also introduced to demonstrate the project scope. The research and GIS application outlined in the remaining sections of this research paper reflect an ongoing watershed management initiative in the UT watershed. This research paper briefly describes some of the characteristics and issues in the watershed that are related to this work. The overall problems associated with dams and barriers are explored in Chapter 2 and the GIS methodology and analysis are described and summarized in Chapters 3 and 4. While the GIS application outlined employs commonly used GIS analysis tools, the application to barrier mitigation (as applied here) is new.

Chapter 2: Background

2.1 Upper Thames River Watershed Description

2.1.1 Hydrology

The Thames River system drains 5820 square kilometres of land extending from Lake St. Clair to the highlands of Perth and Oxford counties northeast of London. It is one of the main watersheds in Southern Ontario, and drains approximately 25 percent of the Ontario portion of the Lake Erie drainage basin. (UTRCA, 1998) The basin is 200 kilometres long with a maximum width of 56 kilometres. The Upper Thames River Watershed accounts for approximately 59% of the entire Thames River Basin. On average, approximately 40% of precipitation that falls on the Upper Thames watershed ends up as flow in the river, with the remaining 60% infiltrating into the ground, evaporating or lost to evapotranspiration by plants. Flow in the river is comprised of approximately 65% surface runoff and 35% baseflow (UTRCA, 2006). The Thames River is subject to significant variations in flow rates throughout the year, with annual peak values generally occurring in the period from March to April. Generally there is a surplus of water available during the wet months and a deficit during dry months.

2.1.2 Topography

The topography of the Upper Thames watershed was shaped during the last phase of the Wisconsin Glaciation approximately 14000 years ago. The Thames River is thought to be the first river to have formed in Ontario, forming the glacial spillway for the neighbouring Saugeen, Maitland and Grand Rivers (UTRCA, 2006). The Upper Thames River Watershed lies in a glacial valley with some relief in the upper reaches of the Avon

River upstream of Stratford, in the Woodstock area and in the head waters of Trout Creek upstream of St. Marys, with the remaining areas being relatively flat. The Thames River headwaters are at 380 m and the outlet of the Upper Thames Basin at approximately 210 m above mean sea level (MSL). The highest elevation in the watershed in the Avon River Headwaters, and is at approximately 400 m above MSL (UTRCA, 2006).

2.1.3 Watercourse Characteristics

Watercourses have been widely used for a variety of purposes resulting in alterations to the original characteristics of many systems. Rural and urban development, road construction, recreational uses and agricultural practices have all required some form of watercourse alteration, typically resulting in channelization. This allows for the quick removal of rain and snowmelt by significantly enlarging a channel to accommodate the increased amounts of water. The enlarged channels are designed to contain extreme flows during spring floods and rain events, and are not designed for normal to moderate flows that are experienced at other times of the year. In these drains, stream habitat, floodplain and hyporheic connectivity have been disrupted (Cudmore-Vokey, 2004).

Agricultural land use practices have significantly modified the natural surface water drainage patterns in the Thames River watershed accounting for the majority of alterations through the creation of municipal drains. Municipal drains have been an integral part of Southwestern Ontario’s watercourses and agricultural industry since the 1800’s. The Ontario Drainage Act administered by the Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA), allows for the creation and maintenance of municipal drains. Watercourses in the Upper Thames watershed are categorized as: 47% municipal drains, 28% natural or non-municipal drains, and 25% tiled (closed) watercourses (UTRCA, 2004).

The percentage of natural or non-municipal drains represents just over a quarter of the length of watercourses in the watershed. The majority of the natural watercourses are the main rivers such as the three branches of the Thames River and the lower sections of some of the larger tributaries such as the Avon River. Watercourse classification has been completed based on stream flows (permanent or intermittent), water temperature (warm or cool/cold water), habitat, and indicator fish species (baitfish, trout, pike, bass, etc.). Only 24% of watercourses provide suitable water quality and habitat conditions for sensitive species. Of those watercourses approximately 6% are municipal drains and 18% are natural watercourses (UTRCA, 2006).

2.1.4 Aquatic Species / Habitat

The Thames River is situated in a highly developed part of southern Ontario, where the aquatic community faces many pressures from urban and rural land uses and human activities. In general, species that prefer clear, fast flowing water are declining while those favouring turbid conditions are increasing in abundance. Threats or stressors to the aquatic community include pollution, drainage, channelization, fragmentation or dis-connectivity (i.e. created by barriers such as dams and weirs), drought, nutrient and sediment inputs, siltation, riparian and floodplain disruptions, habitat alteration or destruction, development and introduced species (Cudmore-Vokey, 2004). When moving downstream from the headwaters to medium size tributaries, aquatic habitat generally improves. Improved habitat allows development of a much more complex and productive aquatic community with floodplain and hyporheic zone interactions. A diverse aquatic community is generally present including a diverse fish community that may include Species at Risk (SAR) - (Cudmore-Vokey, 2004).

The Thames River and its tributaries are home to a diverse community of aquatic species, with records of approximately 94 species of fish, 34 species of freshwater mussels, and 30 species of reptiles and amphibians. Approximately 25 of these aquatic species have been federally designated as SAR. The Thames diverse aquatic community is due to a number of factors including the river's range of habitats, favourable climate, nutrient-rich waters, and connection with the Great Lakes. However, in 1986, researchers identified that water quality and fish habitat conditions had deteriorated significantly in the Thames due to their comparisons of surveys from the 1920s and 1940s to 1985. Turbidity and siltation had increased, and stream flow rates changed due to habitat disruptions such as impoundments. They also indicated a decline of species with a preference for clear, fast water and an increase in abundance of species more tolerant of turbidity. In general, these changes pose a distinct disadvantage to most freshwater fishes in the watershed (Thames River Recovery Team, 2004).

2.1.5 Dams and Barriers

The Upper Thames watershed, like most watersheds in Southern Ontario, has many dams and other barriers of varying sizes throughout its boundaries. Many are highly valued by their local communities for their recreational and aesthetic uses as well as their historical significance. Other structures are important for their role in flood control or flow augmentation during low flow. However, dams and other barriers can also have major negative impacts on aquatic ecosystems. The adverse effects include barring migration of fish and wildlife, increasing soil deposition and erosion, altered water quantity and quality, eutrophication (excess nutrients that cause excessive algae growth and a resulting lack of oxygen), and wildlife mortality (UTRCA, 2001).

There were many reasons for the construction of dams and barriers including industrial, agricultural and flood control purposes being the most common. Given the numerous tributaries and extensive development in the Upper Thames (UT) watershed the number of barriers was unknown until recently. Data collection from 2002 – 2003 to compile a complete database of barriers in the watershed was undertaken by the UTRCA identifying 173 barriers in the UT watershed. In many cases these barriers no longer serve the purpose for which they were originally constructed and in some cases are in poor condition. Reducing the negative impacts of barriers in UT watershed and in the province of Ontario is ongoing and typically targets these structures. Removal has been an accepted approach to deal with unsafe, obsolete or unwanted dams for many years but can be costly and time consuming highlighting the need to prioritize efforts.

2.2 The Barrier Issue

2.2.1 History of Dams

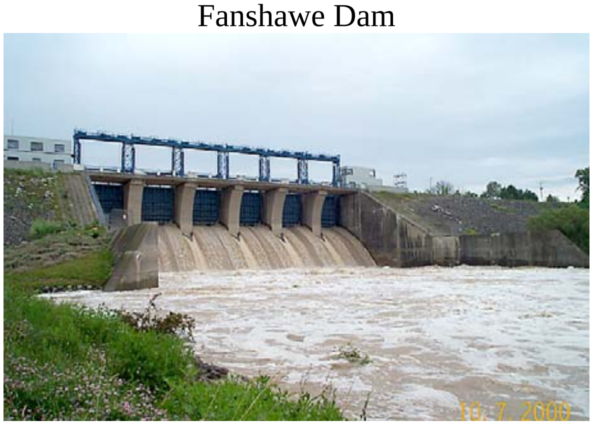
The first dam on record in Ontario was built on the Cataraqui River near Kingston in 1782. Early dams were built to harness the energy of watercourses for milling lumber and grains, for irrigation of livestock and crops and for flood control (River Alliance of Wisconsin, 2000). Early dams were built using wood cribs that were filled with rock and by the 1860s dozens of mills existed in Ontario with 90 mills in operation on the Humber River alone (Heaton, 2002). With the increased arrival of European settlers, communities across Ontario formed around the mills and they became a sign of prosperity and growth. With the development of electricity in the late 1800s came the creation of larger dams used to drive electric turbines. Ironically this was a cheaper source of power for mills which resulted in the abandonment of many of the smaller mill dams.

Dams and barriers have also been created throughout the history in Ontario for the movement of cargo ships, irrigation, reliable domestic water supply, invasive species control (such as sea lamprey) and recreation. It is suggested that by 1973, approximately 72% of the almost 17,000 kilometres of tributaries to the Great Lakes Huron, Erie and Ontario were blocked by dams (Heaton, 2002). Similarly in the United States over the last 100 years the US Army Corp of Engineers has documented approximately 75,000 dams greater then 1.8 metres in the United States (Trout Unlimited, 1999).

2.2.2 Flooding and Dams

The flood event associated with Hurricane Hazel in 1954 that resulted in loss of life and extensive property damage also had two effects on dams and barriers in Southern Ontario. First the floodwaters associated with the storm are reported to have washed away many smaller outdated dams in Southern Ontario. Second an increased awareness of the dangers associated with living near rivers brought forth a new way of managing rivers and floodplains. Newly created regulatory agencies, known as Conservation Authorities, developed floodplain regulation policies and led the construction of flood control dam structures, floodwalls, dykes and stream channelization projects (Figure 2.1).

Fanshawe Dam



West London Dyke

(Photos UTRCA 2005)

Figure 2.1: Examples of Flood Control Structures in the Upper Thames River Watershed

Many dams still serve valuable functions today. For example, Fanshawe Dam (shown above) is credited with reducing floodwaters to the City of London in July 2000 and is estimated to have prevented over $50 million of flood damage. However, with the changing needs of society many dams have been abandoned or neglected and are now in a state of disrepair. In addition to the ecological impacts noted above, some dams are considered public safety concerns as a result of their poor condition and costs to repair structures are significant. Costs associated with dam repairs have fostered increasing consideration for their removal. Removal however is not a new concept. It has been suggested that “people have been removing dams for as long as we have been building them”, in the past this has typically been due to the economics of maintaining them (River Alliance of Wisconsin, 2000).

2.2.2 The Impacts of Barriers

Dams and other structures such as road and train crossings, culverts, and weirs can create barriers or impoundments on watercourses. Research on the topic of dam and barrier mitigation is mainly focused on the mitigation or removal of dams. Less information exists on the mitigation of other watercourse barriers. Mitigation efforts in the UT watershed have focused not only on dams but also on other barriers as it is believed that some impacts are common to both. To clarify working definitions are provided for both dams and barriers; generally speaking the term “dam” is based on purpose while the term “barrier” is based on construct (De Laronde, 2001).

> Dam – structures built with the key purpose of water storage, typically built directly on a watercourse where there is room for water storage or retention. This storage of water creates flooding forming a pond or lake referred to as an impoundment.
>
> Barrier – structures constructed for purposes other then water retention that restricts the movement of fish and/or aquatic wildlife. These include such things as debris, perched culverts, concrete steps or steep gradients. Dams are barriers but not all barriers are dams (De Laronde, 2001). For the

purpose of this research barriers are structures that do not create significant impoundments.

Dams and barriers have significant effects on a watercourse related to the physical, chemical and biological processes that occur in the system. The changes that occur in a watershed ecosystem along a healthy naturally flowing ecosystem represent a complex gradient that has been adapted to over thousands of years (Heaton, 2002). The introduction of unnatural barriers can drain watercourses of the chemical, physical and biological resources that support the natural processes associated with the ecosystem gradient. For example, the physical process of sediment transport to replenish downstream river sections is interrupted by barriers often creating sediment build up behind a barrier.

The Ontario Stream Rehabilitation Manual (Heaton, 2002) categorizes the potential impacts of barriers into five categories. These include physical effects, hydrologic effects, water quality effects, natural heritage effects and social effects. Table 2.1 is adapted to summarize these effects.

Table 2.1: Impacts of Barriers (modified after Heaton, 2002)

Physical Effects:

- Altered channel form (meander pattern, gradient, creation of still water)
- Inhibited sediment transport process and the movement of debris that is important to downstream habitat
- Sediment built up behind the barrier that can gradually fill in the impoundment
- Drastic vertical drop that impacts riverine habitat
- Impoundments that decrease light penetration in the river
- Loss of floodplains and the water filtration benefits they create

Hydrologic Effects: • Arrested water flow • Flow regulation resulting in altered stream flow (i.e. loss of spring freshets that can degrade aquatic habitat by inhibiting annual sediment flush) • Velocity barriers that can be created by weirs and culverts • Spread of water flow across wide spillways resulting in diffused flow
Water Quality Effects: • Stratification with warmer surface waters that can lead to downstream temperature increases • Pollution can be trapped with sediments that accumulate behind barriers • Eutrophication associated with nutrients trapped behind a barrier that can result in algae blooms • Reduced dissolved oxygen • Increased bacteria concentrations associated with temperature increases in impoundments
Natural Heritage Effects: • Fragmentation of habitats • Inhibited gene flow between inhabitants reducing biological fitness of aquatic populations • Reduced flow of leaf litter and sediments affecting aquatic insect population that rely on it for a food source and habitat • Migration of fish can be blocked impairing natural reproduction • Reduced current can impair migration motivation in fish and disorient young fish and delay their downstream movement • Disrupted movement of wildlife along the corridor
Social Effects: • Inhibited navigation • Pose public safety hazard and create liability issues for owners • Require ongoing maintenance and repair • Impaired water quality can reduce visual aesthetics (i.e. algae blooms) • Sedimentation that can require dredging

Focusing on the ecology of a river system, there are clearly long term consequences associated with dams and barriers. Ecological impacts associated with the removal of barriers have also been documented but are typically limited short term ecological consequences if removal is done correctly. Five key ecological impact categories are examined in Angela Bednarek’s (2001) research paper “Undamming Rivers: A Review of the Ecological Impacts of Dam Removal”. These include flow regime, transformation from reservoir to river system, water quality, sediment transport and connectivity. Descriptions of these five impacts are adapted from Bednarek (2001).

2.2.2.1 Flow Regime

The physical and biological characteristics of a river system are largely a result of its flow regime. Flow in a river system fluctuates significantly according to seasons creating a dynamic system that is capable of supporting a wide range of species adapted to the flow variations. Barriers disrupt these natural cycles and the regulation of flow can result in conditions that are suited to fewer generalist species able to withstand the conditions (Bednarek, 2001). With the removal of barriers and return to more natural flow regimes there is a documented increase in biodiversity and populations of native species. This is directly attributed to the rehabilitation of habitat that has been documented to occur with the return to natural flow regime, such as the increase in riparian vegetation improving spawning conditions (Bednarek, 2001).

2.2.2.2 Transformation from Reservoir to River

Impoundments created by many barriers result in the transformation of river systems to lake-like systems. The result is altered species composition favouring species that are better adapted to lake settings. Often this leads to population decline of desirable cold water species such as salmon and trout. Removal of the barrier can result in the return to a riverine habitat and promote the return of native aquatic species that depend on such habitat. Based on natural free-flowing conditions of the system it may also result in a change in thermal regime (from warm to cool) by reducing the surface area available for warming the water (Graf, 2003). The return to a river system can also improve the dissolved oxygen regime that exists in reservoir systems and negatively impacts fisheries (Graf, 2003) Terrestrial species can also benefit with increased land available for terrestrial vegetation used as migration corridors and habitat for birds and mammals.

Ecological impacts associated with this transformation may also occur. Species that prefer lake like conditions such as ducks, muskrats and introduced or stocked sport-fish can decline in the area. The negative impact to species that prefer reservoir habitat is a consequence of removal and return to native riverine species that is not always desired by some stakeholders. For example impoundments created by dams can be favourable for certain aquatic assemblages including popular sport fish that appeal to the sport-fishing public but have overall implications for the aquatic ecosystem (Born, 1998). In some cases large dams with deep impoundments and bottom discharge can result in coldwater fisheries downstream of the dam when cooler deep water is discharged (Graf, 2003). Return to a riverine system in such cases may result in the downstream loss of a coldwater fishery.

2.2.2.3 Water Quality

Dams and barriers often convert fast moving river systems into slower moving impoundments that increase surface area and potentially increase temperature. Stratification can occur creating layers in the reservoir that do not mix or transfer oxygen well. Depending on the type of barrier draw-down method, water from deeper in the reservoir can send either colder water potentially low in oxygen downstream or warm surface water that increases downstream temperature. Both can affect downstream species composition. Warmer conditions in reservoirs can also foster bacteria growth and promote anoxic conditions resulting in additional nutrient loading from accumulated sediments, and potentially result in harmful blue-green algae blooms (Nurnberg, 2005).

Removal of the barrier will often restore the river's natural temperature range and mitigate many of the water quality effects documented. However, negative short term impacts can also occur such as increased turbidity and supersaturation. The increase in velocity and air pressure can elevate oxygen to above natural levels and potentially kill fish downstream as a result of gas-bubble disease (Bednarek, 2001). In cases of large impoundments the rate of final draw down of an impoundment when undertaking removal is important. If drawdown occurs too quickly there can be water quality and erosion implications (Graf, 2003). The discharge rate should be staged and slow enough to avoid a downstream flood wave and to ensure the concentration of sediments released is not too great or long in duration (Graf, 2003)

2.2.2.4 Sediment Transport

Sediment transport that is vital in a riverine system is often blocked when barriers are created. The transport of sediments creates diverse habitats and distributes nutrient rich sediments throughout the system. This process is disrupted by barriers and accumulations of sediments often develop upstream behind dams/barriers (Doyle, 2005). The movement of rocks and cobble downstream of barriers is also restricted when flows are regulated. This negatively impacts species diversity and aquatic health as the various sediments typically transported by a river are necessary for spawning, feeding and breeding. Removing barriers can redistribute trapped sediments, re-establishing the natural transport process and restoring spawning habitat.

Successful removal of barriers must consider the redistribution of sediments to minimize any potentially negative impacts. Redistribution of sediments can increase turbidity, damage spawning grounds and produce water quality problems if not considered in the removal process. Significant impacts can occur if the sediments accumulated contain toxics that have attached to sediments. For example, removal of the Fort Edward Dam on the Hudson River in New York resulted in the release of tons of PCB-laden sediments downstream (Trout Unlimited, 1999). The mobilization of sediments associated with dam/barrier removal can also affect the eggs of fish species that have been laid in the watercourse substrate (Heinz Center, 2002). Evaluation and minimization of these potential impacts need to be carefully considered in timing and management of a dam/barrier removal process (Heinz Centre, 2002).

2.2.2.5 Connectivity

Barriers disrupt conductivity by physically fragmenting river systems, and can block the migration of fish and other wildlife (Grant, 2001). This impact is common to most types of barriers while some of the other ecological impacts identified, such as water quality impacts, are more specifically related to dams. Reproduction in fish species is dependent on reaching appropriate spawning grounds that can be prevented by barriers. While some barriers have structures installed for fish passage they are only suitable for some species and can slow movement and increase predation in the area where fish wait to move up the structure (Bednarek, 2001). The effects of barriers on migratory fish are well documented, in many cases barriers have no fish passage structures completely barring migration (Doyle, 2005). Overall removal of barriers is proven to greatly improve the odds of successful reproduction by providing access to upstream spawning habitats (Doyle, 2005). For example, the response of fish communities to the removal of Woolen Mills dam on the Milwaukee River was examined in five 1 km study reaches and cumulatively demonstrated improved habitat and fish assemblages (Doyle, 2005).

While the main goal of barrier removal may be enhanced habitat and migration for target species, potentially adverse impacts can occur to other taxa when connectivity is restored (Doyle, 2003). Some barriers successfully block the movement of exotic or non-native species, separate competing species or block upstream movement of genetically different fish stocks or those contaminated with toxins. For example, removal of the Marmot Dam in Oregon is opposed because it currently separates hatchery salmon stocks from wild stocks (Doyle, 2003). In some cases, barriers are constructed with the sole intention of preventing the upstream movement of invasive species. For example weirs have been constructed on many Great Lake tributaries to prevent spawning runs of parasitic sea lampreys (Doyle, 2003). In such cases the trade-offs between impacts and benefits of barrier removal can complicate decision making and potentially warrant the maintenance of some structures.

2.3 The Benefits of Dams and Barriers

It is clear that the ecology of river systems can be improved with the removal of barriers. However, there are still some benefits associated with barriers in addition to those identified in the Section 2.2.1, highlighting the history of dams and why they were originally created. Hydro-electric power generation is considered by many to be a clean and renewable alternative in comparison to fossil fuel options. While similar ecological impacts exist, and sometimes even greater impacts due to greater regulation of flows and creation of multiple dams in series along a river, other power generating options can be considered more harmful to the environment. Additionally, economic impacts associated with the removal of dams used in the production of hydropower must be weighted against the environmental impacts (Kuby, 2005). In some cases hydro-generating facilities can be included in structures that are created for other purposes as is the case with the Fanshawe Dam created for flood control but retro-fitted for hydropower generation.

Reservoirs created by dams offer recreational opportunities that would otherwise be unavailable. Many reservoirs offer valued recreational opportunities such as boating, swimming and fishing. “Flat-water” recreation is considered a significant economic activity given the popularity of power boating and fishing in reservoirs which is estimated to be a $28 billion a year industry in the United States (Heinz Centre, 2002). Some barriers also have historical significance that warrants their upkeep as cultural landmarks. While the removal of barriers may be appropriate in many situations it is important to understand the value of some structures. In the United States it is estimated that only one percent of documented dams will be considered for removal (River Alliance of Wisconsin, 2000). Removal efforts are clearly focused on the abundant modest and often outdated structures that are located in small or mid-sized channels (Doyle, 2005). Removal of larger structures is a subject of much greater debate given their increased political profile (Grant, 2001). Mitigation techniques other than removal may be more appropriate for these larger structures.

2.4 Remediation Efforts

Over the last decade there has been an increase in public scrutiny of barriers that are considered obsolete, are in a state of disrepair, pose safety concerns or are identified to have an impact on the ecosystem. In addition the social values associated with barriers are "slowly changing from nostalgic to pragmatic" (Heaton, 2002). In recent years ecological research has advanced the understanding of river systems and documented the severe ecosystem disruptions caused by dams (Born, 1998). Removal of barriers is identified to be an effective long term tool for the restoration of river systems as there are few human actions that have had as significant an impact on river systems (Higgs, 2002). However, removal of barriers is not appropriate in all situations and other mitigation techniques including partial removal, creation of fishways, by-pass channels, rocky ramps, outlet conversions and changes to dam operations can reduce impacts. Alternatives to the use of dams that have also become more accepted include stronger policies for the avoidance of development in floodplains, restoration and protection of wetlands as flood storage, stronger regulations on water taking and increased maintenance of riparian buffers. However, in some situations the benefits associated with some barriers may outweigh the impacts making it necessary for the ongoing maintenance of some structures.

Stream rehabilitation that includes barrier mitigation comes only after a long and sometimes challenging process is followed. Varied interest in the barrier can generate conflict between different stakeholder groups. The local economics, cultural heritage, public safety and environmental concern associated with the barrier can make removal a politically contentious issue. Often there is limited local support for removal of barriers as it results in the loss of impounded water that is often cherished by property owners and businesses for recreation and aesthetics (Born, 1998). To improve the likelihood of success with barrier mitigation projects, a process that considers socioeconomic impacts and local stakeholder perspective needs to be followed (Born, 1998). To achieve this in the UT Watershed a planning process that employees a Class Environmental Assessment (EA) process is followed for public structures, and for private structures an Environmental Screening process has been developed. This EA process is employed as it is considered economically and environmentally responsible, a consistent, streamlined and easily understood process, flexible and is an accepted process that is familiar to agencies and the public (UTRCA, 2004).

The planning process used by the UTRCA requires that a definition and understanding the problems associated with the barrier must first be developed. This process alone is a significant effort that can involve historic research, monitoring, modeling and surveys of the local community or stakeholders to understand current issues. This background information can then be used to document the impacts of the barrier and lead to the design of various rehabilitation alternatives. As dictated by the EA process, significant consultation, notice and publication of the project is necessary throughout the process. Consultation with stakeholders and regulating agencies is also necessary and application for review of proposed work and permitting must be conducted. This can include site visits and circulation of plans to various government agencies at various levels for review and approval, including:

- Fisheries and Oceans Canada for approval under the federal Fisheries Act,
- Ontario Ministry of Natural Resources under the Public Lands Act and/or the Lakes and Rivers Improvement Act,
- Transport Canada under the Navigable Waters Protection Act,
- Local Municipality for review and comment (potential proponent of EA if structure is owned by a municipality),
- Local Conservation Authority under the Conservation Authorities Act – Ontario Regulation for Development, Interference with Wetlands and Alteration to Shorelines and Watercourses.

With a preferred alternative identified and all applicable permits in place an implementation plan must then be developed that includes project phasing to meet permit requirements (i.e. timing windows that avoid sensitive fish spawning seasons), work planning, selection and hiring of contractors and development of a budget. Fundraising or grant application may also be necessary depending on project costs. A monitoring plan needs to be created for monitoring conditions during and after construction. Monitoring results document changes and assess construction impacts of the project in an effort to improve future projects and to report changes to stakeholders. Monitoring programs make it possible to assess the predicted outcomes and determine if goals have been meet or if compensating adjustments are needed in future projects (Heinz Centre, 2002).

It is estimated that the costs associated with barrier removal can range from $500 to $200,000 (Heaton, 2002). The project range based on the size and type of structure from small projects that can be undertaken by volunteers using hand tools to those that are larger requiring contractors and extensive reconstruction work. For example, the Dingman Weir removal project in London cost approximately $25,000 plus additional in-kind agency staff time to work through the process, see Figure 2.2 below.

Before	After
	
	(Photos UTRCA 2005)

Figure 2.2: Dingman Weir Before and After

The costs associated with barrier removal are estimated to be 3 to 5 times less expensive in comparison to costs of maintaining (i.e. dredging, inspection, repair) obsolete structures (Trout Unlimited, 1999). In the United States 465 dam removals were documented in 2000 and case studies and techniques are being shared to encourage additional removals (Trout Unlimited, 1999). Barrier removal in Ontario also seems to be increasing but the number of barriers removed is unavailable.

Chapter 3: Methodology

3.1 Overview

The ecological impacts of dams and barriers are considered cumulatively using a spatial analysis process to prioritize mitigation efforts. The analysis was completed using ESRI ArcGIS version 9.1 coupled with the 3D and Spatial Analyst extensions. The ArcHydro data model tools were used to develop a watershed model and to populate the supporting relational database. Data associated with watershed monitoring and the barrier inventory conducted by the UTRCA are considered in the model to characterize their effects and target them for mitigation as part of watercourse rehabilitation efforts.

The watershed model was used to delineate catchments for each of the applicable barriers identified in the watershed. The methodology applied in the research derives various size catchments using a digital elevation model, a watercourse network and their interaction with barrier locations. The catchments are used to characterize the drainage area associated with each barrier through the application of GIS overlay and summary functionality. These catchment characteristics in combination with barrier-specific characteristics were used to develop a priority barrier listing to target for mitigation.

3.2 Problem

The significant resources required to mitigate the ecological impacts of dams/barriers limits the amount of rehabilitation work that can be undertaken. Therefore it is necessary to target efforts for the greatest improvements in aquatic ecosystem health. Characteristics of the dams/barriers alone are not sufficient to identify their impact.

Spatial variation in the type and quality of aquatic ecosystems in proximity to the dams/barriers must also be considered. Adapting the ecosystem concept that considers impacts for a watershed unit needs to be applied to the barrier situation. A watershed model capable of deriving barrier catchment areas is needed. The characteristics of the catchments, barrier condition and functionality then need to be considered in a weighted decision support process to best identify priority areas of efforts. This process needs to be flexible to allow for inclusion of additional data, adjustment of weighting and update as progress towards barrier mitigation or repair are undertaken.

3.3 Spatial Analysis

3.3.1 Data Refinement – Pre-processing

The dam and barrier database created in 2002 and 2003 is integral in the analysis. The database was created using an inventory of dams/barriers from 1991 and geo-referencing it using base data and orthoimagery to confirm documented sites and to identify additional dams/barriers. Site visits were undertaken by an aquatic biologist to examine and document characteristics of each barrier and to locate them using GPS. The inventory resulted in an increase in the number of known dams/barriers from 78 in 1991 to 173 in 2003. This information is maintained as a point layer in the UTRCA GIS. Given these points will be used to simulate an outlet point for the catchment area of each barrier, it was important to refine the data set to accurately support watershed modelling.

Three main issues had to be addressed in the barrier inventory point data to facilitate the GIS analysis. These include adjusting the location of the barrier points to ensure they are located on a watercourse, removal of duplicate dams/barriers located at one site and excluding dams/barriers that are not located on the watercourse network (off-line). Each of these data refinements is demonstrated with examples below. Refining the database resulted in the reduction in the total number of points in the data set to 128 for use in the analysis.

3.3.1.1 Barrier Location Adjustment

The GPS equipment used for acquiring the spatial coordinates of the dams/barriers was a Trimble Scout hand-held GPS unit. On average the GPS unit used was capable of locating dams/barriers to within approximately 50 metres of the true location. The product specification rates accuracy at 25 meters (Trimble, 1995), yet given some of the locations and tree canopy characteristics such accuracy was not possible. In comparison to current GPS technology the GPS locational accuracy is poor but reflects the best available technology at the UTRCA when the field work was conducted. Prior to processing the watershed model to derive catchments for each barrier, it was necessary to adjust the location of some of the points to ensure the location was accurately placed on a watercourse. The spatial analysis tools in ArcGIS provide an option for “point snapping” during processing however it was determined through testing that the tolerances needed to snap points to a watercourse were too large. In some instances using the snapping functionality would result in errors in the analysis when points shift to incorrect locations on a watercourse or to another watercourse altogether.

Refining the data interactively prior to final processing provided an opportunity to quality check the data through comparison with the GIS watercourse network and orthoimagery. Each point was examined and its location adjusted manually to ensure it intersected the watercourse layer and matched any visible evidence in the orthoimagery describing location. For example, Figure 3.1 below depicts a barrier adjustment for a point originally located off the watercourse network, in addition the visible water impoundment seen in the orthoimagery typical of a dam/barrier helps further refine the point location. The distance a point location was adjusted was noted in the attribute table to facilitate future data refinement if additional site visits are conducted in the future.

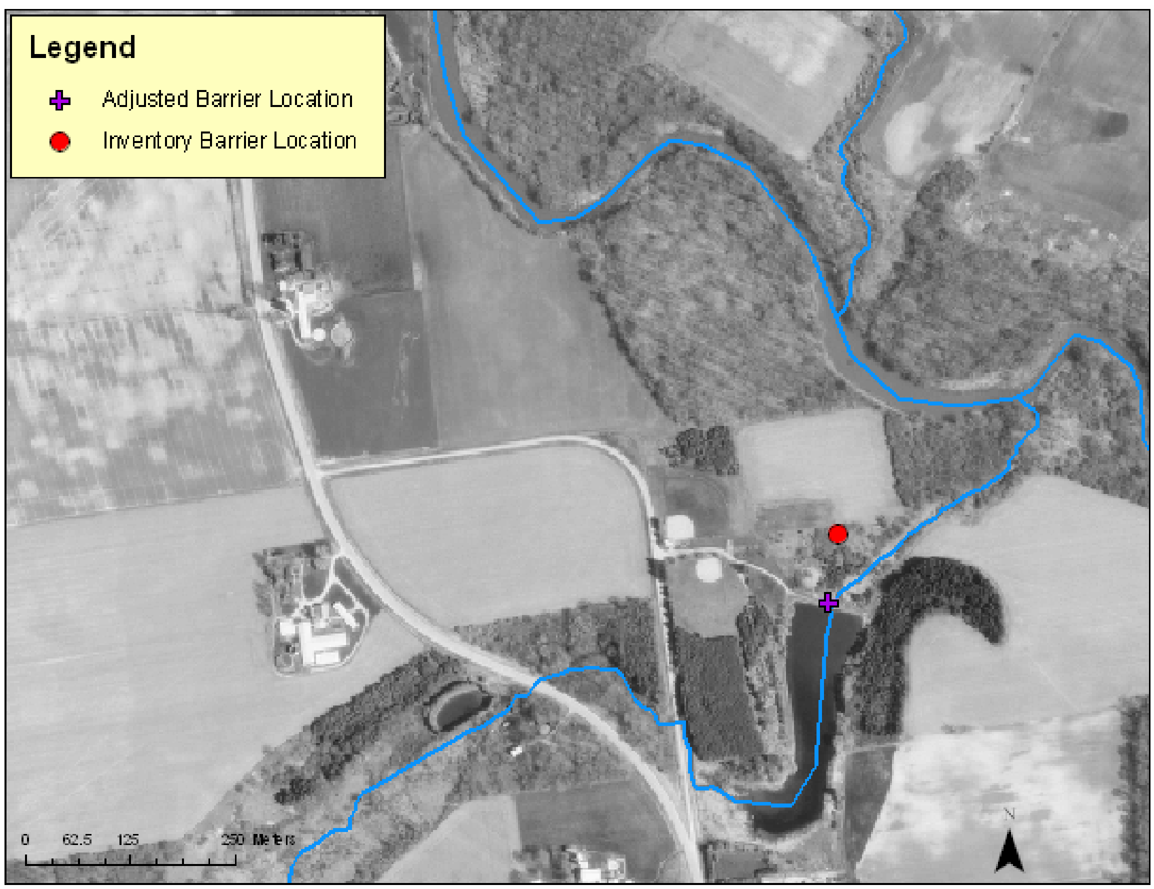


Figure 3.1: Barrier Location Adjustment

3.3.1.2 Multiple Barrier Sites

In some instances multiple barriers are located within very close proximity to one another and need to be represented by a single barrier in the watershed processing function used. The spatial resolution of all raster data derived in the analysis is 10 by 10 metre cells (100 m^2) as adopted from the original DEM. Given the spatial resolution and relatively close proximity of some barriers, this could result in the creation of very small catchments that are impossible to use in the analysis. In these cases one point was used to represent all barriers at the site. This occurred at one site in the watershed and the point was documented in the attribute table to identify a site where more then one structure may need to be considered in a rehabilitation project. The example seen in Figure 3.2 demonstrates this at a historic mill site location north of London Ontario that employs multiple barrier structures to divert water outflow for various uses or by-pass.

3.3.1.3 Off-Line Barriers

Numerous dams/barriers inventoried are representative of “off-line” impoundments. Off-line barriers are disconnected from the watercourse network of the watershed and include such things as old quarries or ponds that are created from groundwater or by partial diversion of surface water from a nearby watercourse. These barriers are considered to be low priority for mitigation efforts because they are not fully connected to the watercourse network of the watershed and are expected to have less overall ecological impact.

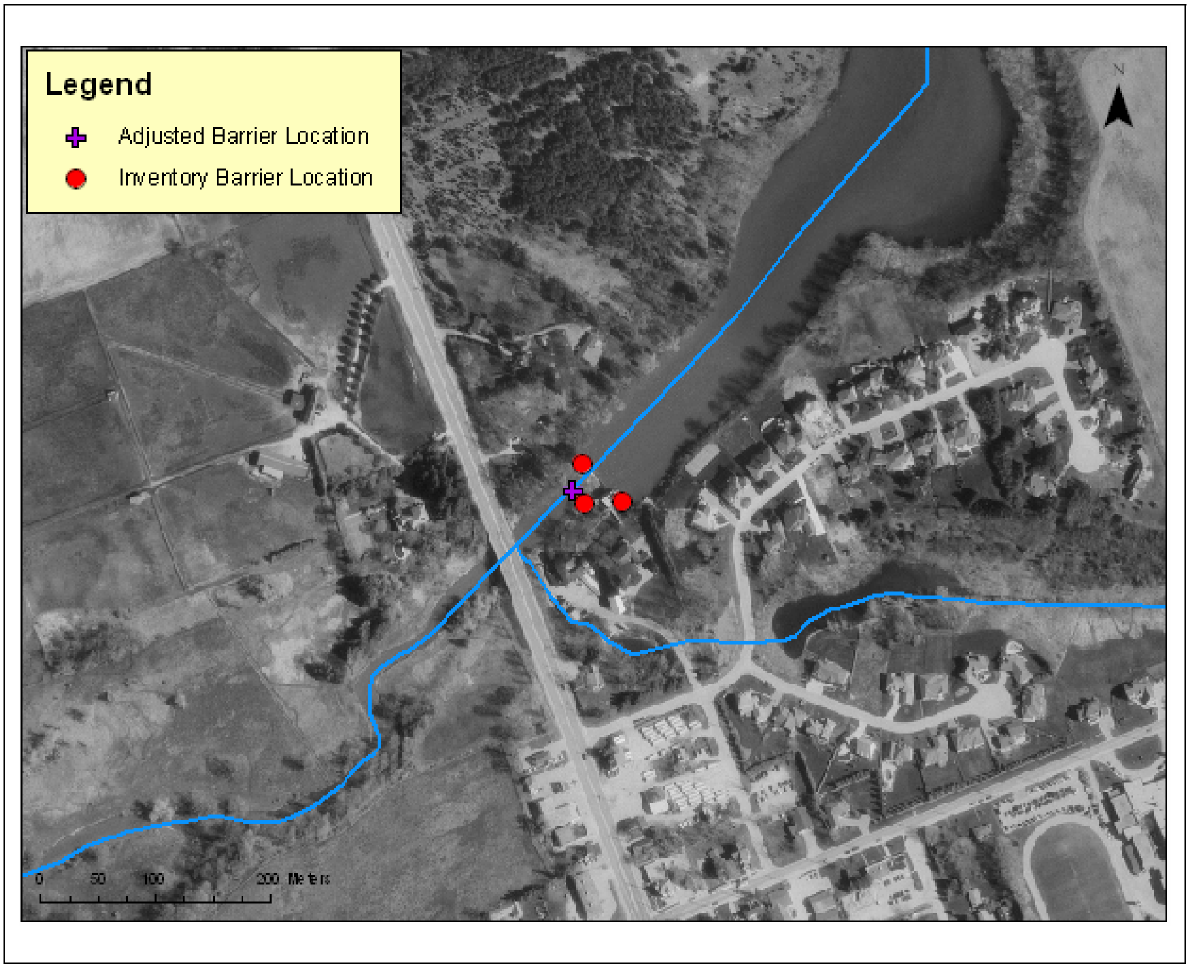


Figure 3.2: Multiple Barriers Site

Off-line dams/barriers were therefore removed from the GIS point data layer prior to the processing of catchments. In addition, attempting to process catchments for points not located on the watercourse network can also result in errors when applying the subwatershed delineation function described in Section 3.3.2.3. For this subwatershed delineation function to produce barrier catchments that can be used in the analysis it is necessary that all points intersect the watercourse network.

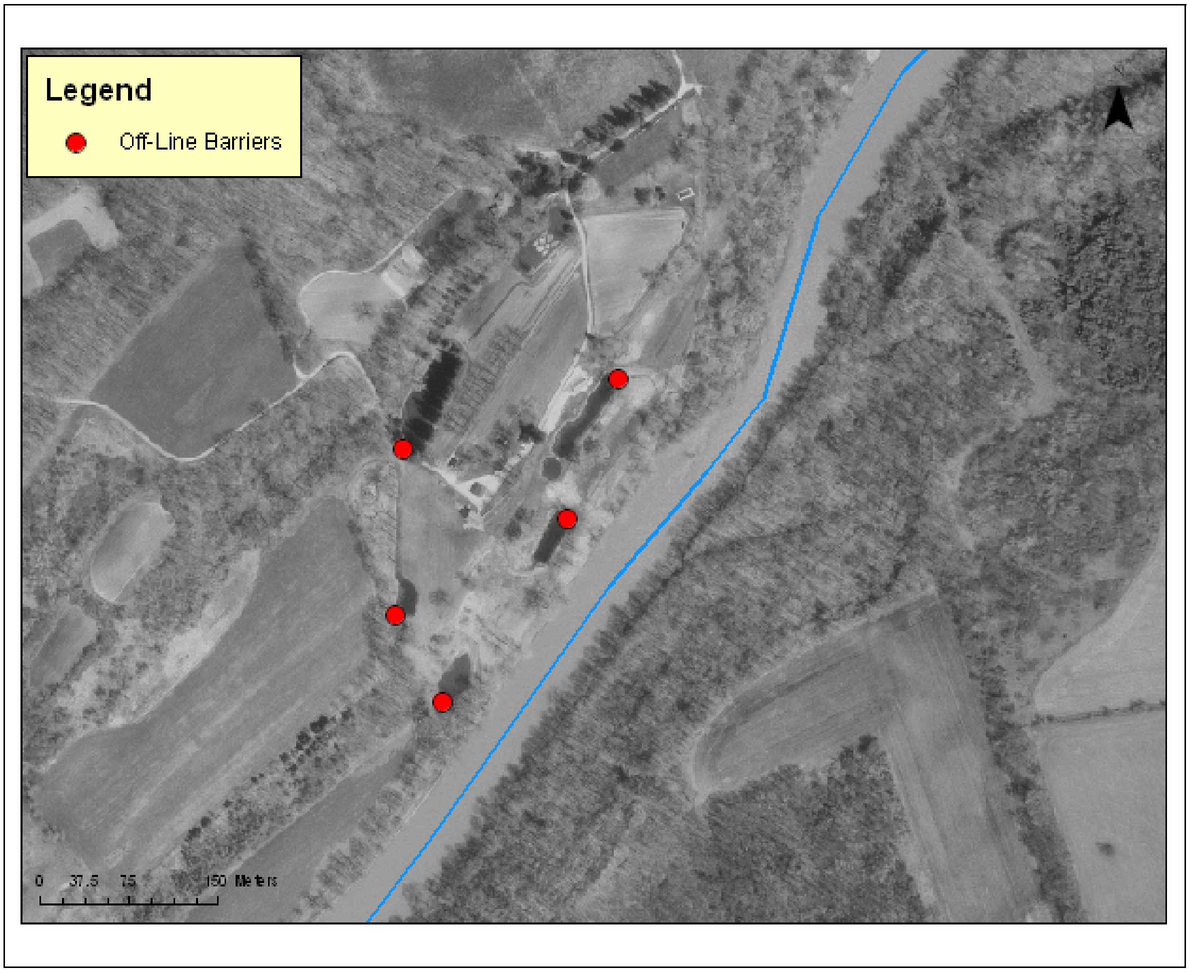


Figure 3.3: Off-Line Barriers

3.3.2 Building a Watershed Model for Barrier Assessment

3.3.2.1 Arc Hydro

Watershed analysis was conducted using the Arc Hydro data model framework. The tools employed by Arc Hydro use functionality that is available in ArcGIS and the Spatial and 3D Analyst software extensions. A separate Arc Hydro toolbar is included with the application that uses well described hydrologic terminology to apply the appropriate GIS functionality in development of the data model. The Arc Hydro toolbar, Figure 3.4, groups functions into six categories and automatically uses the necessary GIS functionality as needed (ESRI, 2005). The research methodology is adapted from the Arc Hydro framework and utilizes selected functions of terrain preprocessing and watershed processing. Unique value data fields and attributes useful for managing linkages between data layers are automatically created when applying the Arc Hydro framework. Unique values including GridID, HydroID and DrainID (described below).

- GridID - an attribute identifying the derived raster catchment, included in the attribute tables for the drainage line features and catchment polygon features creating a linkage between the raster and vector data layers.

- HydroID – a feature identifier that is system generated and is unique within the ArcHydro project geodatabase. This attribute is used in various data layers to identify how various features are related. For example an attribute called NextDownID created by ArcHydro in the catchment polygon and drainage line data layers is populated with the HydroID value of the respective downstream catchment or drainage line.

- DrainID – is another example of how the HydroID is used to identify related features as it is the HydroID of the catchment draining to the specific drainage point.

(Maidment, 2002)

These attributes create relationships between various feature layers including the watercourse network, catchments and the drainage points associated with each catchment (in this case barrier locations).

Figure 3.4: Arc Hydro Tool Bar - Version 1.1 (Source: ESRI, 2005)

Using a DEM that is hydrologically conditioned made it unnecessary to use the DEM reconditioning functions that exist in Arc Hydro, it is however important to note this functionality. Reconditioning a DEM may be a critical step in creating a similar model depending on the quality of the DEM used, as it is necessary to ensure the surface drainage pattern is identified in the DEM (ESRI, 2005). This makes it possible to generate the raster watercourse network and define watersheds accurately. The hydrologically conditioned DEM used in this research was jointly created by the UTRCA and the Ontario Ministry of Natural Resources in 1999. The ANUDEM interpolation tool in the Arc Info GIS was used to create the DEM that incorporates a user defined watercourse network to ensure streams and rivers represent local minima in the DEM (Kenny, 1999). In comparison, the DEM reconditioning function in Arc Hydro uses the AGREE method to hydrologically condition elevation models. Both methods produce similar results, however the AGREE method can provide improved results in accurately depicting stream networks in flat areas (Hellweger, 1997).

3.3.2.2 Terrain Preprocessing

Using the DEM, a series of layers were created to use as inputs for the watershed processing function. Terrain preprocessing generates key datasets, including raster layers depicting flow direction, flow accumulation, the watercourse network and watershed catchments. From the raster layers a series of vector GIS layers is created including watercourse line features, catchment polygons and drainage points. The vector layers are created in a geodatabase and include the appropriate unique attributes for linkage between created layers. Terrain preprocessing performs the initial analysis to prepare for additional modelling options and can identify potential problems with the terrain model created to help avoid propagation errors in the later stages of analysis (ESRI, 2005). The Arc Hydro methodology applied in this research is described below according to the main processes used and the applicability to barrier mitigation analysis. Additional layers are created in the development of an Arc Hydro data model but only those used in the analysis are described.

Flow Direction:

Using the DEM a flow direction raster layer is created simulating the direction that water flow would occur in the watershed. This process considers the elevation value at each raster cell and replaces it with a value identifying the direction of flow from that cell to the neighbouring cell that represents the steepest descent (ESRI, 2005). The data model defines values for each cell that correspond to a flow direction defined by the "eight direction pour point model" based on the values of the neighbouring eight cells, as shown in Figure 3.5 (Maidment, 2002). The flow direction grid is used as an input layer in the definition of catchments for barrier sites. The layer also supports the analysis as the input layer for the generation of the flow accumulation layer used to define the watercourse network.

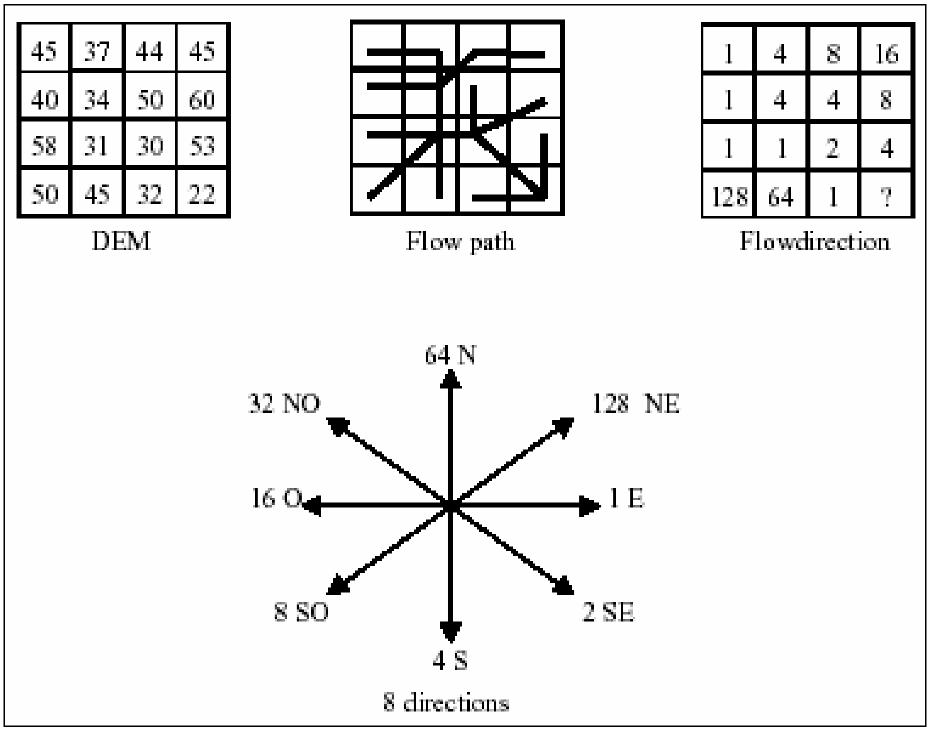


Figure 3.5: Flow Direction (Source: ESRI, 2005)

<u>Flow Accumulation:</u>

The flow accumulation process creates a raster layer that records the number of cells that drain into each cell. The flow accumulation layer simulates the drainage area associated with each raster cell, as shown in Figure 3.6. The raster model stores a value representing a count of cells that "drain" into every cell. This is easily converted to area values as each cell represents 100 m^2 in the UT watershed model. When working with a hydrologically conditioned DEM the results of this process clearly define the watercourse network pattern. This reflects the high accumulation values for water flow in the watershed that increase as you move downstream from the headwaters of a system. This layer then serves as the sole input to the stream definition process that applies a threshold minimum value to the flow accumulation cell values to define a raster watercourse network.

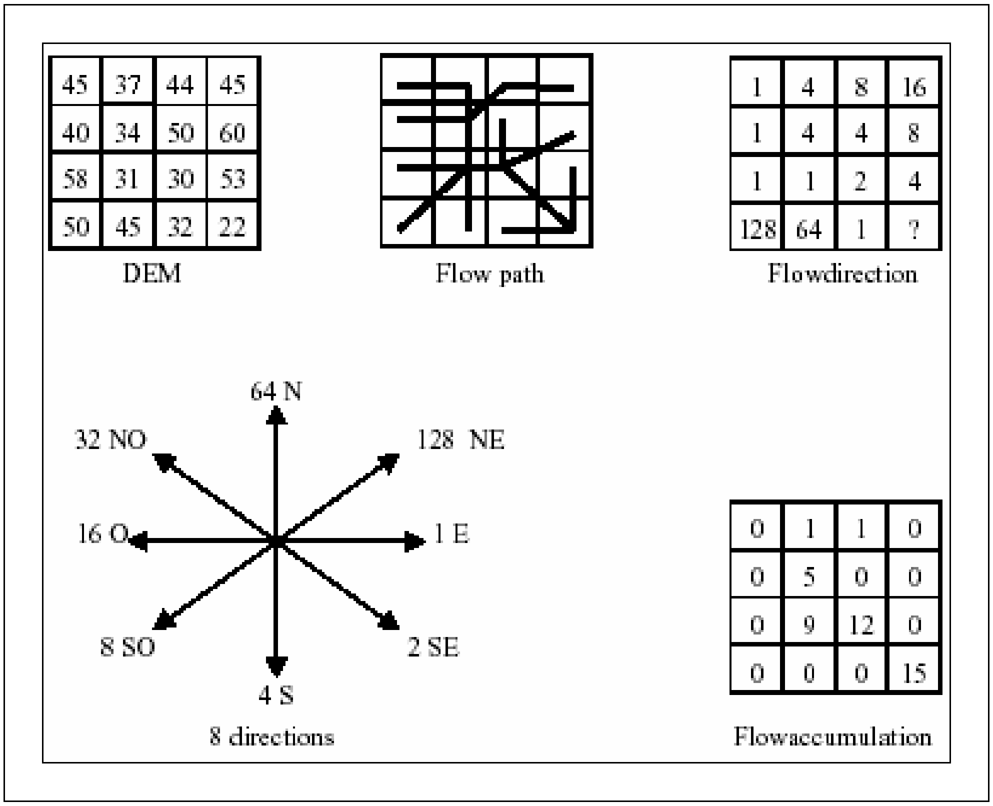


Figure 3.6: Flow Accumulation (Source: ESRI, 2005)

<u>Stream Definition:</u>

Stream Definition is computed based on a user-defined threshold for the drainage area. This value is taken from the flow accumulation grid used as an input in the stream definition process. This determines the scale of the watercourse network and the number of subwatersheds defined in subsequent steps of the data model. The default threshold recommended in Arc Hydro is 1% of the total drainage area of the entire study area. In the case of the Upper Thames watershed this translates into a definition of only those streams with an upstream drainage area of approximately 34 square kilometres or more. Given that many of the barriers identified are located on low order watercourses (headwaters) it is necessary to significantly decrease the size of this threshold to ensure lower order streams are defined in the watercourse network.

Reducing the threshold to define a watercourse network for drainage areas equal to or greater then 2 km^2 was determined to create a network with sufficient detail to represent watercourses at all barrier sites. This required significantly more processing time, compared to the default 1%, but was used to refine barrier locations, as identified above in Section 3.3.1.1. By ensuring raster watercourses were delineated at all barrier sites it is possible to adjust barrier points to ensure they intersect the raster watercourse network at accurate locations when processing to define catchments.

3.3.2.3 Watershed Processing

With the development of the basic Arc Hydro water and terrain model it is possible to perform some hydrologic analysis (ESRI, 2002). A key task in watershed analysis is the ability to summarize the properties of catchments or watersheds (ESRI, 2002). This functionality is employed using the “Batch Subwatershed Delineation” function from the watershed processing tools to define catchments for each barrier site. Significant additional functionality exists in the watershed processing category but only the functions used in the research analysis are described.

Batch Subwatershed Delineation

This function is used for delineating subwatersheds or catchments for a set of points in a user-defined data layer. The refined barriers point layer is used as the “BatchPoint” feature input layer to delineate catchments. Included with Arc Hydro is a tool for creating point layers to be used as input in this process. The tool automatically creates four attribute data fields that are populated interactively as features by the user. Given the interactive point tool was not used, it is necessary to create matching attribute fields in the barrier point data layer for the tool to run. The subwatershed delineation process produces errors and is not completed unless these fields are created and populated. The attribute fields required include:

- NAME – name of point feature (existing barrier name),
- DESCRIPT – description of point feature (existing barrier identification number),
- BATCHDONE – binary value of 1 or 0; with 1 indicating a subwatershed has been created for the specific point and 0 indicating a subwatershed has not be created – this value automatically changes during processing of each point (all barriers are given a value of 0 prior to processing),
- SNAPON - binary value of 1 or 0 indicating if point snapping should be used to shift point location to nearest defined stream network feature (all barriers given a value of 1 to allow snapping to the nearest water feature).

The flow direction layer and watercourse network created using the terrain preprocessing functions are also used as inputs for this process. The process generates a point layer representing the catchment outlet that closely matches the barrier input point file. Some points are slightly shifted as a result of the snapping functionality and adjustment of all points to the centre of the appropriate 100 m^2 raster cell. Most importantly a polygon layer defining the drainage area catchment associated with each barrier is produced as shown in the example below (Figure 3.7). This layer is used in combination with watercourse information to characterize the drainage areas associated with each barrier.

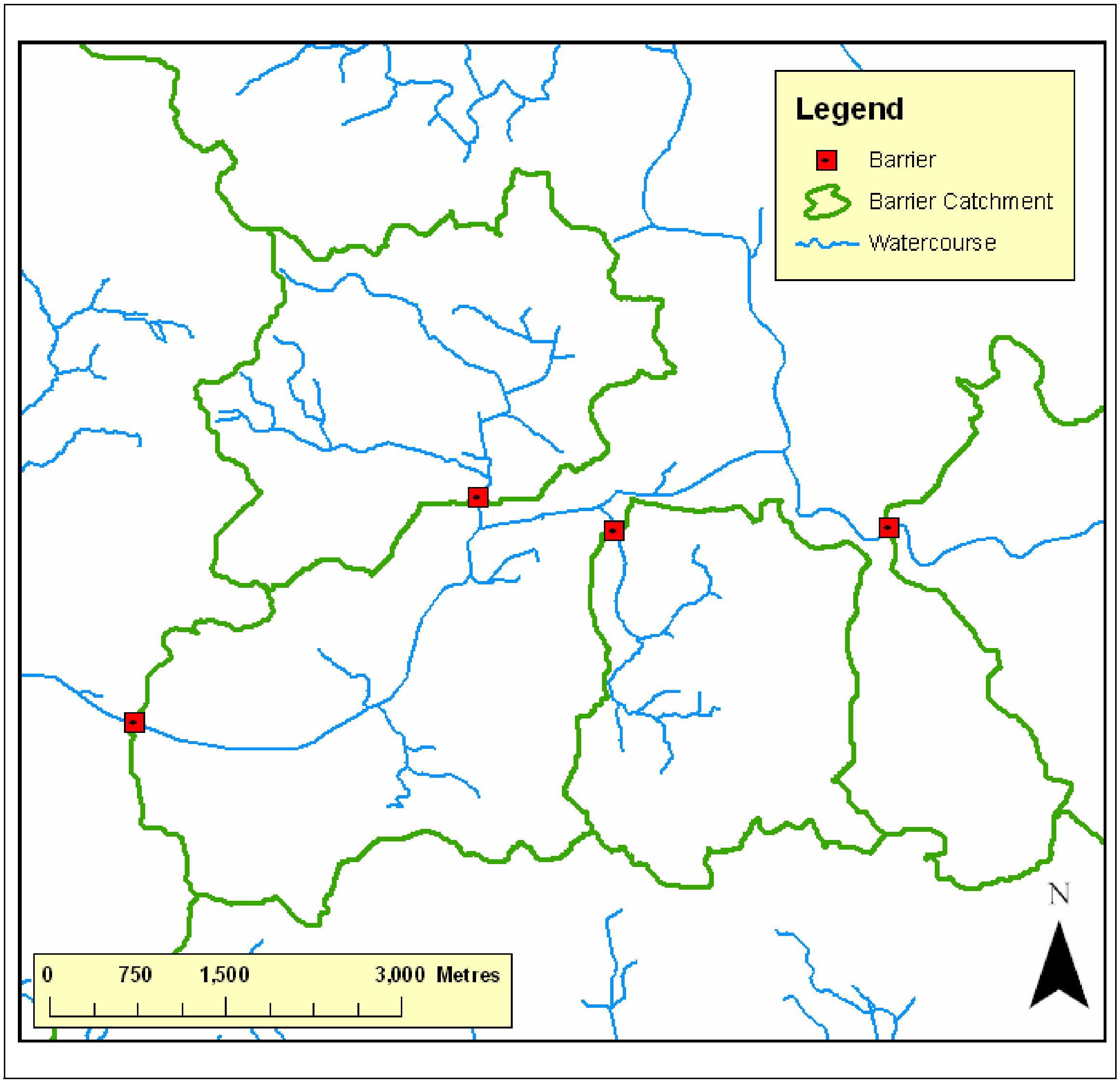


Figure 3.7: Barrier Catchments

3.3.3 Characterizing Barrier Catchments

The fourteen criteria used to characterize barriers are described below. The criteria were developed in consultation with a Technical Advisory Committee (TAC). The TAC worked to identify the criteria to prioritize barriers in the watershed and also helped to refine a methodology for assessing individual barriers once selected for potential mitigation. Individual barrier assessment is conducted using an environmental assessment or screening approach as outlined in Appendix A. Representation on the TAC included staff from a range of stakeholders with aquatic ecosystem expertise including: Fisheries and Oceans Canada (DFO), Ministry of Natural Resources – Lake Erie Management Unit (MNR-LEMU), Ministry of the Environment (MOE), Ministry of Natural Resources – Aylmer and Guelph District (MNR), Municipal and UTRCA staff.

The criteria establish a priority ranking of barriers. High ranking barriers are intended to be considered a priority for mitigation and trigger use of the assessment process. For this reason the criteria used do not include a detailed review of each barrier. More detailed examination will be the focus of the secondary assessment process (UTRCA, 2004). For example, detailed studies of stream morphology, hydrology, water and sediment quality and quantity are considered too detailed for this process but represent some of the more detailed variables that are explored in a barrier-specific assessment. In general, aquatic ecosystem elements were incorporated into the criteria to recognize that the basis of the project is Lake Erie watershed basin health (UTRCA, 2004). The criteria used were agreed to by the TAC and represent best available data for use in this level of analysis. The criteria will likely evolve and additional variables will be considered when data to support them are available for the entire watershed. Scoring for each criterion has been developed in ascending order, higher scores indicate greater priority for mitigation. The criteria are intended to balance qualitative and quantitative parameters.

Criteria:

1. Flood Control Structure (FCS) – This information is taken from the barrier inventory identifying if the original purpose of the structure is flood control. Given the importance of flood control dams in the watershed those with an intended flood control purpose are scored low in comparison to those that were created for other purposes that score high. These values are binary (either is or is not) and are given a weighted score value of 5 or 0.

2. True Flood Control Structure (TFCS) - This information is taken from the inventory and UTRCA flood control documentation. In some cases the intended purpose was for flood control yet in current form the structure no longer serves a flood control function. Again those that are considered true flood control structures are scored low in comparison to those that do not serve this function that score high. These values are binary (either is or is not) and are given a weighted score value of 5 or 0.

3. Known Impediment (KI) – Structures that are known to interfere with the movement of target fish species were given higher values. Known migratory routes taken from historical information coupled with current fisheries assessment information were used to score this criterion. Aquatic biologists interpreted the existing information and determined values ranging from 1 to 5.

4. Mitigated (MIT) – Some barriers have been mitigated for the movement of targeted fish species and are therefore given lower values as some form of mitigation has already been employed. For example, Springbank Dam located in London is operated through the placement or removal of stop logs that are typically removed during key fish spawning seasons. This information is taken from records on the operation of the structure, the site visit associated with the barrier inventory and from historical information related to fisheries movement. This criterion is scored by aquatic biologists with numbers ranging from 1 – 5 as it is recognized that some of the mitigation efforts employed are not 100% effective.

5. Mitigation Required (MIT_REQ) - This criterion considers a variety of factors such as whether the structure is a known impediment, if it is the first barrier that migratory lake-run species will come into contact with and if the necessary habitat for the species exists upstream of the barrier. Emphasis is on barriers that are identified to be the first obstacle from Lake St. Clair and those near or on the main branches of the Thames River. Mitigation is considered to be required for

migratory (lake run species) to have access to other areas and higher values with a range of 0 - 5 are assigned by aquatic biologists. For example, Springbank Dam scores 5 as it is the first barrier to fish migration on the Thames River upstream from Lake St. Clair.

6. Fish Community (FISH_COM) - More sensitive fish communities and migratory species are assigned a higher value. These values are derived from the UTRCA drain/watercourse classification project using the underlying fisheries information in combination with the known presence of aquatic SAR. This criterion is derived using GIS analysis by coupling the attributes of the drain/watercourse classification data layer with the applicable barrier catchment using overlay and reclassification analysis. Values ranging from 1 – 5 are recorded for this criterion (more detail is provided below).

7. Stream Order (SO) – The value of this criterion is relative to order of the stream on which the barrier is located. Stream order is derived from a GIS data layer that employees the Strahler stream order algorithm (classifies stream segments based on the number of tributaries upstream. Stream order ranges from 1 – 7 in the UT watershed and this criterion is scored according to actual stream order, those with an order greater then 5 are assigned the maximum value of 5. Strahler order was used (as opposed to i.e Shreve or Horton order) as it results in fewer stream order values overall which facilitates comparison between watercourses. This information is derived from GIS spatial join analysis combining stream order information with the barrier point data layer.

8. Tributary to Thames (TRIBTHMS) – This variable can be described as the number of "steps away from the Thames" a barrier is located in terms of the level of tributary. For example the Thames River and its main branches will have higher values than a tributary to the Thames and a direct tributary of the Thames will score higher in comparison to one of its tributaries. Scores are determined from mapping by aquatic biologists and is based on the premise that the main Thames, north and south branches and their immediate tributaries will be more important to migratory species. This is similar in nature to the stream order criterion except this variable also increases the rank of lower order streams that are direct tributaries of the Thames River. Scores for this variable range from 0 – 5.

9. Intermittent/Permanent (I_P) – Intermittent stream systems do not sustain water flow throughout the entire season and dry up at certain times of the year. Barriers located on intermittent streams or representing catchments with significant amounts of intermittent streams are considered lower priority for mitigation as the benefits will also be intermittent. This criterion is derived using GIS analysis by coupling the attributes of the watercourse classification GIS data layer with the applicable barrier catchment using overlay analysis. Values ranging from 1 – 5 are recorded for this criterion (more detail is provided below).

10. Cold/Cool Water (COLDCOOL) – Cold or cool water systems are considered more desirable and provide habitat for a more diverse and native selection of species. Therefore, cool or cold water systems are given higher values. These values are derived using GIS analysis by coupling the attributes of the watercourse classification GIS data layer with the applicable barrier catchments using overlay analysis. Values ranging from 0 – 5 are recorded for this criterion (more detail is provided below).

11. Additional Watercourse Length Available (LENGTH) – Removal of a barrier or mitigation that will allow passage by aquatic species to the watercourses upstream of the barrier. The greater the total length of watercourses opened increases the associated benefits. The longer the length of a watercourse available beyond a structure results in a higher value. These data were derived using GIS analysis summing the total length of all watercourses in each barrier catchment and ranking them from 0 – 5 using a five natural break categories (more detail is provided below).

12. Structural Hazard (STR_HAZ) – Derived from the site visits and dam safety inspections where applicable. This provides an indication of the structure condition and if the structure is considered hazardous or in need of repair. Higher values are associated with structures that are in poor condition as often these structures are more likely candidates for mitigation or removal as an option when considering potentially costly repairs. Values ranging from 0 – 5 are used to reflect structural condition.

13. Risk of Invasion (INVASION) – Removal or mitigation of barriers to allow fish and aquatic species passage can have negative results in the displacement of native species by exotic species. This variable is scored (0 – 5) based on recent and historic information identifying species composition throughout the system. With an increased risk of exotic species displacing native species a lower value is given for this criterion reflecting one of the few benefits to aquatic species that can be associated with barriers.

14. Cultural Significance (CULTURAL) – While difficult to assess, barriers with perceived cultural value are given a lower rank in this category. Some barriers are known to be landmarks in the community and some resistance to change can occur when considering barrier mitigation or removal. This variable is assessed and given a value between 1 – 5 based on observations during site visits such as the existence of trails, recreational boating or evidence of other recreational activities or community use near the structure or impoundment. Higher values are given to barriers that are perceived to have less cultural significance although this is not conclusive until site specific barrier assessments are conducted. This variable is the most difficult to assess and cultural significance can be one of the most difficult hurdles to overcome when barrier mitigation efforts are proposed.

(UTRCA, 2004)

GIS functions for data storage and visualization are helpful when ranking many of the criteria used. When determining rank for the four criteria: fish community (FISH_COM), stream permanence (I_P), temperature regime (COLDCOOL) and additional length of watercourse available (LENGTH) each is considered cumulatively for the entire barrier catchment. Variables for fish community, stream permanence and temperature regime are derived using GIS overlay analysis that combines barrier catchments and an existing watercourse classification data layer. The watercourse layer includes attributes for each of these three variables and the overlay procedure imposes the unique catchment identifier (HydroID) to the watercourse network. Summary tables are generated from these data defining the characteristics of all watercourses associated with each catchment. For example total length of watercourses in a catchment that are intermittent versus permanent. Developing ranking values for each of these criteria was achieved using such statistics. Comparison of catchment watercourse characteristics upstream and downstream was necessary for some variables. For example, species composition is compared from catchments on either side of the barrier to determine if species are isolated or restricted by the barrier. The variable for additional length of watercourse (LENGTH) summarizes the total length of all watercourses in each barrier catchment.

3.3.4 Scoring and Weighting

All variables are given a score from zero to five making it possible for a maximum score of 70 points. The 0 – 5 range used was considered manageable by the TAC for characterizing each variable for a barrier. It is recognized however that some variables should be weighted higher than others. To achieve this, a weighted linear combination process was applied in the analysis to emphasize variables considered most critical and determine scenarios to support decision making. This process involves rescaling attribute scores according to a common evaluation scale (Heywood, 2002). Developing scenarios by using adjusted weighting are useful in decision support and can be altered to reflect priority concerns associated with barrier mitigation.

3.4 Summary

The spatial analysis applied in this research is similar to most studies employing GIS analysis in that it is only possible with significant data acquisition effort. Data used in support of this project have been collected for many years through ongoing monitoring programs. The analysis is used to assess barriers in the watershed and can incorporate changes in the data sets over time. Weighting variables also makes it possible to adapt the analysis to changing situations or priorities. Therefore the results to follow are a reflection of current priorities and could be adjusted in the future.

Chapter 4: Results and Discussion

4.1 Priority Barriers

Using the data compiled to score each of the criteria described in Chapter 3 a "top twenty" list of barriers was created. The top twenty are identified by totalling the scores for all criteria and identifying those that score highest. Twenty-three barriers are identified given the duplication of scores making it necessary to include an additional three barriers scoring the same as the twentieth top priority. The scores for these barriers range from a high of 57 to a low of 48. Focusing on barriers with the top twenty scores is considered appropriate given the significant cost and time potentially required to mitigate each barrier. Revision of the top priority barriers may occur semi-annually or as the number of barriers change through mitigation efforts or discovery of new barriers. Therefore the "top twenty" is temporary and will shift over time with the changes in the watershed. Targets have been set to mitigate three barriers per year while the top twenty identified in this research are the priority. Lower priority barriers will be considered if opportunities are presented, such as community pressure or funding opportunities.

Weighting has not been adjusted to favour any variables of the criteria for this ranking. It is important to note however that in developing the criteria some bias has been introduced. Specifically, the flood control functionality of barriers is considered in two categories and in each, barriers score either a 5 or a zero resulting in high positive scores or very low scores, not a range. This bias is recognized, and when reviewed by the advisory committee, it was agreed that the resulting emphasis on structures that do not serve for flood control was warranted. Mitigation efforts could include barrier removal or alteration and it is recognized that the reality of this occurring at flood control structures is very limited. No flood control structures scored high enough to be included in the top priority list. Figure 4.2 shows the location of the priority barriers and their respective catchment areas.

The priority barrier catchments combined cover approximately 1,800 km^2 representing greater than half of the UT watershed. On average, catchment areas for the priority barriers are large in comparison to others. The average area for the 23 priority barriers is approximately 78 km^2 while the overall average area for all barriers is approximately 25 km^2 and those not in the top twenty average approximately 14 km^2. In addition the priority barriers score significantly higher than the overall average in the categories for fish community (FISH_COM), tributary to the Thames (TRIBTHMS) and stream permanence (I_P). Figure 4.1 compares the average scores of the priority barriers with the overall average scores for all barriers. In addition to these ecological criteria, structural hazards associated with priority barriers are well above average, highlighting possible safety concerns or need for repairs. Structural concerns can present opportunities for removal or mitigation when options for repair are considered. Removal can often be presented as a viable long term option when compared with expensive ongoing repair costs.

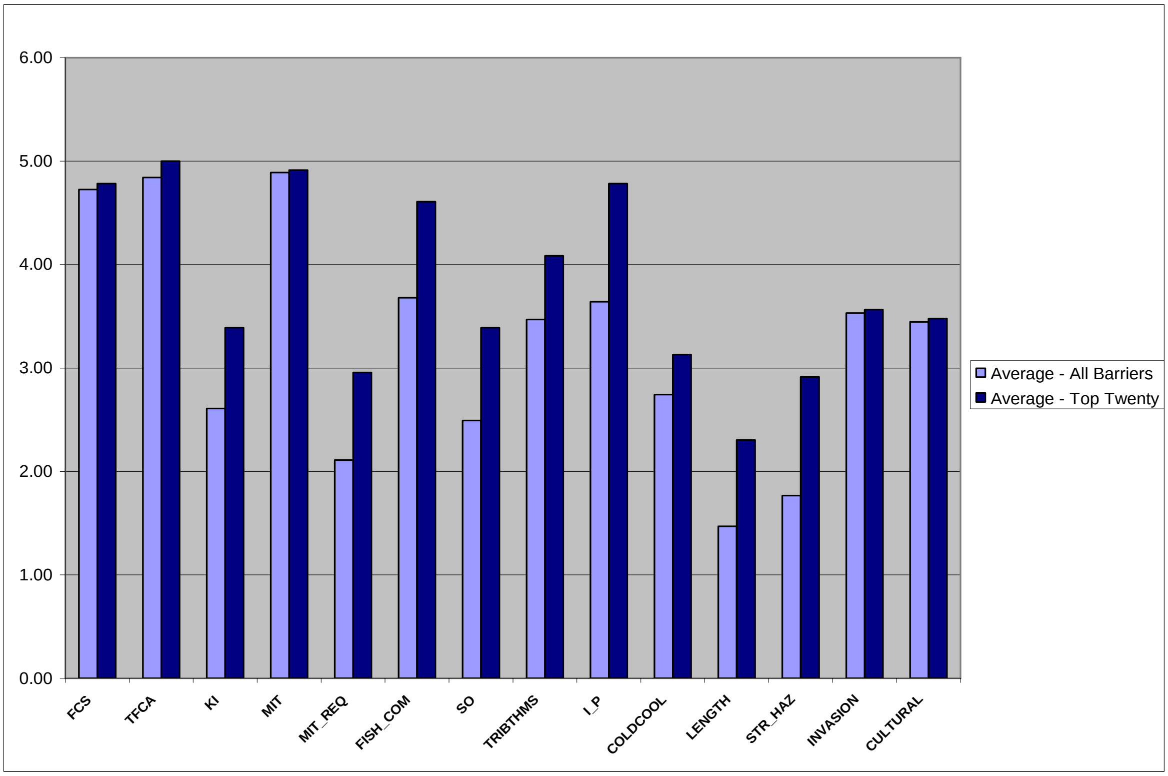


Figure 4.1: Average Scores vs Priority Barrier Average Scores

The high average score for fish community indicates that populations of desirable fish species have been found in the priority barrier catchments or in those directly downstream. These include top level predator species such as smallmouth bass, trout and other gamefish. All twenty-three high priority barriers are located on either main river channels, such as a branch of the Thames, or are direct tributaries of a main channel. In addition all catchments associated with the priority barriers have large percentages of watercourses that have permanent year round water flow.

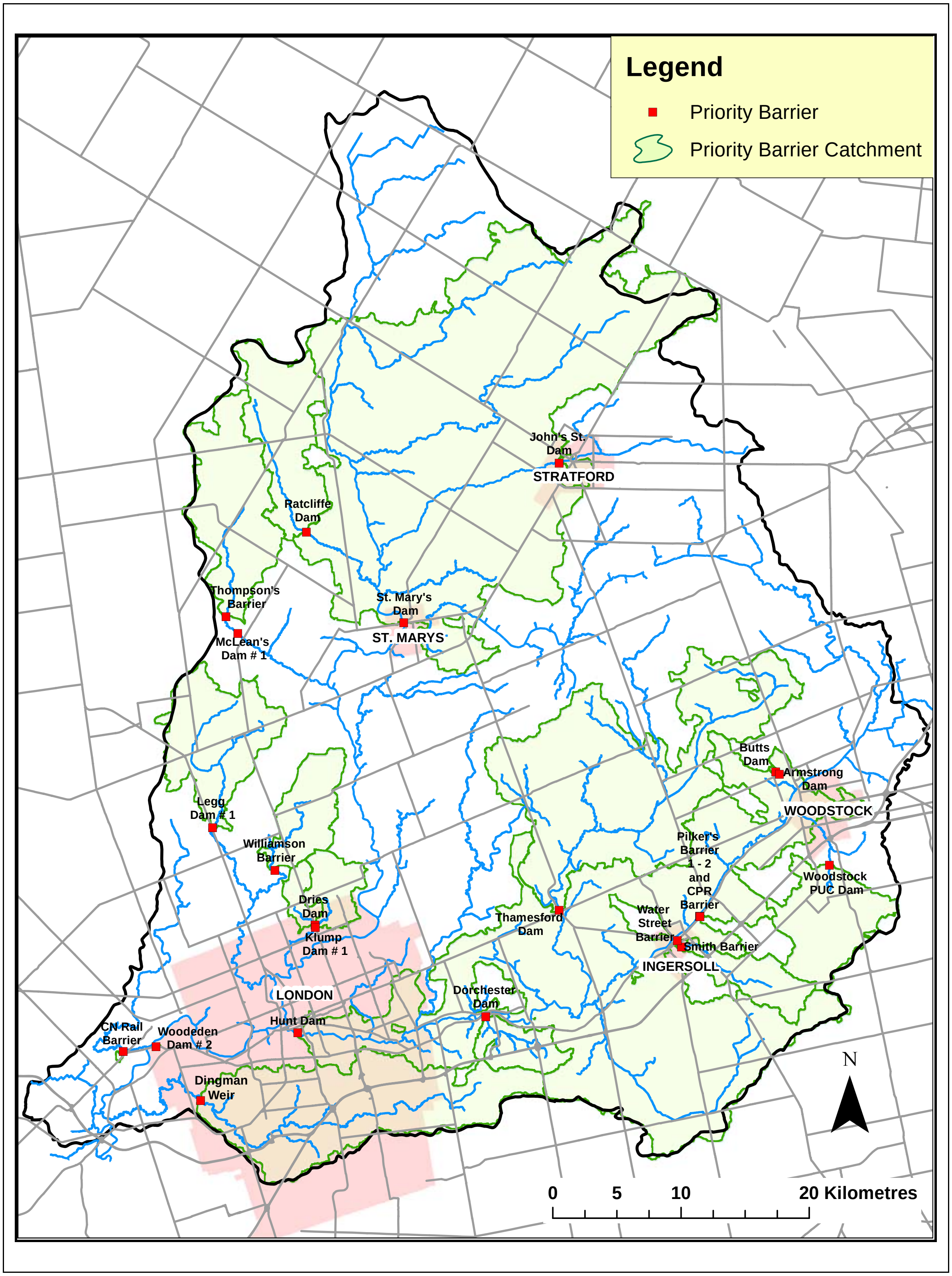


Figure 4.2: Priority Barriers

4.1.1 Analysis

Four of the fourteen criteria used to identify priority barriers employed spatial analysis techniques based on the watershed model described in Section 3.3.2. The analysis applied GIS overlay functionality to impose the spatial extent of the barrier catchments on the watercourse network. This is done by assigning the HydroID of each catchment to all watercourses in the watershed that are impacted by a dam/barrier. Attribute summaries for these watercourses can then be translated into scores for fish community, watercourse permanence, temperature regime and length of watercourses criteria for each barrier catchment. Extensive work to previously classify all watercourses with a letter ranging from A – F has been undertaken making this analysis possible. This work is based on a DFO municipal drain classification protocol for drainage works that has been extended in the UT watershed to classify all watercourses. Key in this classification are variables for fish community, permanence and temperature regime that can be used for analysis. Table 4.1 below summarizes the watercourse classifications as defined by DFO.

Table 4.1: DFO Drain Classification Definitions

Classification	Description
A	permanent cold water flow without trout or salmon present
B	permanent warm water flow, gamefish present, unstable habitat
C	permanent warm water flow, baitfish only present
D	permanent cold water flow with trout present
E	permanent warm water flow, gamefish present, stable habitat
F	intermittent flow

4.1.1.1 Fish Community

Fish species composition has been identified for all watercourses in the UT watershed based on over 600 fish samples taken over the last five years combined with historic data records. Fish communities in each watercourse have been grouped into three main categories, reflecting the DFO drain classification protocol:

1. Top-level predator – fish that forage on other fish species and would be considered near the top of the aquatic food chain (i.e. longnose gar, northern pike, yellow perch, walleye, rock bass, largemouth bass and smallmouth bass).
2. Salmonid/Trout – fish that typically require cooler water and high water quality (i.e. brook trout, brown trout, and rainbow trout)
3. Baitfish – other fish common to watercourses in the watershed (i.e. fish from the minnow family, sunfish family, sucker family and darter species)

Species identified through ongoing fish sampling are maintained in a database that automatically groups species according to these three categories. The results are linked to the GIS watercourse layer making it possible to summarize the fish community associated with each barrier using the catchments created. The scores for the fish community criteria are shown for all barrier catchments in Figure 4.3.

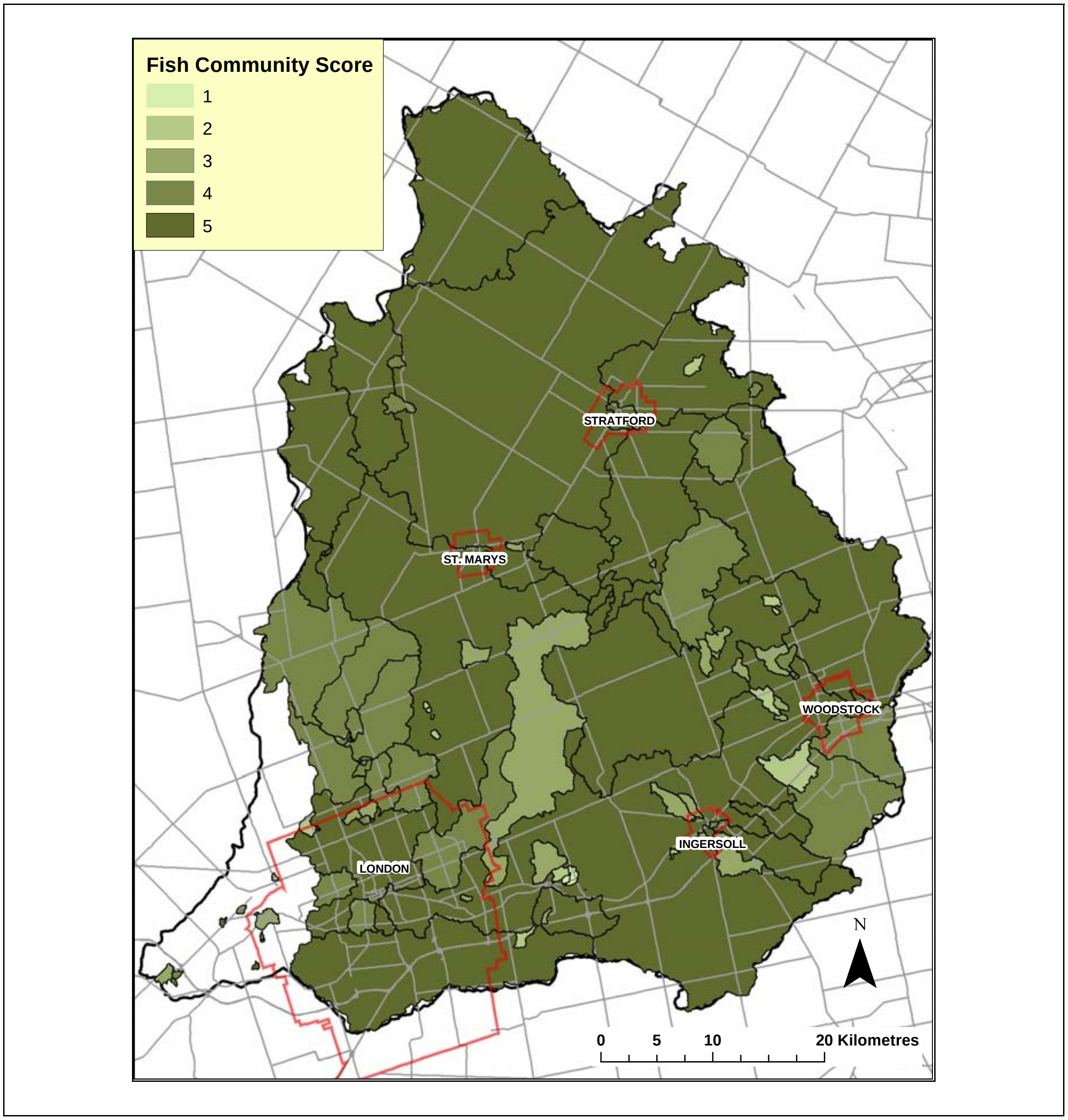


Figure 4.3: Fish Community Scores

To determine the fish community score for each barrier catchment the sum of the length of watercourse supporting top-level predators and/or salmonid/trout species was calculated using GIS summary tables. Baitfish watercourses are not included in the summary as all watercourses in the watershed support these species. The summary tables are created for each of the barrier catchments using the unique HydroID value for each barrier catchment. Figure 4.4 demonstrates this process by focusing on two barrier catchments each located on a tributary of the South Thames River near the small town of Dorchester (located approximately 4 km. east of London). The barrier catchment near the northeast corner of the town scores a low value of 1 in the fish community criteria with no watercourses supporting top-level predators or salmonid/trout species. The catchment extending southeast from the town scores a high value of 5 in the fish community criteria with approximately 7.9 km and 9.8 km of watercourse supporting top-level predators or salmonid/trout species respectively.

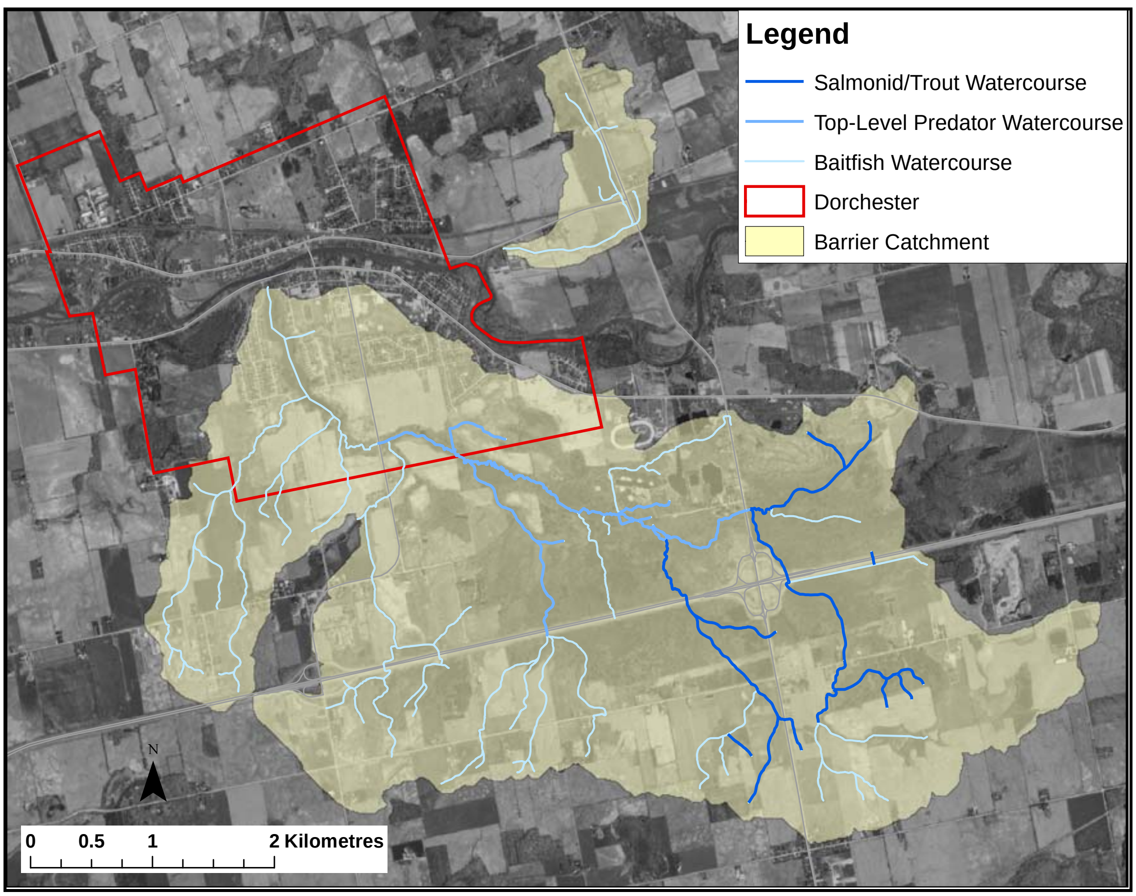


Figure 4.4: Watercourse Fish Community Characteristics (Dorchester)

4.1.1.2 Watercourse Permanence

Intermittent watercourses are defined as those that become dry for a period of more than two months of the year (DFO, 2000). While such watercourses can provide spawning habitat for some fish species they are considered a lower priority for barrier mitigation efforts, Figure 4.5 shows the barrier catchment scores for watercourse permanence.

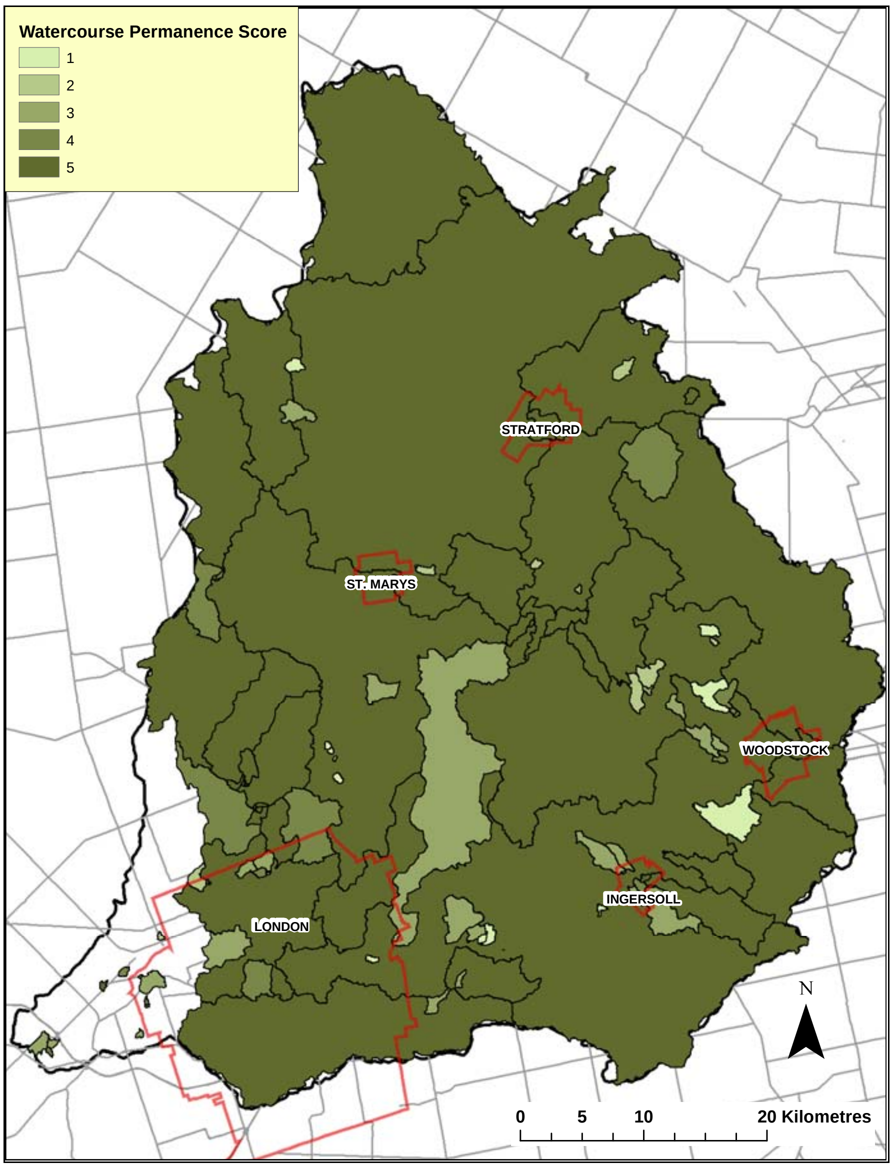


Figure 4.5: Watercourse Permanence Score

Total length of intermittent versus permanent flow watercourses in each barrier catchment was used to determine the scores for this criterion using GIS summary tables. The barrier catchments in the Dorchester area are also used to demonstrate the scoring for this criterion below. The barrier catchment near the northeast corner of the town scores a low value of 1 in watercourse permanence category as all watercourses in the catchment are identified to have intermittent flow. The barrier catchment extending southeast from the town scores a high value of 5 given that approximately 26.7 km. of watercourse in the catchment are identified to have permanent year round water flow.

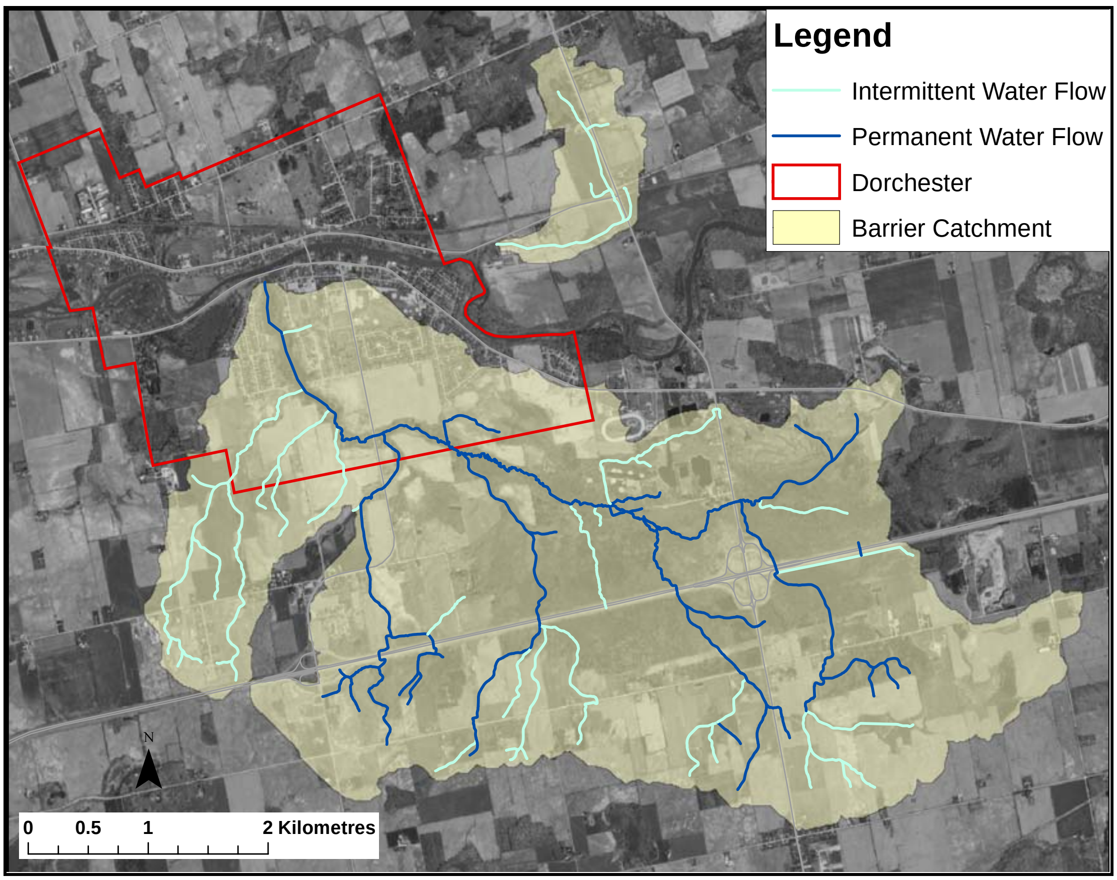


Figure 4.6: Watercourse Permanence (Dorchester)

4.1.1.3 Temperature Regime

Cold or coolwater systems are considered more desirable as they can support fish species such as trout and salmon that cannot tolerate warmer water temperatures. Cold/coolwater systems are given high scores as priority catchments for barrier mitigation efforts, Figure 4.7 shows the barrier catchment scores reflecting water temperature regime.

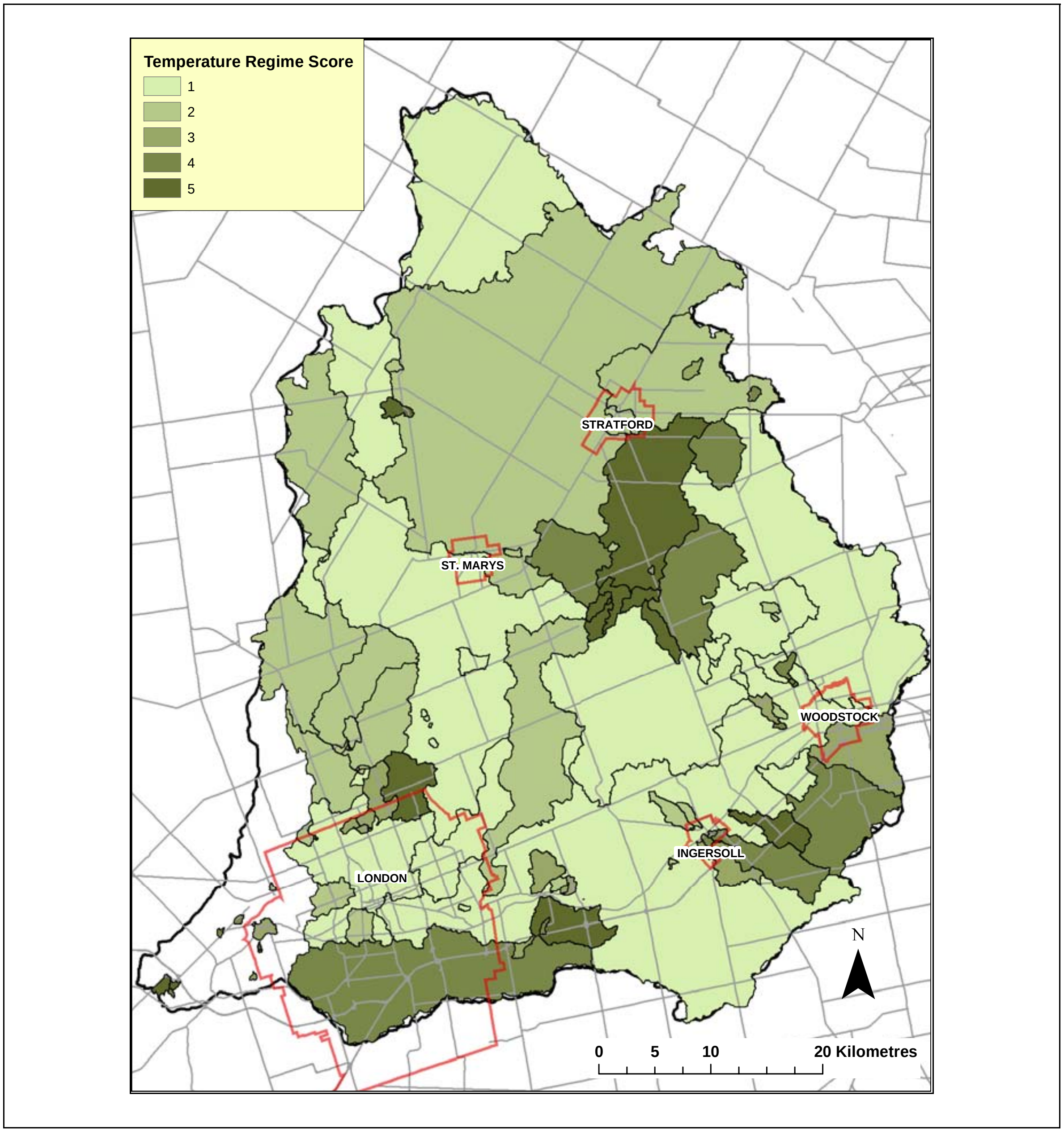


Figure 4.7: Temperature Regime Score

Cold or coolwater watercourses are fairly uncommon in the highly developed UT watershed. The average score for temperature regime is 2.75. Total length of cold or coolwater watercourses were used to develop a score for each barrier catchment. Figure 4.8 compares two barrier catchments located on tributaries of the South Thames River between Ingersoll and Woodstock. The catchment closest to Woodstock scores a low value of 1 with no cold/coolwater watercourses. The catchment closest to Ingersoll scores a high value of 5 given the 7.7 km. of cold/coolwater watercourses located within its boundary.

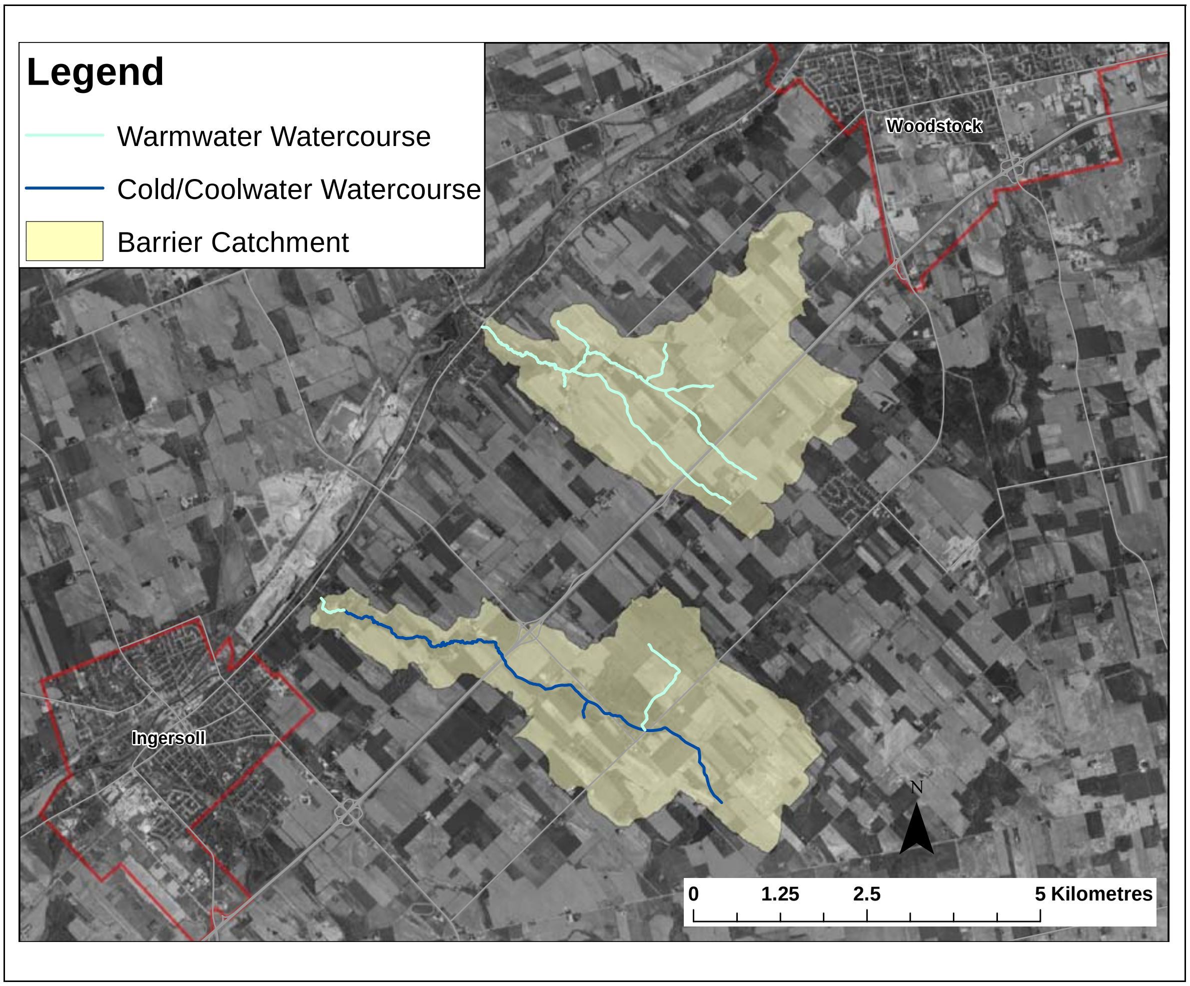


Figure 4.8: Watercourse Permanence (Dorchester)

4.1.1.4 Length of Watercourses

The variable for additional length of watercourse (LENGTH) summarizes the total length of watercourses in each barrier catchment. The natural breaks (Jenks) method is used to classify the total lengths of watercourses in the catchments into five categories. This method groups features that are most similar (catchments with similar total lengths of watercourses) and maximizes the difference between the groupings. The data ranges from catchments with as little as 6 metres of watercourse to those with over 700 kilometres. The five groupings computed in the GIS are translated directly into the ranking of this criterion with barrier catchments containing larger lengths of watercourses receiving the highest values. Table 4.2 summarizes the five categories used to score this criterion.

Table 4.2: Total Watercourse Length Scores

Score	Total Watercourse Length (metres)
1	6.3 - 16870.3
2	16870.3 - 49546.7
3	49546.7 - 100330.3
4	100330.3 - 327127.3
5	327127.3 - 706462.8

4.1.1.5 Summary - Catchment Based Criteria

The four criteria outlined above are important in the analysis conducted as they consider catchment-wide characteristics and impacts. The spatial analysis supporting the ranking of the criteria for fish community, stream permanence and temperature regime was used to guide aquatic biologists in developing scores. Summarizing these variables according to barrier catchments provided decision support for those with expertise in aquatic ecosystem health. Interpretation of the catchment-based criteria is necessary as some cases require variables to be considered in combination with others. In other cases it is necessary to consider both up and downstream characteristics when determining a score. For example it is possible to find coldwater fish species in watercourses that have not been identified as cold or coolwater given the extensive monitoring necessary to define temperature regime, indicating potential unknown cold/coolwater watercourses. In contrast the analysis for the total length of watercourse criteria utilized GIS-based spatial analysis and summary techniques to group and score the criterion without need for interpretation.

4.1.1.6 Non-Catchment Based Criteria

GIS functionality also plays a supporting role in scoring criteria that did not consider cumulative watercourse characteristics of the barrier catchments. For example stream order was calculated for each barrier using functionality available in ArcMap. Stream order previously calculated using a GIS algorithm exists as an attribute of the watercourse layer that was transferred to the barrier data layer using the spatial join function. Ranking criteria such as identification of barriers located directly on tributaries of the Thames River or risk of invasion by exotic species also benefit from standard GIS functionality. Aquatic biologists are able to quickly review each barrier site in combination with other GIS data layers to determine scores for such variables.

4.1.2 Barrier Inventory Update

Since this research began with the inventory in 2002, some changes have occurred in respect to barriers across the watershed. In preliminary findings Dingman Weir was identified as a high priority barrier and was used as a pilot project to test the barrier assessment planning framework. This pilot study resulted in removal of the weir in 2005 and has served to refine the barrier assessment planning framework to use in future projects. Examination of the second priority barrier, a perched railway culvert located on Oxbow Creek, has also been undertaken. Currently costs and structural requirements given its function as a rail crossing make mitigation of this barrier prohibitive. The barrier will remain in the inventory to be considered again in the future. Dorchester Mill Pond Dam the number six priority barrier has recently had extensive rehabilitation work undertaken as a result of the significant cultural value associated with the resulting pond. Mitigation of the ecological impacts associated with the barrier and consideration for the significant upstream coldwater system were not included in the rehabilitation. Reassessment of this structure would reduce its priority ranking as it would no longer exhibit any structural hazards.

Figure 4.9: Oxbow Creek Rail Culvert and Dorchester Mill Pond Dam

4.2 Refining Priorities

The ranking of watershed barriers is the main product associated with the research methodology applied and is intended to promote assessment of mitigation opportunities. The data and methods used to determine the priorities listed above can be updated with data from ongoing monitoring efforts and with the identification of new barriers or removal of existing barriers. Such adjustments would reshape catchments and in combination with specific barrier characteristics result in a re-ordering of priorities. Based on the results identified and with increased experience gained from mitigation efforts over the last three years it is also possible to suggest some refinements that alter the results as presented. Two refinements are described including adjustment of barrier catchments and the use of a weighted linear combination to adjust the relative value associated with some of the criteria used.

4.2.1 Catchment Adjustment

Visually examining the priority barriers and the catchments using GIS highlights some characteristics that merit revision. While many of the catchments associated with the priority barriers are large, some are small as a result of multiple barriers existing in series on a single watercourse. Nine of the identified priority barriers are located in combination with other barriers along the same watercourses and are within a distance of 300 to 2000 metres. These barriers rank high given the underlying data and mitigation efforts should consider the cumulative impacts of multiple barriers on such small stretches of a watercourse system. Mitigation or removal of a single barrier in these cases may only result in shifting the impacts a few hundred metres upstream where the next barrier is located. In addition to the high priority barriers another eight barriers (not priority ranking) are also within a similar small distance of these barriers. In these instances it is necessary to consider the entire catchment area of all barriers on a single watercourse when prioritizing. This will increase the likelihood of success in overall rehabilitation of a watercourse system.

Reflecting this in the watershed model requires adjustment of the barrier point data used to determine outlet points for the catchments. The furthest downstream barrier is retained in the point data while others close by on the same watercourse system are removed. This input when used in the watershed processing function replaces the series of small catchments with a larger one. It is important in these instances to identify in the data that the single downstream barrier is one in a series of structures. Additional resources to mitigate barrier impacts for the watercourse will be required given that multiple dams/barriers would need to be addressed. Figure 4.10 below demonstrates this, showing the Smith and Water Street barriers on a tributary of the South Thames River. Both barriers in this example are considered high priority and slight adjustments to criteria associated with barrier and catchment are necessary given the adjusted boundary.

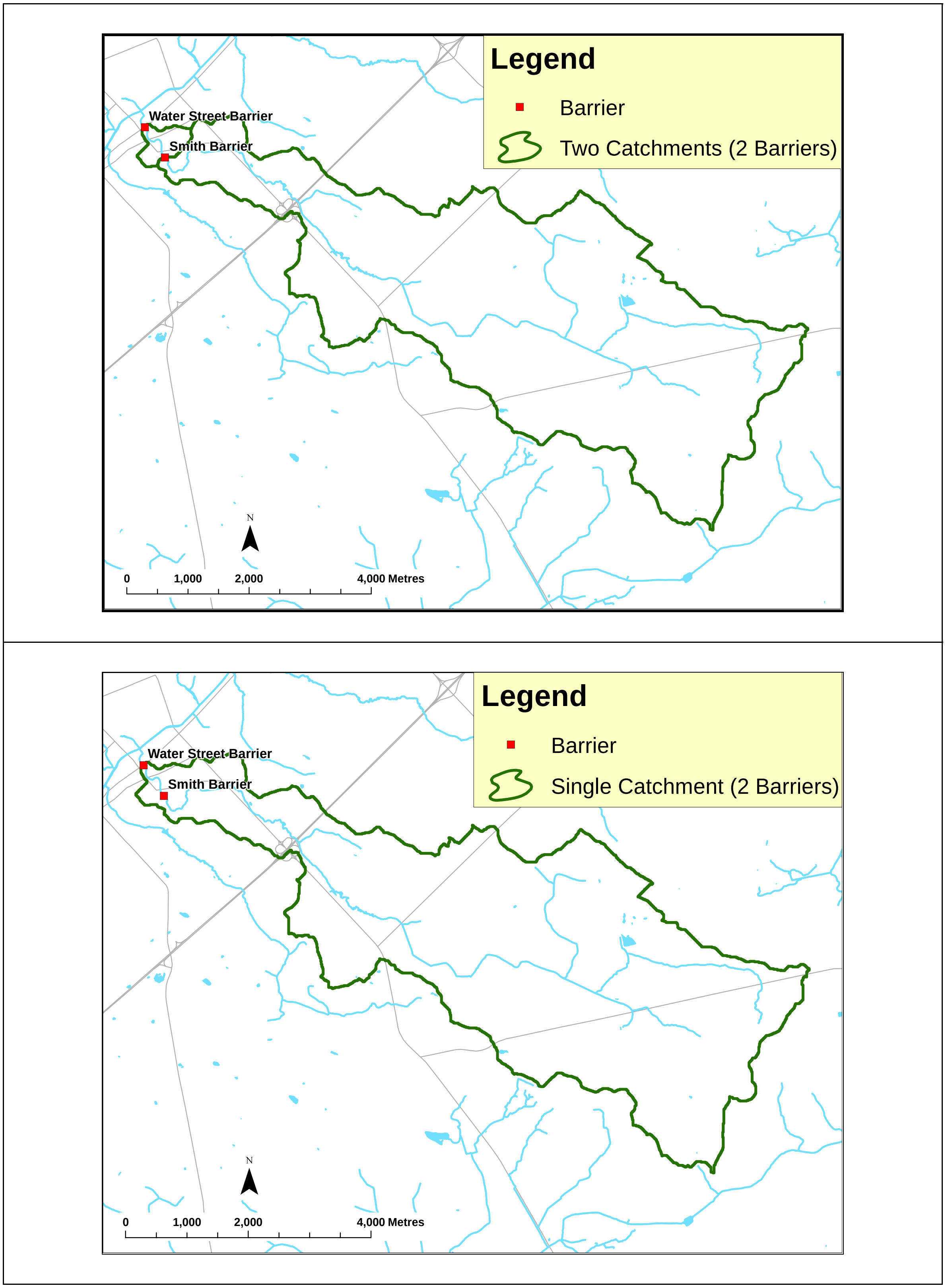
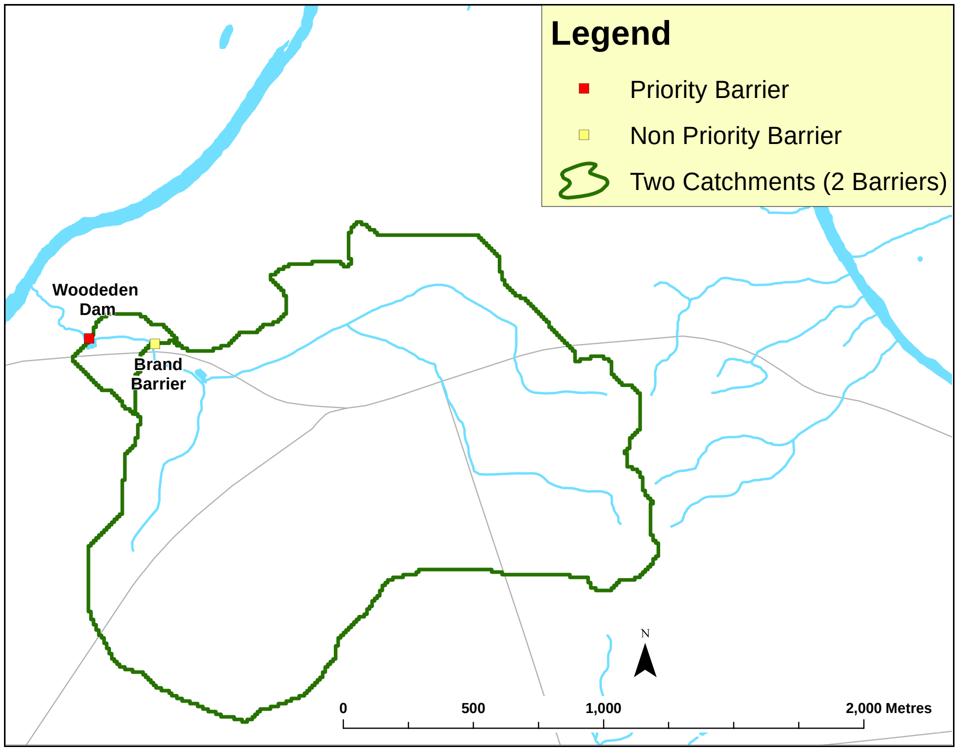


Figure 4.10: Smith and Water Street Barriers - Catchment Adjustment

The second example shown in Figure 4.11 is similar, however in this instance it pairs two barriers that are separated by six points in the original ranking with only one making the priority list. In this instance the barriers are located on a tributary of the main branch of the Thames River and are separated by 300 metres. Considering combinations of barriers in a single catchment supports more extensive rehabilitation of a watercourse. Impacts associated with barriers are not simply shifted up or down stream to the next barrier. When pairing lower priority barriers with priority barriers this way additional barriers that may not be a priority presently but could be in the future are addressed.

Considering economies of scale and the momentum associated with a barrier mitigation project such refinement may increase the number of barriers removed by considering them in combination. The detailed environmental assessment or environmental screening planning process could be used to develop mitigation options for multiple barriers in a single initiative saving time and resources. However, it is recognized that this could also have detrimental effects on barrier removal. These include potential increased costs and possible complications when involving additional stakeholders associated with the additional barrier(s).



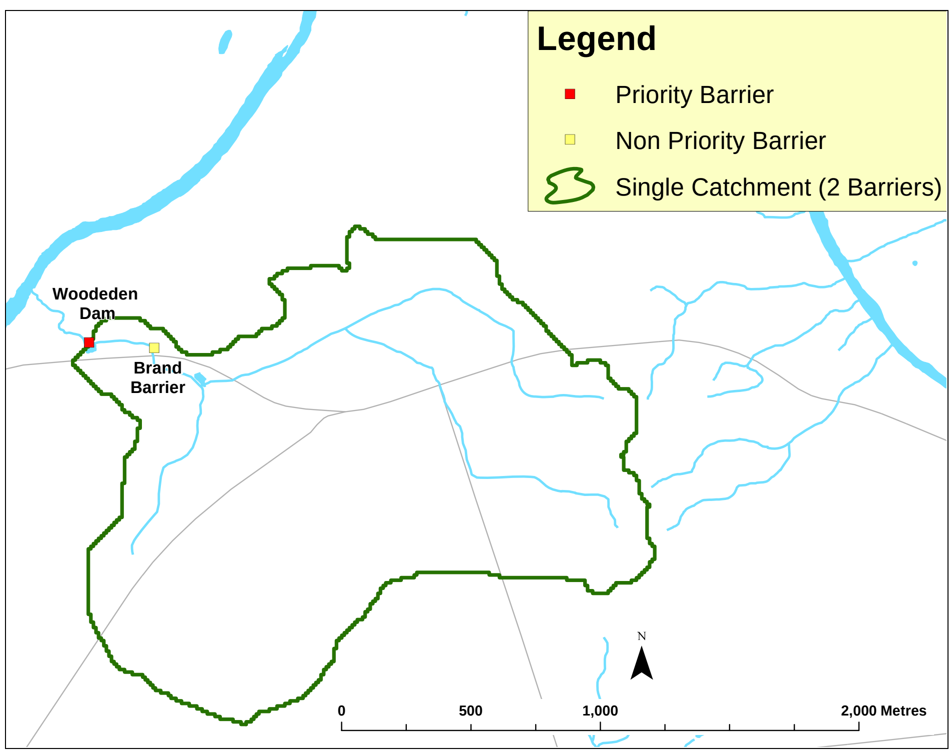


Figure 4.11: Woodeden and Brand Barriers - Catchment Adjustment

When considering the ecological impacts associated with barriers these catchment adjustments are believed to better address the collective effects on a larger system. While both examples shown here combine two barriers, examples of systems that have as many as five barriers in a single stretch of watercourse less then 500 metres long exist in the watershed. Reviewing the twenty-three original priority barriers identified an additional eight barriers located on the same watercourse within a distance of 2 km or less as well as nine of the identified priority barriers that should also be considered in combinations of at least two.

4.2.2 Weighted Linear Combination

Identifying priority barriers using weighted linear combination makes it possible to alter priority ranking without having to adjust barrier scores. This is done by weighting variables considered more important and reducing others. This process makes it possible to consider various scenarios that reflect new information or adjustments to priorities. For example, based on experiences with barrier mitigation projects in the watershed, it has become increasingly clear that cultural significance associated with barriers and/or the resulting impoundments have been underestimated. Efforts to consider mitigation efforts have been rejected in favour of maintaining dams as a result of strong community attachment to the cultural and recreational opportunities created. Working towards mitigation or removal in these cases can prove costly and have a low likelihood of success. Given the limited public understanding of the impacts of dams/barriers it is believed that efforts to adjust cultural bias with respect to barrier mitigation are better spent educating the public and disseminating information on mitigation experiences (The Aspen Institute, 2002).

4.2.2.1 Culturally Weighted Scenario

A scenario that considers increased weighting for the cultural significance criterion was completed to refine the ranking as a reflection of strong public opinion. In this case the weight of the cultural significance variable is doubled in comparison to each of the other variables. This is accomplished by rescaling all criteria by first multiplying them by a number (or fraction) prior to totalling. The total of the weights used in this combination must equal 1. To double the weight associated with the cultural significance criteria those scores are multiplied by 0.12 while the remaining variables are multiplied by 0.06. The intention is to reduce the prominence of barriers in the priority ranking with potentially strong culturally significant characteristics, the equation applied is shown below.

RANK = (FCS*.06) + (TFCS*.06) + (KI*.06) + (MIT*.06) + (MIT_REQ*.06) + (FISH_CON*.06) + (SO*.06) + (TRIBTHMS*.06) + (I_P*.06) + (COLDCOOL*.06) + (LENGHT*.06) + (STR_HAZ*.06) + (INVASION*.06) + (CULTURAL*.12) (1)

The highest score possible in this scenario is 4.5 and the results for the 128 barriers range from a low of 2.2 to a high of 4. The resulting priority list includes 24 barriers (top twenty scores inclusive) and replaces three of the original priority barriers with 4 alternatives. Table 4.3 and Figure 4.12 compare the priority barriers associated with the weighted process to the original priority list.

Table 4.3: Priority Barriers vs Culturally Weighted Priority Barriers

Barrier Name	Original Score	Barrier Name	Weighted Score
1. Dingman CA Dam	57	1. Dingman CA Dam	4.0
2. Oxbow Creek Rail Culvert	56	2. Oxbow Creek Rail Culvert	3.8
3. Hunt Dam	54	3. Hunt Dam	3.7
4. Thamesford Dam	53	4. Smith Barrier	3.5
5. Smith Barrier	53	5. St. Mary's Dam	3.5
6. St. Mary's Dam	52	6. Water Street Barrier	3.5
7. Dorchester Mill Dam	51	7. Thamesford Dam	3.4
8. Woodstock PUC Dam	50	8. Dorchester Mill Dam	3.4
9. Dries Dam	50	9. Klumps Dam # 1	3.4
10. Klumps Dam # 1	50	10. Ratcliffe' Dam	3.4
11. Ratcliffe' Dam	50	11. Centerville CPR Barrier	3.4
12. Water Street Barrier	50	12. Pilker's Dam # 1	3.4
13. Centerville CPR Barrier	49	13. Butts Dam	3.4
14. Pilker's Dam # 1	49	14. Armstrong Dam	3.4
15. Thompson's Barrier	49	15. Dries Dam	3.3
16. John's St. Dam	49	16. John's St. Dam	3.3
17. Woodeden Dam # 2	48	17. Woodeden Dam # 2	3.3
18. Butts Dam	48	18. Pilker's Barrier # 2	3.3
19. Armstrong Dam	48	19. Williamson Barrier # 3	3.3
20. Pilker's Barrier # 2	48	20. McLean's Dam # 1	3.3
21. Legg Dam # 1	48	***21. Turner Dam***	3.3
22. Williamson Barrier # 3	48	***22. Christie Barrier***	3.3
23. McLean's Dam # 1	48	***23. Pottersburg Cr. CPR Barrier # 2***	3.3
		24. Cormier Dam	3.3
* Note: highlighted barriers identify exclusions in culturally weighted scenario.		* Note: highlighted barriers identify additions in culturally weighted scenario.	

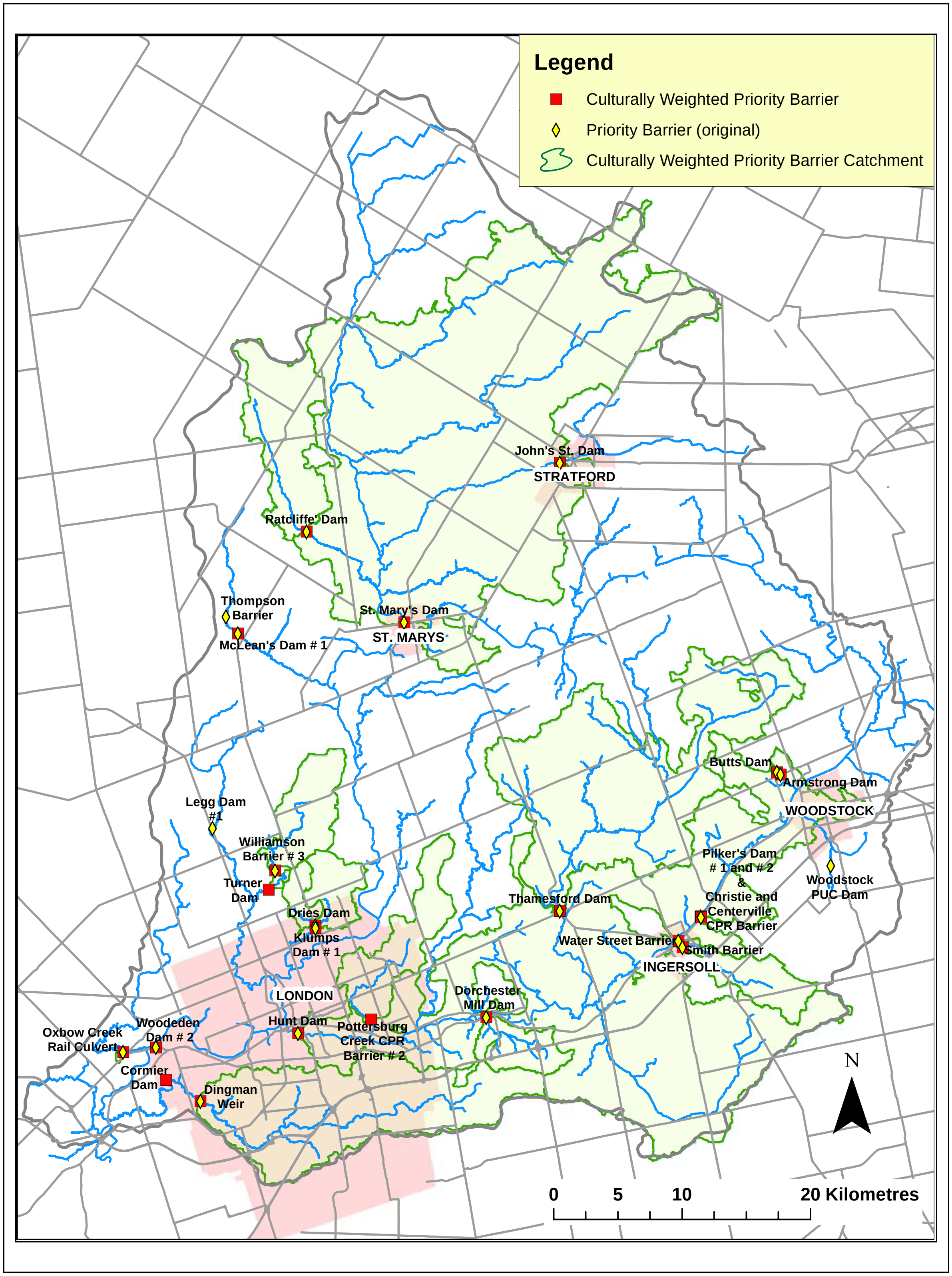


Figure 4.12: Priority Barriers – Culturally Weighted Scenario

4.2.2.2 Catchment Weighted Scenario

The four criteria reflecting conditions in the barrier catchments that consider up and downstream impacts are given additional weighting in this scenario. As described above it is important to consider the drainage area associated with a barrier when assessing its priority for mitigation of ecological impacts. This scenario is developed to add weight to the variables that consider the characteristics of the barrier catchment. The intent is to identify priority barriers that favour ecological rehabilitation of the entire barrier catchment. In this scenario the weights associated with the fish community (FISH_COM), temperature regime (COLDCOOL), permanence (I_P) and total length of watercourse (LENGTH) are criteria whose scores are multiplied by 0.0875 while the remaining variables are multiplied by 0.065. In this scenario the four catchment based criteria account for 35% of the weighted score. This represents approximately 25% higher weight for each of the four targeted criteria in comparison to the other criteria. The scenario was developed for the purpose of this research and does not represent a consensus by the advisory committee. The results presented below for this scenario demonstrate the significant effect that weighting criteria can have on results, the equation applied is shown below.

RANK = (FCS*.065) + (TFCS*.065) + (KI*.065) + (MIT*.065) + (MIT_REQ*.065) + (FISH_CON*.0875) + (SO*.065) + (TRIBTHMS*.065) + (I_P*.0875) + (COLDCOOL*.0875) + (LENGHT*.0875) + (STR_HAZ*.065) + (INVASION*.065) + (CULTURAL*.065) (2)

The highest score possible in this scenario is 5 and the results for the 128 barriers range from a low of 2.35 to a high of 4.44. The resulting priority list includes 23 barriers (top twenty scores inclusive) and only three of the original priority barriers are included.

Table 4.4 and Figure 4.13 compares the priority barriers associated with this scenario to the original priority list.

Table 4.4: Priority Barriers vs Catchment Weighted Priority Barriers

Barrier Name	**Original Score**	**Barrier Name**	**Weighted Score**
1. Dingman CA Dam	57	1. Thamesford Dam	4.44
2. Oxbow Creek Rail Culvert	56	***2. Powell Drain Dam***	4.33
3. Hunt Dam	54	3. Centerville CPR Barrier	4.20
4. Thamesford Dam	53	***4. Glenfell SubDiv Barrier # 4***	4.09
5. Smith Barrier	53	5. Hunt Dam	4.00
6. St. Mary's Dam	52	***6. H Loyens Dam # 6***	3.96
7. Dorchester Mill Dam	51	***7. Nicoll Dam***	3.94
8. Woodstock PUC Dam	50	***8. Och's Dam***	3.85
9. Dries Dam	50	***9. Blum Barrier***	3.78
10. Klumps Dam # 1	50	***10. Thornton Dam # 2***	3.74
11. Ratcliffe' Dam	50	***11. Prosser Dam # 1***	3.74
12. Water Street Barrier	50	***12. Gazdig Dam # 2***	3.72
13. Centerville CPR Barrier	49	***13. Van Nes Dam # 1***	3.70
14. Pilker's Dam # 1	49	***14. Smit's Dam***	3.68
15. Thompson's Barrier	49	***15. Mcaskill Dam***	3.68
16. John's St. Dam	49	***16. Harrington CA Dam***	3.67
17. Woodeden Dam # 2	48	***17. Sunningdale GC Barrier # 2***	3.67
18. Butts Dam	48	***18. H Loyens Dam # 1***	3.65
19. Armstrong Dam	48	***19. Van Nes Dam # 2***	3.63
20. Pilker's Barrier # 2	48	***20. Simonis Dam***	3.61
21. Legg Dam # 1	48	***21. Maxwelton Brae's Dam***	3.61
22. Williamson Barrier # 3	48	***22. Gumerson Barrier***	3.61
23. McLean's Dam # 1	48	***23. Holcroft Rd. Dam***	3.61
* Note: highlighted barriers identify exclusions in catchment weighted scenario.		* Note: highlighted barriers identify additions in catchment weighted scenario.	

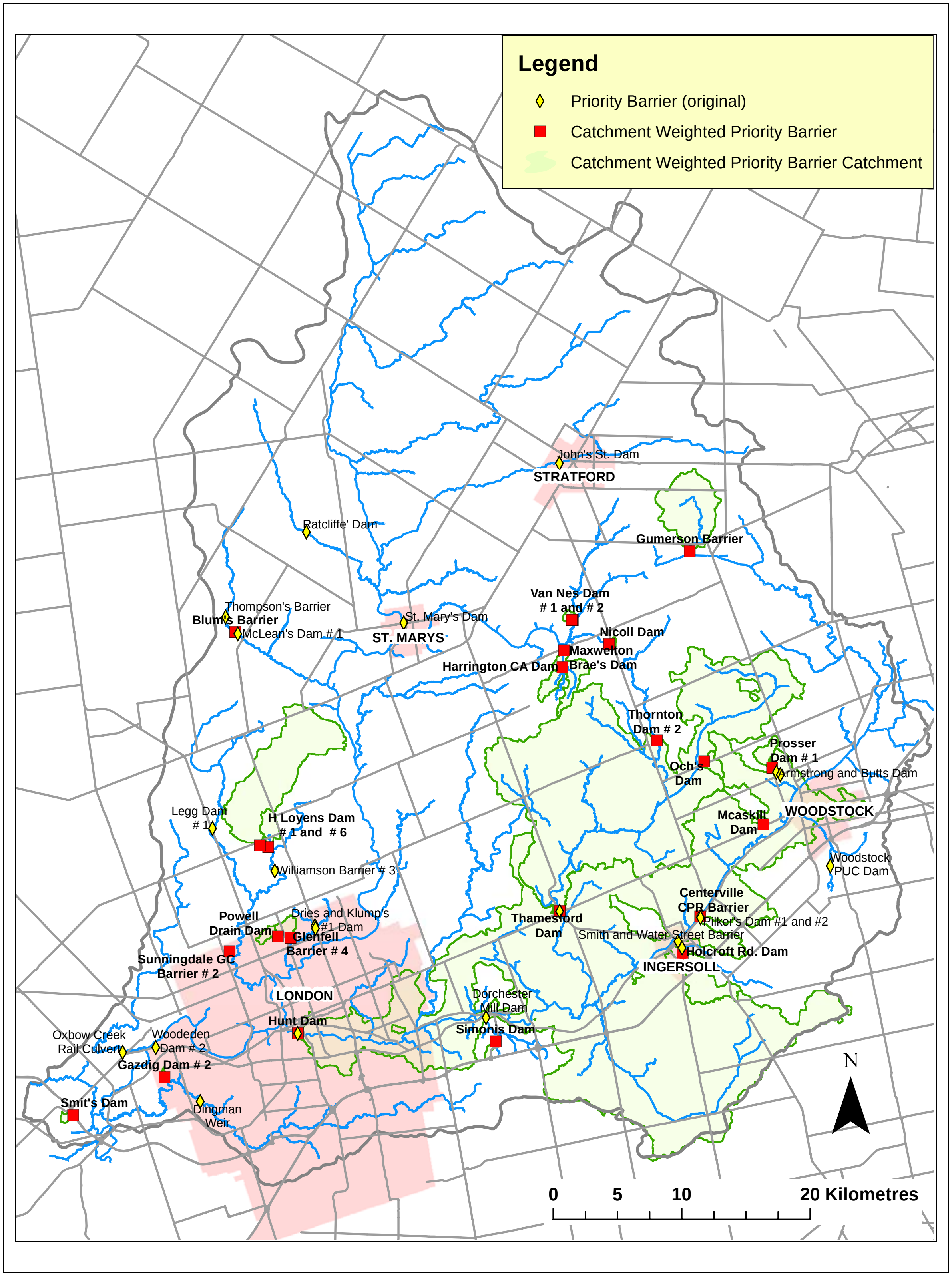


Figure 4.13: Priority Barriers – Catchment Weighted Scenario

The examples demonstrate how weighting criteria can adjust the priority list, even with adjustment to only one category. The ability to use the data compiled to reflect priority issues through weighting creates flexibility and can be used to explore and compare alternative scenarios. The advisory committee can weight the criteria applied according to changing priorities over time. It is important to note the scenarios explored in this research are examples of weighted linear combination developed to demonstrate two specific scenarios based on the researcher's perceptions and input from one aquatic biologist. Techniques such as pairwise comparison could be applied to consider input from the technical advisory committee to weight each variable. Such a process would result in a weighting scenario more reflective of "expert opinion" and provide more defensible results.

4.3 Community Outreach / Education

Developing a priority list for barrier mitigation is a starting point for addressing the impacts they create. While many barriers have been inventoried and included in this research it is estimated that the number of barriers in the watershed could double. The priorities identified here can be targeted for mitigation given the criteria used but there is no guarantee it will occur. Increasing awareness of these efforts and communicating findings, issues and rehabilitation options fosters support for reducing the impact of barriers in the UT watershed. Barriers not included in the priority listing are also targeted for mitigation. The information compiled in this research makes it possible to quickly identify the main issues associated with a wide range of structures. It is hoped that communicating the successful stories of barrier mitigation will encourage other stakeholders to consider such options. In addition, many structures are in poor condition and by communicating this research it may promote consideration of options to remove or mitigate when repairs are needed. It is important to demonstrate that mitigation options, such as removal, eliminate or greatly reduce the need for ongoing maintenance given the return to more natural conditions.

Chapter 5: Conclusions and Next Steps

5.1 Conclusions

The impacts of aquatic dams and barriers have been quantified using watershed analysis tools available in GIS. An ecologic approach has been employed to consider cumulative impacts of barriers, adapting the watershed concept to more localized barrier catchments. Analysis that utilized fourteen criteria to prioritize dams/barriers for mitigation efforts was undertaken in an effort to support ongoing watercourse rehabilitation efforts. Watershed modelling was conducted using the GIS functionality of the ArcHydro data model available for ArcGIS software. Working with a hydrologically conditioned DEM, a watershed model was developed and used in combination with the dam/barrier inventory to develop catchment areas for each dam/barrier. With spatial refinements to the dam/barrier inventory data the watershed model was successfully used to define catchments for 128 barrier sites in the UT watershed. These catchments provide the first step in the analysis conducted to consider the full spatial extent of the ecological impacts associated with dams/barriers.

Ecologic characteristics reflected in criteria for fish community, watercourse permanence, temperature regime and total watercourse length were examined for the barrier catchments. Existing GIS data holdings from ongoing watercourse monitoring and classification work made it possible to analyze each of these criteria separately for all barrier catchments, using standard GIS overlay analysis. The characteristics of three of the four criteria were summarized for individual barrier catchments using GIS and were reviewed by aquatic biologists to develop standardized scores. The total length of watercourses within each catchment were summarized and grouped according to the natural breaks data classification scheme. The five classification categories used translate directly into scores for the length criterion. The catchment-based criteria scores were considered with scores for other barrier or site-specific criteria, such as structural integrity, and were summed to identify barriers that are considered to be the highest priority for mitigation efforts. The ranking used was translated into a “top twenty” priority list based on the criteria and scoring agreed to by a technical advisory committee with expertise in aquatic ecosystem health and restoration.

Two additional scenarios were developed using weighted linear combination analysis to increase the influence of specific criteria on the ranking. The first scenario is intended to reflect the observation that rehabilitation efforts associated with dam/barrier mitigation projects are often rejected by the local community given their cultural attachment to the structures and the recreational and cultural opportunities they provide. The culturally weighted scenario doubles the weight of the cultural significance score compared to other criteria in an effort to avoid targeting mitigation efforts that will be rejected due to local community opposition. The resulting priority list in this scenario replaces three dams/barriers with four that are considered less culturally significant. The second scenario explored increasing the weight of the catchment based criteria in an effort to develop a more ecologically-based priority listing. By increasing the weighting of each catchment-based criterion by approximately 25% over other criteria resulted in significant changes to the top twenty priority barriers. Only three of the original priority barriers remain in the top twenty for the catchment weighted scenario.

The results attempt to begin a process to address a significant stressor to water quality and the aquatic ecosystem of the Upper Thames Watershed. The analysis undertaken provides a basis for considering all dams/barriers in the watershed so scarce resources can be best directed. The findings are simplified into a priority listing of best bets for reducing barrier associated impacts and provide a starting point for watercourse rehabilitation efforts.

5.2 Next Steps

Opportunities for further investigation related to the research conducted in this project include expanding the area of application to the Lower Thames Watershed, further exploration of weighted scenarios and continued or expanded data collection. Expanding the analysis to consider barriers throughout the entire Thames River Watershed is a logical next step for this research. Barrier assessment and mitigation efforts are aimed at improving aquatic ecosystem health in the Lake Erie basin. Closer proximity to Lake St. Clair and lake-run fish species make the Lower Thames watershed an ideal area for expanded research. Historic barrier inventories have been encoded to a GIS database as part of the barrier inventory. However, significant data acquisition is necessary through barrier site visits to develop a database matching the existing Upper Thames data catalogue.

The use of weighted linear combination explored in this research project reflects only limited input for determining criteria weights. When performing such multi-criteria analysis it is clear that weighting criteria can significantly change results. It is also well known that determining criteria weights to use in the analysis can be a significant challenge. This is reflected in the development of such techniques as pairwise comparison used to help prioritize multiple criteria. Developing a weighted scenario that employees the expert opinion of the existing technical advisory committee could develop a scientifically defensible scenario. Finally, continued data compiled from ongoing watershed monitoring efforts is necessary for such applications to work and for results to be quantified. Identification of data gaps and the development of additional criteria could improve the overall application of GIS analysis in aquatic barrier mitigation efforts. Monitoring changing conditions in the watershed could also be used to demonstrate and the benefits of dam and barrier mitigation to the watershed community.

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APPENDIX A:

Thames River Watershed Barrier Assessment Project Proposed Planning Framework Discussion Paper

October 2004

Background and Context for the Discussion Paper

In 2003, the Upper Thames River Conservation Authority (UTRCA) partnered with the Ontario Ministry of Natural Resources (OMNR) under the *Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem* (COA) to conduct assessment, monitoring, rehabilitation and/or restoration projects in the Lake Erie Basin. The Thames River is considered to be part of the Lake Erie Basin by way its drainage path to Lake St. Clair.

Specifically, three projects were developed in order to meet Lake Erie Basin ecosystem objectives as outlined below:

Project # 1. Thames River Demonstration Subwatershed

The Dingman Creek Subwatershed was selected as the Demonstration Subwatershed for a few reasons. First, Dingman Creek ranked quite low in the UTRCA Watershed Report Card program and was identified as an ideal candidate for focused rehabilitation efforts. Second, there is a high level of community interest in the subwatershed, as reflected in the Dingman Creek Community-Based Enhancement Strategy. Lastly, there is a substantial amount of background information provided by the 1995 Dingman Creek Subwatershed Study (DCSS) and more recently from the 2003 Dingman Creek Subwatershed Study Update (DCSSU).

The project will target actions to improve the health of the Dingman Creek watershed including:

a) Reforestation;
b) Facilitating the preparation of environmental farm plans and implementing Best Management Practices; and
c) Investigating the possibility for removal of a concrete weir and subsequent channel restoration. This investigation will include assessing the benefits associated with removing the barrier as well as the potential adverse impacts such as invasion by exotic species and sediment release. Rehabilitation efforts will be accompanied by enhanced monitoring to detect ecosystem response.

Project # 2. Thames River Watershed Barriers Assessment

Approximately 230 watercourse barriers have been identified in the Thames River watershed (180 in the Upper Thames River and 50 in the Lower Thames). These impact water quality, water flow and fish movement and migration. This project will assess impacts and prioritize barriers for removal. The project will be implemented over a three year period:

Year 1 (2003-04)

- Finalize barrier inventory database
- Establish criteria for assessing and prioritizing barriers
- Evaluate and prioritize all Thames River Watershed barriers against the criteria

Year 2 (2004-05)

- Develop a Plan for assessing the potential removal or mitigation of the "top 3" barriers.
- The Action Plan will include a proposed planning process for assessment that will be applied to a test case of one of the "top 3" barriers.

Year 3 (2005)

- Develop a generalized guide for the assessment and mitigation of barriers to guide future actions. This guide is intended for use on a broader scale and will hopefully bring various agencies, municipalities involved to a common understanding of process and long-term benefits of barrier removal or mitigation.

Project # 3. Habitat and Water Quality Monitoring

This project will assess and monitor the thermal and flow regimes, habitat, sediment, macrophytes and benthic community of the Thames River.

This existing benthic monitoring program on the upper Thames will be expanded to the lower Thames, downstream of Delaware; sediment and macrophyte sampling will be conducted at traditional MNR sites on the lower Thames and Upper Thames sites will be added; temperature monitoring meters will be purchased and added to each site; and municipal drain data collection will be extended to natural watercourses.

The project will build on several existing monitoring initiatives conducted by the Upper Thames River Conservation Authority and will augment historical data on water flow, habitat availability, benthos and municipal drains. The project will be implemented over a three year period:

Year 1 (2003-04)

- Stream health and habitat baseline data (benthic, macrophyte and sediment surveys, water quality monitoring, backpack electrofishing to assess fish community in wadeable reaches

Year 2 (2004-05)

- Continue data collection as in Year 1.

Year 3 (2005)

- Final project report due. The data will contribute to a Thames River Fisheries Management Plan and updates to Watershed Report Cards in 2005.

Proposed Planning Framework

Early in the process of developing selection criteria and prioritizing watercourse barriers as part of the Thames River Watershed Barrier Assessment Project, UTRCA recognized that a planning framework needed to be applied to ensure a consistent approach in the assessment of watercourse barriers in the Thames Watershed, particularly with the implementation of this project being extended over a period of years. To address the issue of planning framework, this discussion paper was developed.

The purpose of this paper is to present a proposed planning framework that will be applied to the planning and implementation of barrier assessment projects. The proposed framework will be applied to the Dingman Creek Weir as a test-case. The Dingman Creek Weir assessment provides a link between *Project #1 Demonstration Subwatershed* and *Project # 2 Thames River Watershed Barrier Assessment.* The discussion paper supports both by providing a recommended planning framework. The discussion paper format is based on a similar approach taken in the Springbank Dam Environmental Assessment.

Ontario Environmental Assessment Act

It is proposed that watercourse barrier assessments be planned in accordance with the requirements of the Ontario Environmental Assessment Act (OEAA). The OEAA is applicable to most public sector undertakings including works by Ontario Government Ministries and Agencies, Municipalities, Conservation Authorities and Public Utilities as well as selected private sector undertakings.

An environmental assessment framework is being recommended for watercourse barrier assessment in the Upper Thames River Watershed because:

- The EA process is a reasonable mechanism to carry out an undertaking in an efficient, timely, economic and environmentally responsible manner;
- It is a consistent, streamlined and easily understood process for planning and implementation;
- It is flexible enough to tailor the planning process to a specific project taking into account environmental setting, local public interest and unique project

requirements; and
- It is a legislated and accepted process that is familiar to agencies and the public.

Application of the Class Environmental Assessment

It is anticipated that the requirements of the OEAA can be met by following the applicable Class Environmental Assessment process. The Class EA affords considerable efficiencies to the proponent, partners, agencies and the public by grouping projects with similar characteristics that have an expected range of environmental effects and by following a pre-approved predictable process. The Class EA establishes criteria for screening projects to determine an appropriate category, and an evaluation and consultation process to be applied to each project as appropriate. The process that is implemented through the Class EA ensures that the intent of the OEAA is met by providing identification of issues and concerns and the preferred means of addressing them with regard to environmental management, protection, minimizing effects and adopting appropriate mitigation measures.

Based on the analysis of various Class EA documents, there are a few different Class EAs that may have some application to watercourse barrier assessment. These include the Class Environmental Assessment for Flood and Erosion Control Projects (Conservation Ontario 2002), the Municipal Class Environmental Assessment (Municipal Engineers Association, 2000) and the Class Environmental Assessment for MNR Resource Stewardship and Facility Development Projects (MNR 2003).

It is important to note that all of the Class EAs mentioned above are similar in their ability to satisfy the requirements of the Ontario Environmental Assessment Act, since they all have been developed to deal with projects that have common characteristics, occur frequently and have known or predictable environmental effects that are responsive to standard mitigation measures. In addition, all Class EAs recognize the importance of incorporating public and agency consultation into their respective planning and design processes and all Class EAs allow the option to bump-up the project to an Individual EA. In this regard, application of any of these Class EAs to barrier assessment would adequately ensure that the requirements of the OEAA are met.

Proponency

Section 1 (1) of the EA Act defines a proponent as, *as person who, (i) proposes to carry out an undertaking, or (ii) is the owner or person having charge, management or control of an undertaking*. Although ownership and/or responsibility for a given facility may play a role in assessing who the proponent is, by definition, it is simply the person who is actually carrying out the undertaking.

In the Class Environmental Assessment for MNR Resource Stewardship and Facility Development Projects, MNR is typically recognized as the proponent for projects undertaken following this Class EA. However, the MNR Class EA recognizes that many projects traditionally undertaken by MNR are now being carried out through partnership programs. In these cases, MNR is responsible for screening the project to determine the appropriate category. MNR can then apply the of the Class EA or request the partner to fulfill the requirements of the Class EA themselves and report back to the ministry. This would mean that the partner would be accountable to the MNR for the completion of certain requirements in accordance with the MNR Class EA.

In the Municipal Class EA, the term proponent refers to 1) the municipality, Public Utility or Ontario Clean Water Agency or private sector developer/landowner which is carrying out the project, or which is ultimately responsible for the works; or 2) whoever else is approved to use the Municipal Class EA. The proponent is ultimately responsible for project compliance with the Municipal Class EA.

The Municipal Class EA does recognize that partnerships occur; specifically there is recognition of municipal/private sector partnerships and partnerships among municipalities. In these cases, the partners may be recognized as co-proponents or may select a lead proponent to carry out the project planning and implementation.

The Municipal Class EA does not explicitly recognize the potential for partnership amongst municipalities and Conservation Authorities or other government agencies. It would be worthwhile exploring the definition of partnerships under the Municipal Class EA further, particularly with regard to Conservation Authorities (CAs) since CAs are essentially municipal-based agencies supported in large part by levies collected from municipalities within the watershed. As a "provincial/municipal partnership", Conservation Authority funding and program priorities are generated at both the local and provincial level. As such, there is much potential for CAs to play the role of municipal agent in the implementation of watershed or conservation-based programs. This role needs further investigation and interpretation in the context of the Municipal Class EA and its application.

The proponents of the Class Environmental Assessment for Flood and Erosion Control Projects (Conservation Ontario 2002) are recognized as the Conservation Authorities within the meaning of the Conservation Authorities Act. However, the CO Class EA recognizes that a Conservation Authority may enter an agreement with any party to plan, design and implement an undertaking subject to the CO Class EA. In such cases, each/all of the parties to the agreement will be proponents under the CO Class EA and will be subject to it requirements but the Conservation Authority will ultimately be responsible for ensuring the requirements of the CO Class EA are met.

Furthermore, the CO Class EA recognizes *that where there is a partnership project that meets the definition of an undertaking under the CO Class EA and any of the partners' approved Class EAs, such as the Municipal Class EA, then the partners will decide which Class EA will be applied. If the decision is to use the CO Class EA then the proponent*

Conservation Authority shall provide written justification for making that decision in the Notice of Filing.

Generally, the CO Class EA makes better recognition of the potential for Conservation Authority/Municipality partnerships. However, in cases where the Municipal Class EA is selected, there should be a similar onus on the proponent to justify the decision. This is the premise that was followed in the recent case of the proposed reconstruction of Springbank Dam in London. The Conservation Authority was responsible for the operational management and maintenance of the dam, and acted as project managers on behalf of the City. However, because the City was the principle owner of the structure and the financier of the project, the City was considered the more appropriate choice as the proponent and as such, the Municipal Class EA was believed to be the more applicable process.

If the UTRCA had been considered the project proponent in this case then it is possible that Springbank Dam rehabilitation could have qualified as a remedial flood and erosion control project. However, since the principle function of the dam is one of recreation and since the potential for significant flooding and erosion impacts was considered low even if the dam were to fail, selection of the CO Class EA solely on project type was considered somewhat tenuous and the final decision was that the Municipal Class EA seemed more appropriate.

Project Type

Each of the three Class EAs discussed provides a description of the class of undertakings to which the Class EA is applied. As well, each Class EA categorizes undertakings according to project complexity and anticipated environmental impact.

In broad terms, the Municipal Class EA is applicable to municipal infrastructure projects such as roads, water and wastewater project undertaken by the municipality, Public Utilities Commission (PUC), Ontario Clean Water Agency (OCWA) or private land developers/landowners (for specific selected activities). Projects can include new works, expansive/upgrades to existing facilities or retirement of existing facilities.

In comparison, the CO Class EA applies specifically to remedial flood and erosion control project undertaken by Conservation Authorities. Such projects are required to protect human life and property from flooding or erosion, and do not include works to facilitate development.

Finally, the MNR Class EA provides for resource stewardship and facility development projects including their planning, design, construction, operation, maintenance, rehabilitation and retirement or decommissions, as conducted by MNR or MNR in co-operation with its partners. Examples of the types of projects subject to the MNR Class EA include access points, docks, access roads, dam and dykes, fish stocking, fishway, shoreline and stream bank stabilization, dredge/fill ponds, canoe routes and solid waste disposal.

One factor that obscures our understanding of the applicability of these Class EAs to watercourse barrier assessment is the fact that none of the Class EAs discussed here specifically include the *removal* of a dam or barrier in their list of undertakings. The Municipal Class EA recognizes *works undertaken for the purposes of flood control and erosion control, which may include reconstruction of a dam or weir* and the *reconstruction of a weir or dam at the same location where the purpose, use and capacity are changed.*

The MNR Class EA recognizes that in recent years, the ministry has been reviewing the functions of many dam/dykes with a view to decommissioning those that no longer serve a management purpose consistent with corporate goals and objectives. However, decommission of watercourse barriers is not explicitly identified in the list of undertakings.

The CO Class EA contains a section that specifically deals with operations, maintenance or retirement. This section provides some interpretation of undertakings that involve decommissioning. The Class EA states that retirement refers to a situation which the purpose or use of a structure of capital work as approved under this Class EA or it predecessor is no longer necessary and it operation is cancelled. This may involve demolition of a structure of change in purpose, use or capacity. Such activities will be planned in accordance with the CO Class EA. If works are proposed that do not fall within the definition “retirement”, they will be considered as new undertakings and subject to the planning and design process described in the CO Class EA.

Application of Environmental Screening

For barrier assessment projects on private land, where the structure is also privately owned, the undertaking may not be subject to the Environmental Assessment Act. However, this does not alleviate the requirement for appropriate permits and approvals for the work involved.

For projects on private land, we recommended that an environmental screening be completed internally, by the lead review agency and be included in the project file. For example, if the Conservation Authority is the lead review agency facilitating barrier assessment projects on private land then the CA would complete and environmental screening prior to the project design. The environmental screening would become part of the project file and could be circulated to other agencies as part of the permits/approvals stage.

In larger projects, on public land, the environmental screening is a component of the Class EA process, regardless of what Class EA is applied. For the Thames River

Watershed Barrier Assessment Project, UTRCA recommends the adoption of the Environmental Screening Table that appears as part of the Conservation Ontario Class EA for Remedial Flood and Erosion Control Projects (2002). This table is provided in Appendix A. If this recommendation is implemented, the environmental screening would become a common element to all barrier assessment projects, regardless of ownership, proponent or applicability of the Class EA.

The Municipal Class EA does not include a formal environmental screening table as presented in the CO Class EA however the screening could be applied as part of the Municipal Class EA process, with no impact on that process. The MNR Class EA contains a screening table similar to the CO Class EA which would be applied with application of the MNR Class EA.

Canadian Environmental Assessment Act

It is beyond the scope of this discussion paper to provide details about CEAA screening and CEAA requirements. However, it should be noted here that in addition to meeting requirements of the Ontario Environmental Assessment Act, it is anticipated that barrier assessments may be subject to the requirements of the Canadian Environmental Assessment (CEAA) if triggered by a Federal approval from such agencies as the Department of Fisheries and Oceans (DFO) or the Transport Canada.

In any event, with respect to selecting an appropriate Class EA for barrier assessment projects, the potential requirement for CEAA applies equally to all Class EAs and therefore is not an influencing factor in the selection of one Class EA over another.

Dingman Creek Weir Assessment - Test Case

The Dingman Weir has been selected as a test case for the proposed planning framework outlined in this discussion paper. The applicability of the various Class EAs described in this discussion paper was examined with the following results:

MNR Class EA

The funding for the Thames River Watershed Barrier Assessment Project and the planning and implementation of the Dingman Creek Weir Assessment is being provided through the Upper Thames River Conservation Authority through their partnership with the Ontario Ministry of Natural Resources (OMNR) under the *Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem* (COA). However, while funding has been afforded through a ministry initiative, MNR is not considered a proponent in this case because they do not own, operate or manage the Dingman Creek Weir and will not play a lead role in the planning, design and implementation of the project.

Municipal Class EA

The Dingman Creek Weir structure and the land surrounding the weir site (Dingman Creek Conservation Area) are owned by the City of London. Safety and liability related to the deteriorating condition of the structure and public use are a responsibility of the City of London and are a significant factor in the need to assess the future of this barrier. As owner, the City of London would be an appropriate proponent for an assessment project under the Municipal Class EA.

CO Class EA

As stated above, funding for the Thames River Watershed Barrier Assessment Project and the planning and implementation of the Dingman Creek Weir Assessment is being provided through the Upper Thames River Conservation Authority through their partnership with the Ontario Ministry of Natural Resources (OMNR) under the *Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem* (COA). In considering the funding source, and the resources used in planning and implementation of the Dingman Creek Weir Assessment, this project could represent the type of "provincial/municipal partnership" that is recognized by the CO Class EA. Application of the CO Class EA was considered feasible, however, **in this case the Municipal Class EA appears to be the most reasonable choice because the Dingman Creek Weir is owned by the City of London, as such, the City will be considered the proponent.** This decision is consistent with the decision to follow the Municipal Class EA for the Springbank Dam Rehabilitation project.