Engineering Ltd.

Final Report for:

LACOMBE COUNTY, PONOKA COUNTY, CITY OF LACOMBE, TOWN OF BLACKFALDS

MASTER DRAINAGE PLAN

For the Wolf Creek and Whelp Brook Watersheds

Date: August 31, 2014

Proud of our Past… Building the Future

www.mpe.ca

#302, 4702 - 49 Avenue
Red Deer, AB T4N 6L5
Phone: 403-348-8340
Fax: 403-348-8331

MPE Engineering Ltd.

Lacombe County
RR 3
Lacombe, Alberta T4L 2N3

May 31, 2014
File: N:\42\10\014\00\R01-1.0

Attention: **Dale Frietag**
Manager of Planning Services

Dear Mr. Freitag**,**

Re: Master Drainage Plan for the Wolf Creek and Whelp Brook Watersheds

We are pleased to submit the Master Drainage Plan for the Wolf Creek and Whelp Brook Watersheds. This document includes a summary of the undertaken methodologies and analyses, and the resulting recommended design criteria and action plan for stormwater management in the Wolf Creek and Whelp Brook watersheds.

We recommend this document be submitted to Alberta Environment and Sustainable Resource Development for approval.

If you have any questions or require clarification, please call me at (403) 314-6129.

We enjoyed working together on this project and look forward to working with you in the future.

Yours truly,

MPE ENGINEERING LTD.

Peter Stevens, P.Eng., FEC, FGC (Hon.)
Senior Project Manager

PS/pp

CORPORATE AUTHORIZATION

This report has been prepared by MPE Engineering Ltd. under authorization of Lacombe County, Ponoka County, City of Lacombe, and Town of Blackfalds. The material in this report represents the best judgment of MPE Engineering Ltd. given the available information. Any use that a third party makes of this report, or reliance on or decisions made based upon it is the responsibilities of the third party. MPE Engineering Ltd. accepts no responsibility for damages, if any, suffered by a third party as a result of decisions made or actions taken based upon this report.

MPE ENGINEERING LTD.

PROFESSIONAL ENGINEER
PETRUS GERARDUS STEVENS
ALBERTA

September 2, 2014

PERMIT TO PRACTICE
MPE ENGINEERING LTD.
PERMIT NUMBER: P 3680
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

EXECUTIVE SUMMARY

Wolf Creek and its major tributary Whelp Brook are the natural watercourses which drain significant portions of four municipalities: Lacombe County, Ponoka County, City of Lacombe, and Town of Blackfalds. Since the area was settled, efforts by individuals and government were made to improve drainage and reduce flooding (ESRD, 2013(a)). Over the past few years, significant rainfall events and various types of development in the watershed have led to renewed concerns of local flooding and erosion expressed by the general public and the municipalities.

In 2012, the four municipalities formed the "Wolf Creek Watershed Study Committee" (WCWSC) to manage a coordinated effort for watercourse improvements and guidance for future development. To that end, the WCWSC retained MPE Engineering Ltd. (MPE) to prepare this Master Drainage Plan (MDP) for the Wolf Creek and Whelp Brook watersheds.

The criteria for future stormwater management systems and facilities required for development in the Wolf Creek watershed are described in this MDP. The adopted guiding principles for design of the storm water management system include:

- minimize flooding, erosion, and water quality impacts in the watershed;
- avoid wetlands where possible, otherwise minimize impacts on wetlands and mitigate where required;
- minimize impacts on the receiving stream, Battle River, as well as downstream development;
- meet or exceed regulatory requirements for stormwater management.

Overall, stormwater runoff will be managed with minor systems and major systems, as required in the Alberta Environment and Sustainable Resource Development (ESRD) 2006 "Standards and Guidelines for Municipal Waterworks, Wastewater & Storm Drainage Systems":

- The minor systems will be consisting of buried pipe systems with a capacity to convey the 1:5 year storm event flows.
- The major system will consist of curbed or ditched streets with a capacity to convey up to the 1:100 year storm event, and stormwater management facilities.

- The discharge rates from stormwater management facilities will be limited to the approved allowable release rates based on the estimated pre-development discharge rates in the watershed.
- The natural hydrographs at the outlets of each of the watercourses will be maintained as closely as possible to minimize the impact on the downstream receiving watercourse, Battle River.

Because insufficient streamflow records exist for the Wolf Creek watershed, their pre-development discharges were estimated using a regional stream flow analysis of hydrologically similar basins with long-term stream flow records, and modelling the Wolf Creek and Whelp Brook channels using HEC-RAS. Results suggest the estimated 1:100 year pre-development unit runoff rate for the Wolf Creek subwatersheds is 2 L/s/ha.

Runoff conditions of the existing and future developed areas of the Wolf Creek watershed were compared using representative hydrographs from selected subwatersheds and routed using the HEC-RAS model. Results suggest that, under post-development conditions, an allowable unit release rate of 2 L/s/ha would *not* increase peak flows in the Wolf Creek and Whelp Brook, and the receiving stream, Battle River. (In comparison, an allowable unit release rate of 5 L/s/ha would increase peak flows in the Wolf Creek and Whelp Brook by about 10%, and about 1% in the receiving stream, Battle River, assuming coincident peaks.)

To meet ESRD guidelines, stormwater management facilities will be required to meet the approved allowable release rate as well as the water quality requirements. As well, each facility will also be sized to remove 85% of the sediment loading (greater than 75 µm) from the development area prior to being released. Where feasible, each facility will have a permanent pool with a volume of at least the runoff generated from a 25 mm rainfall event. Determining whether a forebay would be functional in each storm facility will be done during the design phase.

The adopted guiding principles for design are sensitive to the fact that a greater volume of runoff can be expected under post development conditions compared to pre-development conditions. That is, the duration of elevated discharge rates will be increased under post development conditions, and may increase the risk of erosion in the receiving watercourses. To remedy this, Low Impact Development (LID) will be encouraged and source control practices (SCP) will be implemented where practical, to reduce the total volume of stormwater runoff.

Future stormwater management facilities will be located to avoid wetlands disturbance. In circumstances where impacts to wetlands cannot be averted, the stormwater facilities will be constructed and operated to mimic the wetlands function or compensation approved by the provincial government will be provided.

By adopting the above-described best management practices, the impacts of the proposed development in the Wolf Creek watershed will have negligible impact on Battle River, both quantitatively and qualitatively. The runoff characteristics of the existing watercourses through the Wolf Creek watershed under post-development conditions will be similar to those under pre-development conditions, as demonstrated by the estimated hydrographs presented herein.

The design, construction, and implementation of operation plans of future stormwater management systems will need to be appropriately planned by addressing the relevant issues and design criteria presented herein.

Integral to the successful operation of the stormwater management system is the conveyance capacity of Wolf Creek and Whelp Brook channels. A maintenance program to remove flow impediments (such as deadfall, debris, beaverdams) is therefore an essential component of this plan.

It is recommended that this Master Drainage Plan be submitted to Alberta Environment and Sustainable Resource Development for approval.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

Agencies

AENV	Alberta Environment
AEP	Alberta Environmental Protection
AES	Atmospheric Environment Service Canada
ESRD	Alberta Environment and Sustainable Resource Development
WCWSC	Wolf Creek Watershed Study Committee
WSC	Water Survey of Canada

Terms

BMPs	Best Management Practices
DA	Drainage Area
HWL	High Water Level
Hwy	Highway
IDF	Intensity – Duration – Frequency
LID	Low Impact Development
MDP	Master Drainage Plan
PWL	Permanent Water Level
Q_d	Annual Maximum Daily Discharge
Q_i	Annual Maximum Instantaneous Discharge
Rge	Range
Rd	Road
SCP	Source Control Practices
t_p	time to peak
Twp	Township
URR	Unit Area Release Rate

Units of Measurement

ha	hectares
hr	hour
km^2	square kilometres
L/s/ha	litres per second per hectare
m	metres
m^3	cubic metres
m^3/s	cubic metres per second
mm	millimetres

1.0 INTRODUCTION

Wolf Creek and its major tributary Whelp Brook are the natural watercourses which drain significant portions of four municipalities: Lacombe County, Ponoka County, City of Lacombe, and Town of Blackfalds. Since the area was settled, efforts by individuals and government were made to improve drainage and reduce flooding (ESRD, 2013). Over the past few years, significant rainfall events and various types of development in the watershed have led to renewed concerns of local flooding and erosion expressed by the general public and the municipalities.

In 2012, the four municipalities formed the "Wolf Creek Watershed Study Committee" (WCWSC) to manage a coordinated effort for watercourse improvements and guidance for future development. To that end, the WCWSC retained MPE Engineering Ltd. (MPE) to prepare this Master Drainage Plan (MDP) for the Wolf Creek and Whelp Brook watersheds. The MDP addresses alleviating the current flooding, erosion, and drainage issues, while developing a conceptual drainage plan for future development, including recommended Best Management Practices (BMPs) for managing stormwater in the watershed.

1.1 Scope of Analysis

The primary objectives of this Master Drainage Plan Study are twofold:

- to determine the channel conveyance capacities, the capacity constraints, and their locations, of Wolf Creek and Whelp Brook.
- to produce a Master Drainage Plan for the Wolf Creek watershed which meets the requirements of WCWSC as well as Alberta Environment and Sustainable Resource Development (ESRD).

Specific tasks performed for the study include:

- Data and information compilation (reports, surveys, LiDAR, ESRD files review, internet searches).
- Hydrology analysis of the study area (compilation of recorded streamflow data, estimation of missing data, regional streamflow analysis, flood event hydrograph development).
- Fisheries habitat assessment (fisheries habitat types and quality at selected typical locations).
- Assessment of stormwater storage and stormwater quality requirements.

- Assessment of minor and major drainage systems for the 1:5 year and 1:100 year return period storm events, respectively.
- Development of a Master Drainage Plan.

The analyses were based on existing data and reports as well as site inspections performed during the study. This study is an aggregated assessment of the study area and does not include detailed assessment of individual subdivisions and lots. These will be assessed during the detailed design stage for each development project.

2.0 WATERSHED DESCRIPTION

As shown in Figure 1, the Wolf Creek watershed has a drainage area of 524 km^2, with its headwaters southeast of the City of Lacombe, and empties into the Battle River about 36 km to the north, near the Town of Ponoka. Located in the western portion of the Wolf Creek watershed, Whelp Brook is the largest subwatershed, having a drainage area of 307 km^2. The Town of Blackfalds is in the headwaters of Whelp Brook which empties into Wolf Creek about 30 km to the north.

The watershed lies within the Central Parkland natural subregion, on the boundary of the Western Alberta Plains and the Eastern Alberta Plains physiographic regions. The watershed contains well drained topography as well as shallow topographical relief containing numerous potholes, sloughs and shallow lakes characterized by poor drainage. Land use is predominantly agriculture with some natural areas and growing clusters of urbanization.

About 20 km of the main stem of Whelp Brook is about 3 km west of, and parallels, the main stem of Wolf Creek. Whelp Creek crosses Hwy QE2 twice, while Wolf Creek crosses Hwy QE2 four times and Hwy 2A once.

Wolf Creek and Whelp Brook have been identified as fish bearing from their mouths upstream to about 3 km north of the City of Lacombe (west and downstream of Hwy QE2). Any works in or near these designated reaches also require consideration of the fish habitat and approvals from regulatory agencies.

About 13 km of the main stem of Wolf Creek, from within the City of Lacombe to the boundary of Lacombe County and Ponoka County was channelized in the early 1980s and is maintained by the City of Lacombe under a *Water Act* approval. The City of Lacombe releases its treated wastewater into Wolf Creek.

2.1 Physiography

Within the Wolf Creek watershed, the elevation varies from 1000 m in the southeast to 805 m at the confluence with Battle River to the north. With the exception of Whelp Brook, tributaries of Wolf Creek generally flow westward with gradients up to about 1%. On the other hand, tributaries of Whelp Brook generally flow eastward with gradients also up to about 1%.

The mainstems of Wolf Creek and Whelp Brook for the most part parallel each other and flow northward. The upper reach of Wolf Creek, from Hwy 12 in the City of Lacombe to Hwy 604, the channel gradient averages a relative mild 0.06%. From Hwy 604 northward to the confluence of Whelp Brook, the gradient steepens to an average of 0.23%. The lower reach of Wolf Creek, from the confluence of Whelp Brook to Battle River, the gradient averages 0.15%. The channel gradient of Whelp Brook, from Twp Rd 41-0 to Twp Rd 41-2 averages a relatively mild 0.06%, and from Twp Rd 41-2 to the confluence with Wolf Creek averages 0.14%.

The watershed lies in the Black Soil Zone, with soils generally medium textured, including loams and silty loams. Contained within the Central Parkland sub-region, the watershed also has hummocky and ground moraines, and deposits of fine textured glaciolacustrine and coarse outwash (Alberta Agriculture, 2008).

2.2 Climate

The Wolf Creek watershed has a continental climate, with cool summers and cold winters. According to the 1971-2000 climate normals for Lacombe, the warmest daily average temperature of 15.4C occurs in July, and the coldest daily average temperature of -12.3 occurs in January. Total annual precipitation is 446 mm, 80% of which is rainfall. On average, the wettest month is July with almost 90 mm of rain. The average annual areal evaporation is 397 mm (AEP, 2001).

2.3 Wetlands

Wetlands exist within the Wolf Creek watershed; however, it does not appear that a comprehensive wetland inventory of the Wolf Creek watershed has yet been compiled, and it is beyond the scope of this study.

The overall development philosophy for the Wolf Creek watershed will follow the provincial guidelines and current policy. As such, disturbance to the wetlands will be avoided where possible, and mitigated where needed.

2.4 Land Use

Based on available data (Battle River Watershed Alliance, 2011, Alberta Agriculture, 2008), the watershed area is about 10% in natural or undisturbed condition, about 5% developed, and the remainder in agricultural production.

The majority of the developed area consists of the entire developed area (about 70% of the 20.89 km^2) of the City of Lacombe and a small portion (about 10% of the 16.36 km^2) of the Town of Blackfalds, and isolated areas consisting of Hamlets, light industrial areas adjacent to the urban areas, and a few subdivisions.

2.5 Existing Stormwater Management Systems

Currently, the only stormwater management systems in the Wolf Creek watershed are located within the City of Lacombe and the Town of Blackfalds, and in recently developed subdivisions outside these two centres. The majority of the urban areas have detention facilities which were designed to release flows at pre-development rates estimated at the time.

2.6 Proposed Developments

In the foreseeable future, development in the watershed will be limited to a few areas:

- City of Lacombe: about 8 km^2, limited to within the existing boundaries.
- Town of Blackfalds: about 5 km^2, within the existing boundaries, drains into the Whelp Brook watershed.
- Lacombe County: about 10 km^2, immediately west of the City of Lacombe and the Town of Blackfalds.
- Ponoka County: about 5 km^2, near existing Hamlets and subdivisions.

The total area for all the potential development over the next twenty years is estimated to be about 28 km^2, or about 5 % of the entire Wolf Creek watershed area.

3.0 STORMWATER MANAGEMENT CONSIDERATIONS

In designing and developing a stormwater management system, key factors need to be considered, including the effects of urbanization, stormwater management concepts and philosophy, and stormwater quality and enhancements. These are more fully addressed below.

3.1 Effects of Urbanization

As a consequence of urban development, both the volumes and rates of stormwater runoff are generally increased compared to previously natural watersheds. Runoff is increased when natural land surfaces are covered by impervious surfaces (buildings, roadways, parking lots), and when natural depressions are removed. Additionally, hydraulically efficient structural drainage systems such as storm sewers and ditches cause runoff to drain away faster (i.e. reduce the time of concentration of runoff).

3.2 Stormwater Management Concepts

The primary approach to control the runoff from urban development that discharges into natural watercourses, and endorsed in the ESRD "Stormwater Management Guidelines for the Province of Alberta", is the use of storage facilities to reduce the rates of runoff to allowable levels.

On-site storage of any type generally refers to storage of excess runoff within the development prior to its discharge into downstream drainage systems, with gradual (controlled) releases of the temporarily stored water after the peak of the runoff inflow has passed. Storage facilities alone do not reduce the total volume of runoff, but rather they redistribute the rate of runoff over a period of time. The types of on-site storage facilities include roof-top storage, depressions (trap lows) in parking lots and streets, and multi-purpose detention ponds. The latter can be either dry or wet storage, where wet storage is defined as maintaining a permanent water level in a pond.

Following ESRD Guidelines, stormwater management in the Wolf Creek watershed will be comprised of the following concepts.

Minor systems

- ESRD Guidelines state that generally the minor system should be designed to convey the 1:5 year design flow. To meet these guidelines, design details such as trap lows may be required for areas with large percentage of impervious area (e.g. commercial areas) while maintaining the ESRD guidelines for overland flows (major system) shown in Table 3.1.

- Consist of storm sewers, manholes, and catch basins.
- Direct flows to stormwater facilities for peak flow attenuation and water quality enhancement prior to release.

Major systems

- Accommodate all runoff in excess of the minor system capacity.
- Designed to safely convey runoff resulting from a storm event up to 1:100 year return period, without causing flooding damage to homes and property.
- Consist of curbed or ditched streets, pathways, ditches/swales, and other overland flow paths as well as existing watercourses, and stormwater facilities.
- ESRD guidelines require that the following criteria are met for the major system:
  - Depths and velocities of runoff flows on streets shall be within acceptable limits, as shown in Table 3.1.

Table 3.1: Depth – Velocity Criteria for Overland Flow

Flow Depth (m)	Maximum Flow Velocity (m/s)
0.80	0.5
0.32	1.0
0.21	2.0
0.09	3.0

  - Depth of flow in streets must not exceed 0.3 m.
  - Depths of standing (ponding) water in streets must not exceed 0.5 m.

  Final design will ensure these requirements will be met.
- Conventional design criteria for a typical storm pond, from ESRD guidelines, are presented in Table 3.2.

Table 3.2: Stormwater Pond Design Criteria

Parameter	Criteria
Side Slopes	5H:1V (inside) 3H:1V (outside)
Permanent Water Depth	2.5 m recommended (2.0 m minimum)
Active Water Depth	2.0 m (maximum) above permanent water level (PWL)
Freeboard	0.3 m (minimum) above high water level (HWL)
Berm Width	3.0 m minimum, 5.0 m preferred

- Where feasible, stormwater wet ponds will be constructed to provide peak flow attenuation and water quality treatment. These constructed ponds:
  - Will be located considering the location, type, and areal extents of each development.
  - Will have two primary components: a permanent pool with a volume equivalent to a runoff from a 25 mm rainfall, and an active volume capable of detaining up to a 1:100 year runoff event while maintaining a maximum allowable release rate.
  - the permanent pool will be maintained through natural runoff.
  - in some instances, natural wetlands may receive additional runoff volumes; additional regulatory approvals will be required.
- Released runoff will continue to be routed through the natural watercourses.

Low Impact Development practices

- will be adopted where feasible in conjunction with conventional stormwater management practices. Appendix E contains information on LID practices.

3.3 Stormwater Quality Requirements and Enhancement

Stormwater management facilities will be constructed to enhance stormwater quality. ESRD has stormwater quality enhancement requirements for all developments that drain directly or indirectly into a watercourse. Currently, specifications require that 85% of the sediment loading greater than 75 µm from a development area must be removed prior to discharge. This standard applies here because the receiving watercourse will be Wolf Creek, Whelp Brook, and any of their tributaries.

Upon entering these facilities, flow velocities of runoff will be reduced, which causes silt to be deposited in the facilities and thereby reduces the degree of potential water quality impacts downstream.

These types of ponds are most effective in enhancing stormwater quality for the more frequent (e.g., less than 1:2 year) runoff events which convey the greatest overall volume of pollutants. This effectiveness occurs because these relatively frequent rainfall events produce relatively lower runoff volumes and consequently less surcharge and water depth in the stormwater pond.

Regardless of stormwater pond type, there is a maintenance requirement to periodically remove accumulated sediment, to maintain operating efficiency of the pond.

3.4 Low Impact Development Techniques

To reduce the increased rate and volume of runoff generally produced by development, there are techniques which can be incorporated in the design and construction of developments at the local level. The suite of these techniques is commonly referred to as 'Low Impact Development' (LID). Adoption and implementation of one or more of these techniques has the added benefits of:

- potentially reducing the required capacities of stormwater detention facilities and conveyance structures,
- promoting the recharging of aquifers,
- protecting riparian and wetland areas, and
- maintaining and improving the aquatic health of water bodies.

The suite of techniques includes, but is not limited to:

- green roofs (e.g., vegetation, precipitation storage)
- rainfall capture and re-use (e.g., rain barrels)
- conservation landscaping (e.g., flora species, location, soil preparation)
- bioretention and rain gardens (e.g., improved infiltration and enhanced evopotranspiration)

- end-of-pipe enhancements (e.g., reduced capacity requirements in association with the other LID techniques)

Details of LID techniques and further discussion are provided in Appendix E.

4.0 METHODOLOGY

To establish the design criteria of the Wolf Creek watershed stormwater systems, the runoff characteristics under pre-development conditions must be determined. The estimated peak flow rates are used as a basis for establishing the allowable discharge rates from future stormwater systems under post-development conditions, and the routing of representative subwatershed hydrographs through the study area provide a means to establish the impacts of adopted stormwater management practices on Wolf Creek, Whelp Brook, and the downstream receiving watercourse, Battle River.

4.1 Pre-Development Flow Rates

Ideally, pre-development flow rates in the Wolf Creek subwatersheds would be determined from long-term records of streamflows in the watershed. However, available streamflow records in the watershed are limited to:

- three partial years (2007-2009) on Wolf Creek at Twp Rd 41-0 (Water Survey of Canada streamflow gauging station 05FA026),
- five partial years (2008-2012) on a Whelp Brook tributary (Alberta Agriculture and Rural Development research project Site 301).

Because these data are insufficient to determine reliable estimates of peak flow rates for various return periods, a regional analysis was performed with data of nearby streamflow gauging stations which were hydrologically similar and with an adequate period of record:

- 05CC011, Waskasoo Creek at Red Deer, DA=487 km^2, 27 years of record (1985-2011)
- 05CD006, Haynes Creek near Haynes, DA=165 km^2, 33 years of record (1979-2011)
- 05CD007, Parlby Creek at Alix, DA=511 km^2, 28 years of record (1984-2011)
- 05FA102, Pipestone Creek near Wetaskiwin, DA=1030 km^2, 40 years of record (1972-2011)
- 05FA014, Maskwa Creek No. 1 above Bearhills Lake, DA=79.1 km^2, 39 years of record (1973-2010)
- 05FA024, Weiller Creek near Wetaskiwin, DA=236 km^2, 20 years of record (1985-2011)

Of the statistical distributions applied to the data, the 3 Parameter log-Normal distribution provided the best fit for all stations. From these results, regression analysis was performed to determine discharge to drainage area relationships for selected return periods. The resulting equations used to estimate discharges in Wolf Creek subwatersheds are presented in Table 4.1, and a summary of the results is presented in Table 4.2.

Table 4.1: Drainage Area – Discharge Equations

Return Period	Maximum Instantaneous Discharge, Q_i, m^3/s
1:2 year	$Q = 0.0055 \times DA^{1.1293}$
1:5 year	$Q = 0.0340 \times DA^{0.9631}$
1:10 year	$Q = 0.0922 \times DA^{0.8657}$
1:20 year	$Q = 0.2080 \times DA^{0.7866}$
1:50 year	$Q = 0.5319 \times DA^{0.6930}$
1:100 year	$Q = 0.9869 \times DA^{0.6315}$

Table 4.2: Estimated Discharge Rates for Wolf Creek Subwatersheds

	Estimated Discharges for Wolf Creek Subwatersheds, m^3/s										
	Wolf Creek					Whelp Brook					Wolf Ck
	Hwy 2A	Twp Rd 41-2	Twp Rd 41-4	Hwy 604	above Whelp Bk	Twp Rd 41-0	Twp Rd 41-2	Twp Rd 41-4	Hwy 604	above Wolf Ck	at Battle R
Total Drainage Area, km^2	78	99	119	151	156	87	151	166	190	311	524
1:2	0.75	0.99	1.21	1.59	1.65	0.85	1.59	1.77	2.06	3.59	6.48
1:5	2.26	2.84	3.39	4.27	4.40	2.51	4.27	4.67	5.32	8.56	14.14
1:10	4.01	4.92	5.77	7.10	7.30	4.40	7.10	7.70	8.66	13.27	20.84
1:20	6.40	7.72	8.93	10.77	11.05	6.98	10.77	11.60	12.90	19.01	28.65
1:50	10.89	12.85	14.59	17.21	17.61	11.75	17.21	18.38	20.18	28.40	40.77
1:100	**15.46**	**17.97**	**20.18**	**23.46**	**23.95**	**16.56**	**23.46**	**24.90**	**27.12**	**37.02**	**51.47**

The resulting estimated 1:100 year pre-development unit runoff rate varied from 2 L/s/ha for the smaller watersheds to 1 L/s/ha for Wolf Creek at Battle River. The runoff rates reducing as drainage area increase suggests significant routing effects (temporary channel and overbank storage) are occurring along the channel. Details of the analysis are provided in Appendix C.

4.2 Pre-Development Hydrographs

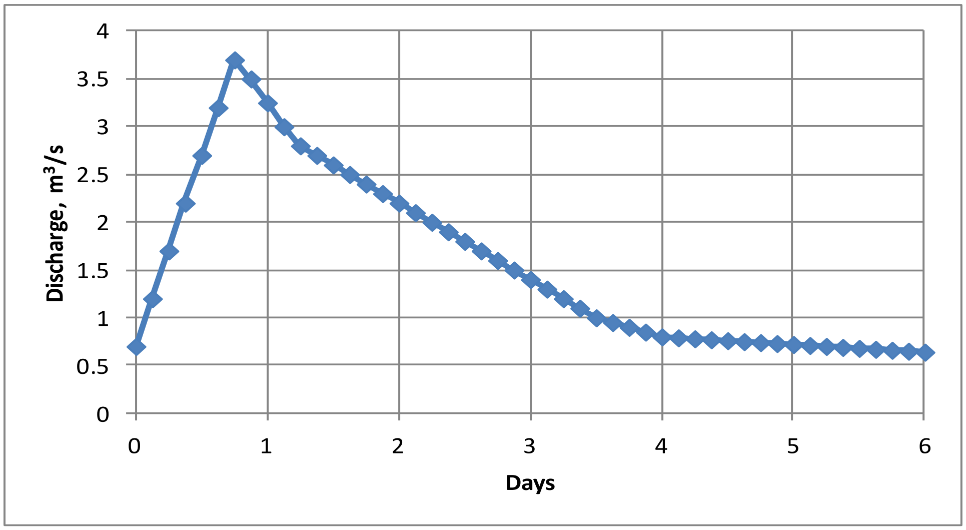
To establish pre-development flow characteristics in the Wolf Creek watershed, the following steps were performed:

- Produce representative hydrographs for the Wolf Creek watershed.
- Route the subwatershed hydrographs through Wolf Creek and Whelp Brook using the HEC-RAS model to determine the pre-development hydrograph at the Wolf Creek outlet.

For this study, subwatershed boundaries were established at easily identifiable locations such as at Township Roads and Highways, as well as at the confluences of Whelp Brook and Wolf Creek, and at the outlet of Wolf Creek into Battle River. The subwatersheds are delineated in Figure 2.

Because each Wolf Creek subwatershed is not gauged, their representative hydrographs were estimated from limited available historic data in the watershed. A review of the data revealed a single event which was acceptable for developing a representative unit hydrograph for all subwatersheds. This event occurred in July 26 to July 31, 2011 at the Alberta Agriculture research Site #301 (drainage area = 47 km^2) in the Whelp Brook subwatershed, the hydrograph of which is presented in Chart 4.1. A unit hydrographs was then calculated, preserving the characteristics (e.g., time to peak, duration of flow) of the original hydrograph. The 1:100 year flood event hydrographs for each identified subwatershed were then calculated using 2 L/s/ha to determine peak flowrates. Appendices C and D provides details of the analysis.

Chart 4.1: Whelp Brook Site #301 Hydrograph of July 26-31, 2011



4.3 Post Development Conditions

To determine the design requirements for post-development conditions, and to determine the resulting impact of development on flows in the Wolf Creek watershed, the following steps were performed:

- Estimate the hydrographs under post-development conditions of subwatersheds where future development is expected.
- Route the post-development conditions scenario through the HEC-RAS model.
- Compare the pre-development and post-development hydrographs at the Wolf Creek outlet.
- Compare the Wolf Creek outlet hydrographs with flows in the Battle River.

Details of the analysis are provided in Appendix D. Overall results of the post-development modelling are discussed in Section 5.

4.4 Channel Capacity

Because some sections of Wolf Creek and Whelp Brook channels are prone to flooding, consideration should be given to managing runoff rates to minimize downstream flooding and to improving channel conveyance capacity. To determine channel capacities and identify which sections are susceptible to flooding and whether any structures exist which may be limiting conveyance capacity, a HEC-RAS model, with more than 200 cross-sections representing the Wolf Creek and Whelp Brook channels in the study area, was developed. Using the steady (constant) flow rates shown on Table 4.2, capacities of channel reaches and structures were established.

The methodology is more fully described in Appendix D, with results presented and discussed in Section 5.

5.0 RESULTS

To manage stormwater for future development in the Wolf Creek watershed which meet ESRD guidelines, how minor and major systems including stormwater ponds, as well as LIDs and channel conveyance requirements will be incorporated into the stormwater management design, are discussed. The foreseen degree of impact to the Battle River is also discussed.

5.1 Allowable Unit Release Rate

The allowable unit release rate is derived from the estimated pre-development flow rates for the 1:100 year flood event. For the Wolf Creek watershed, the allowable unit release rate is estimated to be 2 L/s/ha. In comparison, allowable unit release rates for nearby municipalities and recently approved by ESRD are:

- 2.5 L/s/ha - Ponoka
- 2.6 L/s/ha – Sylvan Lake
- 3.0 L/s/ha – Red Deer
- 3.1 L/s/ha – TES Subdivision, Lacombe County
- 5.0 L/s/ha – County of Red Deer
- 6.0 L/s/ha – Blackfalds

Comparatively, the Wolf Creek watershed has a relatively low allowable unit release rate. This is not unexpected, considering the hydrology of the watershed and hydraulic characteristics of the main channels.

5.2 Minor and Major Systems

The minor system throughout the Wolf Creek watershed will convey stormwater through a pipe network adequately sized for relatively frequent runoff events, as described in Section 4.2. Minor systems will drain into storm ponds for appropriate peak flow attenuation and adequate water quality treatment prior to release to the receiving stream.

The major system throughout the Wolf Creek watershed will convey all stormwater runoff in excess of the capacity of the minor system. The major system will be comprised of:

- surface flow on roadways, following ESRD Guidelines for velocity-depth criteria (Table 3.1)

- open ditches and watercourses
- stormwater facilities

5.3 Stormwater Ponds

The stormwater facilities will be constructed as wet ponds in accordance with ESRD guidelines. Because the design of individual stormwater facilities depends on site specific conditions, the design details will be provided by others. These facilities will be constructed when development occurs.

5.4 Impacts to Wetlands

The overall development philosophy of the Wolf Creek watershed is to maintain the natural landscape features of the area. As such, disturbance to the wetlands will be avoided where possible, and mitigated where needed. In some instances, wetlands may become integral to the overall stormwater treatment process, In other instances where circumstances allow, wetlands will be designed to treat runoff to ESRD acceptable standards and constructed. While these ponds will continue to treat runoff similarly to the natural wetlands, and have the 'look' of wetlands in the area, they will be modified from the natural versions of the wetlands.

Other wetlands will likely be impacted as developed proceeds. Current knowledge suggests constructed wetlands cannot be made to function as natural wetlands. As a result, any mitigation of lost wetlands may also involve alternate forms of mitigation such as constructing aquatic habitat, enhancing riparian vegetation, and education. As development progresses, discussions with the appropriate regulatory agencies are recommended to ensure the current wetland policies and related regulations are followed, and adequate wetlands mitigation or compensation occurs.

5.5 Impacts to Battle River

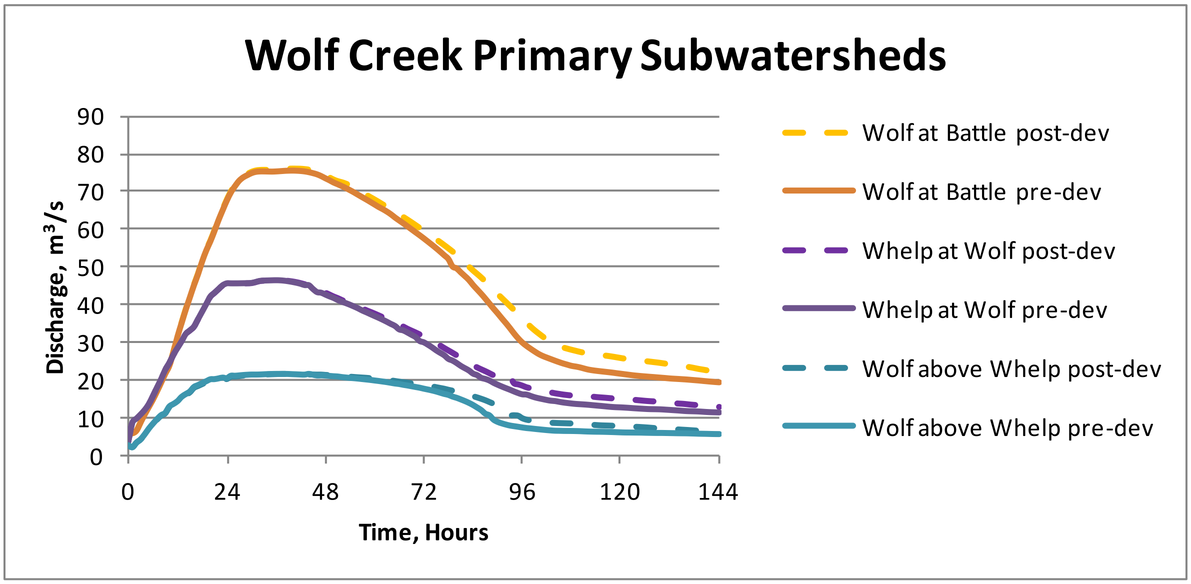
The Battle River has a shallow gradient and is subject to overbank flooding. As well, the Town of Ponoka is about 5 km downstream of Wolf Creek. As such, impacts from Wolf Creek stormwater runoff, both in quantity and quality, to Battle River have been considered. To minimize downstream impacts, appropriate design of proposed stormwater management facilities must incorporate the elements described herein.

The degree to which Battle River will be impacted from a water quantity perspective in terms of flow rates and timing is demonstrated by comparing the estimated 1:100 year pre-development to the corresponding post-development hydrographs of Wolf Creek, and then comparing these flows with the Battle River flows. The Wolf Creek hydrographs are shown in Chart 5.1; their development is described in Appendix D. As can be seen, the Wolf Creek hydrograph under post development conditions is very similar to pre-development conditions.

Under pre-development and post-development conditions, the 1:100 year peak runoff rate from Wolf Creek is less than 20 % of the peak flow of 452 m^3/s in Battle River. For the 2 L/s/ha scenario, there is no incremental increase of peak flows. (In comparison, for the 5 L/s/ha scenario, the *incremental* increase in peak flow is about 1% of Battle River peak flow.) This leads to the conclusion that the impact on Battle River from a quantity perspective may be considered to be negligible.

From a water quality perspective, the impact on Battle River is expected to be minimal if not negligible considering ESRD Guidelines will be met or exceeded with the construction and operation of the stormwater facilities and the adoption of LID practices.

Chart 5.1: Comparison of Pre-development and Post-development 1:100 year Flood Hydrographs For 2 L/s/ha Release Rate



5.6 Low Impact Development

Low Impact Development (LID) involves applying source control measures (such as rain gardens, additional topsoil depth, grass swales, etc.) on a site level basis. These source controls, when properly designed, provide additional reduction of the runoff peak flow and volume from the site, as well as reduce sedimentation and other pollutants from leaving the site. During the design of future development phases, the implementation of these source control practices will be encouraged, where practical.

5.7 Road Crossings and Channel Capacity Improvements

Several road crossings exist along Wolf Creek and Whelp Brook. The local crossings were designed for at least the 1:20 year flood event, while the major crossings (i.e. primary highways) were designed for the equivalent of at least the 1:50 year flood event. For any rare flood events (e.g., greater than the 1:100 year flood event), these crossings would cause some *incremental* local backflooding, considering that the floodplain would be inundated whether or not the crossing existed. The backflooding locations are shown in Figure 3.

In instances where an increase in conveyance capacity is required, consideration should be given to channel longterm stability, available right-of-way width, impacts to riparian areas, and cost. A typical improved channel cross-section is presented in Figure 4. Features of this cross-section include:

- A primary channel, which provides efficient conveyance of low flow and sufficient depths for fish during low flow conditions.
- A secondary channel which provides efficient conveyance of high flow and habitat cover opportunities for fish.

To mimic natural conditions, the plan layout of constructed channels should incorporate meanders, and the primary channel should also meander within the secondary channel where practical. Layout design and channel dimensions will depend on factors such as available right-of-way width, topography, and channel gradient. Final design should also consider:

- No reduction of overbank storage, so peak flows are not increased downstream.
- The impact to fisheries habitat; the fisheries assessment in Appendix B provides guidance on existing conditions, appropriate habitat loss prevention measures, and mitigation measures.
- These channel modifications will require regulatory approval(s) including under the *Water Act*.

5.8 Channel Clearing

As development increases in the watershed, it is essential to maintain the conveyance capacity of the Wolf Creek and Whelp Brook mainstem channels so that adjacent lands are not adversely impacted. Under the current *Water Act,* approval is *not* required if the channel maintenance falls under all the following criteria:

- only debris (e.g., woody and plant debris including beaverdams, and man-made items) is removed from the watercourse;
- equipment (machinery) or vehicles do not enter the water;
- the removal of debris will not alter the bed and shore of the watercourse;
- the removal of debris will not include alteration or excavation of the bed and shore of the water body;
- all access permissions are acquired;
- the removed debris is moved to a location where it will not re-enter any water body; and
- the removal of debris will not result in a significant downstream erosion.

These criteria are included in this Master Drainage Plan, so on approval, the ability to conduct channel maintenance is assured. It should be noted that approval of this Master Drainage Plan under the *Water Act* does *not* infer approval under any other legislation.

6.0 STORMWATER MANAGEMENT PLANNING FOR DEVELOPMENTS

The owners of future development in the watershed will be responsible for providing appropriate design of stormwater management facilities and complementary LID where feasible. The issues and criteria to be addressed include, but not limited to:

Regulatory Requirements

- Municipal development permit
- Provincial
  - Current ESRD stormwater management standards and guidelines
  - Wetlands policy
  - Outfall Code of Practice
  - Water Act
  - Environmental Protection and Enhancement Act
  - Public Lands Act
- Federal
  - Fisheries Act
  - Navigable Waters Protection Act
  - Migratory Birds Act

Design Criteria

- Allowable unit release rate of 2 l/s/ha.
- Impact on receiving watercourse and downstream development to be minimized.

Stormwater Management Components

- Types and locations of stormwater facilities.
- Adoption of LID and source control practices.
- Impact of LID and source control practices on sizing of conventional stormwater facilities.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This Master Drainage Plan (MDP) addresses the current and future stormwater management design criteria and facility requirements for the Wolf Creek watershed. This includes determining the allowable discharge rates from all future facilities to limit post development release rates to pre-development rates, as well as providing adequate storage and treatment to stormwater flows before being discharged into Wolf Creek and eventually into the Battle River.

Major and Minor Systems

Stormwater runoff from future developments will be conveyed in either the minor system or the major system, as required in the ESRD Stormwater Management Guidelines (AEP, 1999). The minor storm flows will be conveyed primarily through a buried pipe system with a capacity of the pre-development 1:5 year storm event flow. The major storm system will be conveyed through a combination of curbed or ditched streets as well as the existing watercourses. All stormwater flows from the developed areas will be routed through stormwater facilities before being discharged into Wolf Creek, Whelp Brook, or any of their tributaries.

Stormwater Systems Modelling

Modelling of future stormwater systems and stormwater facilities can be completed using single event analysis (e.g., SWMHYMO) and continuous event modelling (e.g., QHM), to determine required sizing of stormwater facilities to meet the approved allowable release rates.

Stormwater Facilities

Future stormwater facilities in the Wolf Creek watershed will depend on location, size, type, ownership, and duration of construction to completion of development. As such, the specific locations and required footprints of stormwater facilities are not provided herein; however, general criteria to be considered when locating such facilities include:

- At or near the outlet of a development, or prior to entering the receiving watercourse.
- One large detention facility or pond complex is preferable over numerous small stormwater ponds for individual developments because a permanent pool can then be established, which provides improved water quality treatment, and can be a public and environmental amenity.

- Incorporation of a natural wetland in the system, if allowed, can further improve water quality treatment.

All stormwater facilities will be designed for quality and quantity treatment as required in the ESRD guidelines:

- Each stormwater pond is to be sized to meet current regulatory requirements (e.g., current standards require removal of 85% of the sediment loading (greater than 75 µm) from the developed areas prior to release.
- Where feasible, each pond will also contain a permanent pool with a volume of the runoff generated from a 25 mm rainfall event.
- The recommended allowable unit release rate for this Master Drainage Plan is 2 L/s/ha.

Impacts to Wetlands

There are wetlands scattered throughout the Wolf Creek watershed. For the identified areas of future development, some wetland areas may be impacted; however, constructed stormwater facilities will be constructed and operated to mimic the wetlands function. Any required additional mitigation or compensation will be incorporated during the planning phases of future development.

Impacts to Battle River

The runoff characteristics of the existing watercourses in the Wolf Creek watershed under post development conditions will be similar to those under pre-development conditions, as demonstrated by the estimated hydrographs presented in Section 5.4. As shown, the impacts from the expected future development in the watershed will have negligible impact to Battle River, both quantitatively and qualitatively.

Low Impact Development

The implementation of source controls throughout the developed area is recommended. This will decrease runoff peak flow as well as the total runoff volume, and reduce sedimentation and pollutants from leaving the site. As an added benefit, the minimum active storage volumes of stormwater management facilities may be reduced where appropriate and practical source controls (LIDs) are implemented.

Channel Maintenance Approval

Integral to the successful operation of the stormwater management system is the conveyance capacity of Wolf Creek and Whelp Brook channels. A maintenance program to remove flow impediments (such as deadfall, debris, beaverdams) is therefore an essential component of this plan. The degree of maintenance will be determined considering the potential impact on fisheries habitat. The fisheries assessment in Appendix B provides guidance on existing conditions, appropriate habitat loss prevention measures, and mitigation measures.

Inclusion of the channel maintenance program as described herein, with this Master Drainage Plan, provides an efficient and long term means to allow this activity under the *Water Act*.

Final Design

It should be noted that during final design of stormwater management facilities, any details presented herein may be modified or changed as further information and data become available. While exact locations and sizes of pipes and ponds will be designed in the future, their intended functions will remain as described herein.

Alberta Environment and Sustainable Resource Development Approval

It is recommended that this Master Drainage Plan be submitted to Alberta Environment and Sustainable Resource Development for approval under the *Water Act*.

8.0 REFERENCES

Alberta Agriculture and Rural Development, 2012. Recorded streamflows for research project Site 301.

Alberta Environment, 2006. "Standards and Guidelines for Municipal Waterworks, Wastewater & Stormwater Drainage Systems", January 2006.

Alberta Environment, 1988. "Regional Runoff Characteristics Red Deer River Basin", Hydrology Branch, February, 1988.

Alberta Environment, 1992(a). "Flood Frequency Analysis Lacombe Floodplain Study", DRAFT, Hydrology Branch, December, 1992.

Alberta Environment, 1992(b). "Flood Frequency Analysis Ponoka Floodplain Study", by Mustapha, A. M., and De Boer, A., Hydrology Branch, Technical Services Division, March 1992.

Alberta Environment and Sustainable Resource Development, 2014. "Southern Alberta pre-development release rates" email by Andrew Patton, April 30, 2014.

Alberta Environment and Sustainable Resource Development, 2013(a). Various *Water Act* files for Wolf Creek and Whelp Brook.

Alberta Environment and Sustainable Resource Development, 2013(b). Preliminary 2013 streamflows for various streamflow gauging stations.

Alberta Environment and Sustainable Resource Development, circa 2011(a). "Water Act: Approvals" Fact Sheet.

Alberta Environment and Sustainable Resource Development, circa 2011(b). "Spring Run-off Flood Prevention" Fact Sheet.

Alberta Environmental Protection, 1996. "Lacombe Flood Risk Mapping Study", River Engineering Branch, June, 1996.

Alberta Environmental Protection, 2001. "Evaporation and Evapotranspiration in Alberta", by C. Abraham, Water Sciences Branch, January, 1999, datasets extended in 2001.

Battle River Watershed Alliance, 2011. "State of the Battle River and Sounding Creek Watersheds Report".
http://www.battleriverwatershed.ca/sites/default/files/Battle%20River%20Watershed%20Report.Web_.pdf

Environment Canada, 2014. "Climate Normals 1971-2000 Lacombe CDA."
http://climate.weather.gc.ca/climate_normals/results_e.html?stnID=2106&prov=&lang=e&dCode=4&dispBack=1&StationName=lacombe&SearchType=Contains&province=ALL&provBut=&month1=0&month2=12

Hydrotech Consulting Ltd. and B.K. Hydrology Service, 1994. "Ponoka Flood Risk Mapping Study", for Alberta Environmental Protection, River Engineering Branch, October, 1994.

Palliser Environmental Services Ltd., 2013. "Fisheries Assessment of Wolf Creek and Whelp Brook, Master Drainage Plan", prepared for Lacombe County, City of Lacombe, Ponoka County and Town of Blackfalds, November, 2013.

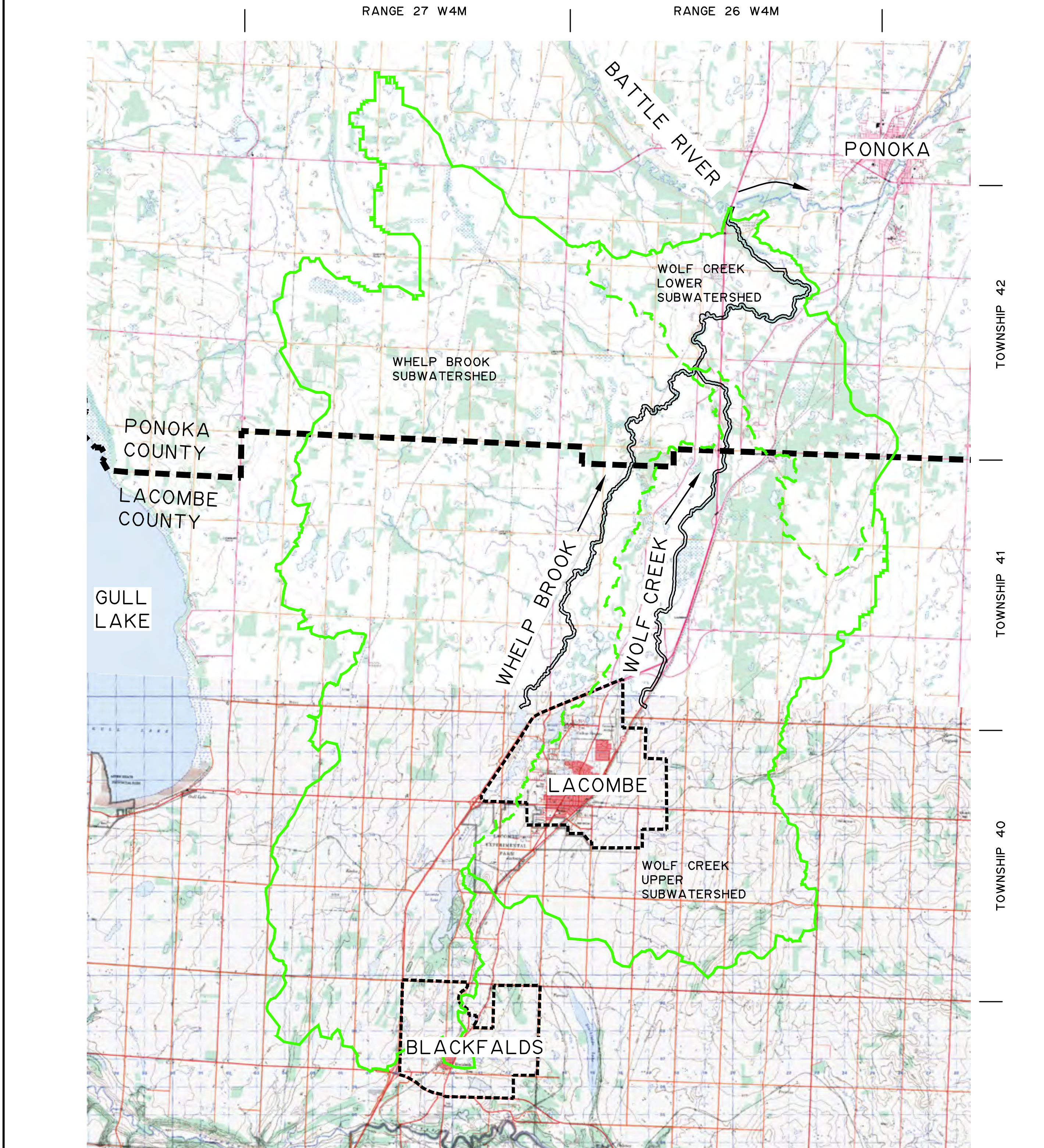
Province of Alberta, 2000. "Water Act Revised Statutes of Alberta 2000, Chapter W-3".

U.S. Army Corps of Engineers, 2010. "HEC-RAS User's Manual", Hydrologic Engineering Center, January, 2010.

Water Survey of Canada, 2013. Historic streamflow records for selected streamflow gauging stations.

APPENDIX A

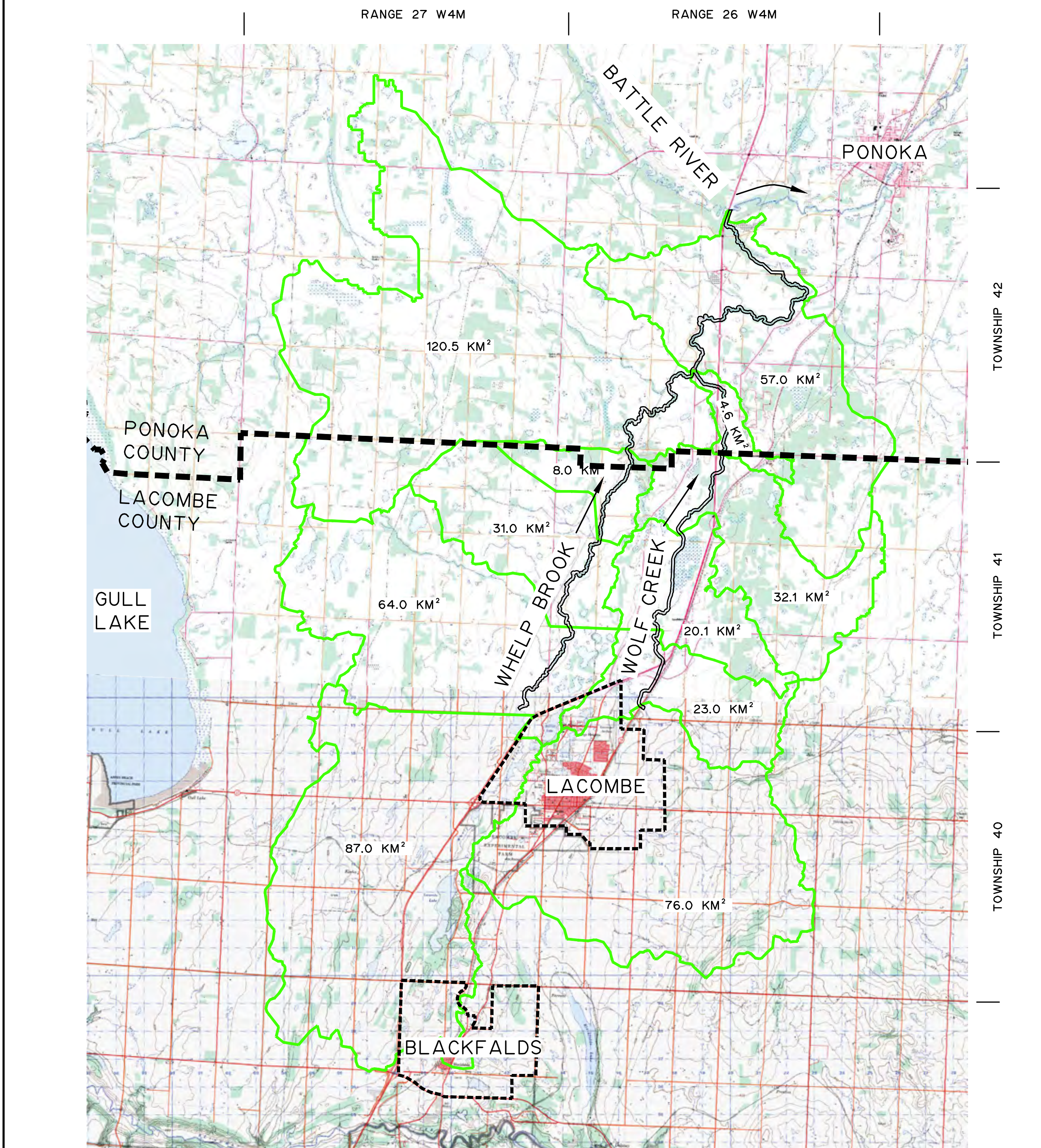
FIGURES



MPE Engineering Ltd.

LACOMBE COUNTY	
WOLF CREEK AND WHELP BROOK LOCATION PLAN	

SCALE: 1:200 000	DATE: JANUARY 2014	JOB: 4210-014-00	FIGURE: 1

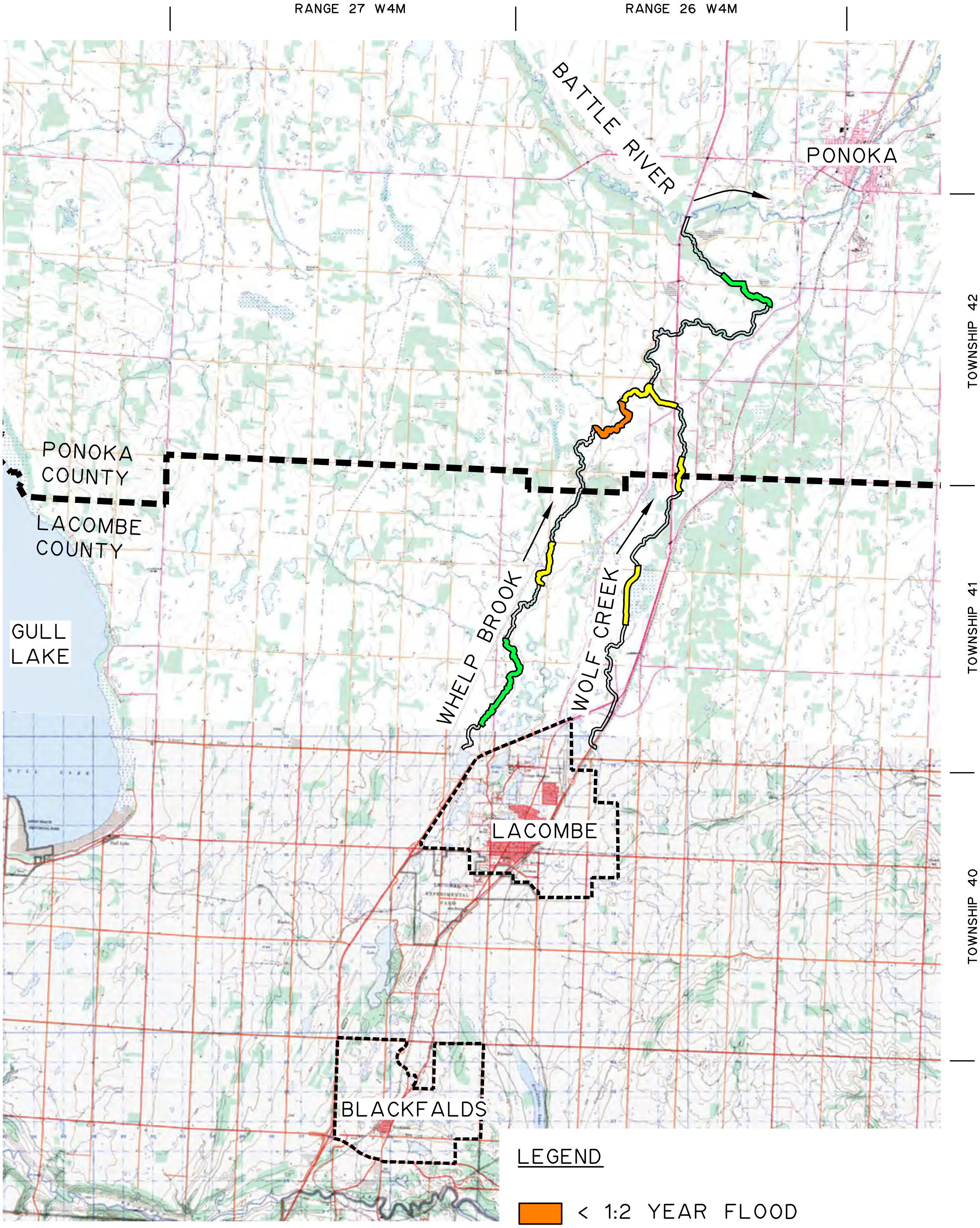


Engineering Ltd.

LACOMBE COUNTY

WOLF CREEK AND WHELP BROOK SUBWATERSHED BOUNDARIES

SCALE: 1:200 000	DATE: JANUARY 2014	JOB: 4210-014-00	FIGURE: 2



LEGEND

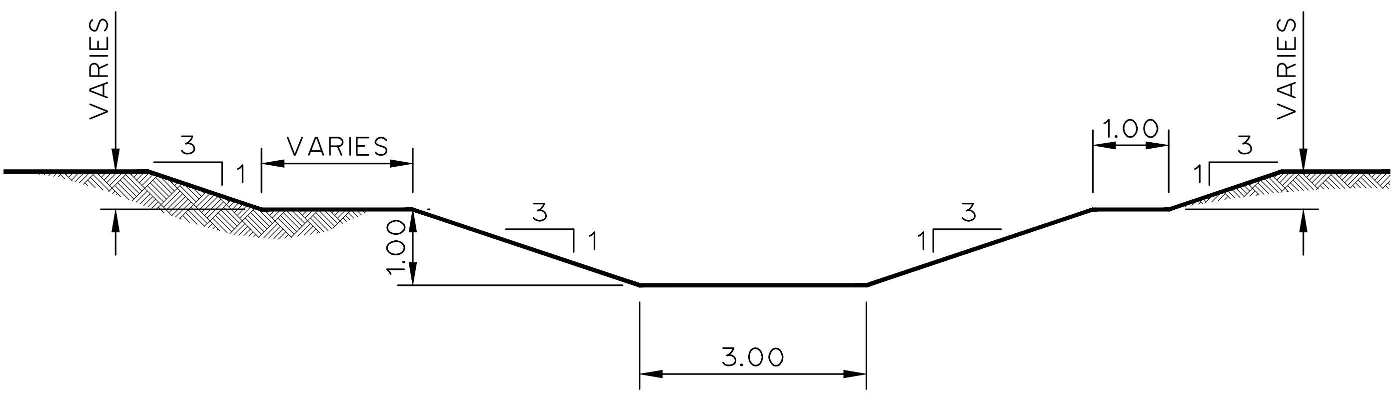
- < 1:2 YEAR FLOOD
- BETWEEN 1:2 AND 1:5 YEAR FLOOD
- BETWEEN 1:5 AND 1:10 YEAR FLOOD

MPE Engineering Ltd.

LACOMBE COUNTY

WOLF CREEK AND WHELP BROOK
AREAS PRONE TO FLOODING

SCALE: 1:200 000	DATE: JANUARY 2014	JOB: 4210-014-00	FIGURE: 3



MPE Engineering Ltd.	LACOMBE COUNTY
	WOLF CREEK AND WHELP BROOK TYPICAL IMPROVED CHANNEL CROSS SECTION

SCALE: 1:100	DATE: JANUARY 2014	JOB: 4210-014-00	FIGURE: 4

APPENDIX B

FISHERIES HABITAT ASSESSMENT REPORT
BY PALLISER ENVIRONMENTAL SERVICES LTD., 2013

Palliser Environmental Services Ltd.

FISHERIES ASSESSMENT OF WOLF CREEK AND WHELP BROOK, MASTER DRAINAGE PLAN

Prepared for:
Lacombe County, City of Lacombe, Ponoka County and Town of Blackfalds

November 2013

BOX 94, MOSSLEIGH
ALBERTA, T0L 1P0

INTRODUCTION

MPE Engineering Ltd. on behalf of Lacombe County, City of Lacombe, Ponoka County and the Town of Blackfalds is preparing a Master Drainage Plan for the Wolf Creek and Whelp Brook watersheds. Over the past few years, significant rainfall events and various types of development in the watershed have led to renewed concerns of local flooding and erosion expressed by the general public and the municipalities. This has led to the requirement for a Master Drainage Plan.

Palliser Environmental Services Ltd. was retained by MPE Engineering Ltd. to conduct an assessment of Wolf Creek and Whelp Brook with regards to fisheries and aquatic habitat. Wolf Creek has been identified as a Class C waterbody[1] by Alberta Environment and Sustainable Resource Development (ESRD) from its mouth, upstream for approximately 26 km to a point approximately 6 km northeast of the city of Lacombe. Whelp Brook has been identified as a Class C waterbody by ESRD from its mouths upstream for approximately 18 km to the northern boundary of the city of Lacombe. Any works in or near these areas of Wolf Creek or Whelp Brook will require consideration of the fish habitat and may require approvals from regulatory agencies. Field data (e.g., fish sampling, habitat mapping) from this study would be used to support regulatory submissions to Fisheries and Oceans Canada (DFO) and Alberta Environment and Sustainable Resource Development should instream construction/modification be proposed at either creek.

METHODS

A fisheries assessment was completed at three Wolf Creek sites (Sites 1 to 3) and three Whelp Brook sites (Sites 4 to 6) from August 6th to 8th, 2013 (Figure 1). The six sites were chosen based on the preliminary results of an assessment by MPE Engineering Ltd. which identified the sites as having the potential to provide nominal additional conveyance capacity.

At each site, a 300 to 330 m reach was assessed. The site was mapped to show features such as substrate, channel units (e.g., riffle and pool), aquatic vegetation and instream cover (e.g., boulders, logs) and riparian vegetation. Photographs were taken of representative sections of the study area. Three to four cross-section transects were completed at each site to measure wetted width, channel width, bankfull width and depth, water depth and velocity, substrate composition, bank stability, bank slope, bank height, bank composition and vegetation cover. Water quality was measured for pH using a Hanna® pHep4 pen (Model 98127). Conductivity (µS/cm) and total dissolved solids (mg/L) were measured using a Hanna® DiST pen (Model 98311). Dissolved oxygen (mg/L), oxygen saturation (%) and water temperature (^{o}C) were measured using a daily-calibrated YSI® Model 55 oxygen meter. Where flow was present, a discharge (m^3/s) was calculated using a Swoffer® Model 2100 velocity meter using the velocity-area method.

Where appropriate, fish sampling was completed at each site using a Smith-Root® Model 20 backpack electrofisher (battery-powered). Fish were sampled by electrofishing all available

[1] Class C watercourse: Moderate sensitivity; habitat areas are sensitive enough to be potentially damaged by unconfined or unrestricted activities within a water body; broadly distributed habitats supporting local fish species populations (AENV 2000).

habitat types. Four to six minnow traps (Gee style) baited with hard dog food kibbles were set along the shoreline of each site overnight in water depths ranging from 0.2 to 1 m. At sites where conditions were ideal (open water, low instream debris), a small seine net (6 mm Ace mesh, 1.8 m D x 10.1 m L) was dragged through the water column to capture small fish. All captured fish were held in 20 L pails for a short duration, identified to species, measured for length (sub-set) and returned to the creek.

A review of historical fisheries and water quality data was completed to supplement the information and data collected during this study. Historical fish capture data from the FWMIS online database (Fisheries and Wildlife Management Information System) (http://xnet.env.gov.ab.ca/imf/imf.jsp?site=fw_mis_pub) was used to supplement the fish capture data from this study. Additional fisheries and water quality data was obtained from Christiansen (1977). The online 'Inventory of Sampling Locations and Water Quality Data' (Environment and Sustainable Resource Development: ESRD) was searched for water quality data related to Wolf Creek or Whelp Brook. A request was made to ESRD-Enterprise Data and Information Management for water quality data collected at Wolf Creek in 1984 and 1990.

GENERAL SETTING

The Wolf Creek watershed has a drainage area of 544 km^2, with its headwaters originating southeast of the City of Lacombe, and draining into the Battle River about 36 km to the north, near the Town of Ponoka. The Wolf Creek watershed lies within the Central Parkland natural sub-region, on the boundary of the Western Alberta Plains and the Eastern Alberta Plains physiographic regions. The watershed has shallow topographical relief containing numerous potholes, sloughs and shallow lakes, and is characterized by poor drainage. Land use is predominantly agriculture with some natural areas and growing clusters of urbanization. About 13 km of the main stem of Wolf Creek, from the City of Lacombe to the boundary of Lacombe County and Ponoka County, was channelized in the early 1980s, and has been periodically maintained. The City of Lacombe releases its treated wastewater into Wolf Creek. The Queen Elizabeth II Highway (QE2 Highway) crosses Wolf Creek four times and Highway 2A crosses Wolf Creek once (MPE Engineering Ltd. 2013).

Located in the western portion of the Wolf Creek watershed, Whelp Brook is the largest sub-watershed, having a drainage area of 307 km^2. The Town of Blackfalds is in the headwaters of Whelp Brook which drains into Wolf Creek about 30 km to the north. About 20 km of the main stem of Whelp Brook is about 3 km west of and parallel to the main stem of Wolf Creek. The QE2 Highway crosses Whelp Brook twice (MPE Engineering Ltd. 2013).

WATER QUALITY

Christiansen (1977) in a study of the Battle River basin indicated that most tributaries to the Battle River are intermittent streams suffering from interrupted flow and stagnation during times of low precipitation. Beaver activity was reported as high in most of the Battle River tributaries and often provides the only areas with sufficient water to support fish during midsummer. Most tributary streams were identified as over enriched with nutrients from agricultural runoff and municipal effluent resulting in enhanced primary productivity (i.e., abundant algae and aquatic plants). Wolf Creek was specifically identified as having a substrate of mud and organic ooze, flowing in the spring with intermittent flow later in the year, low turbidity, summer stagnation with overwintering unlikely for most fish species but with potential northern pike and white sucker spawning. Channel depths averaged 1 m and up to 2.5 m at beaver ponds. Summer stagnation and blocked culverts were identified as problem areas for Wolf Creek. Duckweed and algae were identified as abundant during late summer (Christiansen 1977).

Table 1 summarizes the historical water quality data available for Wolf Creek. Although the data is limited (4 to 9 samples) and was collected from 23 to 29 years ago, it does provide some useful information. Table 1 supports the conclusion of Christiansen (1977) that tributaries to the Battle River were over-enriched with nutrients. Chlorophyll a concentrations at Wolf Creek ranged from 8.2 to 27.2 mg/m^3. Total phosphorus ranged from 0.17 to 4.60 mg/L and was 3 to 92 times greater than the provincial guideline of 0.05 mg/L for the protection of aquatic life (Table 1). Similarly, total nitrogen ranged from 1.0 to 12.36 mg/L and was 1 to 12 times greater than the provincial guideline of 1.0 mg/L for the protection of aquatic life (Table 1).

Most of the total metals were below the guidelines for the protection of aquatic life (Table 1). One of four samples contained total arsenic (6.7 µg/L) that was above the total arsenic guideline (5.0 µg/L) of for the protection of aquatic life. Arsenic is used in metallurgical applications and in manufacturing wood preservatives. Arsenic compounds are also used in herbicide, pharmaceutical and glass manufacturing. The largest natural source of arsenic entering surface waters is that from weathered rocks and soils. Levels of total arsenic in uncontaminated surface waters are generally less than 2 µg/L (CCME factsheet). The elevated total arsenic concentration found at Wolf Creek may have been due to natural and/or anthropogenic inputs. Toxic effects of total arsenic on aquatic life have been found to range from 50 µg/L (alga species *Scenedesmus obliquus*) to 1000 µg/L (water flea: *Ceriodaphnia dubia*) (CCME factsheet).

The four samples collected in 1990 had total cadmium concentrations ranging from 1 to 3 µg/L, which was above the total cadmium guideline of 0.076 µg/L for the protection of aquatic life. Cadmium is a relatively abundant element which is primarily used in batteries and metal plating of steel. In Canada, cadmium concentrations in freshwater range from <0.1 to 122 ug/L (CCME Factsheet) and its presence in Wolf Creek is probably due to natural occurrences. Fathead minnows exposed to 4.5 to 37 ug/L of cadmium showed no adverse effects on survival, growth or reproduction. However, 57 ug/L of cadmium decreased the survival of developing fathead minnow fry (USEPA 1978). Generally, cadmium concentrations of <12 µg/L have not been found to cause adverse effects on less-sensitive aquatic life (e.g., non-salmonids) (USEPA 1978).

Each of the four samples collected in 1990 had total iron concentrations ranging from 364 to 593 µg/L, which was above the total iron guideline of 300 µg/L for the protection of aquatic life. Iron is one of the most abundant elements in the earth's crust and it is an important component of clay soils. Its elevated concentration in Wolf Creek is probably due to natural occurrence. The toxicity of iron to aquatic life has been found to be related to the dissolved fraction of iron and

Table 1 - Selected historical water quality data from Wolf Creek (1984 and 1990). Data collected from near Highway 2 at Township Road 425 (1700 m upstream of mouth). Red boxes indicate guideline exceedance for protection of aquatic life. Nutrient and miscellaneous guidelines are from AENV (1999) and metal guidelines from CCME (http://st-ts.ccme.ca/?lang=en).

	1984-04-10	1984-05-01	1984-05-08	1984-05-15	1984-05-23	1990-04-03	1990-05-22	1990-08-28	1990-10-09	Guideline
NUTRIENTS AND BIOLOGICAL										
Chlorophyll a (mg/m^{3})						8.2	34.1	8.6	27.2	
Nitrogen, Total (mg/L)	1.72	5.53	12.36	8.02	1.7	3.65	1.27	1.01	1.00	1
Phosphorus, Total (mg/L)	0.19	1.30	4.60	1.95	0.46	0.36	2.05	0.26	0.17	0.05
TOTAL METALS										
Arsenic (µg/L)						1.9	6.7	4.0	2.5	5
Barium (µg/L)						80	87	131	121	
Cadmium (µg/L)						1	2	3	2	0.076
Chromium (µg/L)						2	4	4	5	
Cobalt (µg/L)						<1	1	1	1	
Copper (µg/L)						2	1	2	3	4
Iron (µg/L)						593	461	364	480	300
Manganese (µg/L)	218	80	100	170	190	124	137	156	250	
Mercury (µg/L)						<0.1	<0.1	<0.1	<0.1	0.026
Molybdenum (µg/L)						2	2	2	1	73
Nickel (µg/L)						4	6	5	5	150
Selenium (µg/L)						0.1	0.1	0.1	<0.1	1
Vanadium (µg/L)						3	5	5	4	
Zinc (µg/L)						4	1	1	4	15
MISCELLANEOUS PARAMETERS										
Alkalinity, total (mg/L)	215	409	560	467	356	123	342	332	359	
Hardness, total (mg/L)	230	255	191	239	285	124	299	296	334	
Oxygen, dissolved (mg/L)	9.1	9.0	10.9	10.8	11.7	7.8	8.5	3.8	8.2	5 and 6.5
pH (pH units)	7.9	7.9	8.3	8.5	8.5	8.3	8.2	7.6	8.4	6.5 to 8.5
Conductance (µS/cm)	606	997	1240	1035	787	319	744	685	753	
Temperature, water (°C)						3.2	11.5	14.1	6.4	
TDS (mg/L)	337	572	731	623	469	231	487	465	491	
Turbidity (NTU)						5.4	3.4	3.8	5.4	

not the particulate (total) fraction of iron. The United States EPA recommends dissolved iron concentrations of less than 1000 μg/L of dissolved iron for the protection of aquatic life. Dissolved iron concentrations at Wolf Creek ranged from 120 to 289 μg/L and were considerably lower than the USEPA guideline.

Data from 1984 and 1990 at Wolf Creek indicates that pH (ranging from 7.6 to 8.5) was always within the provincial recommended guideline of 6.5 to 8.5 for the protection of aquatic life (Table 1). During this study, the pH at Wolf Creek ranged between 7.3 and 8.2 and was within the provincial guideline (Tables 4, 6 and 8). At Whelp Brook, the pH ranged from 7.0 to 7.4 and was also within the provincial guideline (Tables 10, 12 and 14).

Dissolved oxygen data from April and May 1984 and April to October 1990 generally met the guideline for the protection of aquatic life at Wolf Creek, with the exception of August 28, 1990 when the dissolved oxygen was 3.8 and did not meet the acute (5 mg/l) or chronic (6.5 mg/L) guidelines (Table 1). Dissolved oxygen from August 2013 at Wolf Creek (this study: 5.72 to 7.48 mg/L) met the acute guideline (5 mg/L); however, oxygen at Sites 2 and 3 (Tables 6 and 8) may not have met the chronic guideline (7-day mean, >6.5 mg/L). Compared to Site 1 (sand substrate and sparse aquatic vegetation), Sites 2 and 3 had abundant aquatic vegetation and thick deposits of organic substrate. In aquatic systems, algae and aquatic plants are the primary sources and consumers of oxygen. Extensive diurnal variation in oxygen concentrations is often observed in creeks and rivers with dense growths of aquatic plants. Sunlight promotes intense photosynthesis (oxygen production) during daylight hours, particularly in late afternoon, with lower oxygen concentrations often observed at night, just before dawn, as a result of plant respiration (oxygen consumption) (Hynes 1970; Hauer and Hill 1996). Water quality data at Sites 2 and 3 was collected at 1:00 pm and probably represents a maximum daily oxygen concentration. Dissolved oxygen concentrations at night may have been less than 5 mg/L as aquatic plant respiration and the breakdown of organic matter are oxygen consuming processes.

The dissolved oxygen at the Whelp Brook sites ranged from 1.85 to 4.13 mg/L and did not meet the acute guideline and probably did not meet the chronic oxygen guideline (Tables 10, 12 and 14). The oxygen data at sites 4 and 6 was collected at 9:30 am and 9:00 am, respectively; therefore late afternoon oxygen concentrations may have been higher at these sites.

Christiansen (1977) identified the winter breakdown and decay of organic material as resulting in significant oxygen depletion during the winter and the creation of toxic hydrogen sulphide gas, generally resulting in winter fish kills of fish remaining in the tributaries to the Battle River. Summer kills were also known to occur under ideal conditions. Based on the results of this study, it is probable that Wolf Creek (Site 3) and Whelp Brook (Sites 5 and 6) are likely to suffer from severe oxygen depletion and hydrogen sulphide toxicity based on the abundance of aquatic plants and the thick deposits of organic matter. Wolf Creek (Site 2) and Whelp Brook (Site 4) are also likely to have similar winter kills; however, the presence of beaver dams would provide deeper water that may allow some fish tolerant of low dissolved oxygen (e.g., fathead minnow and brook stickleback) to survive overwinter. Wolf Creek (Site 1) had a sand substrate and sparse aquatic vegetation and is likely to have sufficient oxygen concentrations during the winter to allow the survival of fish.

Conductivity in 1984 and 1990 at Wolf Creek ranged from 319 to 1308 µS/cm (Table 1). During this study at Wolf Creek conductivity ranged from 844 to 1146 µS/cm (Tables 4, 6 and 8) and was within the historical range. At Whelp Brook, conductivity ranged from 745 to 1308 µS/cm (Tables 10, 12 and 14). The highest conductivity at both Wolf Creek and Whelp Brook occurred at the most upstream sites and the lowest conductivity at the downstream sites (Tables ? to ?). This is probably the result of the greater influence of overland runoff and municipal effluent on the smaller water volumes at the upstream sites (i.e., less dilution).

FISH COMMUNITY

The historical fish sampling data for Wolf Creek and Whelp Brook is summarized in Table 2. Fish captured during this study are summarized in Table 3.

At Wolf Creek, historical fish sampling occurred at seven sites (HF1 to HF7) between October 2005 and October 2011 using minnow traps and electrofishing. In total four fish species were captured. Three species of small-bodied forage fish have been captured: fathead minnow *Pimephales promelas* (408), brook stickleback *Culaea inconstans* (85) and lake chub *Couesius plumbeus* (5). The large-bodied forage fish white sucker *Catostomus commersoni* (13) was also captured (Table 2). During this study, white sucker (3), brook stickleback (3), fathead minnow (1) and longnose dace *Rhinichthys cataractae* (5) were captured at Wolf Creek. Longnose dace have not previously been captured in Wolf Creek. The longnose dace were captured at a small riffle at Site 1. This riffle was the only riffle observed at any of the six sites during this study. Longnose dace are typically found in moderate to fast water over a coarse substrate (Scott and Crossman 1973). The white sucker captured were small, immature juveniles ranging from 110 to 140 mm length (Table 3). The expected fish community at Wolf Creek based on historical and recent fish sampling is white sucker, fathead minnow, brook stickleback and lake chub and all four species are probably abundant in the creek. Longnose dace are likely uncommon in Wolf Creek and would probably be found in locations where fast-flowing water and coarse substrate occurs (e.g., downstream of culvert/bridges and beaver dams) such as the small riffle observed at the bridge at Site 1. Northern pike (*Esox lucius*) have not been captured in Wolf Creek based on the FWMIS database or this study but they may occur in lower Wolf Creek (downstream of Site 1) which is not impacted by beaver dams and confluences with the Battle River which contains northern pike. Habitat conditions at the downstream Wolf Creek location (Site 1) were poor for northern pike due to shallow water and an absence of instream cover. It is doubtful that northern pike would occur at Site 2 as the prevalence of beaver dams in this area would hinder upstream movement; however, habitat conditions at Site 2 might provide open-water rearing and feeding habitat for northern pike if they were present due to the deeper water and instream cover (aquatic vegetation, sunken logs). At Site 3, the small channel was choked with aquatic vegetation and would provide poor habitat for northern pike.

At Whelp Brook, historical fish sampling occurred at four sites (HF8 to HF11) between December 2006 and April 2009 using minnow traps and electrofishing. In total, three fish species were captured. Two of the small-bodied forage fish were again captured: fathead minnow (2) and brook stickleback (36). White sucker (52) was also captured (Table 2). During this study, white sucker (76) and lake chub (63) were captured at Whelp Brook with the majority captured at Site 4 (Table 3). Lake chub have not previously been captured in Whelp Brook; however, this is a wide-spread, hardy species that is probably locally abundant in both Wolf Creek and Whelp Brook. The expected fish community at Whelp Brook based on historical and recent fish sampling is white sucker, fathead minnow, brook stickleback and lake chub and all four species are probably abundant in the creek. Longnose dace may occur in locations where fast-flowing water and coarse substrate occurs (e.g., downstream of culverts and beaver dams); although, no such habitat types were observed in Whelp Brook. It is doubtful that northern pike would occur in Whelp Brook as the prevalence of beaver dams in Wolf Creek and Whelp Brook would hinder upstream movement. Habitat conditions at the downstream Whelp Brook location (Site 4) might provide open-water rearing and feeding habitat for northern pike if they were present. Sites 5 and 6 at Whelp Brook are unlikely to provide northern pike habitat due to beaver dams, poor water quality, poor overwintering habitat and vegetation-choked channels.

Fish captured in the Battle River near the mouth of Wolf Creek include northern pike, white sucker, lake chub, longnose dace and Iowa darter (*Etheostoma exile*) (FWMIS online). Although having little potential for overwintering fish, the Battle River tributaries (including Wolf Creek) were identified as providing marsh areas for northern pike spawning and rearing and spawning for white sucker and some minnow species in areas with running water (Christiansen 1977).

Table 2 – Summary of historical fish (HF) sampling at Wolf Creek (HF1 to HF7) and Whelp Brook (HF8 to HF11), Ponoka County and Lacombe County, Alberta. Refer to Figure 1 for sample locations.

Location	Date	Method	Fish Species	No. Captured	Comments
WOLF CREEK					
HF1	Oct 6, 2005	electrofishing	brook stickleback	6	
			fathead minnow	406	
HF2	Oct 1 & 7, 2007	minnow traps	--	0	wetted width: 9.3 m rooted width: 6.7 m water depth: 1.5 m
HF3	Oct 31, 2011	electrofishing	white sucker	13	
			lake chub	5	
			brook stickleback	75	
HF4	May 25, 2008	minnow traps	--	0	wetted width: 4.5 m rooted width: 9.0 m
HF5	May 25, 2008	minnow traps	brook stickleback	1	wetted width: 8 m rooted width: 10 m
HF6	May 5 & 25, 2008	minnow traps	brook stickleback	3	wetted width: 5 m rooted width: 9 m
			fathead minnow	2	
HF7	May 25, 2008	minnow traps	--	0	wetted width: 1.5 m rooted width: 4.0 m -dense algae
WHELP BROOK					
HF8	Oct 1 & 7, 2007	minnow traps	brook stickleback	34	wetted width: 3.7 m rooted width: 4.5 m water depth: 1.0 m
			white sucker	52	
HF9	Apr 21, 2009	electrofishing	brook stickleback	1	wetted width: 5 m rooted width: 5 m
			fathead minnow	2	
HF10	Dec 18, 2006	electrofishing	--	0	
HF11	Oct 7, 2007	minnow traps	brook stickleback	1	wetted width: 1.0 m rooted width: 3.5 m water depth: 0.35 m

Note: HF10 and HF11 are fish sample sites at a tributary to Whelp Brook

Table 3 – Summary of fish sampling at Wolf Creek and Whelp Brook, August 6th to 8th, 2013.

Location	Method	Effort	Fish Species	No. Captured	Fork Length (mm)
Wolf Creek (Site 1)	electrofishing	567 s	white sucker longnose dace	3 5	110 – 140 45 – 80
	minnow traps	5 traps (17 hours)	--	0	--
Wolf Creek (Site 2)	minnow traps	6 traps (20 hours)	--	0	--
Wolf Creek (Site 3)	minnow traps	5 traps (19.5 hours)	--	0	--
	seine net	4 hauls	brook stickleback fathead minnow	3 1	37 – 45 20
Whelp Brook (Site 4)	minnow traps	6 traps (17.5 hours)	--	0	--
	electrofishing	725 s	--	0	--
	seine net	1 haul	lake chub white sucker	63 74	23 – 70 31 – 95
Whelp Brook (Site 5)	minnow traps	4 traps (19 hours)	white sucker	1	55
Whelp Brook (Site 6)	minnow traps	5 traps (17.5 hours)	white sucker	1	52

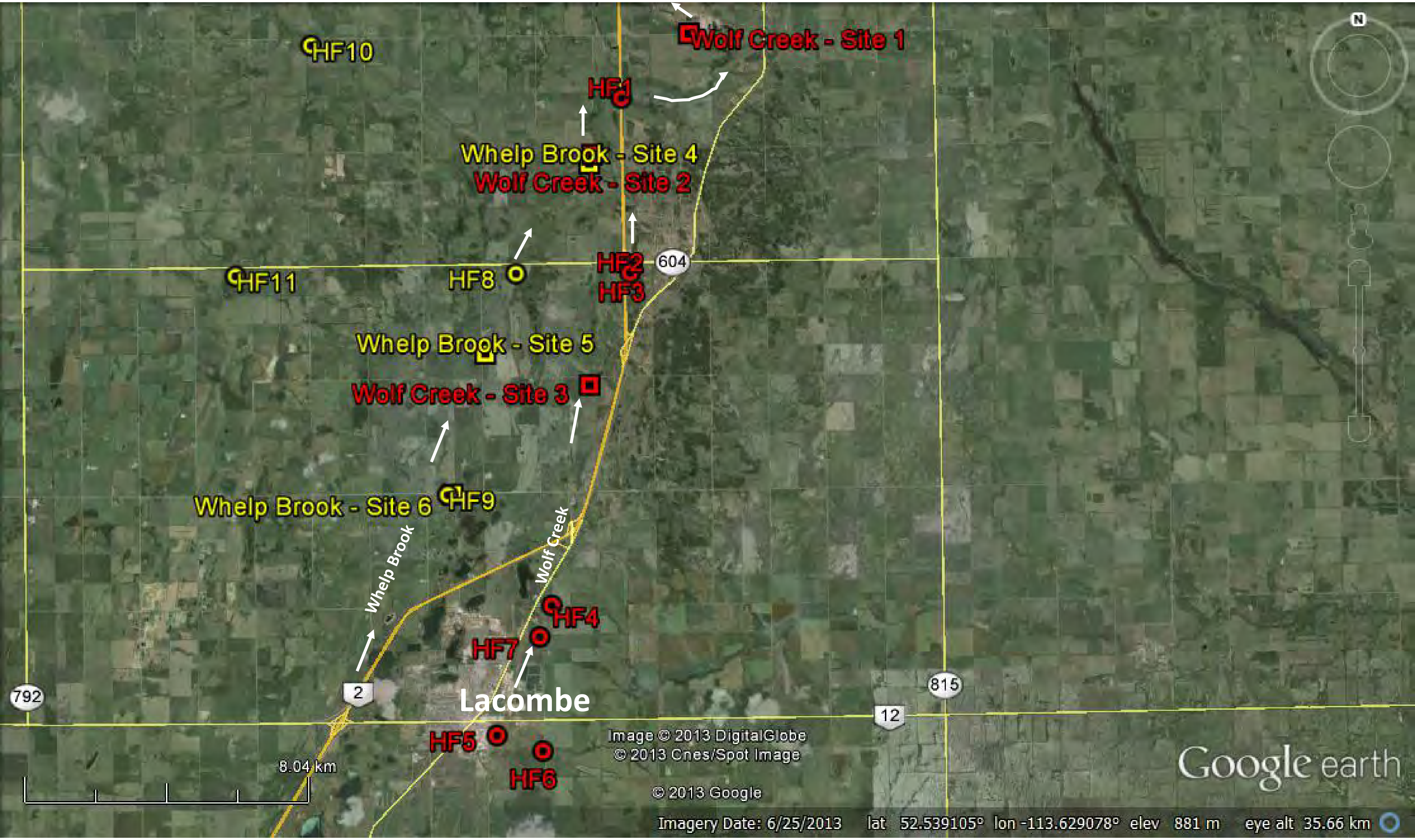


Figure 1 – Sample site locations at Wolf Creek (Sites 1 to 3, red text) and Whelp Brook (Sites 4 to 6, yellow text). Historical fish sampling sites are shown for Wolf Creek (HF1 to HF7) and Whelp Brook (HF8 to HF11). HF10 and HF11 are tributary to Whelp Brook fish sample sites. White arrows indicate flow direction.

HABITAT ASSESSMENTS

Wolf Creek (Site 1)

This site is located on Matejka Road immediately east of Highway 2 in Ponoka County. This portion of Wolf Creek is located adjacent to an active gravel pit and has been channelized. The creek flows under a bridge located at Matejka Road (Figure 2). This portion of Wolf Creek has a very low gradient (0.13%) with a straight channel pattern. The creek at this site had homogeneous habitat features comprising a firm sand substrate and typical water depths between 0.17 and 0.37 m (Photos 1 and 2). The channel units were dominated by glide units with a small riffle and two small pools occurring near the bridge (Figure 3, Photo 3). The wetted widths ranged from 5.0 to 7.1 m and the channel widths ranged from 5.0 to 8.5 m. Water velocities were slow and ranged from 0.22 to 0.28 m/s. The calculated water discharge was 0.325 m^3/s (Figure 3; Tables 4 and 5).

Submerged aquatic vegetation was very sparse (5%) and included coontail *Ceratophyllum demersum* (sparse), Richardson's pondweed *Potamogeton richardsonii* (sparse), vernal water-starwort *Callitriche verna* (very sparse) and filamentous algae (very sparse) (Figure 3). No emergent aquatic vegetation was noted. Instream cover was very low at 5% coverage due to the sparse aquatic vegetation and lack of pools, boulders and logs. Water clarity was high. The dissolved oxygen was moderately high (7.48 mg/L) and above the acute and chronic guideline for the protection of aquatic life (5.0 and 6.5 mg/L, respectively).

The riparian area was comprised almost entirely of grasses, particularly reed canary grass. There were a few scattered shrubs near the bridge that were located back from the creek bank and did not contribute to overhead cover. Overhead cover was low (20%). The creek banks were moderately high along the right-downstream bank (0.9 to 3.7 m) and moderate along the left-downstream-bank (1.2 to 1.8 m). The higher banks along the right-downstream-bank were due to a berm, constructed presumably to prevent flooding of the adjacent gravel pit. The banks were steeply-sloped (30 to 75^o) and generally stable with high vegetative cover. Within the study area there was evidence of light cattle grazing; however, upstream of Matejka Road (outside of study area) there was evidence of heavy cattle grazing along the streambanks (Photo 4).

Fish were sampled with five minnow traps set overnight and a backpack electrofisher. White sucker (3) and longnose dace (5) were captured. In addition, three small white suckers were observed during electrofishing but not captured (Table 3). The white suckers were captured in areas with overhanging bank grasses and the longnose dace were all captured at a small riffle near the bridge.

Generally, fish habitat sensitivities to construction/channel modifications at Site 1 would be low as the site is channelized and currently has poor fish habitat. Any construction/channel modifications proposed at Site 1 should include meanders to allow more channel-forming activities that would increase the fish habitat diversity.

Figure 2 – Aerial view of Wolf Creek (Site 1), Ponoka County, Alberta. Direction of flow indicated by white arrow.

Table 4 – Wolf Creek (Site 1) Watercourse Information

Project and Location Information	
Project	MPE Engineering Ltd.
Date	August 6, 2013
Assessed By	S. Stoklosar & S. Riemersma
Watercourse Name	Wolf Creek (Site 1)
Tributary to	Battle River
Proposed Construction	Master Drainage Plan- additional conveyance capacity
UTM Coordinates	12 U 321692 E 5835275 N
Legal Land Description	NE23-42-26-W4 SE26-42-26-W4
Topographic Map No.	83A12 (Ponoka)
General Location	Located adjacent to Matejka Road immediately east of Highway 2 in Ponoka County, approximately 5.5 km southwest of Ponoka.
Length Assessed (m)	300

Water Quality	
Time	10:00 am
Air Temperature (°C)	15
Water Temperature (°C)	18.2
Conductivity (uS/cm)	844
Dissolved Oxygen (mg/L) **Saturation (%)**	7.48 79.2
TDS (mg/L)	557
pH	8.2
Water Clarity	clear

General Information	
Adjacent Land Use	gravel pit
Dominant Riparian Vegetation	grasses
Watercourse Navigable	generally too shallow, perhaps by canoe at higher flow
Natural Obstructions	none except low flow
Artificial Obstructions	none: bridge is a clear span
Stream Pattern	straight
Stream Gradient (%)	0.13% (low)
Groundwater Seepage Present	none observed
Evidence of Angling	none

Instream Cover	
Total Instream Cover (%)	**5**
Woody Debris (%)	<1
Boulders (%)	
Aquatic Plants (%)	90
Deep Pools (%)	10
Surface Turbulence (%)	
Turbidity (%)	

Aquatic Vegetation	
Total Plant Coverage (%)	**5**
Emergent (%)	
Floating-leafed (%)	
Submergent (%)	90
Free Floating (%)	
Filamentous Algae (%)	10
Macrophytic Algae (%)	

Overhead Cover	
Total Overhead Cover (%)	**20**
Woody Debris (%)	
Undercut Bank (%)	15
Grasses and Forbes (%)	85
Trees and Shrubs (%)	

General Description of Assessed Site

-Evidence of cattle grazing, particularly upstream of Matejka Road.

-Very homogenous habitat dominated by sand substrate, glide channel unit, and overhanging grasses. Low instream cover.

-Discharge at site: 0.325m^3/s.

Table 5 - Wolf Creek (Site 1) Transect Descriptions

Parameter	**Transect Location**														
	0 m upstream			**190 m upstream**			**280 m upstream**			**____ m**			**____ m**		
Channel															
bankfull width (m)	11			11			13.5								
bankfull depth (m)	1.5			1.8			1.8								
channel width (m)	7.9			5.0			8.5								
wetted width (m)	7.1			5.0			5.7								
	1/4	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**
water depth (m)	0.17	0.20	0.26	0.37	0.30	0.26	0.30	0.30	0.29						
water velocity (m/s)[2]	0.23	0.23	0.27	0.25	0.27	0.22	0.28	0.32	0.27						
Substrate															
% organic															
% fines	100 (sand)			100 (sand)			80 (sand)								
% gravel							20								
% cobble															
% boulder															
embeddedness (N,L,M,H,VH)	Very High			Very High			Very High								
Banks	**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**		
bank height (m)	1.2 / 0.9			1.5 / 3.7			1.8 / 3.0			/			/		
bank slope (^{o})	75 / 60			45 / 30			45 / 30			/			/		
bank stability (**L**ow, **M**oderate, **H**igh)	H / H			H / L			M / M			/			/		
vegetation cover (%)	100 / 90			100 / 90			80 / 80			/			/		
undercut depth (m)	0.0 / 0.10			0.2 / 0.4			0.0 / 0.0			/			/		
bank composition[3]															
% fines	100 / 100			100 / 100			100 / 100			/			/		
% gravel	/			/			/			/			/		
% cobble	/			/			/			/			/		
% boulder	/			/			/			/			/		

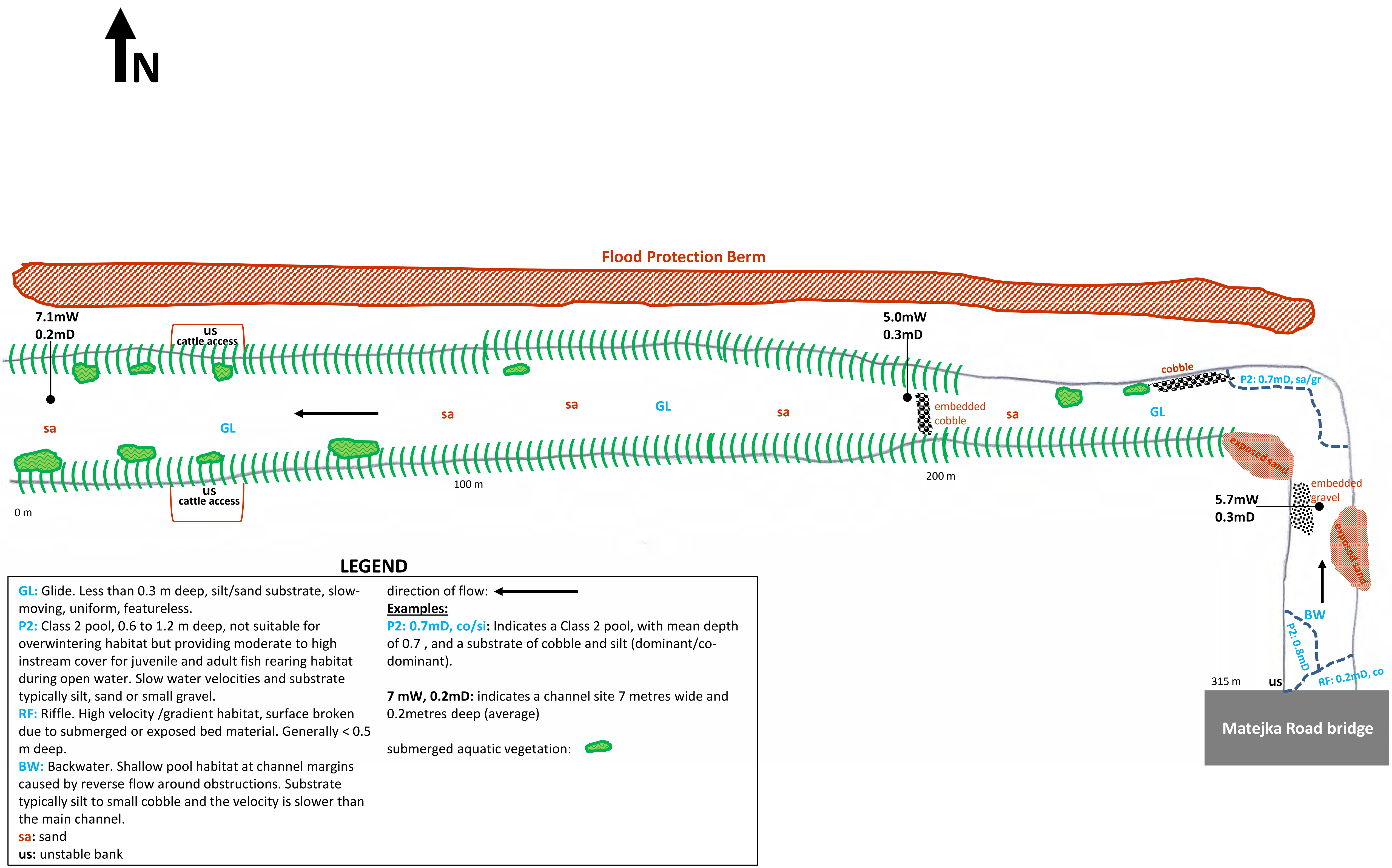


Figure 3 - Habitat map of Wolf Creek (Site 1), August 2013. Total length of mapped area is 315 m.

↓**Photo 1:** *View upstream from 0 m (downstream limit of study area), Wolf Creek (Site 1), August 6, 2013. Note the grass banks and sand substrate.*

↓**Photo 2:** *View upstream from 200 m, Wolf Creek (Site 1), August 6, 2013. The creek is narrower here and more influenced by the over-hanging grasses.*

↓**Photo 3:** *View upstream at 285 m to Matejka Road bridge, Wolf Creek (Site 1), August 6, 2013. Note the small riffle.*

↓**Photo 4:** *View upstream from Matejka Road bridge, Wolf Creek (Site 1), August 6, 2013. Streambanks have been heavily impacted by cattle.*

Wolf Creek (Site 2)

Site 2 is located on Range Road 26-3 near Township Road 42-2 in Ponoka County, immediately west of Highway 2. Wolf Creek flows under a bridge located at Township Road 42-2 (Figure 4). This portion of Whelp Brook has a very low gradient (0.24%) with an irregular meandering pattern. Site 2 at Wolf Creek was influenced by beaver activity with two beaver dams in a 300 m reach; although, the beavers appeared older and in disrepair and it was evident that the site had been flooded to a higher level in the past (deadfall, old beaver channels etc.). The creek had thick deposits of soft organic substrate and water depths were generally >1.0 m. The wetted widths ranged from 11 to 16 m (Figure 5, Tables 6 and 7).

The channel had moderate densities of aquatic vegetation (30% coverage) with no visible water movement, except at beaver dams (Photos 5 to 10). Aquatic vegetation included arum-leafed arrowhead *Sagittaria cuneata* (moderately dense), vernal water-starwort (sparse), coontail (moderately dense) and common duckweed *Lemna minor* (moderately dense). Instream cover was high at 50% coverage due to the submerged aquatic vegetation and abundant woody debris (Figure 5). Water clarity was high. The dissolved oxygen was moderate (6.08 mg/L) and may have been below the chronic guideline for the protection of aquatic life (6.5 mg/L: 7-day average). This site during the winter would likely suffer from anoxia and high concentrations of hydrogen sulphide due to the abundance of organic matter.

The riparian area at this site was healthy with a range of grasses, forbs, shrubs and trees (all age-classes) (Photos 5 to 10). Overhead cover was moderately high (30%) and largely provided by trees/shrubs and overhanging logs and grasses. There was no evidence of cattle grazing at this site. The creek banks were moderately high (1.0 to 2.0 m), moderately- to steeply-sloped (30 to 90^{o}) and stable with high vegetative cover (Table 7).

Fish sampling was conducted with six minnow traps set overnight. Backpack electrofishing was attempted but deep water and very soft substrate made for unsafe conditions. No fish were captured but a local resident reported that he had observed small fish (i.e., “minnows”) in the creek. White suckers and lake chub are likely present as they were captured in Whelp Brook (Site 4) which is located immediately upstream of Site 2. In October 2005, fish sampling (Site HF1) with an electrofisher 5.7 km downstream captured brook stickleback (6) and fathead minnow (406). Similarly, in October 2011, fish sampling (Site HF3) with an electrofisher 5.6 km upstream captured white sucker (13), brook stickleback (75) and lake chub (5). Sampling with minnow traps 5.8 km upstream of Site 1 in October 2007 did not capture any fish (Table 2).

Generally, fish habitat sensitivities to construction/channel modifications at Site 2 would be moderate, largely due to the healthy riparian area. Any proposed construction/channel modifications should be designed to reduce impacts to the riparian area to the greatest extent possible. Construction activities that occurred from the left-downstream-bank would avoid some impacts to the riparian area as access would be facilitated by nearby roads. Areas of lower density trees and shrubs along the left-downstream-bank would also avoid some impacts to woody vegetation.

Figure 4 – Aerial view of Wolf Creek (Site 2), Ponoka County, Alberta. Direction of flow indicated by white arrow.

Table 6 – Wolf Creek (Site 2) Watercourse Information

Project and Location Information	
Project	MPE Engineering Ltd.
Date	August 6, 2013
Assessed By	S. Stoklosar & S. Riemersma
Watercourse Name	Wolf Creek (Site 2)
Tributary to	Battle River
Proposed Construction	Master Drainage Plan- additional conveyance capacity
UTM Coordinates	12 U 318836 E 5831941 N
Legal Land Description	SW15-42-26-W4 NW10-42-26-W4
Topographic Map No.	83A12 (Ponoka)
General Location	Located adjacent to Range Road 26-3 near Township Road 42-2 in Ponoka County, immediately west of Highway 2, and approximately 9.5 km southwest of Ponoka.
Length Assessed (m)	300

Water Quality	
Time	1:00 pm
Air Temperature (°C)	21
Water Temperature (°C)	18.8
Conductivity (uS/cm)	922
Dissolved Oxygen (mg/L) **Saturation (%)**	6.08 65.3
TDS (mg/L)	648
pH	7.3
Water Clarity	clear

General Information	
Adjacent Land Use	forested area, municipal road
Dominant Riparian Vegetation	grasses, shrubs and trees
Watercourse Navigable	No, abundant deadfall and small beaver dams
Natural Obstructions	beaver dams, deadfall, sunken logs
Artificial Obstructions	none: bridge is a clear span
Stream Pattern	irregular meander
Stream Gradient (%)	0.24% (low)
Groundwater Seepage Present	none observed
Evidence of Angling	none

Instream Cover	
Total Instream Cover (%)	**50**
Woody Debris (%)	30
Boulders (%)	
Aquatic Plants (%)	60
Deep Pools (%)	10
Surface Turbulence (%)	
Turbidity (%)	

Aquatic Vegetation	
Total Plant Coverage (%)	**30**
Emergent (%)	
Floating-leafed (%)	30
Submergent (%)	60
Free Floating (%)	10
Filamentous Algae (%)	
Macrophytic Algae (%)	

Overhead Cover	
Total Overhead Cover (%)	**30**
Woody Debris (%)	40
Undercut Bank (%)	10
Grasses and Forbes (%)	20
Trees and Shrubs (%)	30

General Description of Assessed Site

-No evidence of cattle grazing.

-Abundant instream cover from logs, aquatic vegetation and depth.

-Discharge not possible at site. No visible water movement except for minor amount over small beaver dams.

-Beaver dams present.

-Local landowner reports small fish (i.e., “minnows”) in creek.

Table 6 - Wolf Creek (Site 2) Transect Descriptions

Parameter	Transect Location														
	0 m (bridge)			140 m upstream			200 m upstream			300 m upstream			____ m		
Channel															
bankfull width (m)	20			16			18			17					
bankfull depth (m)	2.4			3.0			2.5			3.0					
channel width (m)	16			11			13			11					
wetted width (m)	16			11			13			11					
	1/4	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**
water depth (m)															
water velocity (m/s)[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Substrate															
% organic	100			100			100			100					
% fines															
% gravel															
% cobble															
% boulder															
embeddedness (N,L,M,H,VH)	Very High			Very High			Very High			Very High					
Banks	**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**		
bank height (m)	2.0 / 1.1			1.0 / 1.5			1.0 / 1.5			2.0 / 2.0			/		
bank slope (^{o})	45 / 30			90 / 45			45 / 30			90 / 90			/		
bank stability (**L**ow, **M**oderate, **H**igh)	H / H			H / H			H / H			H / H			/		
vegetation cover (%)	100 / 100			100 / 100			100 / 100			100 / 90			/		
undercut depth (m)	0.2 / 0.0			0.0 / 0.0			0.0 / 0.1			0.0 / 0.0			/		
bank composition[3]															
% fines	100 / 100			100 / 100			100 / 100			100 / 100			/		
% gravel	/			/			/			/			/		
% cobble	/			/			/			/			/		
% boulder	/			/			/			/			/		

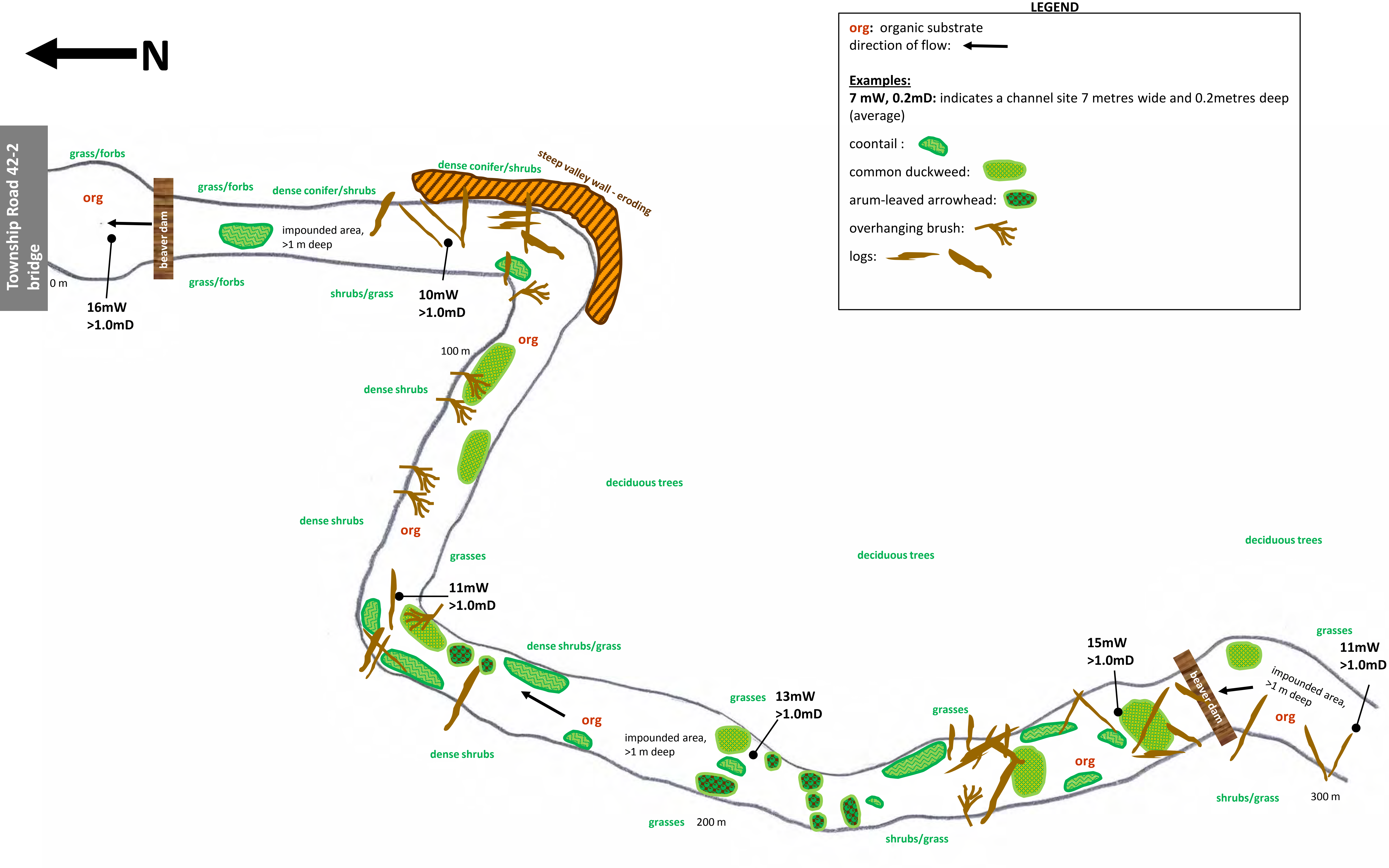


Figure 5 - Habitat map of Wolf Creek (Site 2), August 2013. Total length of mapped area is 300 m.

↓**Photo 5:** *View upstream from Township Road 42-2 bridge, Wolf Creek (Site 2), August 6, 2013. Note the small beaver dam where the creek narrows.*

↓**Photo 6:** *View upstream from 140 m upstream of bridge, Wolf Creek (Site 2), August 6, 2013. Note the healthy riparian area.*

↓**Photo 7:** *View downstream from 200 m upstream of bridge, Wolf Creek (Site 2), August 6, 2013. Note the healthy riparian area and aquatic vegetation.*

↓**Photo 8:** *View upstream from 200 m upstream of bridge, Wolf Creek (Site 2), August 6, 2013. Note the healthy riparian area and instream woody debris.*

↓**Photo 9:** *View downstream from 300 m upstream of bridge, Wolf Creek (Site 2), August 6, 2013. Note the instream woody debris and the small beaver dam in the foreground.*

↓**Photo 10:** *View upstream from 300 m upstream of bridge, Wolf Creek (Site 2), August 6, 2013. Note the instream woody debris and overhead woody debris.*

Wolf Creek (Site 3)

This site is located on Township Road 41-1, immediately west of Highway 2 in Lacombe County. This portion of Wolf Creek was previously channelized. The creek flows through a culvert under Township Road 41-1 (Figure 7). This portion of Wolf Creek has a very low gradient (0.07%) with a straight channel pattern. The creek at this site had homogeneous habitat features comprising a soft organic substrate and water depths between 0.5 and 1.2 m. The wetted widths ranged from 12 to 16 m; however, wetted widths were probably greater than normal as the grasses along the left-downstream-bank appeared to be flooded, perhaps due to downstream obstructions (e.g., dams, culverts) and poor drainage (Photos 11 and 12). Consequently, the channel widths at this site were probably less than the recorded wetted width at the time of the assessment. The open water widths (excluding flooded grasses) were typically 5 to 8 m. (Figure 7, Tables 8 and 9)

The channel was densely choked with aquatic vegetation with no visible water movement. Aquatic vegetation included sago pondweed *Stuckenia pectinata* (dense), coontail (moderately dense), arum-leafed arrowhead (low density), filamentous algae (moderately dense) and common duckweed (moderately dense). Small clusters of bulrush (*Scirpus* spp.) and common cattail (*Typha latifolia*) were present along the shoreline. Instream cover was high at 80% coverage due to the dense aquatic vegetation. Water clarity was high. The dissolved oxygen was moderately low (5.72 mg/L) and below the chronic guideline for the protection of aquatic life (6.5 mg/L). This site during the winter would likely suffer from anoxia and high concentrations of hydrogen sulphide due to the abundance of organic matter.

The riparian area was comprised entirely of grasses and forbs; thus, overhead cover was low (10%). The creek banks were moderately high along the left-downstream bank (1.5 to 1.8 m) and low along the right-downstream-bank (0.1 to 0.7 m). The banks were moderately-sloped (5 to 30^{o}) and stable with high vegetative cover (Table 9). The area adjacent to the creek along the right-downstream-bank was utilized as cattle pasture as evidenced by cattle trails and grazed grasses.

Fish were sampled with minnow traps set overnight and a seine net. Backpack electrofishing was not attempted as deep water, soft substrate and dense vegetation made for unsafe and unsuitable conditions. Brook stickleback (3) and fathead minnow (1) were captured (Table 3).

Generally, fish habitat sensitivities to construction/channel modifications at Site 3 would be low as the channel is choked with aquatic vegetation and fish habitat is poor. Natural channel forming capabilities at this site are probably limited by the low gradient. Any construction/channel modifications proposed at Site 3 should include designs that would increase the fish habitat diversity such as deeper water, a more meandering channel and open water areas free of aquatic vegetation.

Figure 6 – Aerial view of Wolf Creek (Site 3), Lacombe County, Alberta. Direction of flow indicated by white arrow.

Table 8 – Wolf Creek (Site 3) Watercourse Information

Project and Location Information	
Project	MPE Engineering Ltd.
Date	August 6 and 7, 2013
Assessed By	S. Stoklosar & S. Riemersma
Watercourse Name	Wolf Creek (Site 3)
Tributary to	Battle River
Proposed Construction	Master Drainage Plan- additional conveyance capacity
UTM Coordinates	12 U 318378 E 5825475 N
Legal Land Description	SE28-41-26-W4 NE21-41-26-W4
Topographic Map No.	83A12 (Ponoka)
General Location	Located on Township Road 41-1, immediately west of Highway 2 in Lacombe County and approximately 9 km north of Lacombe.
Length Assessed (m)	300

Water Quality	
Time	1:00 pm
Air Temperature (°C)	22
Water Temperature (°C)	18.8
Conductivity (uS/cm)	1146
Dissolved Oxygen (mg/L) **Saturation (%)**	5.72 61.7
TDS (mg/L)	746
pH	7.7
Water Clarity	clear

General Information	
Adjacent Land Use	cattle pasture and cropland
Dominant Riparian Vegetation	grasses
Watercourse Navigable	no, dense aquatic vegetation and culverts present
Natural Obstructions	dense aquatic vegetation
Artificial Obstructions	culvert
Stream Pattern	straight (channelized)
Stream Gradient (%)	0.07% (low)
Groundwater Seepage Present	none observed
Evidence of Angling	none

Instream Cover	
Total Instream Cover (%)	**80**
Woody Debris (%)	
Boulders (%)	
Aquatic Plants (%)	75
Depth (%)	25
Surface Turbulence (%)	
Turbidity (%)	

Aquatic Vegetation	
Total Plant Coverage (%)	**60**
Emergent (%)	5
Floating-leafed (%)	5
Submergent (%)	50
Free Floating (%)	25
Filamentous Algae (%)	15
Macrophytic Algae (%)	

Overhead Cover	
Total Overhead Cover (%)	**10**
Woody Debris (%)	
Undercut Bank (%)	
Grasses and Forbes (%)	100
Trees and Shrubs (%)	

General Description of Assessed Site

-Cattle grazing occurs adjacent to creek along right-downstream-bank.

-Abundant instream cover from dense aquatic vegetation and depth.

-Discharge not possible at site. No visible water movement.

-Creek channelized at this location.

-Homogenous habitat at this location (dense aquatic vegetation, consistent depth and width, organic substrate and grass banks).

Table 9 - Wolf Creek (Site 3) Transect Descriptions

Parameter	Transect Location														
	20 m (upstream of culvert)			100 m upstream			200 m upstream			300 m upstream			____ m		
Channel															
bankfull width (m)	30			23			25			25					
bankfull depth (m)	2.5			2.5			2.5			2.0					
channel width (m)	<15			<12			<13			<16					
wetted width (m)	15			12			13			16					
	1/4	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**
water depth (m)	1.0	1.0	1.2	0.9	1.0	1.2	0.5	1.1	0.5	0.9	1.0	1.1			
water velocity (m/s)[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Substrate															
% organic	100			100			100			100					
% fines															
% gravel															
% cobble															
% boulder															
embeddedness (N,L,M,H,VH)	Very High			Very High			Very High			Very High					
Banks	**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**		
bank height (m)	1.8 / 0.1			1.5 / 0.5			1.5 / 0.7			1.5 / 0.7			/		
bank slope (^{o})	30 / 5			30 / 20			30 / 20			30 / 30			/		
bank stability (**L**ow, **M**oderate, **H**igh)	H / H			H / H			H / H			H / M			/		
vegetation cover (%)	100 / 70			95 / 50			95 / 85			95 / 85			/		
undercut depth (m)	0.0 / 0.0			0.0 / 0.0			0.0 / 0.0			0.0 / 0.0			/		
bank composition[3]															
% fines	100 / 100			100 / 100			100 / 100			100 / 100			/		
% gravel	/			/			/			/			/		
% cobble	/			/			/			/			/		
% boulder	/			/			/			/			/		

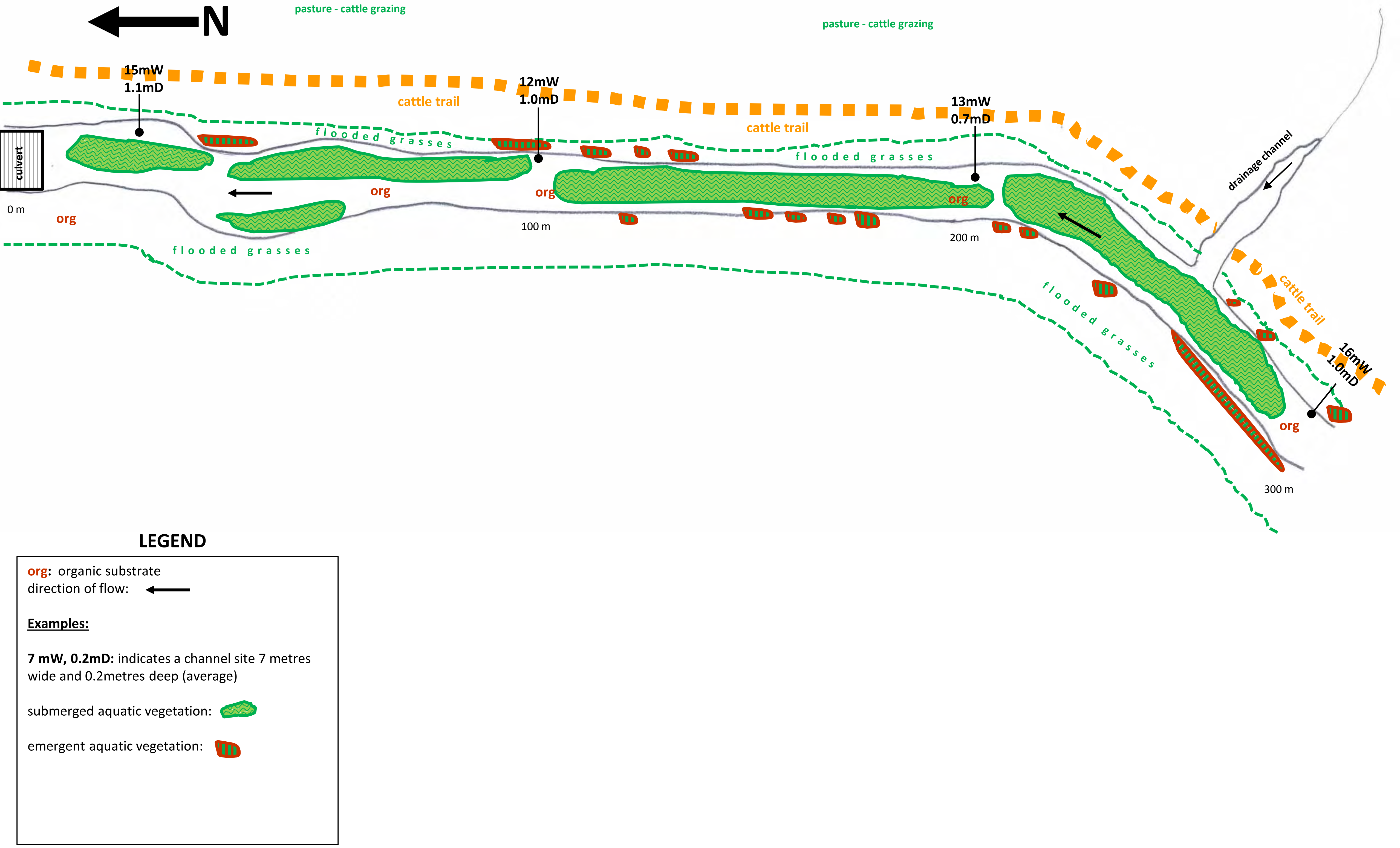


Figure 7 - Habitat map of Wolf Creek (Site 3), August 2013. Total length of mapped area is 300 m.

↓**Photo 11:** *View upstream from Township Road 41-1, Wolf Creek (Site 3), August 7, 2013. Note dense aquatic vegetation and flooded areas (yellow line).*

↓**Photo 12:** *View downstream, 300 m upstream from Township Road 41-1, Wolf Creek (Site 3), August 7, 2013. Note the flooded grasses, common duckweed and cattle trails.*

Whelp Brook (Site 4)

Site 4 is located on Range Road 26-3 near Township Road 42-2 in Ponoka County, immediately west of Highway 2. Whelp Brook flows under a bridge located at Range Road 26-3 (Photo 13). The bridge is located 40 m upstream from the mouth of Whelp Brook at Wolf Creek and is located immediately upstream of Site 2 (Figure 8). This portion of Whelp Brook has a very low gradient (0.13%) with an irregular meandering pattern. Site 4 at Whelp Brook was influenced by beaver activity with two beaver dams in the upstream end of the 300 m reach. The creek had a substrate dominated by thick deposits of soft organic substrate; although, there were a few areas of fine sand present. Water depths typically ranged from 0.18 to 0.90; although, there were a few areas with depths greater than 1.5 m in association with the beaver dams. The wetted widths ranged from 4.8 to 8.1 m and channel widths from 4.9 to 11.9 m (Figure 9, Tables 10 and 11).

The channel had moderate densities of aquatic vegetation (25% coverage) with no visible water movement, except at 300 m upstream where water velocities were very slow (0.02 to 0.04 m/s). Aquatic vegetation included arum-leafed arrowhead (moderately dense), vernal water-starwort (sparse), coontail (moderately dense), sago pondweed (moderately dense) and common duckweed (moderately dense). Low densities of filamentous algae were also observed in the creek. Instream cover was high at 40% coverage due to the submerged aquatic vegetation, woody debris and deep pools (Photos 13 to 18). Water clarity was high. The dissolved oxygen was low (4.13 mg/L) and was below the acute guideline for the protection of aquatic life (5.0 mg/L). This site during the winter would likely suffer from anoxia and high concentrations of hydrogen sulphide due to the abundance of organic matter.

The riparian area at this site was healthy with a range of grasses, forbs, shrubs and trees (all age-classes) (Photos 14 to 18). Overhead cover was moderately high (40%) and largely provided by trees/shrubs and woody debris. There was some evidence of cattle grazing on both sides of the creek. The creek banks were moderately high (0.6 to 1.5 m), low- to steeply-sloped (15 to 90^{o}) and moderately unstable to stable banks with high vegetative cover (Table 11). The only area of moderately unstable banks and lower vegetative cover occurred immediately upstream of the Township Road 42-2 bridge where cattle have been crossing regularly.

Fish sampling was conducted with six minnow traps set overnight, backpack electrofishing and a seine net. No fish were captured with the minnow traps or backpack electrofishing but a seine haul immediately upstream of the bridge captured 74 white sucker and 63 lake chub (Table 3).

Generally, fish habitat sensitivities to construction/channel modifications at Site 4 would be moderate, largely due to the healthy riparian area. Any proposed construction/channel modifications should be designed to reduce impacts to the riparian area to the greatest extent possible. Construction activities that occurred from the left-downstream-bank would avoid some impacts to the riparian area as areas of lower density trees and shrubs along the left-downstream-bank would avoid some impacts to woody vegetation.

Figure 8 – Aerial view of Whelp Brook (Site 4), Ponoka County, Alberta. Direction of flow indicated by white arrows.

Table 10 – Whelp Brook (Site 4) Watercourse Information

Project and Location Information	
Project	MPE Engineering Ltd.
Date	August 7, 2013
Assessed By	S. Stoklosar & S. Riemersma
Watercourse Name	Whelp Brook (Site 4)
Tributary to	Wolf Creek
Proposed Construction	Master Drainage Plan-additional conveyance capacity
UTM Coordinates	12 U 318768 E 5831777 N
Legal Land Description	NE9-42-26-W4
Topographic Map No.	83A12 (Ponoka)
General Location	Located at Range Road 26-3 near Township Road 42-2 in Ponoka County, immediately west of Highway 2 and 9.5 km southwest of Ponoka. Site 4 is located at the mouth of Whelp Brook.
Length Assessed (m)	300

Water Quality	
Time	9:30 am
Air Temperature (^{o}C)	15
Water Temperature (^{o}C)	17.2
Conductivity (uS/cm)	745
Dissolved Oxygen (mg/L) **Saturation (%)**	4.13 43.6
TDS (mg/L)	484
pH	7.4
Water Clarity	clear

General Information	
Adjacent Land Use	forested area and pasture for cattle grazing
Dominant Riparian Vegetation	grass, shrubs and trees
Watercourse Navigable	No, abundant deadfall and small beaver dams
Natural Obstructions	beaver dams, deadfall, sunken logs, log jams
Artificial Obstructions	none: bridge is a clear span
Stream Pattern	irregular meander
Stream Gradient (%)	0.13% (low)
Groundwater Seepage Present	none observed
Evidence of Angling	none

Instream Cover	
Total Instream Cover (%)	**40**
Woody Debris (%)	20
Boulders (%)	
Aquatic Plants (%)	60
Depth (%)	20
Surface Turbulence (%)	
Turbidity (%)	

Aquatic Vegetation	
Total Plant Coverage (%)	**25**
Emergent (%)	
Floating-leafed (%)	30
Submergent (%)	50
Free Floating (%)	20
Filamentous Algae (%)	<1
Macrophytic Algae (%)	

Overhead Cover	
Total Overhead Cover (%)	**40**
Woody Debris (%)	30
Undercut Bank (%)	5
Grasses and Forbes (%)	15
Trees and Shrubs (%)	50

General Description of Assessed Site

-Cattle grazing occurs adjacent to creek along both banks. Cattle present along left-downstream-bank during assessment.

-Abundant instream cover from dense aquatic vegetation, woody debris and depth.

-Discharge not possible at site. No visible water movement.

-Substrate is predominantly organic with some small areas of fine sand present.

-Site is impacted by beavers at upstream end but not to same extent as Wolf Creek (Site 2).

Table 11 - Whelp Brook (Site 4) Transect Descriptions

Parameter	Transect Location														
	10 m (upstream of bridge)			100 m upstream			200 m upstream			300 m upstream			____ m		
Channel															
bankfull width (m)	14.8			8.5			11.5			25[1]					
bankfull depth (m)	1.4			1.7			2.0			1.0					
channel width (m)	11.9			4.9			6.0			8.3					
wetted width (m)	8.1			4.8			5.4			6.6					
	1/4	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**
water depth (m)	0.41	0.30	0.18	0.36	0.60	0.60	0.45	0.90	0.80	0.20	0.21	0.28			
water velocity (m/s)[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03	0.04	0.02			
Substrate															
% organic	100			100			100			50					
% fines										50 (sand)					
% gravel															
% cobble															
% boulder															
embeddedness (N,L,M,H,VH)	Very High			Very High			Very High			Very High					
Banks	**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**		
bank height (m)	1.3 / 0.6			0.7 / 1.0			1.5 / 1.0			1.0 / 0.6			/		
bank slope (°)	45 / 15			90 / 90			35 / 30			45 / 90			/		
bank stability (**L**ow, **M**oderate, **H**igh)	M / M			H / H			H / H			H / H			/		
vegetation cover (%)	60 / 70			100 / 100			100 / 100			100 / 100			/		
undercut depth (m)	0.0 / 0.0			0.5 / 0.1			0.3 / 0.0			0.1 / 0.0			/		
bank composition[3]															
% fines	100 / 100			100 / 100			100 / 100			100 / 100			/		
% gravel	/			/			/			/			/		
% cobble	/			/			/			/			/		
% boulder	/			/			/			/			/		

1 – bankfull width includes an adjacent small side channel (see Figure 9)

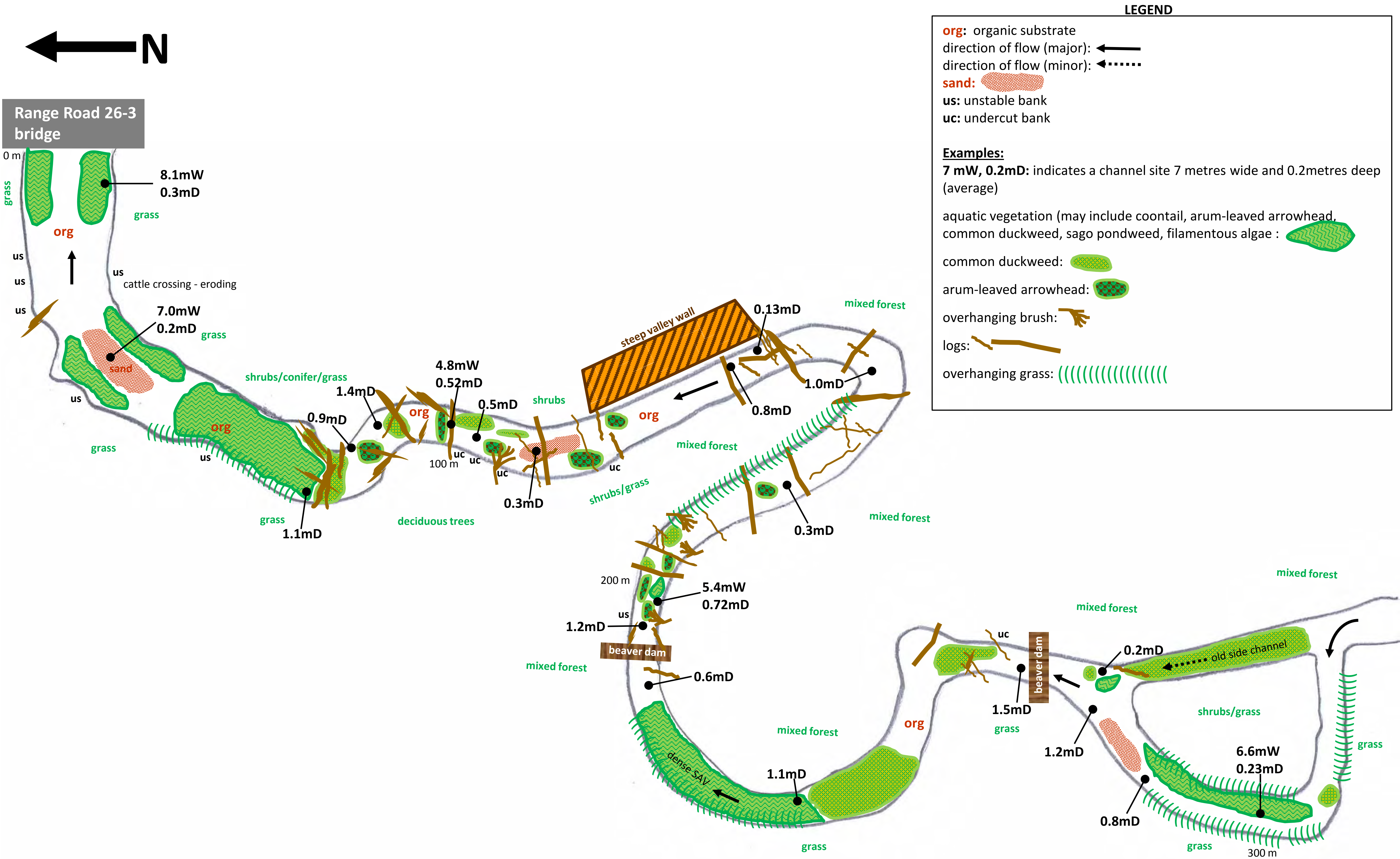


Figure 9 - Habitat map of Whelp Brook (Site 4), August 2013. Total length of mapped area is 330 m.

↓**Photo 13:** *View downstream to the Range Road 26-3 bridge, Whelp Brook (Site 4), August 7, 2013. The rafted woody debris under the bridge is indicative of high water.*

↓**Photo 14:** *View downstream at 100 m upstream of bridge, Whelp Brook (Site 4), August 7, 2013. Note the woody debris and aquatic vegetation.*

↓**Photo 15:** *View downstream at 170 m upstream of bridge, Whelp Brook (Site 4), August 7, 2013. Note the overhead cover provided by woody debris and riparian vegetation.*

↓**Photo 16:** *View upstream at 200 m upstream of bridge, Whelp Brook (Site 4), August 7, 2013. A small beaver dam is present in the background.*

↓**Photo 17:** *View downstream at 230 m upstream of bridge, Whelp Brook (Site 4), August 7, 2013. Note the dense aquatic vegetation.*

↓**Photo 18:** *View upstream at 300 m upstream of bridge, Whelp Brook (Site 4), August 7, 2013. Note the aquatic vegetation and well-vegetated banks.*

Whelp Brook (Site 5)

This site is located on Range Road 26-5 near Township Road 41-4 in Lacombe County. Whelp Brook flows under a bridge located at Township Road 41-4 (Figure 10, Photo 19). This portion of Whelp Brook has a very low gradient (0.13%) with an irregular meandering pattern. Site 5 at Whelp Brook was influenced by beaver activity with two beaver dams in a 300 m reach. The creek had a soft organic substrate and water depths between 0.4 and >2.0 m. The deepest water occurred immediately behind the beaver dams. The wetted widths ranged from 5 to 8 m and the channel widths from 7.0 to 8.0 m. A water discharge was obtained at a beaver dam and was calculated at 0.033 m^3/s (Figure 11, Tables 12 and 13).

The channel had high densities of aquatic vegetation with no visible water movement, except at beaver dams. Aquatic vegetation included arum-leafed arrowhead (low density), northern water-milfoil *Myriophyllum sibiricum* (dense), Richardson's pondweed (moderately dense), common bladderwort *Utricularia vulgaris* (sparse) and common duckweed (moderately dense). Instream cover was high at 60% coverage due to the dense aquatic vegetation and water depth, particularly behind beaver dams (Photos 20 to 24). Water clarity was high. The dissolved oxygen was low (2.90 mg/L) and below the acute guideline for the protection of aquatic life (5 mg/L). This site during the winter would likely suffer from anoxia and high concentrations of hydrogen sulphide due to the abundance of organic matter.

The riparian area was comprised largely of grasses and forbs with some small shrubs along the left-downstream-bank and poplar trees (all age-classes) and willow shrubs along the right-downstream-bank (Photos 22 to 23). Overhead cover was moderately low (20%) and largely provided by trees/shrubs with lesser amounts provided by grasses/forbs. There was no evidence of cattle grazing at this site. The creek banks were low (0.2 to 0.4 m), gently-sloped (10 to 30^o) and stable with high vegetative cover (Table 13).

Fish were sampled with four minnow traps set overnight. Backpack electrofishing was not attempted as deep water, soft substrate and dense vegetation made for unsafe and unsuitable conditions. One small white sucker (55 mm) was captured (Table 3). In October 2007, fish sampling (Site HF8) with minnow traps 4.4 km downstream captured brook stickleback (34) and white sucker (52) (Table 2).

Generally, fish habitat sensitivities to construction/channel modifications at Site 5 would be moderate, largely due to the healthy riparian area. Any proposed construction/channel modifications should be designed to reduce impacts to the riparian area to the greatest extent possible. Construction activities that occurred from the left-downstream-bank (grasses and willows) would largely avoid impacts to the riparian area.

Figure 10 – Aerial view of Whelp Brook (Site 5), Lacombe County, Alberta. Direction of flow indicated by white arrow.

Table 12 – Whelp Brook (Site 5) Watercourse Information

Project and Location Information	
Project	MPE Engineering Ltd.
Date	August 8, 2013
Assessed By	S. Stoklosar & S. Riemersma
Watercourse Name	Whelp Brook (Site 5)
Tributary to	Wolf Creek
Proposed Construction	Master Drainage Plan-additional conveyance capacity
UTM Coordinates	12 U 315526 E 5826553 N
Legal Land Description	SW29-41-26-W4
Topographic Map No.	83A12 (Ponoka)
General Location	Located at Range Road 26-5 near Township Road 41-4 in Lacombe County, west of Highway 2 and 10 km north of Lacombe.
Length Assessed (m)	300

Water Quality	
Time	12:00 pm
Air Temperature (°C)	16
Water Temperature (°C)	16.7
Conductivity (uS/cm)	1078
Dissolved Oxygen (mg/L) **Saturation (%)**	2.90 29.8
TDS (mg/L)	699
pH	7.0
Water Clarity	clear

General Information	
Adjacent Land Use	forested area and municipal roads
Dominant Riparian Vegetation	grass, shrubs and trees
Watercourse Navigable	no, beaver dams present
Natural Obstructions	beaver dams
Artificial Obstructions	none: bridge is a clear span
Stream Pattern	irregular meander
Stream Gradient (%)	0.13% (low)
Groundwater Seepage Present	none observed
Evidence of Angling	none

Instream Cover	
Total Instream Cover (%)	**60**
Woody Debris (%)	5
Boulders (%)	
Aquatic Plants (%)	80
Depth (%)	15
Surface Turbulence (%)	
Turbidity (%)	

Aquatic Vegetation	
Total Plant Coverage (%)	**50**
Emergent (%)	5
Floating-leafed (%)	20
Submergent (%)	50
Free Floating (%)	20
Filamentous Algae (%)	5
Macrophytic Algae (%)	

Overhead Cover	
Total Overhead Cover (%)	**20**
Woody Debris (%)	5
Undercut Bank (%)	
Grasses and Forbes (%)	35
Trees and Shrubs (%)	60

General Description of Assessed Site

-No evidence of cattle grazing.

-Abundant instream cover from dense aquatic vegetation and depth.

-Discharge at site: 0.033 m^3/s

-Substrate is thick deposits of organic matter.

-Site is impacted by beavers with two dams in 300 m reach.

Table 13 - Whelp Brook (Site 5) Transect Descriptions

Parameter	Transect Location														
	5 m (upstream of bridge)			**100 m upstream**			**200 m upstream**			**300 m upstream**			**____ m**		
Channel															
bankfull width (m)	7			13			12			13					
bankfull depth (m)	1.25			1.1			1.2			1.5					
channel width (m)	7			8			8			7					
wetted width (m)	5			8			7			7					
	1/4	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**
water depth (m)	0.70	0.55	0.40	0.80	0.50	0.40	0.80	0.70	0.50	0.90	1.20	0.90			
water velocity (m/s)[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Substrate															
% organic	100			100			100			100					
% fines															
% gravel															
% cobble															
% boulder															
embeddedness (N,L,M,H,VH)	Very High			Very High			Very High			Very High					
Banks	**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**		
bank height (m)	0.2 / 0.2			0.2 / 0.3			0.3 / 0.4			0.2 / 0.3			/		
bank slope (°)	<10 / <10			10 / 20			20 / 30			<10 / <10			/		
bank stability (**L**ow, **M**oderate, **H**igh)	H / H			H / H			H / H			H / H			/		
vegetation cover (%)	100 / 100			100 / 100			100 / 100			100 / 100			/		
undercut depth (m)	0.0 / 0.0			0.0 / 0.0			0.0 / 0.0			0.0 / 0.0			/		
bank composition[3]															
% fines	100 / 100			100 / 100			100 / 100			100 / 100			/		
% gravel	/			/			/			/			/		
% cobble	/			/			/			/			/		
% boulder	/			/			/			/			/		

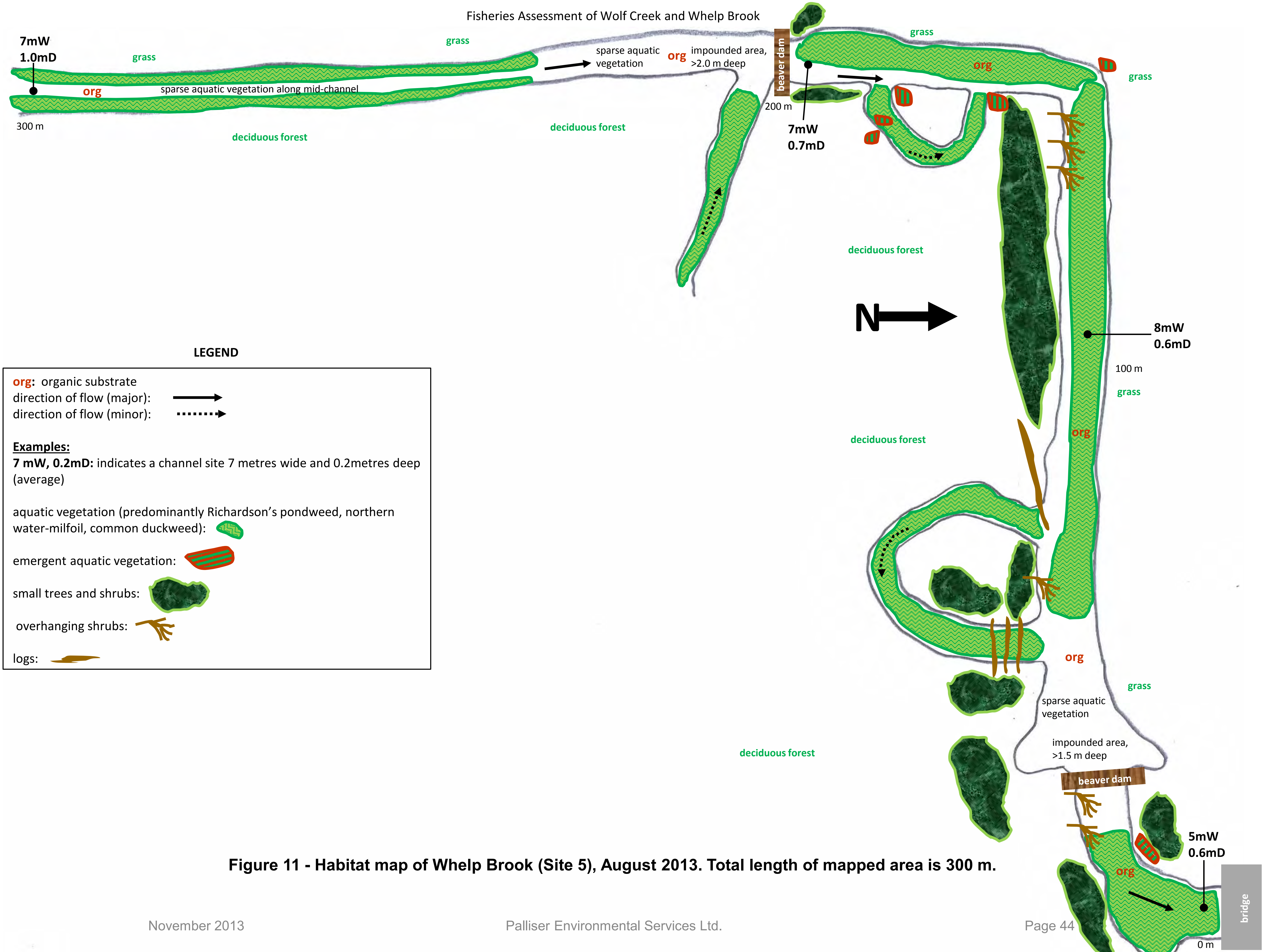


Figure 11 - Habitat map of Whelp Brook (Site 5), August 2013. Total length of mapped area is 300 m.

↓**Photo 19:** *View downstream to bridge at Township Road 41-4, Whelp Brook (Site 5), August 8, 2013. Note dense aquatic vegetation.*

↓**Photo 20:** *View upstream from beaver dam at 40 m upstream of bridge, Whelp Brook (Site 5), August 8, 2013. The water is deep and vegetation is sparse behind dam.*

↓**Photo 21:** *View downstream at 100 m upstream of bridge, Whelp Brook (Site 5), August 8, 2013. Note the dense vegetation.*

↓**Photo 22:** *View upstream at 100 m upstream of bridge, Whelp Brook (Site 5), August 8, 2013. Note the dense grasses along the left-downstream bank (LDB).*

↓**Photo 23:** *View downstream at 200 m upstream of bridge, Whelp Brook (Site 5), August 8, 2013. Note the dense woody vegetation along the right-downstream bank (RDB).*

↓**Photo 24:** *View downstream at 300 m upstream of bridge, Whelp Brook (Site 5), August 8, 2013. Note the grass along the LDB and the dense woody vegetation along the RDB.*

Whelp Brook (Site 6)

This site is located upstream of Township Road 41-2 near Duckett Road in Lacombe County. The creek flows through two culverts under Township Road 41-2 (Figure 12). This portion of Whelp Creek has a very low gradient (0.13%) with an irregular meandering pattern. The creek at this site had homogeneous habitat features comprising a soft organic substrate and water depths between 0.6 and 1.0 m. The wetted widths ranged from 4 to 8 m and the channel widths were less than the wetted widths as water levels appeared high and flooded, perhaps due to downstream obstructions (e.g., beaver dams). No water movement was visible (Figure 13, Tables 14 and 15).

The channel was densely choked with aquatic vegetation with no visible water movement (Photos 25 and 26). Aquatic vegetation included arum-leafed arrowhead (dense), northern water-milfoil (dense) and common duckweed (low density). Instream cover was high at 100% coverage due to the dense aquatic vegetation. Water clarity was high. The dissolved oxygen was low (1.85 mg/L) and below the acute guideline for the protection of aquatic life (5 mg/L). This site during the winter would likely suffer from anoxia and hydrogen sulphide due to the abundance of organic matter.

The riparian area was comprised largely of grasses and some willow shrubs (Photos 25 and 26). A few small clusters of poplar trees (*Populus* spp.) were observed. Overhead cover was low (20%) and largely provided by grasses/forbs with lesser amounts provided by trees/shrubs. The area adjacent to the creek is utilized as pasture and cattle were grazing adjacent to the creek during the assessment. The creek banks were low (0.2 to 0.7 m), gently-sloped (10 to 20^{o}) and stable with high vegetative cover (Table 15).

Fish were sampled with minnow traps set overnight. Backpack electrofishing was not attempted as deep water, soft substrate and dense vegetation made for unsafe and unsuitable conditions. One small white sucker (52 mm) was captured (Table 3). In April 2009, fish sampling (Site HF9) with an electrofisher immediately downstream of Township Road 41-2 captured brook stickleback (1) and fathead minnow (2) (Table 2).

Generally, fish habitat sensitivities to construction/channel modifications at Site 6 would be low as the channel is completely choked with aquatic vegetation and fish habitat is poor. Natural channel forming capabilities at this site are probably limited by the low gradient. Any construction/channel modifications proposed at Site 6 should include designs that would increase the fish habitat diversity such as deeper water and open water areas free of aquatic vegetation.

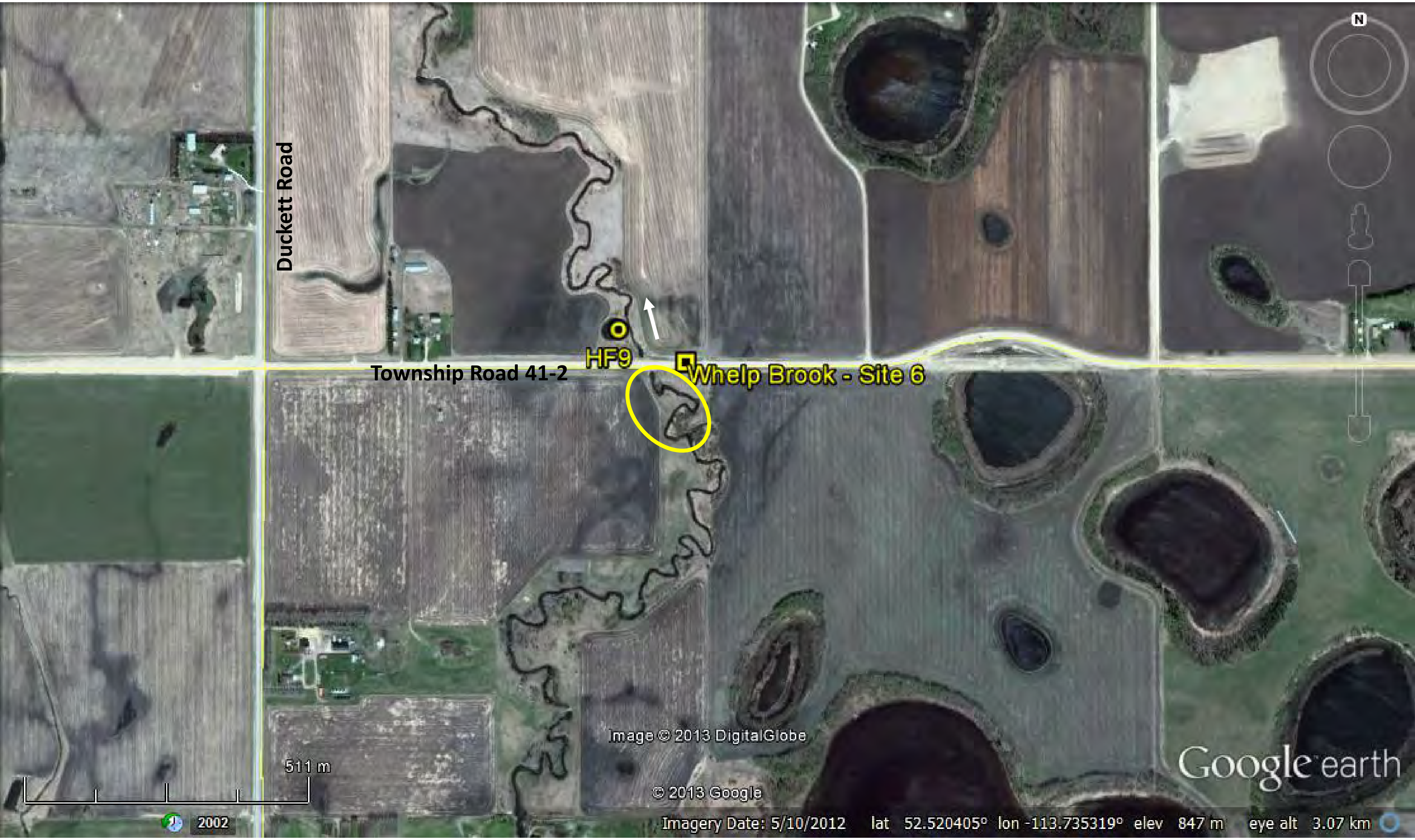


Figure 12 – Aerial view of Whelp Brook (Site 6), Lacombe County, Alberta. Direction of flow indicated by white arrow.

Table 14 – Whelp Brook (Site 6) Watercourse Information

Project and Location Information	
Project	MPE Engineering Ltd.
Date	August 8, 2013
Assessed By	S. Stoklosar & S. Riemersma
Watercourse Name	Whelp Brook (Site 6)
Tributary to	Wolf Creek
Proposed Construction	Master Drainage Plan-additional conveyance capacity
UTM Coordinates	12 U 314332 E 5822515 N
Legal Land Description	SW18-41-26-W4 NW7-41-26-W4
Topographic Map No.	83A12 (Ponoka)
General Location	This site is located on Township Road 41-2 near Duckett Road in Lacombe County, west of Highway 2 and 5.5 km north of Lacombe.
Length Assessed (m)	300
Water Quality	
Time	9:00 am
Air Temperature (°C)	13
Water Temperature (°C)	17.2
Conductivity (uS/cm)	1308
Dissolved Oxygen (mg/L) **Saturation (%)**	1.85 19.4
TDS (mg/L)	850
pH	7.2
Water Clarity	clear
General Information	
Adjacent Land Use	pasture
Dominant Riparian Vegetation	grass, willows
Watercourse Navigable	no, culverts and dense aquatic vegetation
Natural Obstructions	none except very dense aquatic vegetation
Artificial Obstructions	culverts
Stream Pattern	irregular meander
Stream Gradient (%)	0.13% (low)
Groundwater Seepage Present	none observed
Evidence of Angling	none

Instream Cover	
Total Instream Cover (%)	**100**
Woody Debris (%)	
Boulders (%)	
Aquatic Plants (%)	100
Depth (%)	
Surface Turbulence (%)	
Turbidity (%)	
Aquatic Vegetation	
Total Plant Coverage (%)	**100**
Emergent (%)	20
Floating-leafed (%)	
Submergent (%)	75
Free Floating (%)	5
Filamentous Algae (%)	
Macrophytic Algae (%)	
Overhead Cover	
Total Overhead Cover (%)	**20**
Woody Debris (%)	
Undercut Bank (%)	
Grasses and Forbes (%)	75
Trees and Shrubs (%)	25

General Description of Assessed Site
-Cattle grazing at left-downstream-bank. -Abundant instream cover from dense aquatic vegetation. -Substrate is thick deposits of organic matter. .

Table 15 - Whelp Brook (Site 6) Transect Descriptions

Parameter	**Transect Location**														
	10 m (upstream of culverts)			**100 m upstream**			**200 m upstream**			**300 m upstream**			**____ m**		
Channel															
bankfull width (m)	12			12			8			14					
bankfull depth (m)	1.4			0.9			1.4			1.4					
channel width (m)	<8			<7			<5			<4					
wetted width (m)	8			7			5			4					
	1/4	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**	**1/4**	**1/2**	**3/4**
water depth (m)	0.80	1.0	1.0	0.70	0.70	0.75	0.60	0.75	0.80	0.65	0.75	0.70			
water velocity (m/s)[2]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0			
Substrate															
% organic	100			100			100			100					
% fines															
% gravel															
% cobble															
% boulder															
embeddedness (N,L,M,H,VH)	Very High			Very High			Very High			Very High					
Banks	**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**			**LDB / RDB**		
bank height (m)	0.4 / 0.2			0.2 / 0.2			0.6 / 0.1			0.7 / 0.2			/		
bank slope (°)	10 / 10			10 / 10			20 / <10			20 / <10			/		
bank stability (**L**ow, **M**oderate, **H**igh)	H / H			H / H			H / H			H / H			/		
vegetation cover (%)	95 / 100			100 / 100			100 / 100			100 / 100			/		
undercut depth (m)	0.0 / 0.0			0.0 / 0.0			0.0 / 0.0			0.0 / 0.0			/		
bank composition[3]															
% fines	100 / 100			100 / 100			100 / 100			100 / 100			/		
% gravel	/			/			/			/			/		
% cobble	/			/			/			/			/		
% boulder	/			/			/			/			/		

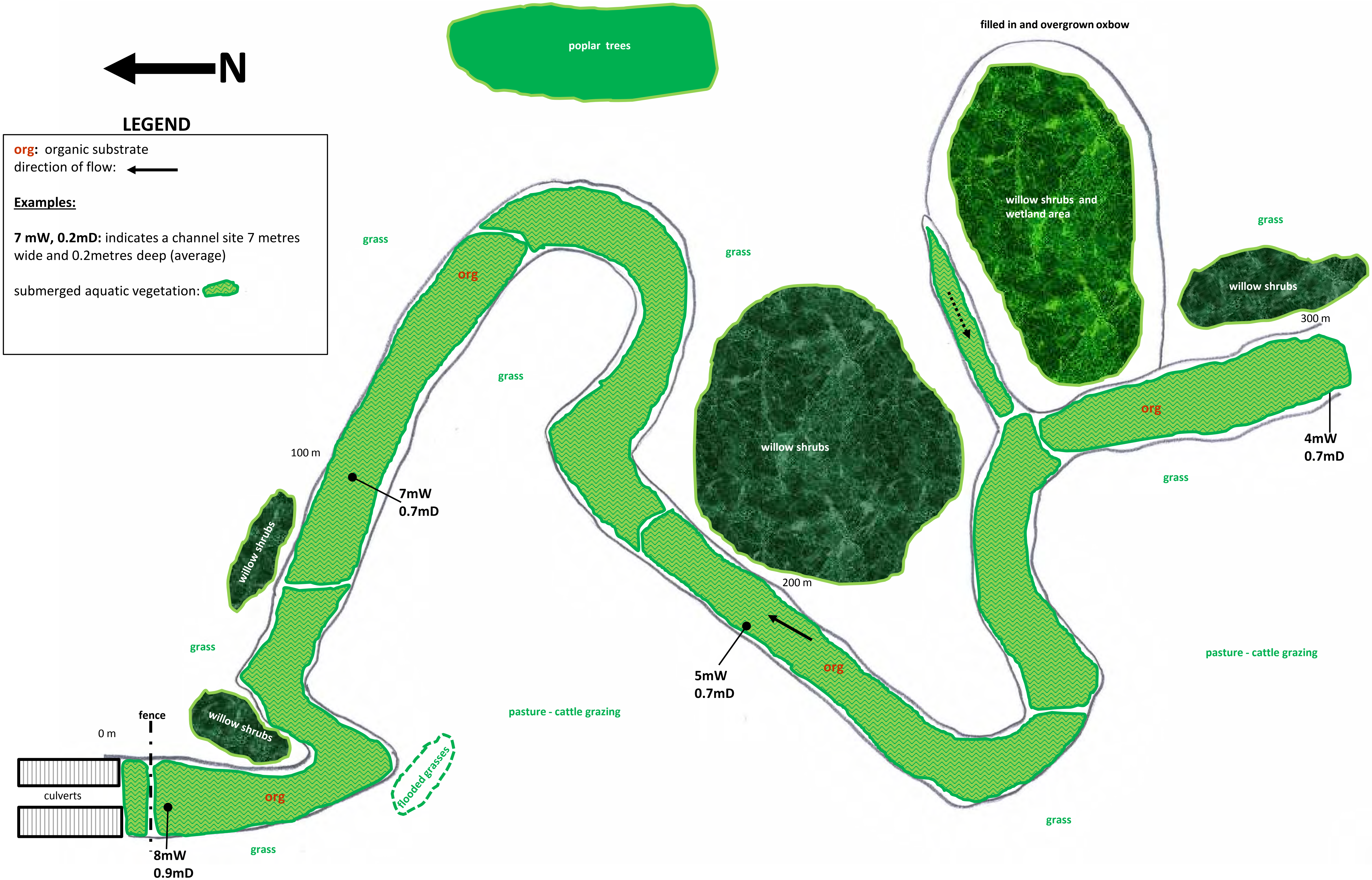


Figure 13 - Habitat map of Whelp Brook (Site 6), August 2013. Total length of mapped area is 300 m.

↓**Photo 25:** *View upstream from Township Road 41-2, Whelp Brook (Site 6), August 8, 2013. Note dense aquatic vegetation.*

↓**Photo 26:** *View upstream, 200 m upstream from Township Road 41-2, Whelp Brook (Site 6), August 8, 2013.*

SUMMARY AND CONCLUSIONS

At the time of this report, no site-specific instream channel improvements to reduce flooding potential have been identified for Wolf Creek or Whelp Brook. Overall, the sensitivity of Wolf Creek and Whelp Brook to instream modifications related to flood reduction activities is likely to be low. Both creeks have poor water quality and likely experience anoxia (low oxygen) as a result of the thick deposits of organic substrate during the summer and in particular during the winter. During this study, three of the six sites had extremely dense stands of aquatic vegetation that limited fish habitat and likely contribute to poor water quality through sedimentation, diurnal fluctuation of oxygen concentrations and the breakdown of organic matter during the winter, likely leading to very low oxygen conditions and hydrogen sulphide. Beaver dams and the associated ponds, although providing refuge habitat during periods of drought, can also limit the movement of fish. Three of the six sites in this study had beaver dams identified within the assessed section. Historical fish sampling in Wolf Creek and Whelp Brook between 2005 and 2011 and fish sampling during this study has not captured any sport fish in the creeks. Sport fish use of these creeks, primarily northern pike, is likely nil to limited and is probably confined to the mouth area of Wolf Creek where it confluences with the Battle River.

Many of the issues regarding water quality and fish habitat at Wolf Creek and Whelp Brook were present and identified in a 1977 study of the Battle River watershed by the provincial government.

Construction activities within the channel and immediately adjacent to Wolf Creek and Whelp Brook would require regulatory approval from Alberta Environment and Sustainable Resource Development (*Water Act*) and Fisheries and Oceans Canada (*Fisheries Act*) with regards to aquatic environment and fish habitat.

General Mitigation Measures

The following general mitigation measures for instream and nearshore construction activities at Wolf Creek and Whelp Brook should be implemented to maintain the aquatic environment:

- The provincial Restricted Activity Periods for instream construction should be adhered to for both creeks. Both creeks are designated Class C watercourses with a Restricted Activity Period of April 16 to June 30. Therefore, instream construction activities are permitted from July 1 to April 15.
- If necessary, fish should be salvaged from any work areas within a proposed work site should they become isolated from the mainstem of the creeks as a result of construction activities/design (e.g., instream berms, dam and pump).
- During construction, all equipment should be refuelled and all hazardous materials stored at least 100 m from the creeks.
- An emergency hydrocarbon spill kit should be maintained onsite in the unlikely event of a hydraulic fluid or fuel leak.
- Exposed topsoil adjacent to the creek should be re-seeded at the completion of construction with an appropriate grass seed mix.

- Construction activities at areas of Wolf Creek and Whelp Brook that have healthy riparian areas with trees, shrubs and grasses (e.g., Wolf Creek – Site 2 or Whelp Brook – Site 4) should be completed in a manner to reduce impacts to the riparian area to the greatest extent possible. This may include ‘no-go zones’, selection of less-sensitive riparian areas and re-establishing shrubs and trees at the completion of construction.
- Areas of exposed topsoil adjacent to the creeks should be contained by silt fencing until vegetation has regenerated sufficiently to hold the soil in place.
- The heavy equipment onsite should be free of mud, grease, oil and fluid leaks on the outside surfaces. The washing of mud-covered buckets, tracks, wheels and other equipment in the creeks should be prohibited.

CLOSURE

We trust the information provided is sufficient to describe the fish community and fish habitat at Wolf Creek and Whelp Brook. If you have any questions, please do not hesitate to contact Scott Stoklosar at 403-479-5668.

Yours truly,

Palliser Environmental Services Ltd.

Scott Stoklosar, M.Sc., QAES, P.Biol.
Senior Fisheries Biologist

REFERENCES

Alberta Environment. 1999. Surface water quality guidelines for use in Alberta. Environmental Sciences Division: Publication No. T/483. 20 pp.

Alberta Environment. 2000. Code of practice for watercourse crossings. *Water Act* - Water (Ministerial) Regulation. 26 pp.

Barton, B.A., and B.R. Taylor. 1996. Oxygen requirements of fishes in northern Alberta rivers with a general review of the adverse effects of low dissolved oxygen. Water Quality Research Journal of Canada 31(2): 361-409.

Canadian Council of Ministers of the Environment (CCME). Cadmium factsheet (online). http://ceqg-rcqe.ccme.ca/

Canadian Council of Ministers of the Environment (CCME). Arsenic factsheet (online). http://ceqg-rcqe.ccme.ca/

Christiansen, D.G. 1977. Battle River basin study: fisheries and wildlife section. Battle River basin study: background information report #8. Alberta Department of Environment and Alberta Fish and Wildlife Division. 265 pp.

Hauer, F.R., and W.R. Hill. 1996. Chapter 5: Temperature, light and oxygen. *In* Methods in Stream Ecology. *Edited by* F.R. Hauer and G.A. Lamberti. Academic Press. 674 pp.

Hynes, H.B.N. 1970. The Ecology of Running Waters. The University of Toronto Press. 555 pp.

MPE Engineering Ltd. 2013. Proposal for Engineering Services for: Master Drainage Plan for the Wolf Creek and Whelp Brook watersheds. Submitted to: Lacombe County, City of Lacombe, Ponoka County and Town of Blackfalds. 50 pp.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184. 966 pp.

United States Environmental Protection Agency (USEPA). 1978. Quality Criteria for Water. U.S. Government Printing Office (258-389/6057). 256 pp.

APPENDIX C

HYDROLOGIC ASSESSMENT

Regional Streamflow Analysis

C.1 Discharge Estimates of Selected Streamflow Gauging Stations

Because insufficient streamflow records exist in the Wolf Creek watershed, peak flow rates in the Wolf Creek subwatersheds were estimated by performing a regional streamflow analysis using data of nearby streamflow gauging stations.

Based on location, basin slope, vegetative cover, and predominant drainage orientation, as well as the results of the Alberta Environment regional study (Alberta Environment, 1988), six Water Survey Canada (WSC) stations located in the region were deemed to be hydrologically similar to Wolf Creek and had sufficiently longterm records. A summary of the selected stations are presented in Table C.1. These were selected for further analysis.

From the WSC website, for each station, the maximum *instantaneous* peak flows (Q_i) and annual maximum *daily* peak flows (Q_d) for all years of record were compiled. For the instances where Q_i was missing and Q_d was recorded, Q_i was estimated using the linear regression of Q_i and Q_d. The completed compilation of data used for subsequent statistical analysis, and the available recorded WSC data for Wolf Creek, is presented in Table C.2.

The Q_i flow data were then tested on several statistical distributions using CFA, a software program accepted by ESRD. The 3-Parameter log-Normal distribution was generally found to be the best fitting distribution, the results of which were adopted as the peak flood flows for each station. Hydrologic details of the six streamflow gauging stations used in the regional streamflow analysis are presented in Table C.3.

Table C.1: Selected WSC Stations for Regional Analysis

WSC Code	Stream Name	Location		Drainage Area		Qi/Qd	Flow Tendency		Years of Record, shaded cells																																																																																																																								
		Lat	Long	Gross	Effective		Timing of Flood	Late Summer	Years of Greatest Recorded Floods, Ranked																																								
		degrees	degrees	km²	km²				72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11
05CC011	Waskasoo Creek at Red Deer	52.3	113.8	486.6	250	1.1996	spring & summer	low flows																			5						1	3										2				4
05CD006	Haynes Creek near Haynes	52.33191	113.363	165	165	1.1351	spring & summer	often no flow																									1							5				3			4	2
05CD007	Parlby Creek at Alix	52.40747	113.1958	511.2	451.9	1.0851	spring	low flows														4											2							1				3				5
05FA012	Pipestone Creek near Wetaskiwin *	53.0	113.3	1030	732.8	1.0797	spring & summer	low flows			1								3			5					2	4																				
05FA014	Maskwa Creek No. 1 above Bearhills Lake	52.8	113.6	79.1	61.2	1.0671	spring	occasional no flow		4	1								2			5																				3						
05FA024	Weiller Creek near Wetaskiwin	53.0	113.3	235.5	90.1	1.2925	spring & summer	occasional no flow																												4						1	5	2				3
05FA026	**Wolf Creek at Twp Rd 410 (Discontinued)**	52.5	113.7	76.3	67.8	1.2927	-	low flows																																				1				

Table C.2: Compiled Q_i and Q_d Data for Selected Hydrometric Stations

= from WSC daily dataset
= void-filled using adopted equation

Wolf Creek at Twp Rd 410, 05FA026

Drainage Area	**gross**	**76.3**	**km²**
	effective	**67.8**	**km²**

Year	PeakFlow	SYM	HH:MM	CODE	MM--DD	MaxAnnu	SYM	MM--DD
1965								
1966								
1967								
1968								
1969								
1970								
1971								
1972								
1973								
1974								
1975								
1976								
1977								
1978								
1979								
1980								
1981								
1982								
1983								
1984								
1985								
1986								
1987								
1988								
1989								
1990								
1991								
1992								
1993								
1994								
1995								
1996								
1997								
1998								
1999								
2000								
2001								
2002								
2003								
2004								
2005								
2006								
2007	4.91					3.8		06--18
2008	1.21		17:46	MST	05--22	0.936		05--22
2009	0.41					0.319		10--22
2010								
2011								
2012								
2013								

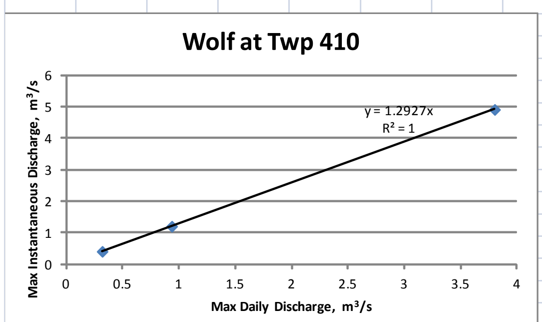


Table C.2: Compiled Q_i and Q_d Data for Selected Hydrometric Stations - continued

= from WSC daily dataset
= void-filled using adopted equation

Wasksoo Creek at Red Deer, 05CC011

Drainage Area gross 486.6 km²; effective 250 km²

Year	PeakFlow	SYM	HH:MM	CODE	MM--DD	MaxAnnu	SYM	MM--DD
1965								
1966								
1967								
1968								
1969								
1970								
1971								
1972								
1973								
1974								
1975								
1976								
1977								
1978								
1979								
1980								
1981								
1982								
1983								
1984								
1985	11.46					9.55		04--03
1986	7.80					6.5		07--19
1987	5.93					4.94		04--05
1988	8.57		0:00		06--08	1.92		03--31
1989	6.08					5.07		04--13
1990	22.9	A	0:00		06--13	19.7		06--13
1991	3.62					3.02		06--27
1992	3.79					3.16	B	03--05
1993	9.60					8	B	03--24
1994	12.12					10.1		05--20
1995	6.36					5.3		06--06
1996	31.67					26.4		04--09
1997	24.11					20.1		04--17
1998	2.32					1.93		06--29
1999	20.39					17		07--16
2000	4.03					3.36		06--08
2001	1.07					0.893	B	04--18
2002	2.06					1.72		08--02
2003	20.03					16.7		04--10
2004	3.90					3.25		08--04
2005	8.38		2:00	MST	04--02	7.37		04--02
2006	11		17:46	MST	08--10	7.98	B	04--03
2007	24.2		6:00	MST	05--06	21.8		05--06
2008	11.9		23:15	MST	08--08	3.96		06--11
2009	6.9		1:15	MST	08--03	1.72		08--03
2010	12.5		18:46	MST	07--13	10.4		07--15
2011	23.75					19.8	A	04--13
2012								
2013								

= from WSC daily dataset
= void-filled using adopted equation

Haynes Creek near Haynes, 05CD006

Drainage Area gross 165 km²; effective 165 km²

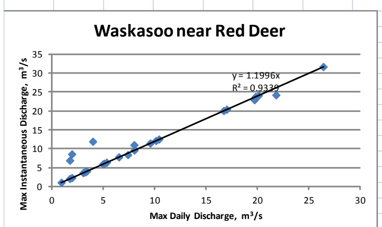
Year	PeakFlow	SYM	HH:MM	CODE	MM--DD	MaxAnnu	SYM	MM--DD
1965								
1966								
1967								
1968								
1969								
1970								
1971								
1972								
1973								
1974								
1975								
1976								
1977								
1978								
1979	1.51		7:00	MST	03--19	1.19	A	03--15
1980	1.52					1.34	E	04--08
1981	0.747		8:20	MST	03--17	0.65		03--17
1982	6.56		17:37	MST	04--18	6.37		04--18
1983	1.27		1:23	MST	07--07	1.05		07--07
1984	0.763		19:00	MST	05--02	0.316		05--03
1985	2.99		13:59	MST	04--03	2.89		04--03
1986	1.43					1.26	B	03--03
1987	4.99					4.4	B	04--05
1988	0.14					0.119		07--29
1989	3.8	B	7:58	MST	04--09	2.67		04--13
1990	1.53		5:00	MST	06--15	1.47		06--15
1991	0.598		16:14	MST	04--05	0.59		04--05
1992	2.37					2.09	B	03--08
1993	1.63					1.44	B	03--26
1994	1.59					1.4	B	03--19
1995	0.441		8:30	MST	03--20	0.333		03--20
1996	21.00					18.5	B	04--09
1997	4.69					4.13	B	04--02
1998	0.073		4:00	MST	07--13	0.069		07--13
1999	4.87		16:00	MST	04--09	4.82		04--09
2000	1.60					1.41		04--01
2001	0.024		22:35	MST	05--21	0.015		06--21
2002	2.02		14:35	MST	04--23	1.63		04--24
2003	8.29		15:30	MST	04--10	7.09		04--10
2004	0.01					0.005		07--09
2005	3.97					3.5	B	04--01
2006	4.39					3.87	B	04--04
2007	8.57		10:00	MST	05--06	7.88		05--06
2008	1.52		1:00	MST	05--03	1.09		05--03
2009	0.397		8:00	MST	04--12	0.386		04--12
2010	8.3		11:30	MST	07--15	6.43		07--15
2011	15.44					13.6	B	04--13
2012								
2013								

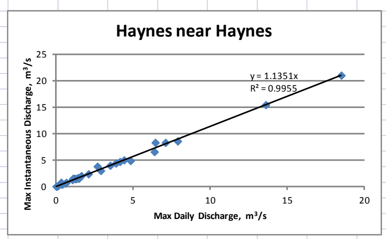
= from WSC daily dataset
= void-filled using adopted equation

Parlby Creek at Alix, 05CD007

Drainage Area gross 511.2 km²; effective 451.9 km²

Year	PeakFlow	SYM	HH:MM	CODE	MM--DD	MaxAnnu	SYM	MM--DD
1965								
1966								
1967								
1968								
1969								
1970								
1971								
1972								
1973								
1974								
1975								
1976								
1977								
1978								
1979								
1980								
1981								
1982								
1983								
1984	2.30					2.12	B	04--01
1985	14.5		0:40	MST	04--04	13.9		04--04
1986	7.41					6.83	B	03--05
1987	9.81		15:40	MST	04--06	9.62		04--06
1988	5.08		7:00	MST	07--18	4.87		07--18
1989	8.77					8.08	B	04--08
1990	8.01		7:35	MST	04--01	7.82		04--01
1991	5.96		14:21	MST	04--06	5.86		04--06
1992	6.40					5.9	B	03--15
1993	5.49					5.06	B	03--26
1994	5.77					5.32	B	03--23
1995	1.39					1.28	B	03--23
1996	21.92					20.2	B	04--11
1997	10.3		3:00	MST	04--03	9.29		04--03
1998	0.893		19:13	MST	07--11	0.849		07--11
1999	13		19:35	MST	04--10	11.2		04--11
2000	7.49					6.9	B	04--02
2001	0.72					0.667	B	04--12
2002	3.79					3.49		04--21
2003	23.3	B	23:01	MST	04--11	20.8	B	04--11
2004	0.855	B	8:19	MST	04--03	0.494	B	04--03
2005	12.80					11.8	B	04--04
2006	9.07					8.36	B	04--06
2007	14.8		15:05	MST	05--07	13.6		05--07
2008	1.44		4:00	MST	06--14	1.36		06--14
2009	1.61					1.48	B	04--14
2010	11.6		8:00	MST	07--17	11.2		07--17
2011	14.11					13	B	04--15
2012								
2013								





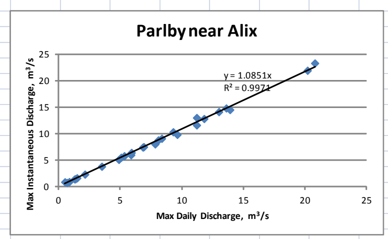


Table C.2: Compiled Q_i and Q_d Data for Selected Hydrometric Stations - concluded

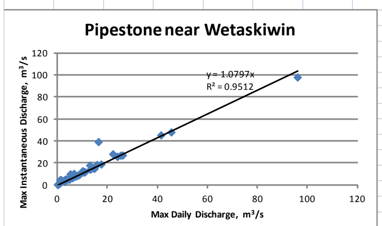
= from WSC daily dataset
= void-filled using adopted equation

Pipestone Creek below Bigstone Creek (05FA022), Discontinued

Pipestone Creek near Wetaskiwin (05FA012)

Drainage Area	**gross**	**1030**	**km^2**	1020 (05FA022)
	effective	**732.8**	**km^2**	843 (05FA022)

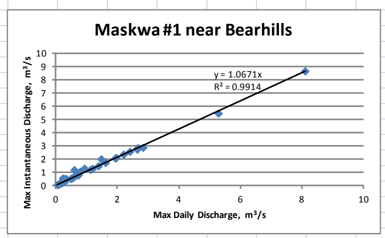
Year	PeakFlow	SYM	HH:MM	CODE	MM--DD	MaxAnnu	SYM	MM--DD
1965								
1966								
1967								
1968								
1969								
1970								
1971								
1972	15.33					14.2	B	04--07
1973	18.5	A	1:00	MST	07--02	15.8		07--02
1974	98		12:20	MST	04--23	96	B	04--23
1975	9.57					8.86	B	04--23
1976	5.36					4.96	B	04--06
1977	4.59		15:10	MST	08--09	2.8		08--10
1978	5.32	B	8:30	MST	03--29	3.37	B	03--29
1979	12.8	B	20:00	MST	03--20	10.1	B	03--20
1980	11.7	B	0:02	MST	04--05	10.2	B	04--06
1981	10.4	B	19:30	MST	03--19	6.6	B	03--17
1982	45.4	B	12:20	MST	04--24	41.4	B	04--25
1983	15		4:35	MST	07--08	14.8		07--08
1984	5.09	B	15:00	MST	04--01	3.96	B	03--25
1985	28.2	B	11:02	MST	04--03	22.2	B	04--03
1986	8.48					7.85	B	03--02
1987	7.87					7.29	B	04--08
1988	1.48		21:28	MST	07--06	0.926		07--06
1989	6.59		20:00	MST	03--20	6.1	B	04--11
1990	48.1		9:45	MST	07--07	45.5		07--07
1991	39.3		7:23	MST	07--06	16.4		07--06
1992	11.66					10.8	B	03--22
1993	9.23					8.55	B	03--28
1994	5.05					4.68	B	03--30
1995	3.21					2.97	B	03--23
1996	14.14					13.1	B	04--10
1997	25.91					24	B	04--13
1998	17.9		15:43	MST	07--05	13		07--06
1999	25.91					24	B	04--13
2000	4.57		19:48	MST	07--02	1.52		07--10
2001	1.06		20:40	MST	07--29	0.687		08--01
2002	6.48					6	B	04--24
2003	11.88					11	B	04--11
2004	4.78		12:25	MST	07--19	1.11		07--19
2005	18.89					17.5	B	04--04
2006	8.58					7.95	B	04--06
2007	26.9		1:20	MST	05--08	25.3		05--08
2008	0.948		11:05	MST	05--16	0.282		05--16
2009	0.23					0.211	B	04--12
2010	10		2:45	MST	07--14	5.17		07--14
2011	27.1		22:00	MST	07--29	26.1		07--29
2012								
2013								



Maskwa Creek No.1 above Bearhills Lake, 05FA014

Drainage Area	**gross**	**79.1**	**km^2**
	effective	**61.2**	**km^2**

Year	PeakFlow	SYM	HH:MM	CODE	MM--DD	MaxAnnu	SYM	MM--DD
1965								
1966								
1967								
1968								
1969								
1970								
1971								
1972								
1973	2.84					2.66		07--01
1974	8.64					8.1		04--20
1975	1.72					1.61	B	04--20
1976	0.54					0.507	B	04--07
1977	0.14					0.13		05--16
1978	0.32					0.297	B	03--29
1979	1.28	B	21:45	MST	04--18	0.924	B	03--18
1980	1.06		10:45	MST	08--28	0.788		08--28
1981	1.47					1.38	B	03--15
1982	5.45		19:50	MST	04--21	5.28		04--22
1983	1.99	B	8:40	MST	04--02	1.47	B	04--02
1984	0.12					0.113	B	03--30
1985	2.73		1:45	MST	04--04	2.64		04--04
1986	0.511	B	21:35	MST	02--26	0.325	B	02--27
1987	0.55					0.512		04--12
1988	0.24					0.225		06--09
1989	0.51					0.479		04--12
1990	2.06					1.93	B	03--31
1991	1.20					1.12		04--04
1992	0.78					0.727	B	03--18
1993	0.60					0.56	B	03--21
1994	0.21					0.2	B	03--17
1995	0.17					0.163	B	03--19
1996	2.09					1.96		04--11
1997	1.27					1.19		04--18
1998	0.12					0.112		06--29
1999	2.56					2.4	E	04--10
2000	0.483	B	6:18	MST	03--29	0.267	B	03--29
2001	0.494		12:00	MST	07--29	0.279		07--29
2002	1.18		7:48	MST	04--25	0.597		04--25
2003	2.35					2.2	B	04--10
2004	0.14					0.135	B	03--29
2005	2.86		14:00	MST	04--05	2.83		04--05
2006	0.31					0.287	B	04--07
2007	0.742		15:45	MST	05--05	0.639		05--05
2008	0.05					0.044	B	04--29
2009	0.09					0.08	B	04--13
2010	0.538		17:45	MST	07--13	0.219		07--14
2011								
2012								
2013								



Weiller Creek near Wetaskiwin (05FA024)

Drainage Area	**gross**	**235.5**	**km^2**
	effective	**90.1**	**km^2**

Year	PeakFlow	SYM	HH:MM	CODE	MM--DD	MaxAnnu	SYM	MM--DD
1965								
1966								
1967								
1968								
1969								
1970								
1971								
1972								
1973								
1974								
1975								
1976								
1977								
1978								
1979								
1980								
1981								
1982								
1983								
1984								
1985	6.99	B	15:06	MST	03--20	6.46	B	03--19
1986	4.59					3.55	B	03--02
1987	0.60					0.465	B	03--31
1988	2.31		14:31	MST	10--24	0.885		07--13
1989	2.56		15:06	MST	10--27	1.35	B	04--04
1990	4.32		19:54	MST	07--04	2.3	B	03--29
1991	1.64					1.27	B	03--30
1992	3.31					2.56	B	03--21
1993	0.85					0.656	B	03--27
1994	0.70					0.544	B	03--21
1995	0.597		6:35	MST	08--19	0.431		08--19
1996	1.80					1.39	B	04--08
1997	4.95					3.83	B	04--13
1998	1.52		1:00	MST	07--06	1.11		06--29
1999	9.31					7.2	B	04--11
2000	0.62					0.48	B	03--31
2001	0.19		9:19	MST	07--29	0.075		07--29
2002	1.46					1.13	B	04--19
2003	5.47					4.23	B	04--10
2004	5.77		14:30	MST	07--05	0.551		07--05
2005	10.9	B	18:45	MST	03--11	8.13	B	04--02
2006	8.05					6.23	B	04--06
2007	10.7		12:30	MST	05--05	7.71		05--05
2008	0.14					0.112	B	04--30
2009	0.09					0.07	B	04--09
2010	6.85		14:30	MST	07--23	4.72		07--23
2011	10.6	B	15:15	MST	04--16	9.19	B	04--16
2012								
2013								

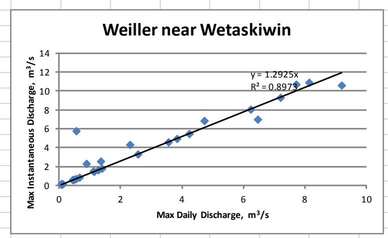


Table C.3: Estimated Maximum Instantaneous Discharges and Selected Hydrometric Data

Station		Waskasoo Ck at Red Deer	Haynes Ck near Haynes	Parlby Ck at Alix	Pipestone Ck near Wetaskiwin	Maskwa Ck No. 1 above Bearhills Lake	Weiller Ck near Wetaskiwin
Basin		05CC011	05CD006	05CD007	05FA012	05FA014	05FA024
Parameter	Unit						
Drainage Area - gross	km^2	486.6	165.0	511.2	1030.0	79.1	235.5
- effective		250.0	165.0	451.9	732.8	61.2	90.1
Period of Record	years	1985 - 2011	1979 - 2011	1984 - 2011	1972 - 2011	1973 - 2010	1985 - 2011
year of greatest recorded peak flow	year	1996	1996	2003	1974	1974	2005
greatest recorded peak flow	m^3/s	31.7	21	23.3	98	8.64	10.9
greatest recorded event unit yield	$m^3/s/km^2$	0.065	0.127	0.046	0.095	0.109	0.046
Frequency distribution		3P log Normal	3P log Normal	3P log Normal	3P log Normal	3P log Normal	3P log Normal
Max Instantaneous Discharge for:							
1:2	**m^3/s**	**8.79**	**1.92**	**6.66**	**10.40**	**0.68**	**2.30**
1:5	m^3/s	17.00	5.43	12.60	23.30	1.97	6.42
1:10	m^3/s	23.70	9.18	16.90	34.90	3.46	10.90
1:20	m^3/s	31.10	14.10	21.50	48.80	5.51	16.70
1:50	m^3/s	42.00	22.70	27.80	70.70	9.33	27.20
1:100	**m^3/s**	**51.30**	**31.20**	**32.90**	**90.50**	**13.20**	**37.50**
1:200	m^3/s	61.60	41.80	38.20	113.00	18.30	50.30
1:500	m^3/s	76.70	59.30	45.80	149.00	26.90	71.80
Unit yield for:							
1:2	**$m^3/s/km^2$**	**0.018**	**0.012**	**0.013**	**0.010**	**0.009**	**0.010**
1:5	$m^3/s/km^2$	0.035	0.033	0.025	0.023	0.025	0.027
1:10	$m^3/s/km^2$	0.049	0.056	0.033	0.034	0.044	0.046
1:20	$m^3/s/km^2$	0.064	0.085	0.042	0.047	0.070	0.071
1:50	$m^3/s/km^2$	0.086	0.138	0.054	0.069	0.118	0.115
1:100	**$m^3/s/km^2$**	**0.105**	**0.189**	**0.064**	**0.088**	**0.167**	**0.159**
1:200	$m^3/s/km^2$	0.127	0.253	0.075	0.110	0.231	0.214
1:500	$m^3/s/km^2$	0.158	0.359	0.090	0.145	0.340	0.305

C.2 Discharge – Drainage Area Relationships

The estimated maximum instantaneous flows of various return periods for the six WSC stations were then plotted against their respective drainage areas to determine the discharge – drainage area relationship for the region.

From the derived data noted above, the relationships between drainage area and discharge for selected return periods were then derived using regression analysis. The best-fit curve was in the form $Q=aDA^b$, where: Q is the estimated discharge, DA is the drainage area of a given sub-basin, in km^2, and a and b are the constants derived from the regression analysis, for each return period.

The drainage areas of the selected stations in the regional streamflow analysis and the Wolf Creek subwatersheds are all greater than 25 km^2, so no adjustments were required for watersheds less than 25 km^2.

These data are presented in Figure C.1 and the linear regression equations are presented in Table C.4.

Figure C.1: Drainage Area – Maximum Instantaneous Flow Relationships

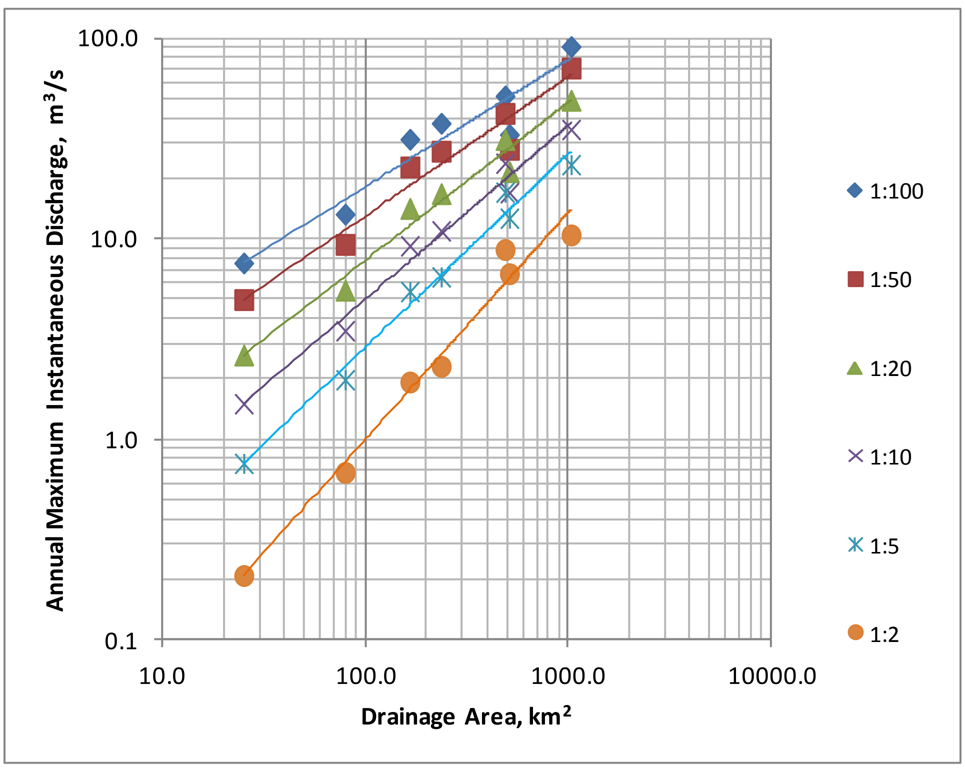


Table C.4: Drainage Area – Discharge Equations*

Return Period	Maximum Instantaneous Discharge, Q_i, m^3/s
1:2 year	$Q = 0.0055 \times DA^{1.1293}$
1:5 year	$Q = 0.0340 \times DA^{0.9631}$
1:10 year	$Q = 0.0922 \times DA^{0.8657}$
1:20 year	$Q = 0.2080 \times DA^{0.7866}$
1:50 year	$Q = 0.5319 \times DA^{0.6930}$
1:100 year	$Q = 0.9869 \times DA^{0.6315}$

**These equations derived from regional analysis are considered to be valid for sub-basins between 25 km^2 and 1000 km^2. To estimate discharge for an ungauged sub-basin less than 25 km^2, the following generally accepted equation was used:*

$$Q_{sb} = Q_{25} * (DA_{sb} / 25)$$

Where: Q_{sb} is the estimated discharge for the particular sub-basin smaller than 25 km^2,
Q_{25} is the discharge for a 25 km^2 sub-basin, estimated using the derived Q-DA equations from the regional analysis, and
DA_{sb} is the drainage area for the particular sub-basin smaller than 25 km^2.

C.3 Discharge Estimates of Selected Subwatersheds

The resulting estimated discharges for selected subwatersheds (at regional road crossings) are presented in Table C.5. These results indicate that the 1:100 year unit maximum instantaneous flowrate varies from 0.3 $m^3/s/km^2$ (3 L/s/ha) for a 25 km^2 watershed, to 0.2 $m^3/s/km^2$ (2 L/s/ha) for a 100 km^2 watershed, to 0.1 $m^3/s/km^2$ (1 L/s/ha) for a 500 km^2 watershed. The reduction of unit flowrates as drainage area increases suggests that, as runoff progresses downstream, there are significant routing effects which attenuate peak flowrates. As such, an overall pre-development unit release rate of 2 L/s/ha appears to be reasonable for the Wolf Creek watershed.

Table C.5: Estimated Discharge Rates for Wolf Creek Subwatersheds

	Estimated Discharges for Wolf Creek Subwatersheds, m^3/s										
	Wolf Creek					Whelp Brook					Wolf Ck
	Hwy 2A	Twp Rd 41-2	Twp Rd 41-4	Hwy 604	above Whelp Bk	Twp Rd 41-0	Twp Rd 41-2	Twp Rd 41-4	Hwy 604	above Wolf Ck	at Battle R
Total Drainage Area, km^2	78	99	119	151	156	87	151	166	190	311	524
1:2	0.75	0.99	1.21	1.59	1.65	0.85	1.59	1.77	2.06	3.59	6.48
1:5	2.26	2.84	3.39	4.27	4.40	2.51	4.27	4.67	5.32	8.56	14.14
1:10	4.01	4.92	5.77	7.10	7.30	4.40	7.10	7.70	8.66	13.27	20.84
1:20	6.40	7.72	8.93	10.77	11.05	6.98	10.77	11.60	12.90	19.01	28.65
1:50	10.89	12.85	14.59	17.21	17.61	11.75	17.21	18.38	20.18	28.40	40.77
1:100	**15.46**	**17.97**	**20.18**	**23.46**	**23.95**	**16.56**	**23.46**	**24.90**	**27.12**	**37.02**	**51.47**

C.4 Flow Hydrographs

This analysis was used to determine volumes and hydrographs for each subwatershed under pre-development conditions. The subwatersheds are identified on Figure 2.

Because each Wolf Creek subwatershed is not gauged, their representative hydrographs were estimated from limited available historic data in the watershed. A review of the data revealed a single event which was acceptable for developing a representative unit hydrograph for all subwatersheds:

- significant runoff (about a 1:10 year return period)
- single rain storm event (less than 24 hours in duration) separated by several days of dry weather.

This event occurred in July 26 to July 31, 2011 at the Alberta Agriculture research Site #301 (drainage area = 47 km^2) in the Whelp Brook subwatershed, the hydrograph of which is presented in Figure C.2. Basic hydrograph characteristics include: duration of runoff of 6 days (144 hours) and Time to Peak of 0.75 days (18 hours).

Figure C.2: Whelp Brook Site #301 Hydrograph of July 26-31, 2011

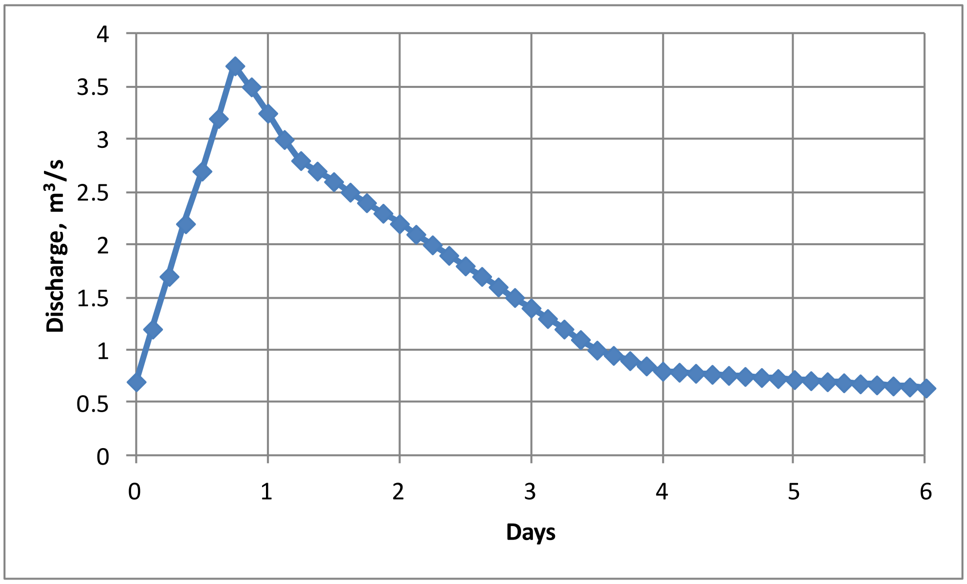


Table C.5 presents the hydrograph data for the Wolf Creek subwatersheds which are used in the routing analysis of HEC-RAS, describe in Appendix D.

Table C.5: Incremental 1:100 Year Hydrograph Data for the Wolf Creek Subwatersheds

sub-watershed	Whelp 41-0	Whelp 41-2	Whelp 41-4	Whelp 604	Whelp 263	Wolf 41-0	Wolf 41-2	Wolf 41-4	Wolf 604	above Whelp	Wolf at Battle R
DA, km2 ->	87	64	31	8	120	76	23	20	32	5	57
time	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
hrs	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
0	3.292	2.422	1.173	0.303	4.541	2.876	0.870	0.757	1.211	0.189	2.157
3	5.643	4.151	2.011	0.519	7.784	4.930	1.492	1.297	2.076	0.324	3.697
6	7.995	5.881	2.849	0.735	11.027	6.984	2.114	1.838	2.941	0.459	5.238
9	10.346	7.611	3.686	0.951	14.270	9.038	2.735	2.378	3.805	0.595	6.778
12	12.697	9.341	4.524	1.168	17.514	11.092	3.357	2.919	4.670	0.730	8.319
15	15.049	11.070	5.362	1.384	20.757	13.146	3.978	3.459	5.535	0.865	9.859
18	17.400	12.800	6.200	1.600	24.000	15.200	4.600	4.000	6.400	1.000	11.400
21	16.459	12.108	5.865	1.514	22.703	14.378	4.351	3.784	6.054	0.946	10.784
24	15.284	11.243	5.446	1.405	21.081	13.351	4.041	3.514	5.622	0.878	10.014
27	14.108	10.378	5.027	1.297	19.459	12.324	3.730	3.243	5.189	0.811	9.243
30	13.168	9.686	4.692	1.211	18.162	11.503	3.481	3.027	4.843	0.757	8.627
33	12.697	9.341	4.524	1.168	17.514	11.092	3.357	2.919	4.670	0.730	8.319
36	12.227	8.995	4.357	1.124	16.865	10.681	3.232	2.811	4.497	0.703	8.011
39	11.757	8.649	4.189	1.081	16.216	10.270	3.108	2.703	4.324	0.676	7.703
42	11.286	8.303	4.022	1.038	15.568	9.859	2.984	2.595	4.151	0.649	7.395
45	10.816	7.957	3.854	0.995	14.919	9.449	2.859	2.486	3.978	0.622	7.086
48	10.346	7.611	3.686	0.951	14.270	9.038	2.735	2.378	3.805	0.595	6.778
51	9.876	7.265	3.519	0.908	13.622	8.627	2.611	2.270	3.632	0.568	6.470
54	9.405	6.919	3.351	0.865	12.973	8.216	2.486	2.162	3.459	0.541	6.162
57	8.935	6.573	3.184	0.822	12.324	7.805	2.362	2.054	3.286	0.514	5.854
60	8.465	6.227	3.016	0.778	11.676	7.395	2.238	1.946	3.114	0.486	5.546
63	7.995	5.881	2.849	0.735	11.027	6.984	2.114	1.838	2.941	0.459	5.238
66	7.524	5.535	2.681	0.692	10.378	6.573	1.989	1.730	2.768	0.432	4.930
69	7.054	5.189	2.514	0.649	9.730	6.162	1.865	1.622	2.595	0.405	4.622
72	6.584	4.843	2.346	0.605	9.081	5.751	1.741	1.514	2.422	0.378	4.314
75	6.114	4.497	2.178	0.562	8.432	5.341	1.616	1.405	2.249	0.351	4.005
78	5.643	4.151	2.011	0.519	7.784	4.930	1.492	1.297	2.076	0.324	3.697
81	5.173	3.805	1.843	0.476	7.135	4.519	1.368	1.189	1.903	0.297	3.389
84	4.703	3.459	1.676	0.432	6.486	4.108	1.243	1.081	1.730	0.270	3.081
87	4.468	3.286	1.592	0.411	6.162	3.903	1.181	1.027	1.643	0.257	2.927
90	4.232	3.114	1.508	0.389	5.838	3.697	1.119	0.973	1.557	0.243	2.773
93	3.997	2.941	1.424	0.368	5.514	3.492	1.057	0.919	1.470	0.230	2.619
96	3.762	2.768	1.341	0.346	5.189	3.286	0.995	0.865	1.384	0.216	2.465
99	3.715	2.733	1.324	0.342	5.124	3.245	0.982	0.854	1.366	0.214	2.434
102	3.668	2.698	1.307	0.337	5.059	3.204	0.970	0.843	1.349	0.211	2.403
105	3.621	2.664	1.290	0.333	4.995	3.163	0.957	0.832	1.332	0.208	2.372
108	3.574	2.629	1.274	0.329	4.930	3.122	0.945	0.822	1.315	0.205	2.342
111	3.527	2.595	1.257	0.324	4.865	3.081	0.932	0.811	1.297	0.203	2.311
114	3.480	2.560	1.240	0.320	4.800	3.040	0.920	0.800	1.280	0.200	2.280
117	3.433	2.525	1.223	0.316	4.735	2.999	0.908	0.789	1.263	0.197	2.249
120	3.386	2.491	1.206	0.311	4.670	2.958	0.895	0.778	1.245	0.195	2.218
123	3.339	2.456	1.190	0.307	4.605	2.917	0.883	0.768	1.228	0.192	2.188
126	3.292	2.422	1.173	0.303	4.541	2.876	0.870	0.757	1.211	0.189	2.157
129	3.245	2.387	1.156	0.298	4.476	2.835	0.858	0.746	1.194	0.186	2.126
132	3.198	2.352	1.139	0.294	4.411	2.794	0.845	0.735	1.176	0.184	2.095
135	3.151	2.318	1.123	0.290	4.346	2.752	0.833	0.724	1.159	0.181	2.064
138	3.104	2.283	1.106	0.285	4.281	2.711	0.821	0.714	1.142	0.178	2.034
141	3.057	2.249	1.089	0.281	4.216	2.670	0.808	0.703	1.124	0.176	2.003
144	3.010	2.214	1.072	0.277	4.151	2.629	0.796	0.692	1.107	0.173	1.972

APPENDIX D

HEC-RAS MODELLING SUMMARY

HEC-RAS Modelling Summary

D.1 Single Event Analysis

A common method of analysis used for stormwater management, and accepted in the province of Alberta, is based on a single storm event, either a real historic storm or a theoretical design storm. For this Master Drainage Plan, an actual hydrograph from recorded data of a single storm event within the watershed has been adopted for single event analysis, as described in Appendix C. Using a recorded hydrograph provides improved confidence over using a hydrograph generated from a rainfall-runoff model which cannot be well-calibrated due to the lack of on-site data.

The referenced design guidelines require that the major drainage system, including storage facilities, be designed to accommodate the runoff resulting from a 1:100 year return period storm event. To determine the potential and relative impacts of development in the watershed, the adopted hydrographs for all subwatersheds were routed through the Wolf Creek and Whelp Brook channels to Battle River using the HEC-RAS model.

D.2 HEC-RAS Computer Model

The Hydrologic Engineering Center's (HEC) River Analysis System (RAS) software is a widely used model which performs one-dimensional steady and unsteady flow river hydraulics calculations. The HEC-RAS User's Manual (HEC-RAS, 2010) provides a detailed description of the model theory, structure, and input data requirements.

The primary data required for the model and the sources of the data are presented in Table D.1.

While the model can include storage facilities, it does not account for any flow losses due to infiltration and depressions in the landscape. As such, the model results may tend to produce greater peak flows and volumes, as well as quicker response times than actual conditions.

A total of 225 cross-sections were produced for the HEC-RAS model, which represents a total of 56 km of channel and floodplain. The distribution of cross-sections is summarized in Table D.2. Because of the volume of data, the model is not provided herein, but the adopted HEC-RAS model is available under separate cover.

Table D.1: HEC-RAS Data Requirements and Data Sources

HEC-RAS Data Requirements	Data Sources
Channel geometry (cross-sections)	• MPE Survey July, 2013 of channel cross-sections near bridges and culverts. • LiDAR (1 m point grid), for 100m wide band centred along channel for Wolf Creek and Whelp Brook; channel bottom elevations adjusted to compensate for water depth. • LiDAR15 (15 m point grid), for floodplain & watershed.
Channel Structures (bridges and culverts)	• MPE Survey July, 2013 and photographs. • Alberta Transportation files. • WCWSC files.
Bank Locations	• MPE site inspections and photographs. • LiDAR. • Google Earth imagery.
Roughness (Manning's n)	• MPE site inspections and photographs. • Google Earth imagery. • HEC-RAS User's Manual. • Professional judgment.
Flow Data	• Water Survey of Canada. • Alberta Agriculture. • Steady Flow: MPE regional analysis results. • Unsteady Flow: MPE subwatershed hydrographs.

Table D.2: HEC-RAS Model Cross-sections

Subwatershed	# Bridges and Culverts	# Cross-sections for Bridges and Culverts	# Channel Cross-sections	Total # Cross-sections
Whelp Brook	7	14	85	99
Wolf Creek above Whelp Brook	6	12	49	61
Wolf Creek below Whelp Brook	6	12	53	65
Total	19	38	187	225

D.3 Pre-development Results

The resulting routed 1:100 year flood event hydrographs at select locations in Whelp Brook are presented in Figure D.1, at select locations in Wolf Creek above Whelp Brook in Figure D.2, and at the major subwatersheds of Wolf Creek in Figure D.3.

Figure D.1: Whelp Brook Subwatersheds 1:100 year Flood Hydrographs

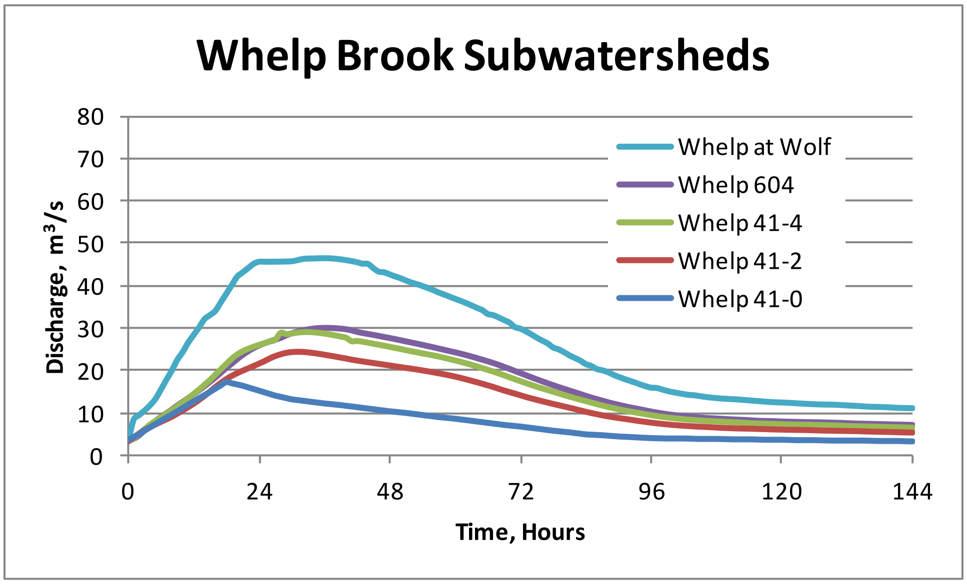


Figure D.2: Wolf Creek Subwatersheds 1:100 year Flood Hydrographs

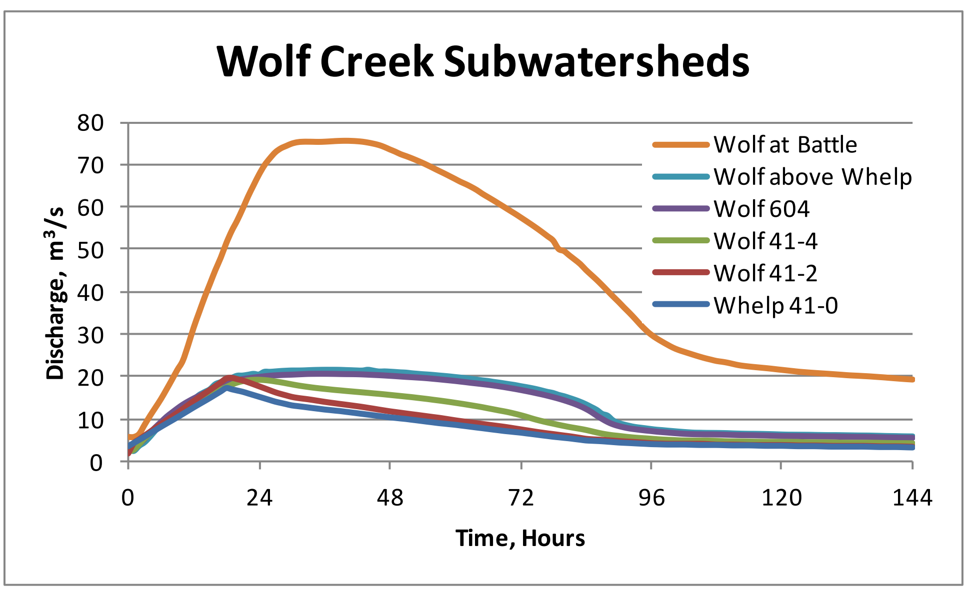
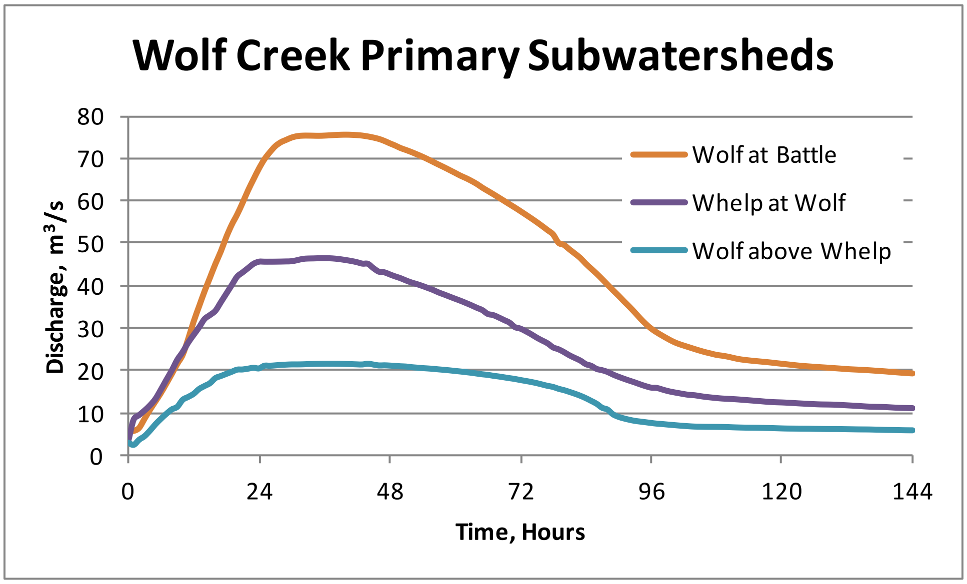


Figure D.3: Wolf Creek Primary Subwatersheds 1:100 year Flood Hydrographs



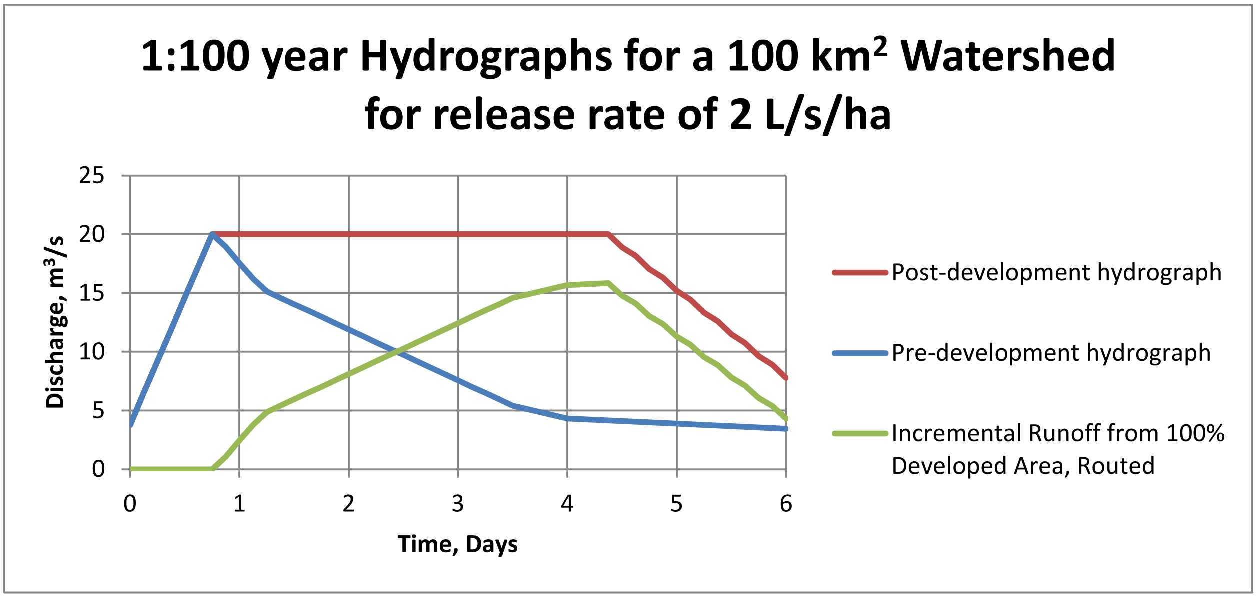
The results suggest:

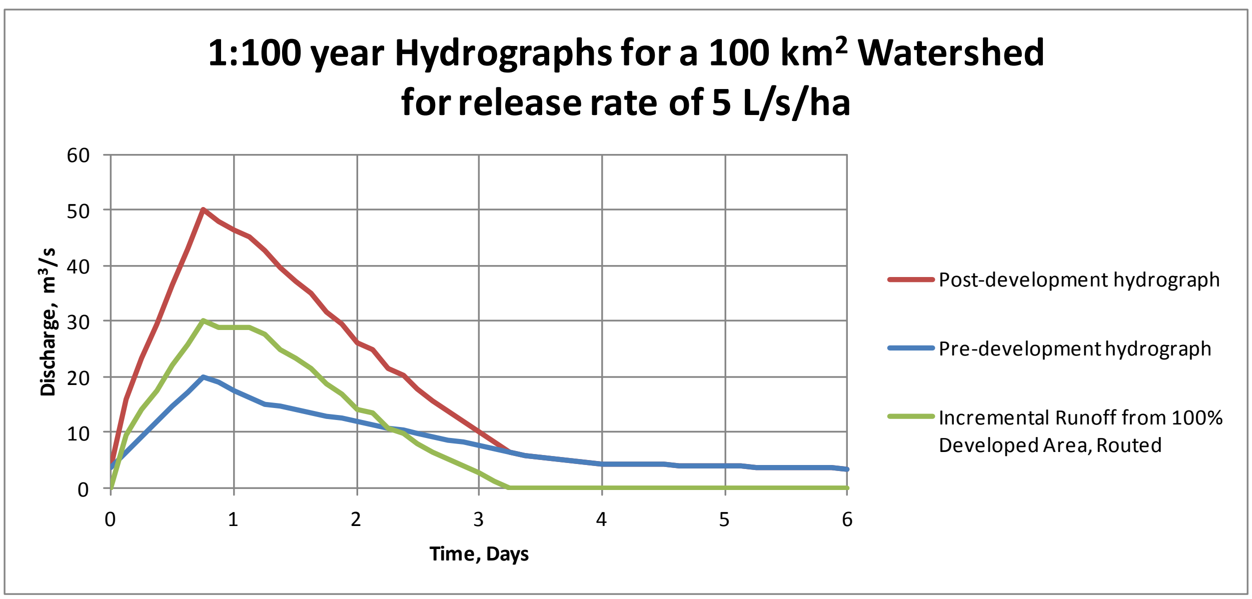
- Significant routing occurs along Wolf Creek and Whelp Brook.
- Peak flow rates at the Whelp Brook and Wolf Creek occur about 24 hours after the flood event begins.
- Peak flows at the mouth of Whelp Brook are about twice the peak flow of Wolf Creek above Whelp Brook.
- Peak flow of Whelp Brook at Wolf Creek is sustained for almost 24 hours before the flood begins to recede, while peak flow of Wolf Creek above Whelp Brook is sustained for almost 48 hours before the flood begins to recede.
- Peak flow of Wolf Creek at Battle River is sustained for almost 24 hours before significant flow rates gradually recede over 48 hours.
- The 1:100 year peak flow of Wolf Creek at Battle River is about 75 m^3/s, which is 0.143 $m^3/s/km^2$ (1.43 L/s/ha) for the entire 524 km^2 Wolf Creek watershed.

D.4 Post-development Results

Because stormwater management facilities will be designed in the future, post-development discharge characteristics are not known at this time. What is known are the potentially allowable unit release rates and the estimated locations and approximate areas for development. From this information, and assuming a post-development runoff volume equal to two times the pre-development runoff volume, post-development hydrographs were constructed for 2 L/s/ha and 5 L/s/ha, and presented in Figure D.4.

Figure D.4: 1:100 year Flood Hydrographs for Pre-development and Post-development Conditions





To determine the relative impacts of expected future development in the Wolf Creek watershed, for each of the identified subwatersheds where development is expected:

- The unit incremental hydrograph was multiplied by the area to be developed, to determine the incremental runoff hydrograph.
- The incremental runoff hydrograph was added to the pre-development hydrograph, to obtain the post-development hydrograph for the subwatershed.
- These hydrographs were then added to the HEC-RAS model and routed.

The resulting routed hydrographs for the primary subwatersheds are compared to the pre-development hydrographs, as presented in Figure D.5.

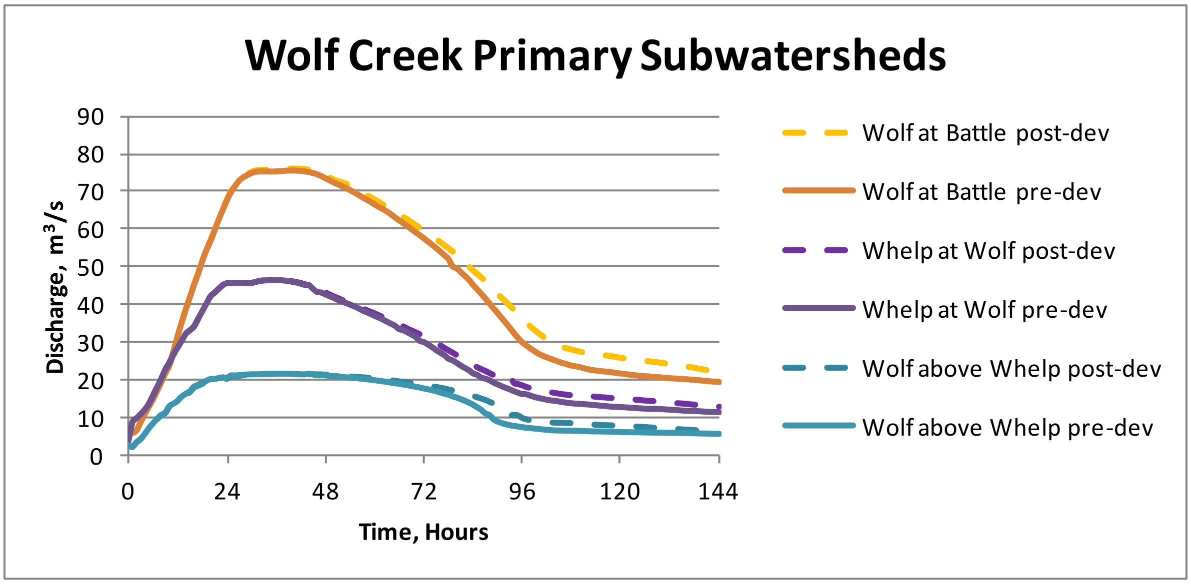
The results suggest:

- For a 2 L/s/ha allowable release rate:
    - The future expected development of an additional 5% of the Wolf Creek watershed has negligible impact on flows in Wolf Creek and Whelp Brook.
    - Peak flow rates under post-development conditions will not change from the pre-development conditions.
    - Under post-development conditions, the 1:100 year peak flow of Wolf Creek at Battle River will remain at about 75 m^3/s, which is 0.143 $m^3/s/km^2$ (1.43 L/s/ha) for the entire 524 km^2 Wolf Creek watershed.

- For a 5 L/s/ha allowable release rate:
    - The future expected development of an additional 5% of the Wolf Creek watershed has minimal impact on flows in Wolf Creek and Whelp Brook.
    - Peak flow rates under post-development conditions will increase by 7.5% over the pre-development conditions.
    - Under post-development conditions, the 1:100 year peak flow of Wolf Creek at Battle River will increase from 75 m^3/s to about 81 m^3/s, which is 0.154 $m^3/s/km^2$ (1.54 L/s/ha) for the entire 524 km^2 Wolf Creek watershed.

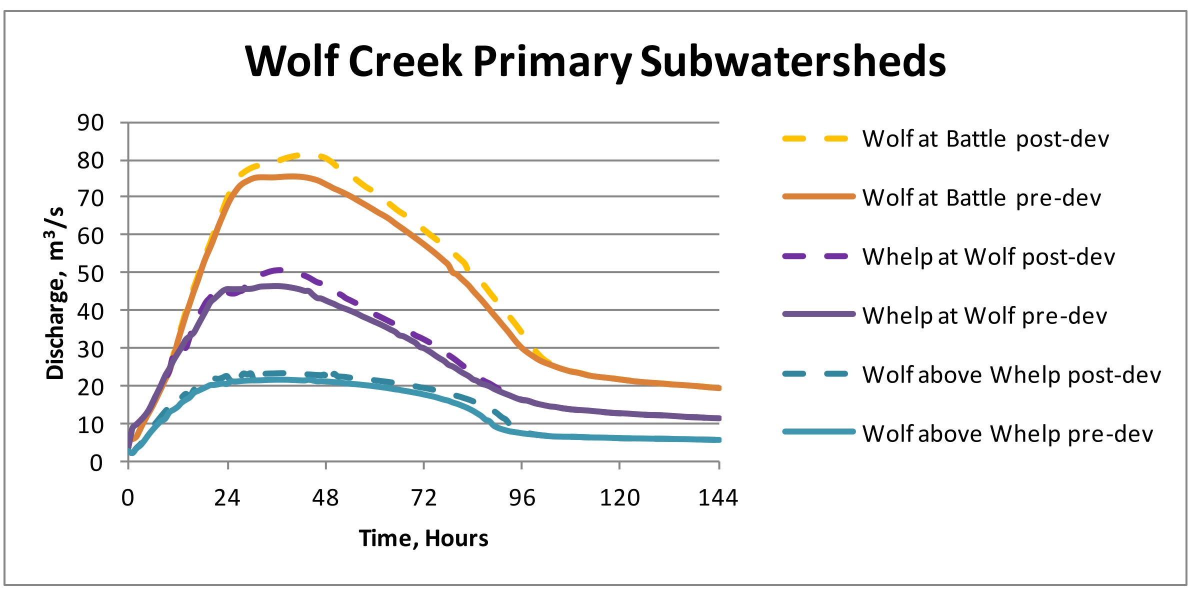
Figure D.5: Comparison of Pre-development and Post-development 1:100 year Flood Hydrographs

For 2 L/s/ha Release Rate



Comparison of Pre-development and Post-development 1:100 year Flood Hydrographs

For 5 L/s/ha Release Rate



Impacts on Battle River

For a 2 L/s/ha allowable release rate:

- Based on the results of the 1994 Ponoka Flood Risk Mapping Study, the 1:100 year peak discharge of the Battle River at Ponoka is 452 m^3/s. In comparison, and assuming coincident peaks, the estimated 1:100 year Wolf Creek discharge of 75 m^3/s represents less than 17% of the Battle River discharge.
- Because the additional discharge from future development will occur after the peak discharge in Battle River, the additional runoff from Wolf Creek will not cause any additional flooding in the Battle River.

For a 5 L/s/ha allowable release rate:

- The estimated 1:100 year Wolf Creek discharge of 81 m^3/s represents less than 18% of the Battle River discharge, or 1% more than for a 2 L/s/ha release rate.
- The additional runoff from Wolf Creek will cause almost imperceptible additional flooding in the Battle River.

D.5 Channel Capacities

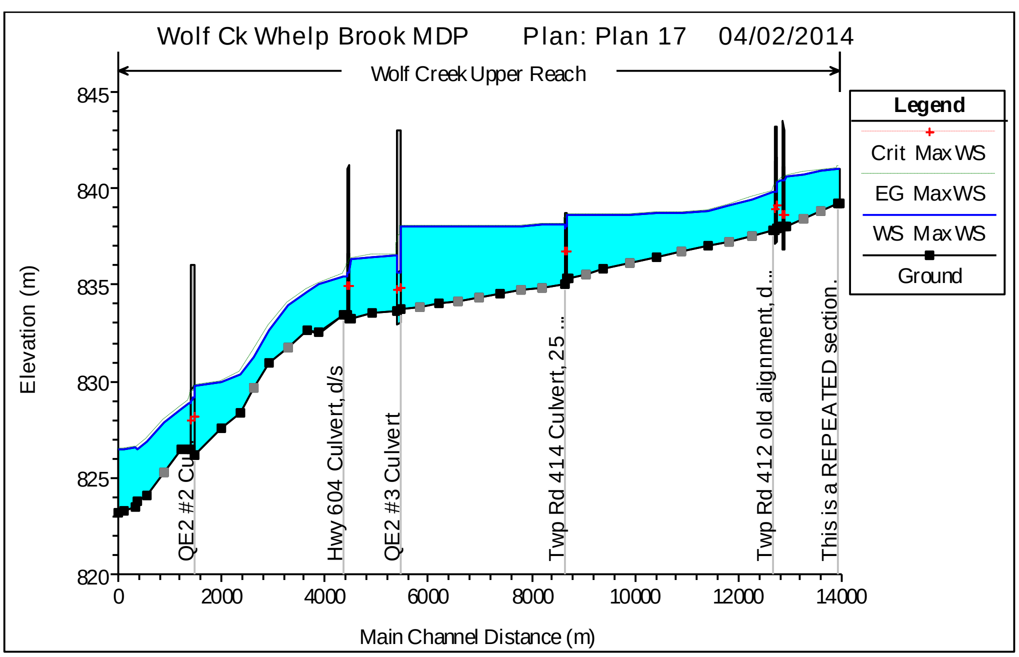
There are areas along Wolf Creek and Whelp Brook which are subject to overbank flooding. Concerns were expressed that channel capacities and channel structures may be causing backflooding. The following steps were undertaken to determine the locations of flooding and the potential causes of the flooding:

- The developed HEC-RAS model was assessed using the steady (constant) flows for selected return periods.
- Model results showing overbank flooding were identified and compared to available aerial imagery and field inspections. The common overbank areas where flooding is likely to occur are summarized in Table D.3 and delineated in Figure 3.
- The developed HEC-RAS model was then assessed using the unsteady (hydrographs) flows for the 1:100 year flood to determine the locations of backflooding.
- Model results showing locations of backflooding effects were identified and compared to field inspections. The locations of backflooding are identified in Figure D.6.

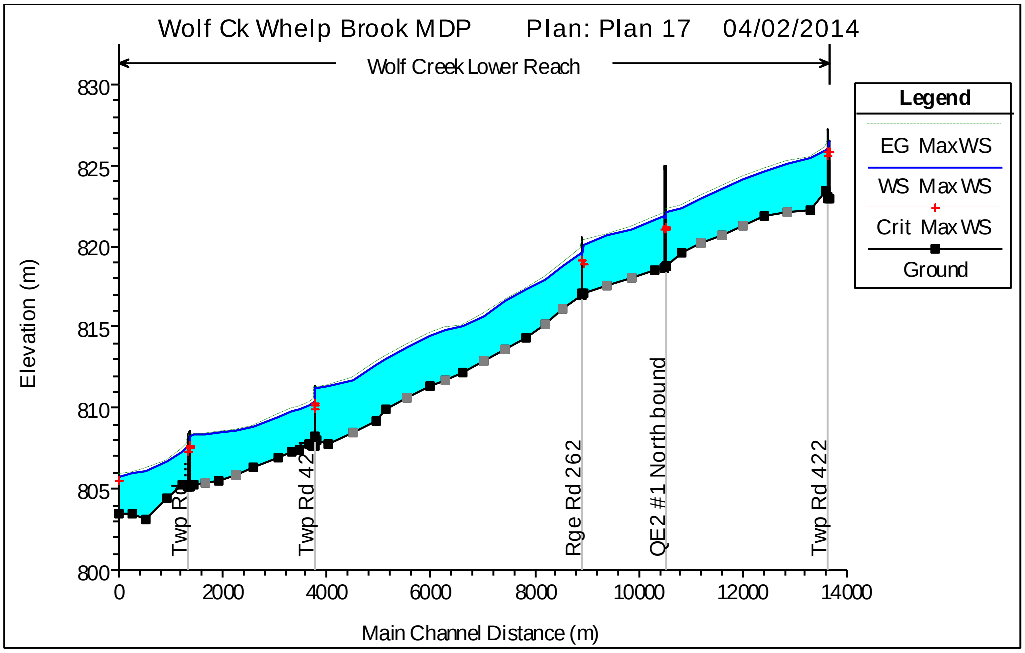
Table D.3: Flood Prone Areas

Flood Event	Municipality	
	Lacombe County	Ponoka County
flood < 1:2		• Whelp Brook between Hwy 604 and confluence with Wolf Creek.
1:2 < flood < 1:5	• Whelp Brook about 200m upstream and downstream of Twp Rd 41-4. • Wolf Creek between 200 m downstream and 500 m upstream of Twp Rd 41-4.	• Whelp Brook about 500m upstream from confluence with Wolf Creek. • Wolf Creek about 500 m upstream from confluence with Whelp Brook. • Wolf Creek about 200 m downstream of Hwy 604.
1:5 < flood < 1:10	• Whelp Brook between Rge Rd 270 and about 300 m downstream of Twp Rd 41-4.	• Wolf Creek about 500 m upstream of Twp Rd 424.

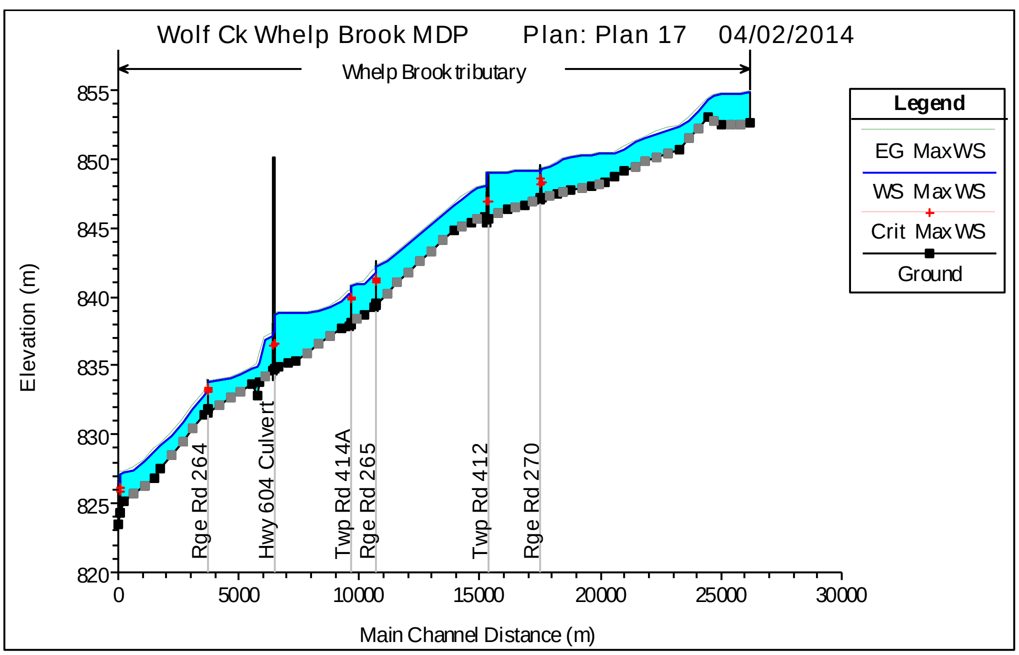
Figure D.6: 1:100 Year Flood Profiles



Wolf Creek Upper Reach



Wolf Creek Lower Reach



Whelp Brook

The flood prone areas typically occur where channel gradients are mildest and bank heights are low, and not necessarily because of inadequate conveyance capacity of crossing structures. Examples include wetlands where channelization has been constructed and low lying meadows adjacent to the channel.

Mitigating local flooding by infilling of these flood prone areas or dyking of the channels in these areas would cause a loss of temporary storage and attenuation of peak flows along the watercourses, thereby increasing the potential for flooding and erosion downstream. These types of mitigation are therefore not recommended without consideration and mitigation of downstream impacts.

Causes of Backflooding

All bridges and culverts were designed to accommodate at least the 1:20 year flood event, and the modelling results suggest this is the case. The crossing structures which appear to be most susceptible to causing backflooding during extreme flood events (i.e., greater than the 1:50 year flood) are:

- Wolf Creek:
  - QE 2 culvert (upstream of Hwy 604)
  - Hwy 604
  - Twp Rd 425
- Whelp Brook:
  - Hwy 604 (upstream wetland)
  - Twp Rd 41-2 (mild channel gradient, poor drainage conditions)

Other significant causes of local backflooding throughout the study areas are channel obstructions, particularly beaver dams. These structures can cause local flooding even during normal flow conditions, and are impediments to fish migration (Palliser Environmental Services Ltd, 2013). To remedy this, regular channel maintenance and beaver activity management is required. It is recognized that naturally occurring 'large woody debris' structures are useful fisheries habitat. As such, all those structures which do not impede flow should remain undisturbed.

Channel Conveyance Improvements

Where improvements to channel conveyance may be required, consideration should be given to channel longterm stability, available right-of-way width, impact s to riparian areas, and cost. A typical improved channel cross-section is presented in Figure 4. Features of this cross-section include:

- A primary channel, which provides efficient conveyance of low flow and sufficient depths for fish during low flow conditions.
- A secondary channel which provides efficient conveyance of high flow and habitat cover opportunities for fish.

To mimic natural conditions, the plan layout of constructed channels should incorporate meanders, and the primary channel should also meander within the secondary channel where practical. Layout design and channel dimensions will depend on factors such as available right-of-way width, topography, and channel gradient.

APPENDIX E

LID TECHNIQUES

Low Impact Development (LID)

In contrast to conventional stormwater management, Low Impact Development (LID) emphasizes source control practices where rainfall is returned to natural hydrologic pathways through infiltration and evapotranspiration or is reused at the source. Source control has been described as a shift to a proactive approach that eliminates the cause of stormwater problems. A development is defined as 'low impact' if post-development runoff conditions mimic predevelopment rates and volumes.

Awareness of LID practices and their implementation came to the forefront of stormwater management from several aspects:

- Increasing general public and political awareness of water, watersheds, and the connectivity of causes and effects of activities in a watershed.
- Increasing awareness and expectations of watershed stakeholders that jurisdictions take proportionate responsibility for watershed protection.
- General regulatory agency requirements to reduce sediment loading in watercourses.
- Recognition that stormwater ponds can be a resource (e.g., for irrigation) to reduce potable water demand during the summer months.
- Growth-related demands on stormwater infrastructure to meet requirements for stormwater ponds in newly developing areas.
- The difficulty and expense of retrofits in established neighbourhoods prone to flooding during high intensity rainstorms, to provide improved service levels more in line with current standards for new development.

LID practices are an emerging discipline in stormwater management and include planning through site design and the application of Source Control Practices (SCPs). SCPs provide a range of benefits from the retention of incident rainfall and runoff from adjacent impervious surfaces, to the treatment of runoff to improve water quality. More traditional end-of-pipe facilities can also play an important role, particularly during more significant precipitation events. These include constructed wetlands, wet ponds and detention storage areas.

Description and Suitability of LIDs

A description of types of LID practices is provided in Table 1.

Table 1: LID and Stormwater BMP Description

Practice	Description, Key Benefits & Disadvantages
Better Planning Practices	The positioning of road and lot layout and the arrangement of buildings on a lot can significantly influence the ability to apply LID practices to a development. Best practices should be used to optimize these aspects at the planning and the design phase of a development.
Maintain Natural Areas	Natural undisturbed areas generally have a higher infiltration and holding capacity than disturbed areas. Minimizing the disturbance of environmental areas will reduce the runoff generated and protect the natural integrity of these areas.
Minimize Impervious Areas	Reducing imperviousness of a development not only reduces the volume of runoff but also provides more opportunity for the pervious area to absorb runoff from the impervious areas. Reducing road widths and reducing building footprint by 'building up' are examples.
Absorbent Landscape	Absorbent landscapes use greater than standard depths of topsoil to provide additional capacity to absorb and hold direct rainfall and distributed runoff from adjacent impervious areas such as paving and roofs. They also promote infiltration and evapotranspiration similar to the original natural areas. Absorbent landscape is likely to have a limited applicability for generally high impervious areas of industrial and commercial sites. Where opportunities do arise, the material for these types of landscape would ideally come from the topsoil stripping process for the building site and may require amendment to achieve the desired properties. Site grading and spreading of surface runoff from impervious areas are important components but the construction and maintenance of these practices is relatively straightforward. It is critical that the absorbent landscape material and subsoil do not become over-compacted during construction or ongoing operation.
Bioretention	Bioretention (commonly called rain gardens) can provide a similar function to absorbent landscapes. If no under-drain is present below the filtration media, it will act as a 'soak-away' area. If an under-drain is present, it will provide more of a runoff filtration process with a reduced infiltration capacity. Bioretention is typically designed to accept concentrated runoff and therefore more suited to accepting roof and road runoff. As rain gardens have a higher hydraulic loading, they need higher levels of design input and higher maintenance requirements, especially during construction, as there is more potential for failure than absorbent landscape. Failure could be caused by being undersized, having unsuitable growing media resulting in ponding, and plant selection not matching wetting and drying regime of the soil. These problems can result in owners removing them due to nuisance issues.
Bio Swales	Bio swales have a similar function to vegetated swales but provide additional treatment capacity through the use of a filtration media and may have an underdrain.

Table 1: LID and Stormwater BMP Description (continued)

Practice	Description, Key Benefits & Disadvantages
Permeable Pavement	Permeable pavements can reduce runoff from hard surfaces by allowing rainfall to infiltrate the surface and be stored in the open underlying pavement from where it percolates further into the ground or evaporates back through the surface. Permeable paving is mostly suited for low traffic areas and requires specialist design, installation, and maintenance requirements and is often costly to install and maintain. Using permeable paving (porous concrete and asphalt, pavers) and gravels and reinforced grassed areas for infrequent vehicle and foot traffic areas are means to reduce the impervious surfaces in developments. Suitable construction, operation and maintenance procedures are required for longterm performance.
Green Roof	Green roofs involve placing a vegetated growing media layer on a roof to enhance evapotranspiration and reduce runoff volumes. They are especially effective in controlling intense, short-duration storms. They are typically used in higher density commercial and residential settings. They provide minimal water quality benefit.
On-site Extended Detention Systems	Extended detention systems involve providing adequate storage to hold the majority of the design rain event on-site so it can be released over an extended period of time, thereby providing only a minimal contribution to the peak flow in the downstream system. They are usually applied at the lot scale to reduce the impacts of redevelopment on downstream flows and can be combined with rainwater reuse systems. They could be provided as roof storage or as a cistern within the building or underground.
Cistern & Irrigation	Rain barrels or tanks that store water from impervious surfaces such as roofs can be used for irrigation. The water balance is actively managed either through an automatic system or users/owners who are dedicated to reusing rainwater. These systems require regular maintenance for efficient and continued operation. Considering these issues, some installations may be prone to neglect or lack of use and therefore may not be fully relied upon for the long-term management of runoff.
Cistern & Non-potable Reuse	Cistern, rain tanks, or vaults can be used for non-potable uses such as toilet flushing or other commercial uses. Stored water should be utilized regularly to be an effective LID practice (e.g. toilet flushing).
Oil & Grit Separator	Oil and grit separators are structures consisting of one or more chambers that remove sediment, screen debris, and separate oil from stormwater. They are particularly well suited to capturing grit, suspended solids, and hydrocarbons from small, highly impervious areas such as parking lots, loading areas and often required to provide pre-treatment before discharge to the off-lot drainage system.
Vegetated Swales	The main function of vegetated swales is to convey runoff in a manner that allows some infiltration and water quality treatment, while providing flood protection capacity during a significant rainfall event. Slope and vegetation cover are important components to encourage siltation and to minimize erosion.
Stormwater Reuse	Stormwater that is captured in wet ponds and other storage facilities can be reused for irrigation of parks, golf courses, toilet flushing in commercial, institutional, and residential buildings, and for industrial processes. The required level of treatment will be dependent on the level of exposure to humans and required quality for the intended use.

Table 1: LID and Stormwater BMP Description (concluded)

Practice	Description, Key Benefits & Disadvantages
Wet Ponds	Wet ponds are traditional end-of-pipe solutions which are primarily used to reduce peak flows and provide water quality treatment, specifically reduction in sediment. They do have a small volume control function due to evaporation, but only limited infiltration capacity into the underlying soils. Designs layouts should incorporate a number of ponds under typical flow conditions to assist de-silting with inundation of the whole area during more significant events.
Constructed Wetlands	Constructed wetlands provide the key functions of retention, detention, and pollutant removal, in addition to providing increased habitat, an amenity, and a buffer zone to adjacent wetlands and streams. Wetlands and ponds usually provide the last opportunity to minimize development impacts, particularly when there is limited ability to incorporate LID practices.
Engineered Natural Wetlands	Engineered natural wetlands involve modifying existing wetlands to improve the hydraulic, biological, and habitat function, and can accept treated stormwater. Any remnant wetlands along watercourses could be candidates for engineered natural wetlands. These wetlands could be constructed as ‘offline wetlands’ or have the potential to provide a flow bypass of the main watercourse flows.

A summary of the performance of potential stormwater management practices, based on an assessment by MPE, is presented in Table 1. The considerations to implement specific SCPs are presented in Table 3, and the general suitability of their implementation in various circumstances is presented in Table 4.

LID practices have been shown to be effective in controlling the volume of stormwater generated either on its own or in combination with wet ponds and wetlands. A number of the preferred LID source control practices are located in the private realm, which raises questions on their long-term operation and performance. Therefore, additional consideration should be given as to how socially acceptable specific LID practices are and the likelihood that they will remain operational. Consideration should also be given to what potential mechanisms or encouragement/incentives can be provided to ensure they remain operational indefinitely.

In addition to hydrologic and hydraulic loading rates, the effectiveness of the various stormwater practices will depend on the level of maintenance and operation compliance that is achieved. In identifying suitable LID practices for future land development, a number of factors should be considered, including function (e.g., volume reduction and water quality treatment capabilities), operation and maintenance requirements, and location (on public or private land). The location is important as the owner is typically responsible for the future maintenance and therefore the long-term performance of a facility.

Table 1: Stormwater BMP Performance Matrix

BMP Practice	TSS Removal	Phosphorus Removal	Volume Reduction	Peak Flow Reduction	O & M Requirements	Capital Cost	Suitability on Private Land	Suitability on Public Land
Better Planning Practices	M	M	M	M	N/A	L	H	H
Maintain Natural Undisturbed Areas	H	H	H	H	L	L	H	H
Minimize Impervious Area	M	M	M	M	L	L	H	H
Absorbent Landscape	H	M - L	H	M	L	L	H	M
Bioretention / Rain Garden	H	M - H	L - M	M - H	H	M	M	H
Permeable Pavement	M	M	L - M	M - H	M - H	H	M	M
Green Roof	L	L	M - H	L - M	M-H	H	H	L
Rain Tank & Irrigation	M	M	M	L	M	H	H	L
Rain Tank for Non-potable Use	M	M	M	L	M	H	H	L
On-site Extended Detention Systems	M	L	L	H	M	H	H	M
Bio Swales	M	M	L - M	M	M	L	L	H
Vegetated Swales	L	L	L	L	M	L - M	H	L
Stormwater Reuse	M	M	M-H	M	M	M	M	H
Oil & Grit Separator	M	L	L	L	H	H	H	M
Wet Ponds	M - H	L	L	H	M	H	L	H
Constructed Wetlands	H	M - H	M	M - H	M-H	H	L - M	H
Engineered Natural Wetlands	M	M	L - M	M - H	M-H	M	L - M	H

Notation: L – Low, M – Medium, H – High, N/A – Not Applicable

Table 3: Considerations for Source Control Practices

Site LID	Design / Install Expertise	I/P Ratio* or capacity used for Design Sizing	Maintenance Requirements	Required to be Operated	Nuisance Potential	Aesthetic Value
Maintain Natural Areas	L	N/A	L	L	L	H
Absorbent Landscape	L	3:1	L	L	L	H
Bioretention / Rain Garden	M	25:1	M	L	L - M	H
Porous Pavement	H	1:1	H	L	L - M	M
Green Roof	H	1:1	M	L	L-M	M-H
Oil and Grit Separator	M	N/A	H	L	M	L
Cistern & Irrigation	M-L	1500 m^3/ha**	M	H	H	L
On-site Detention	L	200 m^3/ha	L	N	L	L
Cistern & Non-Potable Reuse	H	2 – 5 m^3/ha	M	H	H	L

Notation: L – Low, M – Medium, H – High, N/A – Not Applicable

* I/P Ratio is Impervious Area / Treatment Area

** Storage sized per irrigated hectare in Calgary

Table 4: Applicability of Source Control Practices

BMP Practice WQ Treatment	Land Surface Type					
	Roof	Hi Traffic Parking	Low Traffic Parking	Landscape Areas	Road Verge & Footpaths	Roads
Minimize Impervious Area	M	M	H	N/A	L	M
Absorbent Landscape	L	L - M	L - M	H	H	L
Bioretention	L - M	H	H	L	M	H
Vegetated Swales	M	H	H	M	H	H
Bio-swales	M	H	H	L	L	M
Green Roof	H	N/A	N/A	N/A	N/A	N/A
Permeable Pavement	L	L	M	L	M	L
Cistern & Irrigation	H	L	M	L	L	L
Cistern & Toilet Flushing & Process Water	H	L	L - M	L	L	L
Oil & Grit Separator	L	H	H	L	L	L

Notation: L – Low, M – Medium, H – High, N/A – Not Applicable

Performance of Selected LIDs

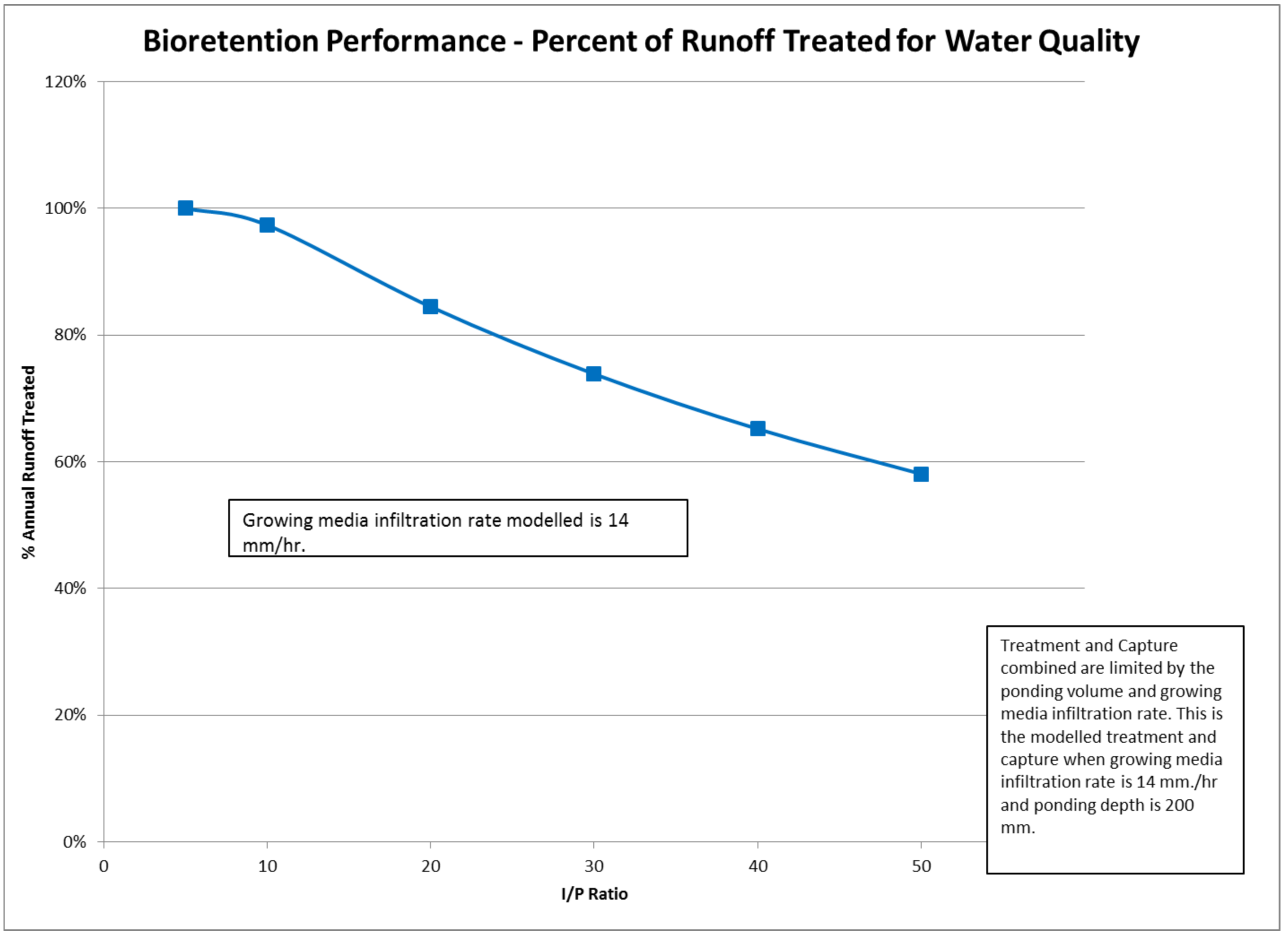
Reductions in Total Suspended Solids (TSS) which can be expected from selected LIDs are presented in Table 5, and the expected performance of a bioretention facility is presented in Figure 1.

Table 5: Typical Stormwater Runoff TSS Concentrations

Land Use	Surface	AENV (1999) EMC* (mg/L)	City of Calgary Lumped EMC˜ (mg/L)
Commercial	Roof	134	180
	Parking Lots	203	
	Other	158^	
Industrial	Roof	113	369
	Paved Parking	364	
	Paved Storage	270	
	Gravel Parking/Storage	1250	
	Other	158^	
Residential	Roof	41	444
	Parking Lots	1790	
	Gravel Pads	1250	
	Other	158	
Road Reserve	Pavement	516	N/A
	Residential Gravel Lanes	1250	
	Residential Paved Lanes	516	
	Other	158^	

* Source: Stormwater Management Guidelines, Alberta Environmental Protection, 1999
˜ Source: Lognormal Distribution of Pollutants, City of Calgary, 2003
^ Source: International Data, General Urban (MUSIC)

Figure 1: Bioretention Performance



Operations and Maintenance Costs

Typical operations and maintenance costs (from City of Calgary) for a stormwater pond are:

Stormwater Pond Cleaning

- Cleaning cycle is 20-25 years.
- Pond cleaning cost on average is $3.5M per pond per cycle; disposal of sediment is $1M-2M per pond per cycle; total for pond cleaning and sediment disposal up to $5.5M (depending on the size of the pond).

Routine maintenance activities

- Maintaining structures, inlet/outlet pipes, keeping safety grills clean etc.: allow for 2% of capital cost per year (these costs do not include landscaping maintenance).

LID Strengths, Weaknesses, Opportunities and Challenges

A summary of LID Strengths, Weaknesses, Opportunities and Challenges for the jurisdictions in the Wolf Creek watershed is provided below.

<table>
<tr>
<td>Strengths

An integrated design process that incorporates stormwater management as a primary planning consideration.
Incorporation of Low impact Development (LID) practices can assist in accommodating non-traditional stormwater drainage systems and minimizing downstream environmental impacts.
Smaller scale development staging could assist the implementation of widespread LID practices.
Opportunities to implement constructed wetlands to improve water quality and meet volume control targets for development projects.

</td>
<td>Weaknesses

Existing and established development reduces the benefits of applying LID practices.
The use of in-stream storage as a significant component for detention storage to achieve a release rate of 2 L/s/ha.
Land areas on the northern portion of OLSH land grades away from the higher areas adjacent to the creek with areas being located below the proposed 1 in 100 year flood elevation.
Limitations of topography and soils to infiltrate stormwater runoff with the source control practices to achieve the runoff volume targets.

</td>
</tr>
<tr>
<td>Opportunities

Adoption of LID practices would provide a more environmentally sustainable stormwater management system.
Applicable techniques of stormwater management within public lands and Rs-O-W include bioretention, bioswales, vegetated ditches, wetlands, wet ponds, and stormwater reuse (irrigation).
Suitable source control practices within private lots are: bioretention, bioswales, rainwater reuse, on-site detention /retention, permeable paving (in low traffic areas), and oil and grit separators.
Incorporate low lying and flood-prone areas adjacent to watercourses as detention areas for extreme flood events.

</td>
<td>Challenges

Implementing and gaining widespread acceptable from stakeholders for the approved Wolf Creek and Whelp Brook Watersheds Master Drainage Plan.
Providing an integrated stormwater drainage system across jurisdictional boundaries, that minimizes potentially conflicting growth plans, varying timelines, and budget constraints.
Meeting future regulatory agency requirements.
Presenting and approving innovative designs that may require compromise with current “status quo” accepted design standards and processes.
How to equably distribute the cost of stormwater infrastructure.

</td>
</tr>
</table>

Detention Storage Requirements

Detention storage requirements largely depend on expected volume of runoff to be generated by the specific development (e.g., parkland, residential, commercial, industrial, etc.) and the degree to which best management practices are adopted and maintained. As such, detention storage requirements are more appropriately determined during the planning and design stages of developments.

Enhanced Stormwater Management Options in the Wolf Creek Watershed

Development continues in the Wolf Creek watershed, and regulatory requirements regarding stormwater management continue to become more stringent. Adopting LID practices in the watershed may be prudent before conditions become unacceptable and solutions (e.g., retrofitting alternatives in established neighbourhoods) are difficult and expensive. Not only do LID practices complement conventional stormwater management, they can also offset the volume requirements (and cost) for stormwater management facilities.

To minimize impacts in the Wolf Creek watershed, three components of stormwater management practices can be employed:

- minimize the generation of runoff.
- retain runoff on-site through evapotranspiration, infiltration and re-use.
- capture, hold and re-use runoff within a development or regional system.

The types of LIDs to be adopted, and their number and location, will be designed during the application phases of future development.

Retention Pond Complex

Consideration could be given to constructing one or more large retention pond complexes to divert runoff from Wolf Creek. These facilities would decrease total volume of runoff from Wolf Creek through infiltration (replenish groundwater), evaporation, and evapotranspiration. Potential locations for these facilities include natural low depressions and abandoned gravel pits.

MDP Objectives and LIDs

Key objectives of the Wolf Creek watershed MDP include:

- Stormwater detention facilities shall be provided to limit the 1:100 year flow to 2 L/s/ha from the local contributing catchment.
- Supplementing the function of stormwater detention facilities should incorporate evaporation, infiltration, and reuse of stormwater to achieve a reduction in produced runoff volume.
- Protection of land from flooding and erosion.
- Protection of water quality.
- Improved watershed hydrology by reducing stormwater runoff volume through reuse and infiltration.
- Proper operation and maintenance of facilities (e.g., cleaning of retention ponds).
- Appropriate stakeholder involvement.
- Sustainable funding mechanisms.

The objectives encompass the need for pollution reduction with stormwater treatment facilities such as wet ponds and constructed wetlands. In established neighbourhoods, where land for stormwater treatment is unavailable, retrofit options which should be considered include purchasing land for stormwater facilities, constructing infiltration basins and bioretention areas, replacing impervious areas, and installing oil/grit separators.

Emerging Future Runoff Requirements

Some emerging stormwater management controls relate to phosphorus loading entering watercourses. For example, the implementation of the Bow River Phosphorus Management Plan is expected to result in tighter controls on water quality discharges along with the higher requirements for TSS loadings to the Bow River. These requirements in part are reflected in the recent approach of requiring volume control targets for new developments.

In the City of Calgary, wide volume control targets have also been introduced for new development as a water quality control measure. Therefore most development will need to incorporate evaporative, infiltration and reuse to achieve a stipulated annual average volume target.

APPENDIX F

PHOTOGRAPHS

Images are presented from downstream (north) to upstream (south).

Images are segregated into 4 sections:

1. **Wolf Creek lower reach**
   - **Battle River to confluence with Whelp Brook**
   - **Lies in Ponoka County**

2. **Wolf Creek upper reach**
   - **Whelp Brook confluence to QE 2 north of City of Lacombe**
   - **Lies in Ponoka County and Lacombe County**

3. **Wolf Creek City of Lacombe**
   - **QE 2 north of City of Lacombe to City of Lacombe**
   - **Lies in Lacombe County and City of Lacombe**

4. **Whelp Brook**
   - **Wolf Creek to QE 2**
   - **Lies in Ponoka County and Lacombe County**

<u>This Section:</u>

1. **Wolf Creek lower reach**

Wolf Creek: Battle River to Whelp Brook

Twp Rd 425 (Gee Road)

Looking upstream (south) at bridge.

Looking downstream (north) from bridge.

Twp Rd 425 (Gee Road)

Looking downstream (north) at bridge.

Looking upstream (south) from bridge.

Twp Rd 424

Looking upstream (south) at bridge.

Looking downstream (north) from bridge.


Looking downstream (north) and west from north of bridge.

Twp Rd 424

Looking downstream (north) at bridge.


Looking upstream (south) from bridge.

C & E Trail in SW 24-42-26-W4

Looking downstream (north) at Wolf Creek wide floodplain.

C & E Trail in NE 14-42-26-W4

Looking north at incised Wolf Creek channel with debris.

Rge Rd 262

Protecting trees from beaver activity (west of bridge).

Rge Rd 262

Looking upstream (west) at bridge.

Looking at downstream, east of bridge.

Looking downstream (east) from bridge.

Rge Rd 262

Looking downstream (east) at bridge.

Looking upstream (northwest) from bridge.

Rge Rd 263 in NE 16-42-26-W4

Looking downstream (northeast) at Wolf Creek wide floodplain.

Looking southeast at sinuous Wolf Creek channel with debris.
Note variation in channel within one quarter section.

Rge Rd 263 in SE 16-42-26-W4

Looking north at incised Wolf Creek channel.

Twp Rd 422

Looking upstream (south) at bridge.

Looking downstream (north) from bridge.

Twp Rd 422

Looking upstream (northeast) at bridge.


Looking upstream (northwest) from bridge.

Images are presented from downstream (north) to upstream (south).

Images are segregated into 4 sections:

1. **Wolf Creek lower reach**
   - **Battle River to confluence with Whelp Brook**
   - **Lies in Ponoka County**
2. **Wolf Creek upper reach**
   - **Whelp Brook confluence to QE 2 north of City of Lacombe**
   - **Lies in Ponoka County and Lacombe County**
3. **Wolf Creek City of Lacombe**
   - **QE 2 north of City of Lacombe to City of Lacombe**
   - **Lies in Lacombe County and City of Lacombe**
4. **Whelp Brook**
   - **Wolf Creek to QE 2**
   - **Lies in Ponoka County and Lacombe County**

<u>This Section:</u>

2. Wolf Creek upper reach

Wolf Creek: Whelp Brook to City of Lacombe

Hwy 604 (Twp Rd 420)

Looking upstream (south) at culvert.

Looking downstream (north) from Hwy 604.

Looking upstream (south) from Hwy 604.

Twp Rd 41-4

Looking downstream (north) from Twp Rd 41-4.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream (south) from Twp Rd 41-4.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Twp Rd 41-2 – original alignment

Looking upstream (south) at culvert.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking downstream (north) from Twp Rd 41-2.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Twp Rd 41-2 – original alignment

Looking downstream (north) at culvert.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream (south) from Twp Rd 41-2.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Twp Rd 41-2 – 2013 alignment

Looking downstream (south) at culvert.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream (north) from Twp Rd 41-2 (2013 alignment).

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Twp Rd 41-2 – 2013 alignment

Looking downstream (northwest) at culvert.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream from Twp Rd 41-2 (2013 alignment).

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

QE 2 (north of City of Lacombe)

Looking upstream (southwest) at box culvert.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream (northwest) from bridge.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Images are presented from downstream (north) to upstream (south).

Images are segregated into 4 sections:

1. **Wolf Creek lower reach**
   - **Battle River to confluence with Whelp Brook**
   - **Lies in Ponoka County**
2. **Wolf Creek upper reach**
   - **Whelp Brook confluence to QE 2 north of City of Lacombe**
   - **Lies in Ponoka County and Lacombe County**
3. **Wolf Creek City of Lacombe**
   - **QE 2 north of City of Lacombe to City of Lacombe**
   - **Lies in Lacombe County and City of Lacombe**
4. **Whelp Brook**
   - **Wolf Creek to QE 2**
   - **Lies in Ponoka County and Lacombe County**

<u>This Section:</u>

3. Wolf Creek City of Lacombe

Wolf Creek: QE 2 north of City of Lacombe to City of Lacombe

Hwy 2A

Looking downstream (west) at Hwy 2A culvert from CPR.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream (east) at CPR box culvert from Hwy 2A.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream (east) from CPR.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Twp Rd 41-0

Looking upstream (south) at bridge.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

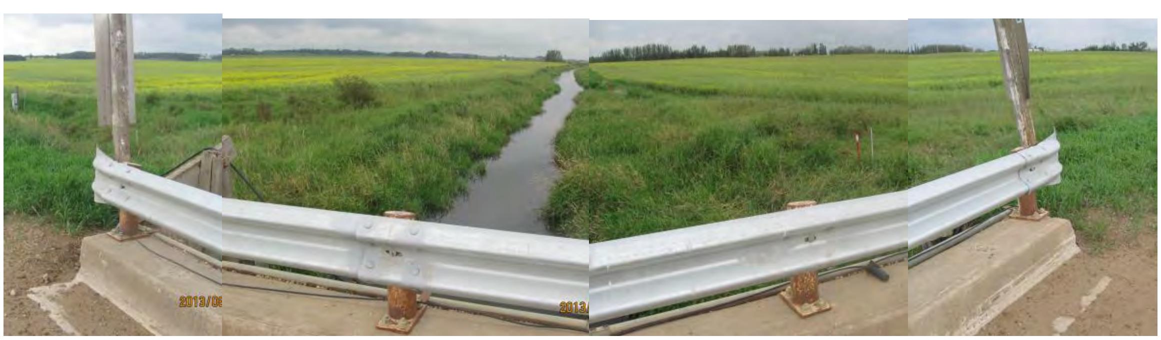
Looking downstream (north) from Twp Rd 41-0.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Twp Rd 41-0

Looking downstream (north) at bridge.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.



Looking upstream (south) from Twp Rd 41-0.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Wolf Creek Drive

Looking downstream (east) from Wolf Creek Drive.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Wolf Creek Drive

Looking downstream (east) at triple culverts.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream from Wolf Creek Drive.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Hwy 12

Looking upstream (south) at bridge.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking downstream (north) from Hwy 12 towards CPR trestle bridge.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Hwy 12

Looking downstream (northwest) at bridge.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream (south) from Hwy 12.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

45 St.

Looking upstream (west) at triple culverts.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking downstream (east) from 45 St.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

45 St.

Looking downstream (southeast) at triple culverts.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Looking upstream (southwest) from 45 St.

Note: this reach is under a *Water Act* licence held by the City of Lacombe for maintenance.

Images are presented from downstream (north) to upstream (south).

Images are segregated into 4 sections:

1. **Wolf Creek lower reach**
   - **Battle River to confluence with Whelp Brook**
   - **Lies in Ponoka County**

2. **Wolf Creek upper reach**
   - **Whelp Brook confluence to QE 2 north of City of Lacombe**
   - **Lies in Ponoka County and Lacombe County**

3. **Wolf Creek City of Lacombe**
   - **QE 2 north of City of Lacombe to City of Lacombe**
   - **Lies in Lacombe County and City of Lacombe**

4. **Whelp Brook**
   - **Wolf Creek to QE 2**
   - **Lies in Ponoka County and Lacombe County**

<u>This Section:</u>

4. Whelp Brook

Whelp Brook

Rge Rd 263

Looking upstream (west) at bridge.
Note: confluence with Wolf Creek at right.

Looking downstream (east) from Rge Rd 263.
Note: confluence with Wolf Creek in background.

Looking upstream (south) at Wolf Creek immediately upstream of Whelp Brook confluence.
Note beaverdam at centre left.

Rge Rd 263

Looking downstream (east) at bridge.

Looking upstream (west) from bridge.

Rge Rd 264

Looking upstream (west) at bridge.

Looking downstream (east) from bridge.

Rge Rd 264

Looking downstream at bridge.


Looking upstream from bridge.

Hwy 604

Looking upstream (southeast) at culvert.

Looking downstream (northeast) from Hwy 604.

Looking upstream (south) from Hwy 604

Twp Rd 41-4 A

Looking downstream (south) at bridge.

Looking upstream (north) from bridge.

Twp Rd 41-4 A

Looking upstream from bridge.

Beaverdam 20 m upstream of bridge.

Looking upstream along Rge Rd 26-5 from Twp Rd 41-4 A.

Rge Rd 26-5

Looking upstream (west) at bridge.

Looking downstream (east) from bridge.

Looking upstream (west) from bridge.

Twp Rd 41-2


Looking upstream (southeast) at twin culverts.


Looking downstream (north) from Twp Rd 41-2.

Twp Rd 41-2

Looking downstream (northeast) at twin culverts.

Looking upstream (south) from Twp Rd 41-2.

Rge Rd 27-0

Looking upstream (west) at bridge.

Looking downstream (northeast) from bridge.

Looking upstream (southwest) from bridge.

QE 2

Looking upstream (north) along QE 2.

Looking upstream (southeast) at box culvert.

Looking downstream (west) from QE 2.