Vermilion River Water Supply & Demand Study

Prepared for

the North Saskatchewan Watershed Alliance

North Saskatchewan Watershed Alliance

Golder Associates

June 2009

Vermilion River Water Supply and Demand Study

Submitted to:
North Saskatchewan Watershed Alliance
5th Floor, Century Place
9803 - 102A Avenue
Edmonton, Alberta
T5J 3A3

FINAL REPORT

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June 12, 2009

North Saskatchewan Watershed Alliance
5th Floor, 9803-102A Avenue
Edmonton, AB T5J 3A3

Attention: Mr. David Trew, Executive Director

Re: Vermilion River Water Supply and Demand Study – Final Report

Dear Mr. Trew:

We are pleased to submit our final report on the Vermilion River Water Supply and Demand Study. We have enjoyed working with you and your team on this challenging project. We trust that the findings of the study are of assistance to the North Saskatchewan Watershed Alliance in the development of a water management plan for the Vermilion River Basin.

Please contact me at (403) 260 2292 should you require any clarification regarding this report.

Yours truly,

GOLDER ASSOCIATES LTD.

Anil Beersing, Ph.D., P.Eng.
Project Director
Principal, Senior Water Resources Engineer

ACKNOWLEDGEMENTS

Golder Associates Ltd. (Golder) acknowledges the assistance of Mr. Graham Watt-Gremm, Basin planner with the North Saskatchewan Watershed Alliance (NSWA), for facilitating the acquisition of project data, guiding Golder's staff during a visit of the Vermilion River Basin in November 2008, and coordinating the review of the report during its various drafts.

Golder appreciates the comments provided by the members of the Vermilion River Basin Steering Committee during the meetings where Golder presented the findings of the study. The comments were very useful during the finalization of the study report. Golder thanks Ducks Unlimited Canada for providing the wetland and drained area inventory, which was a key source of data for the hydrologic modelling for this study.

The overall direction provided by Mr. David Trew, Director of the NSWA, is gratefully acknowledged by Golder's study team members.

Executive Summary

Golder Associates Ltd. (Golder) was commissioned by the North Saskatchewan Watershed Alliance (NSWA) to conduct a water supply and demand study on the Vermilion River Basin (VRB). The NSWA has identified the VRB as one of the most altered basins in the North Saskatchewan River watershed. Impacts include variable water supply, flooding, water quality issues, and impaired aquatic ecosystem health. Impacts on water quantity and quality are thought to result from wetland drainage and modification, livestock management, tillage and municipal and industrial development.

The goal of the *Vermilion River Water Supply and Demand Study* was to support the*Vermilion River Watershed Management Project* by integrating and assessing existing hydrologic information in the VRB, generating new knowledge on hydrologic functions in the basin, and developing tools to support water resources planning and management in the basin. Specific objectives of the *Vermilion River Water Supply and Demand Study* were to:

- Determine the current water yield (including variability) in the VRB and its sub-basins.
- Compare current and future water demand in the basin and its sub-basins with water yield.
- Implement a hydrologic model for the Vermilion River Basin to:
  - assess the effects of drainage systems and wetlands on the hydrology of the basin;
  - assess the effects of present flood control structures on the hydrology of the basin; and,
  - support future evaluation of management alternatives, growth scenarios and potential climate change effects.

Overview of Vermilion River Basin

The Vermilion River Basin is located in the Parkland Natural Region of Alberta. The towns of Vegreville, Vermilion and Two Hills are the three largest population centres in the basin. Land use in the basin is dominated by agriculture, with smaller amounts of disturbance associated with transportation, industry, and municipal use. The Vermilion River drains 7,860 km^2 or approximately 14% of the land in the North Saskatchewan River watershed. The Vermilion River is a non-glacier fed tributary to the North Saskatchewan River. Most of the flow in the river occurs during the spring snowmelt period, with summer rainstorms contributing on average a relatively smaller proportion of the annual discharge, but which can occasionally generate large floods. The flow regime in the Vermilion River is characterized by lengthy periods of low flows.

The prairie landscape in the eastern part of Alberta is characterized by areas with internal drainages, i.e., areas that do not drain to the main receiving stream, but instead drain to local sloughs or wetlands. This is especially relevant in the Vermilion River Basin, which has a total gross drainage area of about 7,860 km^2, but an effective drainage area of only 2,360 km^2. Thus, about 70% of the basin does not contribute to flows in the Vermilion River during the two-year flood conditions.

Groundwater is an important source of municipal, commercial and industrial water supply for much of the Vermilion River Basin, as well as supplying water to most rural residents. Data from the Alberta Environment Groundwater Information Database indicates there are currently over 13,000 water supply wells in the basin. In addition to its importance as a reliable source of water for human activities, groundwater serves a key role as the source of baseflow to the Vermilion River and its tributaries, maintaining water levels in prairie wetland ecosystems and maintaining soil moisture conditions in a semiarid climate. In contrast, the surface flow regime is characterized by lengthy periods of low flows and zero discharge has been recorded on several occasions.

Water Yield from Vermilion River Basin

The first objective of the study was to estimate the mean annual runoff (annual yield) and mean monthly runoff (monthly yield) at several locations along the Vermilion River Basin. The mean annual yield is the arithmetic average of all the annual runoff volumes at a given location in the Vermilion River. It is usually expressed as a depth of runoff (average flow volume divided by drainage area). Flow data recorded at several of Environment

Canada's hydrometric gauging stations on the Vermilion River were used to determine yield. On average, the Vermilion River Basin yields about 52 million cubic metres (Mm^3) of runoff annually at its mouth. The average annual water yield is equivalent to an average water depth of about 22 mm over the effective (contributing) area. The average annual yield (in terms of water depth) varies from 46 mm near the headwaters to about 17 mm near the mouth, illustrating the significant spatial variability of water yield in the basin (higher in the headwaters and lower near the mouth). The highest water yield months are April and May. From late fall to early spring, the yield from the sub-basins in the VRB is very low and nearly zero in some cases. Across the VRB, the average annual yield from the Upper Vermilion Area was estimated at 12 Mm^3, with the cumulative annual yields at the downstream boundaries of the Upper-Middle and Lower-Middle areas of the VRB estimated at 30 and 36 Mm^3, respectively.

The annual variability in runoff from the VRB is significant. For example, the annual yield at the mouth of the VRB near its confluence with the North Saskatchewan River can vary from 10 Mm^3 (10th percentile, value exceeded 90 percent of the time) to about 110 Mm^3 (90th percentile, exceeded 10 percent of the time), illustrating the very high variability in annual yield from year to year. The difference between the 10th and 90th percentile yield is almost twice the average yield, reflecting the wide range in the hydrologic response (very dry to very wet) of the basin.

August and September are the months with the lowest flows during the open-water season. The average, 10th percentile (approximately 10-year dry month) and 90th percentile (approximately 10-year wet month) monthly flow volumes from the VRB during August are 2.8, 0.64 and 6.8 Mm^3, respectively, and during September are 0.66, 0.15 and 1.6 Mm^3, respectively.

Two approaches were used to estimate groundwater yield from the VRB. In the first approach, groundwater recharge for the VRB was based on regional surficial geology and associated permeability data. This information was used to assign average infiltration rates across the VRB, based on the characteristics of the surficial materials and their recharge effectiveness. To better reflect recharge conditions in the VRB, infiltration rates of areas covered by clay-rich till deposits were assumed to be about one percent (1%) of total mean annual precipitation. Results from infiltration and recharge studies conducted in these areas suggest that this modification is reasonable. In areas containing permeable soils, recharge rates ranging from 12 to 20% were applied. Recharge on areas of steep slopes was considered to be insignificant and approximated to zero. In addition to removing steeper areas of the basin from the recharge calculation, areas of probable groundwater discharge were also identified and removed. Additionally, annual precipitation for the basin was reduced to reflect the moisture deficit condition that occurs during the summer months of June, July and August.

An estimated annual groundwater recharge volume of 39 million cubic metres (Mm^3) was calculated for the Vermilion River Basin. This amounts to an average recharge rate of approximately 5 mm per year and represents 1.2% of the average annual precipitation (425 mm) in the basin. This value is in the low range of reported recharge rates (2 to 45 mm/year) and precipitation percentage (2% - 5%) for this type of prairie environment. If it is assumed that the recharge in the areas covered by clay-rich till deposits actually discharges in local sloughs (non-contributing areas) and evaporates, then the total groundwater recharge in the Vermilion River Basin is about 15 million m^3. Among the uncertainties involved in estimating recharge for the Vermilion River Basin is an incomplete understanding of the surface and groundwater interactions within the basin, particularly between the Vermilion River and the two major buried bedrock channel aquifers that underlie a considerable portion of the river system within the basin.

The baseflow separation method was the second approach used to estimate groundwater yield in the VRB. This approach is based on the fact that groundwater is the source of baseflow to streams. Baseflow data at gauging stations in the basin, together with hydrograph interpretation, were used to estimate the groundwater recharge. The method used the minimum baseflow volumes, typically occurring during the winter months, corrected to account for the increased groundwater flux that occurs during wetter periods of the year. The average baseflow hydrograph was estimated "by eye" from all the hydrographs during the 1987 to 2007 period. An approximate average annual baseflow amount was estimated to be about 11 Mm^3 from the baseflow hydrograph. Based on the estimated baseflow hydrographs for the dry years and wet years, the annual baseflow in the Vermilion River at Marwayne is expected to range from 4 to 23 Mm^3, respectively. The total groundwater recharge in the Vermilion River Basin is about 15 million m^3 using the infiltration and precipitation assessment approach. This estimate is relatively close to the average baseflow amount (11 Mm^3) and within the range of annual baseflow amounts derived using the baseflow separation method.

An approximate average annual water balance in the Vermilion River Basin is as follows:

- Average total annual precipitation over the entire VRB ~ 3,300 million m^3
- Average total (surface runoff and baseflow) annual flow volume ~ 52 million m^3
  - Average total annual baseflow volume ~ 11 million m^3
- Annual Losses to evaporation/evapotranspiration ~ 3,250 million m^3

Potential Effects of Future Climate Scenarios on Basin Yield

A key consideration in a water supply assessment is the potential for changes in water supply due to future climate change. Water shortages may become more severe depending on the hydrologic response to climate change. Existing climate change studies on watersheds in Alberta were reviewed to evaluate future variability in water supply due to changing climates. The studies suggest that water yield could decrease in the future, with some probability of an increase, depending on which Global Climate Models and which emission scenarios are being considered. Trends in current climate and stream flow data records at locations close to the VRB also suggest potential decreases in flows in the future. Based on the review of previous studies, the change in mean annual water yield from all sub-basins in VRB could potentially range from an increase of 15% to a decrease of about 23%. Changes in mean monthly flows could be more significant during the summer and fall months when decreases of the order of 40% could occur. In contrast, spring melt could occur earlier as a result of higher spring temperatures, and could result in higher spring floods.

Water Supply-Demand Assessment

An assessment of the current and future water demands with respect to water supply was carried out using available water licence information and the results of a report prepared by AMEC in 2007 on water use in the VRB. It appears that the yield from the entire Vermilion River Basin is adequate to meet the overall basin demand. However, a more detailed comparison of available water supply, particularly, from groundwater, and considering supply-demand on a monthly basis during the late summer and fall months, suggests that the groundwater supply-demand balance in the middle and lower sections of the Vermilion River Basin will generally require more management in the future if demand on groundwater supplies increase and/or summer and fall monthly water supply decreases as a result of future climate changes.

Assuming (conservatively) an overall decrease of about 10% decrease in total mean annual water yield for all sub-basins in the VRB by the 2040s as a result of climate change, it appears that the reduced yield from the Vermilion River Basin is more than sufficient to accommodate the present total water demand and likely future water demands on an annual basis. However, water supply-demand conditions on a monthly or seasonal basis may be more problematic. A reduction of 40% in summer mean monthly flows by the 2040s due to potential future climate scenarios would result in a situation where monthly average licensed allocation and possibly monthly average licensed use may be greater than water supply. Actual water use and supply conditions could become critical more often during dry years. Future groundwater supply and demand conditions could become even more critical than surface water supply-demand conditions if one assumes a reduction of 40% in groundwater yield as summer baseflows. The comparison was qualitative in nature without factoring in the sustainability of the groundwater yield and the monthly distribution of total demand has been assumed to be uniform throughout the year in the absence of specific information.

Hydrologic Model for the Vermilion River Basin

The NSWA has identified the need for a hydrologic model for the VRB to assist it in determining the effects of land and water management initiatives, and in evaluating future scenarios, such as increased development and changes in the climate regimes. The Hydrologic Simulation Program – Fortran (HSPF) model was selected for implementation on the VRB. The Vermilion River Basin was sub-divided into 23 sub-basins, based on the drainage network and the locations of Environment Canada's hydrometric stations selected for calibration and validation of the model. The 23 sub-basins were further sub-divided according to upland/lowland land types, surficial geology, contributing/ non-contributing areas, and ditched/non-ditched non-contributing areas. Information on wetlands and ditched areas was obtained from a map provided by Ducks Unlimited and entitled "Vermilion River Watershed – Anthropogenic Impacts on Surface Water Resources". The effect of ditching on water yield was assumed to occur only in the non-contributing areas of the sub-basins by converting the non-contributing areas into contributing areas, albeit with different model parameters. The calibrated HSPF model was then used to assess and quantify the effects of the present land use patterns and flow control structures on flows in the Vermilion River Basin. The HSPF model, while useful in predicting changes in basin hydrology, is less effective in assessing operating rules for the Morecambe Structure. A planning level tool, STELLA / iThink, was used to simulate the operation rules at the Morecambe Structure and the effects of additional small storage areas in the VRB, using the outputs from the HSPF model as flow inputs.

Key Findings of Study

The following key findings are supported by the results of the simulations with the HSPF and STELLA models set up for the VRB.

- If new drainage works are planned within the basin to drain some areas or to connect non-contributing areas to downstream areas, they should be evaluated for their effects on peak flows and other hydrologic processes before their approval. Increased peak flows caused by increased ditching can lead to erosion of river banks, increased in-stream sedimentation, and possibly flooding and/or changes in water quality.

- It appears that the Morecambe Structure is presently less effective at controlling summer peak flows compared to attenuation of spring peak flows. Notwithstanding the foregoing finding, the structure can control spring floods, which tend to be significantly larger than the summer peak flows. It is also apparent that the procedure for riparian flow releases from the Morecambe Structure can be improved to increase base flows in the Vermilion River downstream of the structure. These findings should be discussed with Alberta Environment Water Management Operations.

- The possibility of increasing the operating range of water level in the Vermilion Lakes should be investigated to address control of summer peak flows and increasing summer and fall riparian flows. However, because of the low gradient of the Vermilion Lakes and channels connecting them, decreased water levels in the lake at Morecambe may still not mitigate upstream high water level events. A more detailed hydraulic study in combination with a decision support tool would be required to investigate the full effects.

- The increased storage from a larger operating range of water level in the Vermilion Lakes, especially at the lower end of the range, can assist in increasing base flows in downstream reaches of the Vermilion River. However, any change in the current operating rules occurs, the effects on riparian systems upstream of Morecambe Structure and/or on possible reduced availability of flow for downstream reaches during the summer months should be assessed before implementation. The low level riparian outlet on the Morecambe Structure should be cleaned for it to function as intended.

- Small storages in the upper sub-basins of the VRB can reduce peak flows in the Vegreville area, and, with a low level outlet for water release, can increase base flows in the Vermilion River. However, the feasibility and effectiveness of these small storages in reducing peak flows depend on two factors:

    - the availability of the necessary topographic relief or existing small water bodies to accommodate the required storage volumes (some potential sites exist in the headwaters of the Holden Drainage District and others in the upper middle portion of the VRB); and,

    - the possibility that spring flood events may fill up the storage facilities that are not sufficiently drained thereafter to reduce the magnitude of summer floods.

  The extreme variability in the magnitude of annual spring and summer peak flows suggests that the operation of the storage facilities may require human intervention often so that during years of moderate to small flood events the entire flow during these events are not retained in these facilities and reduce the late summer and fall flows in the Vermilion River.

Notwithstanding the above concerns, the locations of such small storages and their feasible storage capacities should be investigated for additional benefits such as wetland preservation. Most of the land in the Vermilion River Basin is private property, so it is very important to seek partnerships with the private landowners for such an initiative.

- Additional storage rules should be considered for the STELLA decision-support model, including spring back-flood/summer flow, to better represent the range of available management strategies.

Recommendations of Study

The following recommendations are made as possible next steps towards the development of a watershed management plan for the VRB.

- The HSPF model set up for the Vermilion River Basin can be used as a planning tool to assess the effects of areas proposed to be ditched and/or drained; flood mitigation measures such as off-main stem storage facilities or more effective operation of the Morecambe Structure. More detailed modeling within sub-basins may require refinement of the HSPF model to include finer topographic details and/or watershed processes, or the use of a distributed runoff model that can account for wetland and subsurface hydrology.
- A more refined version of the preliminary STELLA-based planning tool developed for this study with more detailed information on available storage on Bens Lake and Watt Lake can be used to find the best mix of storage volumes and locations while accounting for landowner concerns and other constraints.
- Operational procedures for flood mitigation could be improved with the implementation of real-time flow monitoring system (climate and hydrometric stations). There is significant spatial variability in precipitation in the basin. Addition of climate and hydrometric stations in the upper reaches of the basin would assist in effective operation of the Morecambe Structure.
- There is very little information available on the interaction between surface and groundwater regimes in the basin. It is recommended that an integrated study of these interactions, including the effects of wetland loss and restoration, be investigated in selected sub-basins of the VRB.
- A study on groundwater use and the sustainability of the groundwater regime as well as on future monthly water demand-supply conditions as a result of potential climate change scenarios is therefore recommended. The effects of the return flows to the Vermilion River Basin from water being piped in from outside the VRB should also be assessed.

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1.0 INTRODUCTION

1.1 Background

The North Saskatchewan Watershed Alliance (NSWA) has identified the Vermilion River Basin (VRB) as one of the most altered basins in the North Saskatchewan River watershed. Impacts include variable water supply, flooding, water quality issues, and impaired aquatic ecosystem health. Impacts on water quantity and quality are thought to result from wetland drainage and modification, livestock management, tillage and municipal and industrial development. However, comprehensive water resources information and planning tools for the VRB are limited. Future watershed planning will require an assessment of information gaps, the development of monitoring and research programs, and the development of new assessment tools. These programs will include: hydrological modeling; water quality assessment; land use assessment; water supply and demand assessment; and economic assessments in order to guide decision-making about water management in the basin. The NSWA is working with local municipal and regional partners to assess and improve key attributes of the Vermilion River Basin.

NSWA has identified the need for a study of water supply and demand to provide updated watershed and hydrological information to support planning. The *Vermilion River Water Supply and Demand Study* supports the Vermilion River Watershed Management Project (VRWMP), which is a collaborative initiative between the NSWA, the North East Alberta Water Management Coalition (NEAWMC) and the Alberta North American Waterfowl Management Plan Partners (ANP). The goals of the project are to

- Integrate and assess existing hydrologic information in the Vermilion River Basin;
- Generate new knowledge on hydrologic functions in the basin; and,
- Provide tools to support water resources planning and management in the basin.

Following a Request for Proposals (RFP) dated September 30, 2008, the NSWA retained Golder Associates Ltd. (Golder) to undertake a water supply and demand study of the Vermilion River Basin.

1.2 Objectives of Study

The overall objectives of the *Vermilion River Water Supply and Demand Study* are to:

- Provide technical information to assess the water management issues surrounding drainage activities in the headwaters, flooding in the middle reaches, and unreliability of water supplies in the lower reaches;
- Evaluate how landscape alteration and climate variability in the basin may be contributing to the current water management challenges;
- Evaluate the effectiveness of current water infrastructure in meeting water supply and management needs now and in the future; and,
- Facilitate the development of local knowledge and expertise that can be applied to water management challenges in the basin.

Specific tasks of the study include the following:

- Determine the current water yield (including variability) in the basin and its sub-basins;
- Compare current and future water demand in the basin and its sub-basins with water yield;
- Implement a hydrologic model for the Vermilion River Basin to:

    - assess the effects of drainage systems and wetlands on the hydrology of the basin;
    - assess the effects of present flood control structures on the hydrology of the basin; and,
    - support future evaluation of management alternatives, growth scenarios and potential climate change effects.
- Evaluate current data, identify data gaps and research needs;
- Determine future needs for water supply and flood control; and,
- Provide recommendations for watershed management to sustain a healthy ecosystem and to support long-term water supply.

2.0 WATER YIELD IN THE VERMILION RIVER BASIN

2.1 Hydrologic Regime of the Vermilion River Basin

The Vermilion River Basin (VRB) is located in the Parkland Natural Region of Alberta (Figure 2.1). The basin is irregularly shaped, narrowing near the Town of Vermilion. The Vermilion River drains 7,860 km^2 or approximately 14% of the land in the North Saskatchewan River watershed. The Vermilion River Basin includes all or part of six counties and eighteen towns. The towns of Vegreville, Vermilion and Two Hills are the largest population centres in the basin. These three towns are located adjacent to the Vermilion River. Land use in the basin is dominated by agriculture, with smaller amounts of disturbance associated with transportation, industry, and municipal use.

The Vermilion River flows in a generally easterly direction and joins the North Saskatchewan River about 40 km from the Alberta-Saskatchewan boundary. The river is about 320 km long with varying gradient. Although the river drops an average of about half a metre per kilometre, in any particular reach the gradient may be as high as two metres per kilometre or as low as zero (Alberta Environment 1974). For example, the river has very low gradients near the Two Hills and Vermilion floodplain areas, the Town of Vegreville and within the Holden Drainage District.

2.1.1 Surface Water Regime

The Vermilion River is a non-glacier fed tributary to the North Saskatchewan River. Most of the flow in the river and the largest floods occur during the spring snowmelt period, with summer rainstorms contributing on average a relatively smaller proportion of the annual discharge, but which can occasionally generate localized large floods. The flow regime in the Vermilion River is characterized by lengthy periods of low flows. A review of the series of recorded annual water yield at the hydrometric gauging stations in the basin suggests that the standard deviation of the annual water yield is generally greater than the mean annual yield, indicating considerable variability from year to year. Spatial variability within the basin is also high. A water supply assessment carried out for the NSWA by Golder (NSWA 2007) for the North Saskatchewan River (NSR) watershed estimated that the mean annual runoff (mean annual yield) from the Vermilion River basin was about 25 mm per year on average, which is equivalent to a mean annual discharge of about 59 million m^3 at the confluence with the NSR. The mean annual yield is the arithmetic average of all the annual runoff volumes at a given location in the Vermilion River. It is usually expressed as a depth of runoff (average flow volume divided by drainage area). At a finer scale, however, it is apparent from data at flow gauging stations within the VRB that the water yield from the sub-basins of the VRB varies spatially from about 50 mm/yr near the headwaters to about 18 mm/yr near the confluence with the NSR.

The study of prairie hydrology makes a distinction between effective drainage area, which is the area (contributing area) that actually contributes runoff to the main receiving stream during a flood with a return period of two years, and gross drainage area, which is the area that could be contributing runoff only during extremely wet conditions and are delineated based on topography. The nominal difference between gross area and effective area during a two-year storm is termed non-contributing area. The actual percent of the basin area contributing to runoff may be quite variable on an annual runoff basis, from season to season, or from storm to storm, and it varies as a function of the actual amount of moisture input (precipitation), the antecedent soil moisture conditions and the hydrologic connectivity of the various parts of the basin.

The prairie landscape in the eastern part of Alberta is characterized by areas with internal drainages, i.e., areas that do not drain to the main receiving stream, but instead drain to local sloughs or wetlands. This is especially relevant in the Vermilion River Basin, which has a total gross drainage area of about 7,860 km^2, but an effective drainage area of only 2,360 km^2 (Figure 2.2) Thus, about 70% of the basin does not contribute to flows in the Vermilion River during the two-year flood conditions.

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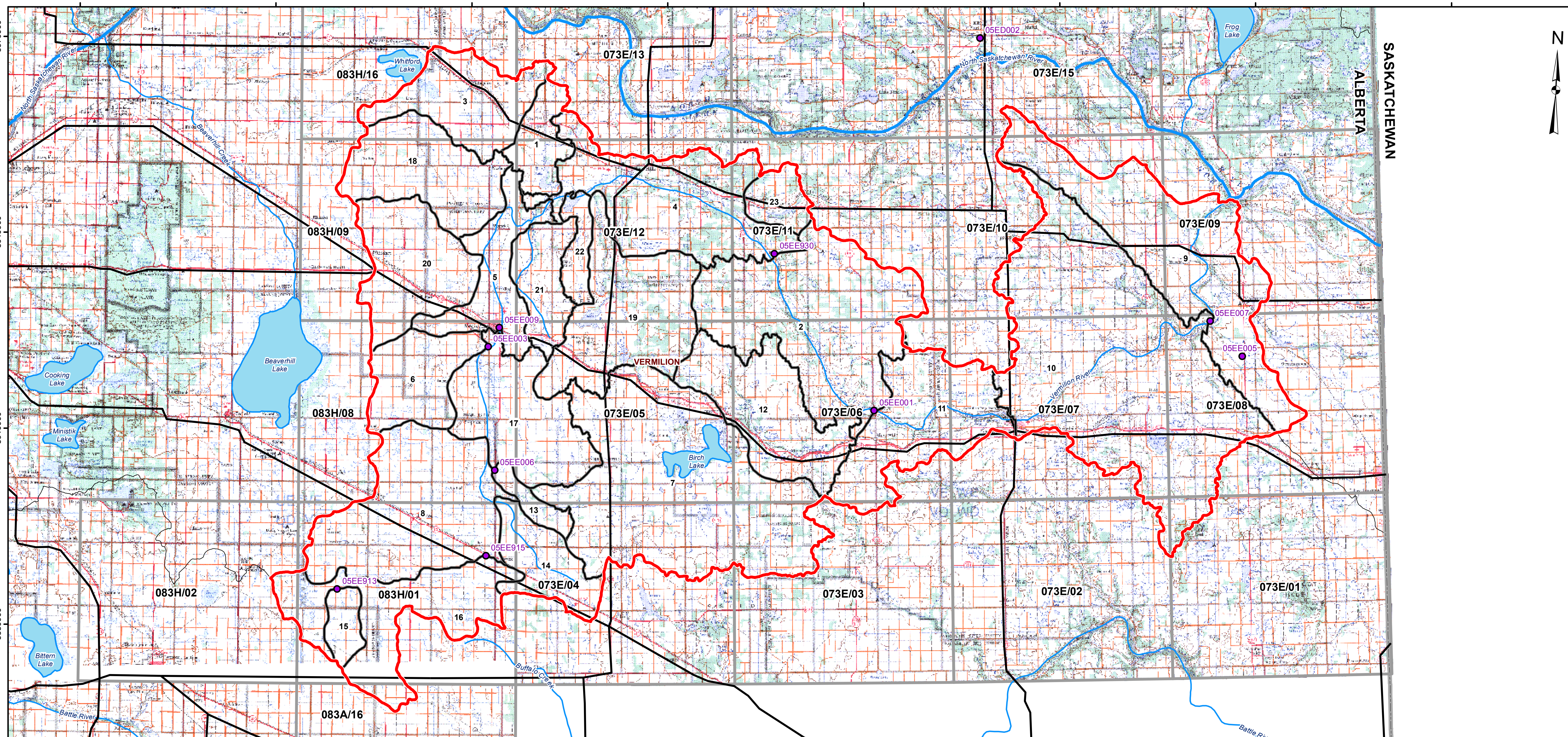


LEGEND

- HYDROMETRIC STATION
- RIVER
- ROAD
- LAKE
- BASIN BOUNDARY
- SUB-BASIN BOUNDARY

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

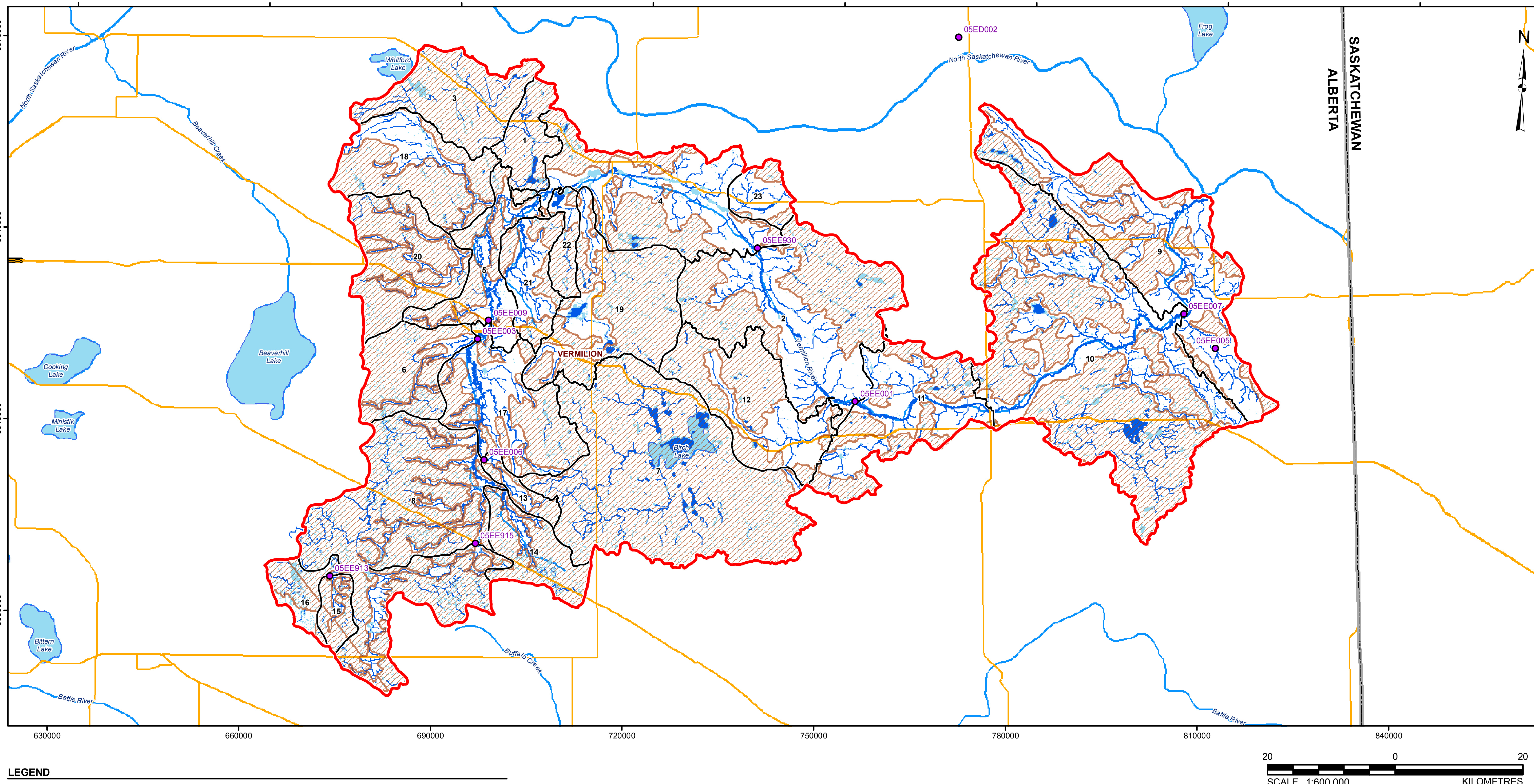
NSWA - Vermilion River Water Supply and Demand Study

TITLE

VERMILION RIVER BASIN

Golder Associates
Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009	**FIGURE: 2.1**	
GIS	JH	09 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		



LEGEND

- HYDROMETRIC STATION
- DIVIDED HIGHWAY
- PRIMARY HIGHWAY
- RIVER
- STREAM - VERMILION RIVER BASIN
- RIVER - VERMILLION RIVER BASIN
- SUB-BASIN BOUNDARY
- BASIN BOUNDARY
- NON-CONTRIBUTING AREA
- LAKE
- LAKE - VERMILION RIVER BASIN - PERMANENT
- LAKE - VERMILION RIVER BASIN - TEMPORARY

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

TITLE

NON-CONTRIBUTING AREAS IN THE VERMILION RIVER BASIN DURING THE TWO-YEAR FLOOD CONDITIONS

Golder Associates
Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009		
GIS	JH	10 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

FIGURE: 2.2

2.1.2 Groundwater Regime

Groundwater is an important source of municipal, commercial and industrial water supply for much of the Vermilion River Basin (VRB), as well as supplying water to most rural residents. Data from the Alberta Environment Groundwater Information Database (AENV 2009) indicates there are currently over 13,000 water supply wells in the basin. In addition to its importance as a reliable source of water for human activities, groundwater serves a key role as the source of baseflow to the Vermilion River and its tributaries, maintaining water levels in prairie wetland ecosystems and maintaining soil moisture conditions in a semiarid climate. In contrast, the surface flow regime is characterized by lengthy periods of low flow and zero discharge has been recorded on several occasions.

The primary mechanism for groundwater recharge in the VRB, and typical of areas that comprise of cold, semiarid climates blanketed primarily by hummocky, clay-rich glacial deposits, involves runoff and collection of snowmelt from upland areas into small, closed depressions creating temporary or seasonal ponds. This type of depression-focused recharge has been studied extensively throughout the Canadian prairies and northern United States (van der Kamp *et al*.1998, 2009; Hayashi *et al.*, 1998, 2003; Berthold *et al.* 2004; Derby *et al.* 2001; Lissey 1971).

In semiarid climates like that of the Vermilion River Basin, evapotranspiration rates typically exceed summer precipitation. Despite large monthly rainfall totals that occur over the summer months of June through August, very little of this water is recharged to the ground. On a monthly basis, potential evapotranspiration rates exceed average precipitation in the basin from May through August. As a result, primary water inputs to groundwater are derived mainly from snowmelt and to a lesser extent by spring and fall precipitation. This appears to be substantiated by water level data from surficial wells in the basin. The hydrograph for observation well #235 (Innisfree, Alberta) in Figure 2.3 shows a sharp water level rise in the spring/early summer in response to recharge from snowmelt runoff followed by water declines throughout the summer. A recharge event, much smaller in magnitude, is also observed during the fall. A large portion of snowmelt runoff, derived from upland areas, accumulates in the adjacent depressions rather than infiltrating the soil because the water cannot initially penetrate the frozen ground. A comparison of potential and actual snowmelt volumes collected from a study site in Saskatchewan (Hayashi 1998b) over a 29-year period suggests snowmelt runoff averages about 35% of winter precipitation. The same study indicates that 75% of the water within the depression infiltrates the subsurface, with the remaining 25% removed by a combination of surface water evaporation and evapotranspiration.

Generally, the subsurface flow system within these depressions is characterized by substantial infiltration under the wetland, lateral flow within the first few metres of the weathered subsurface, evapotranspiration along the margins of the depression and vertical flow to the underlying regional aquifer (van der Kamp *et al.*, 2009). However, because the permeability of the glacial tills underlying the depression typically decreases with depth, the amount of water that reaches the underlying aquifer can be very small on an annual basis. A summary of recharge estimates from prairie depressions to regional aquifer from previous studies (Hayashi *et al.*, 1998b) reveal recharge rates ranging from 2 to 45 mm/year, averaged over their drainage basin. Statistics provided by Alberta Environment indicate that groundwater recharge rates on the prairies range from 2% to 5% of annual precipitation. Results obtained from Hayashi (1998a) in Saskatchewan suggested groundwater recharge accounted for only 1% of annual precipitation.

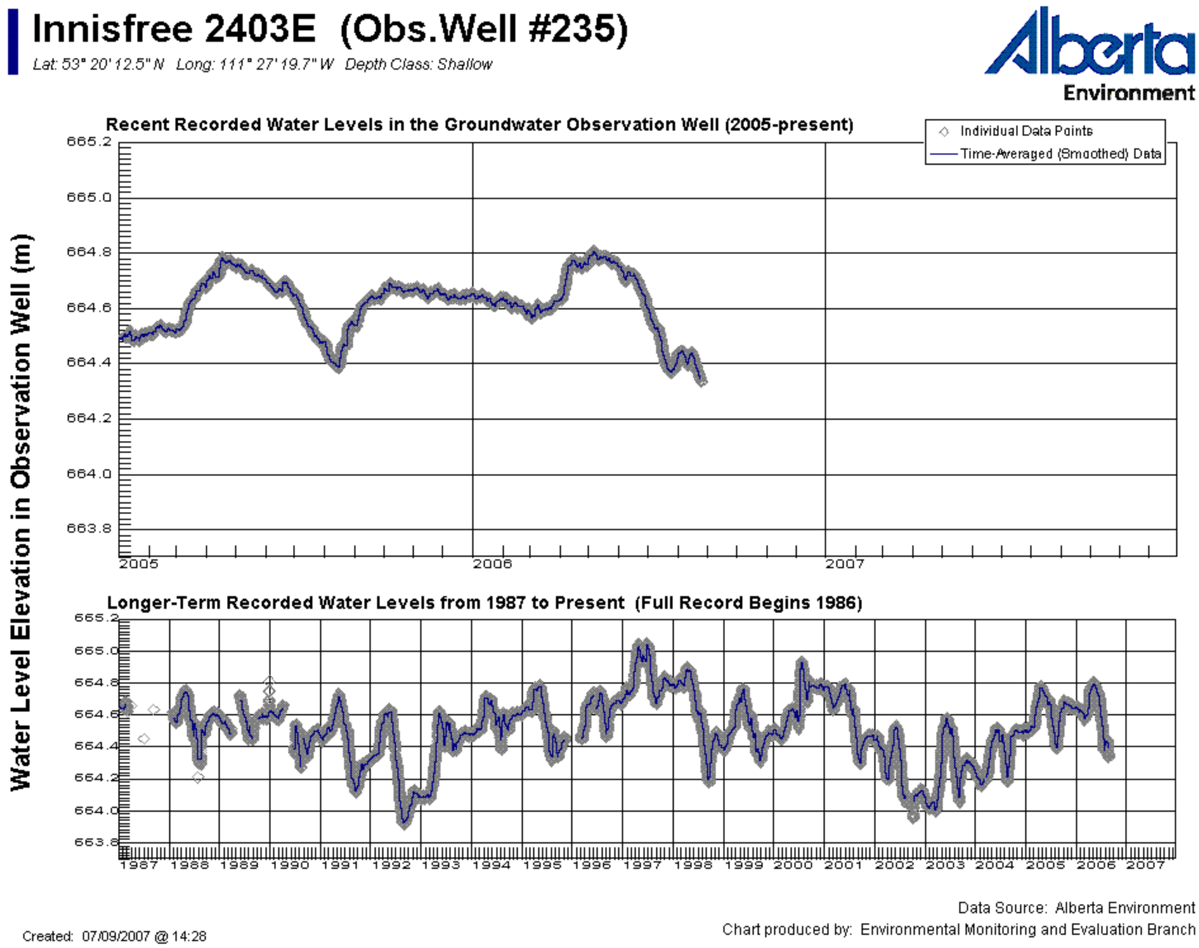


Figure 2.3 Hydrograph of Water Levels in Shallow Groundwater Aquifer at Innisfree, Alberta

2.2 Surface Water Yield Estimates

2.2.1 Approach

The objective of the surface water yield task was to estimate the mean annual runoff (annual yield) and mean monthly runoff (monthly yield) at several locations along the Vermilion River basin. The scope of work also included estimating the quartiles (25^{th} and 75^{th}) and deciles (10^{th} and 90^{th}) of the annual mean and monthly mean flows (yield). There are several hydrometric gauging stations that record stream flows in the Vermilion River Basin. In addition, there are hydrometric stations in the adjacent Battle River Basin that were considered to augment the amount of hydrometric data available. The flow data was used to undertake the surface water yield analysis.

Table 1 (Appendix A) lists the hydrometric stations considered for the water yield analysis, their locations, the period of record used in the analysis for each station, and the effective and gross drainage areas at the station locations. For each hydrometric station selected for analysis, the mean annual runoff (annual yield) and mean monthly runoff (monthly yield) were estimated from the period of record. The coefficients of variation and skewness for the annual yield were used to estimate the quartiles (25^{th} and 75^{th}) and deciles (10^{th} and 90^{th}) on the basis that the annual yield follows a log-normal distribution. The monthly yield percentages were then used to distribute the annual yield for each percentile.

At stations where winter flows are not available, the winter monthly yields were estimated using a percentage of the mean annual runoff. The percentage used for the winter months were based on an approximate percentage derived for stations with recorded winter flows.

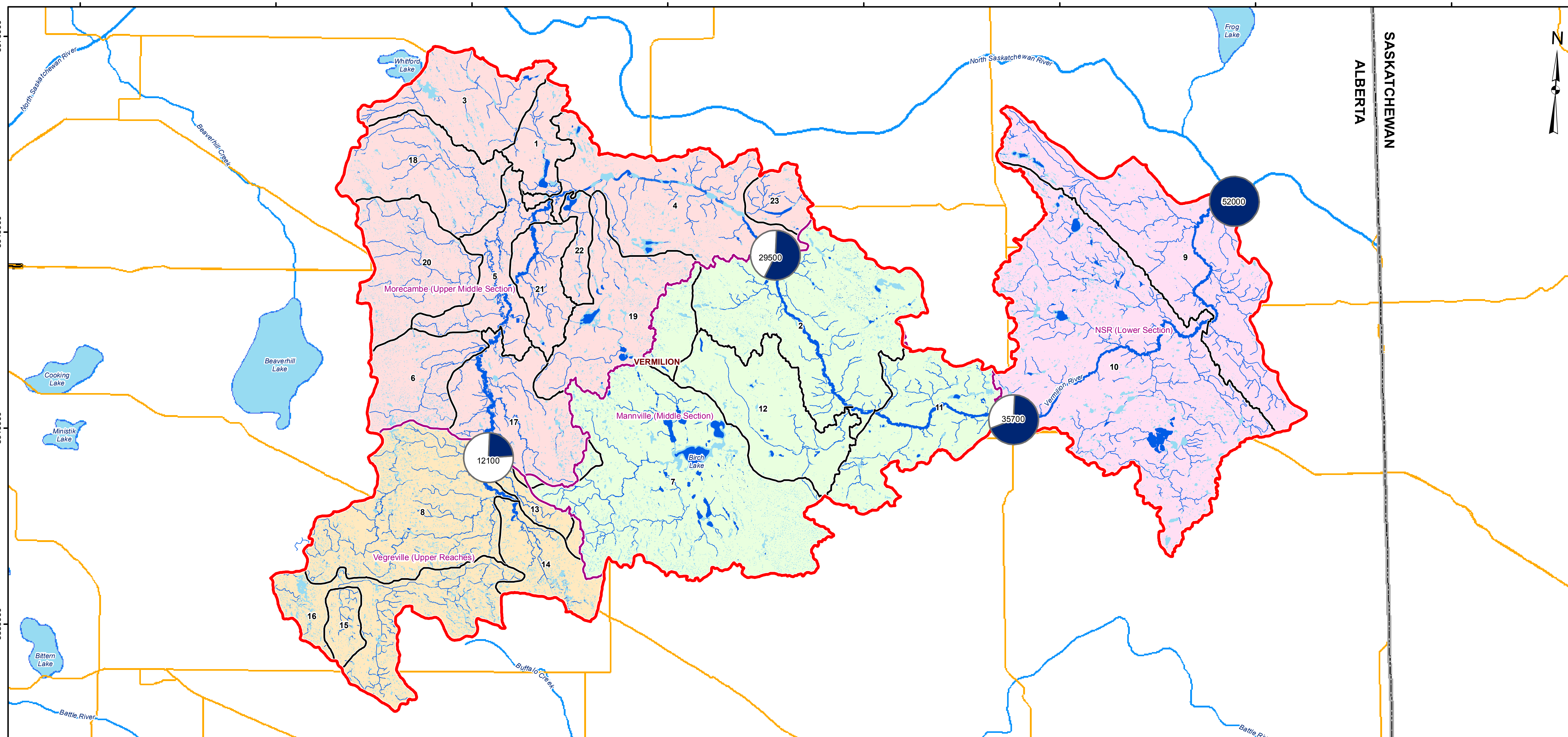
2.2.2 Results

Tables 2 to 5 (Appendix A) provide the results of the water yield analysis for the average case (50^{th} percentile) and the 10^{th}, 25^{Th}, 75^{th} and 90^{th} percentile cases. Table 2 from Appendix A is reproduced as Table 2.1 below. On average, the Vermilion River Basin yields about 52 million cubic metres (Mm^3) of runoff annually at its mouth. The average annual yield is equivalent to an average water depth of about 22 mm over the effective (contributing) area. The average annual yield (in terms of depth) varies from 46 mm near the headwaters to about 17 mm near the mouth, illustrating the spatial variability of water yield in the basin (higher in the headwaters and lower near the mouth). The highest water yield months are April and May. From late fall to early spring, the yield from the sub-basins in the VRB is very low and nearly zero in some cases.

Figure 2.4 shows the spatial distribution of surface water yield in the Vermilion River Basin. The total annual yield of the basin was estimated at 52 Mm^3 or 52,000 dam^3 (1 dam^3 = 1,000 m^3). The four major sub-areas selected for depiction of water supply conditions are the Upper Vermilion Area, Upper-Middle Vermilion Area, Lower-Middle Vermilion Area and the Lower Vermilion Area. The yield on the Vermilion River at the downstream boundary of each major sub-area was estimated from the results shown in Table 2.1 (Table 2 in Appendix A). The annual yield from the Upper Vermilion Area was estimated at 12,100 dam^3. The cumulative annual yields at the downstream boundaries of the Upper-Middle and Lower-Middle areas were estimated at 29,500 and 35,700 dam^3, respectively.

Table 2.1 Annual and Monthly Yields from Sub-Basins in the Vermilion River Basin - Average Case - 50th Percentile Case

Sub-Basin	Representative Hydrometric Stattion Data	Cumulative Gross Area Reported at Hydrometric Station (km²)	Gross Area at Sub-Basin Outlet (km²)	Cumulative Effective Area Reported at Hydrometric Station (km²) -	Effective Area at Sub-Basin Outlet (km²)	Monthly Yield (mm)											
						Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vermilion R @ Bruce-Holden Headwaters-WSC	05EE006		631		136	0.2	0.3	6.7	27.2	2.3	2.6	4.4	0.8	1.1	0.3	0.2	0.2
Waskwei	05EC002		968		237	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4
Vermilion R @ Vegreville-WSC	05EE009	1,620	1,600	367	373	0.0	0.3	3.6	16.6	1.2	0.4	0.6	0.2	0.2	0.1	0.0	0.0
Two Hills	05EC002		932		305	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4
Watt-Bens Lakes	05EC002		420		19	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4
Cotton Creek	05EC002		306		89	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4
Two Hills-Morecambe	05EC002		534		304	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4
Vermilion R @ Morecambe-Beauvallon-WSC	05EE930	3,880	3,792	1,070	1,090	0.0	0.0	0.0	7.0	4.6	0.6	0.4	0.1	0.2	0.1	0.1	0.1
Birch Creek	05FB002		1,265		113	0.2	0.2	0.8	8.1	3.3	1.3	1.5	0.6	0.2	0.2	0.2	0.2
Morecambe-Mannville	05EE005		657		248	0.1	0.1	4.5	9.5	0.7	0.3	1.1	0.8	0.2	0.1	0.1	0.1
Vermilion R @ Mannville-WSC	05EE001-N-Con	5,740	5,714	1,800	1,451	0.0	0.1	0.9	6.7	5.5	1.5	3.1	1.0	0.4	0.4	0.1	0.1
Mannville-Vermilion	05EE005		382		211	0.1	0.1	4.5	9.5	0.7	0.3	1.1	0.8	0.2	0.1	0.1	0.1
Vermilion R @ Vermilion		6,100	6,096	1,850	1,661												
Vermilion-Marwayne	05EE005		1,152		363	0.1	0.1	4.5	9.5	0.7	0.3	1.1	0.8	0.2	0.1	0.1	0.1
Vermilion R @ Marwayne-WSC	05EE007	7,260	7,247	2,000	2,025	0.2	0.3	0.7	6.8	3.4	0.8	1.3	0.8	0.2	0.2	0.2	0.2
Marwayne-NSR	05EE005		615		365	0.1	0.1	4.5	9.5	0.7	0.3	1.1	0.8	0.2	0.1	0.1	0.1
Vermilion R @ NSR		7,860	7,863	2,360	2,390												



20 0 20

SCALE 1:600,000 KILOMETRES

LEGEND

- DIVIDED HIGHWAY
- PRIMARY HIGHWAY
- RIVER
- STREAM - VERMILION RIVER BASIN
- RIVER - VERMILLION RIVER BASIN
- LAKE
- LAKE - VERMILION RIVER BASIN - PERMANENT
- LAKE - VERMILION RIVER BASIN - TEMPORARY
- SUB-BASIN
- BASIN BOUNDARY
- SUB-BASIN BOUNDARY

VERMILION RIVER WATER YIELD

CUMMULATIVE ANNUAL WATER YIELD (DAM^3)

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

TITLE

AVERAGE ANNUAL WATER YIELD IN THE VERMILION RIVER BASIN

Golder Associates
Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009	**FIGURE: 2.4**	
GIS	JH	09 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

The annual variability in runoff from the VRB is significant. For example, the annual yield at the mouth of the VRB near its confluence with the North Saskatchewan River can vary from 10 Mm^3 (10th percentile, value exceeded 90 percent of the time) to about 110 Mm^3 (90th percentile, exceeded 10 percent of the time), illustrating the very high variability in annual yield from year to year. Table 2.2 shows the mean, 10th percentile and 90th percentile of annual yield at three locations in the VRB: Vegreville, downstream of the Morecambe Structure and at the mouth of the Vermilion River near its confluence with North Saskatchewan River. The difference between the 10th and 90th percentile yield is almost twice the average yield, reflecting the wide range in the hydrologic response (very dry to very wet) of the basin.

August and September are the months with the lowest flows during the open-water season. The average, 10th percentile (approximately 10-year dry month) and 90th percentile (approximately 10-year wet month) monthly flow volumes from the VRB during August are 2.8, 0.64 and 6.8 Mm^3, respectively, and during September are 0.66, 0.15 and 1.6 Mm^3, respectively.

Table 2.2 Variability in Annual Water Yield from the Vermilion River Basin

Location in Basin	Total Drainage Area (km^2)	Effective Drainage Area (km^2)	Average Annual Yield (Mm^3)	10th Percentile Annual Yield (Mm^3)	90th Percentile Annual Yield (Mm^3)
Vegreville	1,600	370	12	2	27
Morecambe	3,800	1,100	30	4	66
Mouth near NSR	7,800	2,400	52	10	111

2.3 Ground Water Yield Estimates

2.3.1 Approach using Infiltration Rate and Precipitation

A relatively simple methodology, developed by Golder (Golder 2008) for a recent province-wide water-supply assessment, was initially used to estimate groundwater recharge in the Vermilion River Basin. This estimation method served as a foundation from which a more comprehensive assessment was formulated that would also account for the topographic and climatic characteristics of the basin.

2.3.1.1 Infiltration Estimates

The approach recently developed by Golder for Alberta Environment (Golder 2008) to estimate groundwater recharge for the province's major watersheds was based primarily on regional surficial geology and associated permeability data. This information was used to assign average infiltration rates across the province, based on the characteristics of the surficial materials and their recharge effectiveness. Using a GIS platform, the annual precipitation values were compared to the infiltration rates to provide an estimate of annual recharge for each watershed. The overall results compared favourably with recharge estimates generated using a baseflow separation technique; however, in semi-arid environments, where evapotranspiration rates are higher than average in the province, recharge estimates were often overestimated. Using the average infiltration rates assumed for this province-wide study, the total annual groundwater recharge in the Vermilion River Basin would be approximately 30% (234 million cubic metres) of total annual rainfall (425 mm). This amount of recharge is not plausible as the yield from the VRB is only about 52 million m^3. The results based on the simple approach indicated that, in these areas, the impacts of evapotranspiration likely influenced recharge potential and needed to be accounted for in the estimation procedure.

Findings from extensive studies conducted by Hayashi and others indicate that recharge rates to the regional groundwater system in semi-arid, glaciated prairie environments are much lower than values calculated using the above method. The results suggest that recharge rates may be as low as 1 to 3 percent of total annual precipitation. In the Vermilion River Basin these low-permeability areas make up over 85% (6,730 km^2) of the basin. In the remaining 15% (1,130 km^2) of the basin, more permeable surface soils are present associated with fluvial-type deposits.

To better reflect recharge conditions in the basin, the infiltration rates originally applied to areas covered by clay-rich till deposits (ranging from 7 to 10%) were replaced with one percent (1%) of total mean annual precipitation. Results from infiltration and recharge studies conducted in these areas suggest that this modification is reasonable. In areas where more permeable surface soils are present, the infiltration rates used in original recharge calculations were maintained.

2.3.1.2 Slope Assessment and Groundwater Discharge Zones

The slope or steepness of a surface, in part, controls the amount of time that water remains on the surface. The longer water is retained on the surface, the higher the potential that the water will be able to infiltrate the ground. In steeper areas of the basin, water runs off quickly and the probability of infiltration is low. A slope analysis of the basin was conducted to identify areas of steeper slope.

Using an NTDB (Geobase) Digital Elevation Model (DEM) at an original resolution of 100 m, slope percentages were assigned in a grid format over the basin at an initial cell size of approximately 20 metres x 20 metres. The resulting grid was then re-sampled using bilinear interpolation to a 100-metre grid-cell size to allow for easier processing and a sliding average was calculated for each cell. Finally, for consistency with existing data, the grid was again re-sampled to a 1-km x 1-km grid-cell size. The final dataset was assessed and compared with the topographic data to select an arbitrary slope percentage value (3%) that would be used to eliminate areas with low groundwater recharge potential due to increased runoff. The selection of the 3% slope was based on experience and experimentation with the DEM map, and provided the best definition between the valleys and the areas of steeper slopes. The slope assessment identified approximately 1,600 km^2 of area within the basin with low recharge potential. These areas are located primarily in the central and eastern portions of the basin and along stream and river valleys. These areas, representing approximately 20% of the total basin area, were subsequently removed from the basin recharge calculation. In the clay rich till soils, the recharge was estimated to be about one percent of the fall, winter and spring precipitation, thus the recharge on areas of steep slopes was considered to be insignificant and approximated to zero.

In addition to removing steeper areas of the basin from the recharge calculation, areas of probable groundwater discharge were also identified and removed. Discharge zones represent areas where the groundwater or water table is likely to intersect the land surface. In these situations, groundwater moves from the saturated aquifer to either the land surface or the atmosphere. Areas adjacent to perennial streams, lakes, reservoirs and other surface-water bodies are typical areas of perennial groundwater discharge. The 1:250,000-scale maps were used to identify these types of features. Topographic contour data adjacent to these water bodies were then examined to estimate an average extent that would likely represent a discharge zone. For streams and rivers, a distance of 100 metres was selected; for lakes and ponds a distance of 150 metres was selected. These areas were removed from the basin recharge calculations, however, they represent less than 1% of the total basin area.

2.3.1.3 Precipitation Assessment

Based on the detailed studies of Hayashi *et al.*, much of the groundwater recharged to the basin is derived primarily through the infiltration of snowmelt in topographical depressions, with lesser amounts derived from fall precipitation (as indicated by shallow aquifer hydrographs). Because evapotranspiration losses exceed precipitation during the summer months, the contribution of summer rainfall to groundwater recharge is likely very small. These studies also suggest that the majority of the water remains within the shallow groundwater system, providing soil moisture and ET to uplands; only a very small portion recharges the regional groundwater system.

To account for these characteristics in the recharge estimate, and particularly considering the recurring moisture deficit (ET>P) during the summer months, only precipitation that occurs during the fall, winter and spring months (September through May) was used. Precipitation that occurs during the summer (June, July and August) was removed. The average of combined spring, fall and winter precipitation, compiled from four climate stations in the Vermilion River Basin, collected between 1976 and 2002, ranges between 180 mm to 203 mm, with an average of 196 mm. This represents approximately 47% of the annual average precipitation (425 mm) in the basin.

2.3.1.4 Results

Using the method described above, an estimate of annual groundwater recharge was calculated for the Vermilion River Basin using a combination of percentage of basin precipitation, and assigned infiltration rates based on subsurface characteristics. The effects of topography and climate were also incorporated into the recharge calculation. Areas covered by extensive till deposits recharge volumes were calculated based on 1% of total annual precipitation. In areas containing permeable soils, recharge rates ranging from 12 to 20% were applied. Additionally, annual precipitation for the basin was reduced to reflect the moisture deficit (ET> P) that occurs during the summer months of June, July and August. A slope assessment was conducted to identify and remove steeper areas of the basin where the probability of infiltration/recharge is low. Figure 2.5 outlines the four different infiltration rates within the basin and delineates the steeper areas of the basin that were removed from the recharge calculation.

Table 2.3 summarizes the data used to calculate groundwater recharge for the basin. An estimated annual groundwater recharge volume of 39 million cubic metres (m^3) was calculated for the Vermilion River Basin. This amounts to an average recharge rate of approximately 5 mm per year and represents 1.2% of the average annual precipitation (425 mm) in the basin. This value is in the low range of reported recharge rates (2 to 45 mm/year) and precipitation percentage (2% - 5%) for this type of prairie environment, however, it is appreciably larger than an estimated average annual recharge of 11 million cubic metres derived using the baseflow separation method (see next section). While significant wetland drainage has occurred in the VRB, particularly in the upper sub-basins, the low baseflow amount is likely a reflection of the topography and geology of the basin.

If it is assumed that the recharge in the areas covered by clay-rich till deposits actually discharges in local sloughs (non-contributing areas) and evaporates, then the total groundwater recharge in the Vermilion River Basin is about 15 million m^3. This estimate is now closer to the baseflow amount (11 Mm^3) derived using the baseflow separation method.

Among the uncertainties involved in estimating recharge for the Vermilion River Basin is an incomplete understanding of the surface and groundwater interactions within the basin, particularly between the Vermilion River and the two major buried bedrock channel aquifers that underlie a considerable portion of the river system within the basin. Although these are not extensive, these aquifers are capable of transporting large volumes of water. Additional data would be needed to determine the degree of interaction and connection between these features and surface water features.

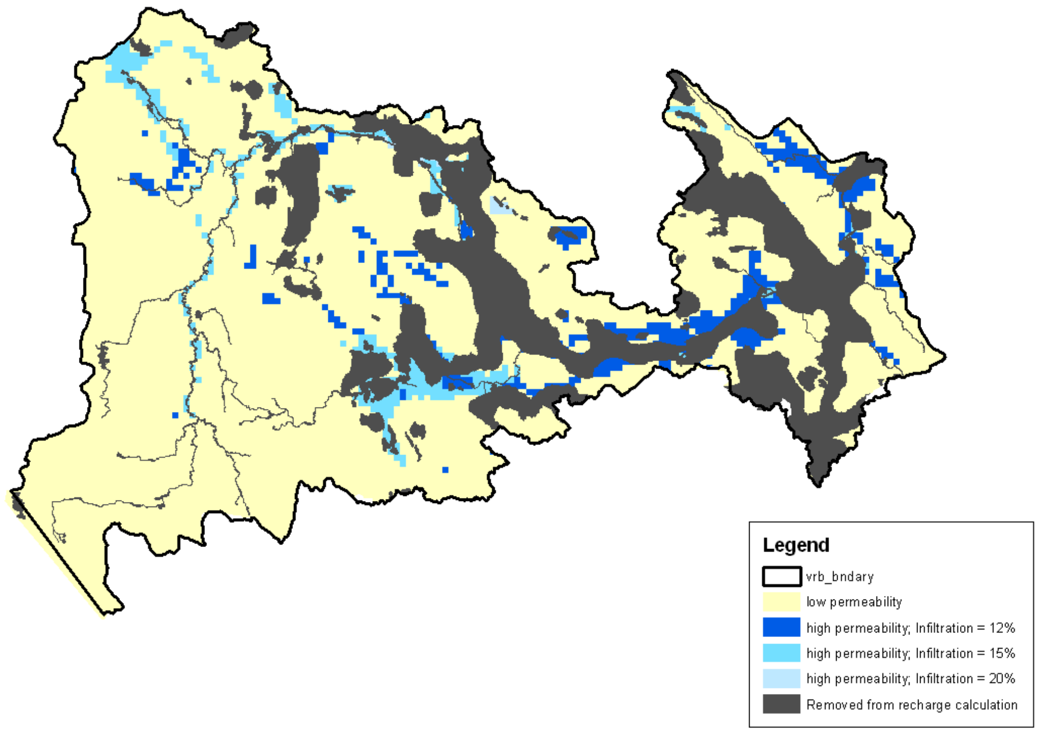


Figure 2.5 Infiltration Rates and Areas of Steep Slope Removed from Groundwater Recharge Estimate in Vermilion River Basin

Table 2.3 Results of Groundwater Recharge Calculations for the Vermilion River Basin

Percent of Precipitation Infiltrating Soil (%)	Precipitation (mm/yr)	Area (km^2)	Basin Recharge Volume (m^3)	Average Recharge per unit area (mm)
1	425	5,445	23,100,000	4
12	196	331	7,800,000	24
15	196	252	7,000,000	29
20	196	9.1	357,000	39
		TOTAL VOLUME (m^3):	38,257,000 (15,000,000 excluding the recharge from the very low permeability area – Row 1)	
		RECHARGE (mm):	4.9	
		PERCENTAGE OF RECHARGE AS TOTAL ANNUAL PRECIPITATION :	1.2%	

2.3.2 Approach using Baseflow Separation Method

The baseflow separation method is based on the fact that groundwater is the source of baseflow to streams. Baseflow data at gauging stations, together with hydrograph interpretation, can be used to estimate the groundwater recharge on a watershed basis. For example, mean February flows represent essentially the base groundwater contribution to streams in much of Alberta. Stream hydrographs can be interpreted, using baseflow separation approaches on annual hydrographs, to estimate the groundwater contribution to flow at other times of the year as well. The method chosen to provide approximate estimates of groundwater recharge and discharge was to use the minimum baseflow volumes, typically occurring during the winter months, corrected to account for the increased groundwater flux that occurs during wetter periods of the year. Baseflow separation was conducted with the flow data at the gauging station 05EE007 (Vermilion River at Marwayne) to capture the recharge for the entire basin.

Figure 2.6 shows the annual hydrographs at hydrometric station 05EE007 (Vermilion River at Marwayne) for the period from 1987 to 2007. The hydrographs have been truncated at a flow of 10 m^3/s to show the low flows during the early spring and late fall months. There are several very wet and very dry years during this period. It appears that the annual hydrographs can be separated into two groups: spring flood flows less than and greater than 3 m^3/s. The extreme variability in runoff conditions from year to year suggests that the estimated baseflow hydrograph is also very variable from year to year. Figure 2.7 and Figure 2.8 show the annual hydrographs for the dry and wet years, respectively.

The average baseflow hydrograph has been estimated “by eye” from all the hydrographs during the 1987 to 2007 period (Figure 2.6) and the effects that the flood control structure at Morecambe may have had on the late summer to late fall flows have been ignored. The winter baseflows have been assumed to be essentially the same at a late fall baseflow of 0.1 m^3/s. Notwithstanding the uncertainties in the baseflow hydrograph, an approximate average annual baseflow amount is estimated to be about 11 Mm^3 from the baseflow hydrograph. This amount is approximately 22% of the total mean annual yield at the mouth of the Vermilion River. Groundwater recharge and subsequent discharge to streams and waterbodies is therefore a significant contributor to flows in the Vermilion River. Figure 2.7 and 2.8 show the estimated baseflow hydrograph for the dry years and wet years, respectively. Based on these two extreme baseflow hydrographs, the annual baseflow in the Vermilion River at Marwayne is expected to range from 4 to 23 Mm^3.

As discussed in Section 2.3.1.4, if one assumes that most of the recharge in the areas covered by clay-rich till deposits actually discharges in local sloughs (non-contributing areas) and evaporates, then the total groundwater recharge in the Vermilion River Basin is about 15 million m^3 using the infiltration and precipitation assessment approach. This estimate is relatively close to the average baseflow amount (11 Mm^3) and within the range of annual baseflow amounts derived using the baseflow separation method.

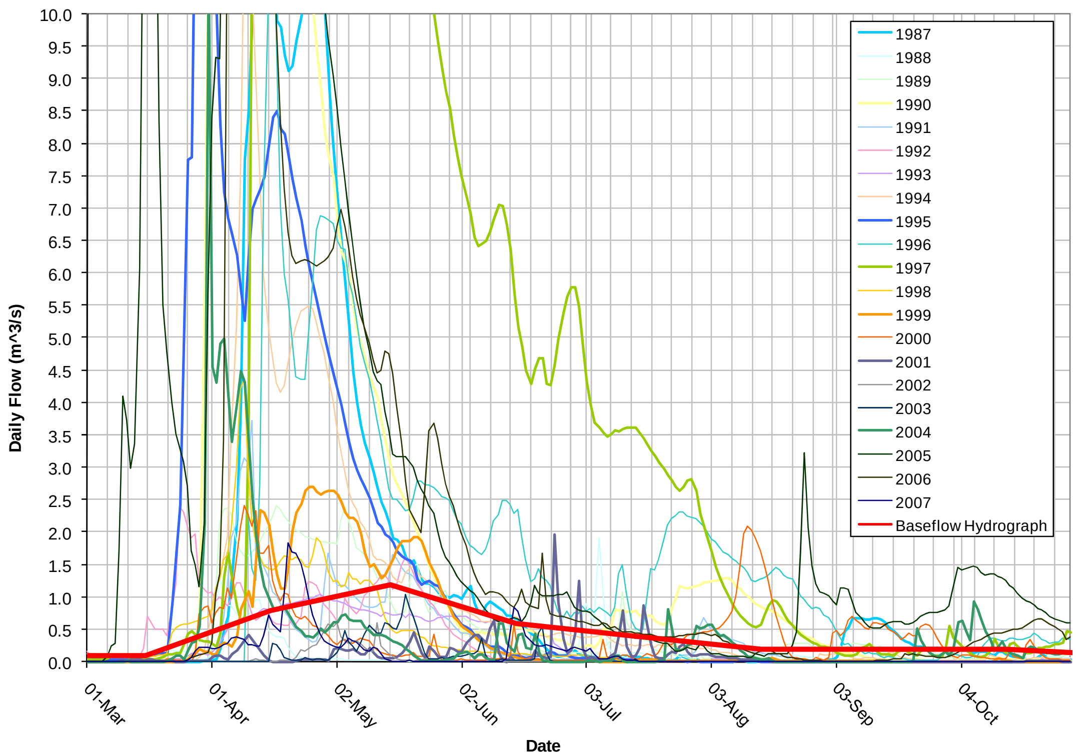


Figure 2.6 Estimated Average Baseflow Hydrograph for Vermilion River at Marwayne

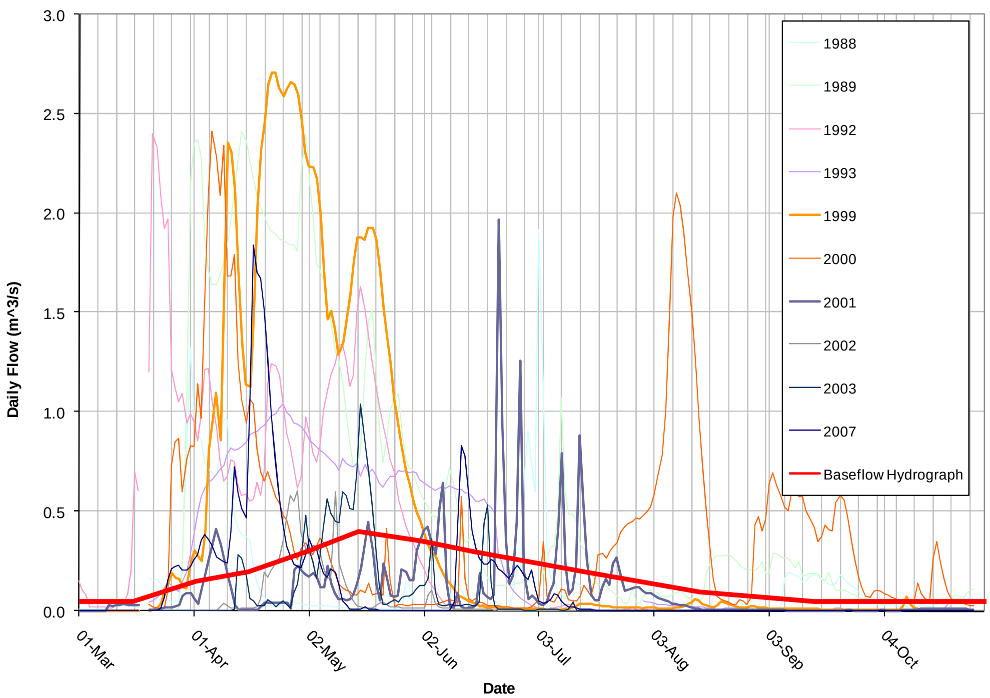


Figure 2.7 Estimated Dry Year Baseflow Hydrograph for Vermilion River at Marwayne

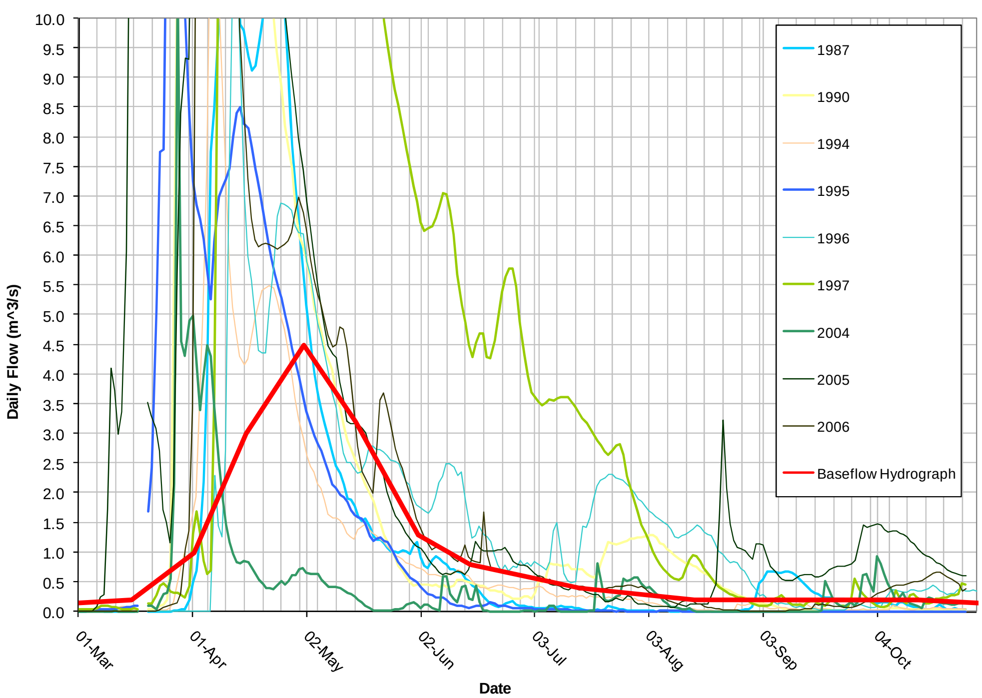


Figure 2.8 Estimated Wet Year Baseflow Hydrograph for Vermilion River at Marwayne

2.4 Water Balance in Vermilion River Basin

An approximate average annual water balance in the Vermilion River Basin is as follows:

- Average total annual precipitation over entire basin ~ 3,300 million m^3
- Average total annual flow volume from Vermilion River ~ 52 million m^3
  - total flow volume is approximately between 1% and 2% of annual precipitation
  - annual baseflow of about 11 Mm^3 is approximately 0.3% of annual precipitation
- Annual losses to evaporation/evapotranspiration ~ 3,250 million m^3
  - evaporation/evapotranspiration losses are approximately 98% of annual precipitation

The water balance is illustrated in Figure 2.9.

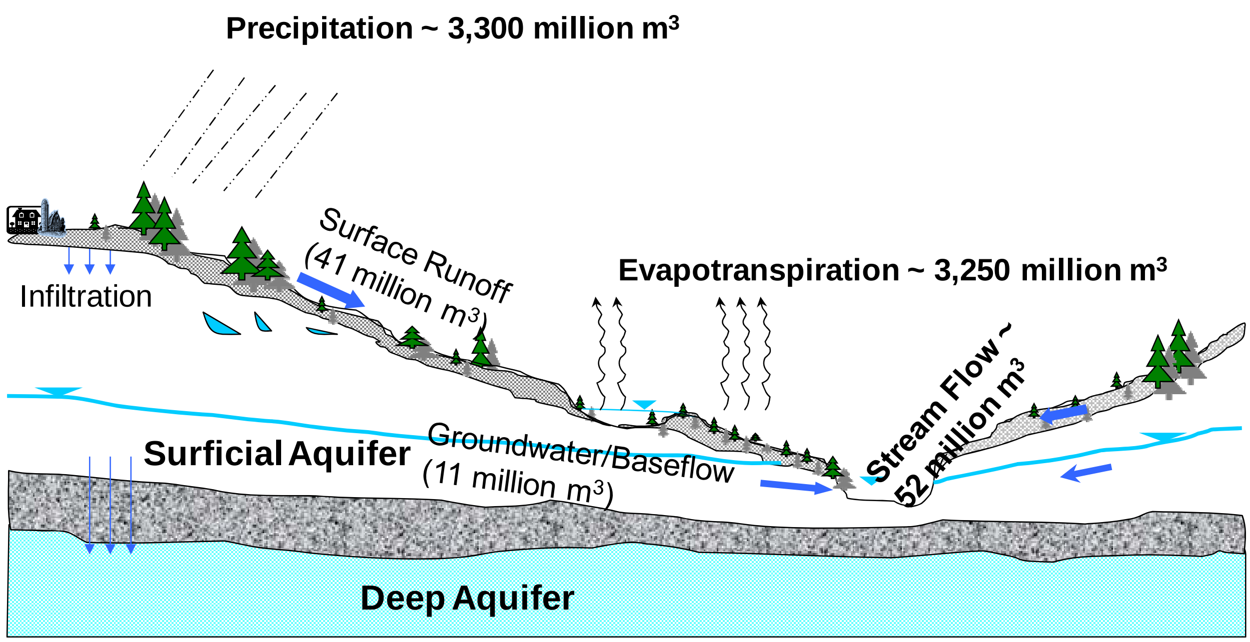


Figure 2.9 Average Year Water Balance in Vermilion River Basin

2.5 Effects of Climate Change on Water Yield

A key aspect of any water supply assessment is the potential for changes in water supply due to climate change. Water shortages may become more severe in the future depending on the hydrologic response to climate change.

2.5.1 Surface Water Yield

For the climate change assessment, existing climate change studies were reviewed to evaluate future variability in water supply due to changing climates. These studies included the recent work by Golder for the NSWA on the NSRB (Golder 2008), the study of the effects of potential climate change on the SSRB by Martz *et al.* (2007) and by Gan (2002), and water availability under potential climate change for Oldman River Basin and its tributaries by Tanzeeba, Gan and Xie (2007). The results from these studies were used to make predictions on the potential effects of future climate change on available water supply in the Vermilion River Basin.

Some of the largest potential changes in surface water quantity under the currently predicted climate scenarios are in the Canadian Prairies. Pietroniro and Toth (2006) present and discuss the results of a study of the water availability in the South Saskatchewan River Basin (SSRB) and its sub-basins under future climate change scenarios. One conclusion of the study that is relevant to the modelling of the effects of climate change on water availability in the VRB was that flow predictions under future climate regimes vary by sub-basin of the SSRB, with general reduction in annual flows for the modelled sub-basins ranging from -13% to -4%.

Tanzeeba *et al.* (2007) used the Modified Interactions Soil-Biosphere-Atmosphere (MISBA) land surface scheme of Meteo-France to predict future water availability in the Oldman River Basin under forecasted climate scenarios. Under most GCM projections, MISBA predicted decreasing runoff and an earlier onset of spring runoff.

Similar to the Oldman River Basin study, Kerkhoven and Gan (2006) applied MISBA to the Athabasca River basin (ARB). Although most of the future climate scenarios predicted increased precipitation in the ARB, all the scenarios resulted in significantly decreased stream flows by the end of the century (2070-2099). This was primarily because of a predicted decrease in the size of the winter snowpack due to warmer winters. Warmer winters result in less snow accumulation and increased evaporation. Mean annual flows were predicted to decrease by almost 25% by the last third of the century. The high flow season also became much shorter.

The results of studies carried out in the South Saskatchewan River and Athabasca River basins suggest that water yield could decrease in the future, with some probability of an increase, depending on the GCMs and emission scenarios being considered. The results show that there is still some uncertainty in the forecasted magnitude of the decrease.

General scientific literature on trends in recorded climate and stream flow data, and specific studies specifically as they pertain to effects on hydrology in Alberta were also reviewed. Gan (1998) applied Kendall's trend analysis method to the maximum, minimum and average air temperature data from 37 weather stations (14 in Alberta, 14 in Saskatchewan, eight in Manitoba and one in Ontario). The results indicate that between 1949 and 1989 the Canadian prairies have experienced warming, especially in January, March, April and June. The Canadian prairies (Alberta, Saskatchewan and Manitoba) have experienced about 20 serious droughts in the nineteenth century and over 10 serious droughts in the twentieth century (Godwin 1986). While it is certain that droughts will continue to occur in the prairies, it is not certain if future droughts will be more severe, more frequent, or both.

Based on an analysis of 50 sets of natural streamflow data, Gan (1998) showed that negative trends are much more prevalent than positive trends. Most of the positive trends occur in March and might be attributed to an earlier onset of spring melt caused by climatic warming. Higher flows in March could result in lower flows later in May and June. It seems that the Canadian prairies have experienced a warmer and somewhat drier climate in the last four to five decades. However, it is not clear that the drier climate has increased the frequency and severity of prairie droughts.

The precipitation and temperature data in the NSRB were analyzed for the presence or absence of statistically significant trends (Golder 2008). Results specific to the data at Vermilion in the VRB are as follows. The temperature data at Vermilion suggest a generally increasing trend. However, these trends are not statistically significant at the 5% level. The data at Vermilion show weak increasing trends in monthly precipitation for most months, however, these trends are not statistically significant. There is not a statistically significant decreasing trend in the spring total precipitation data. Overall, the annual precipitation data shows a statistically not significant increasing trend.

Streamflow data at two hydrometric stations close to the Vermilion River Basin were also analyzed (Golder 2008). The spring flows at Strawberry Creek near the Mouth (Station 05DF004, drainage area of 589 km^2) from 1966 to 2007 show a decreasing trend that is not significant at the 5% level. The summer flows indicate an increasing trend that is not significant at the 5% level. Winter flow data were not available over the period of record, hence, trends for winter and annual mean flows for the recent years cannot be determined. The summer flows at Sturgeon River near Fort Saskatchewan (Station 05EA001, drainage area of 2,390 km^2) from 1935 to 2006 indicate a decreasing trend that is not significant at the 5% level. Spring flows indicate an increasing trend that is not significant at the 5% level. Winter flow data were not available over the period of record, hence, trends for winter and annual mean flows for the recent years cannot be determined. Trend lines fitted to recent flow data are not necessarily accurate predictors of future increases or decreases in flows. Notwithstanding the foregoing statement, linear trend lines fitted to the data suggest that the predicted annual mean flows would decrease by between 4% and 9%, depending on station location, by the year 2035 compared to the baseline period of 1961-1990. These predicted changes in annual yield by 2035 are, however, well within the variability in annual yield from year to year.

In 2008, Golder carried out a study for the NSWA to assess potential changes in the water yield in the North Saskatchewan River Basin (NSRB) using a hydrologic model with future climatic conditions forecasted by several Global Climate Models (GCMs) as inputs. The 1961 to 1990 period was selected as the climatological baseline period for the modelling work. The future conditions have been represented by the 30-year period between 2021 and 2050, which would be representative of the mid-2030s. The ECHAM50M, NCARCCSM3, GFDLC2.1 and CGCM3T47 General Circulation Models, also known as Global Climate Models, (GCMs) were selected for assessing the effects of climate change on the water yield in the NSRB based on a comparison of GCM predictions with observed climate data in the NSRB. Since the predictions of the GCMs have some degree of uncertainty associated with them, therefore several GCMs were considered so that the range of possible predicted impacts could be evaluated. A range of predicted effects should be considered in watershed planning. The IPCC recommends that several climate scenarios need to be considered because a single climate model scenario does not provide a reliable description of the climatic evolution, while ensembles of state-of-the-art climate models, on the other hand, capture the main features of the past climatic evolution. The A1B, A2 and B1 climate scenarios were selected for each GCM. Scenario A1B represents future balanced socio-economic and environmentally-based development; scenario A2 assumes that the current global socio-economic situation will continue in the future; and, scenario B1 represents future development that is more environmentally-based than at present.

The forecasts indicate that NCARCCSM3-SRA1B predicts the largest increase in temperature (about 2.2^{o}C), while ECHAM50M-SRB1 predicts the smallest increase (about 0.3^{o}C). Predictions of changes in precipitation tend to vary significantly between GCMs and even between scenarios for a given GCM. The change in mean annual total precipitation for the forecast period of 2021-2050 from the baseline period of 1961-1990 ranges from a decrease of about 8% (GFLDLC2.1-SRA2) to an increase of about 19% (NCARCCSM3-SRA2), with 10 of the 12 scenarios predicting an increase in precipitation. The forecasted increasing trend in precipitation appears to be consistent with trends in observed data at the climate stations in the NSRB.

Global re-analysis climate data from 1961 to 1990 was used to represent the baseline climate conditions in the NSRB. The modified Interactions Soil-Biosphere-Atmosphere land surface model (MISBA) of Météo France was set up for the North Saskatchewan River Basin (NSRB). The study area was limited to the portion of the NSRB west of Edmonton because data east of Edmonton was not available for that study (Golder 2008). Notwithstanding that the modelling extent did not extend as far as the Vermilion River Basin, the model results provide general indications of the possible effects of climate on the hydrology of the VRB.

Five of the six ECHAM50M and NCARCCSM3 GCM-scenario combinations are predicting increases in annual yield from the baseline 1961-1990 period to the 2021-2050 forecast period that range from 5% to 15%. Only the ECHAM50M-SRA1B combination predicts a decrease of about 11%. The CGCM3T47 and GFLDC21 GCM-scenario combinations are predicting decreases in annual yield that range from 3% to 23%. The predictions of the CGCM3T47 and GFLDC21 GCMs tend to follow trends in observed flow data.

The results of the modelling study showed that the percent changes in monthly yield are much larger than would be implied by the percent changes in annual yield. The percent changes tend to be higher for the winter months when flows are generally low. Increases in mean monthly yields of about 15% tend to occur during the spring months. This result reflects the predicted increase in precipitation (snow) and increase in temperature. Mean monthly yield during the summer months and into the fall tend to decrease with the percent change across the GCMS and scenarios ranging from +15% to -40%. This result suggests that the predicted increase in temperature is causing an increase in evapotranspiration losses during the summer months

2.5.2 Groundwater Yield

Groundwater is, in general, buffered from and less susceptible to the short-term effects of climate variability and change.

2.5.3 Assumed Change in Water Yield Due to Future Climate Scenarios

Based on the review of the literature on climate change studies in Alberta and trends in current climate and stream flow data records at locations close to the VRB, the change in mean annual water yield from all sub-basins in VRB could potentially range from an increase of 15% to a decrease of about 23%. Changes in mean monthly flows could be more significant during the summer and fall months when decreases of the order of 40% could occur. In contrast, spring melt could occur earlier as a result of higher spring temperatures, and could result in higher spring floods.

3.0 WATER SUPPLY-DEMAND IN THE VERMILION RIVER BASIN

3.1 Introduction

The purpose of this task was to describe current and future water demands of various sectors, based on available licence information and existing reports, for four major sub-areas of the Vermilion River Basin (VRB), and to compare the demands with estimated supply (water yield) from the major sub-areas. The four major sub-areas selected for depiction of water supply-conditions on an area-cumulative basis are the Upper Vermilion Area, Upper-Middle Vermilion Area, Lower-Middle Vermilion Area and the Lower Vermilion Area.

3.2 Water Demand

Key water use sectors in the VRB include agriculture, municipal and residential. Historic and current water licence information available from the NSWA and a study on water demand in the Vermilion River Basin by AMEC (AMEC 2007) was used for the demand estimates. Table 3.1 (AMEC 2007) provides a summary of the current water licence allocations, water uses, and return flows in the VRB.

Table 3.1 Water Allocation and Use by Source: Groundwater and Surface Water and by Sector

Sector		No of licences	Licensed allocation and use (dam^3)			Estimated use (dam^3)
			Allocation	Water use	Return flow	
Municipal Sector	Surface water	5	155	106	49	49
	Groundwater	70	2,504	1,095	1,409	510
	Total	**75**	**2,659**	**1,201**	**1,458**	**558**
Agricultural Sector	Surface water	3,078	1,661	1,661	-	1,435
	Groundwater	2,143	2,399	2,399	-	1,265
	Total	**5,221**	**4,060**	**4,060**	**-**	**2,700**
Commercial Sector	Surface water	8	314	314	-	314
	Groundwater	3	102	102	-	102
	Total	**11**	**417**	**417**	**-**	**417**
Petroleum Sector	Surface water	-	-	-	-	-
	Groundwater	1	2	2	-	2
	Total	**1**	**2**	**2**	**-**	**2**
Industrial Sector	Surface water	-	-	-	-	-
	Groundwater	1	1	1	-	1
	Total	**1**	**1**	**1**	**-**	**1**
Others	Surface water	55	3,252	3,122	131	3,122
	Groundwater	-	-	-	-	-
	Total	**55**	**3,252**	**3,122**	**131**	**3,122**
All Sectors	Surface water	3,146	5,383	5,203	180	4,920
	Groundwater	2,218	5,008	3,599	1,409	1,881
	Total	**5,364**	**10,391**	**8,802**	**1,589**	**6,800**

The reaches of the Vermilion River above the Vermilion Dam are not considered to be good fish habitat and water that would be assigned for instream flow needs were not included in the water supply-demand assessment. The Instream flow needs (IFN) for a sustainable aquatic ecosystem at a coarse level, can be expressed as a percentage (15%) of the mean annual flow in a stream. This represents a simplified interpretation of the Alberta IFN Desktop Method, which suggests that in the absence of site-specific knowledge or other objectives, 85% of the natural flow above the 80% flow exceedance value be reserved for IFN (100% reserved below that threshold). It can be expected that consistent application would generally result in a maximum of 15% reduction from natural flow (natural supply). This approach would in general stipulate not only annual volume preservation but also seasonal (and monthly and weekly) preservation of natural flow regime. Such detailed examination is beyond the scope of this study.

3.3 Current Water Supply-Demand Conditions in the Vermilion River Basin

Using the results of the water yield analysis carried out for this study and the water demand information provided by the NSWA and other information reproduced from a study on water demand in the Vermilion River Basin by AMEC (AMEC 2007), graphics depicting existing and possible future (2025) water supply-demand conditions were created for each of the four major sub-areas of the VRB as well as for the overall VRB. For each of the major sub-areas of the VRB and for the VRB itself, available water supplies and allocated water demands are presented. First, the long-term annual average water supply and current allocation are compared using a multi-annular chart for each sub-area and for the VRB. Second, the seasonal variability of the water supply is presented along with the average annual water demands for the VRB.

Figure 3.1 presents water demand from both surface and groundwater sources for the entire VRB with respect to the average annual total basin water yield (including both surface runoff and surficial groundwater). Figure 3.2 presents only the groundwater demand in comparison to the average baseflow contribution (Section 2.2.4) to the river flow.

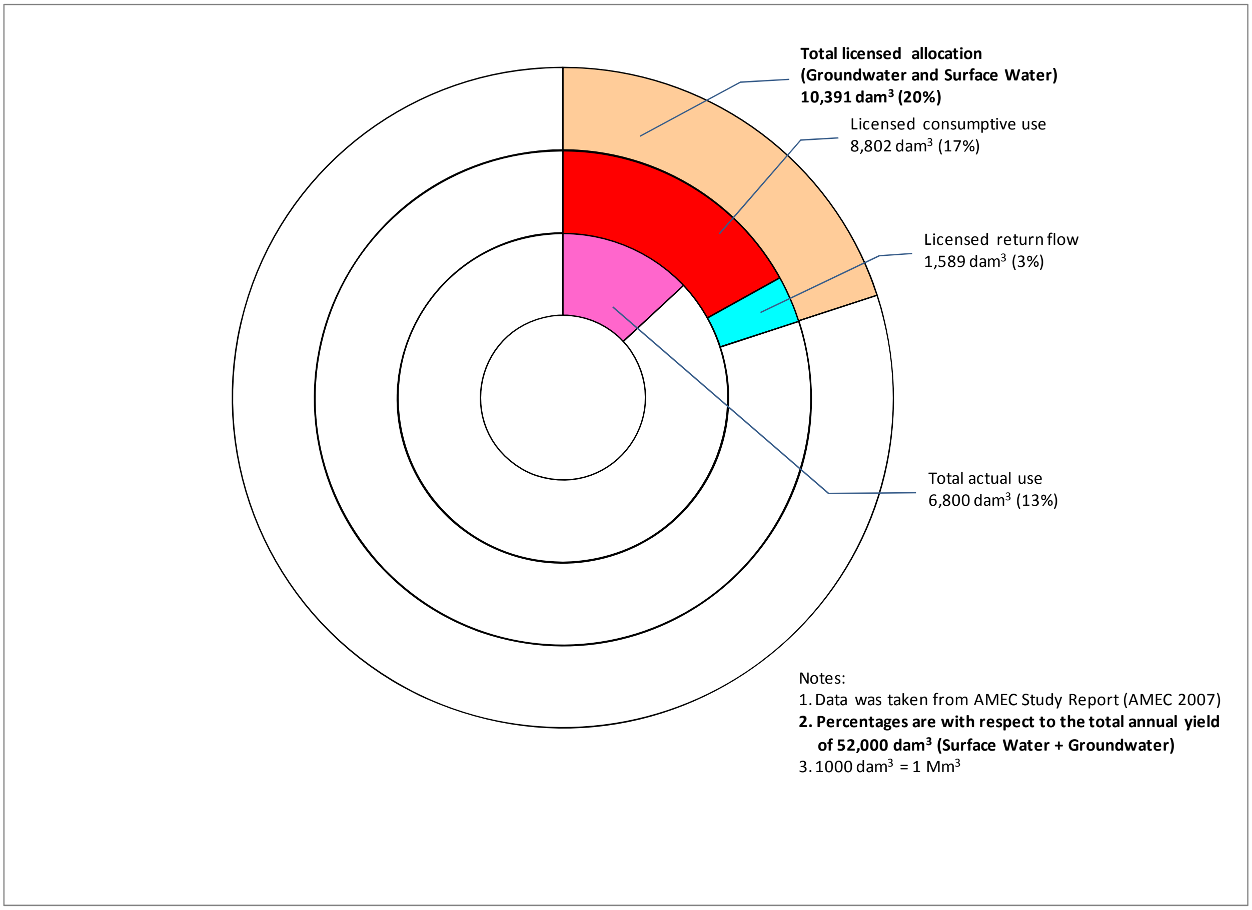


Figure 3.1 Water Demand-Supply in the Vermilion River Basin – Surface and Ground Water

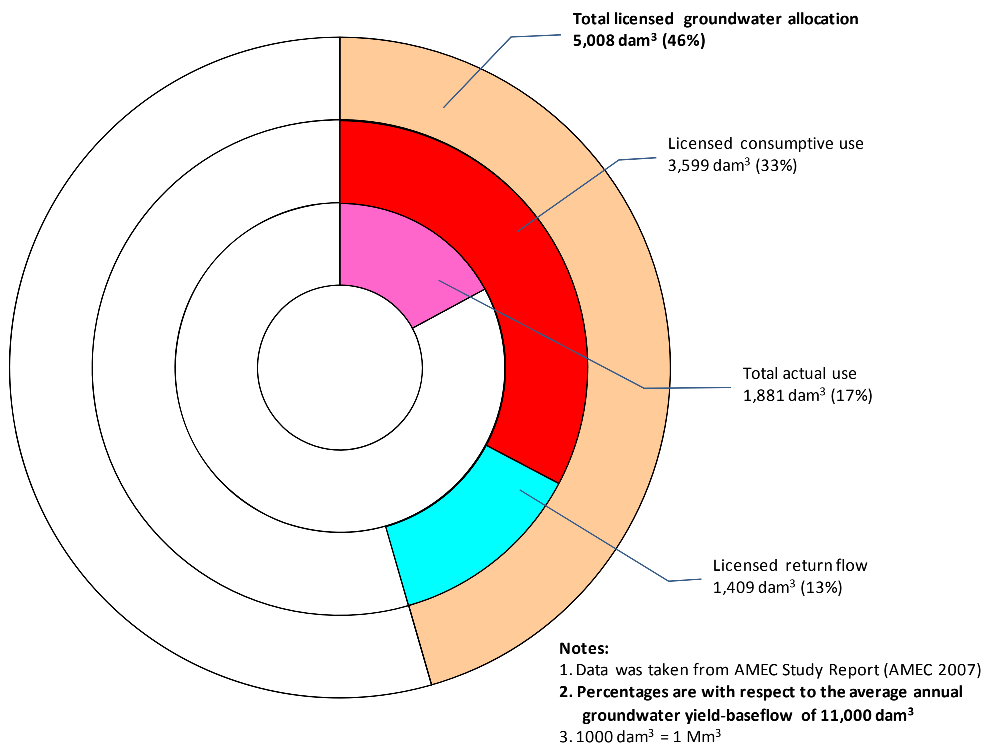


Figure 3.2 Water Demand-Supply in the Vermilion River Basin – Ground Water

The innermost ring of a multi-annular chart uses the entire circumference as equivalent to the basin's water yield. Successive rings around the core ring are used to represent the current water demand expressed as a percentage of the basin's water yield. The outer represents the total amount allocated (licensed), which consists of a licensed consumptive use portion and a licensed return portion. The latter is represented in the second ring from the outermost one. The third ring shows the estimated actual use. The water demands by various sectors (e.g., municipal, agricultural, etc.) are given in Table 3.1.

Figure 3.3 shows the monthly distribution of total (surface and groundwater) water yield and the monthly average of all licensed allocation, licensed use, estimated use for 2005 and the projected use for 2025 (high growth case). The lower and upper limits on monthly yield represent the 10^{th} and 90^{th} percentiles, respectively. The monthly distribution of total demand has been assumed to be uniform throughout the year in the absence of specific information. Figure 3.3 shows that total water supply (2005-current and 2025-forecasted) could be an issue during the fall months of relatively dry years.

Figure 3.4 shows the monthly distribution of the estimated average annual baseflow (Section 2.2.4) and the monthly average groundwater licensed allocation, groundwater licensed use, estimated groundwater use for 2005 and the project groundwater use for 2025 (high growth case). The lower and upper limits on the monthly baseflow represent the estimated amounts during a dry year and a wet year, respectively. The monthly distribution of groundwater demand has been assumed to be uniform throughout the year in the absence of specific information. Figure 3.4 shows that total water supply (2005-current and 2025-forecasted) could be an issue during the late summer and fall months of relatively dry years.

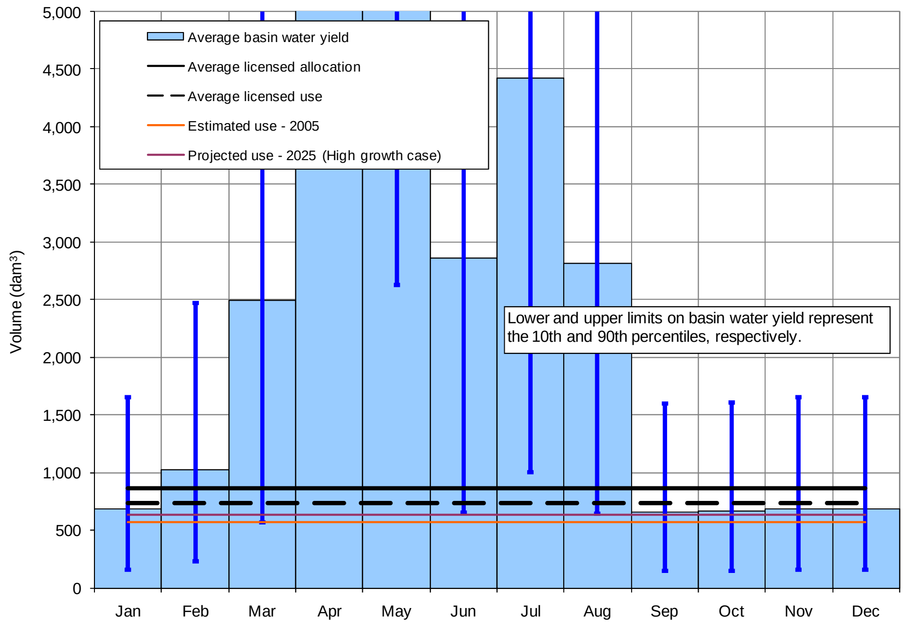


Figure 3.3 Distribution of Combined Groundwater and Surface Water Supply and Demand in the Vermilion River Basin (AMEC Report Data)

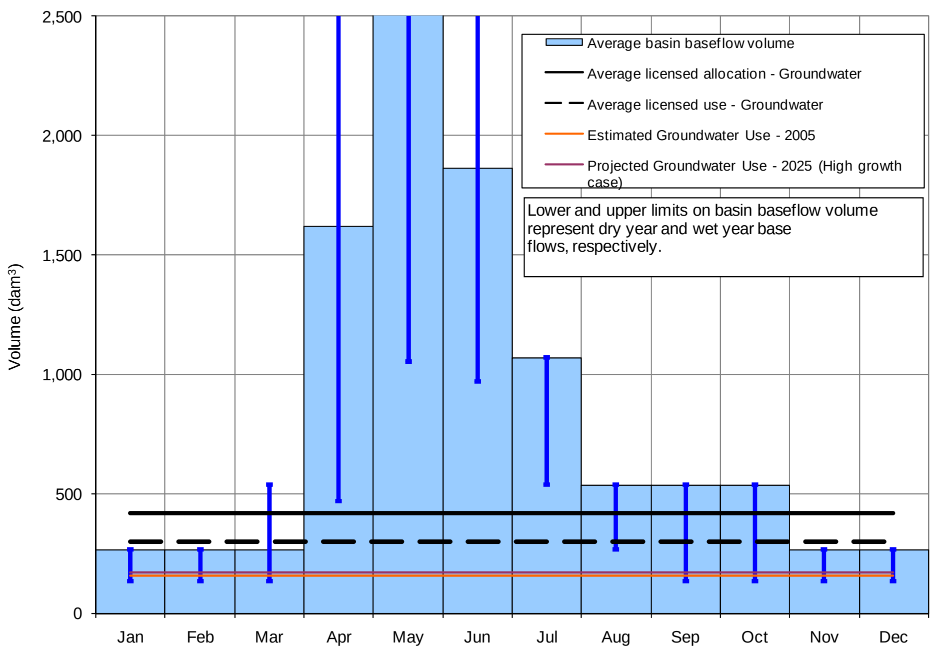


Figure 3.4 Distribution of Groundwater Water Supply and Demand in the Vermilion River Basin (AMEC Report Data)

Figure 3.5 illustrates the water demand-supply assessment on a cumulative basis from the upper part of the basin (Figure 3.5a), through the middle portion (Figure 3.5b) to the lower portion (Figure 3.5c) of the basin. The supply and demand include both the surface water and groundwater components.

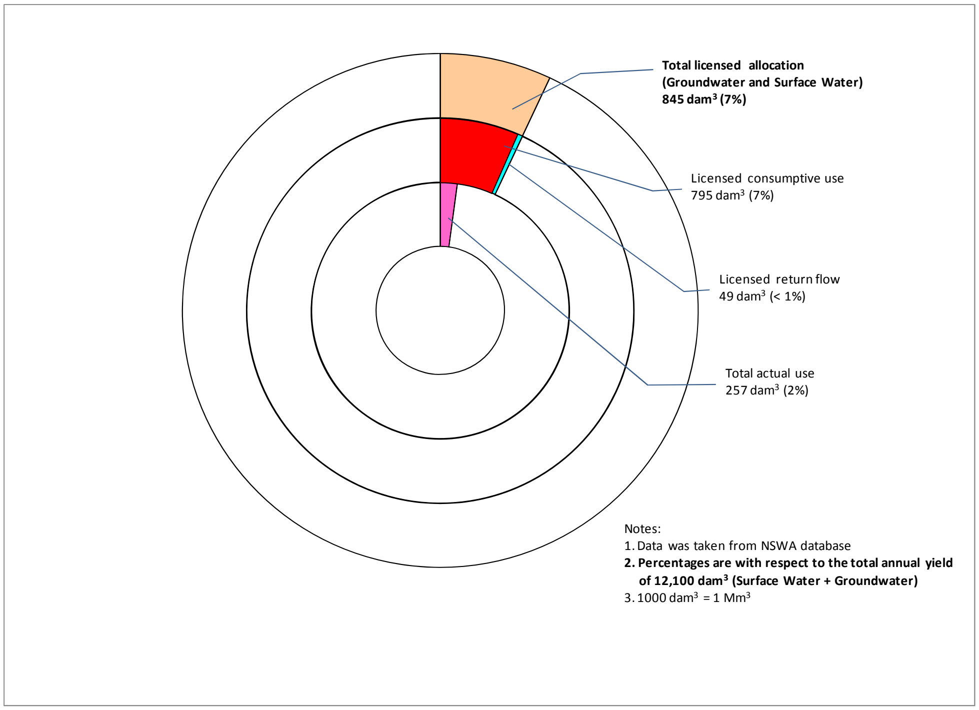


Figure 3.5(a) - Upper Reaches of Vermilion River Basin

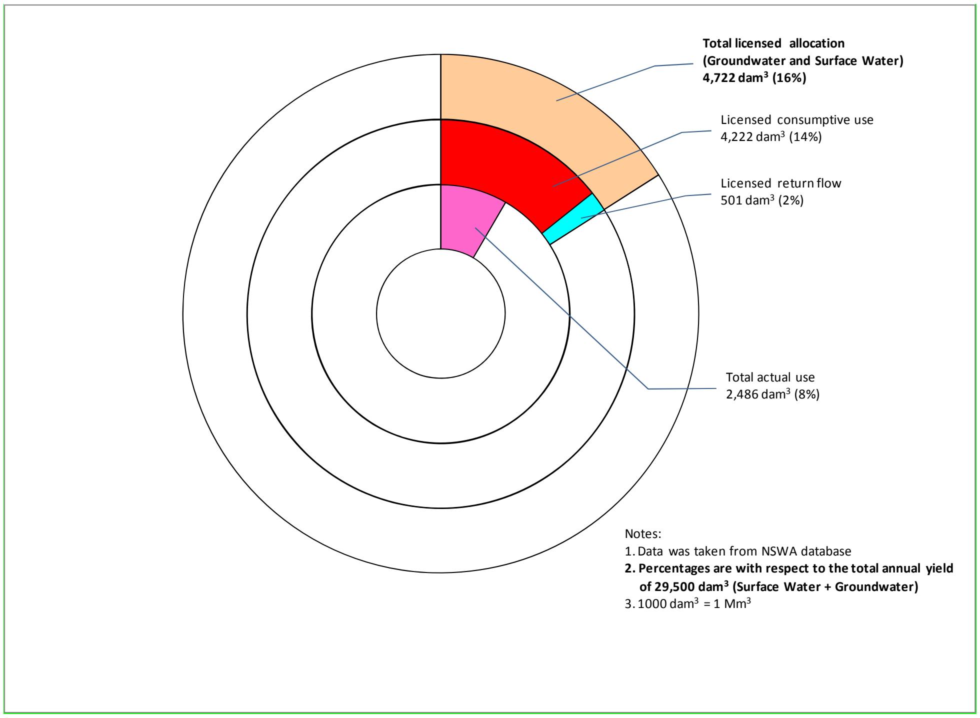


Figure 3.5(b) - Upper and Upper Middle Sections of Vermilion River Basin

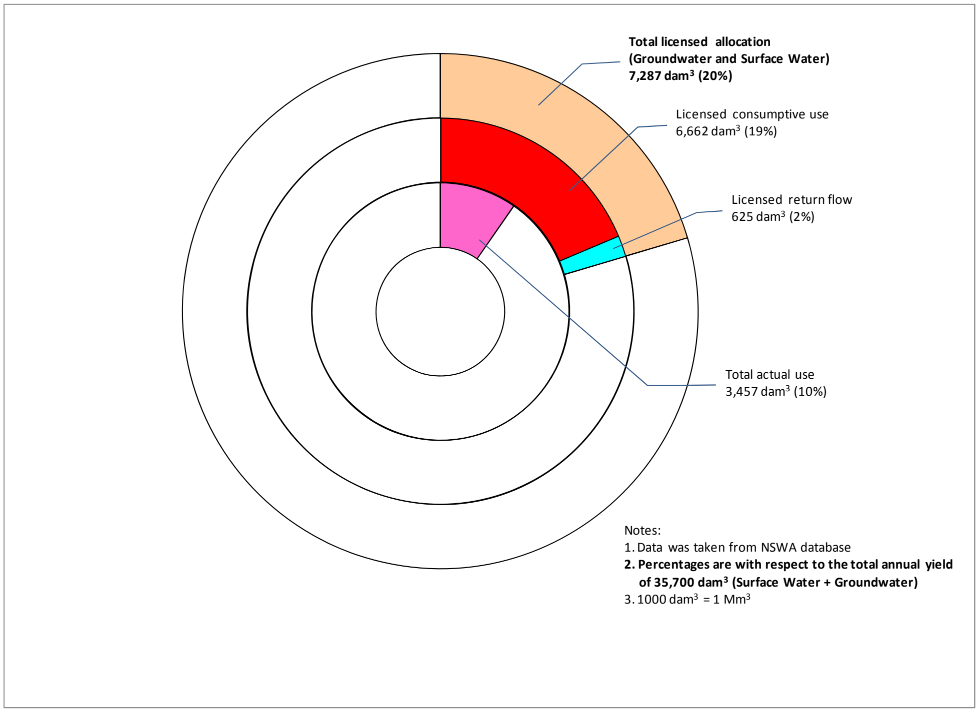


Figure 3.5(c) - Upper, Upper Middle and Middle Sections of Vermilion River Basin

Figure 3.5 Surface and Groundwater Water Supply–Demand Assessment in Sub-Areas of the Vermilion River Basin

Figure 3.6 illustrates the groundwater supply-demand for the each of the four sub-areas of the Vermilion River Basin. For the groundwater assessment, each sub-area was considered on an individual basis (in contrast to a cumulative assessment for the total surface and groundwater assessment), with the baseflow for each sub-area prorated from the basin average annual baseflow estimate of 11 Mm^3. It appears from Figure 3.6 that the groundwater supply-demand in the middle and lower sections of the Vermilion River Basin will generally require more management in the future if demand on groundwater supplies increase. It is noted that the assessment is qualitative in nature without factoring in the sustainability of groundwater yield.

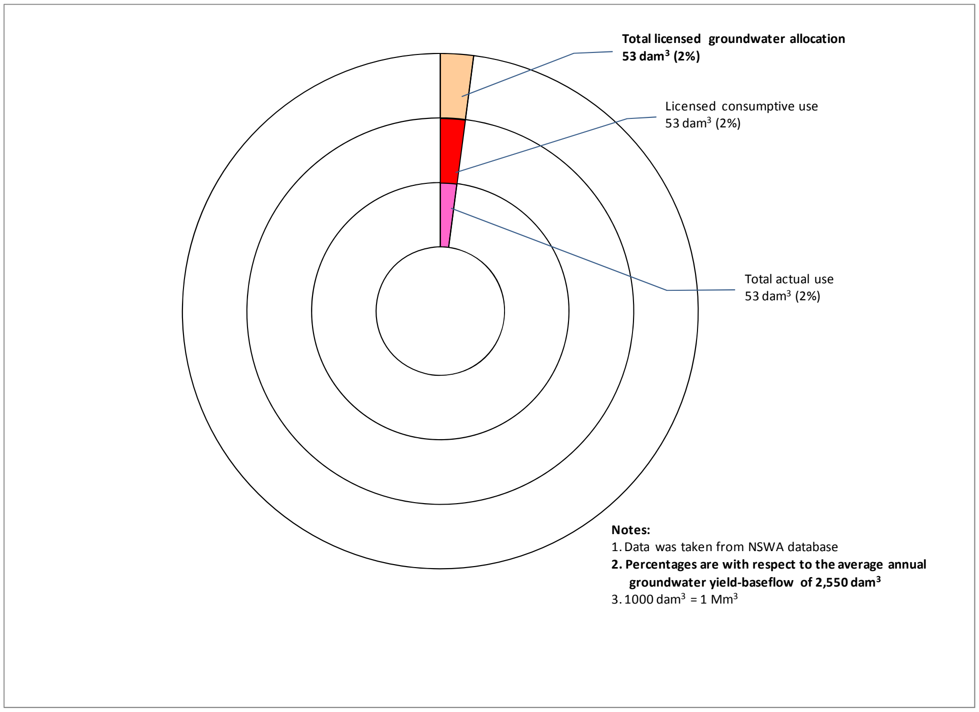


Figure 3.6(a) - Upper Section of Vermilion River Basin

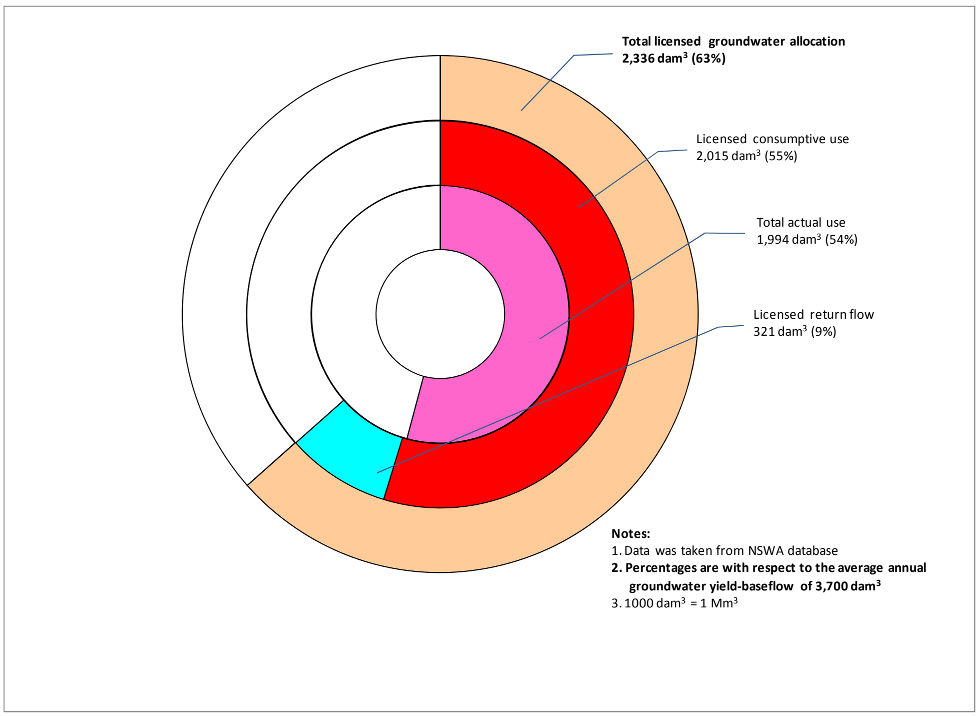


Figure 3.6(b) - Upper Middle Section of Vermilion River Basin

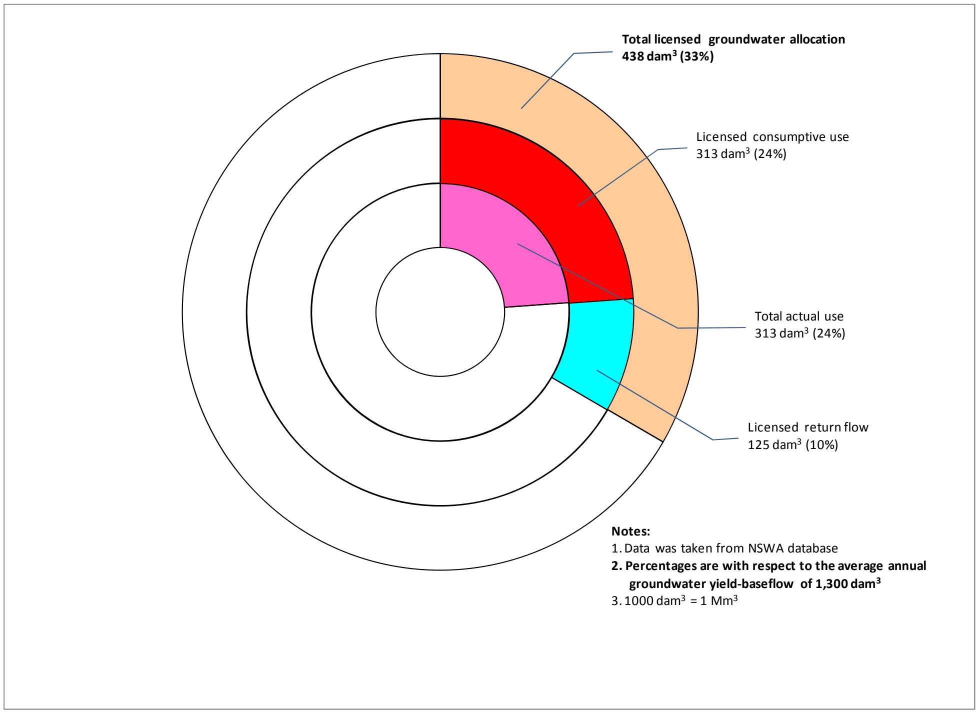


Figure 3.6(c) - Middle Section of Vermilion River Basin

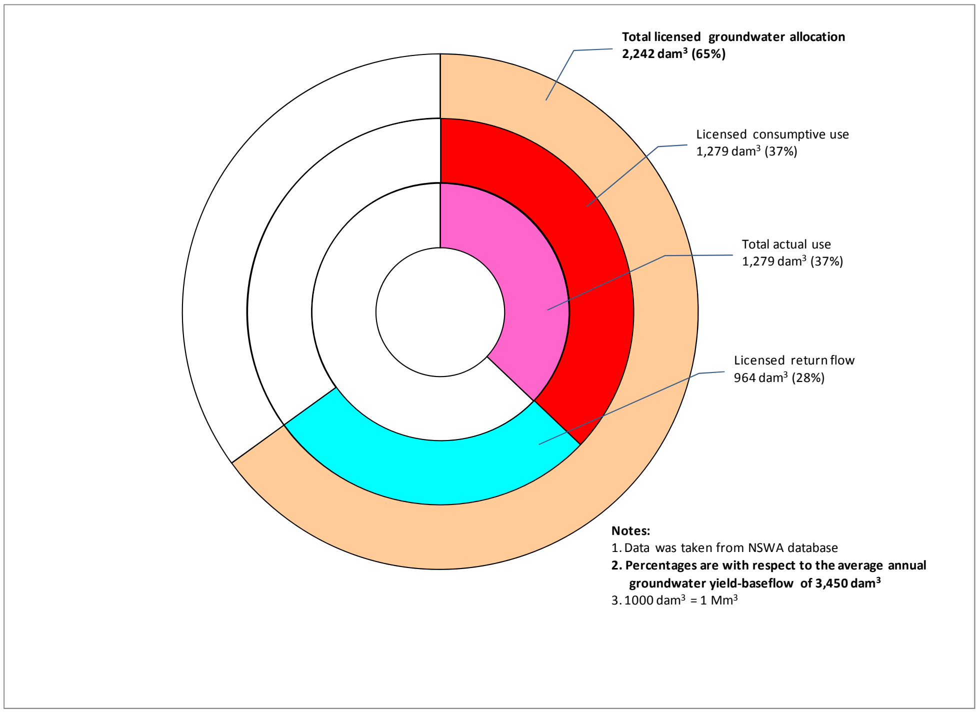


Figure 3.6(d) - Lower Section of Vermilion River Basin

Figure 3.6 Groundwater Water Supply–Demand Assessment in the Four Sub-Areas of Vermilion River Basin

3.4 Future Water Supply-Demand Conditions in the Vermilion River Basin

As discussed in Section 2.4, based on a review of the literature on climate change studies in Alberta and trends in current climate and stream flow data records at locations close to the VRB, the change in mean annual water yield from all sub-basins in VRB could potentially range from an increase of 15% to a decrease of about 23%. Changes in mean monthly flows could be more significant during the summer and fall months when decreases of the order of 40% could occur. In contrast, spring melt could occur earlier as a result of higher spring temperatures, and could result in higher spring floods.

Assuming (conservatively) an overall decrease of about 10% decrease in total mean annual water yield for all sub-basins in the VRB by the 2040s as a result of climate change, it appears that the reduced yield from the Vermilion River Basin is more than sufficient to accommodate the present total water demand and likely future water demands on an annual basis. However, water supply-demand conditions on a monthly or seasonal basis or segregated into surface water supply-demand and groundwater supply-demand may be more problematic, and the actual conditions would be dependent on the actual variability in water demand during a year. This information is not available for the assessment for this report. Figure 3.3 suggests that a reduction of 40% in summer mean monthly flows by the 2040s due to potential future climate scenarios would result in a situation where monthly average licensed allocation and possibly monthly average licensed use may be greater than water supply. Actual water use and supply conditions could become critical more often during dry years. Figure 3.4 shows that future groundwater supply and demand conditions could become even more critical than surface water supply-demand conditions if one assumes a reduction of 40% in groundwater yield as summer baseflows. A recent study by UrbanSystems and Golder (2005) indicates that new water supplies need to be developed (including piping from outside of the VRB) to address future increases in water demand.

A study on groundwater use and the sustainability of the groundwater regime as well as on future monthly water demand-supply conditions as a result of potential climate change scenarios is therefore recommended. The effects of the return flows to the Vermilion River Basin from water being piped in from outside the VRB should also be assessed.

4.0 HYDROLOGIC MODEL FOR THE VERMILION RIVER BASIN

4.1 Initial Model Considered

The NSWA has identified the need for a hydrologic model for the VRB to assist it in determining the effects of land and water management initiatives, and in evaluating future scenarios, such as increased development and changes in the climate regimes. A number of hydrologic models with a wide range of complexity, data requirements, and expertise requirement can be implemented. Three models in particular were initially considered. These were the Hydrologic Simulation Program – Fortran or HSPF model; HEC-HMS model, and MIKE-SHE model. Each model has its strengths and limitations.

HSPF and HEC-HMS are public domain models with extensive model documentation. HSPF is a lumped conceptual model that requires extensive calibration for both pre-development and post-development conditions to be useful for assessing the effects of land use changes. The appropriate data must be available for a successful calibration. The model can be run as a distributed model by sub-dividing the VRB into sub-basins. HSPF can be run in both a continuous mode (useful for investigating changes in seasonal and annual yield) and on an event basis (useful for investigating flood flows from storm events).

HEC-HMS is also a lumped conceptual model that can be used in a quasi-distributed mode. The extent of calibration is less onerous than that of HSPF, however, HEC-RAS is run mostly in an event-based mode, so that continuous simulation of flows may not be practical with this model.

MIKE-SHE is a physically-based distributed model with good modules for simulating the interaction between groundwater and surface water. The data requirements for the model are very extensive, although approximations and assumptions can be made if data are not available. The model can be run in a continuous mode. One potentially significant drawback of MIKE-SHE is that a license is required for the model, with the cost of a license about $25,000 or more, depending of modules required.

Golder discussed the model selection and recommended the HSPF model during a meeting on November 12, 2008. The NSWA agreed with the recommended selection. The next section provides the rationale for recommending HSPF.

4.2 Selection of HSPF as the Hydrologic Model for the Vermilion River Basin

HSPF uses a version of the Stanford Watershed Model (Crawford and Linsley 1966), which is a deterministic, lumped, conceptual hydrologic model and so it has modest data requirements. It distributes the incoming rainfall into canopy interception, impervious areas, upper zone which will appear as surface runoff or interflow, and infiltration into the lower zone storage divided into active and inactive groundwater storages. The three conceptual storages regulate soil moisture and groundwater storages, while evapotranspiration can extract moisture from the interception, upper, lower and groundwater storages. The model uses monthly potential evapotranspiration as inputs, with actual evapotranspiration calculated internally by the model using parameters calibrated for the specific basin conditions (vegetation cover, open water areas, etc.). Runoff from the channel inflow is routed by a hydrologic routing technique that accounts for attenuation by the storage effect of the channel.

Since its initial development nearly twenty years ago, the HSPF model has been applied throughout North America and numerous countries and in various climatic regimes around the world. The modules for simulating hydrologic processes within the model (e.g., snowmelt runoff, infiltration, etc.) are reasonably sophisticated for the purposes of this project. Based on the numerous world-wide practical applications, a database of HSPF calibration parameter values have been compiled through the joint sponsorship of both the U.S. Environmental Protection Agency and the U.S. Geological Survey as reference for practitioners. The availability of reference calibration parameters significantly improves the efficiency (i.e., reduces time requirement) of model calibration and validation. In addition, reference to the experience and results of other applications increases the defensibility of the outputs from HSPF.

Experience with sophisticated models indicates that much of the effort associated with hydrologic implementation is spent on data acquisition and management. Hence, it is essential that a successful comprehensive model include a sound data management component. The HSPF model software is based on a comprehensive data management system operating on direct access. The HSPF simulation modules draw required input data from time series stored in its data management system and are capable of writing output to it. Because these data transfers require very few instructions from the user, the effort required with setting up this hydrologic model for large and complex watersheds is minimized. In addition, the HSPF model includes the following tools which are not necessarily available as a package in other hydrologic model software:

- Source code, executable version, user's guide, and technical support;
- A windows-based and independent interactive interface that is fully integrated with a software product, GenScn, that provides the ability to change an HSPF input sequence interactively, run the model, and analyze results graphically; and,
- WDMUtil, a tool used to manage and create the watershed data management files (WDMs) that contain the meteorological data and other time series data used by HSPF.

Under the sponsorship of U.S. EPA and USGS, HSPF continues to undergo refinement and enhancement of its component simulation capabilities, along with user support and code maintenance activities.

Following the model selection, the HSPF model was calibrated and validated for the Vermilion River Basin. This process and the results are described in the next sections.

4.3 Calibration and Validation of HSPF

The calibration and validation of the HSPF model require baseline climate, physiography and hydrology data for several sub-basins within the VRB. The general steps for calibrating and validating the HSPF model on the Vermilion River basin are as follows:

- Compile flow data from gauged sub-basins of the VRB for calibration and validation purposes.
- Compile climate data (temperature and precipitation) within or close to gauged sub-basins.
- Sub-divide VRB into a number of sub-basins to capture changes in the landscape, changes in flow regime, sub-basin slope (uplands and lowlands), river slope, surficial geology, dominant vegetation cover, etc.
- Delineate contributing and non-contributing areas (under natural or unaltered conditions) of each sub-basin.
- Identify gauged sub-basins that have been affected by drainage ditches, wetland loss, etc., during the period of available climate and flow data. Estimate percent of sub-basin affected.
- Assess period when changes in flow in river occurred because of flood control structures during the period of available climate and flow data.
- Select gauged sub-basins that are in natural conditions, with altered landscape, and with varying proportions of contributing and non-contributing areas.
- Calibrate the HSPF model on selected gauged sub-basins. Start with sub-basins under natural conditions and determine model calibration parameters. Move to sub-basins with altered

landscapes using calibration parameters for natural conditions on portions of sub-basins with these land types. Determine model calibration parameters for altered sub-basins.

- Validate model calibration parameters on lager sub-basins that incorporate the sub-basins used for calibration in addition to other sub-basins with the several land types. Fine-tune the calibration parameters.
- Incorporate the hydraulic characteristics of flow control structures in the model.
- Run the calibrated and validated HSPF model for the entire VRB and for the longest period for which flow data are available. Assess the performance of the calibrated model by comparing statistics of the observed and simulated flow series at the several hydrometric stations in the VRB.
- Summarize key hydrologic variables (annual and monthly water yield particularly) at selected locations within the main stem of the Vermilion River.

4.4 Results of Calibration and Validation of the HSPF Model

4.4.1 HSPF Model Setup

4.4.1.1 Characteristics of the Vermilion River Basin

The Vermilion River Basin is located in the glaciated area of the Canadian prairies that is characterized by significant depression storage. The key basin characteristics considered in the set-up of the HSPF model are as follows. Maps depicting these characteristics are provided in Appendix B.

- Glacial (combination of clay, silt and sand) surficial geology, covering about 82% of the basin, is dominant.
- Most of the upstream portion of the basin is characterized by lowland areas (i.e., areas with overland slopes less than 0.5%). The middle to lower portion of the basin is mostly upland areas (i.e., areas with overland slopes greater or equal to 0.5%).
- About 70% of the basin area is classified as non-contributing during average years, although part of or all this area can be contributing during major storms.
- About 6% of the basin area is classified as waterbodies, of which 5% as temporary and 1% as permanent features.
- Some portions of the contributing/non-contributing areas of the basin have been ditched or drained for agricultural purposes. The actual portions are incorporated within the model in the drainage area specifications for each sub-basin.
- In order to control flooding during major storms/snowmelt events, two major flow control structures have been built along the main stem of the Vermilion River, namely, the Morecambe Structure and the Vermilion River Dam.

4.4.1.2 Representation of Basin Characteristics in the Model

The various basin characteristics were represented or conceptualized as follows. A schematic of the HSPF model set up for the Vermilion River Basin is provided in Appendix C.

- The Vermilion River Basin was sub-divided into 23 sub-basins, based on the drainage network and the locations of the Environment Canada Hydrometric Stations selected for calibration and validation of the model.

- The 23 sub-basins were further sub-divided based on upland/lowland areas, surficial geology, contributing/ non-contributing areas, and ditched/non-ditched non-contributing areas. Information on wetlands and ditched areas was obtained from a map provided by Ducks Unlimited (Ducks Unlimited Canada 2004) and entitled “Vermilion River Watershed – Anthropogenic Impacts on Surface Water Resources”.

- The effect of ditching on water yield was assumed to be occurring only in the non-contributing areas of the sub-basins by converting the non-contributing areas into contributing areas, albeit with different model parameters. While ditching of contributing areas would also affect the hydrologic response of these areas, the ditching may not necessarily increase water yield significantly, compared to the effect of ditching on originally non-contributing areas. The primary effects of ditching contributing areas would be shorter times to peak flows and somewhat increased peak flows, however, these effects would not be as significant as those due to ditching of originally non-contributing areas.

- The temporary (i.e., depression storage) and permanent waterbodies (i.e., lakes) within the Vermilion River Basin were identified using the National Hydrology Network (NHN) data. Most of these waterbodies were located in the non-contributing areas of the basin.

- The temporary waterbodies were assumed to have a maximum depth of 30 cm in order to allow them to dry up through evaporation after the summer months. Given the generally low infiltration capacity of the landscape, infiltration from these lakes was not considered in the model.

- For the cases where a water body had both permanent and temporary components, the permanent portion was assumed to have a maximum depth of 3 m and the temporary portion around the permanent portion was assumed to have a maximum depth of 20 cm.

- The flows generated from the non-contributing areas were assumed to be collected into “fictitious” temporary/permanent reservoirs, which were only allowed to discharge to the downstream channel once these lakes were filled, i.e., they contributed flows only during major storms/snowmelt events.

- The percentage of non-contributing areas that was assumed to be contributing only at high flows (i.e., during major storms/snowmelt events) ranged from 100% for areas above Vegreville (WSC Station 05EE009) to 0% (for areas draining into Birch Lake, which is a lake with no outlet). About fifty percent of non-contributing areas was assumed to be contributing at high flows for areas below Vermilion River at Vegreville (Station 05EE009) because of the presence of flat areas and/or dead lakes.

- The percentages of non-contributing areas that were assumed to be ditched and contributing all the time ranged from 50% (e.g., for the non-contributing areas near Bruce at WSC Station 05EE915) to 0% (e.g., for the non-contributing areas draining into Beauvallon Lake).

The simulated flows were generated for three cases: [1] ditched with control structures (i.e., Morecambe structure and Vermilion River Dam); [2] ditched without control structures; and [3] no ditching and no control structures (i.e., natural condition without the reservoir created by the Morecambe Structure, for example).

4.4.1.3 Model Data Input

Data used to run the model were as follows:

- To account for the spatial variability of precipitation, precipitation data from Holden, Vermilion River, and Viking stations were used for the upstream part of the basin around Holden. The precipitation data from Vegreville were used for the middle portion of the basin. Precipitation data from Vermilion and Vermilion Airport stations were used for the downstream part of the basin.

- Wind speed and dew point temperature data were from the Edmonton International Airport station, while solar radiation data were from the Edmonton Stony Plain station.
- Air temperature data used for the entire basin were from the Vegreville station, because temperature data are less spatially variable compared to precipitation.
- Evapotranspiration and lake evaporation data were derived by using the Morton Model, with air temperature, dew point temperature, precipitation and solar radiation used as input data.
- Channel cross-sections (i.e., trapezoidal sections) used in generating depth-area-volume-flow tables for the natural condition (i.e., no control structures) were estimated from photos taken during a site visit in November 2008.
- The dimensions of the Morecambe structure and the storage capacity of the Vermilion River reservoir were used to estimate depth-area-volume-flow tables for the Morecambe structure and downstream reaches.
- Recorded stream flows at several hydrometric stations in the basin were used for HSPF model calibration and validation.

4.4.1.4 HSPF Model Calibration Parameters

Table 4.1 provides a summary of HSPF model parameters, their typical and possible range of values, and the calibrated values for the Vermilion River Basin. The hydrologic and watershed characteristics influencing the value of each parameter are also provided.

At least three years of meteorological and hydrologic data are generally required to calibrate the HSPF Model. Calibration begins with an initial estimate of model parameters based on a conceptual representation and the lower and upper limits of each model parameter as described in Table 4.1. Then, the simulated monthly and annual runoff volumes are compared to the observed volumes at hydrologic gauging stations. Appropriate parameters are adjusted until the simulated monthly and annual volumes are acceptably close to the observed values. Individual event volumes are then calibrated.

Table 4.1 Summary of HSPF Model Parameters, Typical and Possible Range of Values, and Calibrated Values for the Vermilion River Basin

Parameter Name	Parameter Description	Unit	Calibrated Value		Typical Range		Possible Range		Function of	Comments
			Lowland	Upland	Min. Value	Max. Value	Min. Value	Max. Value		
(1) Snow Simulation										
LAT	Latitude of Pervious Land Segment (PLS)	degrees	53.375	53.375	30	50	-90	90	location	positive for northern hemisphere
MELEV	Mean Elevation of PLS	feet	variable	variable	50	3000	0	7000	topography	used in convective heat flux equation
SHADE	Shade Fraction of PLS	none	0.5	0.5	0.1	0.5	0	0.8	forest cover, topography	controls radiation to and from the snowpack
SNOWCF	Snow Catch Factor	none	1.05	1.0	1.1	1.5	1	2	gage type, characteristics, location	**calibrated** to snow depth observations
COVIND	Maximum Pack (water equivalent)	inches	3 [5]	8 [10]	1	3	0.1	10	topography, climate	higher for mountanious watersheds
RDCSN	Density of new snow relative to water	none	0.2	0.2	0.1	0.2	0.05	0.3	climate, air temperature	adjust with field snow density data, if available
TSNOW	Temperature at which precipitation becomes snow	deg. F	37.27	37	31	33	30	40	climate, topography	precip. is snow when temperature below TSNOW
SNOEVP	Snow Evaporation Factor	none	0.015	0.03	0.1	0.15	0	0.5	climate, topography	only important in windy, low humidity conditions
CCFACT	Condensation/convection melt factor	none	2.18 [2.38]	2 [2.183]	1	2	0.5	8	climate	**calibrated** to change rate/timing of snowmelt
MWATER	Liquid water storage capacity in snowpack	in/in	0.0598 [0.0641]	0.04 [0.0429]	0.01	0.05	0.005	0.2	climate	adjusted to change timing of snowmelt
MGMELT	Ground heat daily melt rate	in/day	0	0	0.01	0.03	0	0.1	climate, geology	usually small under frozen ground conditions
(2) Rainfall-Runoff Simulation										
FOREST	Fraction of forest cover	none	0.5	0.5	0	0.5	0	0.95	forest cover	only impact when snow is active
LZSN	Lower Zone Nominal Soil Moisture Storage	inches	2 [6]	2 [6]	3	8	2	15	soils, climate	**calibration**
INFILT	Index to Infiltration Capacity	in/hr	0.05 [0.25]	0.01 [0.05]	0.01	0.25	0.001	0.5	soils, land use	**calibration**, divides surface and subsurface flow
LSUR	Length of Overland flow	feet	Variable	Variable	200	500	100	700	topography	estimate from high resolution topomaps or GIS
SLSUR	Slope of overland flow plane	ft/ft	Variable	Variable	0.01	0.15	0.001	0.3	topography	estimate from high resolution topomaps or GIS
KVARY	Variable groundwater recession	1/inches	3 [2]	3 [2]	0	3	0	5	baseflow recession variation	used when recession rate varies with gw levels
AGWRC	Base groundwater recession	none	0.87	0.87	0.92	0.99	0.85	0.999	baseflow recession	**calibration**
PETMAX	Temperature below which ET is reduced	deg. F	40	40	35	45	32	48	climate, vegetation	reduce et near freezing, when snow is active
PETMIN	Temperature below which ET is set to zero	deg. F	35	35	30	35	30	40	climate, vegetation	reduce et near freezing, when snow is active
INFEXP	Exponent in Infilitration equation	none	2	2	2	2	1	3	soil variability	usually default to 2.0
INFILD	Ratio of max/mean infiltration capacity	none	2	2	2	2	1	3	soil variability	usually default to 2.0
DEEPFR	Fraction of Groundwater inflow to deep recharge	none	0	0	0	0.2	0	0.5	geology, gw recharge	accounts for subsurface losses
BASETP	Fraction of remaining ET from baseflow	none	0.2	0.04	0	0.05	0	0.2	riparian vegetation	direct ET from riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0.2	0.04	0	0.05	0	0.2	marsh/wetlands extent	direct ET from shallow GW
CEPSC	Interception storage capacity	inches	variable	Variable	0.03	0.2	0.01	0.4	vegetation type/density, land use	monthly values usually used
UZSN	Upper zone nominal soil moisture storage	inches	0.8715 [0.8427]	0.9449 [0.9136]	0.1	1	0.05	2	surface soil conditions, land use	accounts for near surface retention
NSUR	Manning's N (roughness) for overland flow	none	0.35	0.35	0.15	0.35	0.05	0.5	surface conditions, residue, etc.	monthly values often used for croplands
INTFW	Interflow inflow parameter	none	1.6489 [2.52]	3 [4.585]	1	3	1	10	soils, topography, land use	**calibration**, based on hydrograph separation
IRC	Interflow recession parameter	none	0.3	0.85	0.5	0.7	0.3	0.85	soils, topography, land use	often start with a value of 0.7 and then adjust
LZETP	Lower zone ET parameter	none	0.3797 [0.352]	0.2 [0.1854]	0.2	0.7	0.1	0.9	vegetation type/density, root depth	**calibration**
(3) Channel Routing Parameters										

Parameter Name	Parameter Description	Unit	Calibrated Value		Typical Range		Possible Range		Function of	Comments
			Lowland	Upland	Min. Value	Max. Value	Min. Value	Max. Value		
LEN	Stream reach length	miles	Variable	Variable	0.1	1	0.01	100	topography, stream morphology	used only in computing auxiliary parameters
DELTH	Stream reach length change in elevation	feet	Variable	Variable	10	100	0.1	1000	topography, stream morphology	used only for water quality and sediment
STCOR	stage correction factor	feet	Variable	Variable	0	none	0	none	topography	
KS	Routing weighting factor	none	0.5	0.5	0	0.5	0	0.99	channel slope, flow obstructions	use ks=0.5
DB50	Bed sediment diameter	inches	0.01	0.01	0.01	0.02	0.001	1	channel bed properties	use only in sediment calculations

Notes
(1) Calibrated parameter values are for the lowland and upland areas with Glacial (combination of clay, silt and sand) surficial geology – a dominant surficial geology in this watershed.
(2) [2.52] = represents calibrated parameter values for ditched/drained areas.

Once streamflow volumes are calibrated, flow hydrographs can be calibrated using both interflow and channel routing parameters. The shape of event hydrographs, and to some extent the peak flows, can be calibrated by changing the interflow parameters and the appropriate stage-storage-discharge relationships. In this case of the Vermilion River Basin, a combination of manual and automatic (using PEST) calibration were used to derive the model's basin calibration parameters.

The model calibration is summarized as follows. The rationale for the selected calibration and validation approach is provided in the fifth bullet below.

- Model parameters for the upland areas with glacial (combination of clay, silt and sand) surficial geology were calibrated using the recorded streamflows at Vermilion River Tributary near Bruce (Environment Canada Hydrometric Station 05EE006).
- Model parameters for the lowland areas with glacial (combination of clay, silt and sand) surficial geology were calibrated using the recorded streamflows at Vermilion River Drainage near Holden (Environment Canada Hydrometric Station 05EE913).
- The model parameters were further refined using the streamflow records at the Vermilion River at Vegreville (Environment Canada Hydrometric Station 05EE009) to derive a set of upland and lowland model parameters to represent the land types in the Vermilion River Basin.
- The threshold discharge for releasing flows from the reservoirs collecting water from the non-contributing areas (i.e., contributing only during major storms/snowmelt) was calibrated to be 3 m^3/s.
- The model was then validated with the streamflow records at the Vermilion River near Beauvallon (Environment Canada Hydrometric Station 05EE930), Vermilion River near Mannville (Environment Canada Hydrometric Station 05EE001), and Vermilion River near Marwayne (Environment Canada Hydrometric Station 05EE007). This validation approach (calibration on individual sub-basins and validation at nodes downstream of a number of sub-basins) was selected because the validation sub-basins include a number of land types and a range of area ditched, thus, increasing the rigour of testing the calibrated model.
- The accuracy of the model calibration and validation was evaluated by comparing the measured and simulated flow parameters listed below:
  - mean open water (March to October) flow;
  - mean spring (March 1 - June 15) peak daily flow;
  - 2-, 10-, and 25-year spring (March 1 - June 15) peak flood flows;
  - mean summer (June 16 – October 31) peak daily flow;
  - 2-, 10-, and 25-year summer (June 16 – October 31) peak flood flows; and,
  - mean monthly flow.

4.4.1.5 Model Calibration and Validation Statistics

The statistics of the simulated flow series from the calibration and validation of HSPF are compared with the statistics of the observed series in Table 4.2 (Table 4.2a for mean open water flow, Table 4.2b for spring peak flows, and Table 4.2c for summer peak flows). The HSPF model cannot accommodate the different ways that the Morecambe Structure may have been operated (or not operated) during specific years since its construction. Hence, Table 4.2 shows the statistics of the simulated series generated with and without the Morecambe Structure in operation. Table 4.2 also shows the statistics of the flow series without ditches and the Morecambe Structure (simulating natural pre-development conditions).

The observed and simulated mean open water statistics compare reasonably well for the sub-basins upstream and downstream of the Morecambe Structure. The comparison at the WSC stations downstream of the Morecambe Structure needs interpretation. It appears that the comparison between the observed and simulated statistics with the Morecambe Structure in operation throughout is reasonably good for the 2-year spring or summer floods, but less so for the 25-year spring or summer floods. This may indicate that the Morecambe Structure is not as effective at controlling the more severe floods.

Figures 4.1 and 4.2 show comparisons of the recorded and simulated mean monthly flows at station 05EE009 (Vermilion River at Vegreville) for the concurrent period of 1987 to 2003, and at station 05EE007 (Vermilion River at Manville) for the concurrent period of 1980 to 2003, respectively. The observed and simulated mean monthly flows at Vegreville (05EE009) compare very well. For the WSC station downstream of the Morecambe Structure, the simulated mean monthly flow series for the cases with and without the Morecambe Structure are shown. Figure 4.2 shows that the simulated series with the Morecambe Structure in operation replicate the mean flows during the spring flood months reasonably well. The simulated flows with the Morecambe Structure in operation tend to be generally higher than the observed flows during the late summer and fall months. The HSPF model was set up to replicate the riparian flows from the Morecambe Structure. It appears from the actual riparian flows from the Morecambe Structure have generally been less than they could potentially have been. This result tends to corroborate observations that the lower reaches of the Vermilion River are experiencing low flows in the summer and fall months.

In general, the simulated results show that the model reproduced the measured discharges reasonably well, giving confidence in the resulting hydrologic statistics.

4.5 Implementation of HSPF Model on the Vermilion River Basin

The calibrated model was then used to assess and quantify the effects of the present land use patterns and flow control structures on flows in the Vermilion River Basin. The effects of changes in the land use patterns and hydraulic characteristics of the flow control structures can then be assessed. These are discussed in the next Section.

Table 4.2 Comparison of Observed and Simulated Flow Statistics using the HSPF Model

Table 4.2a Summary of Mean Flow Statistics for the Open Water Period (March - October) for the Vermilion River Basin

Station Name & Number	Period of Flow Record	Basin Area [km²]		Mean Open Water Flow (March - October) [m³/s]			
		Gross	Effective	Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]
SUB-BASINS UPSTREAM OF MORECAMBE							
Vermilion River Tributary near Bruce (Station 05EE006)	1979 - 2003	46.4	19.9	0.039	0.034	na	na
Vermilion River Drainage near Holden (Station 05EE913)	1981 - 1993	56.4	na	0.032	0.022	na	0.016
Vermilion River at Vegreville (Station 05EE009)	1987 - 2003	1620	367	0.341	0.370	na	0.379
SUB-BASINS DOWNSTREAM OF MORECAMBE							
Vermilion River near Beauvallon (Station 05EE930)	1997 - 2003	3880	1070	0.699	1.188	1.215	1.331
Vermilion River near Mannville (Station 05EE001)	1976 - 1983	5740	2320	1.58	2.33	2.72	2.83
Vermilion River near Marwayne (Station 05EE007)	1980 - 2003	7260	2000	1.29	1.91	2.29	2.32

Table 4.2b Summary of Peak Flow Statistics for Spring (March 1 - June 15) for the Vermilion River Basin

Station Name & Number	Period of Flow Record	Mean Spring (March 1 - June 15) Peak Daily Flow [m³/s]				2-Year Peak Flow [m³/s]				10-Year Peak Flow [m³/s]				25-Year Peak Flow [m³/s]			
		Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]	Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]	Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]	Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]
SUB-BASINS UPSTREAM OF MORECAMBE																	
Vermilion River Tributary near Bruce (Station 05EE006)	1979 - 2003	0.769	0.526	na	na	0.454	0.207	na	na	1.72	1.18	na	na	2.80	2.50	na	na
Vermilion River Drainage near Holden (Station 05EE913)	1981 - 1993	0.614	0.371	na	0.240	0.417	0.242	na	0.138	1.39	0.891	na	0.603	2.21	1.38	na	1.03
Vermilion River at Vegreville (Station 05EE009)	1987 - 2003	6.73	7.13	na	5.93	2.69	4.24	na	2.76	18.8	16.2	na	15.5	34.1	26.1	na	29.3
SUB-BASINS DOWNSTREAM OF MORECAMBE																	
Vermilion River near Beauvallon (Station 05EE930)	1997 - 2003	6.68	7.35	16.8	16.3	2.56	3.45	11.3	10.9	25.1	25.3	44.6	44.2	39.4	39.0	64.3	63.8
Vermilion River near Mannville (Station 05EE001)	1976 - 1983	17.4	7.31	22.3	17.4	11.6	2.80	16.0	11.6	39.5	19.6	40.4	39.5	71.0	45.0	68.2	71.0
Vermilion River near Marwayne (Station 05EE007)	1980 - 2003	21.2	7.96	22.99	21.24	12.5	4.31	14.3	12.5	51.1	18.1	55.0	51.1	83.4	30.5	89.9	83.4

Note: na = not applicable

Table 4.2c Summary of Peak Flow Statistics for Summer (June 16 - October 31) for the Vermilion River Basin

Station Name & Number	Period of Flow Record	Mean summer (June 16 - October 31) Peak Daily Flow [m³/s]				2-Year Peak Flow [m³/s]				10-Year Peak Flow [m³/s]				25-Year Peak Flow [m³/s]			
		Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]	Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]	Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]	Recorded	Simulated: Ditched with Structures [Current Conditions]	Simulated: Ditched. No Structures. [No Flood Control]	Simulated: No Ditches. No Structures. [Natural Conditions]
SUB-BASINS UPSTREAM OF MORECAMBE																	
Vermilion River Tributary near Bruce (Station 05EE006)	1979 - 2003	0.148	0.201	na	na	0.035	0.094	na	na	0.584	0.510	na	na	0.967	0.931	na	na
Vermilion River Drainage near Holden (Station 05EE913)	1981 - 1993	0.365	0.447	na	0.243	0.228	0.246	na	0.149	1.14	1.48	na	0.762	1.66	2.20	na	1.11
Vermilion River at Vegreville (Station 05EE009)	1987 - 2003	0.719	3.08	na	2.45	0.255	0.541	na	1.01	1.52	8.41	na	5.44	2.94	25.5	na	10.1
SUB-BASINS DOWNSTREAM OF MORECAMBE																	
Vermilion River near Beauvallon (Station 05EE930)	1997 - 2003	0.418	0.944	1.80	1.85	0.158	0.580	0.768	1.31	1.57	2.37	4.97	5.16	2.47	4.37	7.90	7.25
Vermilion River near Mannville (Station 05EE001)	1976 - 1983	2.44	4.75	13.0	10.8	2.27	2.15	9.76	8.01	5.01	13.4	35.5	29.7	6.17	29.3	48.7	41.0
Vermilion River near Marwayne (Station 05EE007)	1980 - 2003	7.59	2.85	8.44	7.59	2.65	1.35	2.95	2.65	21.0	5.87	23.8	21.0	34.0	11.9	40.3	34.0

Note: na = not applicable

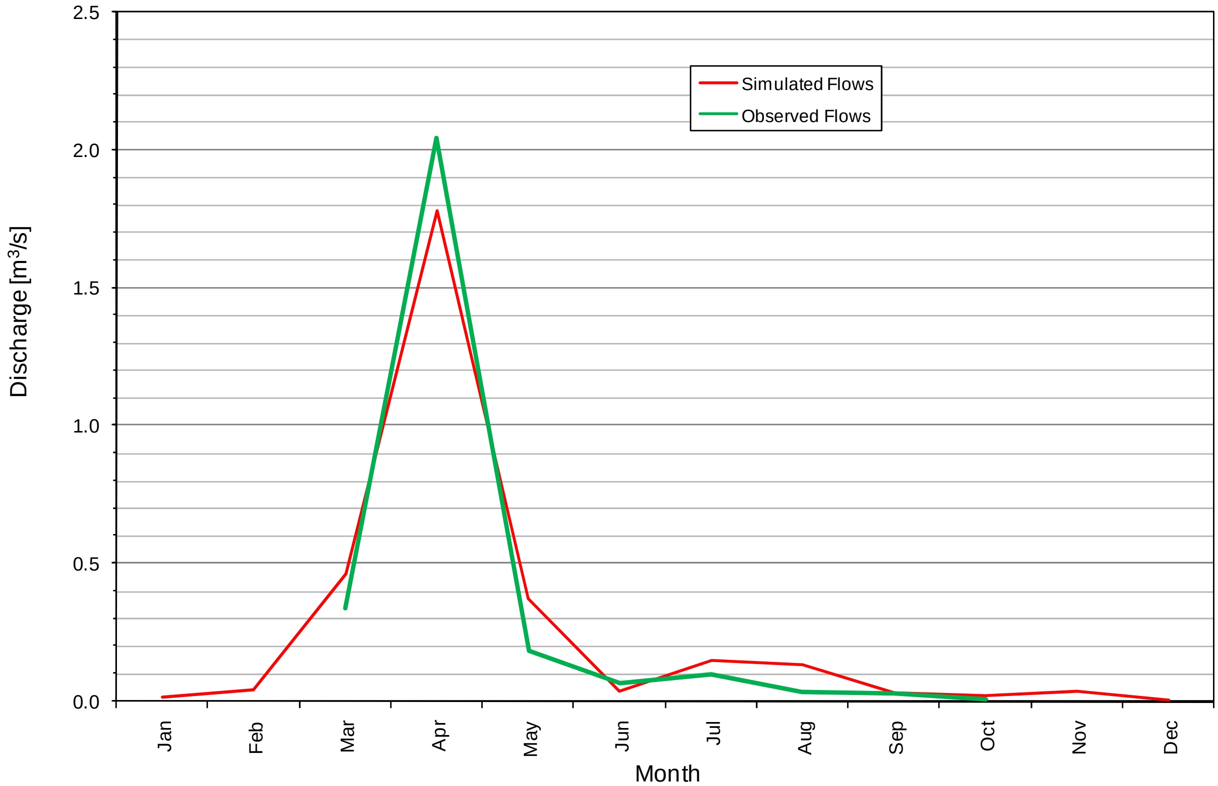


Figure 4.1 Observed and Simulated Monthly Flows at Vegreville - WSC 05EE009 1987-2003

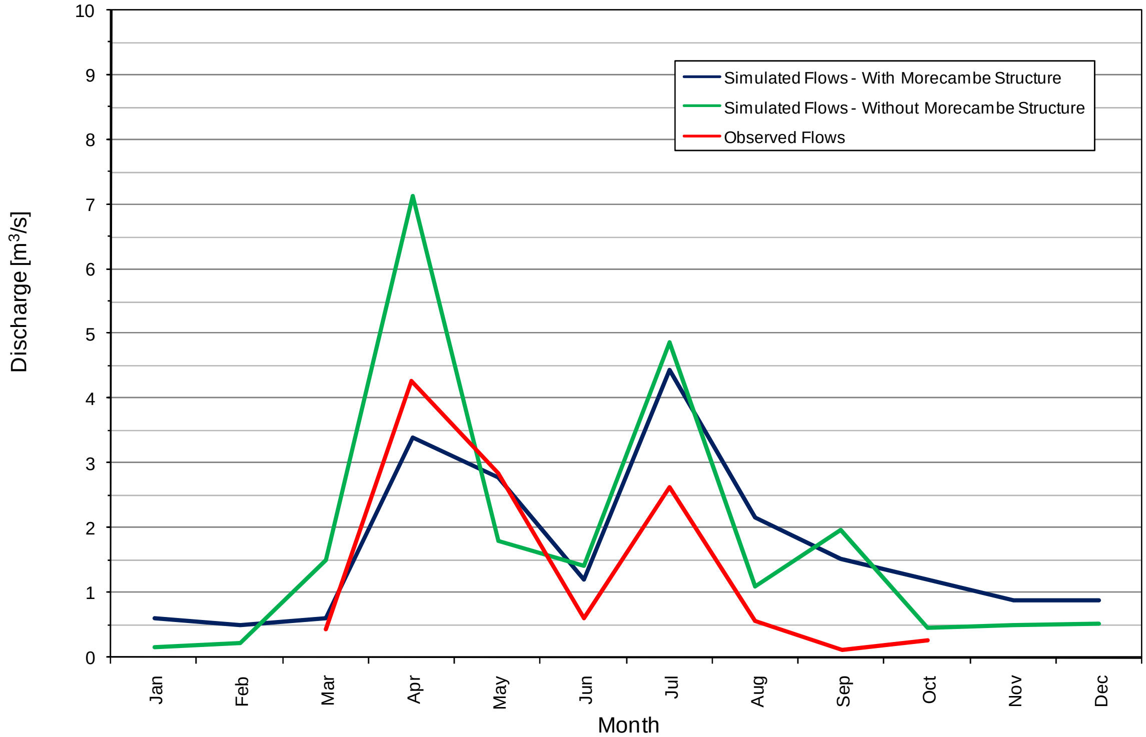


Figure 4.2 Observed and Simulated Monthly Flows at Manville - WSC 05EE001 1976-1983

5.0 EFFECTS OF DRAINAGE ACTIVITIES AND FLOW CONTROL STRUCTURES ON THE HYDROLOGY OF THE VERMILION RIVER BASIN

5.1 Introduction

The NSWA has identified the Vermilion River Basin (VRB) basin as one of the most altered watersheds in the North Saskatchewan River Basin. Impacts on water quantity and quality have been noted and are thought to result from wetland drainage and modification, livestock management, tillage and municipal and industrial development. The water management issues in the VRB include drainage activities in the headwaters, flooding in the middle reaches, and unreliability of water supplies in the lower reaches.

The following description of issues and observations are based on the Vermilion Stakeholder Committee's Recommendation Report (VRORSC 2000). Drainage programs within the VRB have reduced the natural storage of water, thereby reducing the duration of water flow. In the late summer and fall, water levels in the lower reaches of the river have been reduced, and occasionally stop altogether. The natural drainage profile of the VRB is steep in the upper reaches, flat around Two Hills, dropping more steeply through the Mannville area, flat below Vermilion, and then dropping rapidly again to Marwayne. The natural drainage profile results in flooding in the flatter areas of the river, although flooding does occur throughout the VRB.

Section 5 of the report addresses the following:

- Effects of drainage systems and wetland loss on basin hydrology, and,
- Effects of operation of the present flood-control structures on river hydrology and flood attenuation.

The issues and concerns in the VRB, as stated by the VRORSC, are presented first in Section 5. Next, the flow simulations from the HSPF model set up for the Vermilion River Basin are used to describe the effects of present drainage and flow control on the pre-development (without drainage and flow control) hydrology of the VRB. The HSPF model is then used to simulate a number of scenarios:

- Increase in areas ditched in the VRB;
- Addition of off-stream storage in the VRB and release of water during the summer and fall months;
- Modification of operation of the Morecambe Structure by increasing storage and releasing water during the summer and fall months; and,
- Combination of the above scenarios.

The results of the hydrologic assessment are used to provide recommendations for watershed, wetland and riparian management to sustain a healthy ecosystem and to support long-term water supply.

5.2 Drainage Works in the Vermilion River Basin

In the Vermilion River Basin, there has been a long history of drainage programs to improve agricultural production. Some of the drainage programs have been authorized by licenses, but other drainage projects have proceeded without proper authorization (VRORSC 2000). The VRORSC Recommendation Report of December 2000 states that the cumulative impact of drainage in the upper watershed may have increased the frequency and intensity of flooding in the middle reaches of the Vermilion River. Drainage may have also reduced the natural storage of water, thereby reducing the duration of water flow. The VRORSC Recommendation Report suggests that in the late summer and fall, water levels in the lower reaches in the river have been reduced, and occasionally stop altogether. However, it is not apparent that any significant hydrologic modelling or assessment was undertaken at the time to confirm the statements in the VRORSC Recommendation Report of December 2002. This study therefore provides the first formal evaluation of the hydrologic impacts of the drainage of areas in the Vermilion River Basin using a hydrologic model.

5.2.1 Holden Drainage District

The Holden Drainage District was established in 1918 as a local authority to assist farmers drain low-lying lands to increase agricultural production.

Concerns have been expressed by local residents and municipalities about the impact of upstream drainage on downstream land owners within the Drainage District; problems with unauthorized drainage into the District and from within the District; and on the ability of the District to release water into the river system. The cumulative impacts of drainage in the upper VRB may have increased the frequency and intensity of flooding in the middle reaches of the river. Drainage within the middle and lower portions of the VRB may also contribute towards increased frequency and intensity of flooding along the main stem of the Vermilion River.

5.2.2 Recommendations of VRORSC Related to Drainage

The VRORSC recommended that

- Drainage programs be managed so that peak flows are reduced and duration of natural flows increased;
- Storage capacity in the VRB be increased to hold water during periods of high flows and released during periods of low flows;
- Alternative practices, such as wildlife habitat improvements, be encouraged to reduce the amount of land that is drained; and,
- Information be provided to the Local Municipalities and landowners on the downstream impact of drainage programs.

5.3 Flood Control Structures in the Vermilion River Basin

The natural drainage profile of the Vermilion River Basin (VRB) is steep in the upper reaches, flat around Two Hills, dropping more steeply through the Mannville area, flat below Vermilion, and then dropping rapidly again to Marwayne (VRORSC 2000). The VRORSC Recommendation Report of December 2000 states that this natural drainage profile of the VRB results in flooding in the flatter areas of the Vermilion River, although flooding does occur throughout the basin.

5.3.1 Morecambe Structure

The Morecambe Structure is located at the outlet of the last Vermilion Lake, and is the primary flow control structure on the Vermilion River. The structure is designed to allow for pre-lease of water from the Vermilion Lakes, and to allow all flood flow through the structure without increasing the upstream water levels (Vermilion River Stakeholder Committee 2000). The original operating procedures required upstream flow monitoring to determine potential flood threat and operating the gates to drawdown the Vermilion Lakes. Outflow would then be controlled to minimize upstream and downstream flooding.

Since construction of the Morecambe Structure, Alberta Environment has operated it twice in an attempt to reduce flood damage, but it has not been completely successful. Operation of the Morecambe structure in 1983 and 1990 resulted in the flooding of the downstream land owners and damage to hay crops (VRORSC Recommendation Report December 2000). In 1991 there were problems when pre-release to reduce water levels upstream was thought to have increased flooding downstream. The Morecambe Structure was not operated from 1991 till 2004. The structure was operated during the spring and summer of 2005 and 2006.

Operating guidelines for the Morecambe structure are described in a draft document dated January 5, 2006 and prepared by the Vermilion River Operating Review Stakeholders Committee. The guidelines are similar to those in a 1987 report and are directed at reducing flood levels in the Two Hills and Manville floodplains by using the storage potential of the Vermilion chain of lakes to attenuate flood events. The guidelines apply for both the spring and summer flood events, however, normal spring floods are of less concern, except when floods are exceptionally high. Spring floods are considered of benefit to the agricultural community in some reaches because they increase soil fertility and moisture level. However, summer floods cause problems for agricultural activities. Flood mitigation during the spring is limited to post-flood release of floodwater. Post-flood release refers to operation after flooding has occurred to remove excess water from the Two Hills floodplain, return the lakes water level to the normal full supply as soon as possible. This will provide the required back-flood irrigation for the floodplain as well as removing excess water from the fields in a timely manner. Summer flooding requires both pre-flood release and post-flood release.

5.3.2 Recommendations of VRORSC Related to the Morecambe Control Structure

The VRORSC recommended that the Morecambe Structure be operated

- to reduce the severity and duration of upstream and downstream flooding , and the impacts on agriculture in flood prone areas;
- to provide riparian flow downstream during the late summer and fall, but without dropping the water levels in Vermilion Lakes below 598.75 m;
- to not increase water levels in Vermilion Lakes unless impacts on upstream landowners are minimized though implementation of mitigation measures; and,
- in concert with the Vermilion Dam during flood control operations.

The VRORSC also recommended that the number of precipitation and flow monitoring stations in the VRB be increased to improve the flood warning system and to provide better data to manage the flow in the river.

5.3.3 Vermilion Dam

The Vermilion Dam near the Town of Vermilion was constructed in 1980-81 to replace an existing dam that provided a recreation reservoir and a crossing of the river for Highway 41. The dam provides no flood control potential and the only controlled water releases are via a small sluice gate that provides riparian flows. Although all inflows pass directly through the dam, the reservoir provides some storage reduction of peak flows.

5.4 Recommendations of VRORSC Related to Storage Capacity in the Basin

The VRORSC recommended that

- Storage reservoirs be developed in the VRB, particularly in the upper sub-basins (though not unanimously supported by all Committee members) to temporarily hold water during periods of high flow with later slow release to offset the impact of past drainage activities;
- A flow control structure be constructed near the eastern outlet of the Holden Drainage District #1 to temporarily store and attenuate the flows from summer storms; and,

- Multiple small storages be developed on tributary streams in the VRB, in partnership with landowners and government agencies.

5.5 Effects of Drainage Ditches on Basin Hydrology

The hydraulic effect of drainage ditches is generally to decrease the time of concentration of runoff into receiving streams, thereby increasing peak flows and decreasing the duration of runoff events. The effects of drainage ditches and draining of wetlands in the upper sub-basins of the VRB are more complex because the lands that have been drained would be considered as “non-contributing” in their natural state during average hydrologic conditions. One can therefore expect drainage of non-contributing areas to increase the more frequent annual peak flows, but the effect on the more extreme flood events may depend on whether the flood is generated from snow melt events or summer storms.

The simulated flood series at Vegreville show the complex hydrologic response to drainage ditches. Table 5.1 (Table 5.1a for mean open water flow, Table 5.1b for spring peak flows, and Table 5.1c for summer peak flows) shows the flow statistics for three cases: (1) Current conditions with ditches and flow control structures, (2) natural conditions without ditches or flow control structures, and (3) simulated future conditions with drained areas almost the twice the current areas and with the present flow control structure. The latter scenario is very arbitrary in nature and is used only as an example to illustrate the hydrologic effects of increased drainage. Figures 5.1 and 5.2 illustrate the effects of drainage ditches on spring and summer peak flows at Vegreville, respectively. Drainage ditches tend to increase summer peak flows more than spring flood flows, and the increase in summer peak flows tends to grow with increase flood severity (return period increasing). The effect on spring peak flows with a return period greater than 25 years (annual probability of exceedance of 0.04) does not appear to be significant. Increased ditching over the current level of ditching increases peak flows, but the increase is not as significant as that compared to the natural conditions.

Figures 5.3 and 5.4 illustrate the effects of drainage ditches on spring and summer peak flows at Mannville, respectively. The effects of ditching on spring peak flows tends to be less significant downstream of the Morecambe Structure. Increased ditching over the current level has virtually no effect on spring peak flows compared to those under current level of ditching, with the Morecambe Structure in operation. Without the Morecambe Structure in operation, the spring peak flows with and without ditches, while significantly higher than peak flows with the structure in operation, are almost the same for flood flows with return period greater than 10 years. Figure 5.4 shows that the effect of increased ditching is more significant on summer peak flows. The increase in summer peak flows tends to grow with increase flood severity (return period increasing), with higher effect on the more frequent floods (return period less than 15 years) and almost no effect on severe floods (return period greater than 25 years). As discussed in Section 4.4.1.5, the effectiveness of the Morecambe Structure on summer peak flows tends to be less than on spring peak flows.

Figures 5.5 and 5.6 show the effects of drainage ditches on mean monthly flows at Vegreville and Mannville, respectively. Upstream of the Morecambe Structure, ditches tend to increase peak monthly flows and shorten runoff duration. Downstream of the Morecambe Structure, the flow control structure has the primary influence, compared to ditching, on mean monthly flows. The flow control structure, if operated to release riparian flow, can increase the base flow in the Vermilion River during the late summer and fall months.

Table 5.1 Effects of Drainage Ditches on Simulated Flow Statistics using the HSPF Model

Table 5.1a Summary of Mean Flow Statistics for the Open Water Period (March - October) for the Vermilion River Basin

Station Name & Number	Period of Flow Record	Basin Area [km^2] Gross	Basin Area [km^2] Effective	Mean Open Water Flow (March - October) [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]
SUB-BASINS UPSTREAM OF MORECAMBE						
Vermilion River Tributary near Bruce (Station 05EE006)	1979 - 2003	46.4	19.9	0.036	0.034	na
Vermilion River Drainage near Holden (Station 05EE913)	1981 - 1993	56.4	na	0.025	0.022	0.016
Vermilion River at Vegreville (Station 05EE009)	1987 - 2003	1620	367	0.392	0.370	0.379
SUB-BASINS DOWNSTREAM OF MORECAMBE						
Vermilion River near Beauvallon (Station 05EE930)	1997 - 2003	3880	1070	1.18	1.188	1.331
Vermilion River near Mannville (Station 05EE001)	1976 - 1983	5740	2320	2.31	2.33	2.83
Vermilion River near Marwayne (Station 05EE007)	1980 - 2003	7260	2000	1.93	1.91	2.32

Table 5.1b Summary of Peak Flow Statistics for Spring (March 1 - June 15) for the Vermilion River Basin

Station Name & Number	Period of Flow Record	Mean Spring (March 1 - June 15) Peak Daily Flow [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]	2-Year Peak Flow [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]	10-Year Peak Flow [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]	25-Year Peak Flow [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]
SUB-BASINS UPSTREAM OF MORECAMBE													
Vermilion River Tributary near Bruce (Station 05EE006)	1979 - 2003	0.540	0.526	na	0.224	0.207	na	1.17	1.18	na	2.46	2.50	na
Vermilion River Drainage near Holden (Station 05EE913)	1981 - 1993	0.427	0.371	0.240	0.283	0.242	0.138	1.02	0.891	0.603	1.56	1.38	1.03
Vermilion River at Vegreville (Station 05EE009)	1987 - 2003	8.03	7.13	5.93	5.00	4.24	2.76	17.9	16.2	15.5	28.1	26.1	29.3
SUB-BASINS DOWNSTREAM OF MORECAMBE													
Vermilion River near Beauvallon (Station 05EE930)	1997 - 2003	7.42	7.35	16.3	3.50	3.45	10.9	25.5	25.3	44.2	39.3	39.0	63.8
Vermilion River near Mannville (Station 05EE001)	1976 - 1983	7.53	7.31	17.4	2.69	2.80	11.6	20.1	19.6	39.5	49.5	45.0	71.0
Vermilion River near Marwayne (Station 05EE007)	1980 - 2003	8.14	7.96	21.24	4.44	4.31	12.5	18.6	18.1	51.1	31.1	30.5	83.4

Note: na = not applicable

Table 5.1c Summary of Peak Flow Statistics for Summer (June 16 - October 31) for the Vermilion River Basin

Station Name & Number	Period of Flow Record	Mean Spring (March 1 - June 15) Peak Daily Flow [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]	2-Year Peak Flow [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]	10-Year Peak Flow [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]	25-Year Peak Flow [m^3/s] Simulated: Ditched with Structures [Increased Ditching]	Ditched with Structures [Current Conditions]	No Ditches. No Structures. [Natural Conditions]
SUB-BASINS UPSTREAM OF MORECAMBE													
Vermilion River Tributary near Bruce (Station 05EE006)	1979 - 2003	0.244	0.201	na	0.131	0.094	na	0.600	0.510	na	1.03	0.931	na
Vermilion River Drainage near Holden (Station 05EE913)	1981 - 1993	0.529	0.447	0.243	0.284	0.246	0.149	1.76	1.48	0.762	2.64	2.20	1.11
Vermilion River at Vegreville (Station 05EE009)	1987 - 2003	3.51	3.08	2.45	0.612	0.541	1.01	9.22	8.41	5.44	28.2	25.5	10.1
SUB-BASINS DOWNSTREAM OF MORECAMBE													
Vermilion River near Beauvallon (Station 05EE930)	1997 - 2003	0.936	0.944	1.85	0.599	0.580	1.31	2.27	2.37	5.16	4.03	4.37	7.25
Vermilion River near Mannville (Station 05EE001)	1976 - 1983	8.34	4.75	10.8	6.08	2.15	8.01	22.5	13.4	29.7	31.3	29.3	41.0
Vermilion River near Marwayne (Station 05EE007)	1980 - 2003	2.88	2.85	7.59	1.42	1.35	2.65	5.93	5.87	21.0	11.7	11.9	34.0

Note: na = not applicable

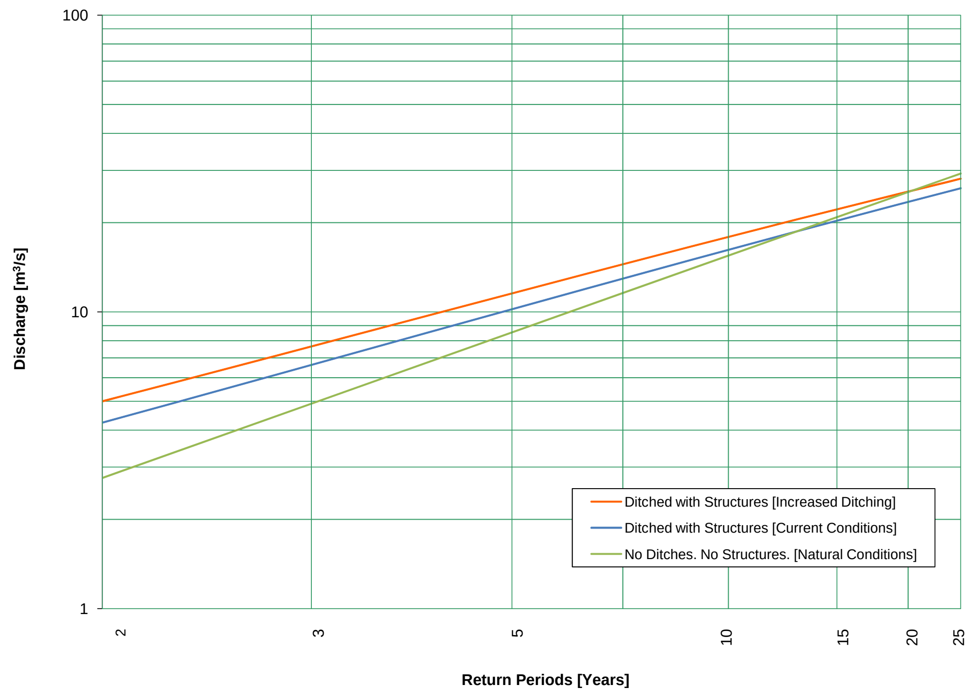


Figure 5.1(a) – Log Scale for Discharge on Y-axis

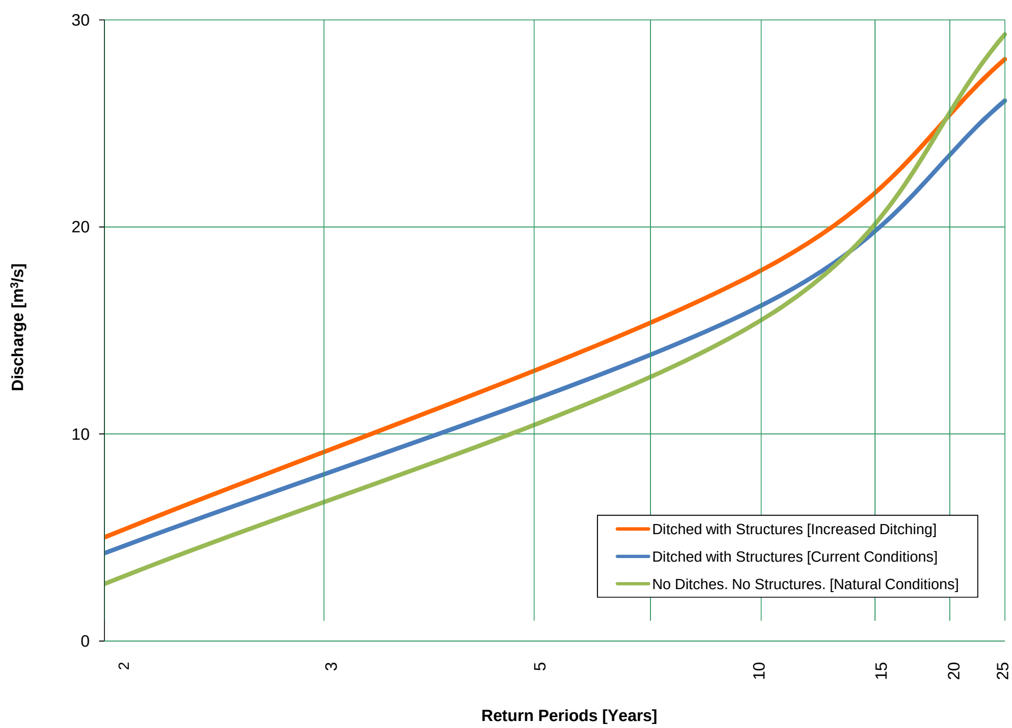


Figure 5.1(b) – Linear Scale for Discharge on Y-axis

Figure 5.1 Effect of Drainage Ditches on Simulated Spring Peak Flows at Vegreville - WSC 05EE009 1987-2003

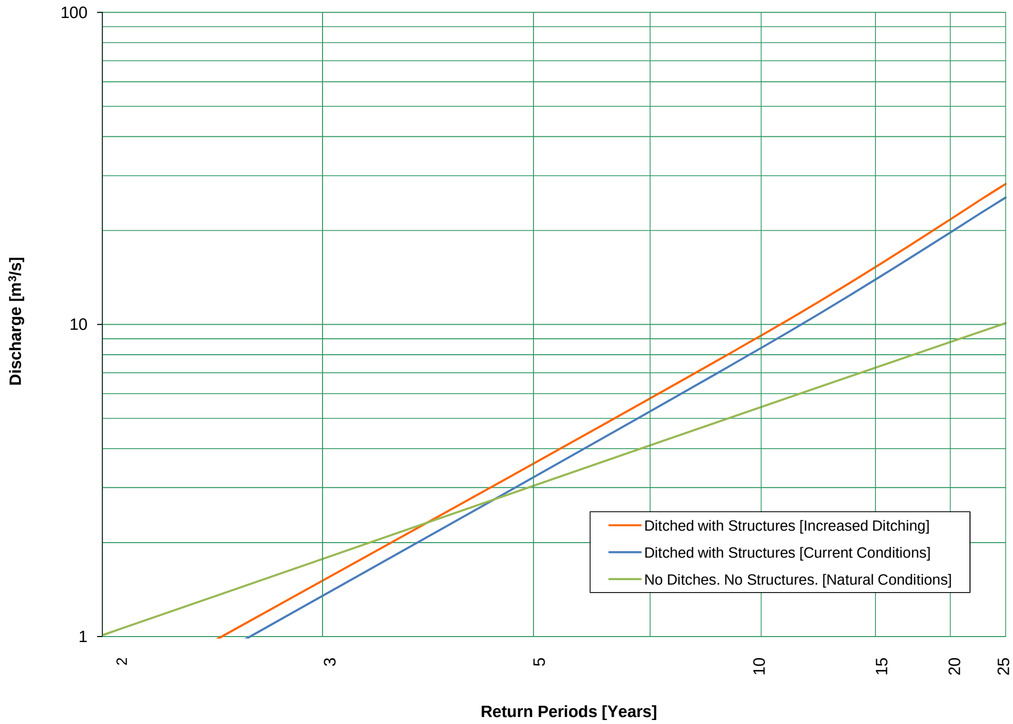


Figure 5.2(a) – Log Scale for Discharge on Y-axis

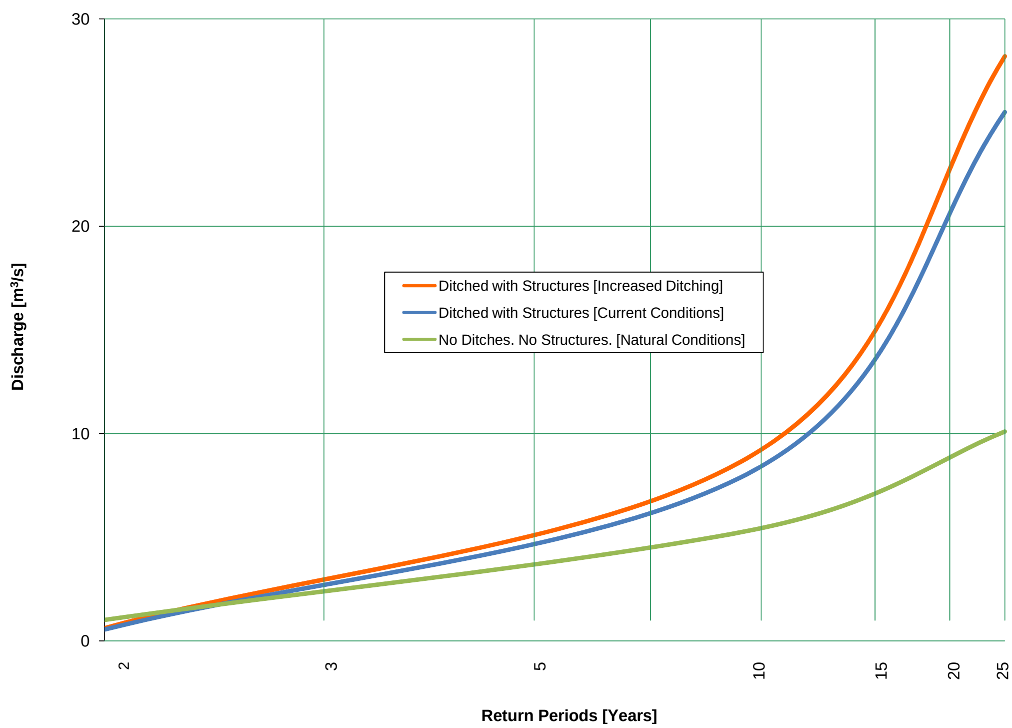


Figure 5.2(b) – Linear Scale for Discharge on Y-axis

Figure 5.2 Effect of Drainage Ditches on Simulated Summer Peak Flows at Vegreville - WSC 05EE009 1987-2003

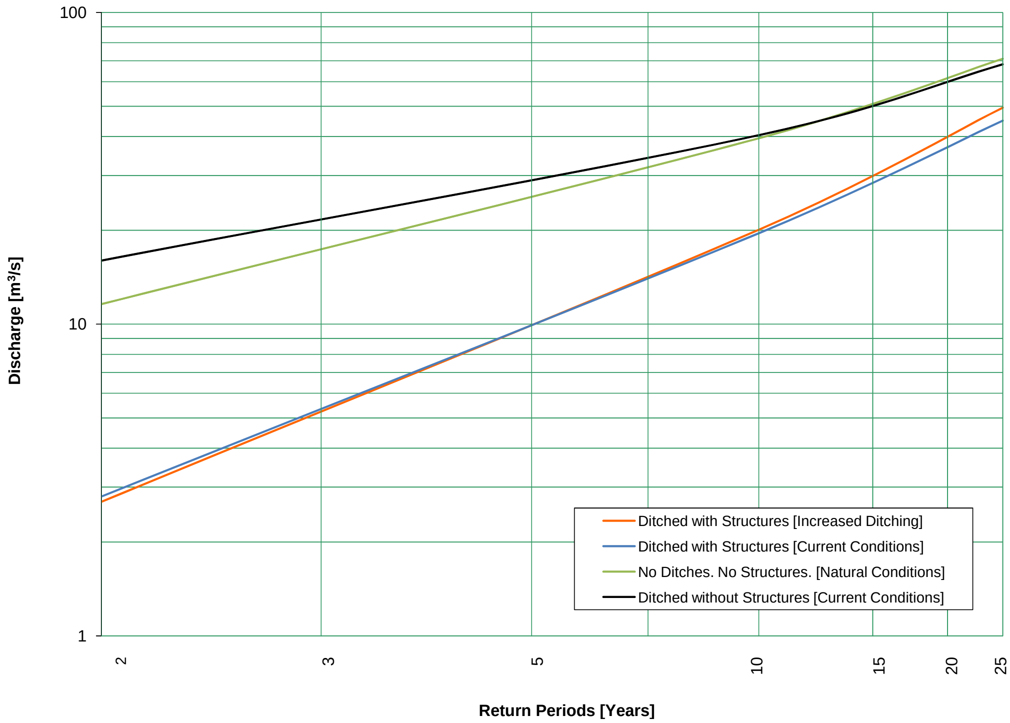


Figure 5.3(a) – Log Scale for Discharge on Y-axis

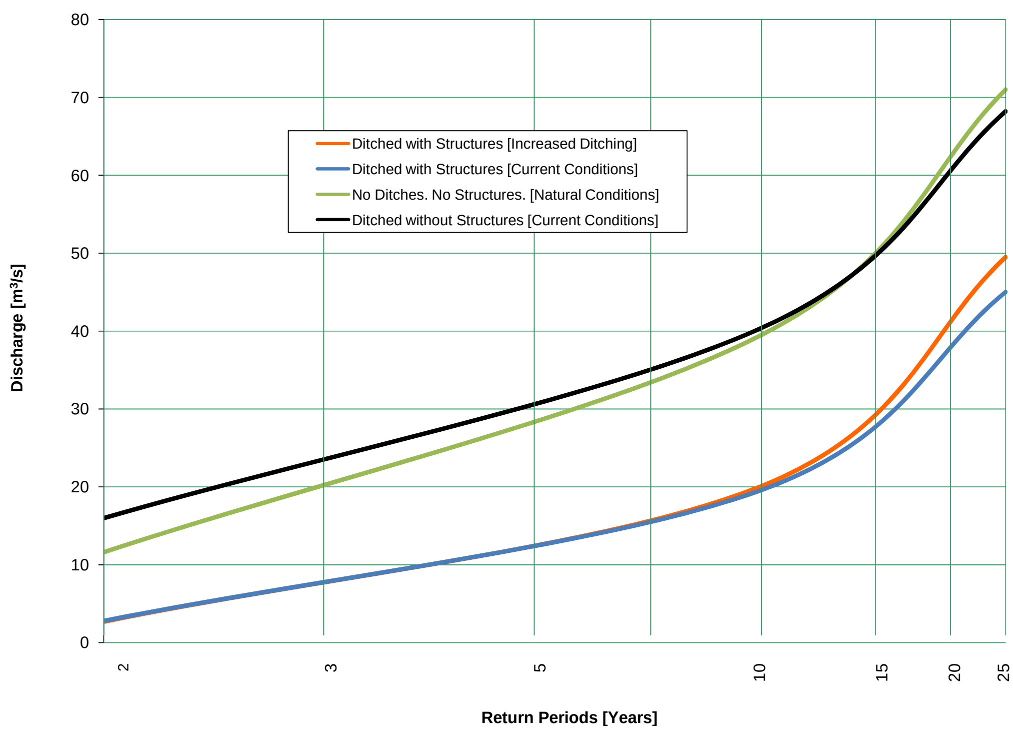


Figure 5.3(b) – Linear Scale for Discharge on Y-axis

Figure 5.3 Effect of Drainage Ditches on Simulated Spring Peak Flows at Mannville - WSC 05EE001 1976-1983

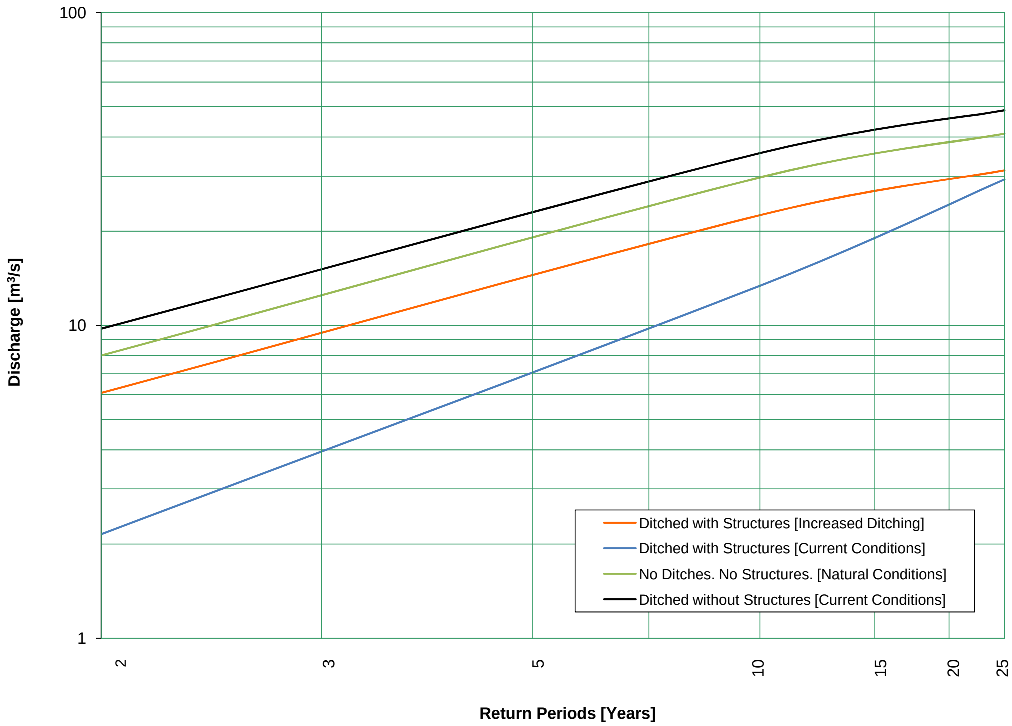


Figure 5.4(a) – Log Scale for Discharge on Y-axis

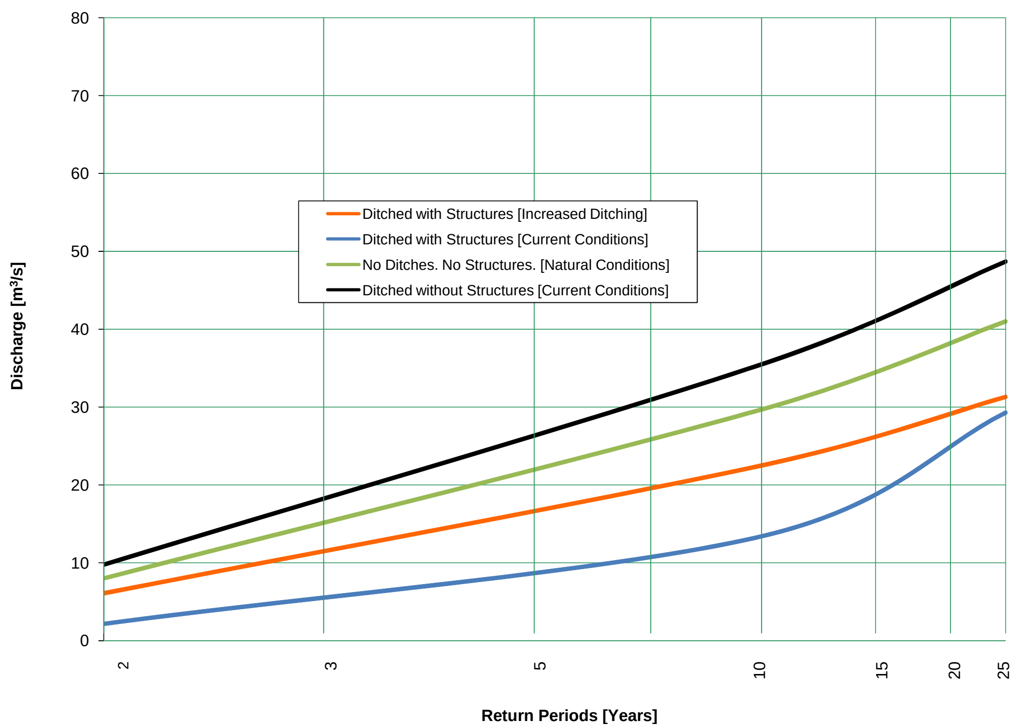


Figure 5.4(b) – Linear Scale for Discharge on Y-axis

Figure 5.4 Effect of Drainage Ditches on Simulated Summer Peak Flows at Mannville - WSC 05EE001 1976-1983

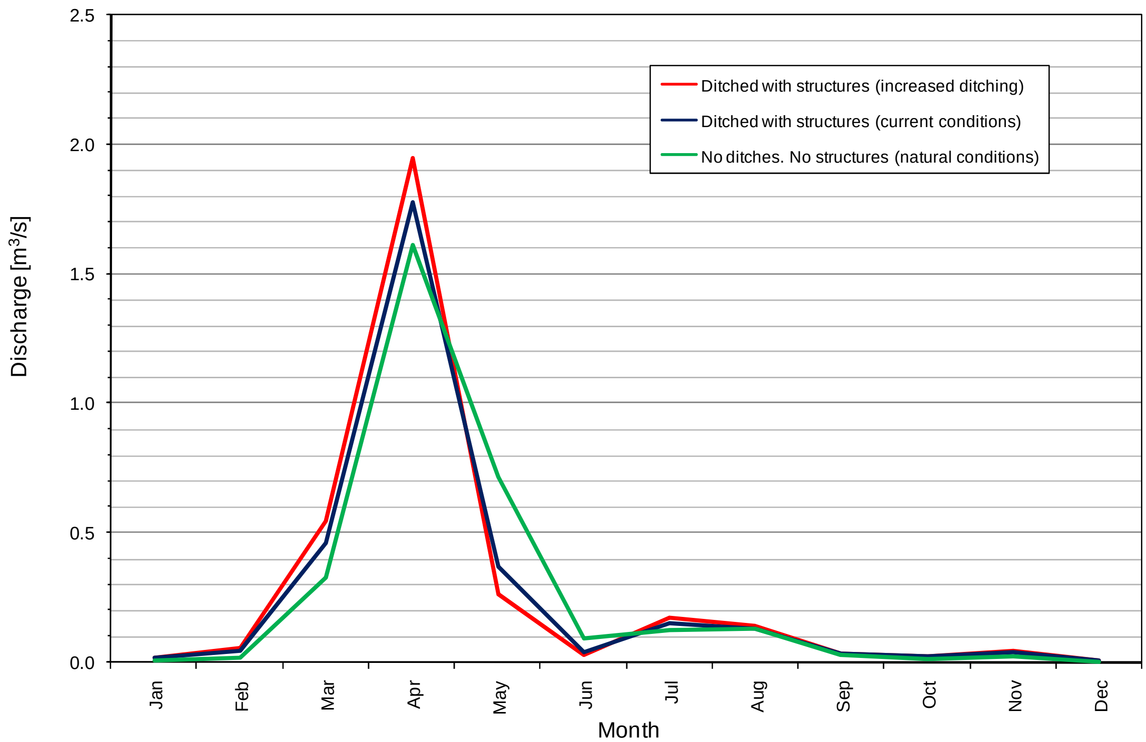


Figure 5.5 Effect of Drainage Ditches on Simulated Mean Monthly Flows at Vegreville - WSC 05EE009 1987-2003

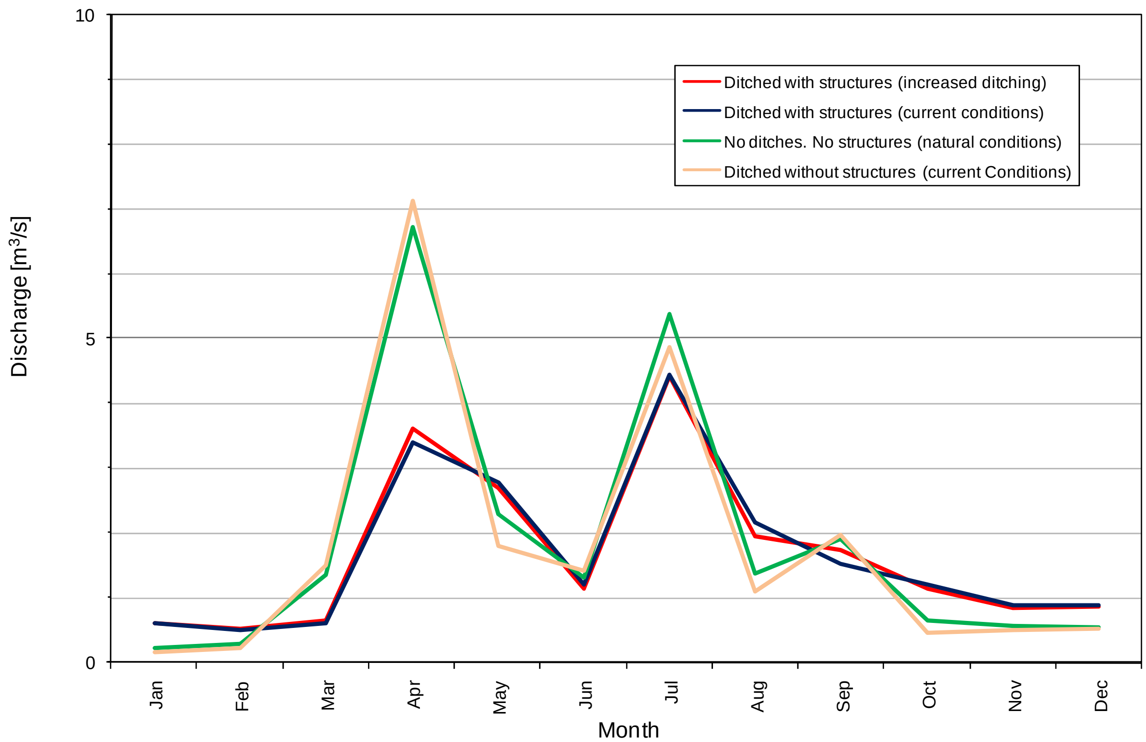


Figure 5.6 Effect of Drainage Ditches on Simulated Mean Monthly Flows at Manville - WSC 05EE001 1976-1983

5.6 Effects of Flow Control Structure on Basin Hydrology

The effect of the flow control structure at Morecambe on downstream spring and summer peak flows, and on mean monthly flows has been discussed in the previous section.

5.7 Effects of Additional Storage Capacity on Basin Hydrology

5.7.1 Small Storages off Main Stem of Vermilion River

The VRORSC recommended in 2002 that storage reservoirs be developed in the VRB, particularly in the upper sub-basins to temporarily hold water during periods of high flow with later slow release to offset the impact of past drainage activities. This recommendation was evaluated by adding two conceptual storage facilities, each capable of storing from 500,000 to 1,000,000 m^3, in the upper VRB between Holden and Vegreville. Two similar storage facilities were located in the middle part of the VRB between the Morecambe Structure and Manville, as well as downstream of Vermilion. The storage facilities were conceptualized as diverting flood flows above a threshold (generally equivalent to the 2-yr to 5-yr flood flow) into storage, with a low level outlet that discharges continuously, but primarily to increase base flows during non-flood periods (between spring and summer, and between late summer and fall). In reality, these conceptual storages could consist of several restored wetlands with structures to provide some control on outflows from them.

Figures 5.7 and 5.8, for simulation nodes at Vegreville and Mannville, respectively, show that there is only a marginal reduction in the peak mean monthly flows and a marginal increase in the base flows during the late summer and fall low flow months. Figures 5.9 and 5.10, for simulation nodes at Vegreville and Manville, respectively, show that there is slight reduction in 5-year to 25-year spring flood flows, with the larger decrease occurring at the Vegreville node. Figures 5.11 and 5.12 show that the effect on summer peak flows is less that observed for spring floods. It appears that the effectiveness of these small storages in reducing peak flows is limited by the possibility that spring flood events may fill up the storage facilities and the latter are not sufficiently drained prior to the summer to reduce the magnitude of summer floods. Increasing the capacity of the small storages significant even beyond that used in the simulation may not be effective because of the limits on the availability of the necessary topographic relief or existing small water bodies to accommodate the required storage volumes.

There may be operational constraints as well. The extreme variability in the magnitude of annual spring and summer peak flows suggests that the operation of the storage facilities may require human intervention often so that during years of moderate to small flood events the entire flow during these events are not retained in these facilities and reduce the flow in the Vermilion River.

5.7.2 Increased Storage at Morecambe Structure on Vermilion River

The VRORSC recommended that the Morecambe Structure be operated to reduce the severity and duration of upstream and downstream flooding, and to provide riparian flow downstream during the late summer and fall, but without dropping the water levels in Vermilion Lakes below 598.75 m. As discussed in Section 5.3, it appears that there is some potential for more effective operation of the Morecambe Structure that could address the VRORSC recommendations. Nevertheless, the effect of increased storage at the Morecambe Structure, which may change the range of operating water level, was investigated to assess if there may be some benefit in reducing floods or increasing riparian flows in downstream reaches. The effects on upstream water levels would have to be addressed as part of a more detailed assessment of the operation of the Morecambe Structure (outside of the scope of this study).

For the purposes of the preliminary investigation, the storage assessment was based on a separate planning tool from the HSPF hydrologic model. The HSPF model, while useful in predicting changes in basin hydrology, is less effective in assessing operating rules for the Morecambe Structure. The planning level tool uses STELLA / iThink as the platform. The tool specifically simulates the operation of storage reservoirs and gate operations to achieve target water levels or releases. However, the tool is currently limited in terms of the amount of information that was available on detailed reservoir operations. For example, it was assumed that the flows in Bens Lake and Watt Lake can be controlled, when presently they are not equipped for such control.

A preliminary assessment of potential storage benefits was conducted, in addition to the hydrologic modelling for natural, existing, and improved drainage conditions. The assessment assumes that spring or early summer events could be partially stored in favour of slow release in late summer to augment low flow conditions.

The storage assessment focused on two cases: existing conditions, and an additional storage option. The existing conditions included the current operation of the lift gates at the Morecambe Structure, and the spillway for the dam at Vermilion. The option for additional storage was intended as an approximate upper limit for storage to reduce the spring flood peak and augment river flows in late summer. The additional storage option consisted of the following:

- Additional 0.3 m operating range at the Morecambe structure, to effectively increase the overall summer-fall change in the target water level. The current range is 0.3 m, and additional storage might increase this range to 0.6 m depending on site conditions and landowner concerns.
- Additional 0.3 m operating range for Bens Lake and Watt Lake.
- New small reservoirs along tributaries, considering up to 40 small dams throughout the watershed. It was assumed that each reservoir would be impounded by an earth embankment dam with a spillway and low level outlet, and that the reservoirs would tend to be 50 m across, 300 m long, with an average depth of 2 m. Ditch plugs could also serve the same purpose, however, the number required would be much higher than assumed for the purposes of this assessment.

Figure 5.13 shows a schematic of the planning tool software that was developed for this assessment.

Two sets of operating rules were considered for the additional storage in the small reservoirs and at the Morecambe Structure:

(1) The additional storage option assumed that flood storage would be filled in April during the spring freshet, to effectively reduce the spring flood volume downstream. This additional storage would then be released in August and September in a controlled fashion. Figure 5.14(a) shows the spring storage operating rule schematically.

(2) The additional storage option assumed that flood storage would be filled in April during the spring freshet, and would be released in May and June to free up storage capacity for summer floods. This summer storage would then be released in August and September in a controlled fashion. Figure 5.14(b) shows the modified spring-summer operating rule schematically.

A comparison is presented on Figure 5.15 and Figure 5.16 of monthly water yield for existing conditions and potential additional storage options, just downstream of the Morecambe Structure and near the NSR, respectively. The results suggest that additional storage capacity within the Vermilion watershed has the potential to increase the late summer flows in the Vermilion River by more than 2 million cubic meters (Mm^3) downstream of Vermilion, most of this is due to flow augmentation from the upper portions of the watershed to reaches downstream of the Morecambe control structure. By comparison, average river flows in late summer (August, September) are about 3 Mm^3 per month or 1.1 m^3/s at the Morecambe structure, and average flows near the NSR are about 4 Mm^3 per month or 1.5 m^3/s. Therefore, late summer flow augmentation has the potential to nearly double the late summer flow, depending on spring or early summer events. The impact of additional storage will be less if some of the storage is not constructed or utilized.

The effect of the modified spring-summer storage operating rule on fall mean monthly flows appears to be similar to that from the spring storage operating rule. However, the effect of the modified spring-summer storage operating rule on flood flows in July does not appear to be significant. The VRORSC recommended that the Morecambe Structure be operated to reduce the severity and duration of upstream and downstream flooding, and to provide riparian flow downstream during the late summer and fall. The preliminary results from the planning tool suggest that there is some potential for more effective operation of the Morecambe Structure that could address the VRORSC recommendation on riparian flow. However, the recommendation on flood flows may be more difficult to achieve based on the current set up of the Morecambe Structure, at least based on the preliminary tool.

The preliminary planning tool was designed to explore general storage options. A more refined version of the planning tool with more detailed information on available storage on Bens Lake and Watt Lake can be used to find the best mix of storage volumes and locations while accounting for landowner concerns and other constraints.

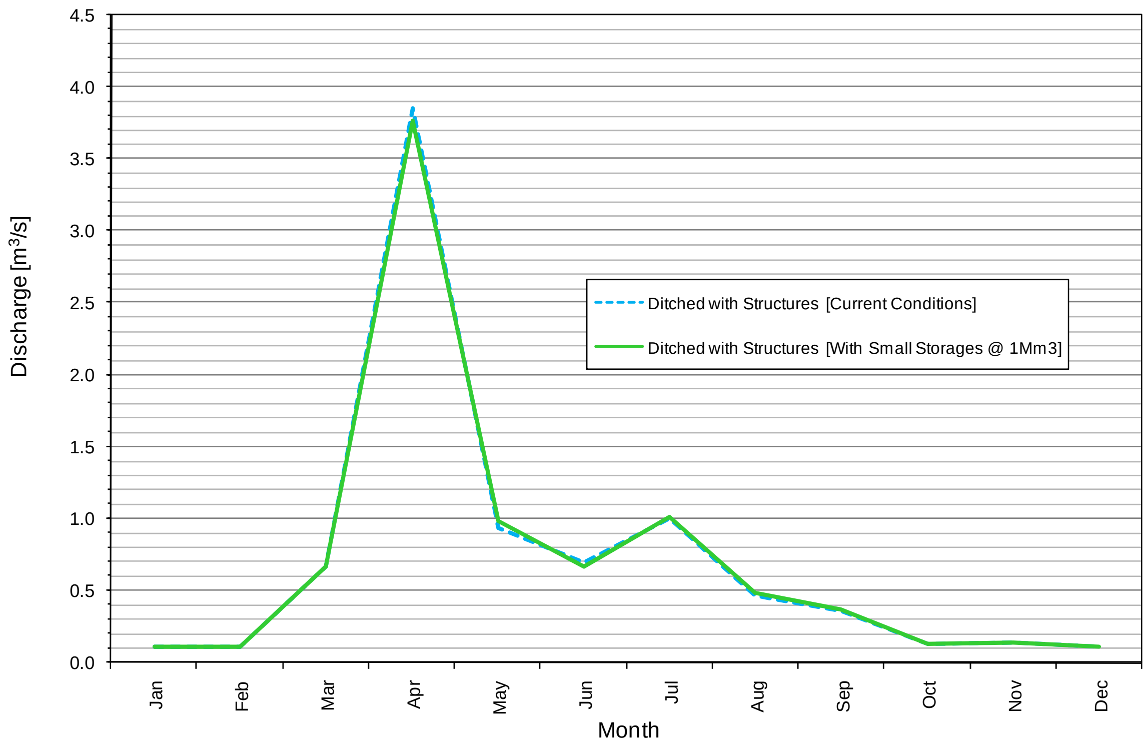


Figure 5.7 Effect of Small Storage Facilities in the Vermilion River Basin on Simulated Mean Monthly Flows at Vegreville - WSC 05EE009 1987-2003

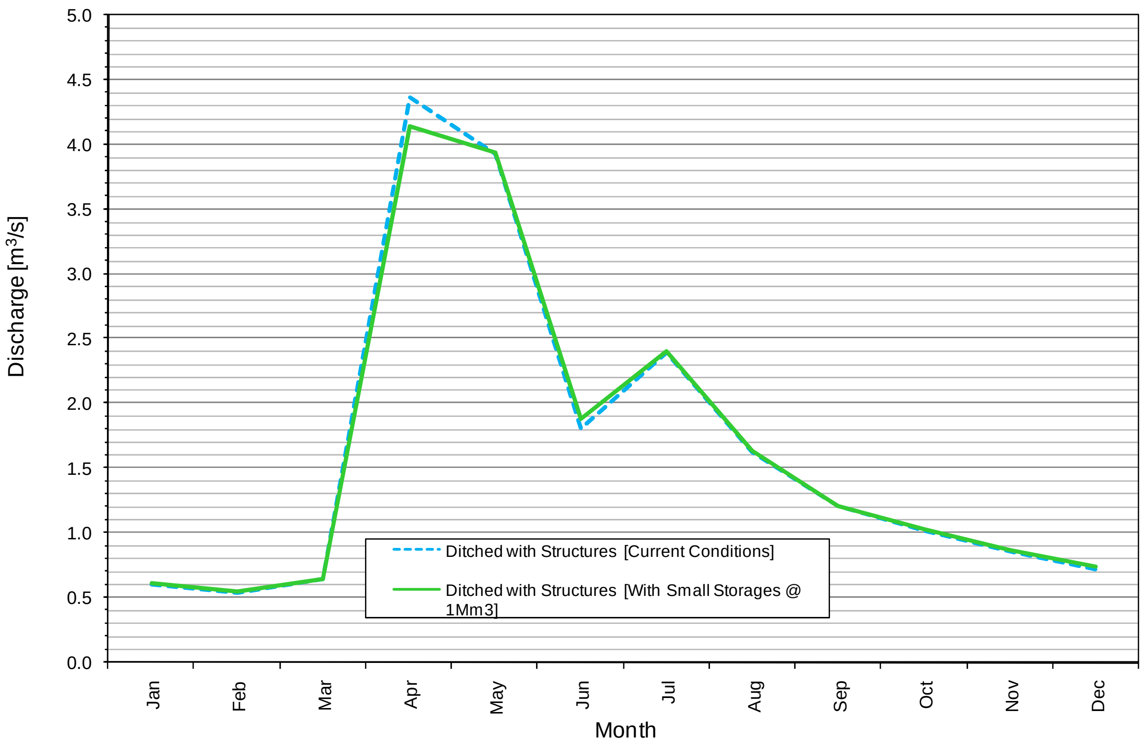


Figure 5.8 Effect of Small Storage Facilities in the Vermilion River Basin on Simulated Mean Monthly Flows at Manville - WSC 05EE001 1976-1983

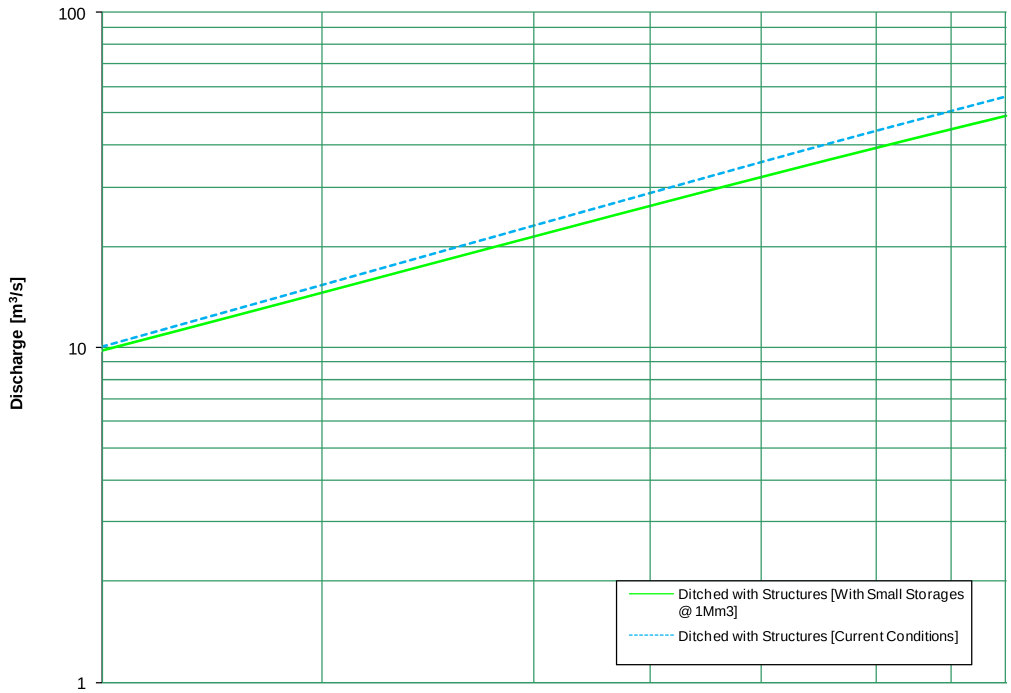


Figure 5.9(a) Log Scale for Discharge on Y-axis

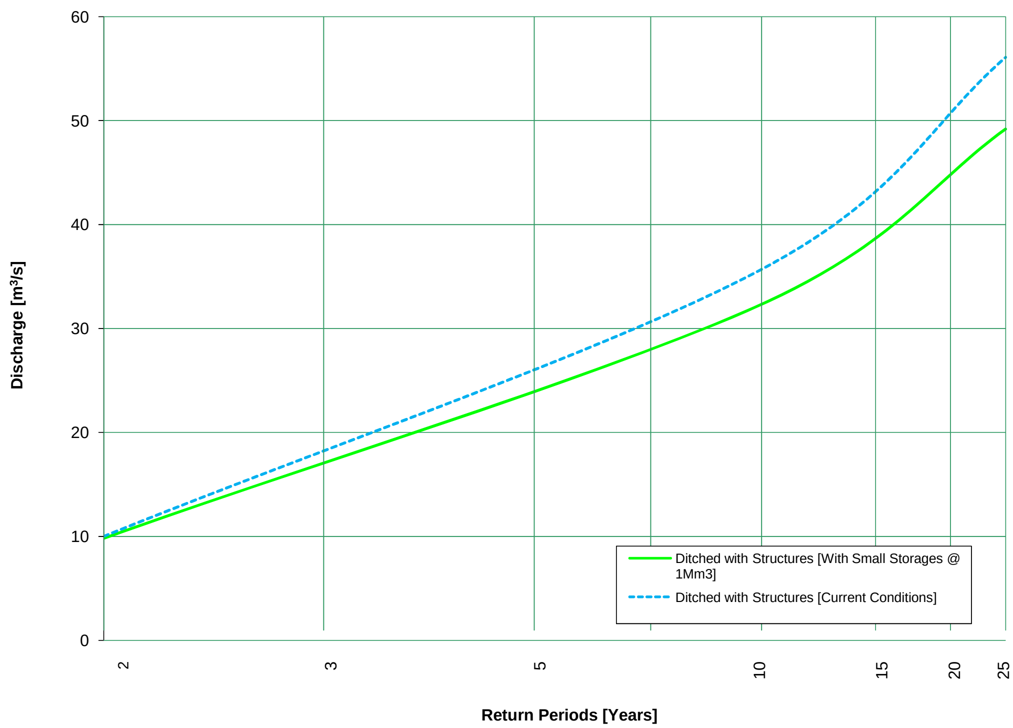


Figure 5.9(b) Linear Scale for Discharge on Y-axis

Figure 5.9 Effect of Small Storage Facilities in the Vermilion River Basin on Simulated Spring Peak Flows at Vegreville - WSC 05EE009 1987-2003

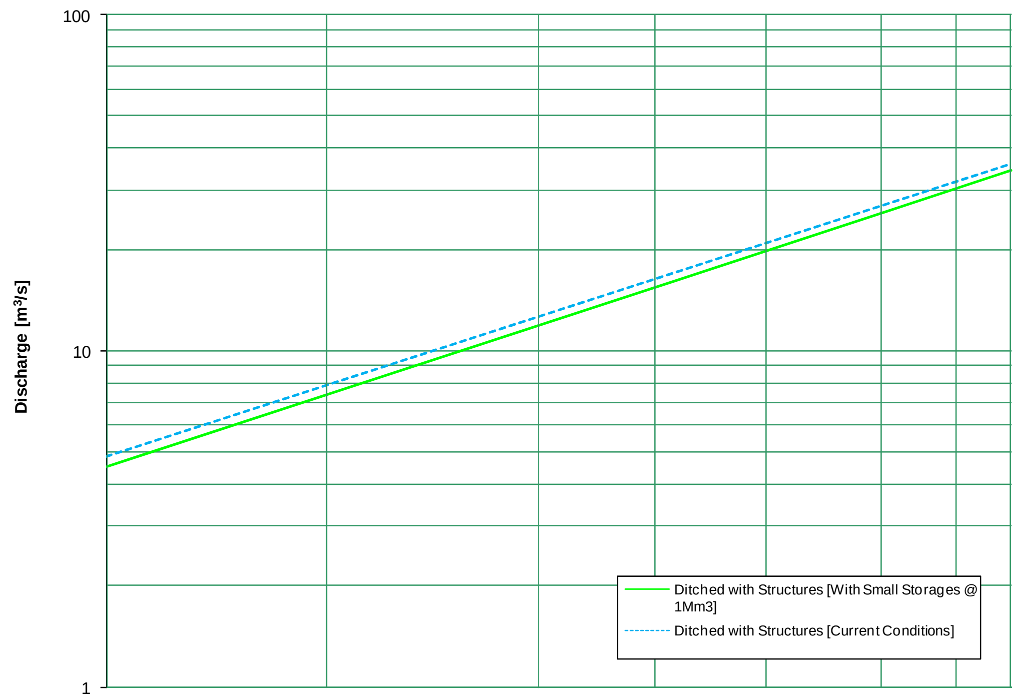


Figure 5.10(a) Log Scale for Discharge on Y-axis

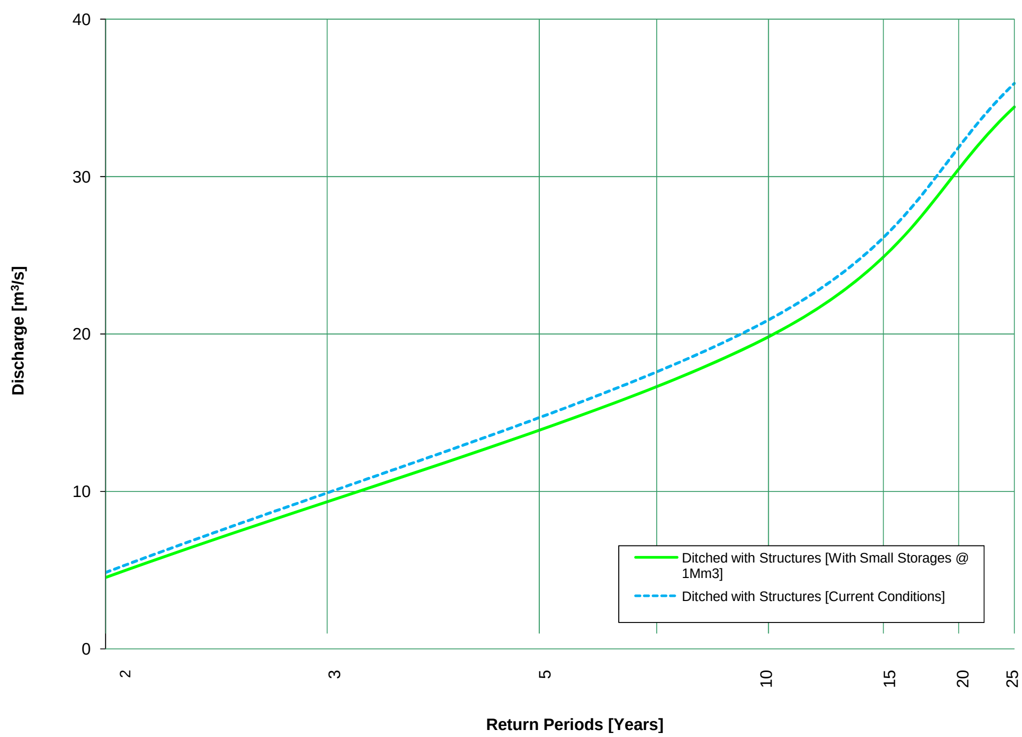


Figure 5.10(b) Linear Scale for Discharge on Y-axis

Figure 5.10 Effect of Small Storage Facilities in the Vermilion River Basin on Simulated Spring Peak Flows at Manville - WSC 05EE001 1976-1983

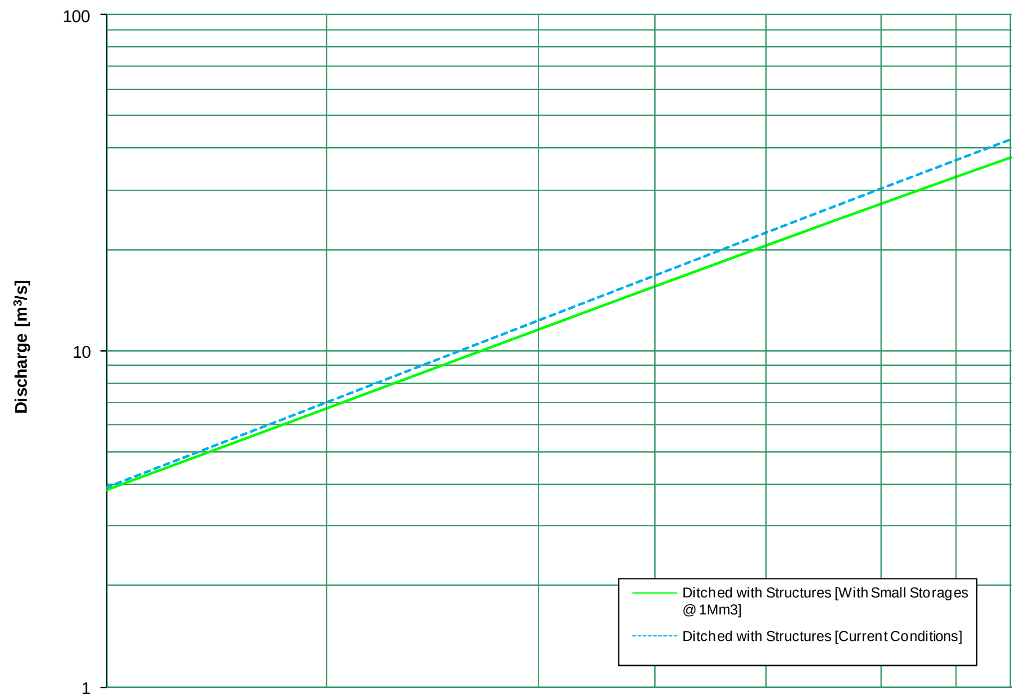


Figure 5.11(a) Log Scale for Discharge on Y-axis

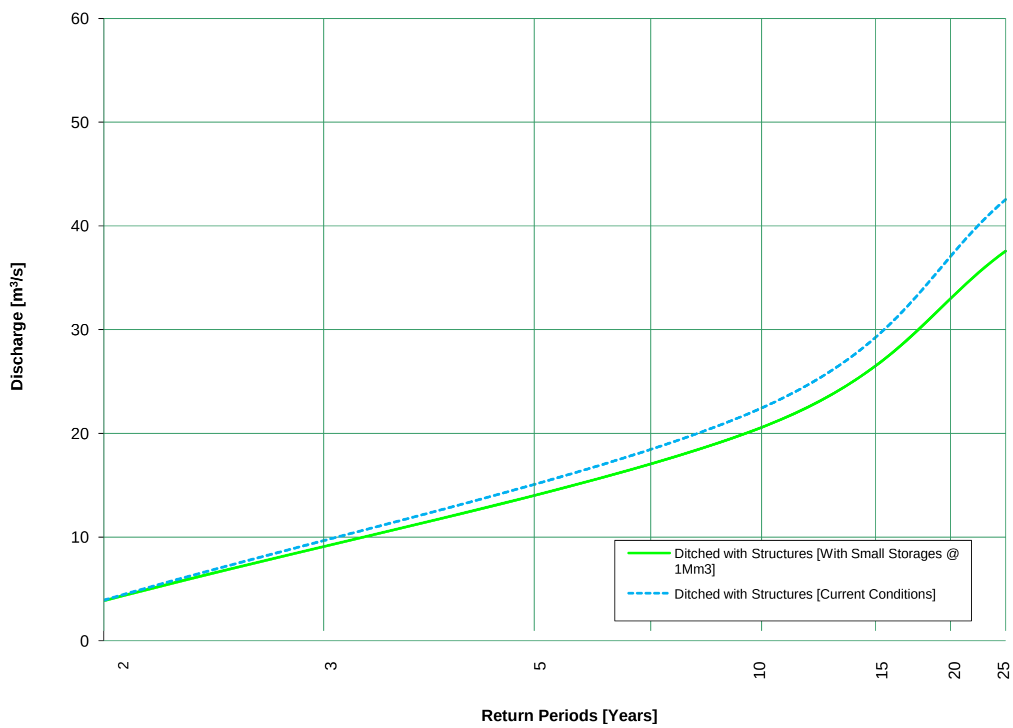


Figure 5.11(b) Linear Scale for Discharge on Y-axis

Figure 5.11 Effect of Small Storage Facilities in the Vermilion River Basin on Simulated Summer Peak Flows at Vegreville - WSC 05EE009 1987-2003

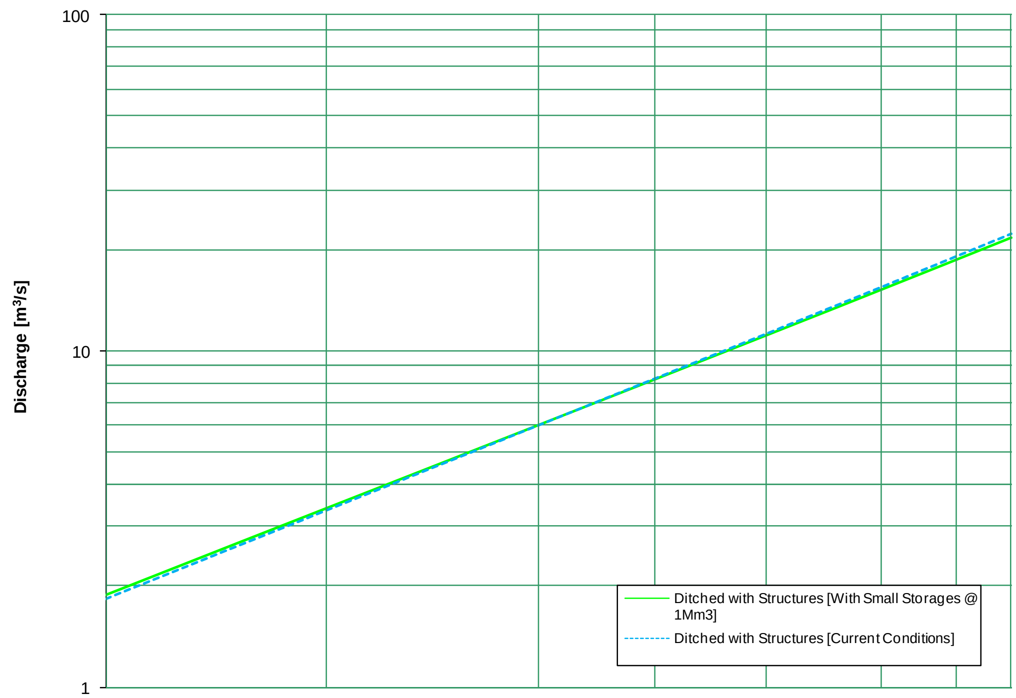


Figure 5.12(a) Log Scale for Discharge on Y-axis

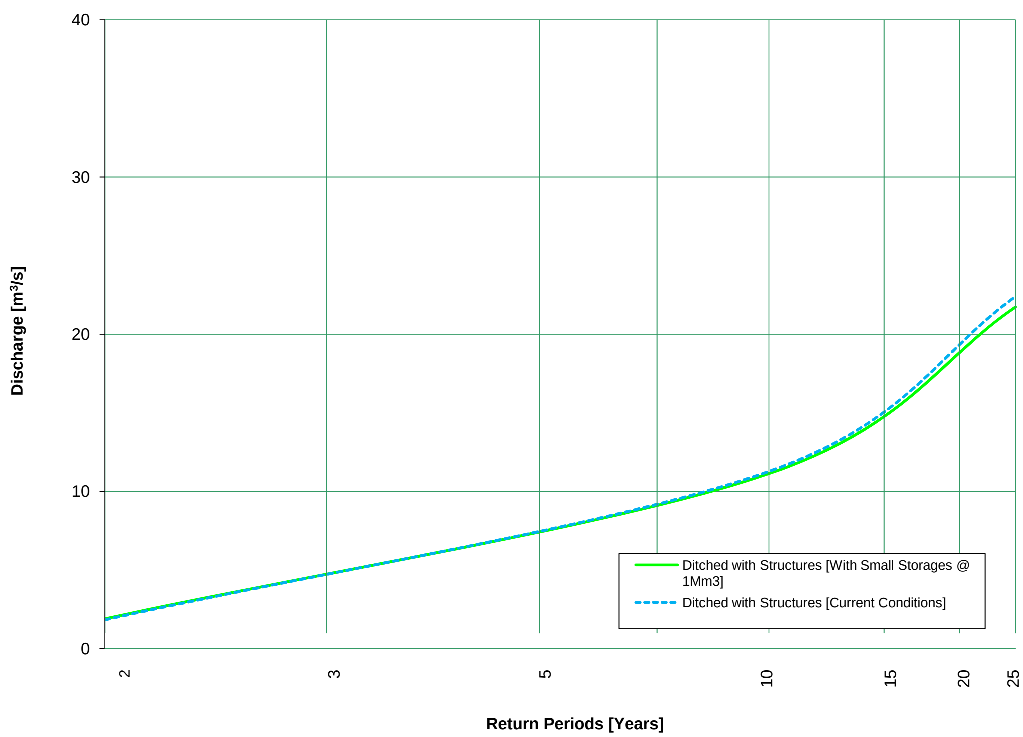


Figure 5.12(b) Linear Scale for Discharge on Y-axis

Figure 5.12 Effect of Small Storage Facilities in the Vermilion River Basin on Simulated Summer Peak Flows at Manville - WSC 05EE001 1976-1983

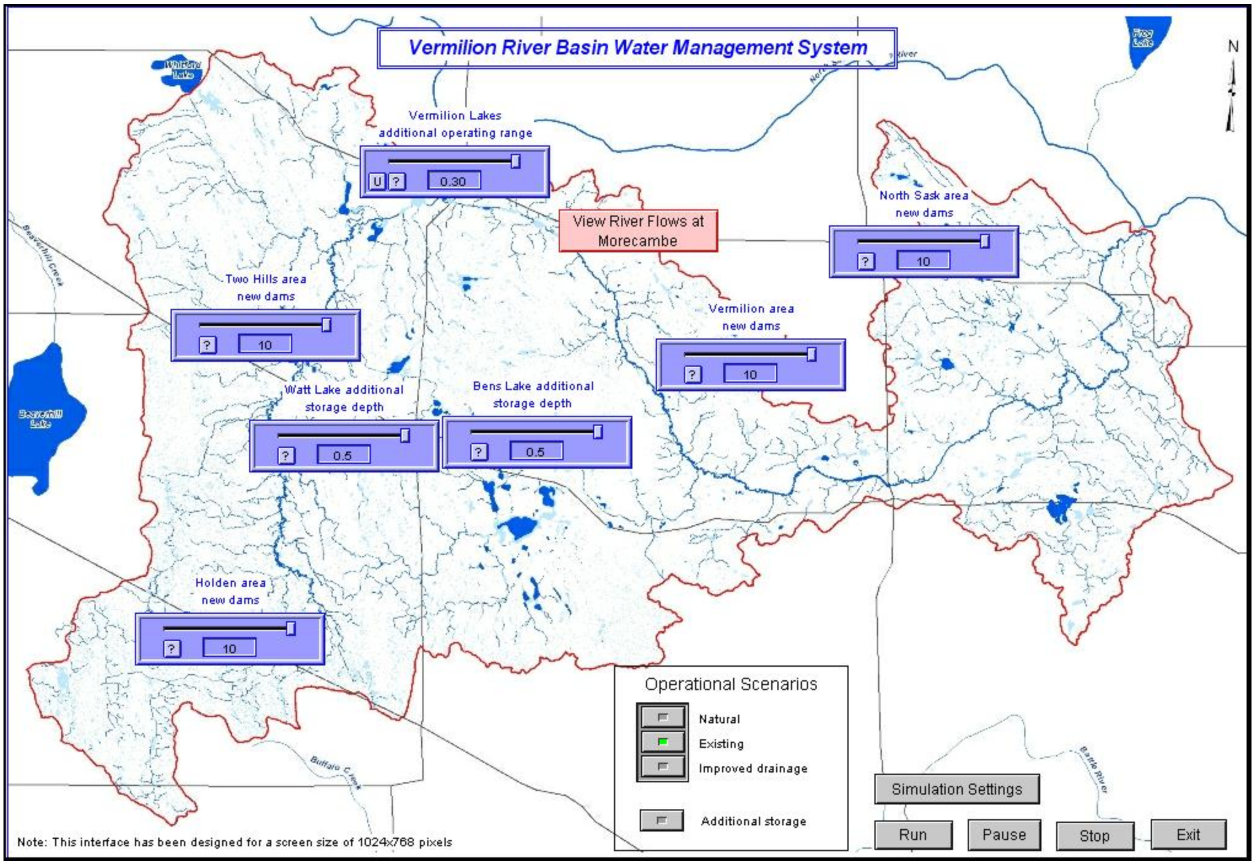


Figure 5.13 Schematic of Storage Planning Tool

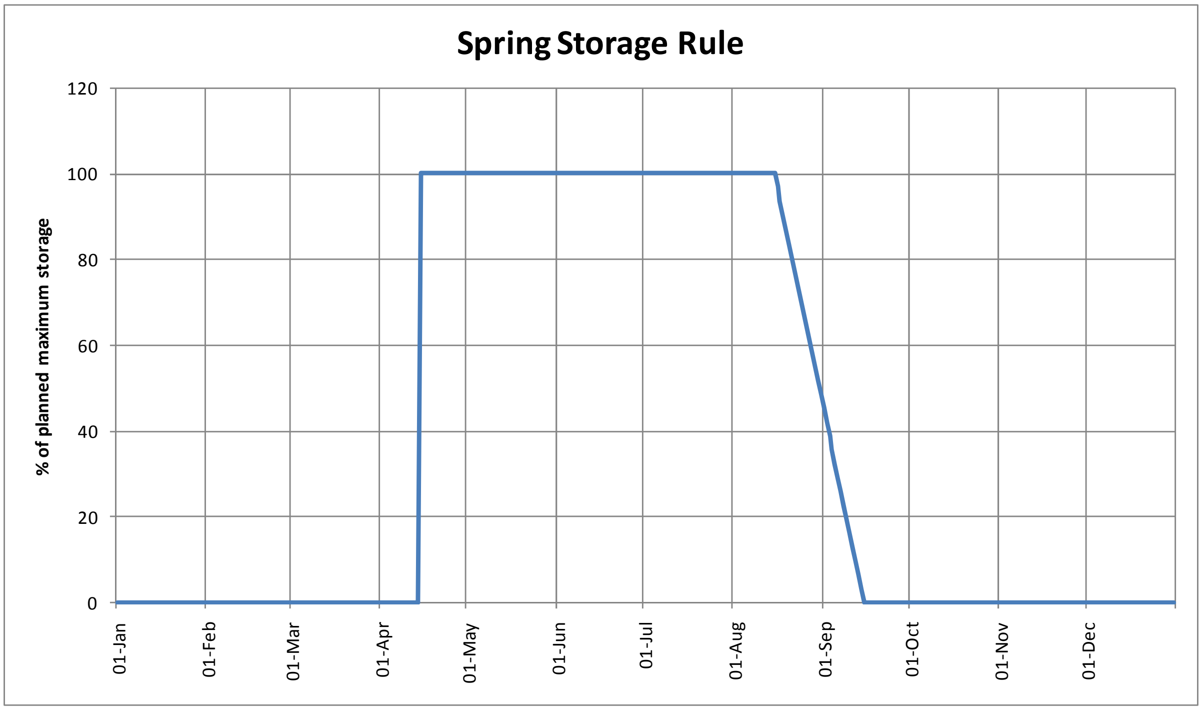


Figure 5.14(a) Spring Storage Operating Rule

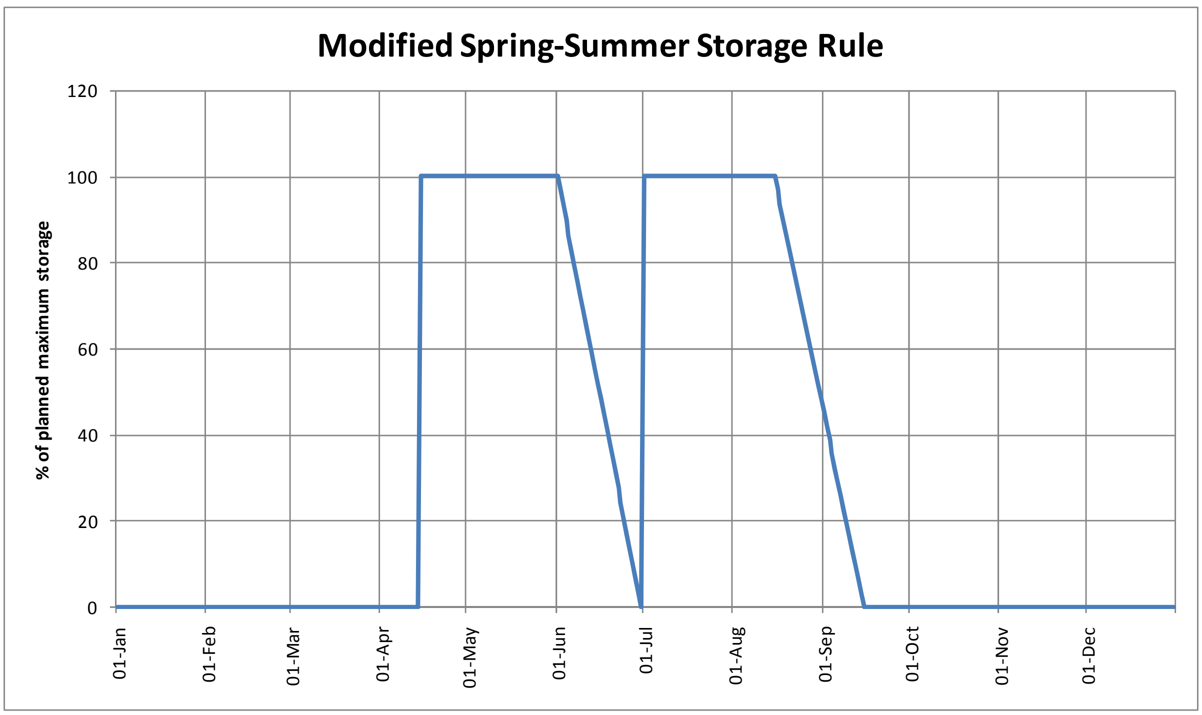


Figure 5.14(b) Modified Spring-Summer Storage Operating Rule

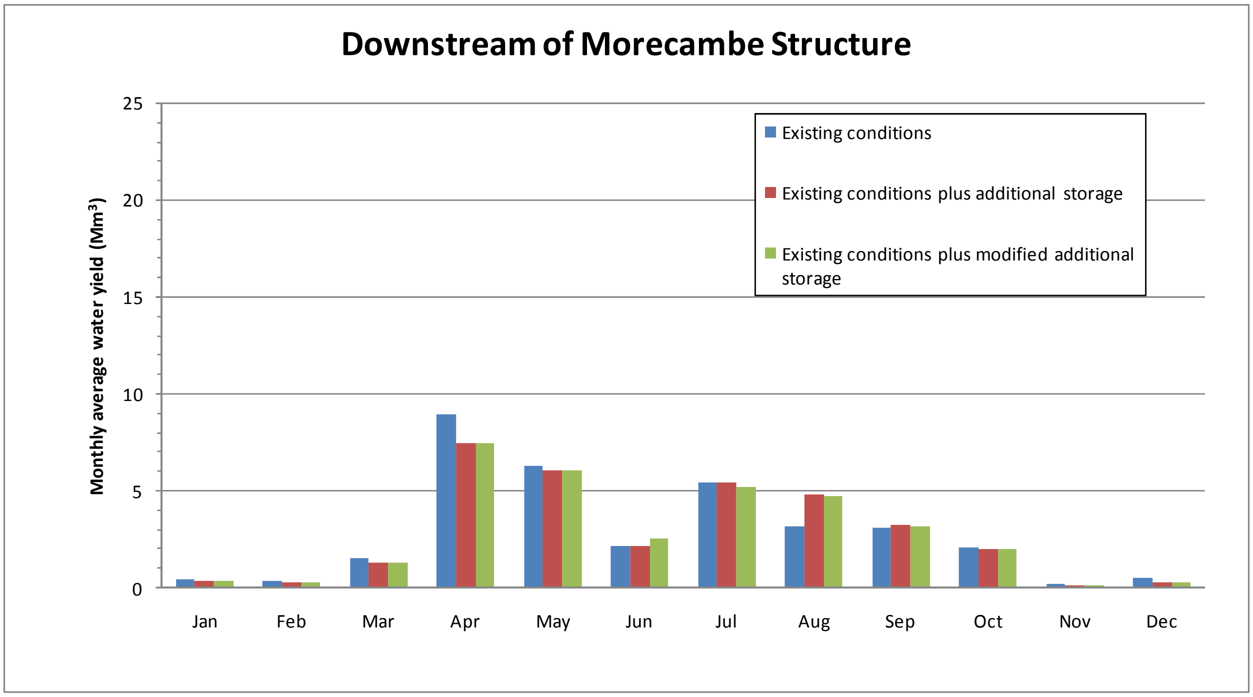


Figure 5.15 Effect of Increased Storage in Small Reservoirs and at Morecambe Structure on Mean Monthly Flows Just Downstream of Morecambe

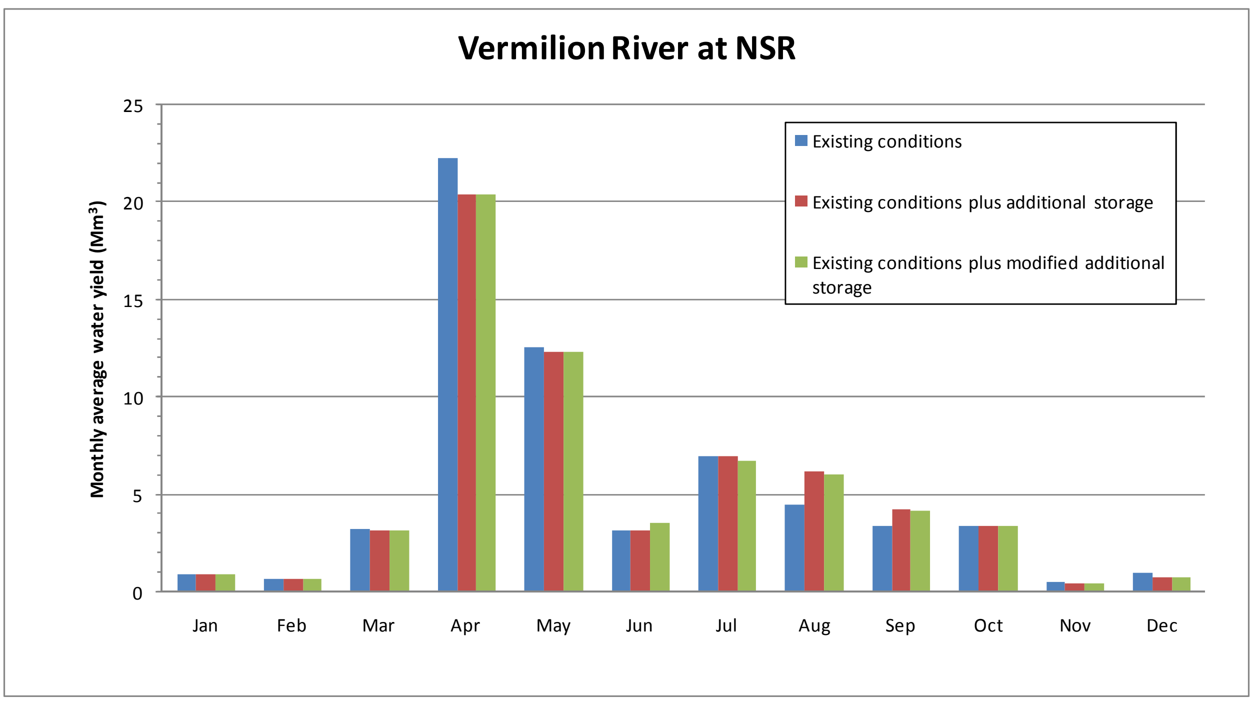


Figure 5.16 Effect of Increased Storage in Small Reservoirs and at Morecambe Structure on Mean Monthly Flows near the NSR

6.0 KEY FINDINGS FOR WATERSHED MANAGEMENT, FLOOD CONTROL AND WATER SUPPLY

This section provides conclusions and recommendations on water supply and flood control measures within the Vermilion River Basin (VRB) to address some of issues identified by the VRORSC. The following key findings are supported by the results of the simulations with the HSPF model set up for the VRB.

- If new drainage works are planned within the basin to drain some areas or to connect non-contributing areas to downstream areas, they should be evaluated for their effects on peak flows and other watershed attributes before their approval. Increased peak flows caused by increased ditching can lead to erosion of river banks, increased in-stream sedimentation, and possibly flooding and/or changes in water quality.

- The operation of the Morecambe Structure should be reviewed in light of the model simulation results presented in this report. It appears that the structure is presently less effective at controlling summer peak flows than spring peak flows. Notwithstanding the foregoing, the structure can control spring floods, which tend to be significantly larger than the summer peak flows. It is also apparent that the procedure for riparian flow releases from the Morecambe Structure can be improved to increase base flows in the Vermilion River downstream of the structure. These findings should be discussed with Alberta Environment Water Management Operations.

- The possibility of increasing the operating range of water level in the Vermilion Lakes should be investigated to address control of summer peak flows and increasing summer and fall riparian flows. However, because of the low gradient of the Vermilion Lakes and channels connecting them, decreased water levels in the lake at Morecambe may still not mitigate upstream high water level events. A more detailed hydraulic study in combination with a decision support tool would be required to investigate the full effects.

- The increased storage from a larger operating range of water level in the Vermilion Lakes, especially at the lower end of the range, can assist in increasing base flows in downstream reaches of the Vermilion River. However, any such change in the current operating should take into account effects on riparian systems upstream of Morecambe Structure and/or on possible reduced availability of flow for downstream reaches during the summer months before implementation. The low level riparian outlet on the Morecambe Structure should be cleaned for it to function as intended.

- Small storages in the upper sub-basins of the VRB can reduce peak flows in the Vegreville area, and, with a low level outlet for water release, can increase base flows in the Vermilion River. However, the feasibility and effectiveness of these small storages in reducing peak flows depend on two factors:

  - the availability of the necessary topographic relief or existing small water bodies to accommodate the required storage volumes (some potential sites exist in the headwaters of the Holden Drainage District and others in the upper middle portion of the VRB); and,

  - the possibility that spring flood events may fill up the storage facilities and the latter are not sufficiently drained prior to the summer to reduce the magnitude of summer floods.

  The extreme variability in the magnitude of annual spring and summer peak flows suggests that the operation of the storage facilities may require human intervention often so that during years of moderate to small flood events the entire flow during these events are not retained in these facilities and reduce the flow in the Vermilion River.

Notwithstanding the above concerns, the locations of such small storages and their feasible storage capacities should be investigated for additional benefits such as wetland preservation. Most of the land in the Vermilion River Basin is private property, so it is very important to seek partnerships with the private landowners for such an initiative.

- The small storages may be existing wetlands. In addition to reducing flood peaks and increasing base flows, government/non-profit organization partnerships with private landowners can assist in preserving or restoring wetlands in this watershed.
- Non-profit organizations (such as Ducks Unlimited Canada) could be called upon to provide technical expertise for wetlands management or restoration. The free knowledge transfer to private landowners would benefit everyone.
- Additional storage rules should be considered for the decision-support model, including spring back-flood/summer flow, to better represent the range of available management strategies.

Recommendations of Study

The following recommendations are made as possible next steps towards the development of a watershed management plan for the VRB.

- The HSPF model set up for the Vermilion River Basin can be used as a planning tool to assess the effects of areas proposed to be ditched and/or drained; flood mitigation measures such as off-main stem storage facilities or more effective operation of the Morecambe Structure. More detailed modeling within sub-basins may require refinement of the HSPF model to include finer topographic details and/or watershed processes, or the use of a distributed runoff model that can account for wetland and subsurface hydrology.
- A more refined version of the preliminary planning tool developed for this study with more detailed information on available storage on Bens Lake and Watt Lake can be used to find the best mix of storage volumes and locations while accounting for landowner concerns and other constraints.
- Operational procedures for flood mitigation could be improved with the implementation of real-time flow monitoring system (climate and hydrometric stations). There is significant spatial variability in precipitation in the basin. Addition of climate and hydrometric stations in the upper reaches of the basin would assist in effective operation of the Morecambe Structure.
- There is very little information available on the interaction between surface and groundwater regimes in the basin. It is recommended that an integrated study of these interactions, including the effects of wetland loss and restoration, be investigated in selected sub-basins of the VRB.
- A study on groundwater use and the sustainability of the groundwater regime as well as on future monthly water demand-supply conditions as a result of potential climate change scenarios is therefore recommended. The effects of the return flows to the Vermilion River Basin from water being piped in from outside the VRB should also be assessed.

7.0 CLOSURE

This report presents the results of the Vermilion River Water Supply and Demand Study undertaken for the NSWA. Please direct any questions or clarification regarding the contents of the report to Anil Beersing at (403) 260 2292.

Prepared by:

Reviewed by:

Oscar Kalinga, Ph.D.
Hydrologist

Anil Beersing, Ph.D., P.Eng.
Principal, Senior Water Resources Engineer

with contributions from:

Dan Brown, M.Sc., P.Geol.
Principal, Senior Hydrogeologist

Verrakcuddy Rajasekaram, Ph.D., P.Eng.
Water Resources Engineer

Michael Bender, Ph.D., P.Eng.
Associate, Senior Water Resources Engineer

Getu Biftu, Ph.D., P.Eng.
Associate, Senior Water Resources Engineer

AB/ab

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APPENDIX A

Results of Water Yield Analysis

Table 1 Vermilion River Basin and Battle River Basin - Runoff Statistics at Hydrometric Stations

Hydrologic Region	Hydrometric Station	Hydrometric Station	Latitude (degminsec)	Longitude (degminsec)	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Percent of Hydrologic Region Contributing to Station (HR-Percent)	Actual Record Length	Regulation and Period	Is it on the main stem?	Start Year for Analysis	End Year for Analysis	Years with No Winter Flow Data	Statistics	Monthly Runoff Statistics												Mean Annual Runoff based on Available Data (mm)	Estimated winter runoff/annual runoff %	Mean Annual Runoff at Station including Estimated Winter Runoff if Applicable (mm)
															Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
		BATTLE RIVER																											
1C	05FB002	IRON CREEK NEAR HARDISTY	524228	1111836	3,500	815	1C-80%, 2C-20%	1964-07	Natural	No	1970	2007	86-07	Mean (mm)	0.15	0.20	0.78	8.09	3.32	1.35	1.48	0.58	0.19	0.22	0.20	0.15	16.0	4%	16.7
															1%	1%	5%	48%	20%	8%	9%	3%	1%	1%	1%	1%			
														STD (mm)			1.42	12.4	6.91	1.66	3.15	1.74	0.37	0.36			23.0		
														CV			1.81	1.53	2.08	1.23	2.12	3.01	1.91	1.63			1.32		
														CS			3.52	4.25	5.23	2.29	4.48	5.69	3.14	3.05			4.23		
	05FC007	YOUNG CREEK NEAR CASTOR	521532	1114344	77	73	1C-90%, 2C-10%	1986-07	Natural	No	1986	2007	86-07	Mean (mm)	0.03	0.30	7.88	4.56	1.97	0.73	3.75	0.51	0.08	0.03	0.03	0.03	19.5	2%	19.9
														STD (mm)			10.4	6.62	4.48	0.99	9.66	1.55	0.24	0.10			21.9		
														CV			1.31	1.45	2.28	1.35	2.58	3.02	2.89	2.88			1.08		
														CS			1.12	2.09	2.59	1.23	2.91	4.08	3.96	3.02			1.12		
	05FE002	BUFFALO CREEK AT HIGHWAY NO. 41	530026	1105157	714	147	1C-100%	1972-06	Natural	No	1972	2006	86-06	Mean (mm)	0.90	1.00	3.45	15.5	5.15	3.83	2.62	1.04	0.87	1.29	1.00	0.90	33.7	10%	37.5
															2%	3%	9%	41%	14%	10%	7%	3%	2%	3%	3%	2%			
														STD (mm)			3.61	18.3	3.30	2.87	2.73	1.43	0.79	0.67			25.8		
														CV			1.05	1.18	0.64	0.75	1.04	1.37	0.91	0.52			0.71		
														CS			1.30	4.45	2.45	1.41	1.53	3.06	0.83	0.84			3.68		
	05FB002	IRON CREEK NEAR HARDISTY	524228	1111836	3,500	815	1C-80%, 2C-20%	1964-07	Natural	No	1965	1969	1965-69	Mean (mm)	0.15	0.20	1.66	9.64	3.48	1.39	1.76	0.61	0.40	0.56	0.20	0.15	19.5	3%	20.2
															1%	1%	8%	48%	17%	7%	9%	3%	2%	3%	1%	1%			
														STD (mm)															
														CV															
														CS															
		VERMILION RIVER																											
1C	05EC002	WASKATENAU CREEK NEAR WASKATENAU	540723	1124658	312	205	1C-100%	1966-06	Natural	No	1978	2006	1978-2006	Mean (mm)	0.30	0.30	0.70	14.1	2.61	2.37	1.04	0.51	0.77	0.69	0.50	0.40	22.8	6%	24.3
															1%	1%	3%	58%	11%	10%	4%	2%	3%	3%	2%	2%			
														STD (mm)			1.78	23.6	6.57	7.44	1.89	1.07	2.28	2.15			45.8		
														CV			2.55	1.68	2.51	3.13	1.81	2.08	2.98	3.10			1.78		
														CS			3.42	2.32	3.93	4.17	2.52	2.43	4.19	3.60			2.68		
	05EE007	VERMILION RIVER NEAR MARWAYNE	532928	1102351	7260	2000	1C-100%	1979-06	Natural	No	1979	2006	1979-2006	Mean (mm)	0.20	0.30	0.73	6.81	3.38	0.84	1.29	0.82	0.19	0.20	0.20	0.20	14.3	6%	15.2
															1%	2%	5%	45%	22%	6%	9%	5%	1%	1%	1%	1%			
														STD (mm)			1.34	6.60	5.55	1.45	3.58	1.84	0.26	0.30			14.7		
														CV			1.83	0.97	1.64	1.73	2.77	2.24	1.34	1.55			0.96		
														CS			2.55	0.64	4.36	4.18	4.64	3.24	1.54	2.88			1.53		
	05EE006	VERMILION RIVER TRIBUTARY NEAR BRUCE	531742	1120254	46.4	19.9	1C-100%	1978-07	Natural	No	1978	2007	1978-2007	Mean (mm)	0.20	0.30	6.69	27.2	2.35	2.58	4.37	0.77	1.14	0.25	0.20	0.20	45.3	2%	46.2
															0%	1%	14%	59%	5%	6%	9%	2%	2%	1%	0%	0%			
														STD (mm)			12.4	38.0	5.16	7.74	16.5	3.91	5.67	0.95			57.5		
														CV			1.85	1.40	2.20	3.00	3.78	5.10	4.97	3.80			1.16		
														CS			2.21	2.41	3.60	3.09	4.96	5.47	5.44	3.67			1.75		
	05EE009	VERMILION RIVER AT VEGREVILLE	532928	1120218	1620	367	1C-100%	1987-06	Natural	No	1987	2006	1987-2006	Mean (mm)	0.04	0.30	3.55	16.6	1.24	0.42	0.61	0.22	0.17	0.05	0.04	0.04	22.9	2%	23.3
															0%	1%	15%	71%	5%	2%	3%	1%	1%	0%	0%	0%			
														STD (mm)			7.36	24.5	3.37	1.36	1.41	0.45	0.45	0.08			35.2		
														CV			2.07	1.48	2.72	3.26	2.30	2.02	2.61	1.53			1.43		
														CS			2.45	2.70	4.20	4.39	2.64	3.32	3.87	2.35			2.48		
	05EE005	STRETTON CREEK NEAR MARWAYNE	532630	1101930	74	56.3	1C-100%	1978-06	Natural	No	1978	2006	1978-2006	Mean (mm)	0.05	0.10	4.47	9.54	0.68	0.31	1.13	0.79	0.18	0.06	0.05	0.05	17.2	1%	17.4
															0%	1%	26%	55%	4%	2%	6%	5%	1%	0%	0%	0%			
														STD (mm)			6.95	9.71	1.60	0.48	3.36	2.15	0.66	0.28			15.5		
														CV			1.55	1.02	2.35	1.54	2.96	2.72	3.61	4.71			0.86		
														CS			1.52	0.96	4.41	1.92	4.53	3.09	3.60	5.35			0.45		
	05ED002	ATIMOSWE CREEK NEAR ELK POINT	535310	1105510	368	312	1C-100%	1975-06	Natural	No	1975	2006	1975-2006	Mean (mm)	0.05	0.10	0.56	7.91	1.25	0.51	0.43	0.26	0.15	0.20	0.10	0.05	11.3	3%	11.6
															0%	1%	5%	68%	11%	4%	4%	2%	1%	2%	1%	0%			
														STD (mm)			1.44	8.48	1.76	1.08	0.92	0.45	0.21	0.25			12.2		
														CV			2.60	1.07	1.41	2.11	2.12	1.75	1.44	1.24			1.01		
														CS			4.20	1.09	2.20	3.44	3.77	2.47	1.91	1.78			1.31		

Table 1 Vermilion River Basin and Battle River Basin - Runoff Statistics at Hydrometric Stations

Hydrologic Region	Hydrometric Station	Hydrometric Station	Latitude (degminsec)	Longitude (degminsec)	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Percent of Hydrologic Region Contributing to Station (HR-Percent)	Actual Record Length	Regulation and Period	Is it on the main stem?	Start Year for Analysis	End Year for Analysis	Years with No Winter Flow Data	Statistics	Monthly Runoff Statistics												Mean Annual Runoff based on Available Data (mm)	Estimated winter runoff/annual runoff %	Mean Annual Runoff at Station including Estimated Winter Runoff if Applicable (mm)
															Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
	05ED003	MOOSEHILLS CREEK NEAR ELK POINT	535603	1104636	41	37.7	1C-100%	1978-07	Natural	No	1978	2007	1978-07	Mean (mm)	0.10	0.30	0.79	10.8	5.41	3.14	2.20	0.43	0.23	0.24	0.10	0.10	23.2	3%	23.8
															0%	1%	3%	45%	23%	13%	9%	2%	1%	1%	0%	0%			
														STD (mm)			1.47	10.1	6.11	5.20	3.22	0.63	0.41	0.44			21.3		
														CV			1.86	0.93	1.13	1.66	1.46	1.47	1.74	1.87			0.87		
														CS			2.34	0.91	1.49	3.34	3.01	2.04	2.91	2.77			0.95		
	05EE930	VERMILION RIVER NEAR BEAUVALLON	533532	1112408	3880	1070	1C-100%	1996-06	Natural	YES	1997	2006	1997-06	Mean (mm)	0.01	0.01	0.02	7.0	4.58	0.58	0.44	0.10	0.16	0.12	0.10	0.05	13.0	1%	13.2
															0%	0%	0%	53%	35%	4%	3%	1%	1%	1%	1%	0%			
														STD (mm)			0.02	12.0	10.7	1.31	1.17	0.17	0.22	0.20			24.9		
														CV			1.26	1.71	2.34	2.27	2.68	1.74	1.37	1.56			1.88		
														CS			1.27	1.75	3.00	2.94	3.15	2.57	1.03	2.12			2.39		
	05EE001	VERMILION RIVER NEAR MANNVILLE	532230	1111030	5740	2320	1C-100%	1958-83	Natural		1965/1976	1970/1983	1976-83	Mean (mm)	0.04	0.10	0.88	6.7	5.54	1.54	3.13	1.03	0.41	0.39	0.13	0.10		2%	20.0
															0%	0%	4%	34%	28%	8%	16%	5%	2%	2%	1%	1%			
														STD (mm)	0.03	0.14	1.78	5.0	6.07	1.89	6.33	1.83	0.78	0.68	0.16	0.09	15.3		
														CV	0.92	1.49	2.02	0.74	1.10	1.23	2.02	1.77	1.92	1.73	1.19	0.91	0.76		
														CS	1.25	2.04	2.50	0.68	1.77	2.93	2.90	2.37	3.16	2.48	1.61	0.70	1.28		
	05EE003	VERMILION RIVER NEAR VEGREVILLE	532754	1120352	1590	613	1C-100%	1967-86	Natural		1968	1986	1968-1986	Mean (mm)	0.05	0.20	2.36	18.9	6.53	1.91	5.27	1.38	0.62	0.19	0.10	0.05	37.1	1%	37.5
															0%	1%	6%	50%	17%	5%	14%	4%	2%	1%	0%	0%			
														STD (mm)															
														CV															
														CS															
	05EE913	VERMILION RIVER DRAINAGE NEAR HOLDEN	530749	1122432	56.4	24	1C-100%	1981-93	Natural		1981	1993	1981-1993	Mean (mm)	0.00	0.30	5.21	9.1	1.16	2.16	8.12	0.35	0.21	0.00	0.00	0.00	26.3	1%	26.6
															0%	1%	20%	34%	4%	8%	30%	1%	1%	0%	0%	0%			
														STD (mm)															
														CV															
														CS															
	05EE915	VERMILION RIVER DRAINAGE NEAR BRUCE	531037	1120406	401	401	1C-100%	1981-83	Natural		1981	1983	1981-83	Mean (mm)	0.00	0.00	0.01	3.9	0.81	2.61	9.52	0.27	0.02	0.00	0.00	0.00	17.1	0%	17.1
															0%	0%	0%	23%	5%	15%	56%	2%	0%	0%	0%	0%			
														STD (mm)															
														CV															
														CS															
	05EC002	WASKATENAU CREEK NEAR WASKATENAU	540723	1124658	312	205	1C-100%	1966-06	Natural	No	1967	1977	1967-77	Mean (mm)	0.40	0.40	0.95	35.2	8.24	1.27	5.51	1.73	1.52	0.77	0.60	0.40	55.2	3%	57.0
															1%	1%	2%	62%	14%	2%	10%	3%	3%	1%	1%	1%			
														STD (mm)													45.8		
														CV													1.78		
														CS													2.68		

NOTES:
[1] The local mean annual runoff (mm) for each hydrologic region (HR) was computed by averaging the mean annual runoff from the local hydrologic stations (i.e., stations recording flows that orginate from within the HR) whenever available, otherwise it was copied from other watersheds in the same hydrologic region or estimated using professional judgement;
[2] If two or more local satations with year round record of streamflow were available, the local mean annual runoff (mm) for each HR was computed from stations with year round record to minimize errors introduced by the etimation of winter runoff, which is the case for HR-10, HR-8, and HR-9A. Otherwise, local runoff values were used to compute the mean value;
[3] The cumulative mean annual runoff (mm) on the main stem of the river was obtained by computing the area-weighted-average of consecutive hydrologic regions (HRs) using EFFECTIVE drainage area of each HR;
[4] STD = Standard Deviation; CV = Coefficient of Variation; CS = Coefficient of Skewness

Table 2 Annual and Monthly Yields from Sub-Basins in the Vermilion River Basin - Average Case - 50th Percentile Case

Sub-Basin	Representative Hydrometric Stattion Data	Cumulative Gross Area Reported at Hydrometric Station (km²)	Gross Area at Sub-Basin Outlet (km²)	Cumulative Effective Area Reported at Hydrometric Station (km²) -	Effective Area at Sub-Basin Outlet (km²)	Monthly Yield (mm) Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Local Annual Yield (mm)	Cumulative Annual Yield (mm)	Cumulative Annual Volume (Mm³)
Vermilion R @ Bruce-Holden Headwaters-WSC	05EE006		631		136	0.2	0.3	6.7	27.2	2.3	2.6	4.4	0.8	1.1	0.3	0.2	0.2	46.2	46.2	
Waskwei	05EC002		968		237	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4	24.3	32.3	12.1
Vermilion R @ Vegreville-WSC	05EE009	1,620	1,600	367	373	0.0	0.3	3.6	16.6	1.2	0.4	0.6	0.2	0.2	0.1	0.0	0.0		23.3	8.5
Two Hills	05EC002		932		305	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4	24.3		
Watt-Bens Lakes	05EC002		420		19	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4	24.3		
Cotton Creek	05EC002		306		89	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4	24.3		
Two Hills-Morecambe	05EC002		534		304	0.3	0.3	0.7	14.1	2.6	2.4	1.0	0.5	0.8	0.7	0.5	0.4	24.3	27.0	29.5
Vermilion R @ Morecambe-Beauvallon-WSC	05EE930	3,880	3,792	1,070	1,090	0.0	0.0	0.0	7.0	4.6	0.6	0.4	0.1	0.2	0.1	0.1	0.1		13.2	14.1
Birch Creek	05FB002		1,265		113	0.2	0.2	0.8	8.1	3.3	1.3	1.5	0.6	0.2	0.2	0.2	0.2	16.7		
Morecambe-Mannville	05EE005		657		248	0.1	0.1	4.5	9.5	0.7	0.3	1.1	0.8	0.2	0.1	0.1	0.1	17.4	24.6	35.7
Vermilion R @ Mannville-WSC	05EE001-N-Con	5,740	5,714	1,800	1,451	0.0	0.1	0.9	6.7	5.5	1.5	3.1	1.0	0.4	0.4	0.1	0.1		20.0	36.0
Mannville-Vermilion	05EE005		382		211	0.1	0.1	4.5	9.5	0.7	0.3	1.1	0.8	0.2	0.1	0.1	0.1	17.4		
Vermilion R @ Vermilion		6,100	6,096	1,850	1,661														29.0	
Vermilion-Marwayne	05EE005		1,152		363	0.1	0.1	4.5	9.5	0.7	0.3	1.1	0.8	0.2	0.1	0.1	0.1	17.4	22.6	45.7
Vermilion R @ Marwayne-WSC	05EE007	7,260	7,247	2,000	2,025	0.2	0.3	0.7	6.8	3.4	0.8	1.3	0.8	0.2	0.2	0.2	0.2		15.2	30.3
Marwayne-NSR	05EE005		615		365	0.1	0.1	4.5	9.5	0.7	0.3	1.1	0.8	0.2	0.1	0.1	0.1	17.4		
Vermilion R @ NSR		7,860	7,863	2,360	2,390														21.8	52.0

Table 3 Annual and Monthly Yields from Sub-Basins in the Vermilion River Basin - 10th Percentile Case

Sub-Basin	Representative Hydrometric Stattion Data	Cumulative Gross Area Reported at Hydrometric Station (km²)	Gross Area at Sub-Basin Outlet (km²)	Cumulative Effective Area Reported at Hydrometric Station (km²) -	Effective Area at Sub-Basin Outlet (km²)	Monthly Yield (mm)												Local Annual Yield (mm)	Cumulative Annual Yield (mm)	Cumulative Annual Volume (Mm³)
						Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Vermilion R @ Bruce-Holden Headwaters-WSC	05EE006		631		136	0.0	0.1	1.3	5.5	0.5	0.5	0.9	0.2	0.2	0.1	0.0	0.0	9.3	9.3	
Waskwei	05EC002		968		237	0.0	0.0	0.1	1.5	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.0	2.6	5.0	1.9
Vermilion R @ Vegreville-WSC	05EE009	1,620	1,600	367	373	0.0	0.0	0.5	2.5	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0		3.5	1.3
Two Hills	05EC002		932		305	0.0	0.0	0.1	1.5	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.0	2.6		
Watt-Bens Lakes	05EC002		420		19	0.0	0.0	0.1	1.5	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.0	2.6		
Cotton Creek	05EC002		306		89	0.0	0.0	0.1	1.5	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.0	2.6		
Two Hills-Morecambe	05EC002		534		304	0.0	0.0	0.1	1.5	0.3	0.3	0.1	0.1	0.1	0.1	0.1	0.0	2.6	3.4	3.7
Vermilion R @ Morecambe-Beauvallon-WSC	05EE930	3,880	3,792	1,070	1,090	0.0	0.0	0.0	0.7	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0		1.3	1.4
Birch Creek	05FB002		1,265		113	0.0	0.0	0.1	1.3	0.6	0.2	0.2	0.1	0.0	0.0	0.0	0.0	2.8		
Morecambe-Mannville	05EE005		657		248	0.0	0.0	1.3	2.8	0.2	0.1	0.3	0.2	0.1	0.0	0.0	0.0	5.1	3.6	5.3
Vermilion R @ Mannville-WSC	05EE001-N-Con	5,740	5,714	1,800	1,451	0.0	0.0	0.3	2.3	1.9	0.5	1.1	0.3	0.1	0.1	0.0	0.0		6.7	12.1
Mannville-Vermilion	05EE005		382		211	0.0	0.0	1.3	2.8	0.2	0.1	0.3	0.2	0.1	0.0	0.0	0.0	5.1		
Vermilion R @ Vermilion		6,100	6,096	1,850	1,661														4.7	
Vermilion-Marwayne	05EE005		1,152		363	0.0	0.0	1.3	2.8	0.2	0.1	0.3	0.2	0.1	0.0	0.0	0.0	5.1	4.0	8.2
Vermilion R @ Marwayne-WSC	05EE007	7,260	7,247	2,000	2,025	0.1	0.1	0.2	1.7	0.9	0.2	0.3	0.2	0.0	0.1	0.1	0.1		3.9	7.8
Marwayne-NSR	05EE005		615		365	0.0	0.0	1.3	2.8	0.2	0.1	0.3	0.2	0.1	0.0	0.0	0.0	5.1		
Vermilion R @ NSR		7,860	7,863	2,360	2,390														4.2	10.0

Table 4 Annual and Monthly Yields from Sub-Basins in the Vermilion River Basin - 25th Percentile Case

Sub-Basin	Representative Hydrometric Stattion Data	Cumulative Gross Area Reported at Hydrometric Station (km²)	Gross Area at Sub-Basin Outlet (km²)	Cumulative Effective Area Reported at Hydrometric Station (km²) -	Effective Area at Sub-Basin Outlet (km²)	Monthly Yield (mm)												Local Annual Yield (mm)	Cumulative Annual Yield (mm)	Cumulative Annual Volume (Mm³)
						Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Vermilion R @ Bruce-Holden Headwaters-WSC	05EE006		631		136	0.1	0.1	2.4	9.5	0.8	0.9	1.5	0.3	0.4	0.1	0.1	0.1	16.2	16.2	
Waskwei	05EC002		968		237	0.1	0.1	0.2	3.1	0.6	0.5	0.2	0.1	0.2	0.2	0.1	0.1	5.3	9.3	3.5
Vermilion R @ Vegreville-WSC	05EE009	1,620	1,600	367	373	0.0	0.1	1.0	4.7	0.3	0.1	0.2	0.1	0.0	0.0	0.0	0.0		6.6	2.4
Two Hills	05EC002		932		305	0.1	0.1	0.2	3.1	0.6	0.5	0.2	0.1	0.2	0.2	0.1	0.1	5.3		
Watt-Bens Lakes	05EC002		420		19	0.1	0.1	0.2	3.1	0.6	0.5	0.2	0.1	0.2	0.2	0.1	0.1	5.3		
Cotton Creek	05EC002		306		89	0.1	0.1	0.2	3.1	0.6	0.5	0.2	0.1	0.2	0.2	0.1	0.1	5.3		
Two Hills-Morecambe	05EC002		534		304	0.1	0.1	0.2	3.1	0.6	0.5	0.2	0.1	0.2	0.2	0.1	0.1	5.3	6.7	7.3
Vermilion R @ Morecambe-Beauvallon-WSC	05EE930	3,880	3,792	1,070	1,090	0.0	0.0	0.0	1.4	0.9	0.1	0.1	0.0	0.0	0.0	0.0	0.0		2.7	2.9
Birch Creek	05FB002		1,265		113	0.0	0.1	0.2	2.5	1.0	0.4	0.5	0.2	0.1	0.1	0.1	0.0	5.1		
Morecambe-Mannville	05EE005		657		248	0.0	0.0	2.0	4.4	0.3	0.1	0.5	0.4	0.1	0.0	0.0	0.0	8.0	6.8	9.8
Vermilion R @ Mannville-WSC	05EE001-N-Con	5,740	5,714	1,800	1,451	0.0	0.0	0.4	3.4	2.8	0.8	1.6	0.5	0.2	0.2	0.1	0.1		10.1	18.2
Mannville-Vermilion	05EE005		382		211	0.0	0.0	2.0	4.4	0.3	0.1	0.5	0.4	0.1	0.0	0.0	0.0	8.0		
Vermilion R @ Vermilion		6,100	6,096	1,850	1,661														8.5	
Vermilion-Marwayne	05EE005		1,152		363	0.0	0.0	2.0	4.4	0.3	0.1	0.5	0.4	0.1	0.0	0.0	0.0	8.0	7.1	14.4
Vermilion R @ Marwayne-WSC	05EE007	7,260	7,247	2,000	2,025	0.1	0.1	0.3	2.8	1.4	0.4	0.5	0.3	0.1	0.1	0.1	0.1		6.3	12.7
Marwayne-NSR	05EE005		615		365	0.0	0.0	2.0	4.4	0.3	0.1	0.5	0.4	0.1	0.0	0.0	0.0	8.0		
Vermilion R @ NSR		7,860	7,863	2,360	2,390														7.2	17.3

Table 5 Annual and Monthly Yields from Sub-Basins in the Vermilion River Basin - 75th Percentile Case

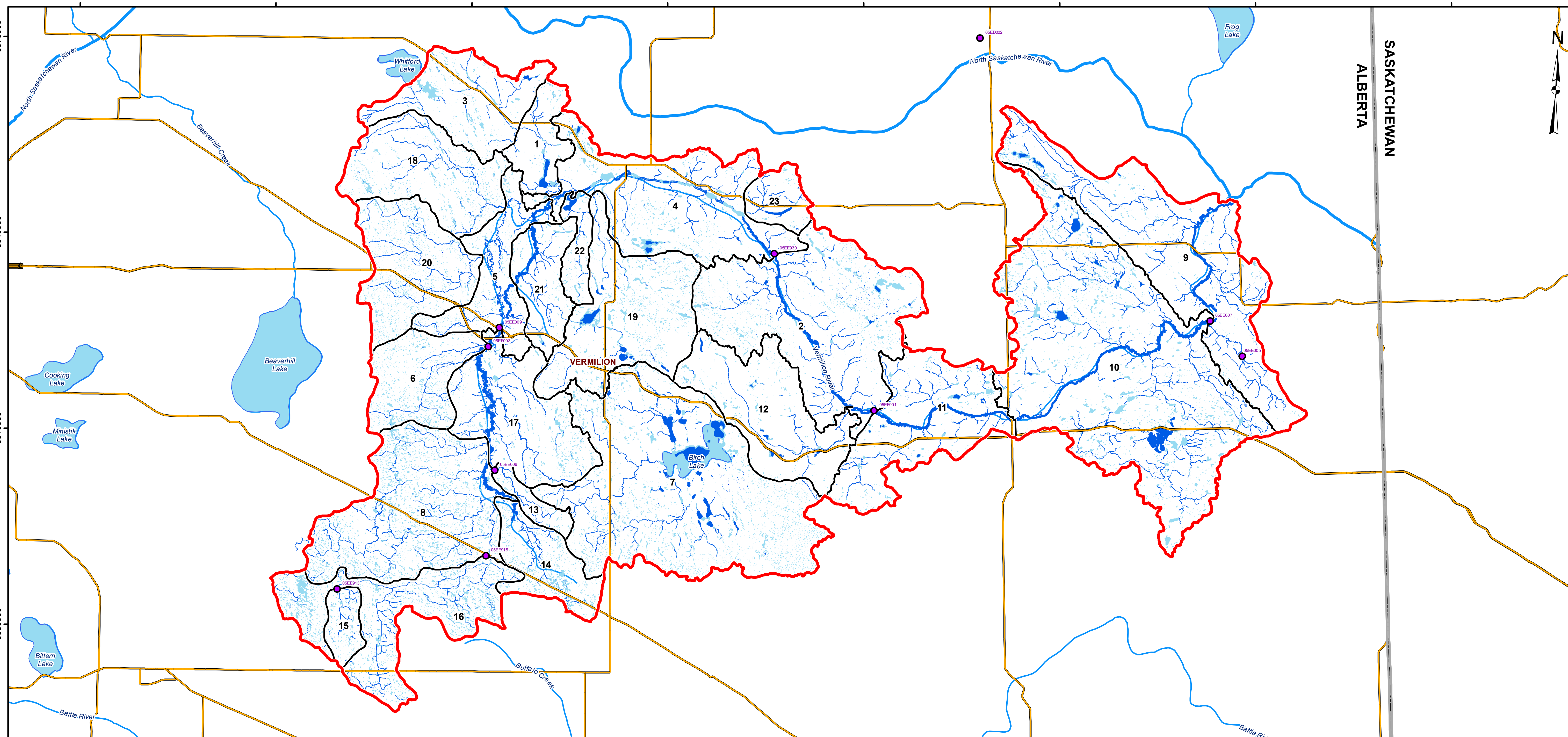
Sub-Basin	Representative Hydrometric Stattion Data	Cumulative Gross Area Reported at Hydrometric Station (km²)	Gross Area at Sub-Basin Outlet (km²)	Cumulative Effective Area Reported at Hydrometric Station (km²) -	Effective Area at Sub-Basin Outlet (km²)	Monthly Yield (mm)												Local Annual Yield (mm)	Cumulative Annual Yield (mm)	Cumulative Annual Volume (Mm³)
						Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Vermilion R @ Bruce-Holden Headwaters-WSC	05EE006		631		136	0.2	0.4	8.2	33.1	2.9	3.1	5.3	0.9	1.4	0.3	0.2	0.2	56.3	56.3	
Waskwei	05EC002		968		237	0.3	0.3	0.8	15.5	2.9	2.6	1.1	0.6	0.8	0.8	0.5	0.4	26.6	37.4	14.0
Vermilion R @ Vegreville-WSC	05EE009	1,620	1,600	367	373	0.0	0.4	4.2	19.4	1.4	0.5	0.7	0.3	0.2	0.1	0.0	0.0		27.2	10.0
Two Hills	05EC002		932		305	0.3	0.3	0.8	15.5	2.9	2.6	1.1	0.6	0.8	0.8	0.5	0.4	26.6		
Watt-Bens Lakes	05EC002		420		19	0.3	0.3	0.8	15.5	2.9	2.6	1.1	0.6	0.8	0.8	0.5	0.4	26.6		
Cotton Creek	05EC002		306		89	0.3	0.3	0.8	15.5	2.9	2.6	1.1	0.6	0.8	0.8	0.5	0.4	26.6		
Two Hills-Morecambe	05EC002		534		304	0.3	0.3	0.8	15.5	2.9	2.6	1.1	0.6	0.8	0.8	0.5	0.4	26.6	30.3	33.1
Vermilion R @ Morecambe-Beauvallon-WSC	05EE930	3,880	3,792	1,070	1,090	0.0	0.0	0.0	7.6	4.9	0.6	0.5	0.1	0.2	0.1	0.1	0.1		14.2	15.2
Birch Creek	05FB002		1,265		113	0.2	0.2	0.9	9.6	4.0	1.6	1.8	0.7	0.2	0.3	0.2	0.2	19.9		
Morecambe-Mannville	05EE005		657		248	0.1	0.1	5.6	11.9	0.9	0.4	1.4	1.0	0.2	0.1	0.1	0.1	21.8	28.1	40.7
Vermilion R @ Mannville-WSC	05EE001-N-Con	5,740	5,714	1,800	1,451	0.0	0.1	1.1	8.4	7.0	1.9	3.9	1.3	0.5	0.5	0.2	0.1		25.1	45.2
Mannville-Vermilion	05EE005		382		211	0.1	0.1	5.6	11.9	0.9	0.4	1.4	1.0	0.2	0.1	0.1	0.1	21.8		
Vermilion R @ Vermilion		6,100	6,096	1,850	1,661														33.4	
Vermilion-Marwayne	05EE005		1,152		363	0.1	0.1	5.6	11.9	0.9	0.4	1.4	1.0	0.2	0.1	0.1	0.1	21.8	26.3	53.2
Vermilion R @ Marwayne-WSC	05EE007	7,260	7,247	2,000	2,025	0.2	0.4	0.9	8.5	4.2	1.0	1.6	1.0	0.2	0.2	0.2	0.2		18.9	37.7
Marwayne-NSR	05EE005		615		365	0.1	0.1	5.6	11.9	0.9	0.4	1.4	1.0	0.2	0.1	0.1	0.1	21.8		
Vermilion R @ NSR		7,860	7,863	2,360	2,390														25.6	61.2

Table 6 Annual and Monthly Yields from Sub-Basins in the Vermilion River Basin - 90th Percentile Case

Sub-Basin	Representative Hydrometric Stattion Data	Cumulative Gross Area Reported at Hydrometric Station (km²)	Gross Area at Sub-Basin Outlet (km²)	Cumulative Effective Area Reported at Hydrometric Station (km²) -	Effective Area at Sub-Basin Outlet (km²)	Monthly Yield (mm)												Local Annual Yield (mm)	Cumulative Annual Yield (mm)	Cumulative Annual Volume (Mm³)
						Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
Vermilion R @ Bruce-Holden Headwaters-WSC	05EE006		631		136	0.4	0.6	14.3	57.9	5.0	5.5	9.3	1.6	2.4	0.5	0.4	0.4	98.5	98.5	
Waskwei	05EC002		968		237	0.7	0.7	1.6	31.9	5.9	5.4	2.4	1.2	1.7	1.6	1.1	0.9	55.1	70.9	26.5
Vermilion R @ Vegreville-WSC	05EE009	1,620	1,600	367	373	0.1	0.7	7.9	36.8	2.7	0.9	1.4	0.5	0.4	0.1	0.1	0.1		51.6	18.9
Two Hills	05EC002		932		305	0.7	0.7	1.6	31.9	5.9	5.4	2.4	1.2	1.7	1.6	1.1	0.9	55.1		
Watt-Bens Lakes	05EC002		420		19	0.7	0.7	1.6	31.9	5.9	5.4	2.4	1.2	1.7	1.6	1.1	0.9	55.1		
Cotton Creek	05EC002		306		89	0.7	0.7	1.6	31.9	5.9	5.4	2.4	1.2	1.7	1.6	1.1	0.9	55.1		
Two Hills-Morecambe	05EC002		534		304	0.7	0.7	1.6	31.9	5.9	5.4	2.4	1.2	1.7	1.6	1.1	0.9	55.1	60.5	65.9
Vermilion R @ Morecambe-Beauvallon-WSC	05EE930	3,880	3,792	1,070	1,090	0.0	0.0	0.0	16.0	10.4	1.3	1.0	0.2	0.4	0.3	0.2	0.1		30.0	32.1
Birch Creek	05FB002		1,265		113	0.3	0.4	1.7	17.7	7.3	2.9	3.2	1.3	0.4	0.5	0.4	0.3	36.6		
Morecambe-Mannville	05EE005		657		248	0.1	0.2	8.8	18.8	1.3	0.6	2.2	1.6	0.4	0.1	0.1	0.1	34.4	54.2	78.6
Vermilion R @ Mannville-WSC	05EE001-N-Con	5,740	5,714	1,800	1,451	0.1	0.2	1.7	12.7	10.5	2.9	5.9	2.0	0.8	0.7	0.3	0.2		37.8	68.1
Mannville-Vermilion	05EE005		382		211	0.1	0.2	8.8	18.8	1.3	0.6	2.2	1.6	0.4	0.1	0.1	0.1	34.4		
Vermilion R @ Vermilion		6,100	6,096	1,850	1,661														63.2	
Vermilion-Marwayne	05EE005		1,152		363	0.1	0.2	8.8	18.8	1.3	0.6	2.2	1.6	0.4	0.1	0.1	0.1	34.4	48.5	98.3
Vermilion R @ Marwayne-WSC	05EE007	7,260	7,247	2,000	2,025	0.4	0.6	1.5	13.8	6.9	1.7	2.6	1.7	0.4	0.4	0.4	0.4		30.8	61.6
Marwayne-NSR	05EE005		615		365	0.1	0.2	8.8	18.8	1.3	0.6	2.2	1.6	0.4	0.1	0.1	0.1	34.4		
Vermilion R @ NSR		7,860	7,863	2,360	2,390														46.4	111

APPENDIX B

Maps Used for HSPF Set Up for Vermilion River Basin



20 0 20

SCALE 1:600,000 KILOMETRES

LEGEND

- HYDROMETRIC STATION
- DIVIDED HIGHWAY
- PRIMARY HIGHWAY
- RIVER
- STREAM - VERMILION RIVER BASIN
- RIVER - VERMILLION RIVER BASIN
- LAKE
- LAKE - VERMILION RIVER BASIN - PERMANENT
- LAKE - VERMILION RIVER BASIN - TEMPORARY
- BASIN BOUNDARY
- SUB-BASIN BOUNDARY

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

TITLE

HYDROMETRIC STATIONS IN THE VERMILION RIVER BASIN

Golder Associates
Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009		
GIS	JH	10 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

FIGURE: B.1

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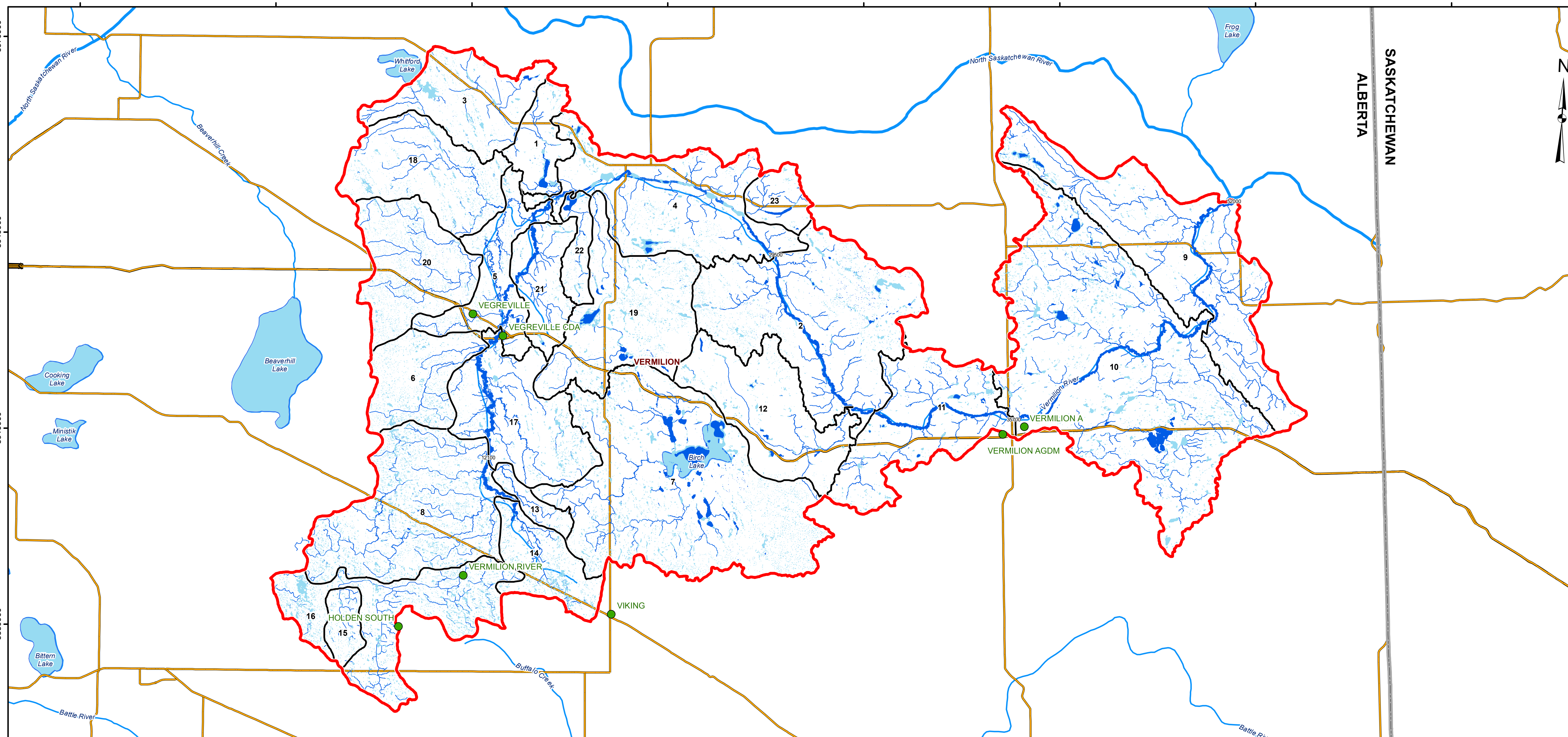


LEGEND

- CLIMATE STATION
- DIVIDED HIGHWAY
- PRIMARY HIGHWAY
- RIVER
- STREAM - VERMILION RIVER BASIN
- RIVER - VERMILLION RIVER BASIN
- LAKE
- LAKE - VERMILION RIVER BASIN - PERMANENT
- LAKE - VERMILION RIVER BASIN - TEMPORARY
- BASIN BOUNDARY
- SUB-BASIN BOUNDARY

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

20 0 20

SCALE 1:600,000 KILOMETRES

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

TITLE

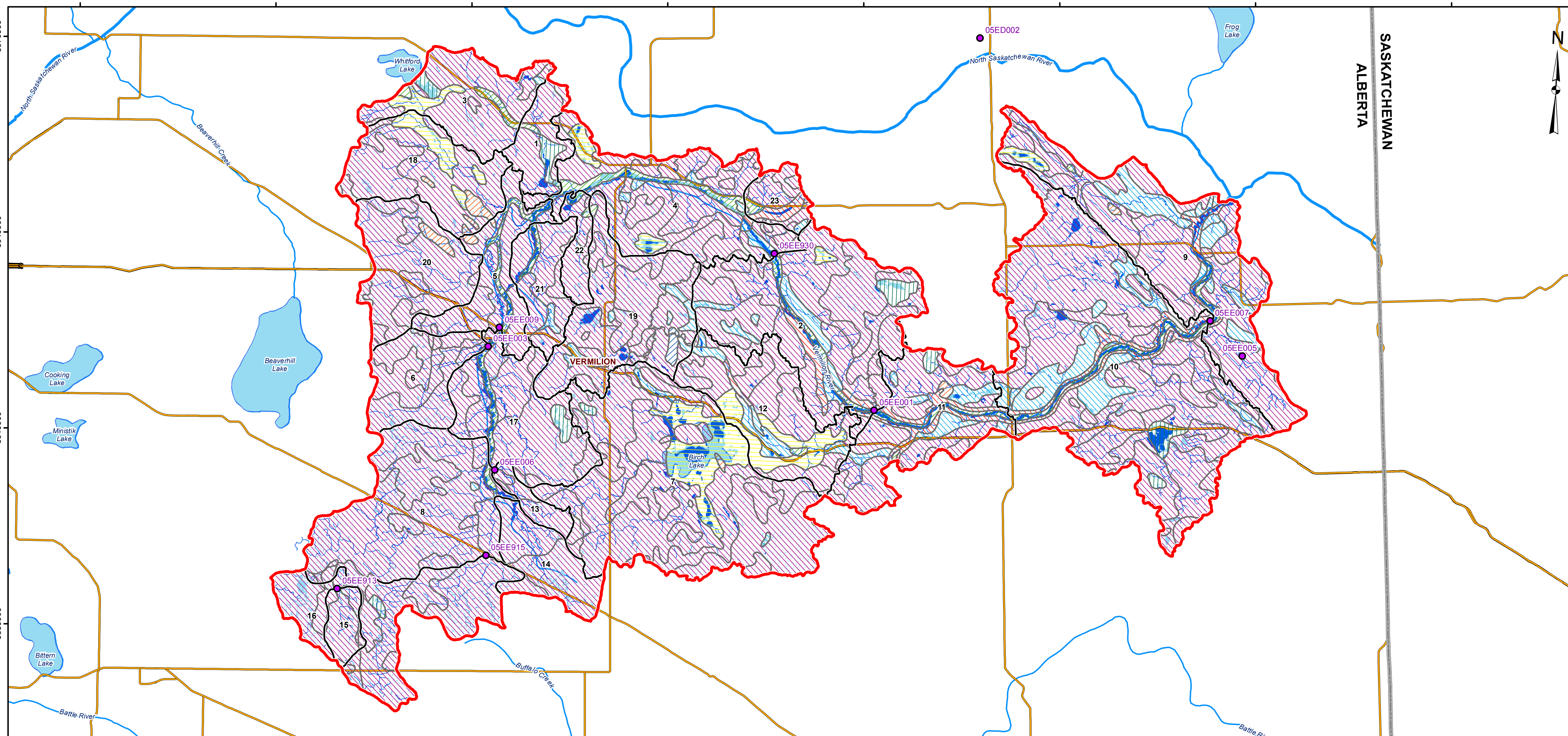
CLIMATE STATIONS IN THE VERMILION RIVER BASIN

Golder Associates

Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009		
GIS	JH	10 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

FIGURE: B.2



20 0 20

SCALE 1:600,000 KILOMETRES

LEGEND

- HYDROMETRIC STATION
- DIVIDED HIGHWAY
- PRIMARY HIGHWAY
- RIVER
- STREAM - VERMILION RIVER BASIN
- RIVER - VERMILLION RIVER BASIN
- LAKE
- LAKE - VERMILION RIVER BASIN - PERMANENT
- LAKE - VERMILION RIVER BASIN - TEMPORARY
- BASIN BOUNDARY
- SUB-BASIN BOUNDARY

SURFICIALGEOLOGY

- EOLIAN
- FLUVIAL
- GLACIAL
- GLACIAL & FLUVIAL, UND
- ICE-CONTACT LACUSTRINE & FLUVIAL, UNDIV
- ICE-CONTACTED FLUVIAL
- LACUSTRINE
- STREAM & SLOPEWASH ERODED

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

TITLE

SURFICIAL GEOLOGY OF THE VERMILION RIVER BASIN

Golder Associates
Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009	**FIGURE: B.3**	
GIS	JH	10 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

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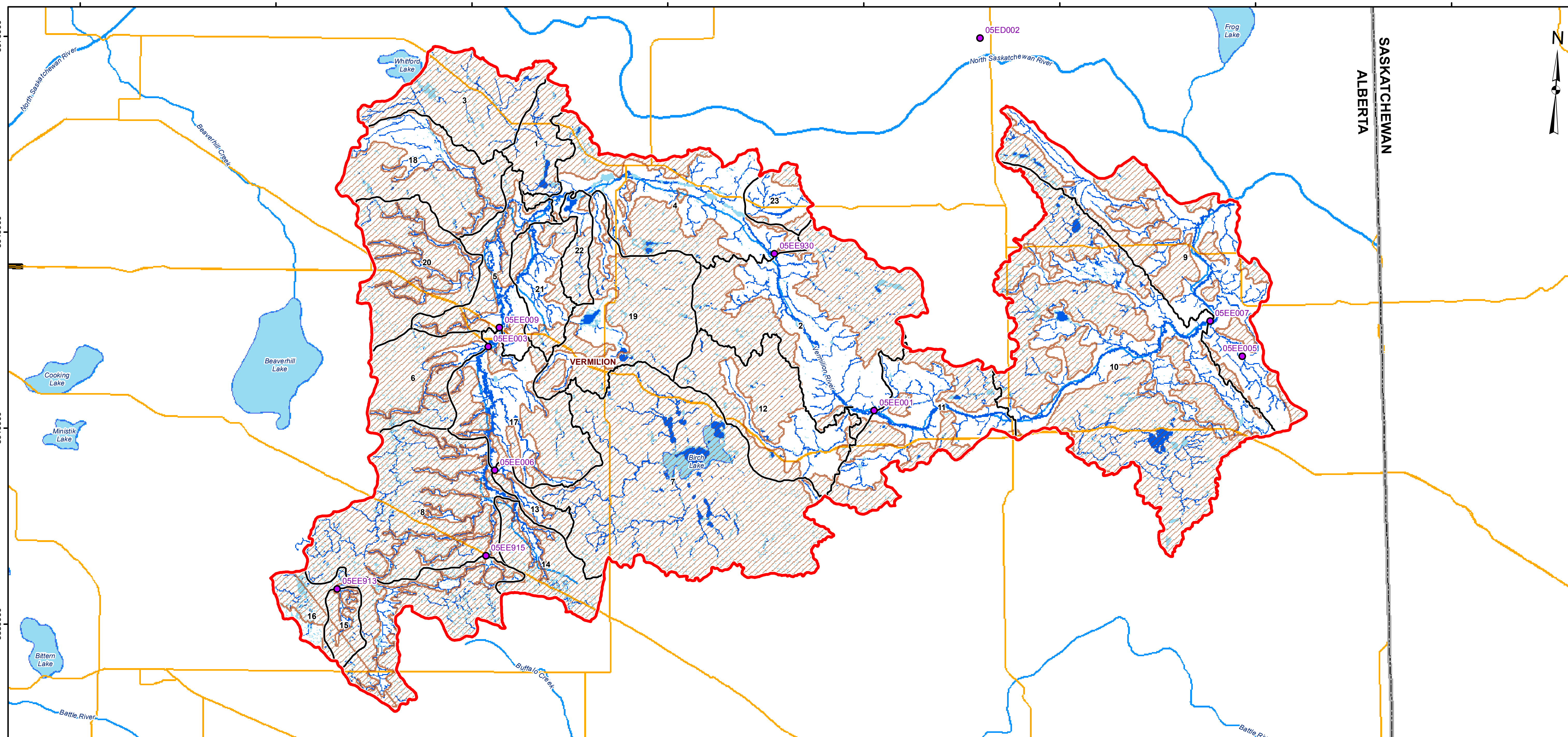

LEGEND

HYDROMETRIC STATION	SUB-BASIN BOUNDARY
DIVIDED HIGHWAY	BASIN BOUNDARY
PRIMARY HIGHWAY	NON-CONTRIBUTING AREA
RIVER	LAKE
STREAM - VERMILION RIVER BASIN	LAKE - VERMILION RIVER BASIN - PERMANENT
RIVER - VERMILLION RIVER BASIN	LAKE - VERMILION RIVER BASIN - TEMPORARY

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

TITLE

NON-CONTRIBUTING AREAS IN THE VERMILION RIVER BASIN DURING THE TWO-YEAR FLOOD CONDITIONS

Golder Associates
Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009	**FIGURE: B.4**	
GIS	JH	10 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

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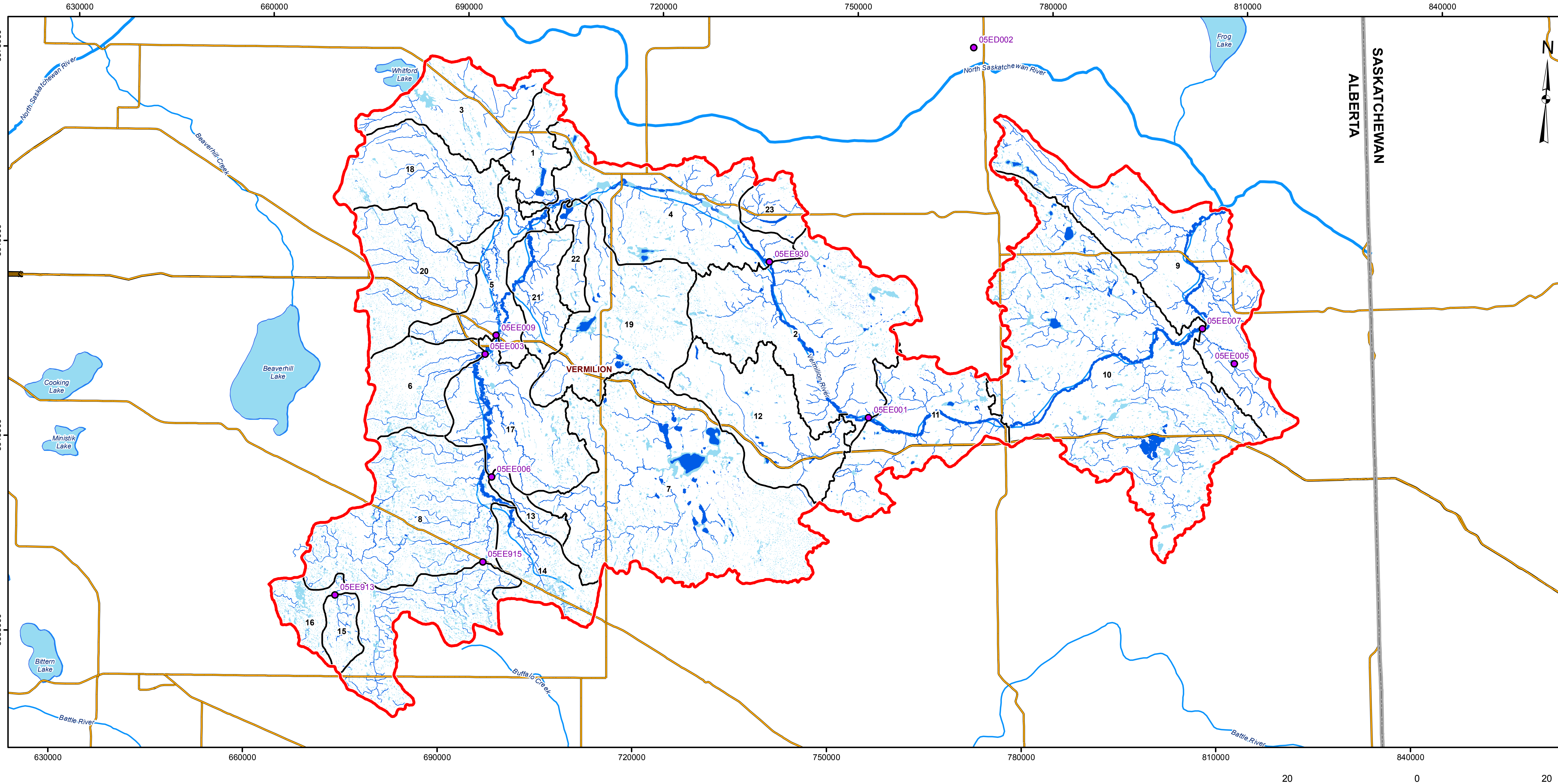


LEGEND

HYDROMETRIC STATION	LAKE
DIVIDED HIGHWAY	LAKE - VERMILION RIVER BASIN - PERMANENT
PRIMARY HIGHWAY	LAKE - VERMILION RIVER BASIN - TEMPORARY
RIVER	BASIN BOUNDARY
STREAM - VERMILION RIVER BASIN	SUB-BASIN BOUNDARY
RIVER - VERMILLION RIVER BASIN	

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

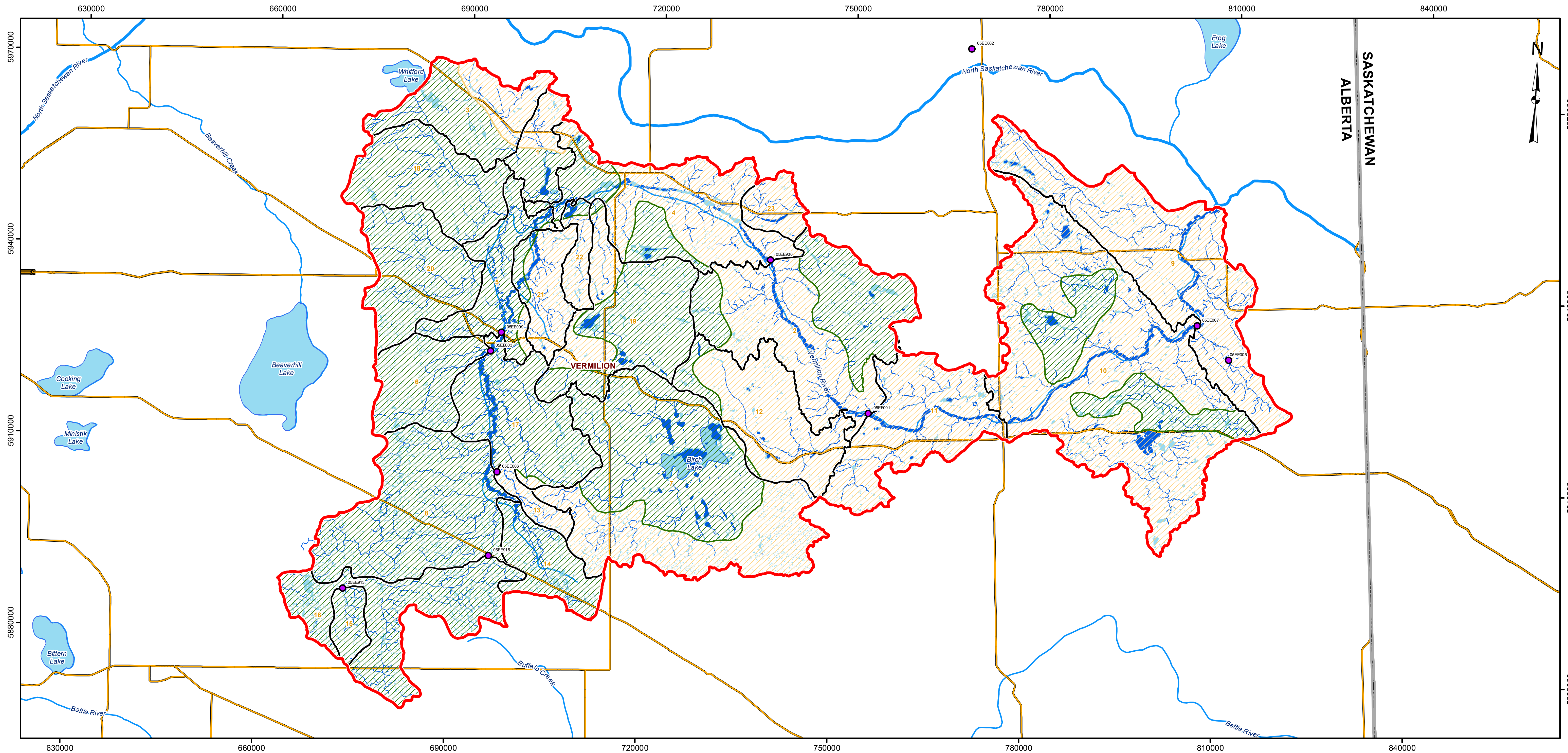
TITLE

OPEN WATERBODIES IN THE VERMILION RIVER BASIN

Golder Associates
Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009		
GIS	JH	10 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

FIGURE: B.5



20 0 20

SCALE 1:600,000 KILOMETRES

LEGEND

HYDROMETRIC STATION	LAKE
DIVIDED HIGHWAY	LAKE - VERMILION RIVER BASIN - PERMANENT
PRIMARY HIGHWAY	LAKE - VERMILION RIVER BASIN - TEMPORARY
RIVER	LOWLAND
STREAM - VERMILION RIVER BASIN	UPLAND
RIVER - VERMILLION RIVER BASIN	BASIN BOUNDARY
	SUB-BASIN BOUNDARY

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

TITLE

UPLANDS AND LOWLANDS IN THE VERMILION RIVER BASIN

Golder Associates
Calgary, Alberta

PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009	**FIGURE: B.6**	
GIS	JH	10 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

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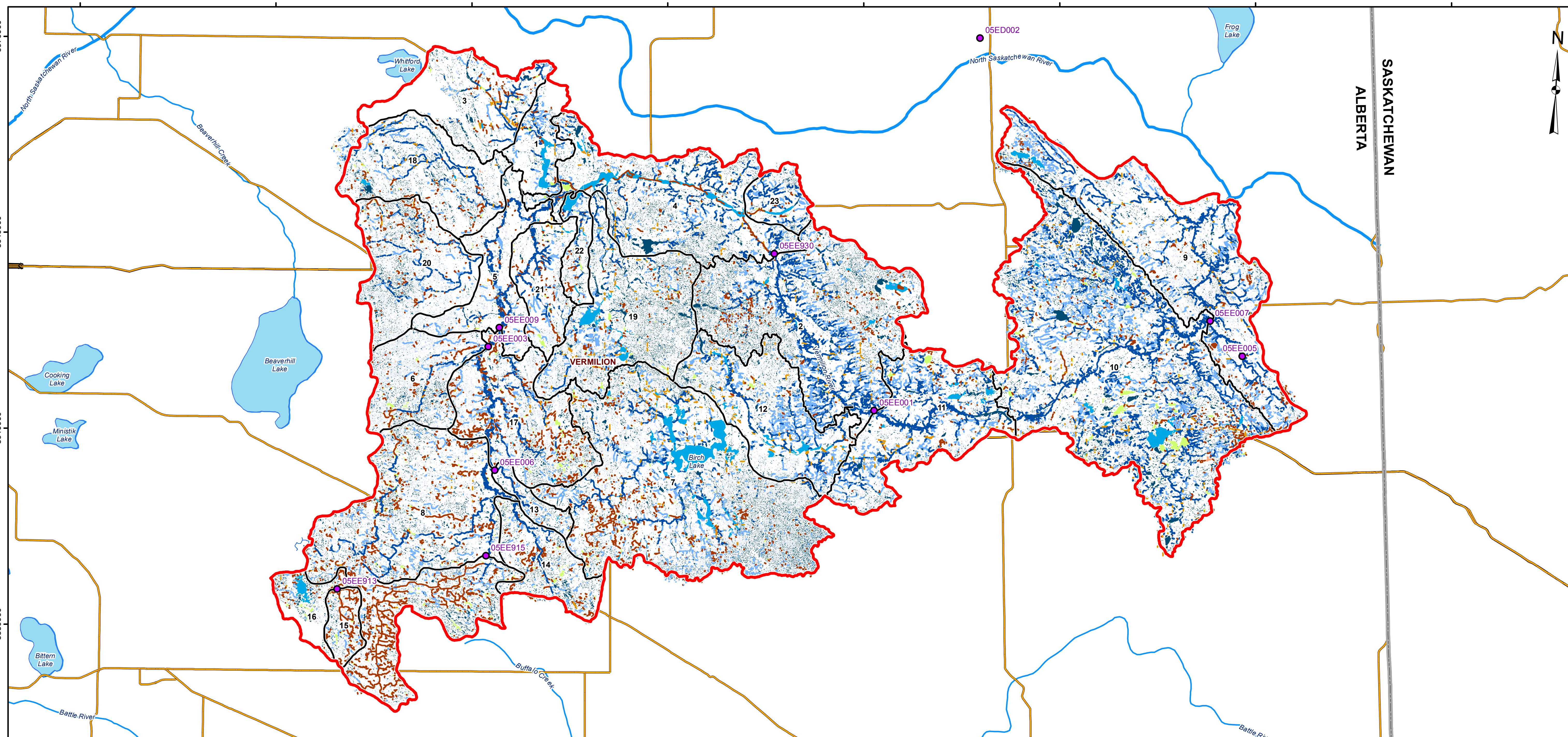

SCALE 1:600,000

20 0 20 KILOMETRES

LEGEND

HYDROMETRIC STATION	LAKE	**BASINS (WETLANDS)**
DIVIDED HIGHWAY	LAKE - VERMILION RIVER BASIN - PERMANENT	ALTERED
PRIMARY HIGHWAY	LAKE - VERMILION RIVER BASIN - TEMPORARY	DRAINED/ALTERED
RIVER	BASIN BOUNDARY	DRAINED/CONSOLIDATED
STREAM - VERMILION RIVER BASIN	SUB-BASIN BOUNDARY	DRAINED/LOST
RIVER - VERMILLION RIVER BASIN		INTACT
CANAL		
DITCH		
STREAM		
STREAM INTERMITTENT		

REFERENCE

Projection: 10TM FOREST Datum: NAD 83

PROJECT

NSWA - Vermilion River Water Supply and Demand Study

TITLE

DRAINED AREAS AND WETLANDS IN THE VERMILION RIVER BASIN

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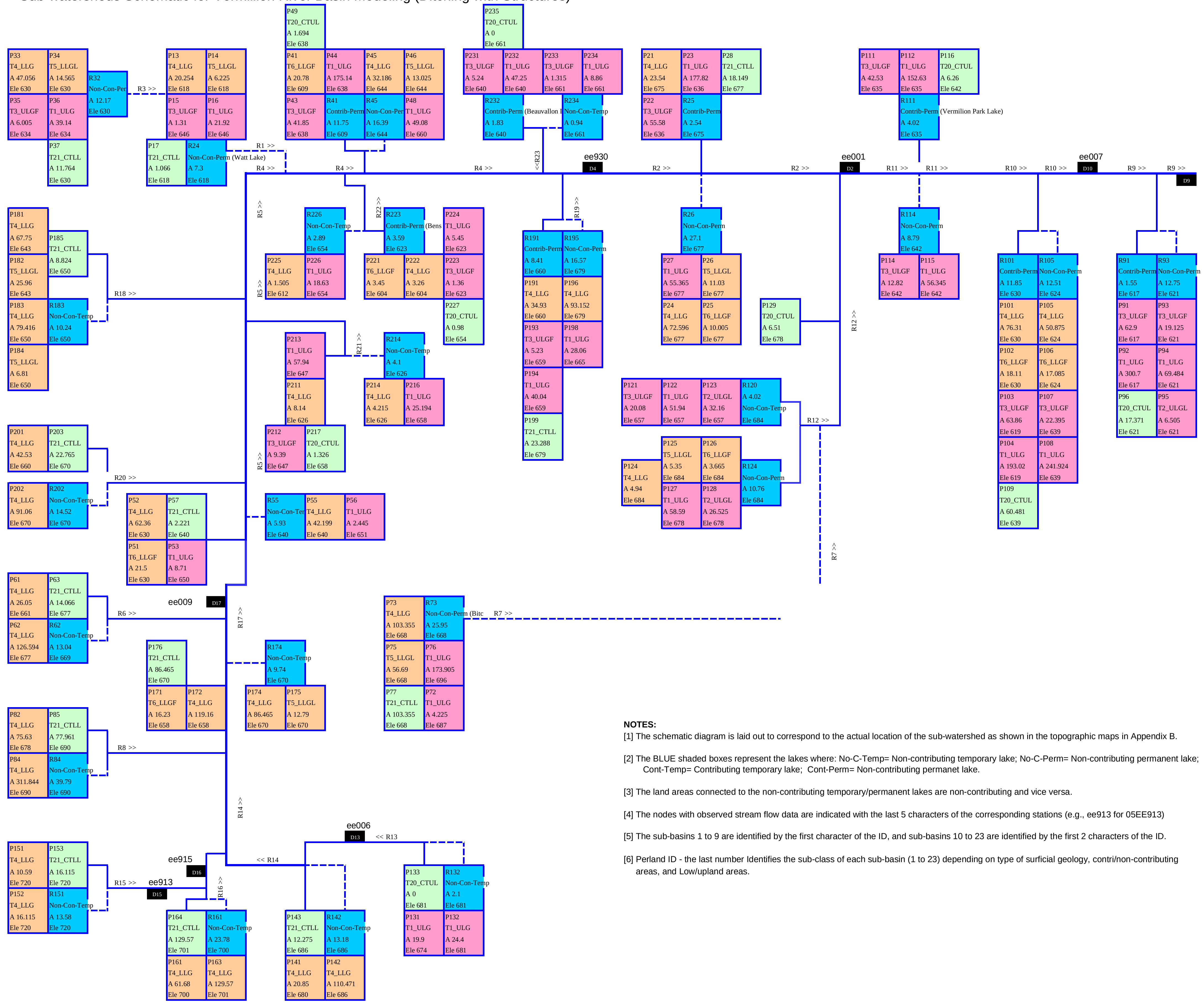
PROJECT NO. 08-1326-0031			SCALE AS SHOWN	REV. 0
DESIGN	PT	20 Apr. 2009		
GIS	JH	10 Jun. 2009		
CHECK	OK	10 Jun. 2009		
REVIEW	AB	11 Jun. 2009		

FIGURE: B.7

APPENDIX C

Schematic of HSPF Set Up for Vermilion River Basin

Sub-watersheds Schematic for Vermillion River Basin Modeling (Ditching with Structures)



NOTES:

[1] The schematic diagram is laid out to correspond to the actual location of the sub-watershed as shown in the topographic maps in Appendix B.

[2] The BLUE shaded boxes represent the lakes where: No-C-Temp= Non-contributing temporary lake; No-C-Perm= Non-contributing permanent lake; Cont-Temp= Contributing temporary lake; Cont-Perm= Non-contributing permanet lake.

[3] The land areas connected to the non-contributing temporary/permanent lakes are non-contributing and vice versa.

[4] The nodes with observed stream flow data are indicated with the last 5 characters of the corresponding stations (e.g., ee913 for 05EE913)

[5] The sub-basins 1 to 9 are identified by the first character of the ID, and sub-basins 10 to 23 are identified by the first 2 characters of the ID.

[6] Perland ID - the last number Identifies the sub-class of each sub-basin (1 to 23) depending on type of surficial geology, contri/non-contributing areas, and Low/upland areas.

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Africa	+ 27 11 254 4800
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Europe	+ 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

Golder Associates Ltd.
102, 2535 - 3rd Avenue S.E.
Calgary, Alberta, T2A 7W5
Canada
T: +1 (403) 299 5600