Vermilion River Water Supply & Demand Study

Report prepared for the North Saskatchewan Watershed Alliance

North Saskatchewan Watershed Alliance

Golder Associates

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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 (10^{th} percentile, value exceeded 90 percent of the time) to about 110 Mm^3 (90^{th} percentile, exceeded 10 percent of the time), illustrating the very high variability in annual yield from year to year. The difference between the 10^{th} and 90^{th} 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, 10^{th} percentile (approximately 10-year dry month) and 90^{th} 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.