STUDY OF

EROSION AND SEDIMENTATION

ON THE MILK RIVER

Submitted to:

Milk River Watershed Council Canada
Milk River, Alberta

Submitted by:

AMEC Earth & Environmental
Calgary, Alberta

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CW2020

EXECUTIVE SUMMARY

The Milk River Watershed Council Canada (MRWCC) retained AMEC Earth and Environmental (AMEC) to undertake a study to review Milk River erosion and sedimentation that may result from a potential future increase in St. Mary River diversion flows into the Milk River. The existing diversion commenced in 1917, and the effects of the diversion on channel morphology have previously been examined (Peters, 1910; Blench, 1954; McLean and Beckstead, 1981, 1987; Bradley). This study attempts to update the original work conducted in the 1980s and to examine the impact of increased diversion discharges on river morphological processes (erosion and sedimentation) and the resulting effects on on ice processes, riparian vegetation, water quality and fisheries.

The design capacity of the St. Mary diversion to the North Fork of the Milk River in Montana was originally 24.1 m^3/s (850 cfs); however, the diversion works have deteriorated to the extent that the current operating capacity is in the range of 18.4 m^3/s to 19.1 m^3/s (650 to 675 cfs). Plans for rehabilitation and possible enlargement of the diversion works are being undertaken with the possibility that flows will be increased to 28.3 m^3/s (1000 cfs) (TD&H Engineering Inc., 2006a and 2006b; Ryan, 2006). This study investigated future scenarios with diversion capacities of 28.3 m^3/s (1000 cfs) and 34.0 m^3/s (1200 cfs).

Modelling of the future scenarios by Alberta Environment provided weekly average flows for the North Milk River, and the Milk River at Milk River (characterizing the gravel bed reach) and at the Eastern Crossing of the International Boundary (characterizing the sand bed reach). AMEC then conducted hydrological analyses to determine flow duration curves and flood frequency curves at these locations. The hydrological assessment concluded that seasonal and peak flood discharges will increase. An increase of over 50% above historical flows (recorded flows) along the entire length of the river within Canada in 20% to 30% of the weeks was projected. Peak flood discharges could increase by as much as 65% beyond present values (for the median annual flood event on the North Milk River) as a result of increased diversion discharges. The effects on flood frequencies diminish for greater return period events and for locations further downstream.

These hydrological results were used to develop and calibrate the U.S. Army Corps of Engineers Sediment Analysis Model (SAM). The SAM model was used to conduct channel stability analyses and evaluate the impacts on the Milk River morphology, resulting from: 1) the existing diversion that has been operating since 1917; and 2) potential St. Mary diversion increases to 28.3 m^3/s or 1,000 cfs and to 34.0 m^3/s or 1,200 cfs. The impact of the existing diversion and potential future diversions on the morphology of the Milk River were assessed by comparing historical surveys and air photographs as well as utilizing available hydrologic and suspended sediment data to undertake sediment budget and regime analyses.

Geomorphological changes to the river resulting from an increase in the diversion discharge to 1000 cfs and to 1200 cfs is expected to have the following effects:

a) For the North Milk River, the mean river width is predicted to increase from 20% to 30% (7 m to 11 m).
b) For the Milk River Gravel reach, the mean river width is predicted to increase from 10% to 20% (6 m to 12 m).
c) For the downstream Milk River Sand Bed reach, the mean river width is expected to increase from 15% to 25% (14 m to 23 m).
d) No significant change in depth or slope is estimated for the North Milk River and for the Milk River Gravel Bed reach.
e) For the Milk River Sand Bed reach, the potential changes to depth and slope are expected to be incrementally small in relation to the changes that have already occurred as a result of the historical diversion (the increase in depth is expected to be less than the 0.2 m 'recorded' increase, and the channel slope is expected to decrease less than the 10% 'recorded' change).

The existing diversion to the Milk River has resulted in channel widening, increased channel sinuosity, and an increase in cut-off activity immediately following the initiation of the diversion (McLean and Beckstead, 1981, 1987). A comparison of previous river survey information from 1915 and 1979/1980 with the information from river channel cross-section surveys obtained for this study in 2007 indicates that the channel is still widening, some 90 years after the diversion was initiated.

As the channel continuously and gradually adjusts towards a new dynamic equilibrium, sediment eroded from the upstream banks will be deposited to form point bars or deposited on the floodplain and in oxbow lakes during periods of overbank flooding. In-channel sediment will continue to move downstream and sediment deposited above bankfull level will be liberated when bank erosion occurs or cut-off channels are created.

Ice jam activity along the Milk River is a regular occurrence. While it is not possible to make a general conclusion on future trends in the frequency of ice jam occurrence, it is postulated that increased flow rates increase the hydrodynamic forces acting on an ice cover. Where conditions are favourable for the development of a break-up ice jam accumulation, an increase in the discharge magnitude is expected to result in an incremental increase in the rate of erosion due to ice jam activity. Sufficient information is not available to provide estimates on current erosion rates or incremental changes in erosion rates from ice action due to diversion activity.

An increased diversion is expected to result in river channel widening by erosion processes that could result in riparian vegetation (i.e. red fescue-needle-and-thread - northern wheat grass type; needle-and-thread - northern wheat grass - bluegrass - buckbrush; sagebrush flats; and saline meadows) losses of up to about 10% from existing values. The potential increased diversion could also cause increased flooding, which could favour plains cottonwood (*Populus deltoides*) regeneration with optimal flooding and seed dispersal conditions.

A review and brief analysis of available water quality data indicated that increased flows would likely decrease concentrations of nitrogen and salts, and increase concentrations of phosphorus. Increased discharges will also result in greater total suspended solids (TSS), particularly within the upper reaches of the river system. In the lower reach, the relationship is poor, likely due to the input of sediment from the badlands areas bordering the river during rainstorm. These additional inputs are not directly related to the river flow. There is a strong positive relationship between TSS and total phosphorus (TP), as TP is mainly found in a particulate form associated with suspended sediments). Increased discharge will increase sediment transport and therefore total phosphorus concentrations in the water column.

Similar to channel stability, fisheries resources and aquatic habitat in the Milk River will undergo a period of change following increased diversion flows until the channel approaches a new dynamic equilibrium. Generally, an increase in flow is expected to result in increased suspended sediment concentration that would negatively affect the fish population. Conversely, channel width increases resulting from erosion will, in time, provide additional fish habitat, especially within the Sand Bed reach of the Milk River.

Data gaps have been identified with respect to ice jam events, water quality data, information on particular fish species and riparian vegetation surveys. Monitoring programs have been outlined to aid in filling data gaps, which should include documentation of ice jam events, riparian vegetation characterization along the entire river length, water quality parameters (monitoring designed to specifically assess diversion effects) and fish populations and habitat use. General guidance has also been provided on erosion mitigation strategies, traditional approaches as well as bioengineering techniques, that can be employed at locations where important facilities or infrastructure are potentially threatened due to channel widening or shifting.

Overall, the Milk River is a dynamic system that is in constant flux. Increases in diversion flows will accelerate river migration and erosion and sedimentation processes. Understanding governing processes of the Milk River channel dynamics and the aquatic environment, in advance, will allow the Milk River Watershed Council Canada to consider and potentially mitigate long-term impacts.

ACKNOWLEDGEMENTS

AMEC acknowledges the assistance of the following Agencies and individuals in providing information during the preparation of this report:

- Milk River Watershed Council Canada - water quality data and mapping information
- PFRA – GIS Mapping of channel migration at Milk River and orthophoto imagery.
- Environment Canada – background reports on sediment and archived information on river surveys
- Landowners who responded to MRWCC survey on river bank erosion.
- AMEC surveyors who had to walk long distances overland to reach the river because of fire bans that prohibited vehicle travel.

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1.0 INTRODUCTION

1.1 Background

The Milk River Watershed Council Canada (MRWCC) retained AMEC Earth and Environmental (AMEC) to undertake a study to review Milk River erosion and sedimentation that may result from a potential future increase in St. Mary River diversion flows into the Milk River. The existing diversion commenced in 1917, resulting in channel widening, increased meander cut-off activity and increased sedimentation (McLean and Beckstead, 1987).

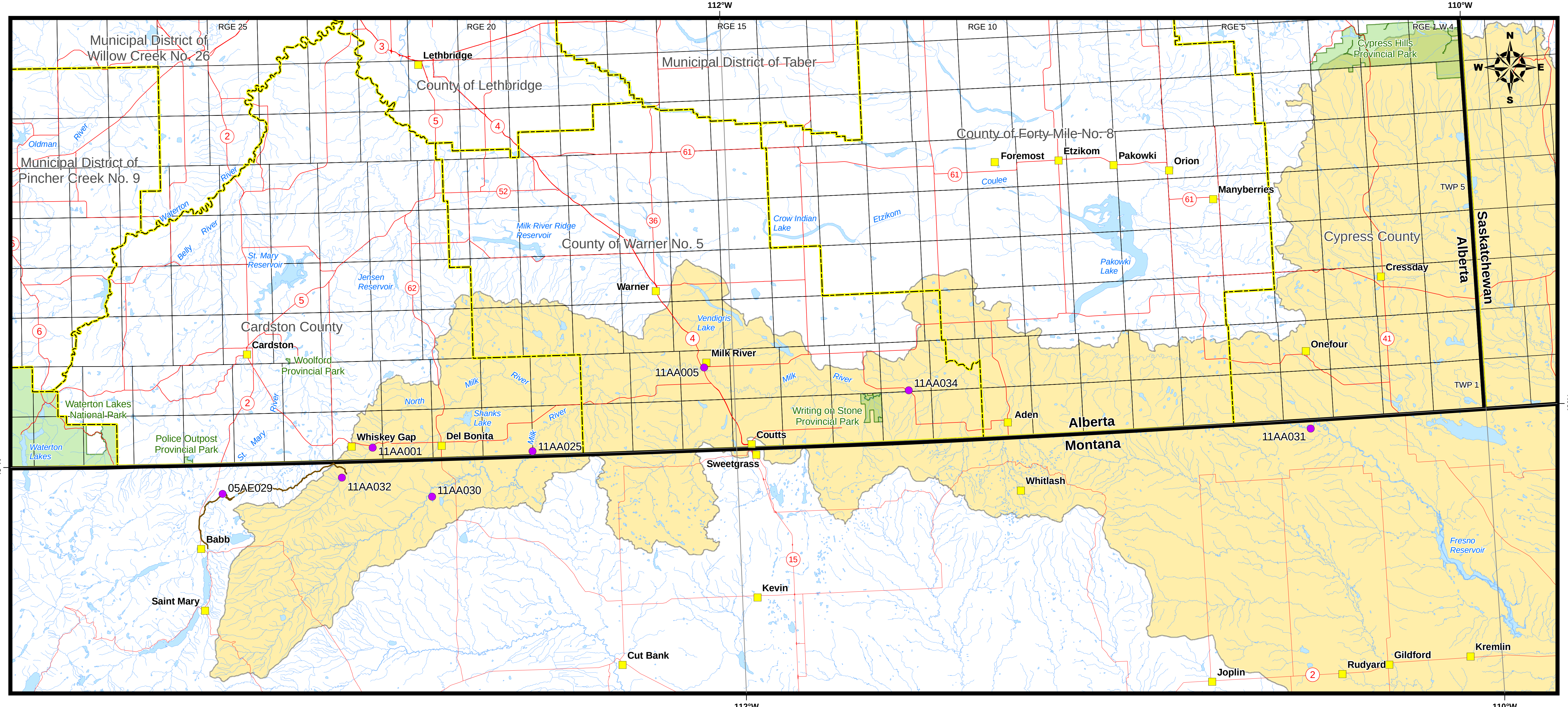
The Milk River is unique in Alberta since it is the only watershed in the province that drains into the Gulf of Mexico. The river originates in Montana and flows north-easterly into Alberta, then turns east to parallel the international boundary for about 345 km (river kilometres), as shown on **Figure 1.1**. Southwest of the Cypress Hills, the river turns southward to re-enter Montana. The Milk River is a tributary of the Missouri River, which joins the Mississippi River and eventually empties into the Gulf of Mexico. The Milk River Watershed is the smallest (6500 km^2) of Alberta's seven major river basins.

A dispute between Canada and the United States on the use of the waters of the St. Mary and Milk Rivers in the late 1800s and early 1900s led to the signing of the Boundary Waters Treaty (BWT) in 1909 and establishment of the International Joint Commission (IJC). The Treaty established (among other things) principles for sharing the water of the two streams for uses in both countries. The IJC was given a mandate to prevent and resolve disputes along Canada-U.S. boundary waters. In 1921, the IJC issued an Order that established the rules by which waters of the St. Mary and Milk Rivers would be monitored and shared by Accredited Officers of the two countries.

Article VI of the BWT provided the United States the right to use the channel of the Milk River in Canada to convey water, diverted from the St. Mary River in the Montana headwaters, to users south and east of the eastern crossing of the Milk River. Responsibility for property damages in Canada caused by conveyance of United States water was the subject of discussion in drafting the Treaty and, from time to time, since the diversion began in 1917. The Treaty provides that legal redress for damages in Canada as a result of such conveyance could be pursued in United States courts. This provision has never been undertaken.

The St. Mary diversion to the Milk River was initiated as part of the Boundary Waters Treaty of 1909 between the United States and Canada. Water from the St. Mary River is conveyed by a canal to the North Milk River in Montana (**Figure 1.1**). After crossing the International Boundary the water flows 80 km before meeting the larger unregulated south branch. The combined north and south branches form the main stem Milk River, which flows an additional 235 km eastwards before re-entering the United States at the Eastern Crossing.

Construction of the St. Mary diversion to the North Fork of the Milk River in the Montana headwater was completed in 1917. The design capacity was 24.1 m^3/s (850 cfs). The diversion works have deteriorated to the extent that the current operating capacity is 18.4 m^3/s to 19.1 m^3/s (650 to 675 cfs). Plans for rehabilitation and possible enlargement of the diversion works are being undertaken (TD&H Engineering Inc., 2006a and 2006b; Ryan, 2006).



Legend

- Milk River Watershed
- National/Provincial Park
- Rural Municipality
- Water
- Road
- Canal
- Town
- Hydrometric Station

10 0 10 20 30

Kilometres

1:750,000

amec

Milk River Watershed Council Canada

Study of Erosion and Sedimentation on the Milk River

Milk River Watershed and Hydrometric Station Locations

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Figure 1.1

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Previous studies have assessed the effects of the St. Mary diversion on the North Milk River and Milk River since 1917. McLean and Beckstead (1981, 1987) and Bradley and Smith (1984) compared pre-diversion discharges to those following diversion and determined that on the North Milk River there was a twenty-fold increase in the average flow and a two-fold increase in the mean annual flood discharge; on the main stem of the Milk River (i.e. downstream of the confluence of the Milk River with the main stem Milk River) the average flow increased by a factor of two and there was little change in the mean annual flood discharge. On the North Milk River, McLean and Beckstead (1981, 1987) found a 55% increase in channel width (11 m), an increase in channel sinuosity and an increase in cut-off activity immediately following the initiation of the diversion that diminished over time. On the Milk River, the effects of the diversion discharges are smaller; channel width increases were determined by Bradley and Smith (1984) to have increased by 10% (5.5 m). The suspended sediment load carried by the river has reduced the storage capacity of the Fresno Reservoir in Montana (U.S. Department of the Interior, 1984).

1.2 Scope of work

The St. Mary diversion has significantly impacted the morphology of the Milk River. Equilibrium in physical and ecological characteristics of the river have adjusted over the past 90 years. Increased diversions in the future may result in another lengthy period of changes and impacts.

The Milk River Watershed Council Canada (MRWCC) has taken a proactive approach in determining how future water management options may affect water quality, water quantity, the aquatic and riparian ecosystems, existing water users and property owners. The MRWCC is concerned that enlarging the diversion works and increased St. Mary River flows in the Milk River will result in increased erosion, sediment transport and silt deposition. The morphological characteristics of the Milk River may be significantly altered in a manner that will have negative consequences for current water users, landowners, and environmental values along the river. The MRWCC retained AMEC to conduct a study to assess potential impacts of increased diversions.

The specific scope of work for the study includes the following tasks:

- Document the extent of erosion and sedimentation along the river, and identify the processes that have contributed to the morphologic changes. The intent is to increase the knowledge of erosion processes, and the contributions of several drivers, such as the diverted flow from the St. Mary River, peak flow events, groundwater infiltration from adjacent aquifers, valley land uses, and ice effects. An improved understanding of morphologic processes will help the MRWCC and water users to develop a watershed management plan and sustainable developments along the Milk River.
- Develop a model capable of predicting erosion and sedimentation processes to assist in the protection of existing infrastructure, and plan future projects.
- Identify critical erosion sites or hot spots and explore management options in order to develop remediation plans to protect infrastructure and property. Remediation plans would include bioengineering techniques.

- Utilize the model to project the future rate and extent of erosion, sediment transport and deposition caused by increased diversions from the St. Mary River.
- Predict how potential changes in river morphology will affect water quality, water quantity, the aquatic and riparian ecosystems, existing water users and infrastructure, and property owners.
- Explore management options to alleviate some of the potential damage that could be caused by erosion and sedimentation.
- Provide a plan for future monitoring of river morphology changes through time.
- Prepare a report on the study, documenting methodology, analyses, findings, conclusions and recommendations.
- Provide river geomorphic information and impacts in a manner suitable for inclusion in the 2007 Milk River State of the Watershed Report.

2.0 HYDROLOGY

2.1 Streamflow data

The objective of the hydrology component is to provide the hydrological input necessary to develop and calibrate the river morphology model. The morphology model would be utilized in combination with regime methods to evaluate changes to morphological characteristics of the Milk River due to potential increases in the St. Mary diversion capacity. The key hydrologic requirements for model development, calibration and analysis of future scenarios are flow duration and flood frequency relationships at representative reaches along the Milk River. Long-term recorded or simulated streamflow data are required to develop these relationships.

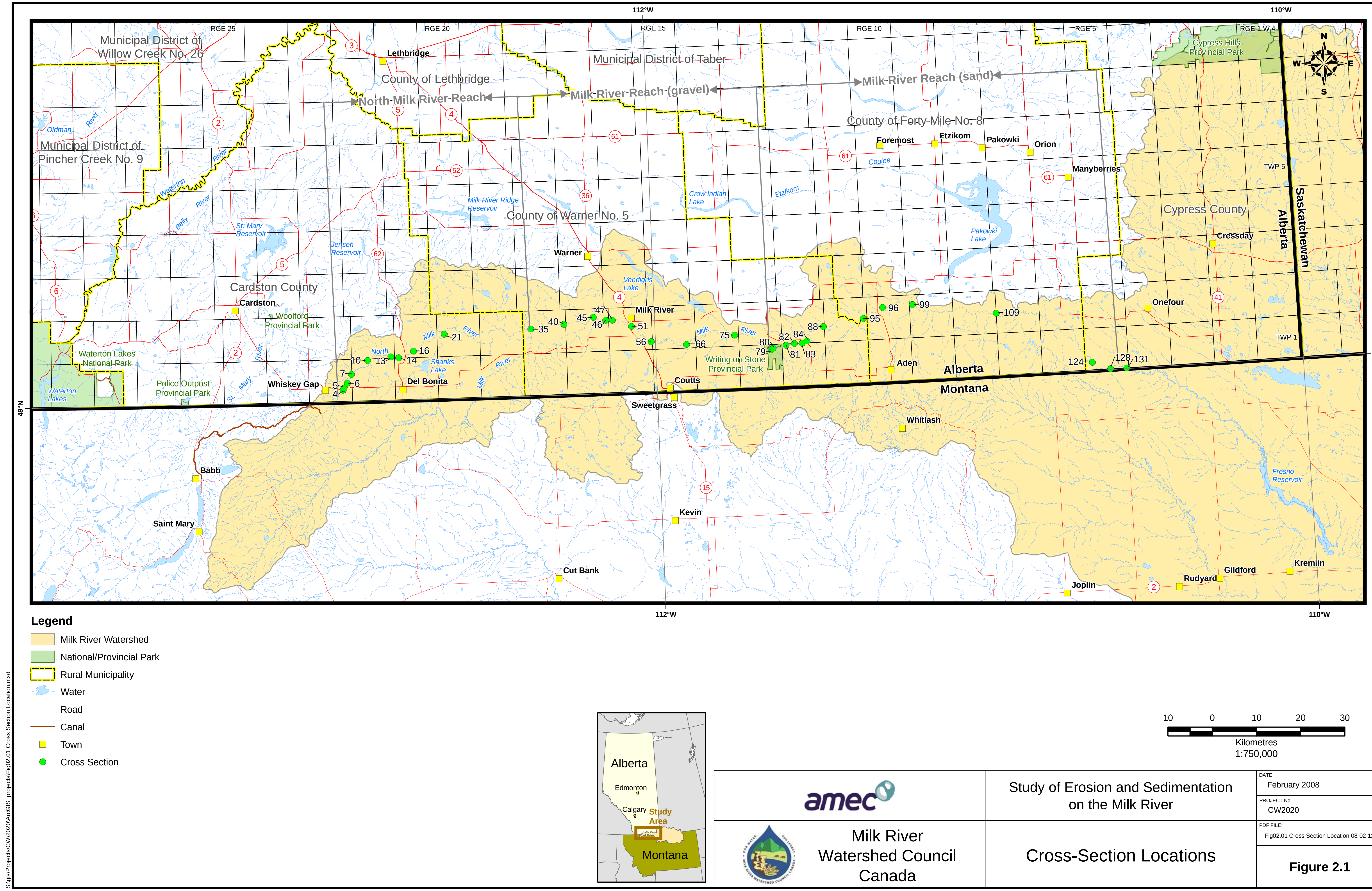
2.1.1 Historic data

The United States Geologic Survey (USGS) and Water Survey of Canada (WSC) have monitored streamflow for various periods at 15 locations in the Milk River Watershed. Of the 15 stations, long-term records exceeding 90 years are available at 5 locations listed in **Table 2.1**. The locations of these 5 hydrometric stations are illustrated on **Figure 2.1**. Data for the 5 station locations provide sufficient hydrological input for model development and calibration, and for projecting future changes in river geomorphology. Information available at the 5 stations includes monthly, daily, and peak instantaneous flows. There were data gaps that were filled at all stations, as discussed later.

TABLE 2.1
Long-Term Milk River Hydrometric Stations

Station Number	Location	Drainage Area (km^2)		Period of Record
		Effective	Gross	
11AA032	North Fork Milk River above St. Mary Canal	149	156	1911 – 2005
11AA001	North Milk River near International Boundary	231	238	1909 – 2006
11AA030 11AA025	Milk River near International Boundary combined with Milk River at Western Crossing of International Boundary	739 946	747 1050	1913 – 1930 1931 – 2005
11AA005	Milk River at Milk River	2460	2720	1909 – 2005
11AA031	Milk River at Eastern Crossing of International Boundary	5280	6490	1909 – 2005

In addition to recorded flows, Alberta Environment (AENV) has reconstructed weekly natural flows at the same 5 locations (shown in **Table 2.1**) for the period 1928 to 2001. Natural flows are estimated by adding upstream recorded or estimated diversions to the streamflow record at hydrometric stations to remove the effects of some of the larger human interventions on the hydrologic regime. Available recorded and natural flow data are required for SAM model development and calibration.



112°W
110°W
49°N
RGE 25
RGE 20
RGE 15
RGE 10
RGE 5
RGE 1 W4
TWP 5
TWP 1
Municipal District of Willow Creek No. 26
Municipal District of Pincher Creek No. 9
County of Lethbridge
Municipal District of Taber
County of Forty Mile No. 8
County of Warner No. 5
Cardston County
Cypress County
North Milk River Reach
Milk River Reach (gravel)
Milk River Reach (sand)
Cypress Hills Provincial Park
Waterton Lakes National Park
Woolford Provincial Park
Police Outpost Provincial Park
Writing on Stone Provincial Park
Lethbridge
Foremost
Etzikom
Pakowki
Orion
Manyberries
Cressday
Onefour
Warner
Milk River
Cardston
Whiskey Gap
Del Bonita
Coutts
Sweetgrass
Aden
Whitlash
Babb
Saint Mary
Kevin
Cut Bank
Joplin
Rudyard
Gildford
Kremlin
Alberta
Montana
Saskatchewan
Oldman River
Waterton River
Belly River
St. Mary Reservoir
Jensen Reservoir
Milk River Ridge Reservoir
Crow Indian Lake
Etzikom Coulee
Pakowki Lake
Vendigris Lake
Shanks Lake
Waterton Lakes
Fresno Reservoir
North Milk River
Milk River
St Mary River
Legend
Milk River Watershed
National/Provincial Park
Rural Municipality
Water
Road
Canal
Town
Cross Section
Alberta
Edmonton
Calgary
Study Area
Montana
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Study of Erosion and Sedimentation on the Milk River
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2.1.2 Future Flow Scenarios

Montana Department of Natural Resources and Conservation (DNRC) and U.S. Bureau of Reclamation (USBR) documents were reviewed to determine whether these agencies have simulated stream flows representative of the future flow regime with an enlarged St. Mary River Diversion capacity (TD & H Engineering Inc., 2006a and 2006b; Ryan, 2006). The objectives of the work carried out by Montana appeared to be to determine changes in diversion canal capacity and apportionment accounting procedures required to enable Montana to capture the full U.S. share of the St. Mary River. While some simulation modelling has been done over a relatively short period (25 years), the model did not extend to the lower reaches of the Milk River in Canada.

In the absence of the required data from DNRC or USBR, the MRWCC requested that Alberta Environment utilize its Water Resource Management Model (WRMM) to simulate flows through Canada for various future canal capacities. The simulated flow data would be analyzed to estimate the flow duration and flood frequency relationships required to estimate future changes in river morphology for increased St. Mary River diversion flow scenarios.

2.2 Data Analysis

2.2.1 Overview

The objective of the hydrology component is to provide the hydrological input necessary to develop and calibrate the U.S. Army Corps of Engineers Sediment Analysis Model (SAM). The key hydrologic requirements for model development, calibration and future scenario runs are flow duration and flood frequency relationships at representative reaches along the Milk River.

For the proposed morphology modelling technique, a key requirement for comparing different flow scenarios, is that the time period that is modelled and the hydrologic analytical techniques used are the same for all scenarios and all locations. Hence, the 74-year period from 1928 to 2001 was selected for the analyses since this is the period that natural flows are available. Future scenarios can be simulated for this period using the AENV Water Resource Management Model (WRMM). The 74-year period is of sufficient length to derive meaningful streamflow statistics.

The hydrologic analyses were restricted to flows during the period from 01 March to 31 October, for the following reasons:

- Flows were not monitored during the winter period at some of the stations.
- St. Mary diversions to the Milk River were zero from the beginning of November to the end of February.
- Milk River flows are usually very low during the winter months and open water river geomorphologic impacts are minimal. Ice impacts are addressed in a separate section of the report.

2.2.2 WRMM Analysis

Simulation modelling to provide flow data for the two future scenarios with enlarged diversion capacities was conducted by Alberta Environment. Characteristics of the modelling and assumptions used were as follows:

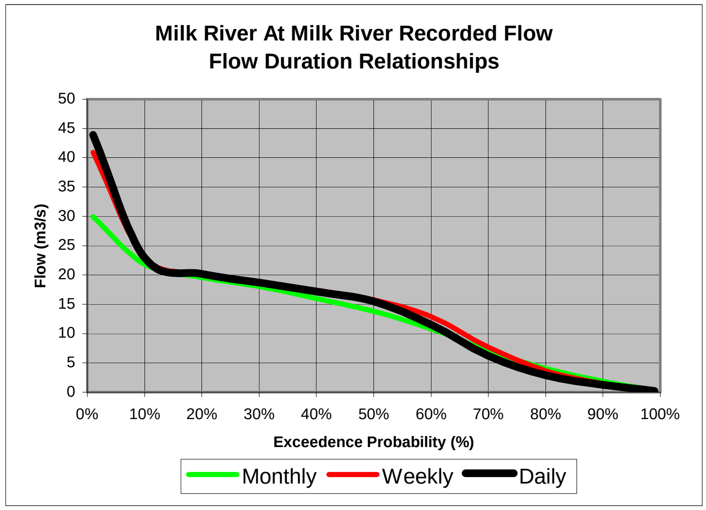
- Flows were simulated over the period from 1928 to 2001. Climatic conditions were incorporated within the simulations. A weekly time step was used in the simulation.
- The current level of water use was assumed (irrigation, municipal, etc.). Water uses were assumed to be at current levels.
- Current apportionment arrangements as per the Boundary Waters Treaty (BWT) and 1921 Order of the International Joint Commission were applied. It was assumed that the diversion works would be operated to divert as much of the U.S. entitlement as allowed, up to the capacity of the diversion works.
- The model simulated flows in the Montana headwaters and as far downstream as the Milk River's eastern crossing of the international boundary.
- Future scenarios considered diversion capacities of 1000 cfs (referred to as "Scen 1000") and 1200 cfs (referred to as "Scen 1200") as measured at the St. Mary syphon. This assumes that seepage losses upstream of the syphon (reported to be 10%) will be controlled by canal lining, or compensated for, by over-diversion upstream of the syphon. Seepage losses upstream of the St. Mary siphon are assumed to return to the St. Mary River. As such, they are not charged against the U.S. entitlement.
- Output was in the form of weekly flow tables for Scen 1000 and Scen 1200.

2.2.3 Flow Duration

The streamflow data for Station 11AA005, Milk River at Milk River, were analyzed to determine the influence of the time step used in the analysis on the flow duration relationship. Time steps considered were monthly, weekly and daily flows. The flow duration data for the three time steps are shown on **Figure 2.2**. The flow duration characteristics are essentially the same for weekly and daily data for exceedance probabilities between 10 % and 50%, which is the range of most interest for use in the SAM model. The time step used for the natural flow data and modelling future scenarios is also weekly. For these reasons, it was decided to base the flow duration analysis on weekly data, keeping in mind that it is comparative information among the various scenarios that is most important rather than absolute values.

Figure 2.2 Flow Duration for Milk River at Milk River for Monthly, Weekly and Daily Time Steps

Exceedance Probability (%)	Discharge (m^3/s)		
	Monthly	Weekly	Daily
1	29.95	40.89	43.90
10	21.80	23.04	22.90
20	19.60	20.23	20.20
30	18.07	18.83	18.70
40	16.00	17.40	17.20
50	13.80	15.76	15.50
60	10.80	12.89	11.50
70	7.07	7.69	6.23
80	4.04	3.63	2.89
90	1.86	1.50	1.25
99	0.313	0.288	0.227



The recorded stream flows for the gauging stations were reviewed for missing data. Data gaps were filled as follows.

- North Fork Milk River above St. Mary Canal – data were missing for substantial periods in March, April and October. It was decided to not use this station for flow duration analysis since the natural flow for the station a short distance downstream, North Milk River near the International Boundary, would provide similar information.
- North Milk River near the International Boundary – missing data in early March 1928 was estimated assuming that uses would be minimal at that time of year. Missing flows were assumed to be equal to the natural flows estimated by AENV.
- Milk River at Western Crossing of International Boundary – missing weekly flow data for 1928 to 1930 were estimated assuming that water uses in these years would be the same as average uses for the same weeks for the period 1931 to 1935. Water uses for the period 1931 to 1935 were estimated as the difference between recorded flows and natural flows estimated by AENV. Actual flows for 1928 to 1930 were then estimated by subtracting the estimated uses from the AENV natural flow values.
- Milk River at Eastern Crossing of International Boundary – missing daily flows for early March in 1928 and 1931 were estimated by correlation with flows at Milk River with a one-day lag. The Coefficient of Determination (R^2) was 0.85.

Weekly mean flow duration decile values were obtained using Excel's data analysis tool (**Tables 2.2 to 2.5**). The exceedance probability indicates the percent of time weekly mean flows are equalled or exceeded for the various scenarios under consideration. The flow duration plots for these locations are included on **Figure 2.3**.

TABLE 2.2
North Milk River near International Boundary Flow Duration Values (m^3/s)

Exceedance Probability (%)	Natural	Recorded	Scen 1000	Scen 1200
1	6.05	21.0	31.9	37.4
10	2.17	19.4	29.3	34.5
20	1.52	18.2	26.0	26.0
30	1.13	17.0	16.6	16.6
40	0.888	15.5	10.1	10.1
50	0.716	12.6	6.33	6.33
60	0.544	5.39	4.62	4.62
70	0.442	1.98	3.68	3.68
80	0.349	1.04	2.80	2.80
90	0.256	0.482	1.49	1.49
99	0.124	0.183	0.306	0.306

TABLE 2.3
Milk River at Western Crossing of International Boundary Flow Duration Values (m^3/s)

Exceedance Probability (%)	Natural	Recorded	Scen 1000	Scen 1200
1	22.6	22.0	22.0	22.0
10	8.37	8.11	8.11	8.11
20	4.86	4.60	4.60	4.60
30	3.01	2.86	2.86	2.86
40	1.93	1.87	1.87	1.87
50	1.26	1.18	1.18	1.18
60	0.877	0.825	0.825	0.825
70	0.565	0.517	0.517	0.517
80	0.329	0.292	0.292	0.292
90	0.076	0.041	0.041	0.041
99	0.000	0.000	0.000	0.000

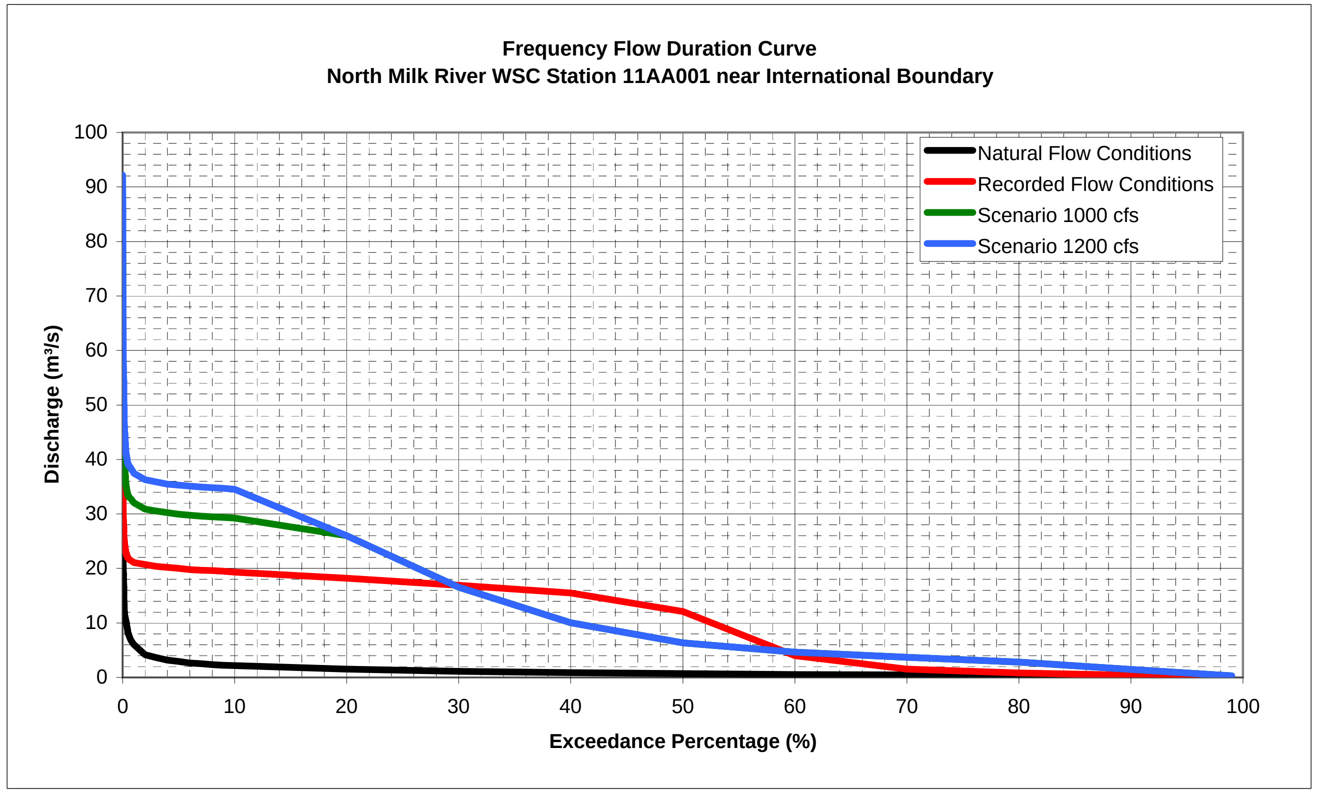
TABLE 2.4
Milk River at Milk River Flow Duration Values (m^3/s)

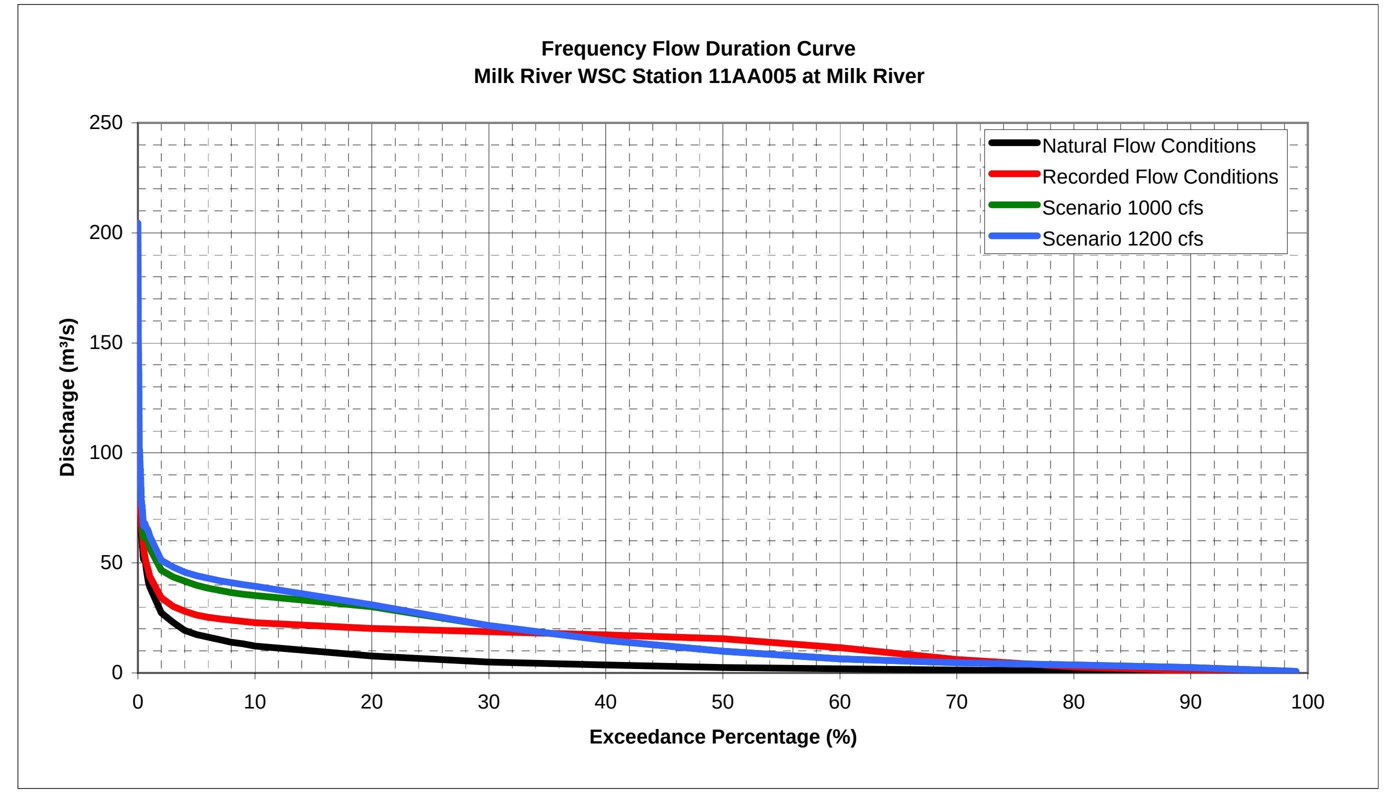
Exceedance Probability (%)	Natural	Recorded	Scen 1000	Scen 1200
1	36.5	40.9	52.8	57.9
10	12.2	23.0	35.2	39.4
20	7.68	20.2	30.2	31.0
30	4.85	18.8	21.5	21.5
40	3.54	17.4	14.9	14.9
50	2.50	15.8	9.83	9.83
60	1.81	12.9	6.46	6.46
70	1.32	7.69	4.64	4.64
80	0.867	3.63	3.58	3.58
90	0.401	1.50	2.51	2.51
99	0.000	0.288	0.729	0.729

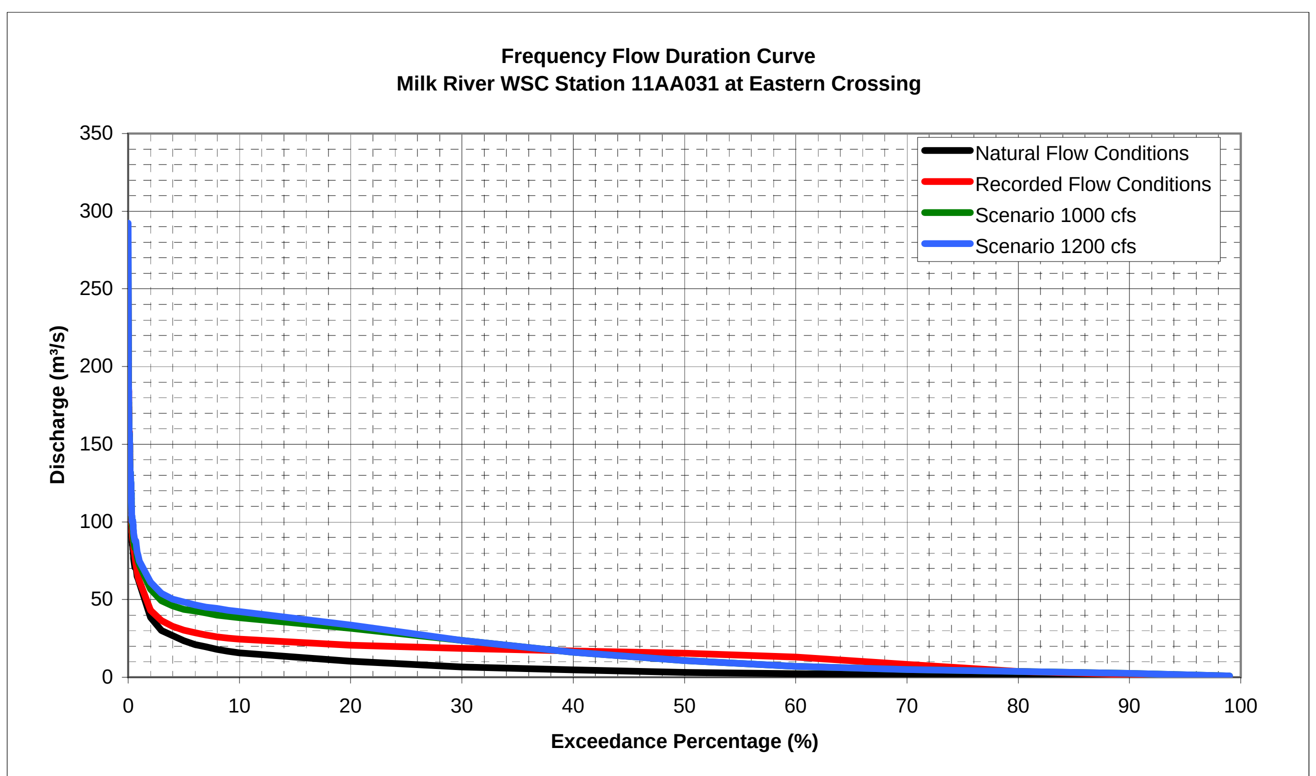
TABLE 2.5
Milk River at Eastern Crossing of International Boundary Flow Duration Values (m^3/s)

Exceedance Probability (%)	Natural	Recorded	Scen 1000	Scen 1200
1	59.4	60.6	71.0	73.2
10	15.6	24.8	38.4	42.3
20	10.3	20.7	31.5	33.6
30	6.69	18.7	23.7	23.7
40	4.71	17.0	16.1	16.1
50	3.11	15.6	10.8	10.8
60	2.24	13.7	7.01	7.01
70	1.56	9.56	4.98	4.98
80	0.966	4.73	3.63	3.63
90	0.377	2.08	2.47	2.47
99	0.000	0.277	0.742	0.742

Daily Mean Flow Duration Curves







Observations from **Tables 2.2 to 2.5** are as follows:

- There is no significant change from the natural condition for the flow duration relationships for the Milk River at Western Crossing of International Boundary. This location is not impacted by the diversion from the St. Mary River.
- For the other three locations, the difference in the flow duration relationship between the natural and recorded conditions is most pronounced for the North Milk River near the International Boundary because of the relatively small drainage area at this location, and the low flows under natural conditions. Diversions from the St. Mary River increased the median flow for the North Milk River by a factor of 18. For the Milk River at the Town of Milk River and Milk River at the Eastern Crossing, median flows were increased by factors of 6.3 and 5.0 respectively.
- For the two future scenarios, Scen. 1000 and Scen. 1200, it is projected that there would be a significant increase over historical flows (recorded flows) at all three locations in 20% to 30% of the weeks. However, it is projected that the median flows would be less than recorded flows for the two future scenarios. This suggests that diversions under low natural flow conditions on the St. Mary River are controlled by apportionment arrangements rather than diversion capacity.

2.2.4 Flood Frequency

The flood frequency analyses were conducted generally following provincial guidelines developed by Alberta Transportation (April 2001). The analyses were somewhat less rigorous than those conducted by Alberta Environment for mapping flood risk areas within communities for purposes of constructing flood control works and implementing land use controls. In such analyses, Alberta Environment searches out evidence of unmonitored flood events to expand the database to the extent possible. That level of effort was felt to be unnecessary for this project since data for less extreme events are of greater interest, and it is the comparison of flood frequency events between the various scenarios that is the key consideration rather than the absolute value.

The recorded flood frequency analysis was based on annual instantaneous flood peaks during the 74-year period 1928 to 2001 at the four hydrometric stations. For all the stations peak instantaneous flows were missing for some years. For all stations except North Fork Milk River above the St. Mary Canal, the missing instantaneous flows could be estimated based on the relationship between peak mean daily flows and instantaneous flows for years when both were recorded. The Coefficient of Determination (R^2) was 0.85 or higher. Monitoring for the North Fork Milk River above the St. Mary Canal hydrometric station was somewhat sporadic. There were over 30 years when both the instantaneous flow and peak mean daily flow were missing. Flood frequency data at this station would be indicative of natural flow of the North Milk River. However, the same information can be obtained from the reconstructed natural flow data for the North Milk River near the International Boundary. Since the characteristics of North Fork Milk River above the St. Mary Canal were not essential to the development and calibration of the SAM model, it was decided to forego filling data gaps and conducting a flood frequency analysis for this station.

HYFRAN software was used to fit three mathematical probability distributions to the 74 recorded and estimated data points at each station: the Log Normal, Pearson Type 3 and Log Pearson Type 3 distributions. Best fit to the recorded flood peaks was determined by comparing the standard deviations, the graphical relationships, and the confidence intervals. The recorded data best-fit distribution determined at each station was utilized for all scenarios at that station, eliminating the possibility that the variation in flood peak flows would be a function of the frequency distribution used.

For the natural flow scenario (Scen. nat), Scen. 1000 and Scen. 1200, only mean weekly databases were available, which necessitated determining relationships between weekly flood peaks and instantaneous flood peaks. Two methodologies were tested for converting weekly flood peaks to instantaneous flood peaks:

a. Regression equations were developed from the recorded weekly and instantaneous databases for each of the four hydrometric stations. In all four cases an excellent relationship was obtained (R^2 equalled 0.99 in all cases). The instantaneous peaks were estimated for the three scenarios based on the weekly flood frequency numbers and the instantaneous/weekly relationships developed from recorded flows.
b. Flood peaks are a function of natural flow due to rainfall and/or snowmelt and the amount of water diverted into the channel. For Scen. nat, the instantaneous peaks for recorded data were decreased by the discharge into St. Mary River water diverted in the Milk River. For Scen. 1000 and Scen. 1200 the instantaneous peaks were obtained by adding the incremental diversion flow to the recorded discharges.

Method a) resulted in unrealistically high estimates of instantaneous flows for Scen. 1000 and Scen. 1200, which suggests that the weekly/instantaneous flood peak relationships for recorded flow does hold for the two scenarios with increased diverted flow. Method b) resulted in reasonable estimates of instantaneous flows for all three scenarios. Method b) was adopted for use in this study.

Flood frequency values for various return periods and probabilities are given in **Tables 2.6 to 2.9**. The probability of exceedance in any year is the reciprocal of the average return period.

TABLE 2.6
Milk River near Western Crossing Flood Frequency Values

Average Return Period (years)	Exceedance Probability in Any Year (%)	Instantaneous Peak Flow (m^3/s)			
		Natural Flow	Recorded Flow	Scen 1000	Scen 1200
200	0.5	222	239	239	239
100	1.0	201	213	213	213
50	2.0	178	185	185	185
20	5.0	144	145	145	145
10	10.0	115	112	112	112
5	20.0	84.0	78.0	78.0	78.0
3	33.3	59.5	52.5	52.5	52.5
2	50.0	38.3	32.7	32.7	32.7
1.43	70.0	19.3	16.8	16.8	16.8
1.25	80.0	10.9	10.7	10.7	10.7

TABLE 2.7
North Milk River near International Boundary Flood Frequency Values

Average Return Period (years)	Exceedance Probability in Any Year (%)	Instantaneous Peak Flow (m3/s)			
		Natural Flow	Recorded Flow	Scen 1000	Scen 1200
200	0.5	107	114	130	133
100	1.0	91.8	100	115	119
50	2.0	76.5	86.3	101	105
20	5.0	56.5	68.2	81.9	86.8
10	10.0	41.6	54.7	67.5	73.1
5	20.0	27.0	41.4	53.3	59.5
3	33.3	17.1	32.4	43.6	49.8
2	50.0	8.90	24.8	35.4	41.4
1.43	70.0	3.00	19.2	29.3	34.5
1.25	80.0	1.64	17.2	27.7	32.2

TABLE 2.8
Milk River at Milk River Flood Frequency Values

Average Return Period (years)	Probability in Any Year (%)	Instantaneous Peak Flow (m^3/s)			
		Natural Flow	Recorded Flow	Scen 1000	Scen 1200
200	0.5%	312	317	328	333
100	1.0%	278	282	290	295
50	2.0%	243	245	252	256
20	5.0%	192	194	201	205
10	10.0%	152	154	161	166
5	20.0%	109	113	122	126
3	33.3%	76.6	82.8	92.8	97.1
2	50.0%	49.3	57.6	68.3	72.4
1.43	70.0%	24.9	35.5	46.3	50.4
1.25	80.0%	14.2	25.8	36.3	40.3

TABLE 2.9
Milk River at Eastern Crossing of the International Boundary Flood Frequency Values

Average Return Period (years)	Probability in Any Year (%)	Instantaneous Peak Flow (m^3/s)			
		Natural Flow	Recorded Flow	Scen 1000	Scen 1200
200	0.5%	383	390	397	399
100	1.0%	349	355	358	360
50	2.0%	312	316	318	320
20	5.0%	256	260	260	263
10	10.0%	208	212	215	218
5	20.0%	155	161	167	170
3	33.3%	112	120	129	133
2	50.0%	75.4	84.2	95.7	99.5
1.43	70.0%	42.3	52.0	64.9	68.7
1.25	80.0%	27.9	37.7	50.6	54.4

Observations from **Tables 2.6 to 2.9** are as follows:

- Flood frequency values for the Milk River near the Western Crossing for Scen. 1000 and Scen. 1200 are the same as the values for recorded flows. St. Mary diversions do not affect flows at this location. Flood flows for most frequencies are slightly lower for the recorded flows than for natural flows because of upstream flow regulation and use.
- Of the three other locations, the difference in the flood flows between the natural and recorded conditions is most pronounced for the North Milk River near the International Boundary. While there is only a modest increase in flood flows for events with a probability of 2% or less, the more frequent flood events have increased substantially. For instance, there is almost a three-fold increase in the annual flood with a 50% probability. The diverted flow comprises a large portion of that flood event. For the Milk River at the Town of Milk River and Milk River at the Eastern Crossing, the 50% flood event increased by 17% and 12%, respectively.
- For the two future scenarios, Scen. 1000 and Scen. 1200, it is projected that there would be a modest increase over historical flood flows (recorded flows) at all three locations. Increases over recorded flows would be most significant for North Milk River where the range from about 15% for the 1% event, to about 65% for the 50% event.

2.2.5 Flow Monitoring

Long-term flow monitoring should be maintained at representative sites to aid in further assessment of flow characteristics and erosion. As discussed above, flow monitoring is presently undertaken by Environment Canada and the US Geological Survey at long-term stations along the Milk River system. The present monitoring is driven by the need for an accurate measurement of the flows diverted from the St. Mary River, and the flow entering and leaving Canada within the Milk River Watershed. Supplementary to their long-term monitoring program in the Milk River Watershed, Environment Canada is known to be gathering additional information on river flows to estimate evaporation losses. Further information can be obtained from Vir Khanna at (403) 292-5310. Alberta Environment is also examining losses due to irrigation withdrawals along the River; contact Dave McGee of Alberta Environment in Lethbridge at (403) 381-5995.

3.0 CHANNEL STABILITY ANALYSIS

Diversion of flow from the St. Mary River into the Milk River Watershed commenced in 1917, resulting in significant impacts to the receiving channel. Previously documented effects of the diversion included channel widening, increased meander cut-off activity and increased sediment yield (McLean and Beckstead, 1987). Potentially, the St. Mary River diversion into the Milk River could be increased in the future resulting in further channel changes.

The objective of the channel stability analysis is to evaluate the impacts to the Milk River morphology, resulting from: (1) the existing diversion that has been operating since 1917; and (2) potential future increases to the St. Mary diversion to 28.3 m^3/s or 1,000 cfs (referred to as "Scen. 1000") and to 34.0 m^3/s or 1,200 cfs (referred to as "Scen. 1200"). The impact of the existing diversion and potential future diversions on the morphology of the Milk River were assessed by comparing historical surveys and air photographs and utilizing available hydrologic and suspended sediment data to undertake sediment budget and regime analyses.

3.1 Background Information

The following information sources were utilized for the channel stability analysis:

- The report *Sediment Data Milk River Watershed*, M. 0. Spitzer, Water Survey of Canada, Calgary, Alberta, January 1988 IWD-WNR(A) – WRB-SS872. Sediment data were collected in the mid-seventies and the early eighties at seven gauging stations situated along the reach of the Milk River from above the western crossing of the International Boundary to immediately below its re-entry into the U.S.A. at its eastern crossing of the International Boundary. The Spitzer report documents the available sediment information, presenting the data in various tabular and graphical formats. In particular, for each gauging station, varying amounts of the following data are documented and discussed:
  - descriptions of the gauging station sites (including air and ground photos);
  - hydrometric details at the gauging stations sites;
  - suspended sediment data (concentration, load and particle size);
  - bed material data;
  - dissolved solids data; and,
  - bed load data (only at the Eastern Crossing site).

  The data are contained in individual appendices for each gauging station, while comparisons among the sites are contained within the main body of the report. For the most part, sufficient data are available to allow reasonable estimates of sediment loadings at various points along the Milk River reach, but these estimates must be based on procedures other than single line regression sediment discharge ratings.
- *Long Term Effects of an Interbasin Diversion on the Milk River*, McLean and Beckstead, (1987) proceedings of the Symposium on Interbasin Transfer of Water Impacts and Research Needs for Canada, National Hydrology Research Centre, Canadian Water Resources Association, Saskatoon, Saskatchewan, 09 and 10 November 1987. A copy of this paper is attached in ***Appendix A***. The McLean and Beckstead (1987) paper reviewed many of the same issues as the current AMEC study and is discussed in greater detail in a subsequent section of this report.

- *Long Term Effects of a River Diversion on the Regime of the Milk River*, 1981, D. G. McLean and G. R. Beckstead is an earlier paper that covers similar material as the paper discussed above. A copy of this paper is also attached in ***Appendix A***.
- The earliest surveys of the river are the legal surveys of 1898–1906 (Alberta) and 1906 (Montana). In 1909, F. H. Peters, Chief Hydrographer, Dept. of the Interior, established seven hydrometric stations along the North Milk and Milk River (**Figure 2.1**) and made estimates of bankfull channel geometry and discharge capacity (Peters, 1910). The hydrometric stations on the North Milk River (llAAOO1), at Milk River town (11AAOO5), and at the Eastern Crossing (11AAO31), have been maintained over the last 90 years. Between 6 July and 27 November 1915, Peters' crews surveyed 131 cross-sections along the entire Canadian portion of the river. A detailed planimetric map was prepared showing the channel and adjacent floodplain. Bed and bank materials, vegetation and other cultural features were frequently noted.
- The first air photo survey of the river was made in 1922 and photos are available for many other years. In 2007, PFRA prepared a comparative overlay of channel location at Milk River Town, which clearly shows historic channel migration. These overlays are presented in **Figures 4.4 and 4.5**, and are based on the AENV maps attached in ***Appendix D***.
- AENV conducted repeat surveys in 1979 and 1980 at 20 of Peters' cross-sections on the North Milk River and at 26 cross-sections on the Milk River. Additional surveys were made at three above mentioned hydrometric stations.
- As part of the current study, AMEC undertook repeat surveys in 2007 at 10 cross-sections on the North Milk River and 11 cross-sections on the Milk River.
- Flow Duration Curves (FDC) and flood frequencies contained in the Hydrology section of this report (**Section 2.0**).

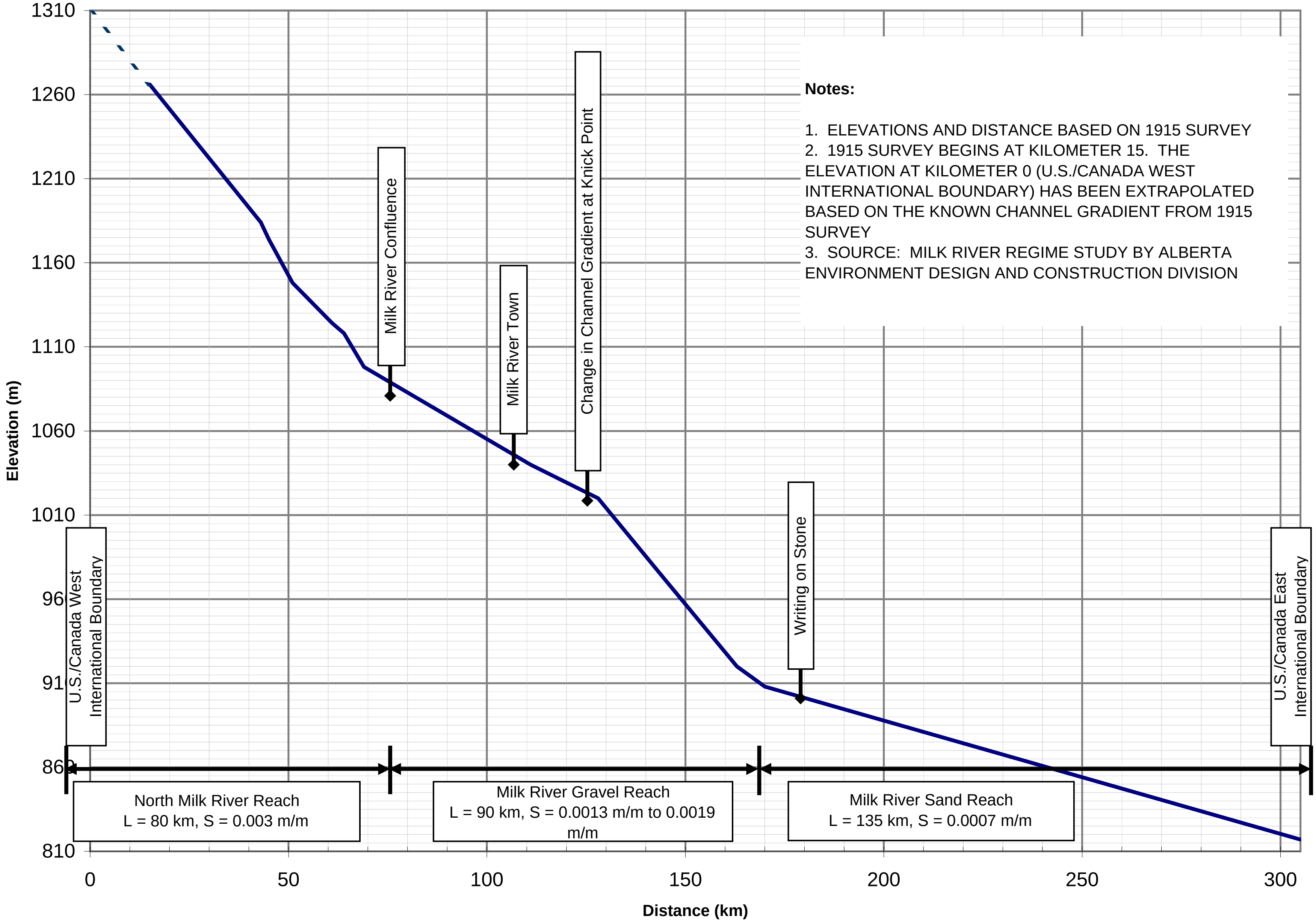
3.2 Study Area

The study area is illustrated on **Figure 1.1**. The total length of Milk River channel in Canada that conveys the diversion flow is 315 km. **Figure 3.1** is a profile of the North Milk River and the Milk River channel that conveys the diversion flows. The study area was sub-divided into the following three reaches:

- The regulated portion of the North Milk River from the U.S. border to the confluence with mainstem Milk River. Hydrologic and streambed gradation characteristics for this reach are based on WSC gauge North Milk River near International Boundary (#11AA001).
- The regulated Milk River from the North Milk River confluence to 15 km upstream of Writing-on-Stone Park, referred to herein as the 'Gravel Bed Reach'. Hydrologic and streambed gradation characteristics for this reach are based on WSC gauge Milk River at Milk River (#11AA005).
- The regulated Lower Milk River which extends from Writing-on-Stone Park to the Eastern Crossing on the Alberta-Montana border, referred to herein as the 'Sand Bed Reach'. Hydrologic and streambed gradation characteristics for this reach are based on WSC gauge Milk River at Eastern Crossing of International Boundary (#11AA031).

The South Branch Milk River, which is unregulated, from the U.S. border to the confluence with North Milk River was not reviewed in this study since it is not subject to diversion flows.

Milk River Channel Profile



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02/14/20089:57 AM

Figure 3.1

3.3 Physiographic and Channel Description

Spitzer (1988) contains the following physiographic description:

> *"The valley of the Milk River, broad in the western portion and canyon type in the east, was not cut by the stream, but rather is the result of the last ice age some 10,000 years ago, when water from the melting ice cut a series of wide channels. Because ice still blocked the natural runoff to the north, the Milk River received meltwater from the Saskatchewan River drainage area and therefore became a wide torrent, carving a large valley. Ultimately, the present drainage system became established, leaving a much shrunken Milk River in an oversized valley.*
>
> *Most of the physical landscape of the basin is a broad, gentle rolling plain through which the Milk River valley is cut.*
>
> *The North Milk River and much of the upper Milk River flow is in a stream cut valley along the course of a much older pre-glacial drainage channel. As a result, the valley is generally wide (up to about 2 km) and has walls composed of glacial till or other valley fill sediments, underlain by sandstone. Occasionally, the river has been deflected outside the course of its pre-glacial channel and in these places the valley is steep-walled and narrow.*
>
> *Downstream of Milk River townsite several wide coulees intersect the Milk River valley. These coulees represent former glacial meltwater channels which flowed at the end of the last continental glaciation. For most of its lower course the Milk River flows in one of these meltwater channels. Throughout part of this lower reach the combination of low rainfall, lack of vegetation and presence of erodible valley deposits has produced extensive areas of badlands which contribute large quantities of silt and sand sized sediment to the Milk River."*

In this study, existing channel conditions, which have resulted from diversion flows since 1917, are referred to as 'recorded' since this is the same period that the WSC streamflow gauges have been operational. Pre-diversion conditions (i.e. prior to 1917) are referred to as 'natural'. Typical channel characteristics for 'natural' and 'recorded (existing)' conditions for each of the study reaches are listed in **Table 3.1** and discussed in the following sections.

The channel slope for the Milk River 'Gravel Bed' reach changes from 0.0013 to 0.0019 m/m, approximately 20 km downstream of Milk River Town (**Figure 3.1**). This distinct change in channel slope is likely due to a geologic control (possibly bedrock or an armour layer) at this location.

TABLE 3.1
Natural (Pre-diversion) and Recorded (Existing) Channel Characteristics

Reach	North Milk River		Milk River Gravel Bed Reach		Milk River Sand Bed Reach	
Parameter	**Natural**	**Recorded**	**Natural**	**Recorded**	**Natural**	**Recorded**
Depth[1] (m)	2.2	2.2	2.6	2.6	1.85	2.2
Width (m)	14 to 30 mean 22	26 to 53 mean 33	32 to 83 mean 57	45 to 85 mean 59	38 to 96 mean 70	71 to 120 mean 96
Slope (m/m)	0.003	0.0035	0.0013 to 0.0019	0.0013 to 0.0019	0.0007	0.0006
$Q_{1:2}$ year (m^3/s)	8.9	24.8	49.3	57.6	75.4	84.2
Median Annual (50% exceedance) Discharge (m^3/s)	0.72	12.6	2.5	15.8	3.1	15.6
20% exceedance Discharge[2] (m^3/s)	1.52	18.2	7.68	20.2	10.3	20.7
Surface Gradation D_{50} (mm)	30		16		0.15	
Sub-Surface Gradation D_{50} (mm)	22		7			
Daily Mean Suspended Sediment[3] (mg/L)	16.3	49.0	72.5	224.2	556.2	1168.0

Notes:

1. Depth is equivalent to maximum channel depth; it is measured from the top-of-bank to the channel thalweg (minimum streambed elevation).
2. The 20% exceedance discharge provides some indication of the higher range of diversion discharges. These discharges are equaled or exceeded 49 days of the year.
3. Daily Mean Suspended Sediment Concentration is based on the following sediment rating curves from Spitzer (1988): **Figures B-9** (North Milk), **D-9** (Milk Gravel), **G-9** (Milk Sand). The concentration is based on the 20% exceedance discharges discussed above.

3.3.1 North Milk River

McLean and Beckstead (1987) contain the following description of the North Milk River:

> *"Prior to the diversion the North Milk River had an irregular, confined meander pattern and displayed alternating pools and riffles. The channel was composed of gravel and sand and the banks were described as predominantly sandy loam (Peters, 1910). Abandoned meander scars on the floodplain indicate that channel shifting and cut-off activity occurred prior to the diversion. Comparison of the early township surveys with Peters' maps showed five cut-offs took place, in the 15 years before the diversion started."*

3.3.2 The Milk River Gravel Bed Reach

McLean and Beckstead contain the following description of the Milk River 'Gravel Bed Reach':

> *"The Upper Milk River had a meandering gravel-bed channel with silty or sandy loam banks. The channel was frequently confined by valley walls composed of stony clay or sandstone. The channel was considerably larger than the North Milk branch due to the large drainage area contributed by the South branch."*

3.3.3 The Milk River Sand Bed Reach

McLean and Beckstead contain the following description of the Milk River 'Sand Bed Reach':

> *"The Lower Milk River displayed a regular meander pattern in 1915 and contained frequent sand waves, mid-channel bars and shoals. Due to a combination of erodible valley wall deposits, lack of vegetation and the occurrence of hydraulic piping in the canyon walls, extensive area of badlands have developed along the Lower Milk River. These areas contribute large quantities of sand and silt sized sediments to the river (Barendregt and Ongley, 1979)."*

3.3.4 Sediment Transport

The following description of sediment transport is contained in McLean and Beckstead (1987):

> *"The Milk River was named by the American explorers Lewis and Clark on account of its high sediment concentrations during spring runoff. Their journal entry for 08 May 1805 states:*
>
>> *'The waters of the river possess a peculiar whiteness being about the colour of a cup of tea with the admixture of a tablespoon of Milk. From the colour of its waters, we called it Milk River.'*
>
> *The first suspended load measurements were collected in 1905 and 1906 at Havre, Montana, 85 km downstream of the Eastern Crossing near its confluence with the Missouri River (Dole and Stabler, 1909; Stabler, 1911). These pre-diversion measurements, which were collected during relatively low flows, provided an estimated sediment load of 300,000 tonnes/year. Additional suspended load measurements were collected at Havre in 1930 and 1931 to provide estimates of sedimentation in Fresno Reservoir (U.S. Engineering Dept., 1933). These measurements indicated seasonal loads of 205,000 tonnes in 1930 and 300,000 tonnes in 1931."*

Spitzer (1988) contains the following discussion on suspended sediment loads on the Milk River:

> *"A limited amount of suspended sediment discharge data are available for sites along the reach of the Milk River. Sediment discharge data are available for North Milk River near the international Boundary (11AAOO1) in 1975, 1976 and 1981; for Milk*

River at Milk River (11AAOO5) in 1981 and 1982; and for Milk River at Eastern Crossing (11AAO31) in 1975, 1981 and 1982. These data are shown by month, in Table 9, along with monthly mean discharges.

By reviewing Table 9 it readily becomes apparent that the sediment load increases dramatically from the upper reach to the lower reach of the Milk River. The most graphic illustration of this is May of 1981, when the recorded sediment discharge at North Milk River near the International Boundary was 2,500 tonnes, at Milk River @ Milk River it was 31,000 tonnes, while at Milk River at Eastern Crossing it was 287,000 tonnes. The mean flows for May for the three sites respectively, were 16.7, 26.4 and 29.8 m^3/s.

Another aspect of sediment discharge in this basin, which Table 9 highlights, is the tendency for the suspended sediment discharge to decrease with the progression of the year in spite of flows remaining fairly constant. Several examples are June to July 1975 at North Milk River near the International Boundary, when the mean monthly flow increased from 6.14 to 8.64 m^3/s, but sediment discharge decreased from 8,600 to 1,800 tonnes. Similarly, in 1982 the sediment discharge at Milk River @ Milk River from April to May dropped from 87,000 to 22,000 tonnes, but the mean monthly flow actually increased from 20.5 to 20.7 m^3/s.

The data in Table 10 further exemplifies the large increase in sediment load in the downstream direction of the Milk River. In 1975 the seasonal load at North Milk River near the International Boundary was 18,900 tonnes, whereas at Eastern Crossing it was 1,730,000 tonnes, nearly a 100-fold increase. The south fork of the Milk River joins the north fork between these two sites, but it is evident from Table 10 that It is not a great contributor of suspended sediment (on average, approximately one-half of the north fork contribution). Similarly, from Table 10, it is evident that the greatest contribution to the suspended sediment load arises between the Town of Milk River and Eastern Crossing.

Bed load measurements have only been made at Milk River Eastern Crossing (11AAO31). In all, three measurements were made in 1976. The results of these measurements indicated that bed load discharge composes less than 5% of the total sediment discharge at the gauge site.

3.3.5 Findings of McLean and Beckstead (1987)

The McLean and Beckstead (1987) paper reviewed many of the same issues as the current AMEC study. The findings of the paper included:

- *The St. Mary diversion induced substantial channel enlargement and cut-off activity on the North Milk River. The greatest cut-off activity occurred up to 35 years after the diversion started. This interval could be interpreted as the time required for the channel pattern to respond to the change in flow regime. Some of the average cross-sectional changes* *observed on the North Milk River could have been predicted quite closely from simple empirical regime methods. However, the cut-off activity and time period required for channel changes to occur could not have been predicted at the present time. Present-day one-dimensional mathematical models would not have provided very useful predictions since most channel changes involved adjustments to the river's plan form.*

- *The greatest impacts from the diversion occurred on the North Milk River where the magnitude and duration of floods were significantly increased. Comparison of the 1915 floodplain maps with historical air photographs and recent topographic maps showed 35 cut-offs occurred along the North Milk River after the diversion started. As a result, nearly 25% of all meanders present in 1915 have developed cut-offs.*
- *The main effect of the cut-offs has been to decrease the channel sinuosity by about 7% and to increase the overall channel slope. Comparison of the channel cross-section surveys showed the average bankfull width on the North Milk River increased from 23 m (range 14–32 m) in 1915, to 31 m (range 23–38 m) in 1980.*
- *Some cross-sections indicated bankfull stage had also increased along the channel due to overbank sedimentation. Comparison of bed elevations showed that general degradation has not occurred along the river. The lack of significant degradation is probably mainly due to the presence of relatively coarse gravel sediments in the streambed.*
- *At the North Milk River hydrometric station the water level at the gauge lowered systematically between 1917 and 1937. It is believed that this shift reflects the increase in the river's channel width rather than degradation.*
- *The most active period for cut-offs and sinuosity changes occurred between 1939 and 1952, up to 35 years after the project had started.*
- *Comparison of historical air photos and maps showed that no major channel pattern changes or cut-off activity occurred on the mainstem Milk River between 1915 and 1980. Furthermore, no long-term channel pattern changes were observed on the unregulated South branch.*
- *The repeat channel surveys showed no change in width occurred along the gravel bed Upper Milk River (referred to as Milk River Gravel Bed Reach in the AMEC study) between 1915 and 1980. Some widening was measured along the sand bed Lower Milk River, although these changes were not statistically significant (at $\alpha = 0.01$). Net aggradation of approximately 0.5 m was also measured along this lower reach.*
- *It appears the net bank erosion along the North Milk River has constituted only a small fraction (less than 10%) of the total sediment yield in the Milk River Watershed. The most important sediment sources in the basin appear to be situated along the lower reach of the river in the badlands.*
- *The changes in meander pattern, channel width and bankfull capacity observed on the North Milk River are interpreted to represent the long-term response of the channel to the increased discharges from the diversion. It appears the North Milk River required more than 50 years to adjust its channel pattern to the change in the discharge regime.*

3.4 Channel Stability Approach for Current Study

The approach selected to evaluate existing and potential future diversion flow impacts to the Milk River morphology is based on the following: 1) the results of the long-term continuous simulation WRMM modelling, which determined stream flows for various scenarios for the period 1928 to 2001; 2) compilation from a physical process model (SAM) to predict how changes in stream flow will affect the physical structure of the channel; and 3) 'regime' approach analyses to predict channel impacts and compare with the results of the SAM model. The first item is the WRMM modelling as discussed in **Section 2** of this report. The selected approach for the channel stability modelling (i.e. SAM model) is discussed in this section.

The following conditions were evaluated within the channel stability analysis:

- natural (pre-diversion) conditions;
- recorded (existing) conditions; and,
- potential future diversion scenarios.

Since channel cross-sections surveys are available for both natural and recorded conditions, the validity of the SAM model and 'regime' estimates for these conditions can be compared to the measured data. This comparison of predicted and measured values can be utilized as the basis for evaluating the impacts from the potential future diversion scenarios.

3.5 Regime Theory and Definition of Channel Forming Discharge

Regime theory states that an alluvial channel adjusts its width, depth and slope in accordance to the amount of water and amount and kind of sediment supplied. Regime channels are those flowing in their own sediment. Regime theory is an important geomorphic concept to assess channel stability.

An important aspect of regime theory is the use of a single representative discharge to determine stable channel geometry. The following explanation of this single representative discharge is contained in Biedenharn *et al.* (2000):

> "*This representative discharge has been given several names by different researchers including dominant discharge, channel-forming discharge, effective discharge, and bankfull discharge. This has led to some confusion. In this report the channel forming discharge and the dominant discharge are equivalent.*
>
> *Channel-forming discharge can be estimated using one of three prescribed methodologies. One such deterministic discharge is the bankfull discharge, which is the discharge that fills the channel to the top of its banks. Another deterministic discharge used to represent the channel-forming discharge is a specified recurrence interval discharge, typically between the mean annual and 5-year peak. This report focuses on a third approach to determine the channel forming discharge, known as the effective discharge. The effective discharge transports the largest fraction of the*

> *bed material load. Because of this, the effective discharge can be a good estimator for channel-forming discharge.*"

The terminology selected for this study, follow the definitions provided above and are summarized below:

Q_{eff} = effective discharge;
Q_{ri} = recurrence interval discharge = $Q_{1:2}$ = 1:2 year recurrence interval flood;
Q_{cf} = channel-forming discharge.

Doyle *et al.* (2007) summarize the importance of using an approach based on general physical principals (i.e. Q_{eff}) rather than relying strictly on an empirically defined and assumed equilibrium state (e.g. regime method):

> "*The construction of a cumulative sediment discharge curve and associated determination of Q_{eff} allows quantification of the sediment budget of a channel for a given hydrologic regime, which provides process-based insight of drivers of current and future trajectories of channel stability, and is thus the recommended measure of channel-forming discharge. Reliance on only return-interval or bankfull discharge for channel design is not recommended for channel design activities."*

3.5.1 Sediment Budget Analysis and the SAM Model

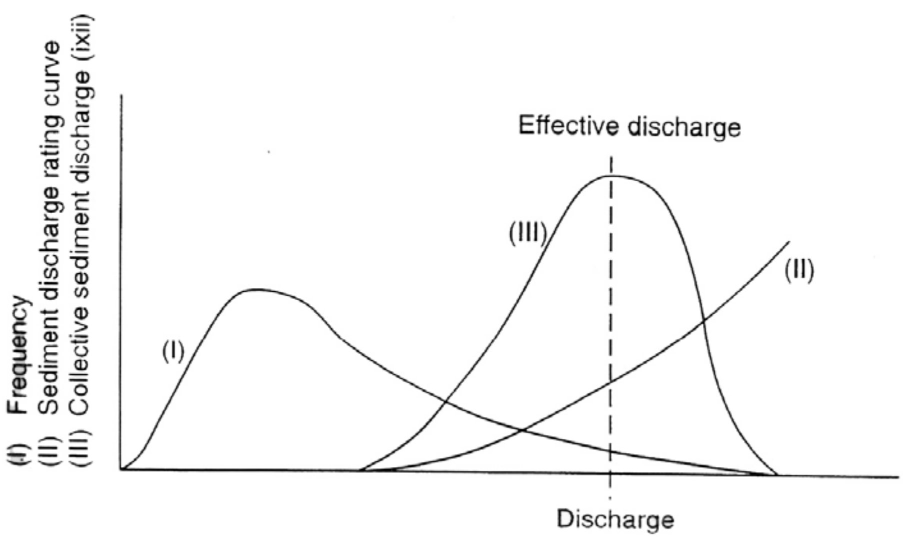
This section describes the physical process model employed to predict how changes in stream flow will affect the physical structure of the channel. The term 'effective discharge' is defined as the discharge that transports the largest fraction of the bed material load (Biedenharn *et al.*, 2000). For example, although a single 100-year flood transports more sediment than a single 2- to 5-year event, the cumulative amount conveyed over the long-term by the more frequent 2- to 5-year events would be greater and would be the effective discharge.

The U.S. Army Corps of Engineers (1994) contains a summary of various methods available to assess channel stability. Many of these methods are based on a single discharge (typically the effective discharge) or a critical shear stress value related to bed material size. The 'effective discharge and sediment impact assessment' approach was selected in this study to analyze the impacts of increased diversion flows on the existing channels. The main advantage of this method is the ability to simulate sediment transport for the entire range of discharges rather than just a single effective discharge value. The U.S. Army Corps of Engineer hydraulic design package, Sediment Analysis Model (SAM) (Thomas *et al.*, 2002), provides the tools to apply this method. The SAM approach includes both bed load transport and sediment yield equations.

The primary purpose of applying the effective discharge and sediment impact assessment approach for this project is to provide indicators related to channel stability and erosion potential, in relation to diversion discharges. This approach is not intended to provide accurate estimates of sediment transport and yield.

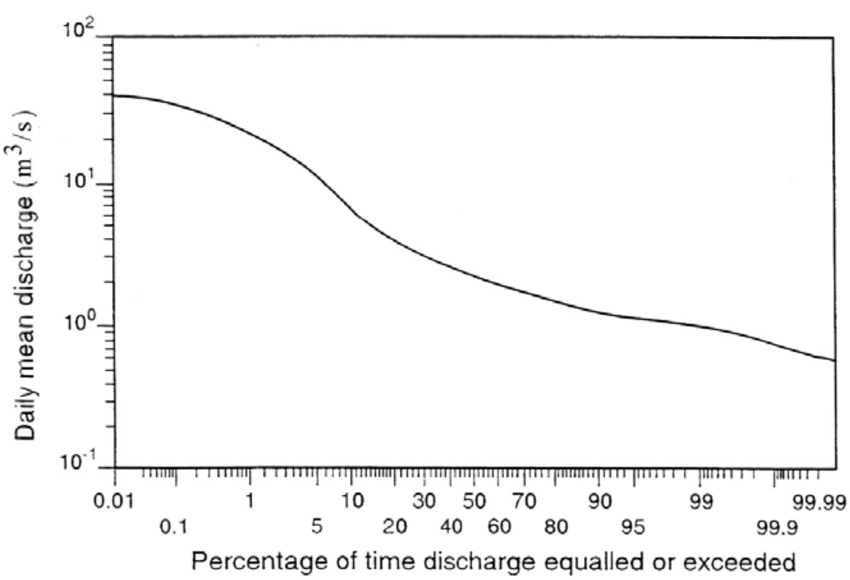
The methods and discussion contained herein are based on Biedenharn *et al.* (2000) and Thomas *et al.* (2002) and are shown schematically on **Figure 3.2**. Curve I is the frequency of various discharges and is derived from the flow duration curve, an example of which is shown on **Figure 3.3**. Curve II, shown on **Figure 3.2**, is the sediment rating curve, which is the relationship between discharge and sediment transport. Curve III, illustrated on **Figure 3.2**, is a histogram of the sediment load conveyed by a stream over an extended period of time, which is obtained by multiplying flow frequency (Curve I) by the sediment transport rating curve (Curve II). The total sediment yield over this duration is the area under Curve III. Channel stability can be evaluated by comparing sediment yields for 'existing flow' and 'post-development flow' scenarios since sediment transport potential serves as a measure of erosion potential (McRae, 1994), hence channel stability.

Figure 3.2 Derivation of Total Sediment Load Discharge Histogram



(Source: Biedenharn, 2000)

Figure 3.3 Daily Mean Flow Duration Curve



(Source: Biedenharn, 2000)

3.5.2 Sediment Transport and Sediment Yield

To determine sediment transport for the entire discharge range, both an annual flow duration curve and a sediment discharge rating curve are developed, as described below. The basic approach is to divide the range of discharges into a number of equal arithmetic classes and then calculate the total sediment load for each flow class. This is achieved by multiplying the frequency of occurrence (Curve I on **Figure 3.2**) of each flow class by the median sediment load for that flow class (Curve II on **Figure 3.2**).

- Flow Duration Curve: grouping of the discharge data is accomplished using a flow duration curve, which is a cumulative distribution function of discharges at a particular location. The flow duration curve is based on approximately 74 years of weekly discharge data that were developed from the WRMM modelling outlined in **Section 2**. **Figure 3.3** is an example of a flow duration curve. The flow duration curve defines the percentage of time a particular discharge is equalled or exceeded. The frequency of occurrence of each discharge class is calculated from this curve.
- Sediment Rating Curve: suspended sediment data is available for the Milk River (Spitzer, 1988) and these were used to 'calibrate' the U.S. Army Corps of Engineer hydraulic design package, Sediment Analysis Model (SAM), (Thomas *et al.*, 2002), by selecting sediment transport equations that provided good agreement with the measured data. SAM, also contains the "SAM aid" utility to assist in the selection of a suitable bed-load transport equation.

A sediment yield analysis (the integration of the flow duration curve with the sediment discharge rating curve) is undertaken to describe the distribution of sediment transporting flows for the various scenarios (i.e. 'natural', 'existing flow', and 'potential diversion'). Comparing 'natural' to 'existing flow' sediment load regimes provides an indication of the channel's sensitivity to future stream flow changes due to the 'potential diversion' scenarios. Various 'potential diversion' scenarios can be evaluated to determine their impact on sediment yield. This comparison of scenarios is discussed in the next section.

3.5.3 Comparison of Flow Scenarios

The impact of diversion flows on long-term channel stability were evaluated using a sediment budget analysis. A Capacity Supply Ratio (CSR) provides the means to compare the sediment load regimes for: (1) 'natural flow' and 'existing flow'; and (2) 'existing flow' and 'potential diversion flows'. Since the impacts of the 'existing flow' diversions to the channel morphology are documented, an indication of future impacts can be determined by comparing the CSRs for the two cases discussed above. The CSR definition and methodology are summarized below.

The 'existing condition' Capacity Supply Ratio (CSR) is defined as the bed material load transported by the 'existing diversion flow regime' due to the sequence of flow events over an extended time period divided by the bed material load transported by the 'natural flow regime'' over the same time period. These loads are calculated by a numerical integration of a sediment transport rating curve and the flow duration curve. A CSR close to unity indicates similar existing and past sediment regimes. Values greater than 1.0 indicate potential erosion and degradation (lowering of the channel bed) and values below 1.0 indicate potential aggradation (raising of the channel bed due to sediment deposition). Diversion into a basin increases flows, resulting in CSRs greater than 1.0, indicating that degradation and erosion will likely occur. The amount that the CSR is greater than 1.0 provides a general indication on the severity of the degradation and erosion.

The 'potential diversion' Capacity Supply Ratio (CSR) is defined as the bed material load transported by the 'potential diversion flow regime' due to the sequence of flow events over an extended time period divided by the bed material load transported by the 'existing flow regime'' over the same time period.

Channel stability can be evaluated by comparing sediment yields for 'natural flow' and 'recorded (existing) flow' or 'recorded (existing) flow' and 'potential future diversion' scenarios since sediment transport potential (i.e. the CSR) serves as a measure of erosion potential McRae (1994), hence channel stability.

3.6 Channel Stability Evaluation Using SAM and Regime Methods

The two methods used for this study to evaluate the impact on the Milk River of the diversion flows are the sediment budget approach, utilizing the SAM model, and the regime approach. The following section contains a discussion of the SAM model calibration. Subsequent sections contain a discussion of various conditions evaluated utilizing both the SAM model and regime methods. Sample SAM model output is included in **Appendix E**.

3.6.1 SAM Model Calibration

Spitzer (1988) contains simulated estimates of mean annual suspended sediment discharge for the period 1960 to 1985. These simulated estimates are based on sediment rating curve regression equation for sites along the Milk River. An adjustment factor is used to provide load estimates much closer to computed loads than does the unadjusted rating curves. The simulated data contained in Spitzer (1988) is shown in **Table 3.2**. Spitzer (1988) contains the following discussion of the simulated data:

> *Having stated that simulated data is available, extreme caution should be used in utilizing these data. The simulated data are derived from simple single regression curve fits which are gross simplifications of concentration versus discharge relations, particularly where hysteresis is evident and where the flow regime is controlled. This is particularly true for sites in the upper Milk River Watershed and in fact, a standard regression equation should not be used for "North Milk River near the International Boundary". The procedure becomes somewhat more valid in the downstream direction. In the upper reaches of the Milk River, there is a hysteresis effect where spring flows carry more sediment than do summer flows of the same magnitude. These loops diminish in the downstream direction, but are still evident even at Milk River at Eastern Crossing. Much of this loop effect can be attributed to the relatively constant summer diversion flow levels. As time progresses, less material becomes available for suspension, but the diversion effect lessens in the downstream direction.*

A comparison has been made between simulated and computed seasonal loads. At the North Milk River near the International Boundary, where three years of seasonal load data are available, the simulated load data, as a percent of the computed load, varied from 42 to 131%; needless to say, a wide disparity. For the Milk River at Milk River, for two years of load data, the differences were 111% and 71%, and at Milk River at Eastern Crossing the differences were 86, 96 and 186% for the three years of available load data.

TABLE 3.2
Measured and Calibration Suspended Sediment Loads

Station	Reach	Measured Spitzer (1988) Simulated Mean Annual Suspended Sediment Discharge 1960 to 1985 (tonnes)	SAM Model Calibration Estimated Mean Annual Sediment Discharge 1960 to 1985 (tonnes)
North Milk River nr Int'l Boundary	North Milk River	15,100	6,600 to 15,700
Milk River at Milk River	Milk River 'Gravel Bed'	111,000	28,300
Milk River at Eastern Crossing	Milk River 'Gravel Bed'	642,000	331,500 to 767,000

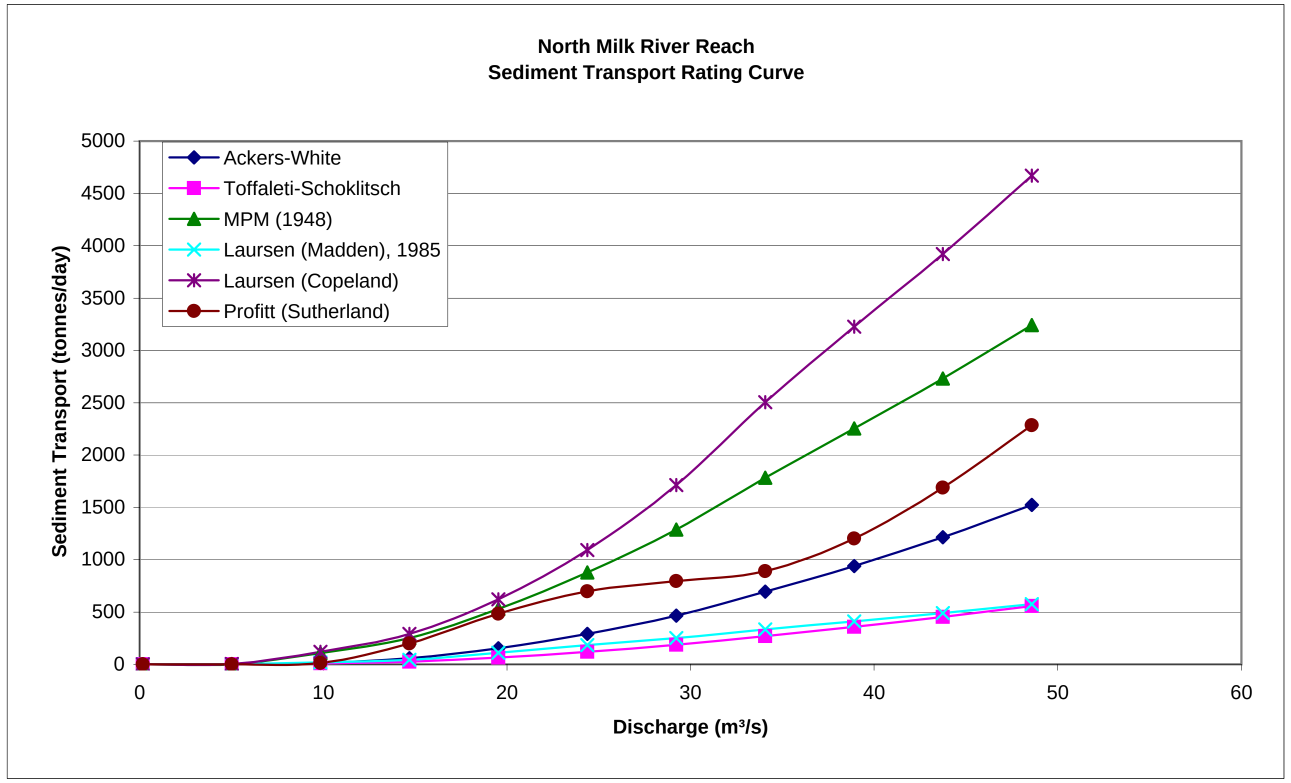
The SAM model was utilized to estimate sediment discharge for the period 1960 to 1985, which is the same as the period simulated by Spitzer (1988). The sediment transport equations in the SAM model that provided reasonable agreement with the simulated Spitzer data were selected for the channel stability modelling of existing, natural and potential future diversion scenarios. The range of estimates for the selected equations from the SAM model are shown in **Table 3.2**.

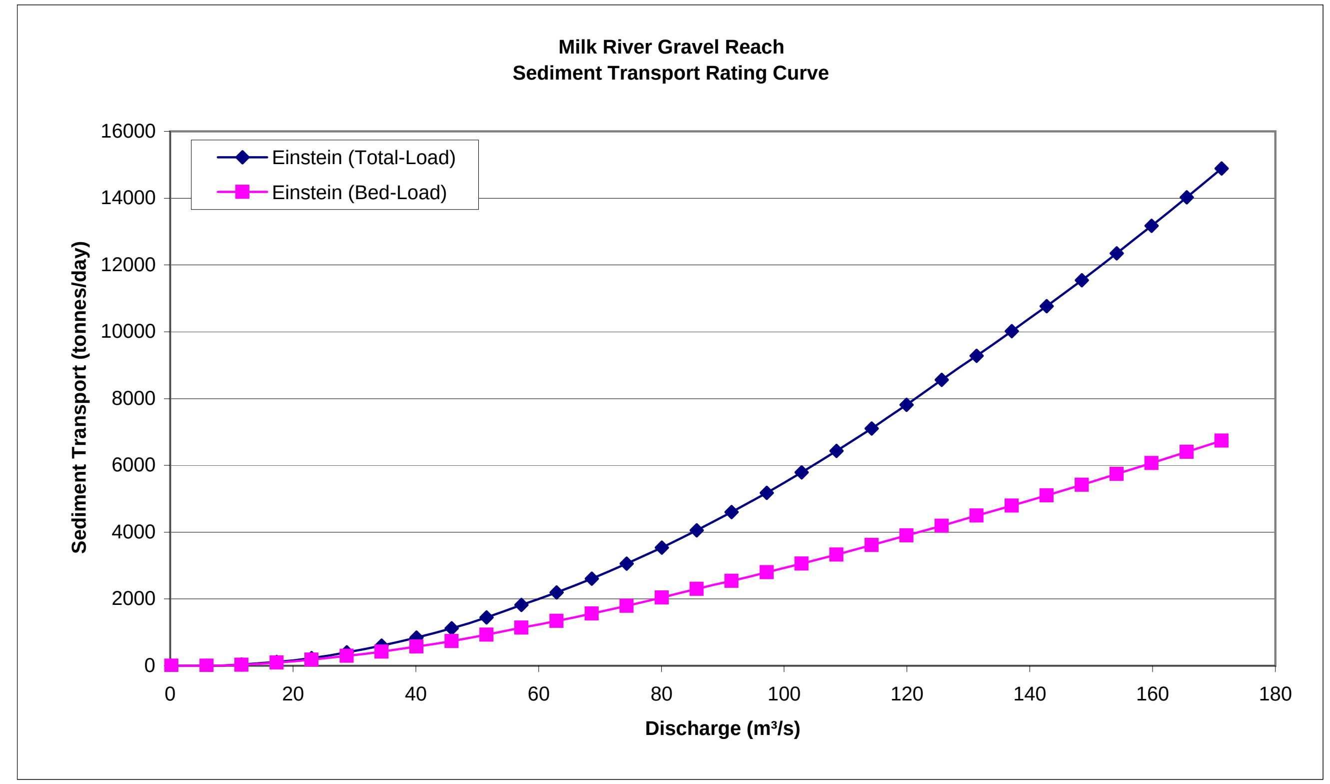
The SAM model sediment transport estimates were based on the following:

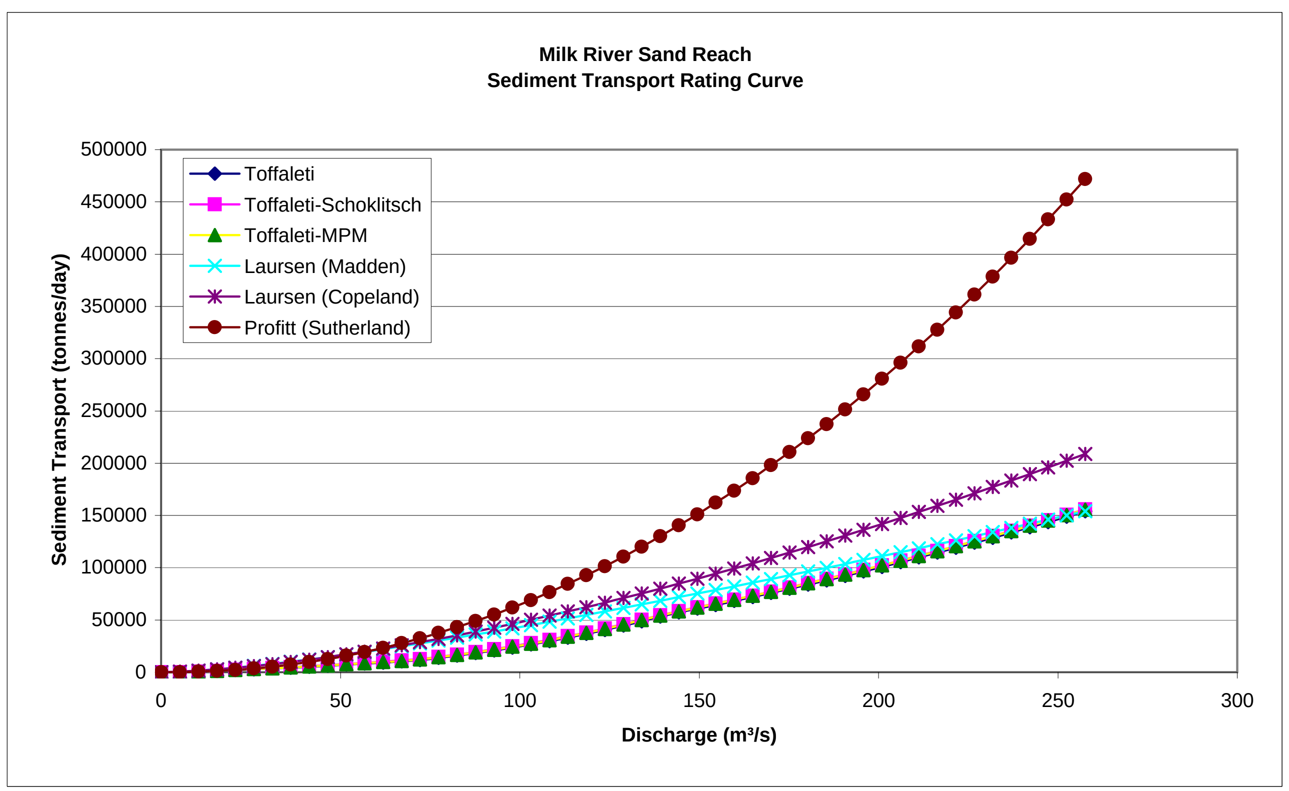
- The Flow Duration Curves derived for the period 1960 to 1985, for the WSC stations selected to represent each reach.
- Bed material gradation data contained in Spitzer (1988) for the WSC stations listed in **Table 3.2**. Spitzer (1988) provides the surface and sub-surface gradations for both the North Milk River and Milk River 'Gravel Bed Reach'. The surface material is coarser grained than the sub-surface material. The North Milk River surface gradation provided better agreement with Spitzer's simulated data and was used for this reach. As discussed in McLean and Beckstead (1987), the bed of the North Milk River is armoured; hence, the use of the surface gradation appears reasonable. The Milk River 'Gravel Bed Reach' sub-surface material provided better agreement with Spitzer's simulated data and was used for this reach. The surface material for the Milk River 'Gravel Bed Reach' is mobile, based on shear stresses for frequently occurring diversion flows. Hence, the use of the sub-surface gradation is appropriate for the Milk River 'Gravel Bed Reach', for all diversion flow scenarios. The surface and sub-surface gradations for the Milk River 'Sand Bed Reach' are similar.

- The "SAM.aid" utility in the SAM program was utilized for guidance in the selection of the most applicable sediment transport function, based on the bed material gradations and hydraulic parameters for a particular reach. The sediment transport equations recommended by the SAM.aid utility are shown on **Figure 3.4** for each of the three reaches. A detailed description of these equations is contained in the SAM Users Manual (Thomas *et al.*, 2002).
- The sediment transport estimates from the SAM model include both suspended sediment and bed load. In comparison, Spitzer estimated only suspended sediment and not bed load. Hence, the SAM model underestimates the total sediment transport as bed load was not accounted for by Spitzer's dataset to which the SAM model was calibrated. For the Milk River 'Sand Bed' reach, the bed load discharge composes less than 5% of the total sediment discharge (Spitzer, 1988). Given the large range in sediment transport estimates from the SAM model, it was felt that increasing the Spitzer data by ±5% to account for bed load, would not significantly impact the results.
- A typical cross-section (a composite based on all surveyed cross-sections for a particular reach) was selected to represent each of the three reaches, based on existing conditions (i.e. the 2007 AMEC surveys).

Sediment Rating Curves for Recorded (Existing) and Potential Diversion Conditions







NOTES:

1. BASED ON 'RECORDED' CONDITION CHANNEL GRADIENTS
2. THE NORTH MILK RIVER AND MILK RIVER 'SAND REACH' CHANNEL GRADIENTS FOR NATURAL (PRE-DIVERSION) CONDITIONS ARE SLIGHTLY DIFFERENT THAN 'RECORDED' CONDITIONS, WHICH RESULTS IN DIFFERENT RATING CURVES

Figure 3.4

3.6.2 Natural (Pre-Diversion) Conditions

The sediment budget methodology for 'natural' conditions was generally similar to that described previously for 'calibration'. For the 'natural' scenario the Flow Duration Curves for the period 1928 to 2001 were utilized. The same bed material data as previously discussed for 'calibration' was utilized, except for the Milk River 'Gravel Reach', where the surface gradation was utilized (see **Table 3.1**). For 'natural' conditions, the surface material for the Milk River 'Gravel Bed Reach' was mobile during high flows and not during typical summer discharges (as is the case for 'calibration'). Hence, the use of the surface gradation is appropriate for the Milk River 'Gravel Bed Reach, for 'natural' conditions. The typical (a composite based on all the surveyed cross-sections for a particular reach) channel geometry used for 'natural' conditions was based on the Peters' 1915 surveys.

3.6.2.1 Effective Discharge and Predicted Regime Characteristics

The results for the 'natural' condition stability analysis are shown in **Table 3.3**. **Figures 3.5 and 3.6** show a comparison of measured widths and channel slopes, for the three channel reaches, and published 'regime' data. The above noted table and figures are discussed below.

- For the North Milk River, the effective discharge estimated from the stability analysis was 10.7 m^3/s, which corresponds well to the 1:2-year return period flood of 8.9 m^3/s. Hence, the effective discharge was selected as representative of the channel forming discharge. The predicted regime width of 23.1 m based on the effective discharge and **Figure 3.5**, is in good agreement with measured mean width of 22 m. The predicted regime slope of 0.0038 m/m based on the effective discharge and **Figure 3.6**, is in good agreement with measured channel slope of 0.003 m/m.
- For the Milk River 'Gravel Reach', the effective discharge estimated from the stability analysis was 50.4 m^3/s, which corresponds well to the 1:2-year return period flood of 49.8 m^3/s. Hence, the effective discharge was selected as representative of the channel forming discharge. The predicted regime width of 50.2 m based on the effective discharge and **Figure 3.5**, is in good agreement with the measured mean width of 52 m. The predicted regime slope of 0.0012 m/m based on the effective discharge and **Figure 3.6**, which is in good agreement with measured channel slope, which ranges from 0.0013 to 0.0019 m/m.
- For the Milk River 'Sand Reach', the effective discharge estimated from the stability analysis was 12 m^3/s, which is only 16% of the 1:2-year return period flood of 75.4 m^3/s. The Milk River 'Sand Reach' drains through the badlands, which contribute a large quantity of sediment, even at relatively low flows. As stated by McLean and Beckstead (1987) there was significant increase in sediment load *"over a distance of 120 km that clearly reflects the contribution of the badlands along the river's lower canyon. The daily measurements showed even minor local rainstorms produced large pulses of sediment. These short-term pulses accounted for more than 50% of the total suspended load measured in 1981."* Due to this somewhat anomalous sediment regime within the badlands, the effective discharge for the Milk River 'Sand Reach' is not a good indicator of channel forming discharge. The 1:2-year return period flood is less than the channel forming discharge since the predicted regime width of 61.3 m, based on the 1:2-year return period flood and **Figure 3.5**, is less

than the measured mean width of 70 m. This difference between measured and predicted regime width may be indicative of the additional width required to convey the large sediment load that is conveyed at even relatively low flows. The predicted regime slope of 0.00015 m/m, based on the effective discharge and **Figure 3.6**, is considerably flatter than the measured channel slope of 0.0007 m/m. This steeper channel slope is likely the result of high sediment loads; that is, the channel requires greater energy (channel slope) to transport the incoming sediment load.

In summary, for natural conditions the 1:2-year return period flood is generally representative of the channel forming discharge for all three reaches. The effective discharge has good agreement with the 1:2-year return period discharge (and hence the channel forming discharge) for the North Milk River and the Milk River 'Gravel Reach'. Due to the large sediment input contributed by the badlands to the Milk River 'Sand Reach', the effective discharge is significantly less than the 1:2-year return period flood; neither of these discharges are representative of the channel forming discharge.

TABLE 3.3
Natural (Pre-diversion) and Recorded (Existing) Condition – Measured and Predicted Regime Characteristics and SAM Model Summary

Note	Reach	North Milk River		Milk River Gravel Bed Reach		Milk River Sand Bed Reach	
	Parameter	**Natural**	**Recorded**	**Natural**	**Recorded**	**Natural**	**Recorded**
Measured Channel Characteristics							
1.	Width (m)	14 to 30 mean 22	26 to 53 mean 35	32 to 83 mean 52	45 to 85 mean 62	38 to 96 mean 70	71 to 120 mean 91
2.	Increase in Width (m)	–	6 to 25 mean 15	–	2 to 13 mean 10.5	–	5 to 34 mean 21
3.	Increase in Width (%)	–	35 to 125% mean 69%	–	2 to 41% mean 25%	–	8 to 89% mean 36%
4.	Slope (m/m)	0.003	0.0035	0.0013 to 0.0019	0.0013 to 0.0019	0.0007	0.0006
Discharge							
5.	Q_{eff} (m^3/s)	10.7	18.3	50.4	20.2	12	18.2
6.	$Q_{1:2}$ year (m^3/s)	8.9	24.8	49.3	57.6	75.4	84.2
7.	Q_{CF} (m^3/s)	10.7	24.8	50.4	57.6	–	–
8.	Median Annual (50% exceedance) Discharge (m^3/s)	0.72	12.6	2.5	15.8	3.1	15.6
9.	20% exceedance Discharge[2] (m^3/s)	1.52	18.2	7.68	20.2	10.3	20.7
Sediment Transport							
10.	SAM Estimated Range of Sediment Transport 1928 to 2001 (tonnes)	7,000 to 30,000	400,000 to 3×10^6	91,000	2×10^6	7×10^6 to 19×10^6	22×10^6 to 50×10^6
11.	Capacity Supply Ratio (CSR)	–	130	–	22	–	2.0
12.	Daily Mean Suspended Sediment[3] (mg/L)	16.3	49.0	72.5	224.2	556.2	1168.0
Predicted Regime Channel Characteristics							
13.	Width based on Q_{CF} (m)	23.1	35.2	50.2	53.6	61.3	64.8
14.	Increase in Width (m)	–	12.1	–	3.5	–	3.5
15.	Increase in Width (%)	–	52%	–	7%	–	6%

Notes:

1. to 4. Measured channel characteristics for Natural conditions (based on the 1915 Pre-diversion survey) and Recorded conditions (based on the 2007 survey).

5. Effective Discharge (Q_{eff}) is the discharge that transports the largest fraction of bed material load.

6. Q_2 is the 1:2 year recurrence interval flood discharge.

7. Q_{CF} is the channel forming discharge. Neither the Q_{eff} or Q_2 is representative of Q_{CF} for the Milk River 'Sand' Reach for 'natural' and 'recorded' conditions.

8. to 9. Median (50%) and 20% exceedance discharges.

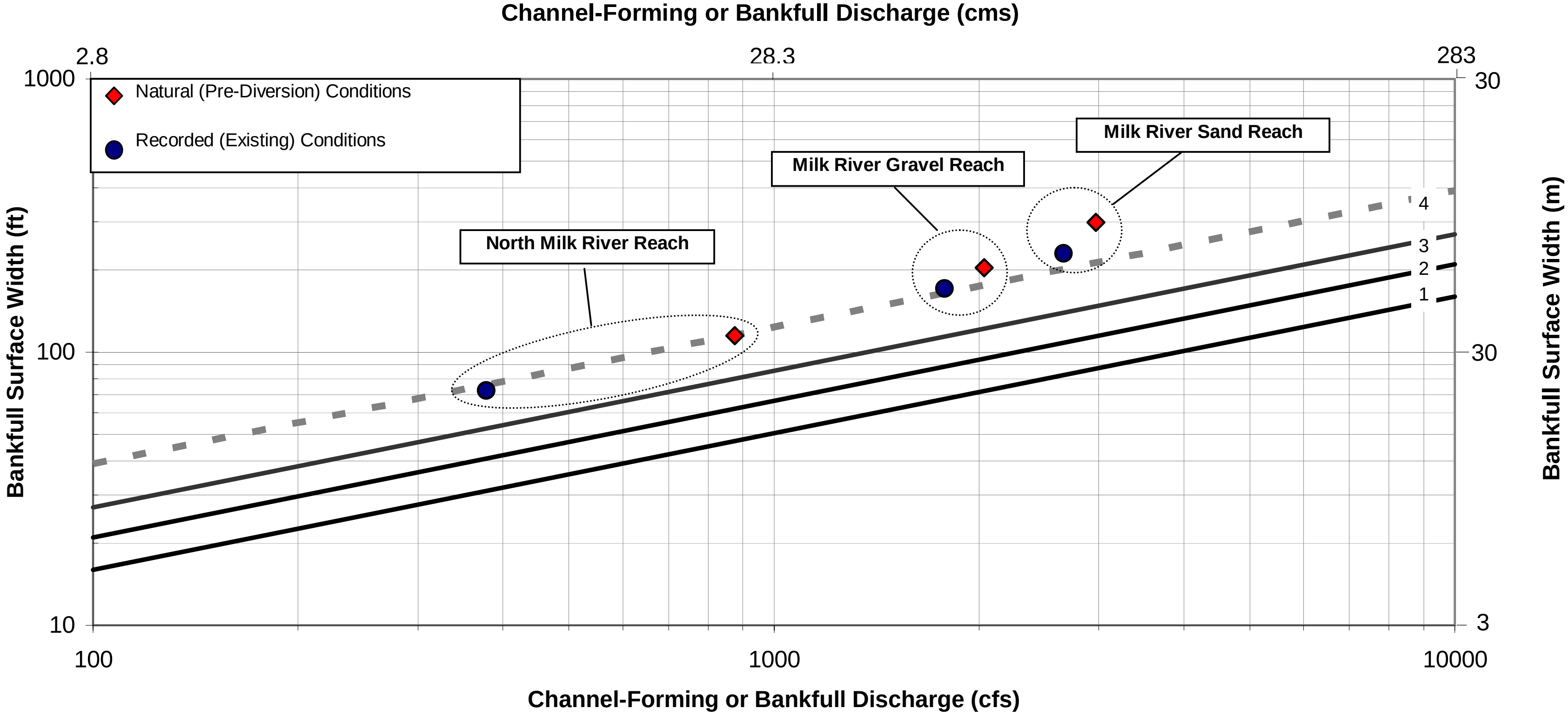
10. Range of cumulative sediment transported estimated for the period 1928 to 2001 using the SAM Model for various sediment transport equations.

11. Capacity Supply Ratio (CSR) is the sediment transported by: (a) the recorded discharges divided by the sediment transported by natural discharges. The CSR provides an indication of the severity of impacts.

12. Daily Mean Suspended Sediment Concentration based on the following sediment rating curves from Spitzer (1988): **Figures B-9** (North Milk), **D-9** (Milk Gravel), **G-9** (Milk Sand). The concentration is based on the 20% exceedance discharges which is equalled or exceeded for 49 days of the year (i.e. the higher range of diversion flows).

13. to 15. Predicted regime channel width based on USCOE (1994) formula: $W = CQ^{0.5}$; where W = width (ft), Q = discharge (cfs), and C = coefficient. 'C' was calculated based on measured widths and Q_{CF} for Natural and Recorded conditions, as shown in **Figure 3.5**. For the Milk Sand reach, the Q_2 was used to estimate regime width.

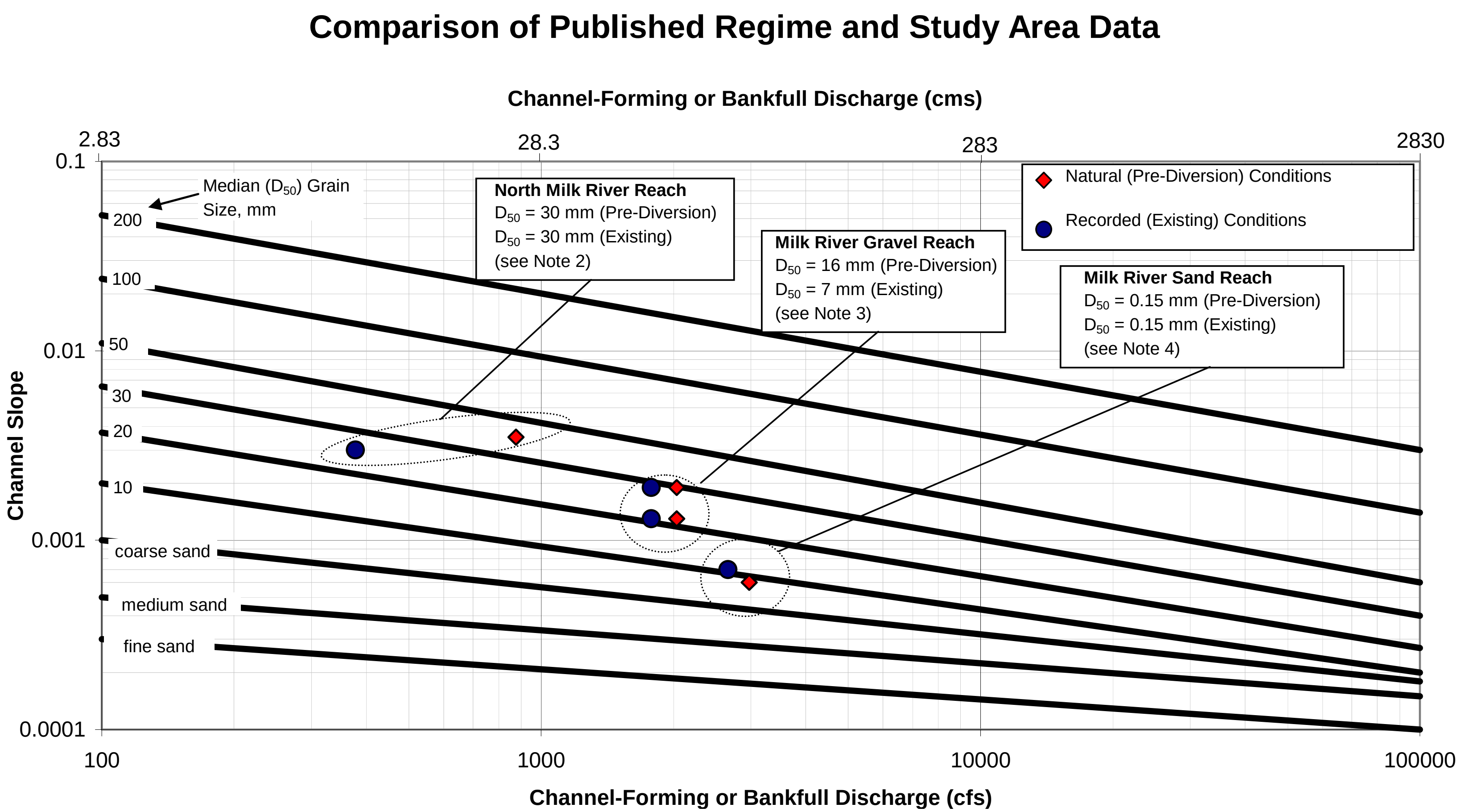
Figure 3.5 Comparison of Bankfull Widths for Published Regime and Study Reaches



Notes:

1. SOURCE FOR PUBLISHED DATA: U.S. CORPS OF ENGINEERS, 1994, FIGURE 5.9, EM1110-2-1418
2. FORMULA IN IMPERIAL UNITS: $W=CQ^{0.5}$ WHERE W=WIDTH (ft), Q=DISCHARGE (cfs), C=COEFFICIENT (SEE NOTES 3,5)
3. FOR PUBLISHED DATA, C=1.6 FOR CURVE 1 AND REPRESENTS STIFF COHESIVE OR VERY COARSE GRANULAR BANKS
   C=2.1 FOR CURVE 2 AND REPRESENTS AVERAGE COHESIVE OR COARSE GRANULAR BANKS
   C=2.7 FOR CURVE 3 AND REPRESENTS SANDY ALLUVIAL BANKS
4. TWO POINTS (NATURAL CONDITIONS AND RECORDED CONDITIONS) ARE SHOWN FOR EACH OF THE THREE MILK RIVER REACHES
5. THE MILK RIVER CURVE (CURVE 4) HAS A 'C' VALUE OF 3.9. THIS IS THE CURVE THAT WAS USED TO PREDICT WIDTHS FOR FUTURE POTENTIAL DIVERSION SCENARIOS
6. RECORDED CONDITIONS FOR MILK RIVER SAND AND MILK RIVER GRAVEL REACHES PLOT ABOVE THE CURVE, POSSIBLY INDICATING THESE CHANNELS ARE NOT IN REGIME FOR DIVERSION FLOW CONDITIONS (RECORDED AND POTENTIAL)

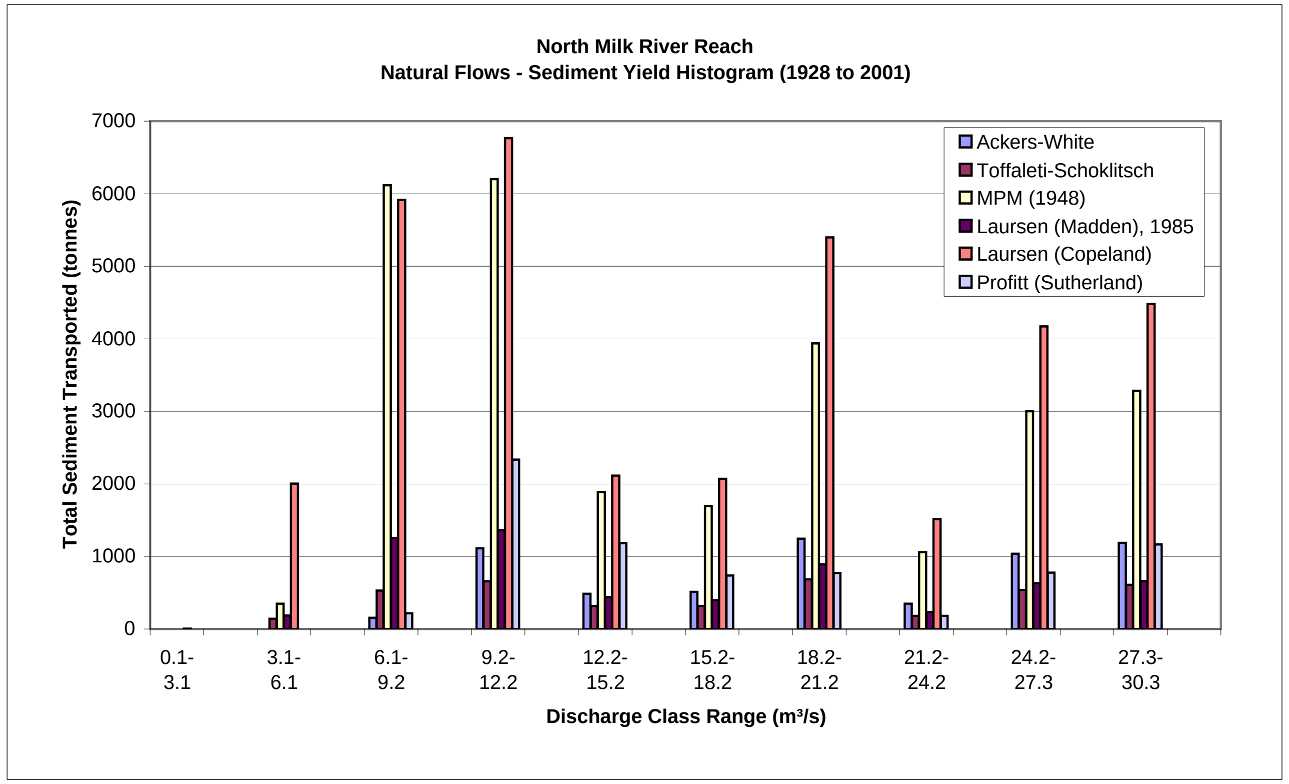
Figure 3.6 Comparison of Channel Slopes for Published Regime and Study Reaches

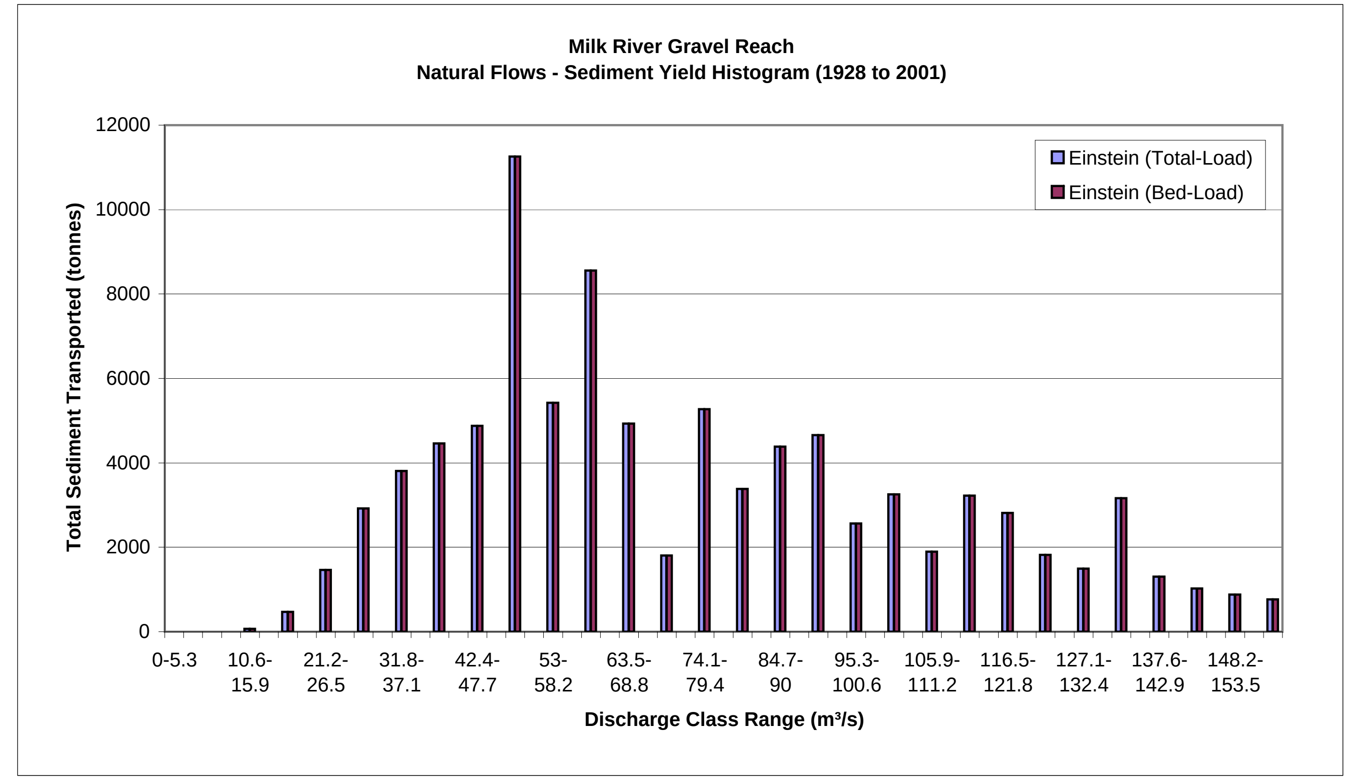


Notes:

1. SOURCE FOR PUBLISHED DATA: U.S. CORPS OF ENGINEERS, 1994, FIGURE 5.11, EM 1110-2-1418
2. NORTH MILK RIVER D_{50} = 30 mm IS FOR SURFACE GRADATION FOR BOTH NATURAL (PRE-DIVERSION) AND RECORDED (EXISTING) CONDITIONS. THE STUDY AREA DATA SHOWS GOOD AGREEMENT WITH THE PUBLISHED DATA FOR NATURAL (PRE-DIVERSION) CONDITIONS
3. MILK RIVER GRAVEL REACH D_{50} = 16 mm IS FOR THE SURFACE GRADATION AND SHOWS GOOD AGREEMENT WITH PUBLISHED DATA. THE D_{50} = 7 mm FOR RECORDED (EXISTING) CONDITIONS IS FOR THE SUB-SURFACE GRADATION SINCE THE SURFACE LAYER IS MOBILE DURING DIVERSION FLOWS. THE RECORDED (EXISTING) CONDITION DATA DOES NOT SHOW GOOD AGREEMENT WITH PUBLISHED DATA.
4. MILK RIVER SAND REACH D_{50} = 0.15 mm IS REPRESENTATIVE OF SURFACE AND SUB-SURFACE GRADATIONS AND DOES NOT SHOW GOOD AGREEMENT WITH THE PUBLISHED DATA.

Sediment Yield Histograms, Natural Conditions





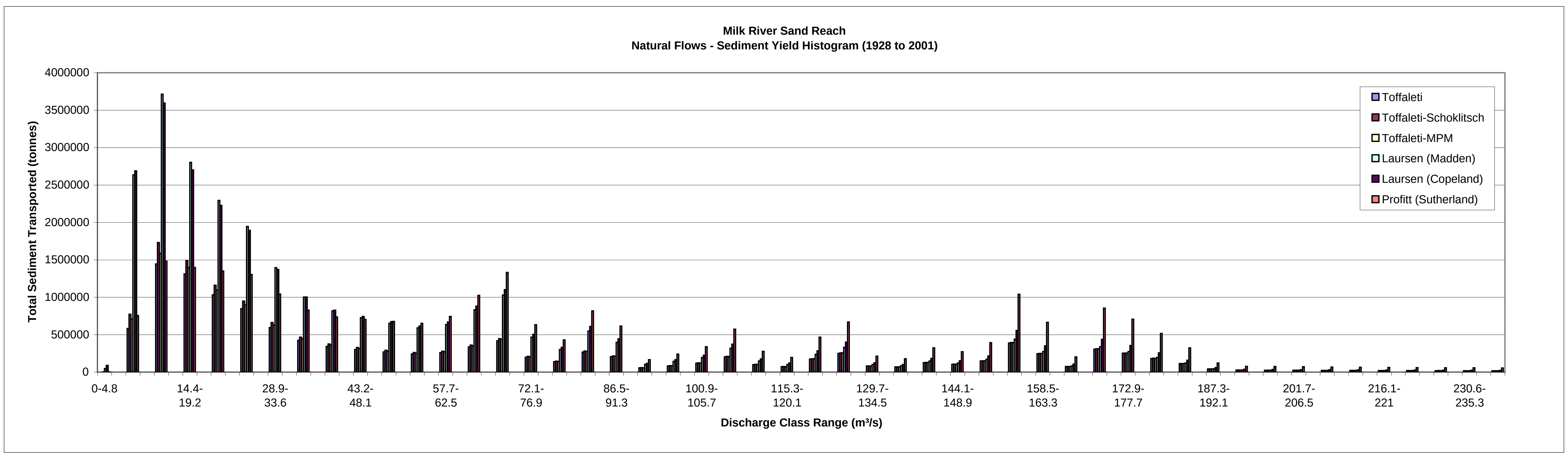


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Figure 3.7

3.6.3 Recorded (Existing) Conditions

The approach and results to model existing channel conditions are summarized below.

- Existing condition flow duration curves (FDC's) were developed for the period from 1928 to 2001, for each of the three Milk River reaches area. The FDC's were based on stream flows contained in **Section 2**, which were generated from the Water Resources Management Model (WRMM) model for each reach.
- The bed material gradation, channel geometry and sediment transport rating curves were the same as that used for the calibration.
- The total sediment yield for the period 1928 to 2001 was estimated for each reach using the SAM model, which integrates the flow duration curve and sediment rating curve information described above. **Table 3.3** is a summary of the SAM model results for the Existing Condition. A sample SAM input/output file for the Milk River 'Gravel Bed' Reach recorded (existing) condition is attached in **Appendix C**.
- The effective discharge for each equation was based on the mean value for the discharge range with the greatest sediment yield. The selected effective discharge was the value upon which the majority of the equations converged. **Figure 3.8** shows the existing condition sediment yield histograms.
- The results for the 'existing' condition stability analysis are shown in **Table 3.3**.

An evaluation of the impact of the 'recorded (existing)' diversion flows on 'natural (pre-diversion)' conditions is based on the evaluation of Capacity Supply Ratio (CSR) and predicted regime channel characteristics. These two methods were discussed previously and are summarized below.

3.6.3.1 Effective Discharge and Predicted Regime Characteristics

- For the *North Milk River*, the effective discharge estimated from the stability analysis was 18.3 m^3/s, which is somewhat less than the 1:2-year return period flood of 24.8 m^3/s. The predicted regime width of 35.2 m based on 1:2-year return period flood and **Figure 3.5**, is in good agreement with the measured mean width of 35 m. Hence, the channel forming discharge corresponds approximately to the 1:2-year return period flood. The measured channel slope for 'recorded' conditions increased to 0.0035 m/m from 0.003 m/m for 'natural' conditions. This steeper channel slope is due to the accelerated development of meander cut-offs resulting from the diversion flows (McLean and Beckstead, 1987). The predicted regime slope of 0.0028 m/m, based on the effective discharge and **Figure 3.6**, is in good agreement with a measured channel slope of 0.003 m/m.
- For the *Milk River 'Gravel Reach*', the effective discharge estimated from the stability analysis was 20.2 m^3/s, which is only 35% of the 1:2-year return period flood of 57.6 m^3/s. For the Milk River 'Gravel Reach', effective discharge is not a good indicator of channel forming discharge. The 1:2-year return period flood is a better indicator of channel forming discharge since there is reasonable agreement between the predicted regime width of 53.6 m based on the 1:2-year return period flood and **Figure 3.5**, in comparison to the measured mean width of 62 m. The decrease in effective discharge from 50.4 m^3/s for 'natural' conditions to 20.2 m^3/s for 'recorded' conditions is due to the diversion flows, which convey significant sediment and can result in erosion. The difference between measured and predicted regime

width may be indicative of the additional erosion caused by the diversion flows, over and above that required by the channel to convey the 1:2-year return period flood. That is the diverted flows, while of smaller magnitude, are sustained for much longer periods of time than flows associated with natural runoff events. As a result, a greater portion of the theoretical sediment transport occurs at lower discharges that are sustained for long periods of time, rather than larger discharges that are infrequent and are of short duration. There was no measurable change in channel slope from 'natural' to 'recorded' conditions. The predicted regime slope of 0.0007 m/m, based on the effective discharge, D_{50} = 7 mm and **Figure 3.6**, is in poor agreement with measured channel slope, which varies from of 0.0013 to 0.0019 m/m. The increase in width that occurred in the Milk River Gravel Bed Reach, that was determined in this study, is contrary to the findings of McLean and Beckstead (1987). The detailed data used by McLean and Beckstead (1987) was not available to confirm their findings. The previous paper by McLean and Beckstead (1981) discussing the Milk River 'Gravel Bed' and 'Sand Bed' reaches, stated that "*actual increases in bankfull width averaged 10% to 20%*". The findings from the 1981 paper are consistent with the findings of the current study.

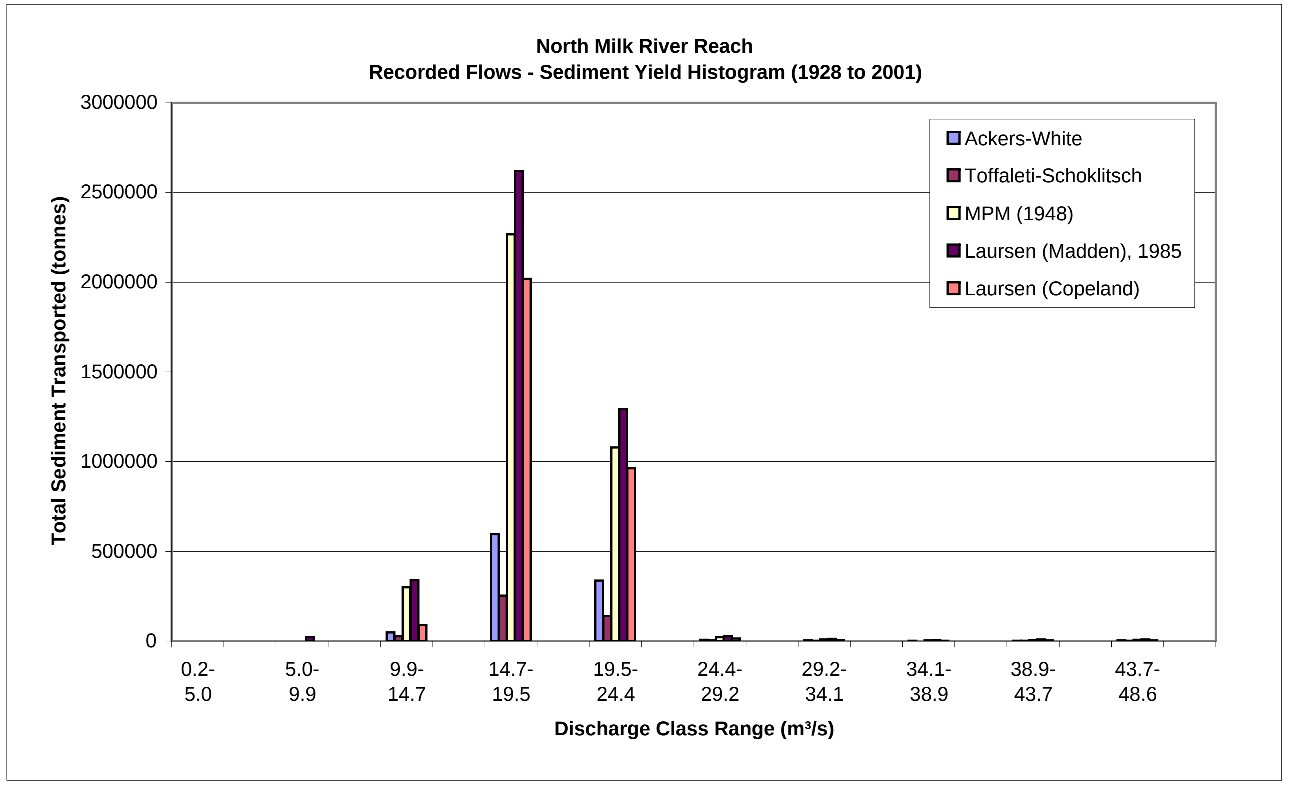
- For the *Milk River 'Sand Reach*', the effective discharge estimated from the stability analysis was 18.2 m^3/s, which is only 22% of the 1:2-year return period flood of 84.2 m^3/s. This increase in effective discharge from 12 m^3/s for 'natural' conditions to 18.2 m^3/s for 'recorded' conditions is due to the diversion flows, which convey a significant sediment load. The 1:2-year return period flood is a poor indicator of channel forming discharge, since there was poor agreement between the predicted regime width of 64.8 m based on the 1:2-year return period flood and **Figure 3.5**, and the measured mean width of 91 m. This may be indicative of the additional erosion caused by the diversion flows, over and above that required by the channel to convey the 1:2-year return period flood. There was no measurable change in channel slope from 'natural' to 'recorded' conditions. The predicted regime slope of 0.00015 m/m, based on the effective discharge and **Figure 3.6**, is considerably flatter than the measured channel slope of 0.0007 m/m. This steeper channel slope is likely the result of high sediment loads. That is, the channel requires greater energy (channel slope) to transport the incoming sediment load.

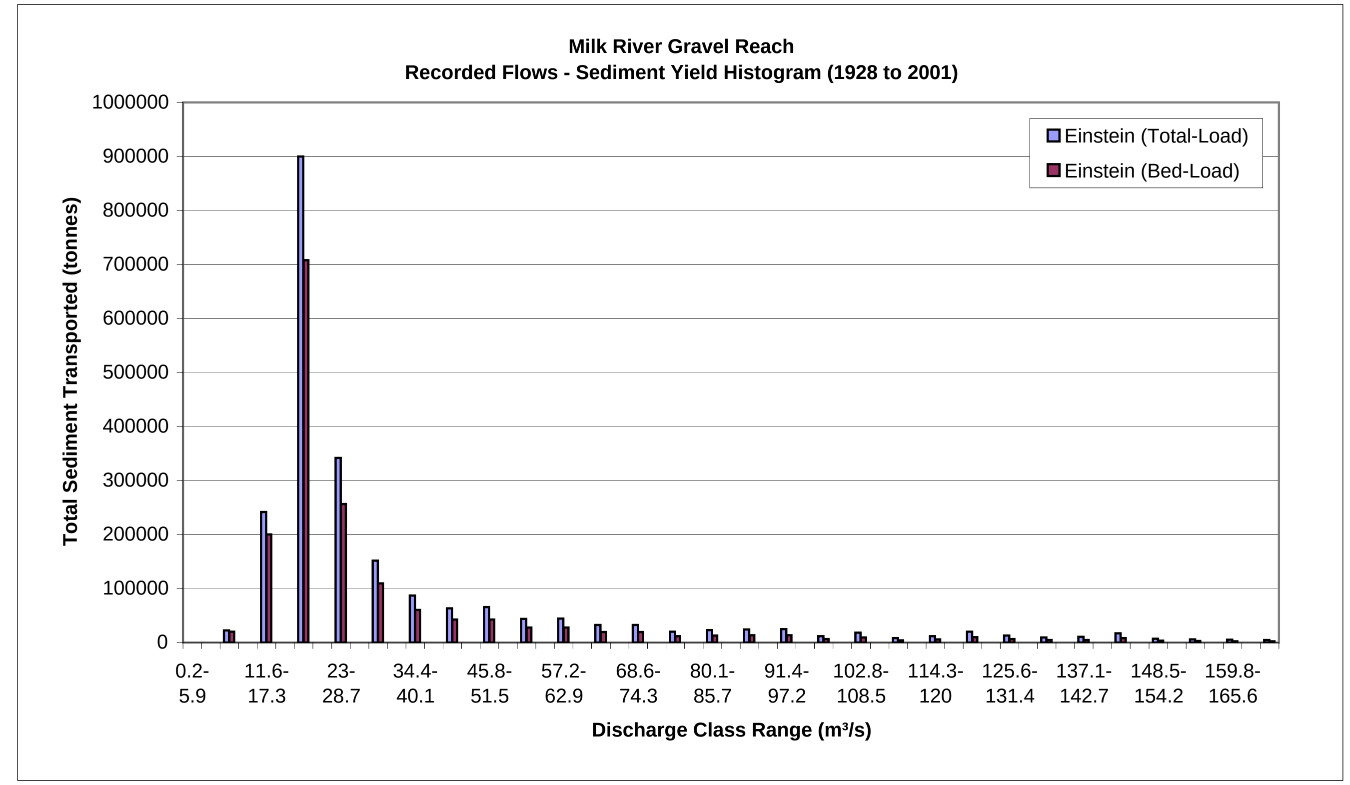
3.6.3.2 Capacity Supply Ratio for 'Recorded (Existing)' Conditions

An indication of the severity of historical effects of diversion discharges is provided by the previously defined Capacity Supply Ratio (CSR), which provides a comparison of existing and potential diversion flow scenarios. The greater the magnitude of the CSR, the greater the potential for erosion and degradation. Within the context of this study, the sediment transport equations and the CSR are only utilized as a general indication of the severity of impacts.

The CSR values are 130, 22 and 2.0 for the North Milk River, Milk River 'Gravel Bed' Reach, and the Milk River 'Sand Bed' Reach, respectively. The CSR reduces by an order-of-magnitude between each reach in sequence. The corresponding percentage increase in measured channel widths was 69%, 25% and 36% for the North Milk River, Milk River 'Gravel Bed' Reach, and the Milk River 'Sand Bed' Reach, respectively. The Milk River 'Sand Bed' Reach had significant changes, although it had by far the lowest CSR. This indicates that: (1) the Milk River 'Sand Bed' Reach is very sensitive to changes, possibly due to fine-grained bed and banks; and (2) CSR's are not comparable between the gravel and sand reaches.

Sediment Yield Histograms, Existing Conditions





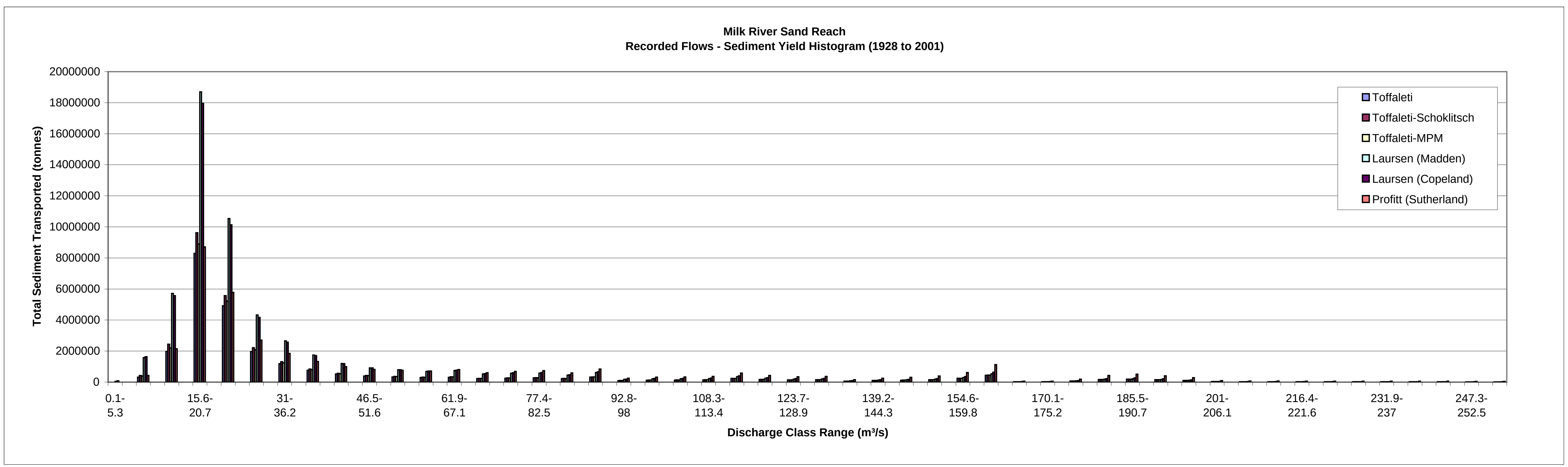


Figure 3.8

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3.6.4 Potential Future Diversion Scenarios and Estimated Channel Changes

A significant advantage of using the modelling approach taken in this study (i.e. WRMM to model stream flows and the SAM model to predict how this will affect the physical structure of the channel) is that various potential diversion flow scenarios can be assessed. Listed below are the potential diversion flow scenarios reviewed:

- an increase of the St. Mary diversion to 28.3 m^3/s or 1,000 cfs (referred to as “Scen. 1000”); and,
- an increase of the St. Mary diversion to 34.0 m^3/s or 1,200 cfs (referred to as “Scen. 1200”).

A similar methodology, as previously described for existing and natural conditions, was applied to evaluate the potential diversion flow scenarios listed above. This methodology is summarized below.

- The flow duration curves (FDCs) for the potential diversion flow scenarios were input into the SAM model for the same 73-year period of time (1928 to 2001) as previously modelled for ‘natural’ and ‘recorded (existing)’ conditions.
- The total sediment yield for the period 1928 to 2001 was estimated for each reach with the SAM model, applying the same sediment transport equations for the ‘natural (pre-diversion)’ and ‘recorded (existing)’ conditions. **Table 3.4** is a summary of the SAM model results for the various development condition scenarios. **Figures 3.9 and 3.10** show the sediment yield histograms for the diversion flow scenarios.

3.6.4.1 Effective Discharge and Predicted Regime Characteristics

For the *North Milk River*, the effective discharges estimated from the stability analysis were 30.8 and 34.8 m^3/s (for Scen. 1000 and Scen. 1200, respectively) which are somewhat less than the 1:2-year return period floods of 31.4 and 35.4 m^3/s (for Scen. 1000 and Scen. 1200, respectively). The predicted regime widths are 42.0 and 45.5 m (for Scen. 1000 and Scen. 1200, respectively) based on 1:2-year return period floods and **Figure 3.5**. Hence, the selected channel forming discharge was based on the 1:2-year return period flood, which is slightly more conservative than the effective discharge.

For the *Milk River ‘Gravel Reach’*, the effective discharges estimated from the stability analysis were 31.1 and 38.8 m^3/s (for Scen. 1000 and Scen. 1200, respectively) which are only 46 and 53% of the 1:2-year return period floods of 68.8 and 72.4 m^3/s (for Scen. 1000 and Scen. 1200, respectively). For the potential diversion flow scenarios for the Milk River ‘Gravel Reach’, neither the effective discharge nor the 1:2-year return period floods are good indicators of channel forming discharge. As the diversion flows increase, the use of the 1:2-year return period flood as an indicator of channel forming discharge becomes unreliable due to the additional erosion that occurs due to the frequently occurring diversion flows. Therefore, the predicted regime width of 58.4 and 60.1 m (for Scen. 1000 and Scen. 1200, respectively), based on the 1:2-year return period floods and **Figure 3.5**, likely under-estimate potential channel width. The use of the Capacity Supply Ratio (CSR), which is discussed below, is a more reliable indicator of future channel changes in this instance.

TABLE 3.4
Potential Diversion Flows – SAM Model Summary and Predicted Regime Characteristics

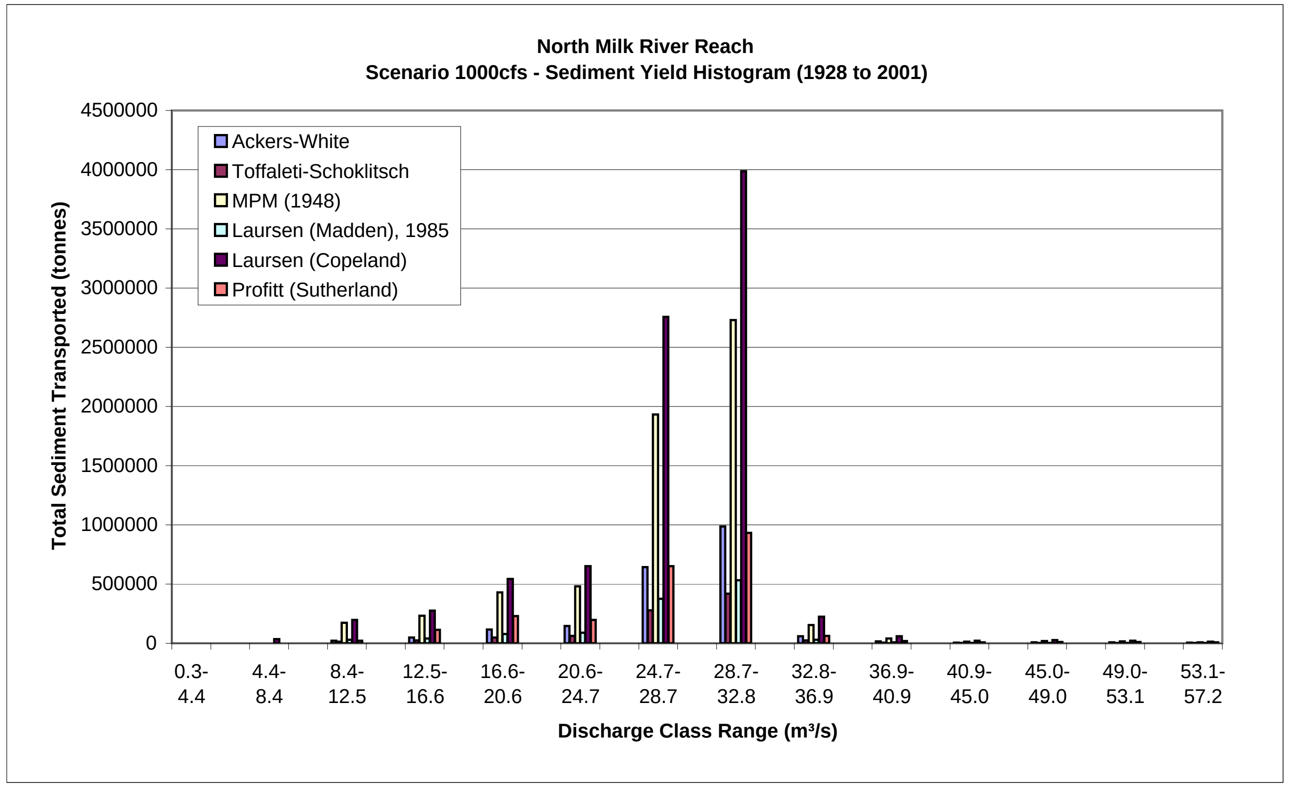
Note	Reach	North Milk River		Milk River Gravel Bed Reach		Milk River Sand Bed Reach	
	Scenario	Scen 1000	Scen 1200	Scen 1000	Scen 1200	Scen 1000	Scen 1200
Discharge							
1.	Q_{eff} (m^3/s)	30.8	34.8	31.1	38.1	37.2	44.5
2.	$Q_{1:2}$ year (m^3/s)	35.4	41.4	68.3	72.4	95.7	99.5
3.	Q_{CF} (m^3/s)	35.4	41.4	–	–	–	–
4.	Median Annual (50% exceedance) Discharge (m^3/s)	6.3	6.3	9.8	9.8	10.8	10.8
5.	20% exceedance Discharge (m^3/s)	26.0	26.0	30.2	31.0	31.5	33.6
Sediment Transport							
6.	SAM Estimated Range of Sediment Transport 1928 to 2001 (tonnes)	1×10^6 to 3×10^6	1.5×10^6 to 7.5×10^6	3×10^6	4×10^6	28×10^6 to 68×10^6	31×10^6 to 13×10^6
7.	Capacity Supply Ratio (CSR)	1.9	2.4	1.5	2.0	1.3	1.5
8.	Daily Mean Suspended Sediment (mg/L)	57.4	57.4	358.7	358.7	1825.1	1825.1
Predicted Regime Channel Characteristics							
9.	Width based on Q_{CF} (m)	42.0	45.5	58.4	60.1	69.1	70.5
10.	Increase in Width (m)	6.9	10.3	4.8	6.5	4.3	5.6
11.	Increase in Width (%)	19%	29%	9%	12%	7%	9%

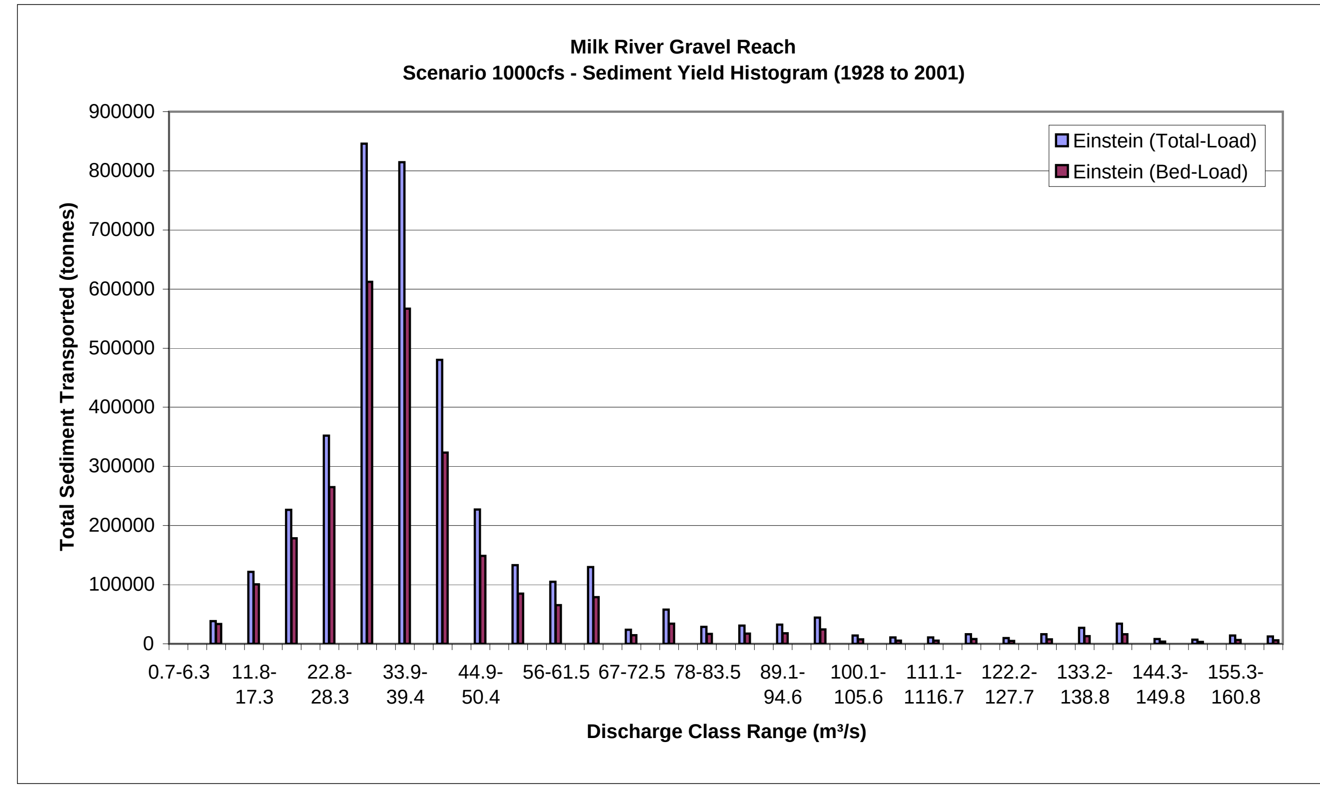
Notes:

1. Effective Discharge (Q_{eff}) is the discharge that transports the largest fraction of bed material load.
2. Q_2 is the 1:2-year recurrence interval flood discharge.
3. Q_{CF} is the channel forming discharge. Neither the Q_{eff} or Q_2 is representative of Q_{CF} for the Milk River 'Gravel' and Milk River 'Sand' Reaches.
6. Range of cumulative sediment transported estimated for the period 1928 to 2001 using the SAM Model for various sediment transport equations.
7. Capacity Supply Ratio (CSR) is the sediment transported by the future scenario discharges divided by the recorded discharges. The CSR provides an indication of the severity of impacts.
8. Daily Mean Suspended Sediment Concentration based on the following sediment rating curves from Spitzer (1988): **Figures B-9** (North Milk), **D-9** (Milk Gravel), **G-9** (Milk Sand). The concentration is based on the 20% exceedance discharges which is equalled or exceeded for 49 days of the year (i.e. the higher range of diversion flows).

9. to 11. Predicted regime channel width based on USCOE (1994) formula: $W = CQ^{0.5}$; where W = width (ft), Q = discharge (cfs) and C = coefficient. 'C' was calculated based on measured widths and Q_{CF} for Natural and Recorded conditions, as shown on **Figure 3.5**. For the Milk Gravel and Milk Sand reaches, the Q_2 was used to estimate regime width.

Sediment Yield Histograms, Scenario 1000





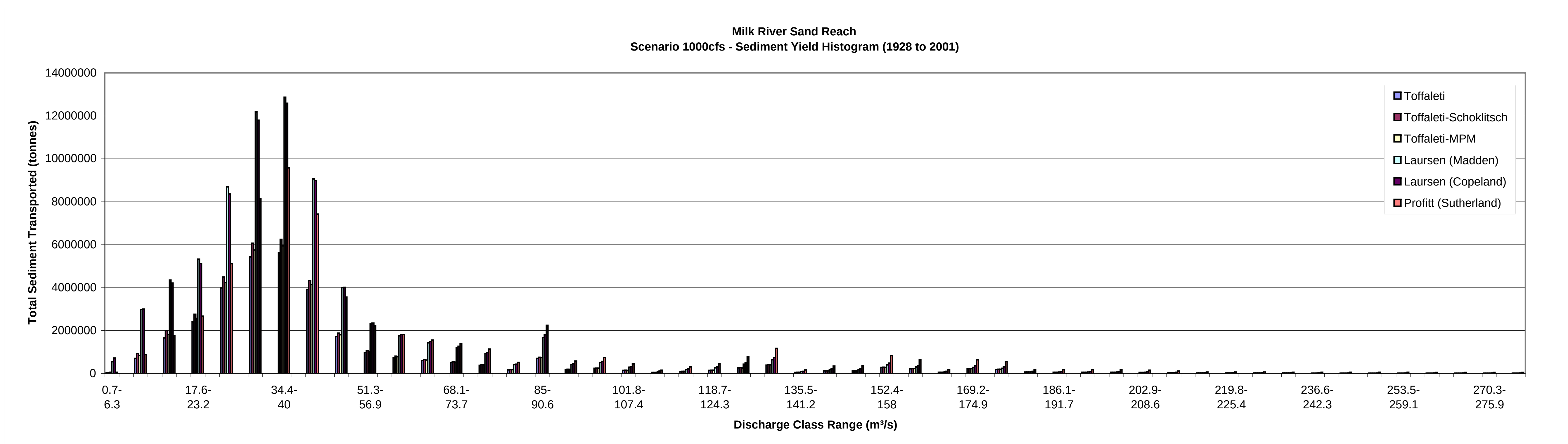
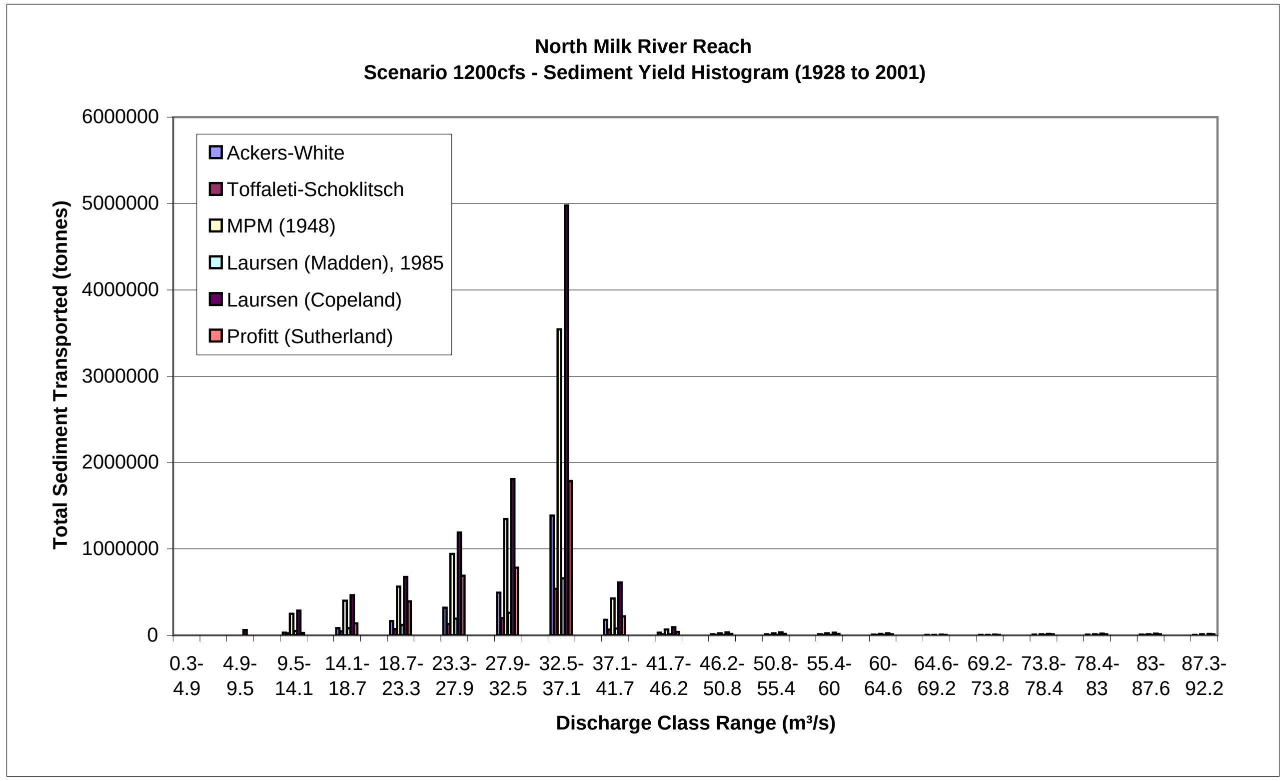
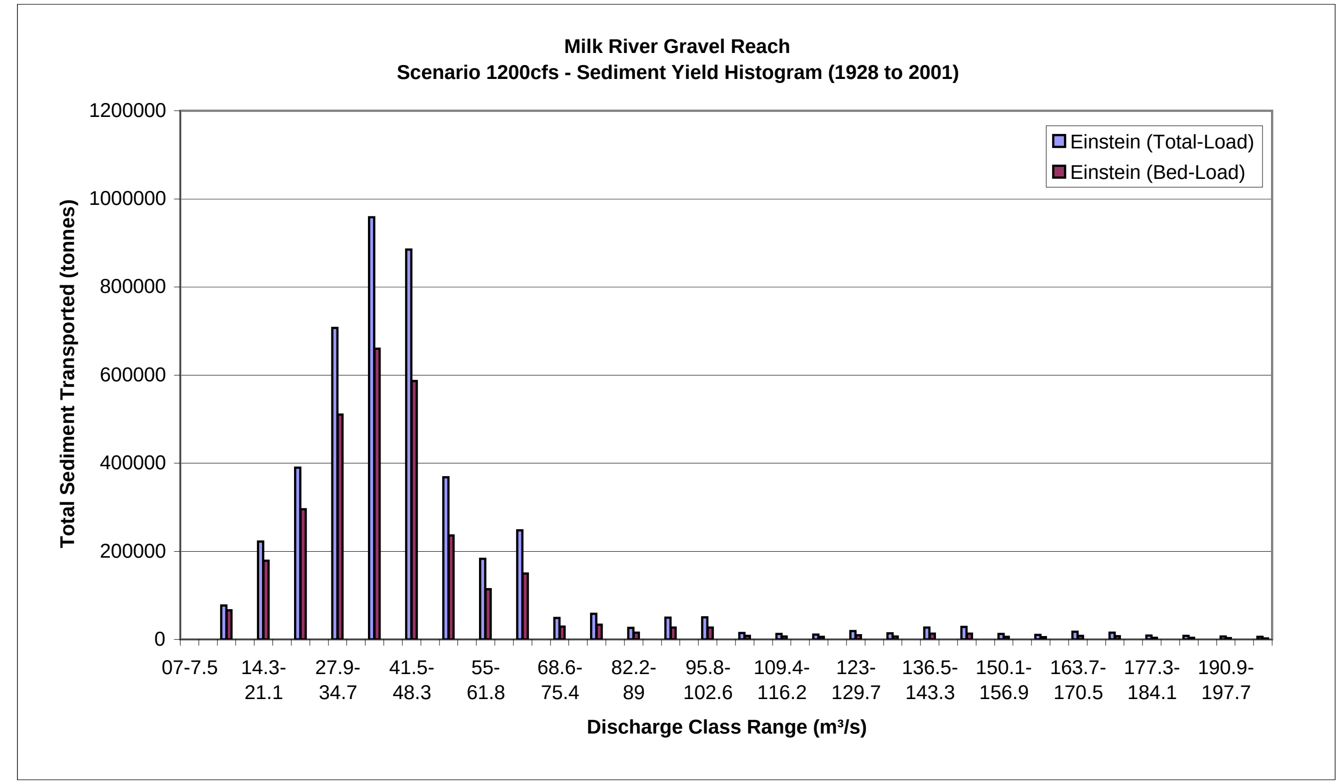


Figure 3.9

Sediment Yield Histograms, Scenarios 1200





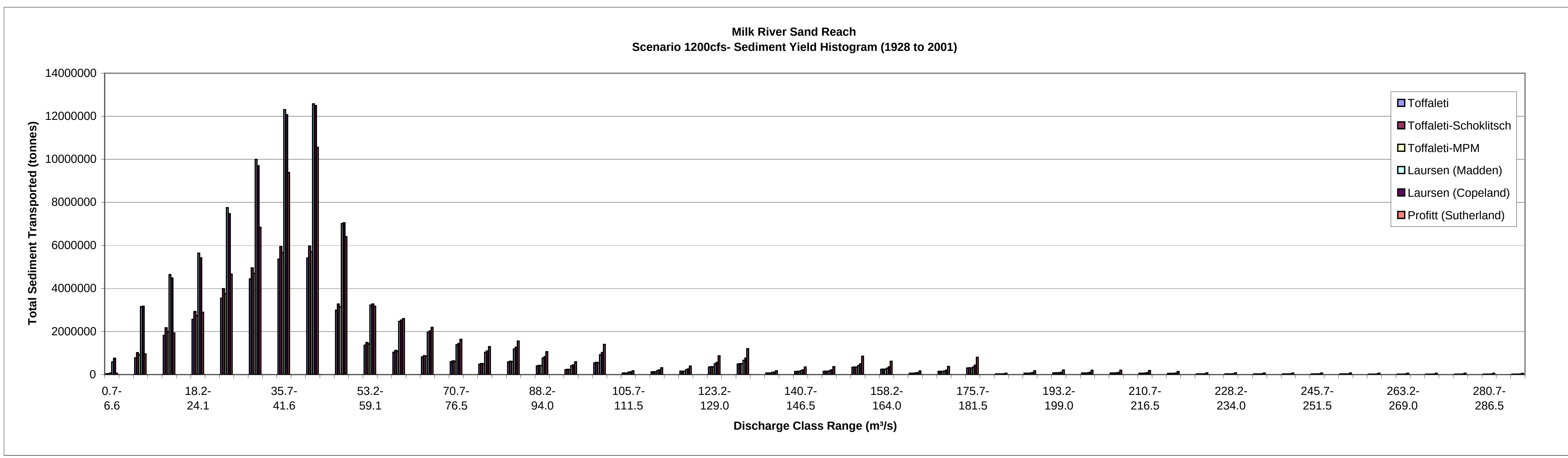


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Figure 3.10

For the *Milk River 'Sand Reach'*, the effective discharges estimated from the stability analysis were 37.2 m^3/s and 44.5 m^3/s (for Scen. 1000 and Scen. 1200, respectively) which are only 39% and 45% of the 1:2-year return period floods of 95.7 m^3/s and 99.5 m^3/s (for Scen. 1000 and Scen. 1200, respectively). For the potential diversion flow scenarios for the Milk River 'Sand Reach', neither the effective discharge nor the 1:2-year return period floods are good indicators of channel forming discharge. As the diversion flows increase, the use of the 1:2-year return period flood as an indicator of channel forming discharge becomes unreliable due to the additional erosion that occurs due to the frequently occurring diversion flows. Therefore, the predicted regime width of 69.1 and 70.5.5 m (for Scen. 1000 and Scen. 1200, respectively), based on the 1:2-year return period floods and **Figure 3.5**, likely under-estimate potential channel width. The use of the Capacity Supply Ratio (CSR), which is discussed below, is a more reliable indicator of future channel changes in this instance.

3.6.4.2 Capacity Supply Ratio 'Potential Diversion' Conditions

The CSR values for the 'potential diversion' conditions for the *North Milk River and Milk River 'Gravel Reach'* are considerably less than 'recorded' conditions. This suggests that the changes for 'potential diversion' conditions should be less than for 'recorded' conditions.

The CSR values for the 'potential diversion' conditions for the *Milk River 'Sand Reach'* are slightly less than 'recorded' conditions. This suggests that the changes for 'potential diversion' conditions could be similar or slightly less than for 'recorded' conditions.

3.6.5 Discussion of the Use of Regime and CSRs for Predicting Channel Changes

For predicting channel changes, the use of the regime approach works best in the instances where the effective discharge is representative of the channel forming discharge. This condition is valid for the North Milk River for all conditions. Hence, the regime approach is the primary method used for evaluating the potential diversion impacts on the North Milk River.

Both the CSR and regime approach can be used to provide an indication of channel change in Milk River 'Gravel Reach'. The regime approach tends to underestimate the change since the frequently occurring diversion flows convey sediment and cause erosion, resulting in a channel that is wider than predicted by the regime approach. Another indication of the severity of change for the Milk River 'Gravel Reach' is provided by comparison with the other two reaches. The severest changes occur on the North Milk River since the diversion flows are such a large portion of the total flows. The next severest changes occur on the Milk River 'Sand Reach' since the finer grained sediments are subject to erosion. The severity of change for the Milk River 'Gravel Reach' is less than the other two reaches. The geological control located at the knick-point between the flatter and steeper channel slope sub-reaches, may also influence channel morphology and should be investigated in future studies.

The use of the regime approach for predicting channel change is poor in instances where the effective discharge is not representative of channel forming discharge. This condition occurs for the Milk River 'Sand Reach' for all scenarios ('natural', 'recorded' and 'potential diversion'). The frequently occurring diversion flows convey sediment and cause erosion (i.e. a disturbed condition) resulting in an over-widened channel. This wider channel is also due to the large sediment loads contributed by the badlands as well as the weak banks. The most appropriate approach for the Milk River 'Sand Reach' appears to be to compare CSRs for recorded and future scenarios. Hence, the CSR is the primary method used for evaluating the potential diversion impacts on the Milk River 'Sand Reach'.

The above noted finding regarding the 1:2-year flood discharge not being representative of the channel forming discharge, for the Milk River 'Gravel' and 'Sand' reaches, for diversion flow conditions is in agreement with Blench (1954) who states:

> *"The writer's opinion (on the effect of releases on the combined river) is that the 600 cusec (i.e.* the existing 17 m^3/s diversion flow*) releases are likely to have a more erosive effect than might be imagined from their ratio to peak flood, because they cause sub-meandering that can attack pockets of silty soil that would escape the effect of large floods."*

The sediment budget methodology used in this report to determine effective discharge provides quantifiable support for Blench's statement. For all diversion flow scenarios ('existing', 'Scen. 1000', and 'Scen. 1200'), the effective discharge is approximately equivalent to the diversion flow. For the Milk River 'Gravel' and 'Sand' reaches, although these effective discharges are considerably less than peak floods (e.g. the 1:2-year flood discharge), they still cause erosion, resulting in a channel wider than required to convey the peak flood.

3.6.5.1 North Milk River Predicted Channel Changes

Scen. 1000 – an increase in channel width in the order of 19% is predicted by the regime method, which as discussed above is applicable for the North Milk River. The regime method somewhat underestimated the 'recorded' changes. Hence, the predicted regime width is increased slightly and a range of potential future widths is provided. This translates to a potential 20% to 25% increase in mean width (7 to 9 m), which results in a future mean width for the North Milk River between 42 m to 44 m. No significant change in depth is estimated since there weren't any 'recorded' changes in bed levels. In the intermediate time-frame (say several decades), the potential increase in slope is expected to be less than the 10% 'recorded' change that occurred. In the long-term, the slope may decrease as the channel becomes more sinuous. This trend is discussed in more detail in **Section 4**. Both the intermediate time-frame increase in slope and the longer-term decrease in slope will result in erosion of the channel banks.

Scen. 1200 – an increase in channel width in the order of 29% is predicted by the regime method, which as discussed above is applicable for the North Milk River. The regime method somewhat underestimated the 'recorded' changes. Hence, the predicted regime width is increased slightly and a range of potential future widths is provided. This translates to a potential 25% to 30% increase in mean width (9 m to 11 m), which results in a future mean width for the North Milk River between 49 m to 46 m. No significant change in depth is estimated since there weren't any 'recorded' changes in bed levels. The potential change to the slope will be similar to those discussed above for Scen. 1000.

3.6.5.2 Milk River 'Gravel Bed' Reach Predicted Channel Changes

Scen. 1000 – based on the CSR and regime approach, as well as a comparison with the other two reaches, there could be a potential 10% to 15% increase in mean width (6 m to 9 m). This could result in a future mean width between 68 m to 71 m. No significant change in depth or slope is estimated since there weren't any 'recorded' changes in bed levels.

Scen. 1200 – based on the CSR and regime approach, as well as a comparison with the other two reaches, there could be a potential 15% to 20% increase in mean width (9 m to 12 m). This could result in a future mean width between 71 m to 74 m. No significant change in depth or slope is estimated since there weren't any 'recorded' changes in bed levels.

3.6.5.3 Milk River 'Sand Bed' Reach Predicted Channel Changes

Scen. 1000 – the CSR is in the order of ±1.3 in comparison to the 'recorded' CSR of 2.0, which resulted in a 36% 'recorded' increase in channel width. Based on the CSR comparison, there could be a potential 15% to 20% increase in mean width (14 m to 18 m). This could result in a future mean width between 105 m to 109 m. The potential increase in depth is expected to be less than the 0.2 m 'recorded' increase. The impact on channel slope is expected to be less than the 10% 'recorded' decrease in slope.

Scen. 1200 – the CSR is in the order of ±1.5 in comparison to the 'recorded' CSR of 2.0, which resulted in a 36% 'recorded' increase in channel width. Based on the CSR comparison, there could be a potential 20% to 25% increase in mean width (18 m to 23 m). This could result in a future mean width between 109 m to 114 m. The potential change to .the depth and channel slope will be similar to those discussed above for Scen. 1000.

4.0 EVALUATION OF CHANGES TO RIPARIAN ZONE

4.1 River Engineering Processes

4.1.1 Erosion

Known areas of erosion along the north Milk River and Milk River were identified through a survey of landowners conducted by the MRWCC in support of this study. AMEC prepared a list of questions for landowners, which the MRWCC distributed to landowners. The results of the questionnaire are summarized in **Table 4.1**.

The locations of these areas of erosion are illustrated on **Figure 4.1**. This figure also shows the location of claimants that were documented in a report by Energy, Mines and Resources (1955). From **Figure 4.1**, AMEC, in consultation with MRWCC, determined that the areas of erosion could be grouped as follows:

1. Upstream sub-reach of North Milk River
2. Downstream sub-reach of North Milk River
3. Milk River at Milk River Town
4. Sand Bed Reach of Milk River

Plan maps for each of the sub-reaches were prepared using recent (c. 2000) digital orthographic aerial imagery provided by PFRA. On most of the maps (with the exception of the area around Milk River Town) the 1915 riverbank locations were marked to illustrate river channel movement since 1915. These maps are illustrated on **Figures 4.2, 4.3 and 4.6**. For the Milk River Town sub-reach illustrated on **Figure 4.4**, channel location information for other years was also available. PFRA prepared this figure using mapping prepared by Alberta Environment, which is included in **Appendix D**. As river location information for multiple years was available, PFRA also prepared a time sequence of river channel movement that is illustrated on **Figure 4.5**.

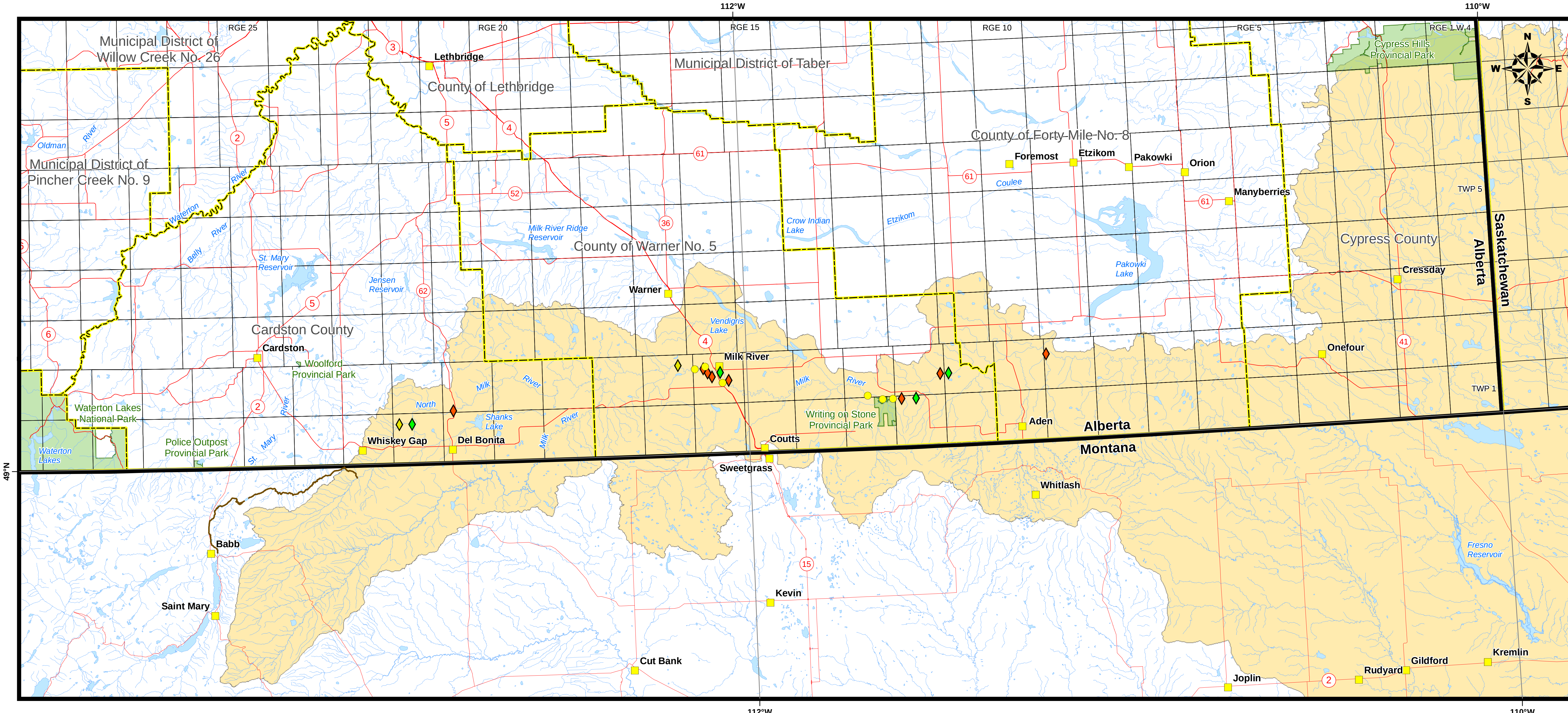
The following observations have been made from **Figure 4.5**:

- Most notable is the development of a cut-off channel in the downstream (right) portion of the sub-reach that occurred between 1915 and 1951.
- Lateral movement of the channel banks occurred elsewhere along the channel. This movement is consistent with downstream meander progression common to meandering river channels like the Milk River.
- There appears to be a consistent tendency towards a more sinuous channel form. This sinuous form would tend to lengthen the channel thereby decreasing the channel slope over time. The tendency to decrease the slope could be as a result of:
  - a reaction within the channel upstream of the pre-1951 cut-off to the local channel steepening caused by the cut-off (which decreased the channel length and steepened the slope); and/or,

TABLE 4.1

LANDOWNER QUESTIONNAIRE RESPONSES ABOUT RIVER EROSION

Survey No.	Legal Land Description	Period	Curent Condition	Location of Erosion				Rate of Erosion	m yr-1	Primary Cause of Erosion	When Does Erosion Occur		Erosion Occurs Mainly During:				What Property is Affected?	How Has Property Been Affected?	Erosion Protection?	How has the St. Mary Diversion Been Affected in Milk River?
				Outside bank	Oxbow Cutoff	Straight Reach	Other				Open Water	Ice Breakup	Gradually	Spring Freshet	Ice Floes	Summer Flood				
1	13-2-12 W4	1939-2007						30 m in 67 years	0.45	Summer flow plus occasional spring ice jams.	Mostly	Occasionally	80%	10%	5%	5%	Pasture/Deer Creek Bridge/Water Intake	Deposited sand produces little grass, eroded pasture is gone		Main cause
2	18-2-11 W4	1939-2007						50 m in 67 years	0.75		Mostly	Occasionally	80%	10%	5%	5%			Rock and gravel underlay 1985	Main cause
3	NW 4-1-12 W4	1939-2007	Eroding			x	inside bend	50 m in 67 years	0.75		Mostly	Occasionally	80%	10%	5%	5%				Main cause
4	NW 26-2-17-W4	1976-2007	Eroding	x		x		50 m in 30 years	1.67	Use of river as a canal.	x	x	x	x	x		Crop land/ Pasture/ Water Intake/ Power Line/ Gas Line	-	Some hand-placed rock and cut down bank 4 years ago - effective so far.	The ice is usually caused to "go out" by the addition of canal water, often at time of spring runoff.
5	SW 21-2-16 W4	1975-2007	On a back water so stable (?)		x (?)		none (?)	2 m in 32 years	0.06	Water eating away at the edges on the outside turn.	x					x	Crop land/ Pasture	-	Our neighbours have been hauling cement blocks and rocks to the river for years. They have had medium success.	-
6	NE 31-2-12 W4	1967-2007	Eroding	x				3 m in 50 years	0.06	Irrigation diversion / June floods / ice.	x	x	x	x	x	x	Pasture/ Farmstead/ Farm Buildings/ Water Intake/ Riparian Areas	Loss of property, loss of Cottonwoods.	-	High water throughout the summer continually erodes river bank
7	NW 14-2-16 W4	1980-2007	Eroding	x				7 m in 27 years	0.26	Extraordinary thick ice due to increased flow level in late fall.		x	x	x	x		Crop land/ pasture/ road/bridge	Erosion of irrigated land base.	No.	It has increased erosion
8	NW 22-2-16 W4	1897-2007	Eroding				inside bend	14-18 m in 20 years	0.7-0.9	Flooding and natural spring seepage.		x		x		x	Pasture/ Municipal property	-	No - discussions have been held with AENV, PFRA, Town of Milk River.	-
9	NE 20-2-16 W4	1976-2007	Eroding	x				13 m in 30 years	0.43	Spring flood levels and sand / gravel bank base.		x			x		Crop land/ Irrigation pivot	Loss of more area will limit the use of a small centre pivot from completing a circle cycle.	No erosion protection has been installed.	Present St. Mary River diversion water levels in the Milk River have not affected bank erosion - loss is due to spring break up.
10	SW 29-2-16 W4	1976-2007	Eroding	x				10 m in 30 years	0.33	High flood levels during spring breakup.		x					Crop land/ Water Intake	Loss of irrigation land and road.	No erosion protection has been installed.	The present flow levels of the St. Mary River diversion into the Milk River so far have not affected erosion though higher levels certainly could.
11	NW 28-1-22-W4	1975-2007	Eroding	x				30 m in 30 years	1	Loose soil with no cover, and too much water too early.	x	x	x				Farmstead/ Farm buildings	River has taken part of the yard and some sorting corrals.	There was a plan with the County to divert the river and the project went and fell through, probably because of Fisheries and Oceans (90s).	When the water is put in, the river does not have a chance to control the force, the N. Milk is treated like a canal by the US and we have our hands tied when we try to make changes to it.
12	NE 30-1-22-W4	1990-2007	Eroding	x				100 m in 20 years	5	Early release of water into the North Fork.	x	x	x				Pasture/ Road/Bridge/ Farmstead	Continuing to break the bank away and is nearing the farm road, also causes a hazard in the calving field for young calves.	No.	Has accelerated the erosion and the North Fork has never had the chance to stabilize, the channel naturally wouldn't handle this much water.
13	SW 5-2-21-W4	1990-2007	Eroding			x	Behind bridge pillar	10 m in 15 years	0.67	There was not proper rip-rap installed under the bridge and at access point for canoers.	x		x				Road/Bridge	There is now a dangerous eddy with large chunks of corrigated metal sticking out from the bridge pillar and the bank has eroded away.	Small cobble was placed by AB Transportation many years ago but has long since washed out.	Because it is so highly regulated, there is not much opportunity for trees and willows to grow and hold the banks together.
14	SW 30-2-9-W4	-2007	Eroding	x				1 m in 2 years	0.5	Water diverted from the St. Mary's River into the Milk River.	x (Mostly)	x (Sometimes)	x		x (Sometimes)		Farm buildings	The river is encroaching on our barn and a flowing well. We have also had to move feedlots and corralls due to the loss of bank.	About 25 years ago a bunch of dead trees (large ones) were rolled over the river bank. They protected the bank for several years until spring flooding swept them away.	The increased waterflow seems to undercut the bank at high flow times, causing about 2 ft of bank to drop in every year. Ice jams have also been a problem. Sandy soil and unnatural water flows cause a greater erosion problem.



Legend

- Milk River Watershed
- National/Provincial Park
- Rural Municipality
- Water
- Road
- Canal
- Town
- Erosion Claimants to 1956

2007 Landowner survey by MRWCC

- < 0.5 m/yr; 0.67; 0.5
- 0.5 to 1.0 m/yr; 1
- > 1.0 m/yr; 5

amec

Milk River Watershed Council Canada

Study of Erosion and Sedimentation on the Milk River

Location of Bank Erosion Sites Identified by Landowners

DATE: February 2008

PROJECT No: CW2020

PDF FILE: Fig04.01 Milk River 08-02-12

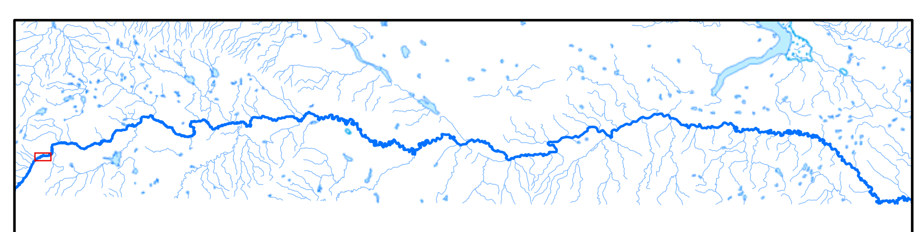
Figure 4.1

S:\gis\Projects\CW2020\ArcGIS_projects\Fig04.01 Milk River.mxd

LEGEND

Milk River Bank (1915)

INDEX MAP



100 50 0 100 200 300

Meters

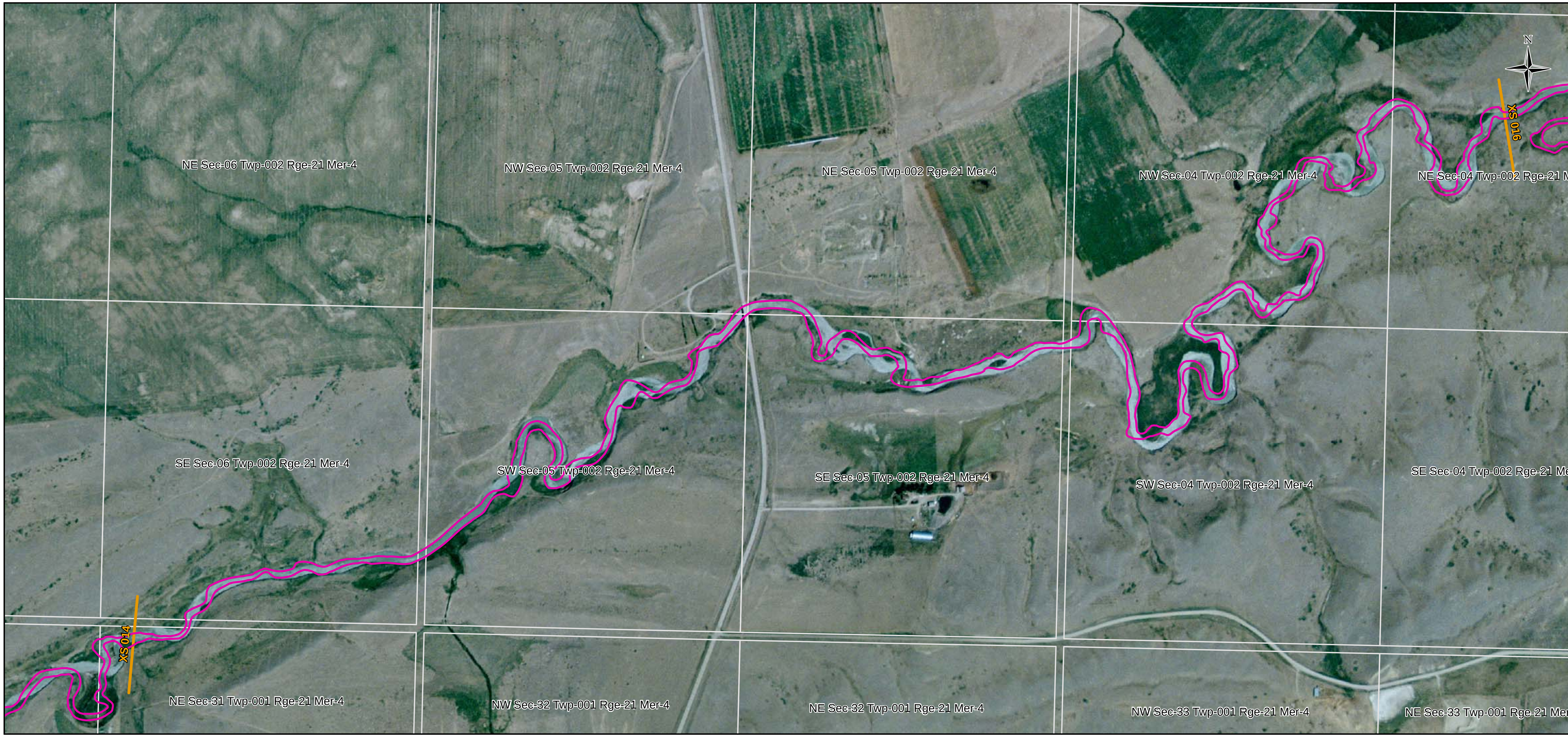
1:8,000

Milk River Watershed Council Canada

Historical River Locations
North Milk River
Upstream Site

DATE: February 2008	**Figure 4.2**
PROJECT: CW2020	Fig4.2_upstream_site_08-02-13
ANALYST: CAF; QA/QC: KW GB GB	amec
PROJECTION/DATUM: UTM Zone 12 NAD83	

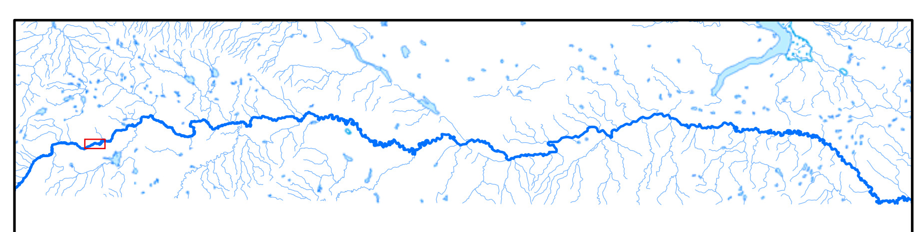
Map Path: S:\gis\Projects\CW2020\ArcGIS_projects\Fig4.2_upstream_site.mxd



LEGEND

- Milk River Bank (1915)
- Cross Section

INDEX MAP



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Meters

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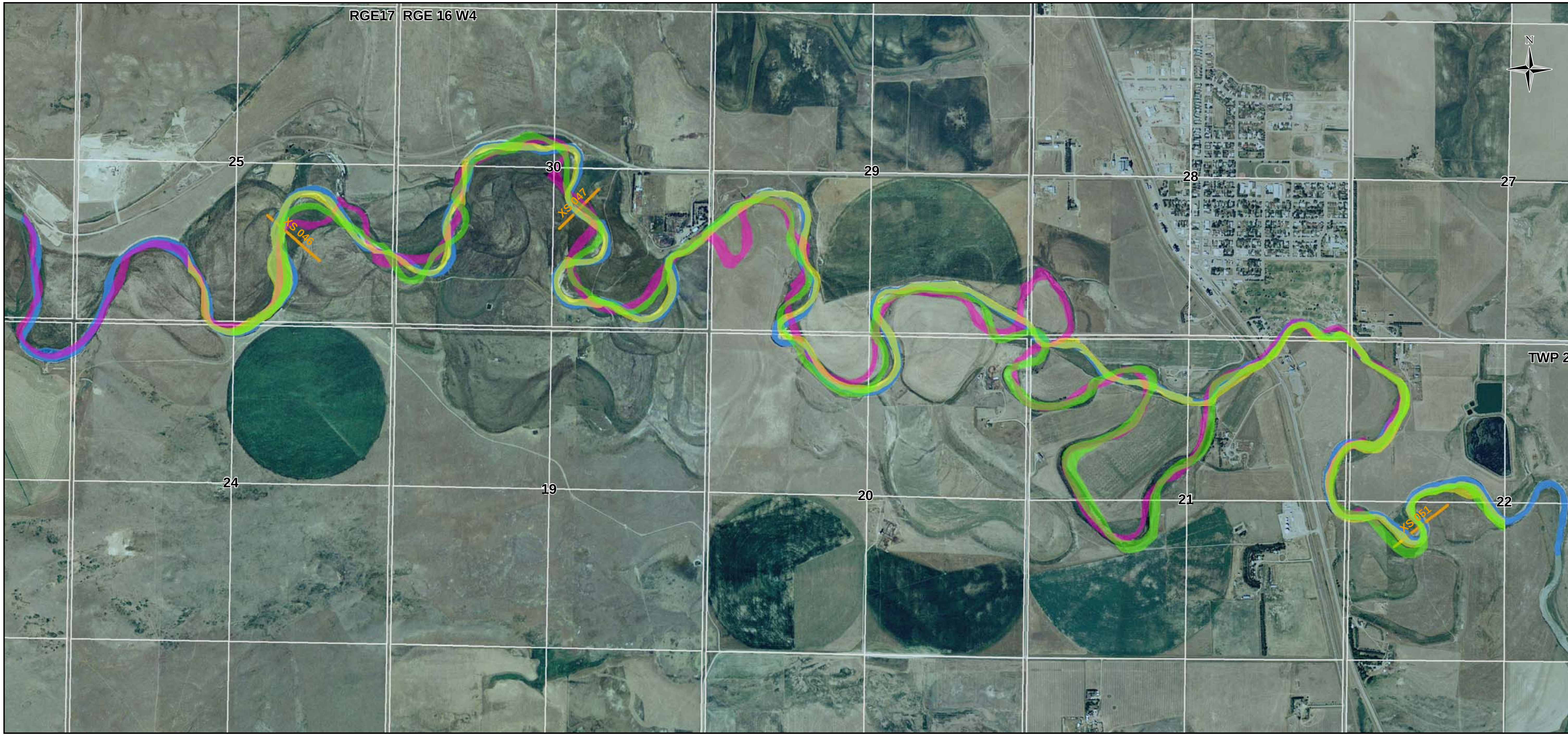
Milk River Watershed Council Canada

Historical River Locations
North Milk River
Downstream Site

DATE: February 2008	**Figure 4.3**
PROJECT: CW2020	Fig4.3_downstream_site_08-02-13
ANALYST: CAF; QA/QC: KW GB GB	amec
PROJECTION/DATUM: UTM Zone 12 NAD83	

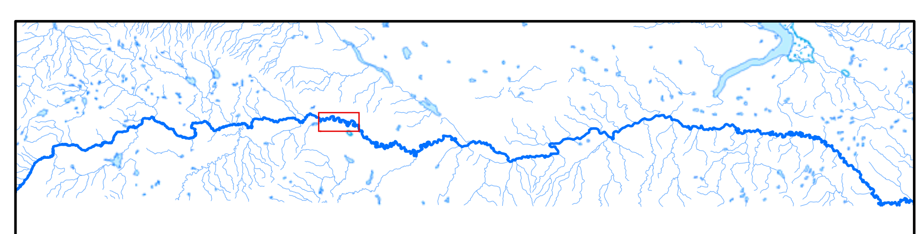
Map Path: S:\gis\Projects\CW2020\ArcGIS_projects\Fig4.3_downstream_site.mxd



LEGEND

- 1999-2000 Banklines
- 1983 Banklines
- 1951 Banklines
- 1915 Bankline
- Cross Section

INDEX MAP



500 250 0 500 1,000

Metres

1:20,000

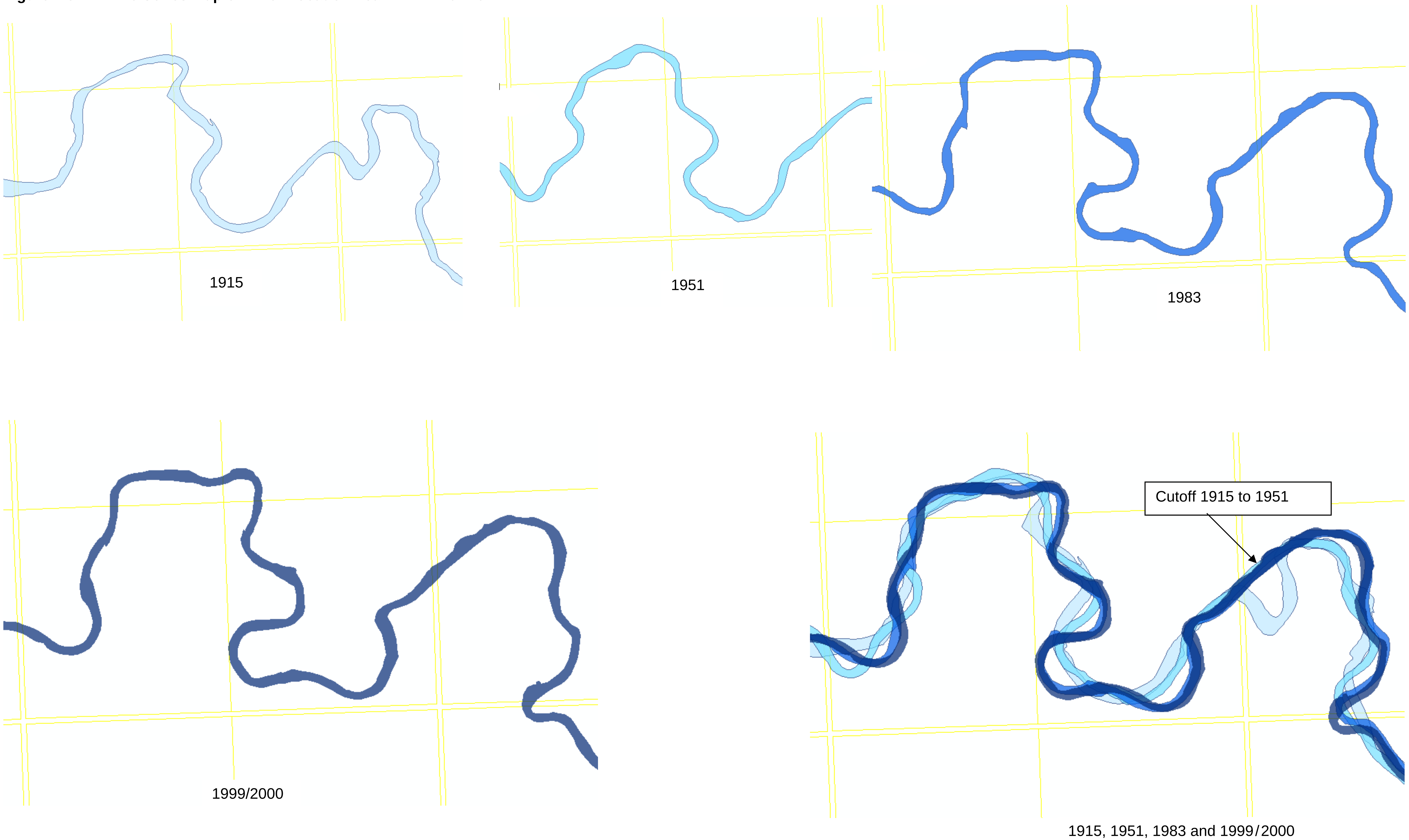
Milk River Watershed Council Canada

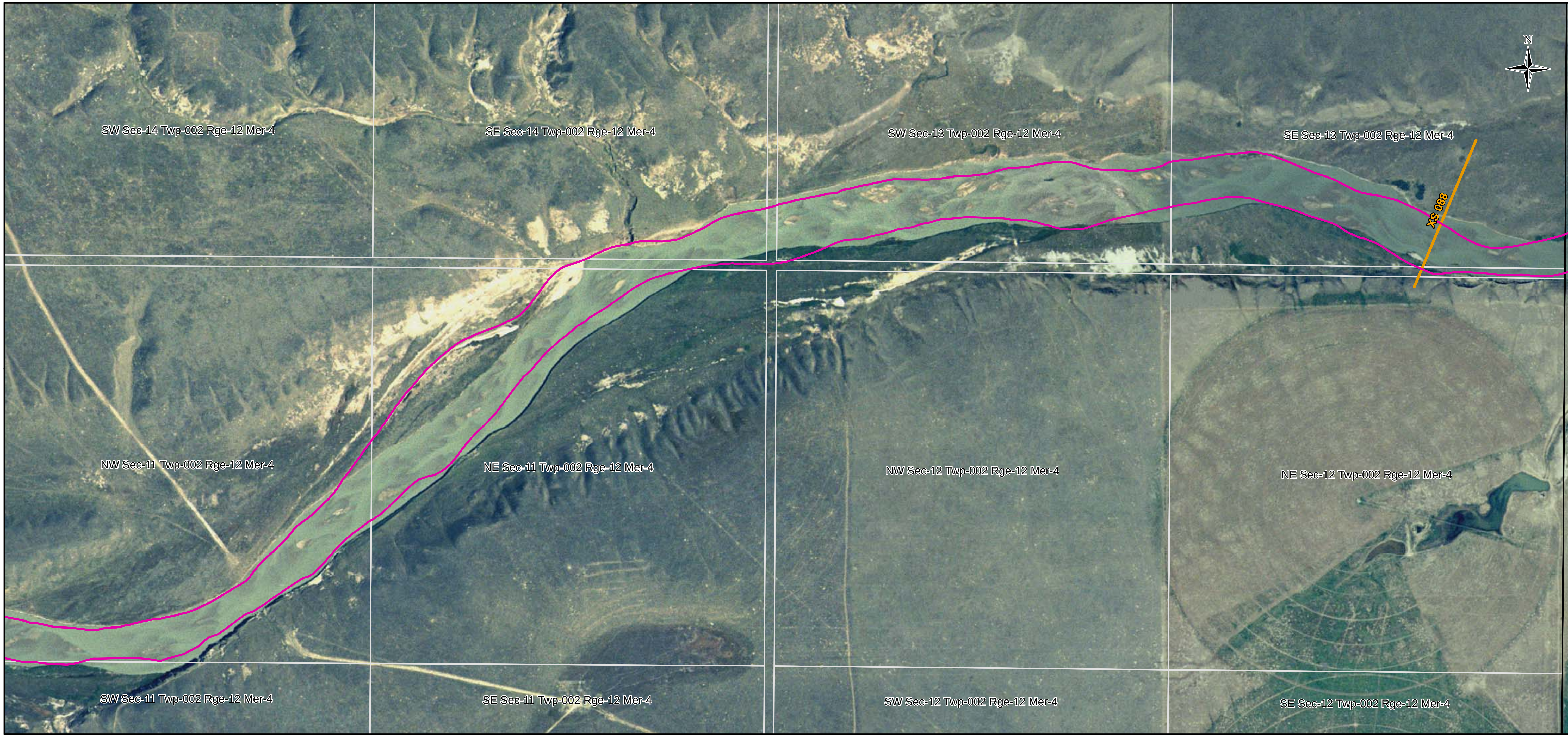
Historical River Locations
Milk River (Gravel Reach)
Milk River Town Site

DATE: February 2008	**Figure 4.4**
PROJECT: CW2020	Fig4.4_channel_evolution _08-02-13
ANALYST: CAF QA/QC: KW GB GB	amec
PROJECTION/DATUM: UTM Zone 12 NAD83	

Map Path: S:\gis\Projects\CW2020\ArcGIS_projects\Fig4.4_channel_evolution.mxd

Figure 4.5 Time Series Map of River Location near Milk River Town

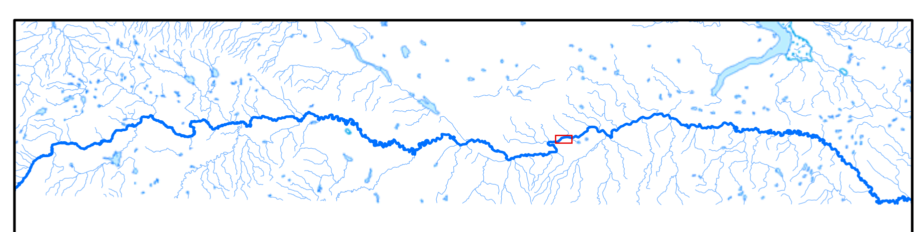




LEGEND

- Milk River Bank (1915)
- Cross Section

INDEX MAP



100 50 0 100 200 300

Meters

1:8,000

Milk River Watershed Council Canada

Historical River Locations
Milk River (Sand Reach)

DATE: February 2008	**Figure 4.6**
PROJECT: CW2020	Fig4.6_stream_site_08-02-13
ANALYST: CAF QA/QC: KW GB GB	amec
PROJECTION/DATUM: UTM Zone 12 NAD83	

Map Path: S:\gis\Projects\CW2020\ArcGIS_projects\Fig4.6_stream_site.mxd

  - o The continued reaction of the channel to diversion flows. As discussed above, the channel will tend to initially steepen as a result of increased flows. As happened following the post-1917 diversion, channel erosion also resulted in cut-off development, which would also tend to steepen the channel slope. This steepening may be considered as an initial to intermediate term response to the diversion. Following that, however, the channel would tend to reduce its slope by increasing its length, i.e. increasing channel sinuosity.
- While the reach downstream of the cut-off is relatively short, it is important to note that the channel in the lower reach downstream of the cut-off is also becoming more sinuous. This is consistent with the response of the channel to increased discharges from the St. Mary diversion.

4.1.1.1 Erosion Rates

Supplementary to information on erosion provided by landowners in **Table 4.1**, AMEC measured erosion rates from the figures noted above to provide comparative long-term erosion rates over the approximately 85 years since 1915. These data are summarized in **Table 4.2**.

The areas of erosion along the river identified for this project have been prepared from responses obtained by the MRWCC to a request distributed to landowners. It represents a sampling of areas along the river where erosion has occurred, as illustrated on **Figure 4.1**. These sites might not identify all areas where erosion has affected land and facilities or could potentially affect both existing or proposed infrastructure. Additional work would be required to characterize historical river erosion patterns and erosion rates along the entire length of the North Milk and Milk rivers. One approach which could be undertaken to fill in this gap would involve digitizing images of the 1915 riverbank locations and overlaying them on recent aerial photo imagery of the river, such as that illustrated on **Figures 4.2, 4.3, 4.4 and 4.6**. With this information and knowledge of the locations of infrastructure such as roads, buildings, etc., vulnerable facilities could be identified. Set-back distances could be compared to erosion rates to prioritize sites for future investigation.

The areas of erosion identified from landowner responses during this study do not necessarily indicate representative locations. For instance, on the North Milk River, the two reaches illustrated on **Figures 4.2 and 4.3** include bridge crossings, which are locations where the river channel is ‘locked-in’ and not free to move. A similar instance is on the Milk River (Gravel Reach) which includes the highway bridge crossing at the Town, as illustrated on **Figure 4.4**. Regardless of the presence of bridge crossings, these locations may still be important locations to monitor, as they represent locations where local landowners are concerned about erosion. Other locations without bridge crossings may also be considered.

Erosion monitoring should be undertaken at locations that are representative of average conditions within each of the three characteristic river reaches. In addition, specific monitoring programs may target vulnerable sites identified by landowner responses or from information obtained through examination of historical river movement in relation to existing or proposed facilities and infrastructure.

TABLE 4.2
EROSION RATES OVER 85 YEARS

		Measured from Orthophotos (Figures 4.2 to 4.5)			Reported from Landowners Questionnaire (Table 4.1)		
Survey No.	Legal Land Description	Period	Rate of Erosion	m yr-1	Period	Rate of Erosion	m yr-1
1	13-2-12 W4	1915 to 2000	50 m in 85 years	0.59	1939-2007	30 m in 67 years	0.45
2	18-2-11 W4	Site not present on Orthophotos			1939-2007	50 m in 67 years	0.75
3	NW 4-1-12 W4	Site not present on Orthophotos			1939-2007	50 m in 67 years	0.75
4	NW 26-2-17-W4	Site not present on Orthophotos			1976-2007	50 m in 30 years	1.67
5	SW 21-2-16 W4	1915 to 1951	90 m in 36 years	2.50	1975-2007	2 m in 32 years	0.06
		1951 to 1983	Cut Off formed, no longer in SW-21-16-W4				
6	NE 31-2-12 W4	Site not present on Orthophotos			1967-2007	3 m in 50 years	0.06
7	NW 14-2-16 W4	Site not present on Orthophotos			1980-2007	7 m in 27 years	0.26
8	NW 22-2-16 W4	1983 to 2000	15 m in 17 years	0.88	1897-2007	14-18 m in 20 years	0.7-0.9
9	NE 20-2-16 W4	1915 to 1951	30 m in 36 years	0.83	1976-2007	13 m in 30 years	0.43
		1951 to 1983	30 m in 32 years	0.94			
		1983 to 2000	5 m in 17 years	0.29			
10	SW 29-2-16 W4	1915 to 1951	30 m in 36 years	0.83	1976-2007	10 m in 30 years	0.33
		1951 to 1983	30 m in 32 years	0.94			
		1983 to 2000	5 m in 17 years	0.29			
11	NW 28-1-22-W4	1915 to 2000	15 m in 85 years	0.18	1975-2007	30 m in 30 years	1
12	NE 30-1-22-W4	1915 to 2000	140 m in 85 years	1.65	1990-2007	100 m in 20 years	5
13	SW 5-2-21-W4	1915 to 2000	30 m in 85 years	0.35	1990-2007	10 m in 15 years	0.67
14	SW 30-2-9-W4	Site not present on Orthophotos			-2007	1 m in 2 years	0.5

Erosion monitoring may be accomplished at two levels of detail. The first, represented by plots obtained from comparative aerial photos is illustrated on **Figure 4.4**. This can be accomplished for all areas along the river and is dependent only on the date and scale of the aerial photos. Finer detail can be obtained by surveying bank locations. The rate of movement can be more closely determined both laterally along the bank and in time. For instance, erosion resulting from ice action can be determined by pre- and post-break-up surveys. Additional surveys during the open-water season can identify the erosion resulting from the diversion flows in concert with natural flood peaks occurring at a particular location. The surveying can employ current GPS techniques or 'old-fashioned' erosion stakes.

4.1.2 Sedimentation

The sediment derived from channel bank erosion along the North Milk River and the Milk River is transported downstream and deposited within the channel or on the floodplain. In addition to the erosion of the channel banks itself, the river transports sediment derived from tributary inflow. As noted above, the badlands area along the lower sand bed reach of the Milk River contributes substantial volumes of sediment to the river. If the river has sufficient energy or capacity to transport the incoming sediment, then the channel will establish a state of quasi-equilibrium where channel bed levels similar to existing conditions will result. If the energy or capacity to transport sediment is inadequate, the channel will either widen to increase transport capacity and/or adjust its slope to provide additional energy. Sediment will otherwise be deposited on the floodplain and in neighbouring oxbow channels during periods of overbank flooding. In-channel sediment will continue to move downstream and sediment deposited above bankfull level will only be liberated when bank erosion occurs or cut-off channels are created.

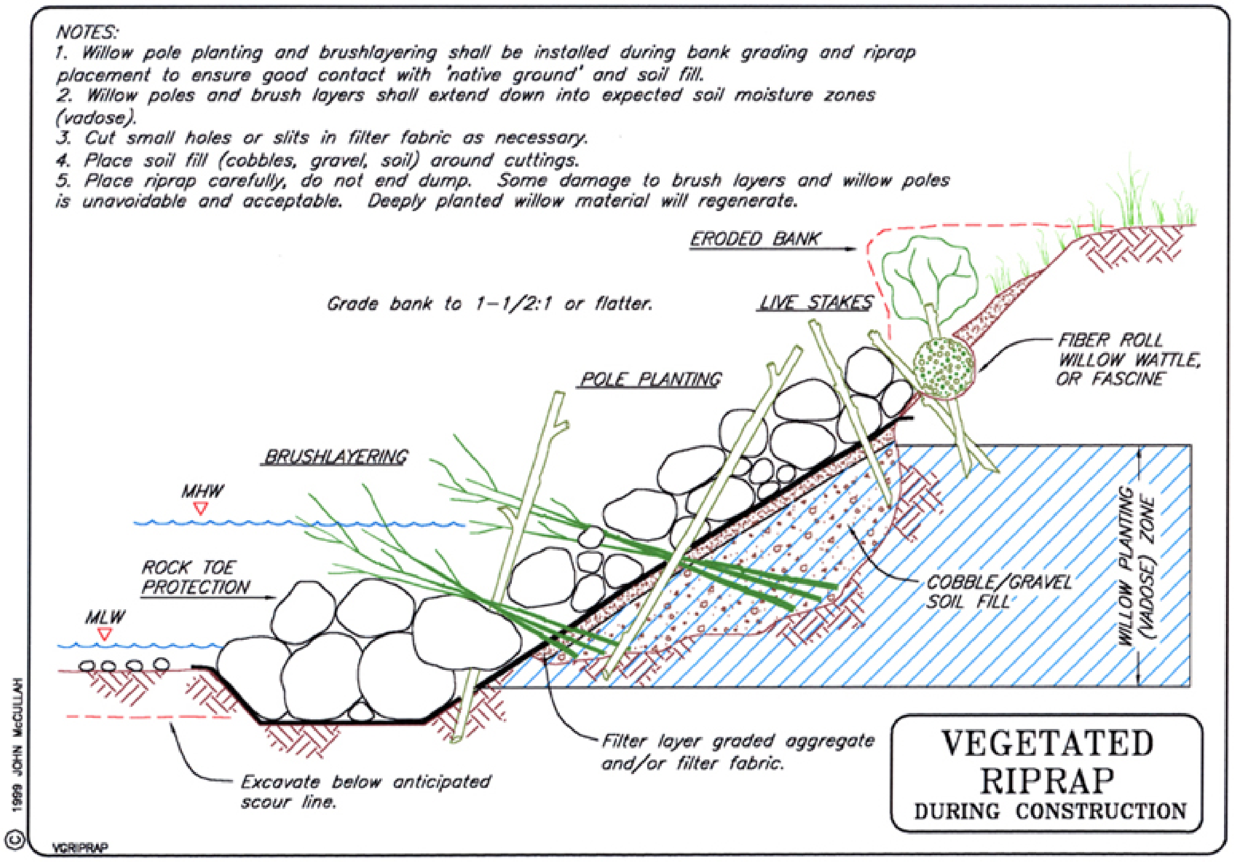
4.1.3 Channel Stabilization Measures

For the North Milk and Milk Rivers, a range of channel stabilization methods can be employed, including:

- bank armouring using riprap and underlying granular filter or non-woven geotextile (filter cloth);
- articulating concrete blocks or A-Jacks and underlying granular filter or non-woven geotextile (filter cloth); and,
- spurs or groynes extending out from the riverbank to break up the current along the bank and promote sedimentation in between the spur structures.

Bank armouring using riprap or articulating concrete blocks is likely to be the primary form of bank stabilization employed along the river. Ice action precludes the use of gabion baskets or gabion mats, as ice movement has been known to tear the wire mesh. Ice action also may limit the use of bio-engineering in association with 'hard' armouring near the toe of the bank to only those cases where the bank slope to be protected extends above the elevation of ice action.

Alternatively, vegetation plantings could be integrated into the bank armouring at the time if construction, such as illustrated below, thereby providing the shade and cover that enhances local fish habitat. If the vegetation doesn't survive, or is periodically scraped away by ice action, the integrity of the bank protection system won't be affected.



Source: ErosionDraw, (http://www.erosiondraw.com/new.htm) by Salix Applied Earth Care, Redding, California.

Riprap or concrete blocks at the toe would need to be designed to withstand hydraulic forces of the water flow during design flood conditions as well as ice forces. The bank stabilization measures would need to extend a sufficient distance upstream and downstream along the affected area and be adequately 'keyed-in' to the bank to prevent outflanking of the measures due to channel shifting and river currents.

Spurs or groynes have not historically been used for bank stabilization along the Milk River. The opportunity exists to use this form of bank stabilization on the Sand Bed reach of the river where sediment loads are high. Spurs would not be well suited to the North Milk River and potentially for the Gravel Bed reach of the Milk River where suspended sediment loads are much lower. The spurs can be constructed either as 'impermeable' structures such as sand/gravel projections out into the channel or as 'permeable' structures comprising pile and timber framework filled with trees and branches. The layout of these structures needs to consider the length projecting out from the bank, the distance the landward end of the structure is keyed into the bank, the angle of the structure to the flow, and the spacing of the structures. Scour protection at the outer end of the structure also needs to be provided.

4.2 Ice Jam Effects

The objectives of the assessment of ice effects were to determine: the locations of historic ice jam events along the river; evidence on the role of ice jam activity with respect to bank erosion processes; evidence as to whether the existing diversion affects ice jam processes; and assessment of potential new diversions on ice jam processes.

4.2.1 Historic Ice Jam Activity

The availability of information on documented ice jam events along the study reach is limited. The following information sources were examined to establish the existence and location of historic ice jam events.

- Alberta Environment (ANEV) records, River Engineering Branch;
- Water Survey of Canada (WSC) hydrometric records;
- published reports; and,
- Interviews with persons known to have local experience with ice jam activity along the study reach.

The following information sources were found to contain evidence of historic ice jam events occurring along the study reach. Most of the correspondence was related to the potential for ice jam-induced flooding. The correspondence regarding the 1976 jam at the Coffin Bridge was related to flooding and the potential for damage to the bridge as a result of the ice jam.

- AENV letter dated 29 January 1976 (file reference: RE 11-11A);
- AENV letter dated 28 April 1976 (file reference: RE11-11A);
- AENV letter dated 29 August 1979 (file reference: RE 11-11A);
- AENV “Ice Jam Problems – Investigation”, record dated 20 March 1997;
- Statements documented in Purcell (1956);
- Report on “Reconnaissance of Milk River and Observations of Erosion”, 29 November to 01 December 1955 (Department of Energy, Mines and Resources, (EMR), 1955); and,
- Telephone conversation with John Ross, Milk River Cattle Co., SW 30-2-9 W4 (Nov. 2007).

Very few ice jam events have been documented through the study reaches. The information sources listed above document only the following ice jam events (the existence of additional documented events may be found through a more exhaustive literature review).

- 20 January 1976 – ice jam on Milk River near Section 29-2-16 W4.
- 18 March 1976 – ice jam on Milk River, Coffin Bridge near Sections 1 and 12-215 W4.
- 1978 – ice jam on Milk River south of Manyberries (“a few ice jams along the reach” near Twp. 2 Rge. 7 W4.
- 1979 – “3 or 4 ice jams between the Town of Milk River and the residence of Mr. W.J. Snow”.
- 1997– ice jam on Milk River at Milk River.

While the list of documented events found during this investigation is short, descriptive accounts by the person interviewed, and text within the above documents, suggest that the formation of ice jams along the Milk River is a regular occurrence. The AENV letter dated 29 August 1979 suggests that "during the annual spring break-up, ice runs and ice jamming are a regular phenomenon on most rivers which go through a freeze-thaw cycle… [and] the Milk River is no exception".

Discussions with John Ross revealed that ice jam events occurred periodically along the Milk River. Several events had occurred over years of his recent memory and that a significant event occurred adjacent to his property some 10 to 15 years ago. During this significant event water levels rose approximately 10 feet and ice overtopped fences. Damage to cattle fences from ice action has become problematic. Mr. Ross also noted one instance where an ice jam formed a channel cut-off downstream of his property.

4.2.2 Bank Erosion Processes

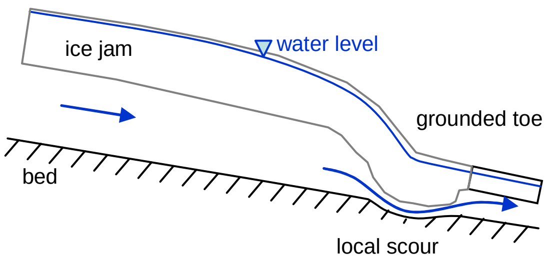
Ettema (2002) provides a comprehensive review on alluvial channel response to river ice processes. Some of the processes are well understood, others are identified only in concept, and some processes are in the early stages of recognition by the river ice research community. The following processes were identified as the most significant contributors towards bank erosion on the Milk River.

1. local scour;
2. channel-thalweg adjustment;
3. bank destabilization; and,
4. meander loop cut-off.

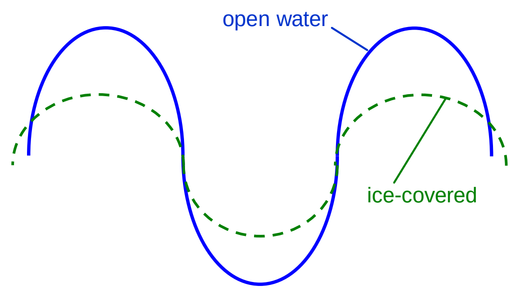
These four processes are listed in increasing order of significance with respect to both the degree of permanence and relative impact. **Figure 4.7** provides a schematic representation of these processes (further described below). These processes are difficult to quantify and attempts to do so were beyond the scope of this study. The following description of these processes provides a means for understanding the impacts of river ice processes on bank erosion. This understanding may form a basis for assessing the relative importance of river ice processes with respect to channel erosion activities and the potential need for further study.

Figure 4.7 Schematic of Bank Erosion Processes
Due to: (a) local scour, (b) channel-thalweg adjustment, (c) bank destabilization, (d) premature meander loop cut-off, and (e) combined bank erosion processes

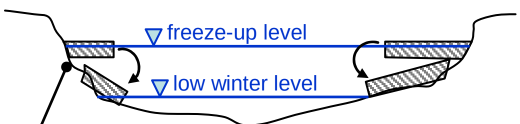
(a) Local scour.



(b) Channel-thalweg adjustement.

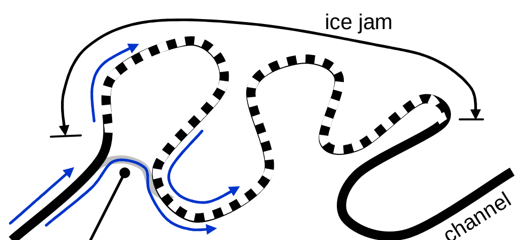


(c) Bank destabilization.



Shorefast ice breaking away and destabilizing banks ("bankfast-ice loading").

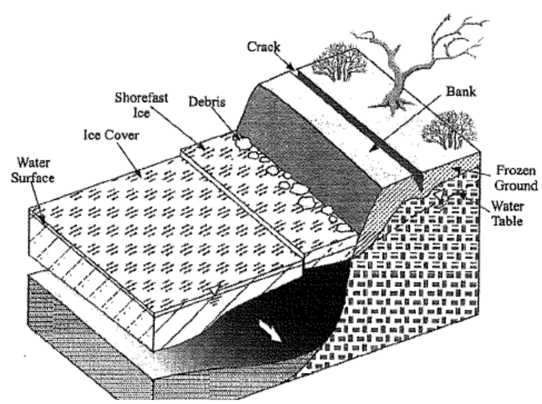
(d) Premature meander loop cutoff.



Overbank flows across wide neck of meander loop due to high ice jam water levels – resulting in meander cutoff.

(e) Combined bank erosion processes (adopted from Ettema, 2002).

Thalweg shift and bank-toe erosion (local scour) combined with bank destabilization processes (e.g. bankfast-ice loading).



4.2.2.1 Local Scour

Local scour may occur as a direct result of the presence of an ice cover. When the ice cover is fixed to the bed/bank or if it is thickened to the point where it no longer floats freely in the channel, flows under the cover are forced through a reduced area causing higher velocities. These higher velocities may result in scour in localized areas. The more extreme condition of local scour occurs at the downstream limit (or "toe") of an ice jam when it becomes partially grounded (the ice jam makes contact with the bed). **Figure 4.7(a)** presents an illustration of this extreme case of local scour.

4.2.2.2 Channel-thalweg Adjustment

In some instances, the presence of ice will limit the flow to some portions of the channel and redirect increased flows to other portions of the channel or to another separate channel path. The channel sections receiving these flows may deepen and create new preferred pathways for future open water flows. These processes become more significant during the formation of thick freeze-up ice accumulations that remain in place over the entire winter period.

Another less apparent process contributes to thalweg adjustment. Given the same hydraulic, geometric, and bed material properties, flows under ice covered conditions tend to reduce thalweg sinuosity; meander loops tend to straighten and shorten as illustrated on **Figure 4.7(b)**. The basic rational for this process is as follows. Under the same flow conditions, the presence of an ice cover increases the resistance to flow resulting in an increase in the cross-sectional area passing the flow and a reduction in flow velocity. The net effect is to reduce the hydraulic gradient. As the hydraulic gradient reduces, the channel seeks a new alignment to achieve a balance between the resistance to flow presented by the channel properties and energy imparted to the flow by gravity – the channel tends to straighten to achieve a higher hydraulic gradient.

4.2.2.3 Bank Destabilization and Erosion

In the context of this report, bank destabilization and erosion describe processes that work towards degradation of the banks directly by ice abrasion/scour and bank-fast ice loading or by less direct means which cause a reduction in soil stability. There are two primary processes that impact the banks directly. The first, easily envisioned process is characteristic to spring break-up where large competent pieces of ice gouge and abrade the banks. This process can be more severe where channel sections present features that protrude into the flow or through sharp bends. The second process is less intuitive and may not be of serious consequence for the Milk River. During freeze-up the shore fast-ice freezes to the banks. During the winter season, flows decrease and water levels drop. Large sections of ice then break away from the banks removing material from the banks – as illustrated on **Figure 4.7(c)**.

The following documented accounts from local residents support the existence of these processes occurring along the Milk River (EMR, 1955):

- "Mr. Hoyt says he has watched the floating ice after spring break-up scraping away the banks on the outside of bends."

- "Mr. Dobracane says he has watched floating ice in the spring wear away the river banks. His opinion is that this is the whole cause of the erosion and that the summer flow has very little effect".
- The EMR (1955) report concluded by stating, "One of the main causes of erosion is undoubtedly the abrasive effect of floating ice after break-up in the spring."

The presence of ice along the banks contributes to bank destabilization and erosion by less direct means. As the banks and shore fast-ice freeze, there is potential for a local increase in groundwater levels within the banks causing an increase in seepage pressures, thereby reducing the stability of the banks. During spring break-up the water levels drop relatively quickly as compared to an elevated water table in a bank comprised of cohesive soils. In this case "rapid drawdown" effects further reduce soil instability. Also, the effects of freeze-thaw cycles that weaken the banks are exacerbated by the presence of ice. **Figure 4.7(e)** illustrates a combination of these processes.

4.2.2.4 Meander Loop Cut-off

Figure 4.7(d) provides a schematic plan view of the development of a meander loop cut-off. When an ice jam forms through a reach of meandering loops the upstream water levels may rise to the point where they overtop the banks. The overtopping flows may then extend across the neck of a meander loop. If this condition is sustained long enough to cause erosion across the neck down to bed levels, then a cut-off occurs. Meander loop cut-offs have been observed on the Milk River by local resident John Ross and the following account obtained from AENV records documents a condition where the processes towards meander loop cut-off were initiated. Mitigative action was taken in this instance to prevent development of a full cut-off. "The Coffin Bridge jam was over a mile long and had grounded out. The normal flow had been going under the jammed region but could not accommodate the increased flows which occurred at this time. Water was flowing around the jam over a pasture, along the road ditch and then back to the main channel."

4.2.3 Impacts of Diversion Activities on Ice Jam Processes

Due to the difficulties associated with quantifying ice jam process, the impacts of diversion activities on ice jam processes can only be examined from a qualitative to quasi-quantitative level. What follows is an attempt to characterize the impacts of diversion activities based on the information collected and scope of this study.

4.2.3.1 Frequency of Ice Jam Occurrence

While evidence suggests that ice jam activity along the Milk River occurs with some regularity, insufficient data exists to easily quantify the frequency of occurrence of ice jam events. However, inspection of reported peak annual flows at representative WSC gauges within the study reach provides a means of assessment on the potential of ice jam activity. The number of instances corresponding to peak flows under ice-affected conditions as compared to those under open-water conditions suggests the relative importance of ice effects within the gauged reach. When high flows occur during ice-affected periods it is plausible that conditions are favourable for ice jam formation. Further, where a significant number of reported peak flows occur during the ice-affected period it is reasonable to anticipate a strong potential for periodic ice jam occurrence.

Table 4.3 provides a summary of the ratio of peak flows occurring under ice-affected conditions at WSC gauges representative of reaches susceptible to ice jam formation. Bearing in mind that the percentage of instances where annual maxima occur under ice effects does not clearly indicate the presence of an ice jam, this crude analysis suggests that conditions are favourable for the development of an ice jam approximately once in every five years at these particular locations. Ice jam activity is expected throughout most of the study reach and ice jams occurring elsewhere within the study reach are not represented by the gauges used for this preliminary analysis. Therefore, it is likely that the frequency of an ice jam occurring anywhere along the study reach is greater than suggested by this crude analysis.

TABLE 4.3
Ratio of Peak Flows Occurring under Ice-Affected Conditions

Station Number	Location	Years of Record	Instances Where Annual Maxima Occur Under Ice-Effects	
			Number of Years	Percent of Total Record
11AA005	Milk River at Milk River	97	22	23%
11AA031	Milk River at Eastern Crossing	95	20	21%

AMEC's scope precluded a detailed examination of the hydrometric records to determine if the St. Mary River diversion was operating at the time these peak discharges occurred. If the MRWCC wishes to further examine the role of the diversion during break-up, then the hydrometric records could be analyzed further.

More refined estimates on the frequency of ice jam occurrence are limited by the scope of work and availability of data. Reliable identification of locations along the study reach that are frequent "hot spots" for ice jam activity is limited for the same reasons. However, based on the information gathered during this study, the following characterizes the historic nature of ice jam behaviour along the Milk River.

- Ice jam activity along the Milk River is a regular occurrence. Depending on the prevailing hydrometeorologic conditions during spring break-up, it is plausible that these events are expected to occur at some point along the entire study reach more frequently than once in every five years.
- Data on documented ice jam events is not sufficient to provide estimates on the potential impacts of diversion activities on the frequency of ice jam occurrence. The development of qualitative estimates may be pursued to assess incremental impacts; however, these efforts are beyond the scope of this study.

4.2.3.2 Ice Jam Severity

In the context of this study, the severity of an ice jam relates to the magnitude of the ice jam event. Ice jams may occur during freeze-up, the winter period, or spring break-up. Typically, ice jams occurring during the freeze-up period are of the lowest magnitude in terms of jam thickness and the height of resulting water levels. Spring break-up jams are typically associated with the most severe type of ice jam resulting in the thickest ice accumulations and highest water levels. Winter jams lie somewhere between the spectrum of severity bounded by the freeze-up and break-up ice jams. This does not necessarily relate to the amount of damage resulting from an ice jam. Winter jams may be particularly damaging when they refreeze in place and inundated areas remain under frozen ice for the remainder of the winter. The presence of a winter jam also increases the likelihood of occurrence of a break-up jam at or near the same location.

Diversion activities are not expected to occur during the freeze-up or winter periods. Therefore the conditions for freeze-up and mid-winter period are expected to remain unchanged for purpose of this study. This further implies that diversion activities are not expected to contribute to incremental changes in river ice processes causing bank erosion during the freeze-up and winter period.

Break-up jams often result from the breaking, transport and subsequent accumulation of an ice cover due primarily to hydrodynamic forces driven by a substantial increase in river flows. A break-up jam has reached its most “severe” state when it has achieved its so-called equilibrium condition. To achieve equilibrium, a sufficient volume of ice supply is required to develop an ice jam section where the flow under the jam is near uniform and the water surface slope is nearly equal to the energy grade slope. Through the equilibrium section depth to the phreatic surface, H, and ice jam thickness remain constant.

The following process was adopted as an attempt to quantify the impact of diversion activities on the potential severity of spring break-up jams. Based on reach averaged channel characteristics outlined in **Table 3.3** and **Table 3.4**, determine the theoretical equilibrium jam thickness and resulting water levels for each distinct reach for various hydraulic conditions (discharge rates). The maximum achievable water level and thickness of an ice jam is primarily a function of: the strength properties of the mass of ice acting as a continuum; the applied drag forces under the accumulation (relating to discharge and ice accumulation roughness); the downstream component of weight of the accumulation (relating to gravity and water surface slope), and the width of the channel. Beltaos (1983) provided a convenient means for combining these effects through a simple dimensional analysis resulting in the development of the following non-dimensional terms relating depth and discharge for equilibrium ice jams.

Non-dimensional depth = H/S_oB
Non-dimensional discharge = (q^2/gS_o)^$^{1/3}/(S_oB)$.

Where: H is the maximum attainable depth to the water surface level (m)
S_o is the slope of the bed (m/m)
B is the channel width (m)
q is the unit rate of discharge ($m^3/s/m$)
g is acceleration due to gravity (m/s^2).

Table 4.4 provides a summary of the computed equilibrium conditions for the various scenarios ranging from conditions prior to diversion activities (Natural) to current conditions (Recorded) and future proposed conditions (Scen. 1000 and Scen. 2000). Hypothetical channel sections based on channel characteristics presented in **Table 3.3** and **Table 3.4** were used to compute an equilibrium ice jam using the default ice-jam parametric values and an adopted ice jam roughness. The values reported in **Table 4.4** are plotted on **Figure 4.8** – data corresponding to observed equilibrium jams as reported by Beltaos (1995) are included for comparison. This provided confidence in the assumed roughness and adopted ice jam parameter values. Further, the adopted channel configuration produces ice jams that are physically possible.

TABLE 4.4
Summary of Equilibrium Jam Analysis

Reach / Scenario	Equilibrium Jam Thickness (m)	Mean Width B (m)	Unit Discharge q (m^2/s)	Slope So (m/m)	Depth to Water Level H (m)	Non-Dimensional Discharge	Non-Dimensional Depth
North Milk River							
1. Natural	1.04	22	0.40	0.0030	1.64	26.8	24.9
2. Recorded	1.77	35	0.71	0.0035	2.54	19.9	20.7
3. Scen 1000	2.3	43.8	0.81	0.0038	3.07	15.3	18.2
4. Scen 1200	2.41	45.5	0.91	0.0038	3.24	16.0	18.5
Milk Gravel Reach							
1. Natural	1.63	52	0.95	0.0019	2.81	36.8	28.4
2. Recorded	1.84	62	0.93	0.0019	2.99	30.4	25.4
3. Scen 1000	2.2	71.3	0.96	0.0021	3.29	23.8	22.1
4. Scen 1200	2.26	74.4	0.97	0.0021	3.37	23.1	21.7
Milk Sand Reach							
1. Natural	1.12	70	1.08	0.0007	2.95	112.6	60.2
2. Recorded	1.17	91	0.93	0.0006	2.90	96.2	53.1
3. Scen 1000	1.21	109.2	0.88	0.0005	2.93	89.2	49.8
4. Scen 1200	1.24	113.8	0.87	0.0005	2.96	85.4	48.3

The U.S. Army Corps of Engineers HEC-RAS model facilitated computation of the variables listed in **Table 4.4**. The adopted composite roughness (combined roughness effects due to the bed and ice) was, $n_{composite} = 0.045$. The adopted roughness value produces equilibrium jam thicknesses that relate well to those observed in the field (see **Figure 4.8**). The HEC-RAS model defaults were adopted for ice jam property values.

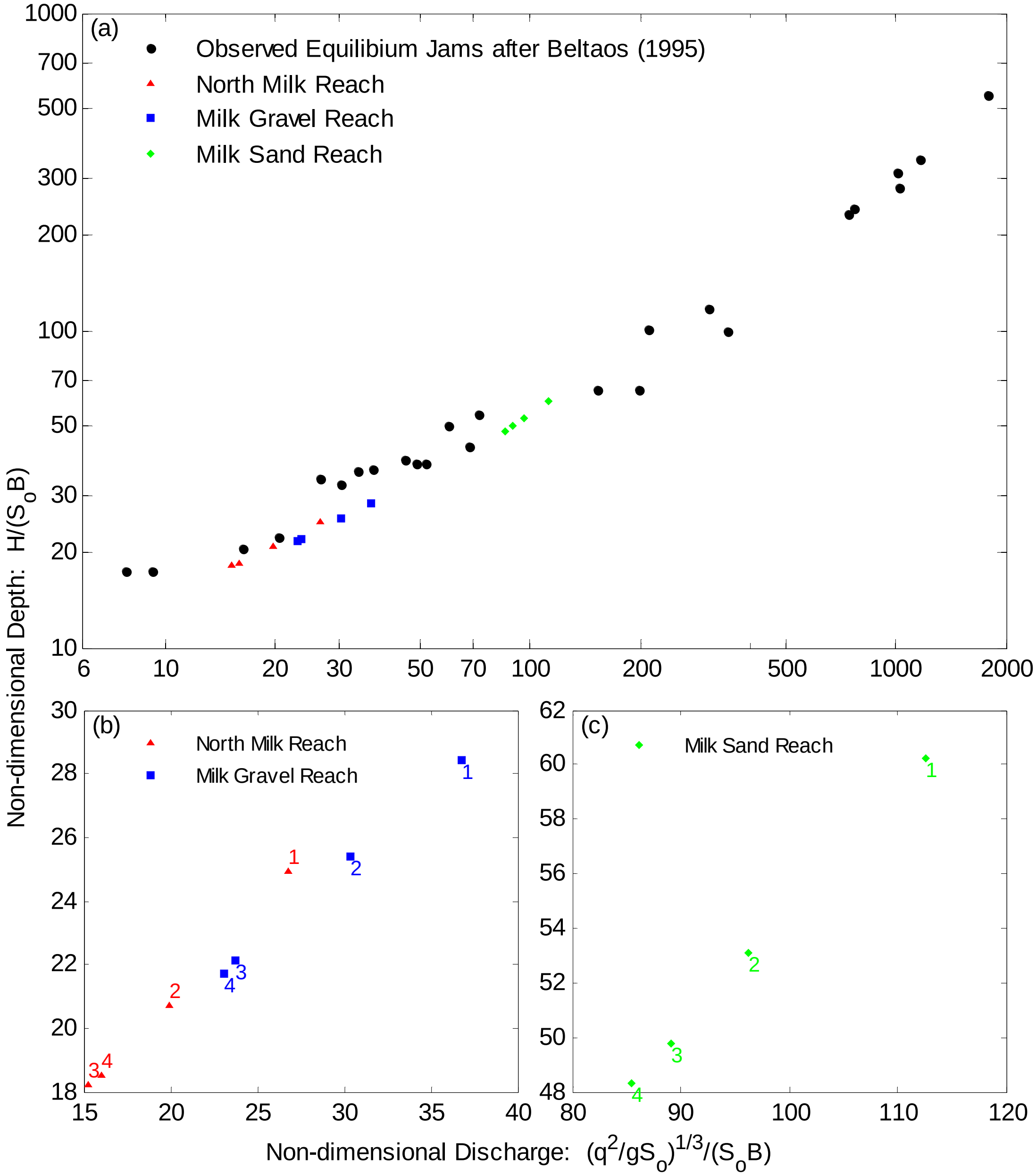
Inspection of **Figure 4.8** suggests that as non-dimensional discharge increases so does non-dimensional depth. As the relative magnitude-of-depth increases so does ice jam thickness. Where channel geometry (channel width and slope) remains constant, an increase in discharge is expected to generate an increase in water level and values plotted on the equilibrium jam curve would tend upwards and to the right. However, when both channel geometry and discharge change (as is the case for this study) values may tend either up or down along the equilibrium jam curve. **Figure 4.8** indicates a shift in values down and to the left along the equilibrium jam curve when moving from Scenario 1 through Scenario 4. Initial inspection of the results presented on **Figure 4.8** may lead one to believe that for this study, ice jam severity is decreasing. However, this is not the case. The absolute change in water levels resulting from spring break-up jams are expected to increase incrementally when moving from Scenario 1 through Scenario 4 (see **Table 4.3**).

Based on the information gathered during this study, the following points characterize the potential impacts of diversion activities on ice jam severity.

- Based on the information gained during this study, it is not possible to make a general conclusion on future trends in the frequency of ice jam occurrence. All other factors being equal, increased flow rates increase the hydrodynamic forces acting on an ice cover. Without further study it is not possible to accurately assess the impact of these increased hydrodynamic forces on the frequency of ice jam formation and resulting ice jam severity.
- Where conditions are favourable for the development of a break-up ice jam accumulation, an increase in the magnitude-of-discharge rates are expected to result in higher water levels and thicker accumulations than for discharge rates of lesser magnitude. This suggests that future diversion activities will result in an incremental increase in the rate of erosion due to ice jam activity. Sufficient information is not available to provide estimates on current erosion rates or incremental changes in erosion rates due to diversion activity.

Figure 4.8 Non-Dimensional Depth Versus Non-Dimensional Discharge

(1) denotes natural conditions; (2) denotes recorded conditions;
(3) denotes Scenario 1000; and (4) denotes Scenario 1200



4.3 Riparian Vegetation

Riparian areas are transitional zones between the aquatic ecosystem of a river, stream, lakes, springs, wetlands and coulees and the surrounding upland area Fitch (2001); Agriculture and Agri-Food Canada (2008). The increased moisture produces unique plant communities. Riparian areas provide important environmental and economic benefits. Some benefits include Agriculture and Agri-Food Canada (2008):

- nesting and foraging sites for migratory songbirds;
- critical habitat for wildlife, such as escape cover and shelter;
- purify water;
- recharge groundwater;
- slow and alleviate floods;
- reduce erosion by water;
- add fertility to floodplain soils; and
- provide forage, shade and sources of water for livestock

4.3.1 Existing Conditions

4.3.1.1 Vegetation Types

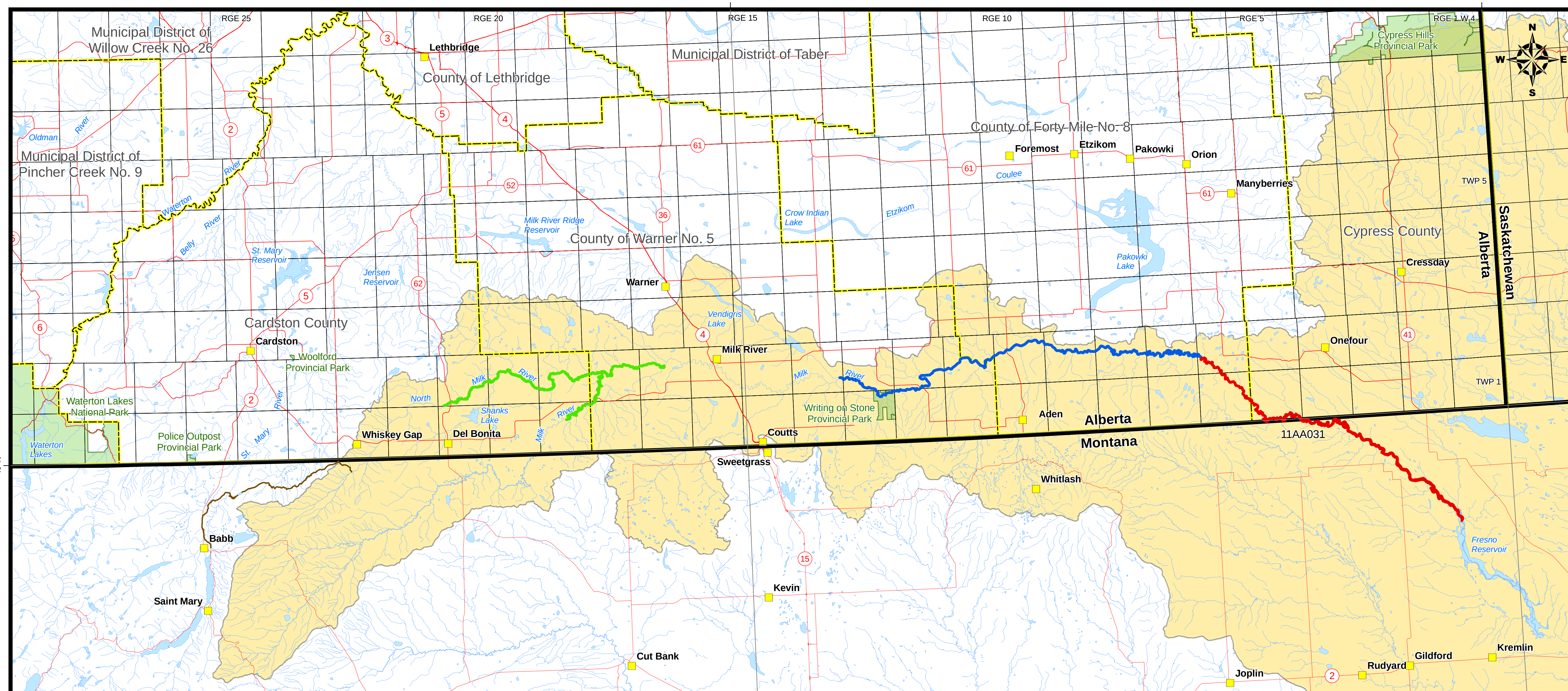
The Milk River watershed is located within two sub-regions of the Grassland Natural Region in Alberta. The largest area, in the eastern section falls within the dry mixed-grass sub-region. The western part of the watershed falls within the mixed-grass sub-region.

The vegetation types along the North Milk and Milk River were described from four previous reports. A review of these projects revealed a lack of vegetation information from the western boundary of the North Milk River to the beginning of the project area by Young *et al.* (1986) and from approximately the confluence of the North and South Milk River to Verdigris Coulee. The project areas are depicted in **Figure 4.9**.

The Milk River has been divided into three reaches based on channel morphology: North Milk River, Milk River Gravel Reach, and Milk River Sand Reach (refer to **Figure 2.1**). The vegetation types that occur within each of these reaches from the above references are listed below in **Table 4.5**.

The plant species nomenclature follows the Alberta Natural Heritage Information Centre 2007 (ANHIC). A list of species prepared by AMEC for this project is provided in **Table F-1** in **Appendix F**. **Table F-2** presents a listing of species prepared by Cows and Fish (2007).

The first vegetation type, Wire rush – wild licorice – sandbar willow Young *et al*. (1986) occurs along sandy and gravelly point bars or meander lobes. These bars, which occur frequently along the North Milk River, are subject to flooding. The vegetation along the point bar is dependent on the water level, therefore emergent species like wire rush, three-square rush, toad rush, common horsetail and wooly sedge are common. Further back from the river's edge redtop, tufted hair grass, sandbar willow and silverweed occur. The dominant species wild licorice, yellow sweet-clover, white sweet-clover and wild vetch occur with increasing distance from the river. Other herbs and shrubs characteristic of this layer are Kentucky bluegrass, slender wheatgrass, goldenrod, silverberry and buckbrush.



Legend

- Milk River Watershed
- National/Provincial Park
- Rural Municipality
- Water
- Road
- Canal
- Young *et al.* (1986)
- Hardy (1990)
- Bradley (1982)
- Town

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amec	Study of Erosion and Sedimentation on the Milk River	DATE: February 2008 PROJECT No: CW2020
Milk River Watershed Council Canada	General Location of Previous Projects	PDF FILE: Fig04.09 Previous Projects 08-02-12 **Figure 4.9**

TABLE 4.5
Vegetation Types Occurring in the Milk River Reaches

Vegetation Type	North Milk River Reach	Milk River Gravel Reach	Milk River Sand Reach	Reference
Wire rush – wild licorice – sandbar willow	X			Young *et al*. (1986)
Red fescue – needle-and-thread – northern wheat grass	X			Young *et al*. (1986)
Needle-and-thread – northern wheat grass – bluegrass – buckbrush	X			Young *et al*. (1986)
Sagebrush flats			X	Bradley (1982)
Saline depressions			X	Bradley (1982)
Meander scrolls	X	X	X	Young *et al*. (1986); Bradley (1982)
Bulrush – common cattail – sedge	X			Young *et al*. (1986)
Plains cottonwood stands			X	Hardy BBT Ltd. (1990); Bradley (1982)

In addition, some accessible point bars were overgrazed by cattle. Introduced species, such as, thistles, common dandelion, common goat's-beard and cocklebur were common. A high degree of salinity is indicated by salt tolerant plants, such as foxtail barley, oak-leaved goosefoot and alkali cord grass.

The second vegetation type (Red fescue – needle-and-thread – northern wheat grass) occurs on levees, which are the result of sediment deposition. Introduced species red fescue, needle-and-thread, northern wheat grass, thread-leaved sedge and bluegrasses dominate these sites with lesser amounts of June grass, pasture sagewort and buckbrush Young *et al*. (1986). Invasive plants may also be present. Along the river's edge wild licorice, wire rush, silverberry, silverweed and foxtail barley occur.

The third vegetation type (Needle-and-thread – northern wheat grass – bluegrass – buckbrush) occurs on the fluvial plain (floodplain) and is variable in composition due to differences in soil drainage, microclimate and degree of cattle usage Young *et al*. (1986). Needle-and-thread, northern wheat grass, bluegrasses, and pasture sagewort are the dominant species; however, on heavily grazed sites tansy mustards, flixweed and buckbrush are abundant. Columbia needle grass, slender wheatgrass, Canby bluegrass and wire rush occur under moister conditions. The shrubs, silverberry, buckbrush, common wild rose and the forbs June grass, silvery perennial lupine, prairie sagewort, sedges, Drummond's milk vetch and yarrow are characteristic plants on the floodplain.

Sagebrush flats occur on the gently sloping pediment surfaces and are dominated by silver sagebrush with a sporadic dense cover of needle-and-thread and wheat grasses Bradley (1982).

On saline areas in the North Milk River Reach, Young *et al.* (1986) stated, spear-leaved goosefoot and oak-leaved goosefoot are common. On braided reach portions of the Milk River Sand Reach, Bradley (1982) states, wire rush, salt grass and alkali cord grass support saline depressions.

The sixth vegetation type (Meander scrolls) occurs within former river channels. These river channels occur due to changes in the river flow and their degree of infilling and colonization by vegetation vary. Small oxbow lakes may occur in the center of the meander scroll and be active during peak flows. Young *et al.* (1986) described the inactive meander scrolls as being dominated by shrubs, buckbrush, silverberry and the forbs, common dandelion, Kentucky bluegrass and wire rush. Tufted hair grass, Kentucky bluegrass, redtop, wire rush, common dandelion and silverberry colonize the moister sites in the old channel bottoms. Other species occurring are slender wheatgrass, wild licorice, goldenrod, creeping thistle and yarrow. Cattle grazing are common; therefore invasive plants have been introduced.

Bradley (1982) described the older meander lobes as a complex patchwork of grassy opening and shrub lands. The grassy openings are composed of Kentucky bluegrass, crested wheatgrass, slender wheatgrass, sand grass, golden bean and silver sagebrush. Buckbrush and prickly rose, make up the low shrub lands with thorny buffaloberry, red-osier dogwood and choke cherry dominating the tall shrub lands.

The seventh vegetation type (Bulrush – common cattail – sedge) composed of bulrushes, common cattails and sedges occur along the wet oxbow margins (Young *et al*. 1986). In better drained areas rushes, alkali cord grass, reed grasses and mints dominate.

Plains cottonwood stands are located along the Milk River from just upstream of Writing-On-Stone Provincial Park to the eastern crossing at the international boundary. Hardy BBT Ltd. (1990) describes the stands as open with well spaced trees ranging in height from 10 to 20 m. They occur along active and inactive meanders in arcuate bands within a 500 m wide meander belt. Mixed grasslands and shrub dominated areas form a mosaic with the cottonwood stands. In mature stands, the shrub layer is dominated by thorny buffaloberry, common wild rose and yellow willow with wild licorice, goldenrod, western wheat grass and Kentucky bluegrass occurring in the herb layer. Along the river's edge, younger stands of plains cottonwood occur in association with the shrub, sandbar willow and a ground cover composed of white sweet clover, yellow sweet clover, golden bean, western wheat grass, and sand grass. Bradley (1982) recorded Indian rice grass and Canada wild rye.

4.3.1.2 River Regime and Vegetation Types

Floodplains develop over time due to deposition and accumulation of similar materials known as aggradation. Sedimentation occurs when sediment supply exceeds the ability of a river to transport the sediment (http://en.wikipedia.org/wiki/Aggradation). There are three phases of floodplain aggradation, which are (Hardy BBT Ltd. 1990):

- a brief rapid period of sedimentation
- an extended period of moderate sedimentation
- a period of negligible sedimentation.

Hardy BBT Ltd. (1990) described the following hydrological events, for the Milk River. The first period (1910) lasted about 10 years and the average rate of sedimentation was 14 cm/yr. The average rate of sedimentation during the second period (1920) was 2.6 cm/yr over 70 years. The floodplain reached a height of 3.0 m after 80 years (1990) and no further aggradation occurred. These rates of sedimentation apply to flows between 15 to 20 m^3/s, with peak flows reaching higher values.

The Milk River floodplain at bankfull stage is approximately 1.5 m above the mean river level (Hardy BBT Ltd. 1990). The floodplain can rise to a mean height of 3.7 m through floodplain deposition (Hardy BBT Ltd. 1990).

Wire Rush – Wild Licorice – Sandbar Willow

This vegetation type occurs on point bars in the North Milk River Reach area. Point bars are deposits of alluvium found on the inside bank of a meander. Point bars form when alluvium is eroded from the outside of a meander bend and deposited on the inside bends of the bend. Therefore, point bars are found at low elevations near normal water level. The point bars in the Milk River Sand Reach occurred at 0.4 m above water level. In addition, point bars are susceptible to flooding.

Red Fescue – Needle-and-Thread – Northern Wheat Grass

Red fescue, needle-and-thread, and northern wheat grass occur on levees. Levees are low embankments on either side of the river. Holmes (1965) describes the formation of levees as '*when the river overflows its banks the current is checked at the margin of the channel and the coarsest part of the load is dropped there*'. Thus the vegetation type formed is drier due to coarser materials and better drainage. Also the vegetation type is located above normal water level.

Needle-and-Thread – Northern Wheat Grass – Bluegrass – Buckbrush

The third vegetation type, as well as the sagebrush flats and saline depressions, occur on the fluvial floodplain. In the Milk River Sand Reach the floodplain varies from 1.5 to 3.7 m above water level. Water levels in relation to the vegetation types are unknown for the North and Milk River Gravel Reach.

Meander Scrolls

Inactive meander scrolls were originally part of the meandering river, but were cut off and over time have filled in with vegetation, which reflects the moist nature of the site. These inactive scrolls would not be susceptible to flooding under the present discharge rates.

Bulrush – Common Cattail – Sedge

If a flood occurs in a meandering river where a narrow neck of land is between adjoining loops, the flow is likely to erode the outer banks and narrow the neck between the channels, creating a cut-off channel and leaving a deserted (ox-bow) channel (Holmes 1965). Later floods carrying silt will turn the ox-bow into a marsh, in this case with bulrushes, common cattail and sedges. Usually these ox-bow formations occur at water level.

Plains Cottonwood Stands

Plains cottonwood stands occur intermittently along the Milk River from Verdigris Coulee to the eastern crossing at the Montana border totalling 102 km (69% of the total length) of the Milk River (Hardy BBT Ltd., 1990). They occur along the floodplain in arcuate bands within a 500 m wide meander belt. As well, younger stands are located on point bars along meandering river channels.

Bradley (1982) and Rood and Mahoney (1990) summarized the adaptations which allow plains cottonwoods to flourish in riparian environments. These are:

- an abundance of seed is produced annually with high viability and the seed has the ability to germinate in water;
- seedlings have rapid shoot and root growth;
- sapling stems are supple and can survive partial burial and complete flooding for up to 10 days;
- mature trees can withstand long periods of partial flooding and tolerate moderate siltation; and,
- mature trees can sprout from stumps after injury.

Hosner (1957) found that seedling survived 30 days of inundation. After the first two years of root development, cottonwood saplings become more tolerant of flooding and drought stress (Pezeshki and Hinckley 1988).

4.3.1.3 Rare Plants

The Alberta Natural Heritage Information Centre (ANHIC) was contacted for rare plants within the riparian zone of the Milk River. A search corridor of 100 m was used, which produced a list of 54 occurrences composed of 26 species. Seven vascular plants and three mosses were located directly adjacent to the Milk River and/or in the riparian zone (**Table 4.6**).

Wallis (1989) completed an inventory of rare plants in the Milk River Natural Area, which is located along the eastern end of the Milk River and includes 2300 ha. The inventory resulted in locating 27 rare plants in total; however, the natural area included the riparian area, slopes leading into the valley bottom and upland sites. Earlier in 1986, Young *et al*. (1986) located the following rare plants (ANHIC 2007): whitlow-grass on fluvial floodplains; tufted hymenopappus on incised and slumped valley sides and fluvial fans; and, prickly milk vetch on gullied valley sides and fluvial fans.

TABLE 4.6
Rare Plants along the North Milk River and Milk River

Element Occurrence	Common Name	Botanical Name	Reach
Herbs	bur ragweed	*Ambrosia acanthicarpa*	Milk River
	prickly milk vetch	*Astragalus kentrophyta var kentrophyta*	
	small-flowered hawk's-beard	*Crepis occidentalis*	Milk River
	tufted hymenopappus	*Hymenopappus filifolius*	North Milk River and Milk River
	Moquin's sea-blite	*Suaeda moquinii*	Milk River
	waterpod	*Ellisia nyctelea*	Milk River
	whitlow-grass	*Draba reptans*	
Moss		*Bryum lonchocaulon*	North Milk River and Milk River
	long-stalked beardless moss	*Desmatodon heimii*	North Milk River and Milk River

4.3.1.4 Land Use

Presently the Milk River Watershed has a multitude of land uses including agriculture, wildlife habitat and recreation. The dominant agricultural uses are for domestic grazing of livestock and irrigated crops. Bradley (1982) quotes previous studies by Wallis (1976) and Ealey and Darling (1980), which state 12 reptiles and amphibian species, 156 birds, 109 bird species, and 22 mammal species occur in the Milk River Valley. According to Bradley and Reintjes (1991) many Albertans choose riparian poplar stands as outdoor recreation environments. In southern Alberta four provincial parks occur in riparian poplar forests, including Writing-on-Stone which occurs in the Milk River Valley. As well, the Milk River Natural Area, Twin River Heritage Natural Area, Verdigris Coulee Natural Area (Crown Reservation), and the Pinhorn Natural Area (Crown Reservation) occur in the Milk River Basin.

4.3.2 Effect of Increased Diversion on Riparian Vegetation

The increased diversion will result in the river channel widening by erosion processes. This process, modelled over a 73-year period, would potentially widen the river between 7 to 18.2 m depending on the reach at 1000 cfs; and, 8.8 to 22.8 m depending on the reach at 1200 cfs. Generally, the river will widen on the outside of the meander bends and on the straighter sections on either side of the river. The inside of the meander bends are areas of deposition. Point bars form on the inside bends of a meander where fluvial sediment is deposited. These bars are important for plains cottonwood development. Potentially, these point bars may increase in size which would be beneficial for plains cottonwood. However the total riparian area could decrease in size due to erosion occurring on the outside of the meander bends and in straighter sections of the river.

4.3.2.1 Loss of Vegetation Types due to Erosion

The effect of increased diversion on riparian vegetation will be discussed within the context of the North Milk River Reach, Milk River Gravel Reach and Milk River Sand Reach. Within these three reaches the areas were reviewed where erosion had been identified by landowner responses (refer to **Figures 4.2, 4.3a, 4.3b, 4.4 and 4.6**). Assuming the riparian zones in the areas identified in these figures are typical of their respective reaches, the potential reduction in riparian area was calculated using the model results based on 73 years. The results are tabulated in **Table 4.7**.

The potential increase in the river's width will cause a loss of riparian vegetation types, particularly those which border the river. Levees will be affected because as the river widens it will erode and undercut the banks. Riparian vegetation on the fluvial plain will be affected as the river widens. The position of the sagebrush flats and saline meadows in relation to the river (i.e. distance to the river's edge) will determine their rate of loss. Because the river generally erodes on the outside edge and the amount of erosion is dependent on the flow rates, the following vegetation types potentially will be affected:

- red fescue – needle-and-thread – northern wheat grass type;
- needle-and-thread – northern wheat grass – bluegrass – buckbrush;
- sagebrush flats; and,
- saline meadows.

The vegetation types that occur on point bars on the inside of the river will receive sedimentation, which will affect the wire rush, wild licorice, and sandbar willow type as well as the plains cottonwood stands. It is not well understood how the young plains cottonwood seedlings from 0 to 10 years will withstand additional sedimentation.

The meander scrolls and oxbow vegetation types may be affected depending on their position in relation to the water's edge. Those types that lie close to the river's edge will be subjected to erosion. The potential impacts over a 73-year model are summarized in **Table 4.8**.

TABLE 4.7
Estimate of Potential Loss of Riparian Vegetation

Parameter	Unit	North Milk River Reach			Milk River Gravel Reach			Milk River Sand Reach		
		Recorded	Scenario 1000	Scenario 1200	Recorded	Scenario 1000	Scenario 1200	Recorded	Scenario 1000	Scenario 1200
Discharge	Q_2 (m^3/s)	24.8	35.4	41.4	57.6	68.3	72.4	84.2	95.7	99.5
Measured channel characteristic	Width of river (m)	26-53	42–43.8	43.8–45.5	45–85	68.2–71.3	71.3–74.4	71–120	104.7–109.2	109.2–113.8
Estimated Channel Characteristics	Increase in width of river (m)		7–8.8 mean 7.9	8.8 - 10.5 mean 9.7		6.2–9.3 mean 7.75	9.3–12.4 mean 10.9		13.7–18.2 mean 16.0	18.2–22.8 mean 21
	Mean width of Riparian area (m)	195	–	–	978	–	–	194	–	–
	Loss of riparian vegetation (%)		4	5		0.8	1		8	11

TABLE 4.8
Potential Impact of Diversion Flow on Milk River Vegetation Types

Vegetation Type	Potential Impact
wire rush – wild licorice - sandbar willow	Low, sediment formation will increase the vegetation type
red fescue – needle-and-thread – northern wheat grass	Moderate; the levees will be undercut by erosion and ice jams
needle-and-thread – northern wheat grass	Low to moderate; increasing the width of the river will decrease the fluvial floodplain
sagebrush flats	Low (dependent on proximity to river)
saline depressions	Low to moderate (dependent on proximity to river)
meander scrolls	Low to moderate (dependent on proximity to river)
bulrush – common cattail - sedge	Low to moderate (dependent on proximity to river)
plains cottonwood	Low reduction in frequency of formation of seedbeds

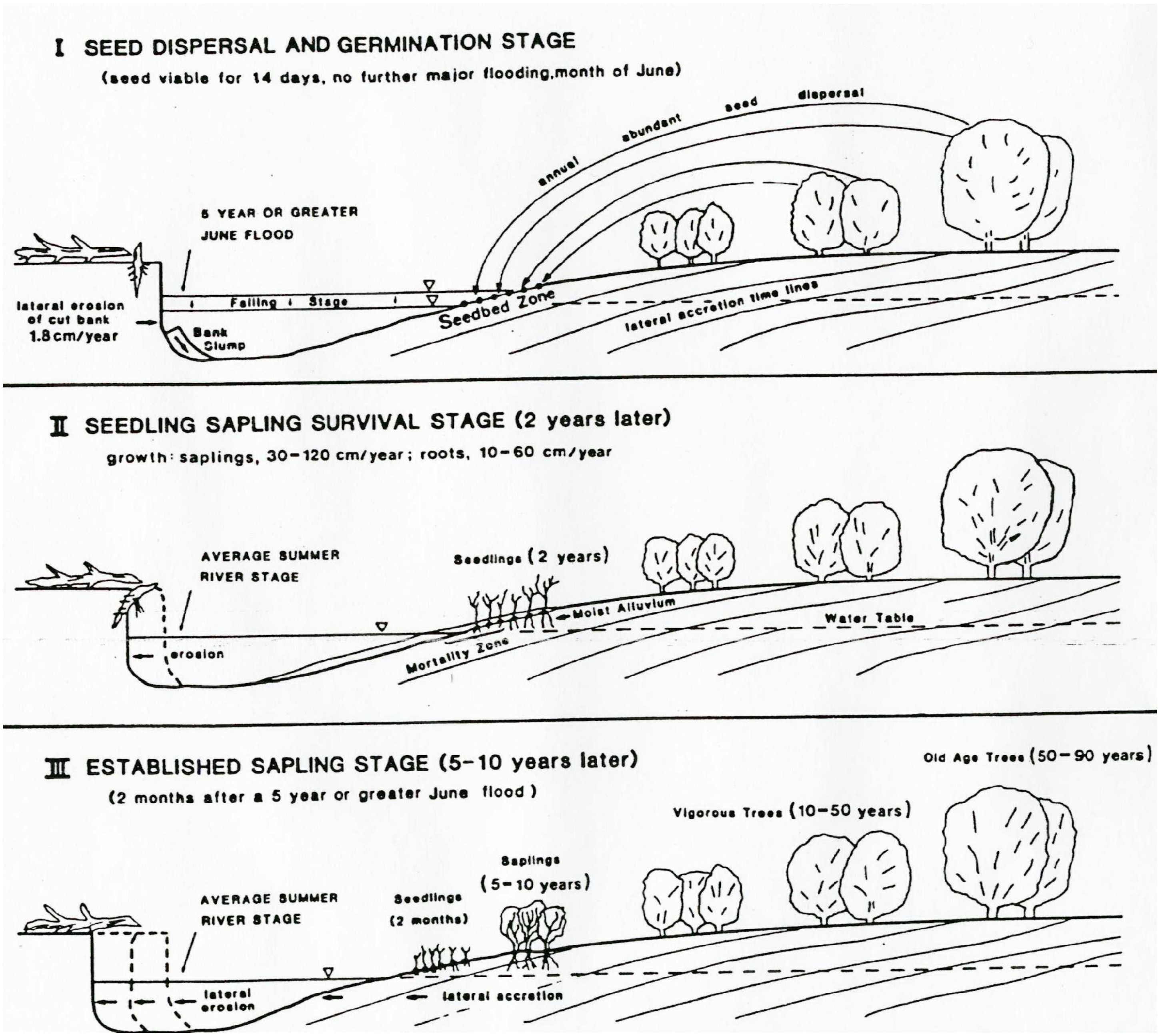
4.3.2.2 Effect of Flooding on Plains Cottonwood Stands

Generally along the Milk River, floods occur in May and June. Following the potential diversion the magnitude of the floods will increase, especially for the North Milk River Reach. **Table 4.7** shows the one-in-two-year flood discharge (Q_2) and the estimated changes due to potential diversion scenarios. The estimated Q_2 ranges from 35.4 to 95.7 for 1000 cfs; and, from 41.4 to 99.5 for 1200 cfs for the North Milk River Reach to the Milk River Sand Reach. The percentage increase for each reach is depicted in **Table 4.9**.

The study did not allow time to examine the response of all the vegetation types to flooding; plains cottonwood was chosen for further examination.

Floods have been shown by Bradley and Smith (1986) to create conditions suitable for cottonwood establishment. In particular, floods which deposit layers of fresh sediment during the period of seed dispersal (01 June to 10 July) appear to enhance the amount of cottonwood survival. The variation in the range and timing of flooding and seed dispersal means establishment is successful only at irregular intervals.

Bradley and Reintjes (1991) describe two types of floods: fringe replenishment and general replenishment. Fringe replenishment occurs on point bars formed by flooding occurring at the time of seed dispersal. Bradley and Smith (1986) developed a model based on their work in the Milk River (**Figure 4.10**) relating to seedling establishment along a meandering channel to regular flood events. The model depicts successional growth of plains cottonwood on point bars formed by flooding. Plains cottonwoods are dependant on new seedbeds being formed through sediment deposition creating new point bars.



amec Earth & Environmental

CLIENT: MILK RIVER WATERSHED COUNCIL CANADA

PROJECT: MILK RIVER EROSION AND SEDIMENTATION

TITLE: A PROPOSED CONCEPTUAL MODEL SHOWING AN ASSOCIATION BETWEEN COTTONWOOD ESTABLISHMENT & RIVER FLOODING AND SEDIMENTATION (BRADLEY AND SMITH 1986)

DATE:	JOB No.:	CAD FILE:	FIGURE No.:	REV.
JANUARY 2008	CW2020	2020-L00.dwg	FIG 4.10	A

Seedling development is dependent on several factors: successful seed production, high flows at the time of seed dispersal, high sediment loads, active channel migration, and floodplain aggradation. Seeds released before or during high flows are usually unsuccessful because they are either washed away by rising water or germinate on sites too high above the water table to survive. Also seeds released after the water level substantially falls, will germinate too low on the floodplain. These areas are susceptible to scouring by ice or burial during a subsequent flood. On the Milk River in 1989 seedling establishment occurred 0.4 m to 0.6 m above mean river level on a fresh layer of sediment (Hardy BBT Ltd. 1990). Hardy BBT Ltd. (1990) reported that plains cottonwood seedlings occur up to 10 years old on point bars.

Good sites for seedling establishment are found along the river bank at intermediate elevations, resulting in the formation of arcuate bands of even-aged poplars parallel to the riverbank, which is common in the Milk River floodplain (Hardy BBT Ltd. 1990).

Large loads of sediment can be deposited on low-lying areas of the floodplain, known as overbank replenishment. Overbank flooding can produces large areas across the full width of the floodplain rather than on the tip of point bars. It has been noted that poplar tree age can be related to high spring flood events. Hardy BBT Ltd. (1990) found all of the trees established between 1911 and 1989 can be related to maximum daily discharges greater than 30 m^3/s during the 0 to 3 years proceeding the year of establishment, and 50% of the trees became established during years when maximum daily flows during the seed dispersal period were greater than 60 m^3/s. In an independent study, Bradley and Smith (1986) found that 92% of plains cottonwood seedlings establishment can be related to a maximum daily discharges greater than 60 m^3/s. The period of record was between 1911 and 1978.

The potential increased diversion could cause higher discharges, causing flooding, which potentially could lead to point bar formation as well as overbank flooding. If the conditions are right (flooding and seed dispersal), plains cottonwood regeneration is favoured.

TABLE 4.9
Estimated Percentage Increase in Flood Discharge

Parameter	Unit	North Milk River Reach			Milk River Gravel Reach			Milk River Sand Reach		
		Recorded	Scenario 1000	Scenario 1200	Recorded	Scenario 1000	Scenario 1200	Recorded	Scenario 1000	Scenario 1200
Discharge	Q_2 (m^3/s)	24.8	35.4	41.4	57.6	68.3	72.4	84.2	95.7	99.5
	Estimated Percentage Increased Discharge		29.9	40.1		15.7	20.4		12.0	15.4

4.3.3 Monitoring

A vegetation monitoring program is recommended to provide an assessment of the changes that will occur as a result of the increased diversion flow. Monitoring is critical in order to develop baseline data and assess any long-term effects. Presently, recent vegetation plot data is lacking, which is a base criteria for developing a monitoring program. In order to measure the changes, two recommendations for baseline data are suggested:

1. Prior to the diversion flow, sampling should occur in order to obtain comparative data from plot sites where direct changes can be measured.
2. Produce a vegetation map depicting the vegetation types, percentages and successional stage. This map can be used to plan and locate the long-term sampling locations. In addition, this map can be used to calculate the potential total loss of vegetation types over the 73-year model. The baseline data should be collected during the summer months prior to the increased diversion flow.

The monitoring program would consist of periodic monitoring along the Milk River floodplain for the first 10 years following the increased diversion. Permanent plots could be established along the Milk River at areas where a bank erosion is of concern and at the plot locations used by Hardy BBT Ltd. (1990) in the Milk River Sand Reach. In addition, plots could be established in the North Milk River and the Milk River Gravel Reach representing vegetation types that could potentially be affected by the diversion. The monitoring program could include both air photograph interpretation as well as ground truthing. The components of the program could include:

- monitoring the entire riparian vegetation using colour air photos in association with ground truthing;
- monitoring sedimentation rates;
- monitoring rates of erosion; and,
- monitoring plains cottonwood survival.

4.4 Water Quality

4.4.1 Existing Conditions

4.4.1.1 Review of Historical Data

Available historical water quality data was reviewed, compiled and analyzed. Data was found primarily from three agencies:

- Alberta Environment (AENV);
- Environment Canada (EC); and,
- the United States Geological Survey (USGS).

The most recent data and specifically focused on the water quality survey was provided by Milk River Watershed Council Canada.

The water quality monitoring sites are presented in **Table 4.10,** and **Figure 4.11.**

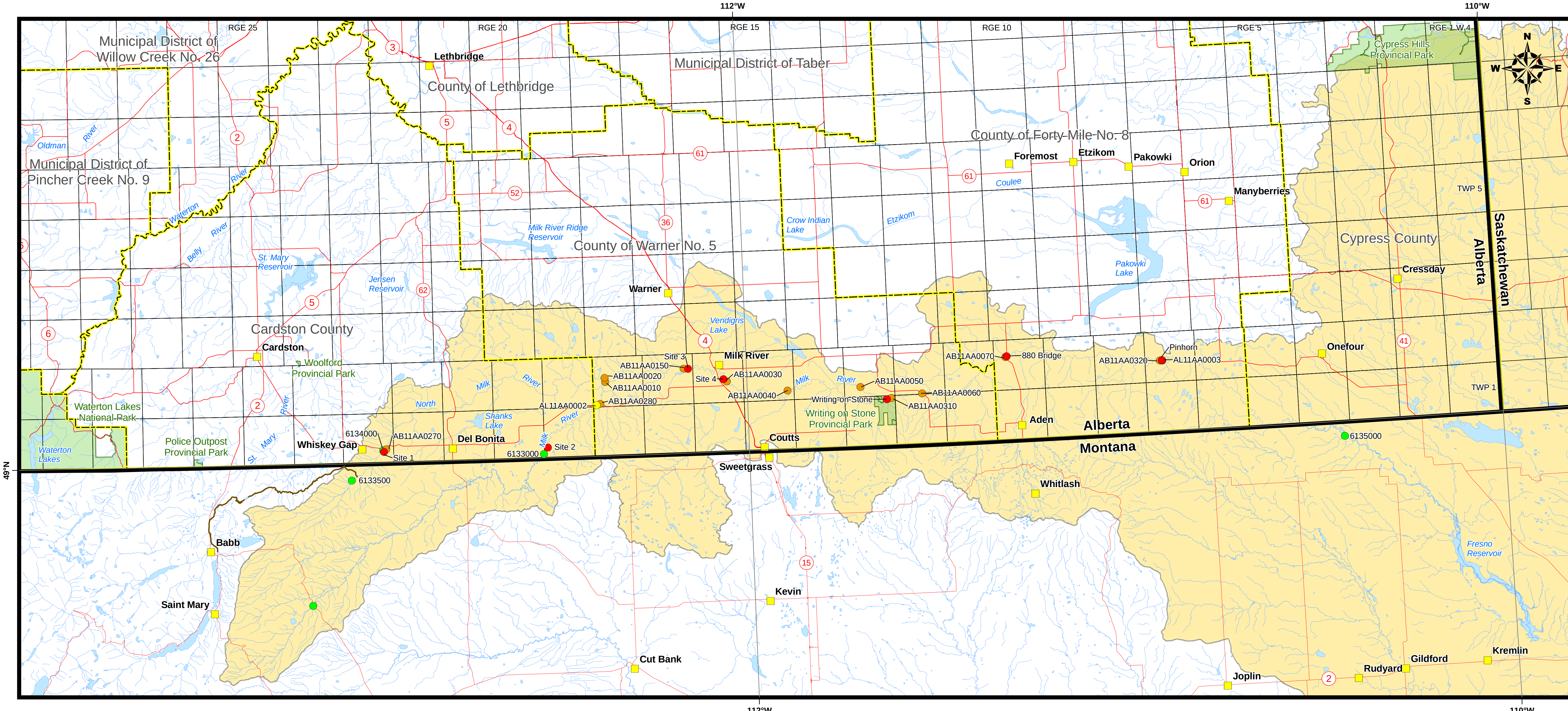
TABLE 4.10
Water Quality Sampling Sites on the Milk River

Stream Reach	Station ID	Station Name	Data Source	Period of Observations
North Milk River	6133500	North Fork Milk River above St. Mary Canal near Browning, MT	USGS	1960-2006
	6134000	North Milk River near International Boundary	USGS	1960-1993
	AB11AA0270	North Milk River near International Boundary, Upstream of Highway 501	AENV / MRWCC*	2006-2007
	AB11AA0020	North Milk River Upstream of Confluence to Milk River	AENV	1986-1987
South Fork Milk River	6133000	Milk River at Western Crossing of International Boundary	USGS/MRWCC*[1]	1960-1993
	AL11AA0002	Milk River at Western Crossing of International Boundary	EC	1960-1965, 1967-1995, 2006-2007
	AB11AA0280	Milk River near Western Boundary at Highway 501	AENV/MRWCC*[1]	2006-2007
	AB11AA0010	Milk River Upstream of Confluence to North Milk River	AENV	1986-1987
Milk River	AB11AA0150	Milk River Upstream of Town of Milk River	AENV/MRWCC*	2006-2007
	AB11AA0030	Milk River Downstream of Town of Milk River	AENV/MRWCC*	1986-1987, 2006-2007
	AB11AA0040	Milk River at Coffin Bridge	AENV	1987-1988
	AB11AA0050	Milk River at Highway 878	AENV	1986-1988
	AB11AA0310	Milk River at Writing-on-Stone Provincial Park	AENV/MRWCC*	2006-2007
	AB11AA0060	Milk River Downstream of Writing-on-Stone Provincial Park	AENV	1987-1988
	AB11AA0070	Milk River at Highway 880	AENV/MRWCC*	1986-1988, 2003-2007
	AB11AA0320	Milk River near Eastern Boundary, at Pinhorn Grazing Reserve	AENV/MRWCC*	2006-2007
	AL11AA0003	Milk River at Eastern Crossing of International Boundary	EC	1960-1995, 2006-2007
	6135000	Milk River at Eastern Crossing of International Boundary	USGS	1960-2006

Note: AENV – Alberta Environment
EC – Environment Canada
MRWCC - Milk River Watershed Council Canada
USGS – United States Geological Survey

* Monitoring program for 2006-2007 initiated by the MRWCC in collaboration with the County of Warner, Cardston County, the County of Forty Mile, Cypress County, Writing-on-Stone Provincial Park and AENV.

[1] Although MRCWW Station is associated with Highway 501, monitoring location is identified to be closer to 6133000 as shown on **Figure 4.11**.



Legend

- Milk River Watershed
- National/Provincial Park
- Rural Municipality
- Water
- Road
- Canal
- Alberta Environment Station
- Environment Canada Station
- US Geological Survey Station
- Milk River Watershed Council Canada Station
- Town

amec

Milk River Watershed Council Canada

Study of Erosion and Sedimentation on the Milk River

Water Quality Sample Stations

DATE: February 2008

PROJECT No: CW2020

PDF FILE: Fig04.11 WQ Sampling Stns 08-02-12

Figure 4.11

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Key water quality parameters which can be affected by the diversion of water include temperature, total suspended solids (TSS), total nitrogen, and total phosphorus. Total Kjeldahl nitrogen (TKN) represents a sum of organic nitrogen and ammonia, which is usually equivalent to total nitrogen. These parameters were analyzed and included calculations of minimum, median and maximum concentrations for sites along the North Milk River (**Table 4.11**), the south fork of the Milk River (**Table 4.12**) and for sites along the Milk River downstream of the confluence of the North Milk River (**Table 4.13**).

The following descriptive analysis for river reaches provided at different sites and for different periods of observations, which is stated in tables heading (**Table 4.11** through **Table 4.14**).

North Milk River

Median temperatures in the sites along the North Milk ranged from 6°C to 14.6°C, with the lowest median value recorded at the most downstream site, just upstream of the confluence with Milk River and the highest median value recorded at the site upstream of Highway 501. Median concentrations for TSS ranged from 5.3 mg/L to 10.5 mg/L, with the lower median concentration also found at the most downstream site. Nutrient concentrations had the opposite pattern with the highest median concentrations observed at the most downstream sites. TKN concentrations were low at all sites, with median concentrations that ranged from 0.21 mg/L to 0.36 mg/L. Median TP concentration ranged from <0.01 mg/L to 0.03 mg/L. (**Table 4.11**)

South Fork of the Milk River

Water temperature in the south fork of the Milk River fluctuates among all the sites, with median concentrations that ranged from 5.5°C to 16.6°C. Median TSS concentrations ranged from 4 mg/L to 14 mg/L, with the highest concentration at the site near Highway 501. The median concentrations for both nutrients were consistent at all the sites, with TKN concentrations that ranged from 0.39 to 0.45 mg/L and TP concentrations that ranged from 0.01 mg/L to 0.018 mg/L. (**Table 4.12**)

Milk River Downstream of the Confluence with the North Milk River

Median temperatures ranged from 7.55°C to 14.8°C, with no spatial pattern observed. Median TSS concentrations ranged from a low of 21 mg/L at the site upstream of the Town of Milk River to a high of 121 mg/L at the site on the Pinhorn Grazing Reserve. There appeared to be a general increase in TSS concentrations as the water moved further downstream. TKN median concentrations were fairly consistent and ranged from 0.22 mg/L to 0.42 mg/L. TP concentrations ranged from low (0.023 mg/L) to a high of 0.106 mg/L. About half of the sampling sites had median TP concentrations that were above the Alberta Surface Water Quality Guidelines (ASWQG) (AENV, 1999) of 0.05 mg/L. Most of the sites which had TP median concentrations above ASWQG were located further downstream. (**Table 4.13**)

Changes in major water quality parameters were found along the river reaches. These changes were associated with a combine effects in the watersheds and diversion as observed at different reaches of the river.

TABLE 4.11
Water Quality in the North Milk River

Parameter	6133500 – North Fork Milk River above St. Mary Canal near Browning, MT (1973-2006)				6134000 – North Milk River near International Boundary (1960-1993)				AB11AA0270 – North Milk River near International Boundary Upstream of Highway 501 (2006-2007)				AB11AA0020 – North Milk River Upstream of Confluence to Milk River (1986-1987)			
	n	min	median	max	n	min	median	max	n	min	median	max	n	min	median	max
Temperature (°C)	84	0.5	9.5	23.5	19	0.5	13	21	24	1.3	14.6	21	13	0	6	19.8
Total Suspended Solids (mg/L)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	24	0.5	10.5	42	13	0.2	5.3	280
Total Kjeldahl Nitrogen (mg/L)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	23	<0.1	0.21	0.46	13	0.26	0.36	1.38
Total Phosphorus (mg/L)	46	<0.01	<0.01	0.09	7	0.005	0.01	0.02	24	0.004	0.009	0.026	13	0.004	0.03	0.62

TABLE 4.12
Water Quality in the South Fork of the Milk River

Parameter	6133000 – Milk River at Western Crossing of International Boundary (1960-1993)				AL11AA0002 – Milk River at Western Crossing of International Boundary (1960-2007)				AB11AA0280 – Milk River near Western Boundary at Highway 501 (2006-2007)				AB11AA0010 – Milk River Upstream of Confluence to North Milk River (1986-1987)			
	n	min	median	max	n	min	median	max	n	min	median	max	n	min	median	max
Temperature (°C)	14	0	14.5	23	333	0	5.5	27.8	16	1.1	16.6	22.9	12	0	5.6	21.6
Total Suspended Solids (mg/L)	n/a	n/a	n/a	n/a	243	<1	8.6	2936	17	3	14	46	12	0.6	4	45
Total Kjeldahl Nitrogen (mg/L)	n/a	n/a	n/a	n/a	46	<0.1	0.4	1.7	16	0.24	0.45	0.85	12	0.22	0.39	0.66
Total Phosphorus (mg/L)	5	<0.01	<0.01	0.02	276	<0.005	0.015	1.32	17	0.004	0.018	0.055	12	0.005	0.01	0.062

TABLE 4.13
Water Quality in the Milk River Downstream of Confluence with the North Milk River

Parameter	AB11AA0150 - Milk River Upstream of Town of Milk River				AB11AA0030 - Milk River Downstream of Town of Milk River				AB11AA0040 - Milk River at Coffin Bridge				AB11AA0050 - Milk River at Highway 878				AB11AA0310 - Milk River at Writing-on-Stone Provincial Park			
	(2003-2007)				(1986-2007)				(1987-1988)				(1986-1988)				(2006-2007)			
	n	**min**	**median**	**max**	**n**	**min**	**median**	**max**	**n**	**min**	**median**	**max**	**n**	**min**	**median**	**max**	**n**	**min**	**median**	**max**
Temperature (°C)	36	0	11.3	23.3	52	0	10.2	22.5	14	-0.1	7.6	19.2	28	-0.1	8.2	20	23	0	14.4	23.4
Total Suspended Solids (mg/L)	36	1	21	210	52	1	25	2410	14	1.6	55	3590	28	1.2	43	4050	24	1	34	386
Total Kjeldahl Nitrogen (mg/L)	35	0.13	0.23	0.57	51	0.13	0.3	2.4	14	0.22	0.34	2.76	28	0.2	0.4	4	23	0.11	0.22	0.41
Total Phosphorus (mg/L)	36	0.003	0.023	0.172	52	0.003	0.0225	0.65	14	0.006	0.031	1	28	0.004	0.0635	1.46	24	0.003	0.026	0.168

Continued

Parameter	AB11AA0060 - Milk River Downstream of Writing-on-Stone Provincial Park				AB11AA0070 - Milk River at Highway 880				AB11AA0320 - Milk River near Eastern Boundary, at Pinhorn Grazing Reserve				AL11AA0003 - Milk River at Eastern Crossing of International Boundary				6135000 - Milk River at Eastern Crossing of International Boundary			
	(1960-1993)				(1986-2007)				(2006-2007)				(1960-2007)				(1986-1987)			
	n	**min**	**median**	**max**	**n**	**min**	**median**	**max**	**n**	**min**	**median**	**max**	**n**	**min**	**median**	**max**	**n**	**min**	**median**	**max**
Temperature (°C)	13	-0.4	12.6	20.4	99	-0.5	10.5	27.5	25	-0.7	14.8	22.7	386	0	7.75	25.6	207	0	12	28
Total Suspended Solids (mg/L)	13	1.6	67.3	2460	99	0.8	78	2700	25	3	121	710	289	<1	100	3824	n/a	n/a	n/a	n/a
Total Kjeldahl Nitrogen (mg/L)	13	0.3	0.42	2.7	99	0.11	0.32	3.61	24	0.17	0.3	0.56	48	<0.1	0.3	2.8	n/a	n/a	n/a	n/a
Total Phosphorus (mg/L)	13	0.01	0.054	0.84	100	0.004	0.064	1.87	25	0.007	0.106	0.335	308	<0.005	0.0565	2	9	<0.01	0.01	0.26

Effects of the Existing Diversion

In order to analyze the effect of the existing diversion from the St. Mary Canal, three sites were examined more closely:

- AB11AA0020 – North Milk River upstream of the confluence with the Milk River, which represents the water quality of flow from the diversion;
- AB11AA0010 – Milk River upstream of confluence to North Milk River, which represents water quality of natural flows in the Milk River prior to the addition of diversion water; and,
- AB11AA0150 – Milk River upstream of the Town of Milk River, which represents the water quality in Milk River after the addition of diversion water.

No further sites were selected downstream of the Town of Milk River as incoming sediment loads from the badlands related to rainfall events cloud the relationship between erosion and flows.

In comparing the medians at the three sites, the following observations can be made:

- *Temperature* – the medians were similar for the North Milk River (6°C) and the Milk River upstream of the confluence (5.6°C), but the median was almost twice as high (11.3°C) at the Milk River sites downstream of the confluence.
- *TSS* – the median TSS concentration was slightly higher in the North Milk River than in the Milk River station upstream of the confluence (5.3 mg/L compared to 4 mg/L). However, at the downstream site, the median concentration (21 mg/L) was approximately four times greater than at either of the upstream sites.
- *TKN* – the median TKN concentrations were similar at the upstream sites (0.36 mg/L and 0.39 mg/L), but was slightly lower (0.23 mg/L) at the site downstream of the confluence.
- *TP* – the median TP concentration was higher in the North Milk River (0.030 mg/L) compared to the upstream site on the Milk River (0.010 mg/L). The median TP concentration at the downstream site was almost midway between those two values (0.023 mg/L).

In summary, there are differences in water quality between the sites on the Milk River before and after the confluence with the North Milk River, which includes flows from diversions, particularly in the concentrations of TSS. Based on the current data and analysis, more data is required before confidence in these differences can be obtained and causes can be determined unambiguously.

4.4.1.2 Milk River Watershed Council Canada Monitoring Program

In 2006, the Milk River Watershed Council Canada (MRWCC) initiated a surface water quality monitoring program. The program collected samples from 10 sites, both on the mainstem of the Milk River and also along a few tributaries. Bi-weekly samples were collected from June through to August. Findings of the first year of the program were reported (Riemersma *et al.*, 2006) and include the following:

- *Water temperature* – the warmest water temperatures were generally recorded at the most downstream sites (i.e. Highway 880 and at the Pinhorn Ranch);

- *Effect of St. Mary Diversion* – when flow is released from the St. Mary River Diversion Canal, there are improvements (i.e. decrease in concentrations) in some of the water quality parameters, such as nitrogen and salts, and deterioration (i.e. increase in concentrations) in other parameters, such as phosphorus. When water is not released from the diversion, the opposite trend in those water quality parameters occurs.
- *Dilution effect of the diversion* – the annual diversion results in flows that may be up to 200 times higher than natural flows in the Milk River. It is hypothesized that the water quality of the St. Mary River is better than the water quality of the Milk River, hence the improvement in water quality when the St. Mary River water is added.
- *Phosphorus trends* – the more common form of phosphorus found in the Milk River is the particulate form, which is bound to sediment particles. The increased flow may result in an increase in suspended sediment transport, thus an increase in phosphorus concentration particularly at the downstream sites.
- *Effect of flow volumes* – low flow periods tend to deteriorate water quality (more turbid and increased algal production).

This monitoring program is ongoing and further data and analysis may result in observations of further trends in water quality parameters.

4.4.1.3 Data Gaps

General observations about the state of the water quality data available in the Milk River watershed include the following:

- *US data* – data about water quality on the US side is sparse, both temporally and the range of parameters (lack of TSS and nutrient data);
- *North Milk River data* – there is a lack of historical data. There is no continuous data set (monitoring programs are fragmented) which makes it very difficult to observe the immediate water quality effects caused by water from the St. Mary diversion;
- *EC data* – EC data provides the most continuous and complete set of water quality data, although there were a few periods when sampling was discontinued. Unfortunately, EC's monitoring station on the west was located on the south fork of the Milk River instead of the North Milk River where data collection would be more relevant to this study.
- *New monitoring program spearheaded by the MRWCC* – this new monitoring program, initiated in 2006, has set up monitoring stations which provide sufficient spatial coverage of the Milk River watershed and collects a wide range of parameters, including nutrients, salts, sediment and bacteria. This program addresses many of the data gaps for water quality data in this watershed.
- Effect of Increased Diversion on Water Quality.
- Analysis of Available Water Quality Data.

EC Data

As noted in **Table 4.10**, only two water quality monitoring stations, which were monitored by EC, had extended historical data for all the parameters of interest (discharge, temperature, TSS, TKN and TP) to complete an analysis. The two stations are: AL11AA0002 – Milk River at Western Crossing of the International Boundary located northwest of the Canada-US border on the south fork of the Milk River; and, AL11AA0003 – Milk River at Eastern Crossing of the International Boundary.

<u>Water Temperature</u>

The relationship between discharge and temperature was explored by analyzing only the samples which contained data for the two parameters as time-series (**Figures 4.12 and 4.13**). The general pattern for both parameters demonstrates a relationship between temperature and flows. However, there is clear pronounced lag between temperature and flows that shows flows rising first, then a subsequent increase in temperature. A regression analysis of temperature versus discharge does not show a strong relationship ($r^2 = 0.01$ for the site at the western crossing and $r^2 = 0.18$ for the site at the eastern crossing), which is likely related to the time lag.

Figure 4.12 Discharge and Temperature Data Time-Series for the Station at the Western Crossing (AL11AA0002)

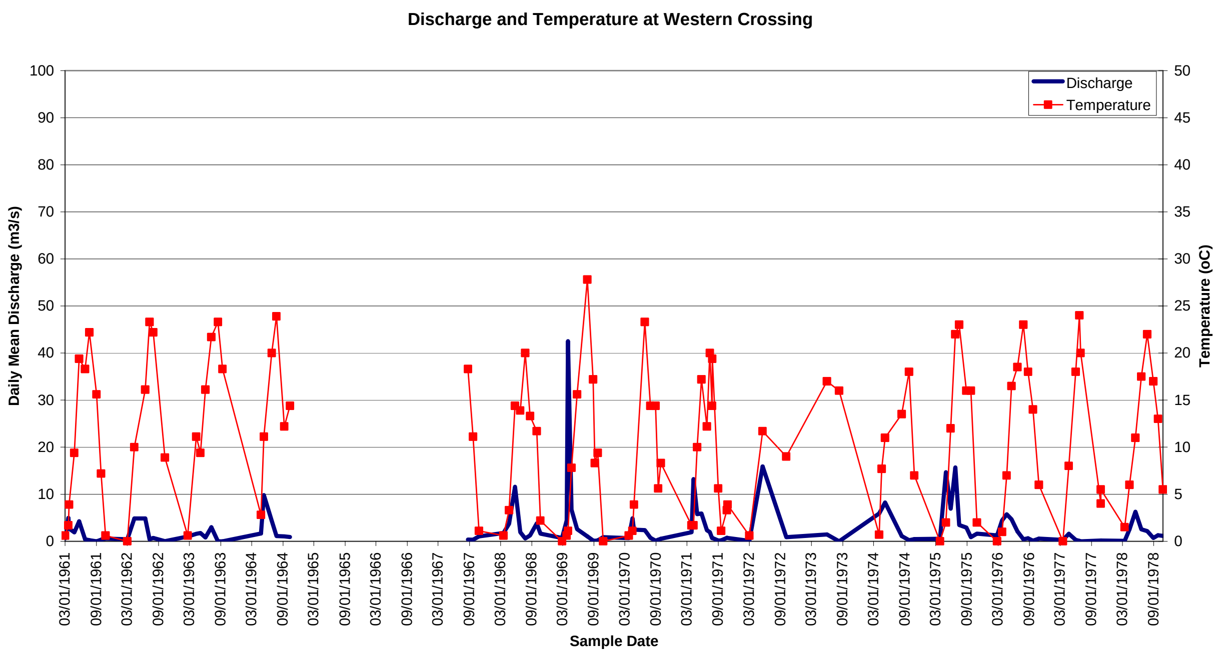
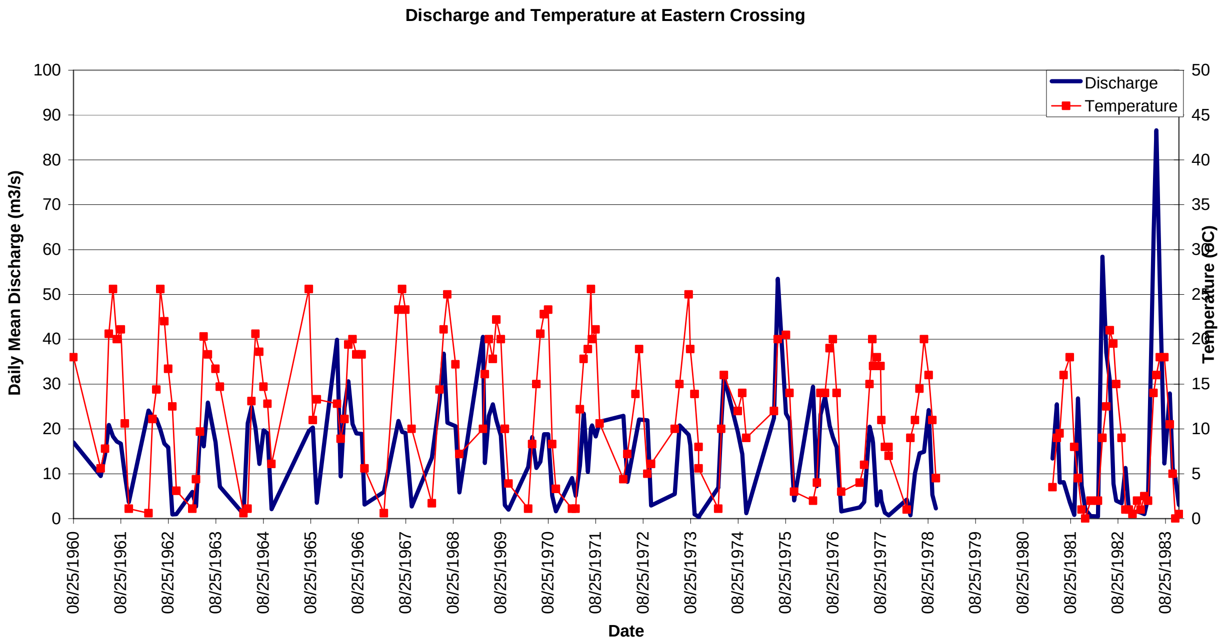


Figure 4.13 Discharge and Temperature Data Time-Series for the Station at the Eastern Crossing (AL11AA0003)



Total Suspended Solids (TSS)

Samples that contained both discharge and total suspended solids (TSS) data for each station were plotted as a time-series (**Figures 4.14 and 4.15**) and showed a relationship. This was further supported by plotting TSS concentration as a function of discharge (**Figures 4.16 and 4.17**). The relationship appears to be stronger in the upstream site at the western crossing but no significant regression was shown for the eastern crossing at the downstream site. The lack of a strong correlation at the downstream site is likely due to the input of sediment from the badlands areas bordering the river during a rainstorm event which are not directly related to the river flow. The regression analysis for the western crossing (**Figure 4.a6**) in particular, indicates a positive relationship (i.e. TSS concentrations increased as discharge increased).

Figure 4.14 Discharge and TSS Time-Series for the Station at the Western Crossing (AL11AA0002)

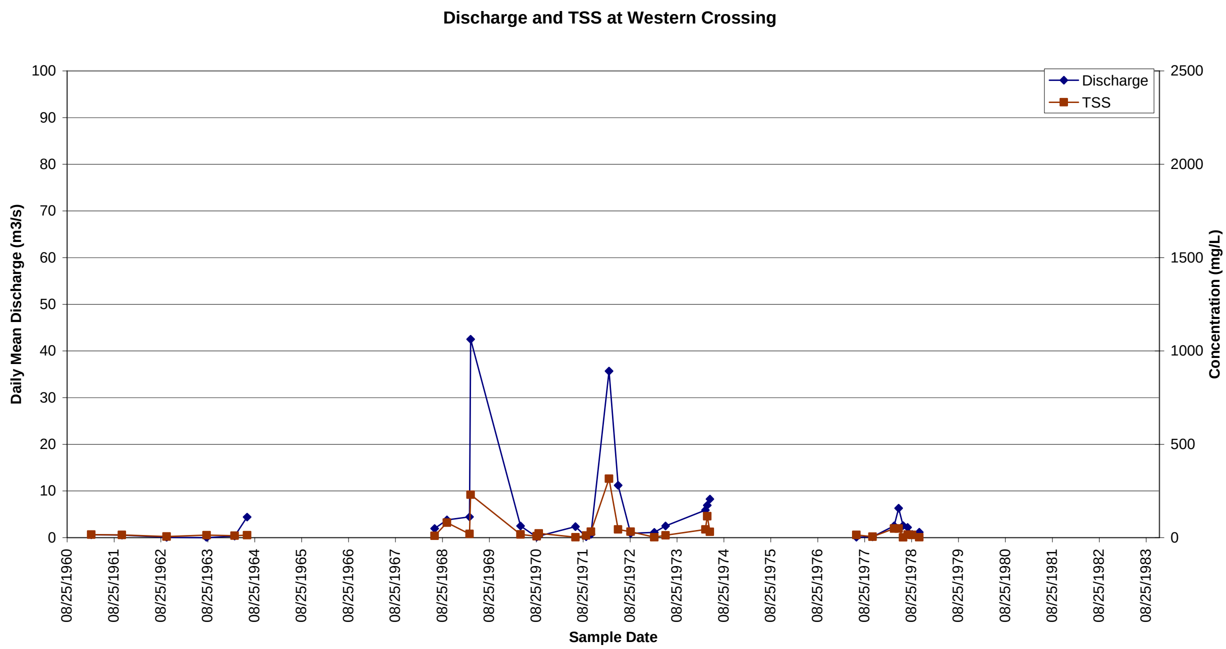


Figure 4.15 Discharge and TSS Time-Series for the Station at the Eastern Crossing (AL11AA0003)

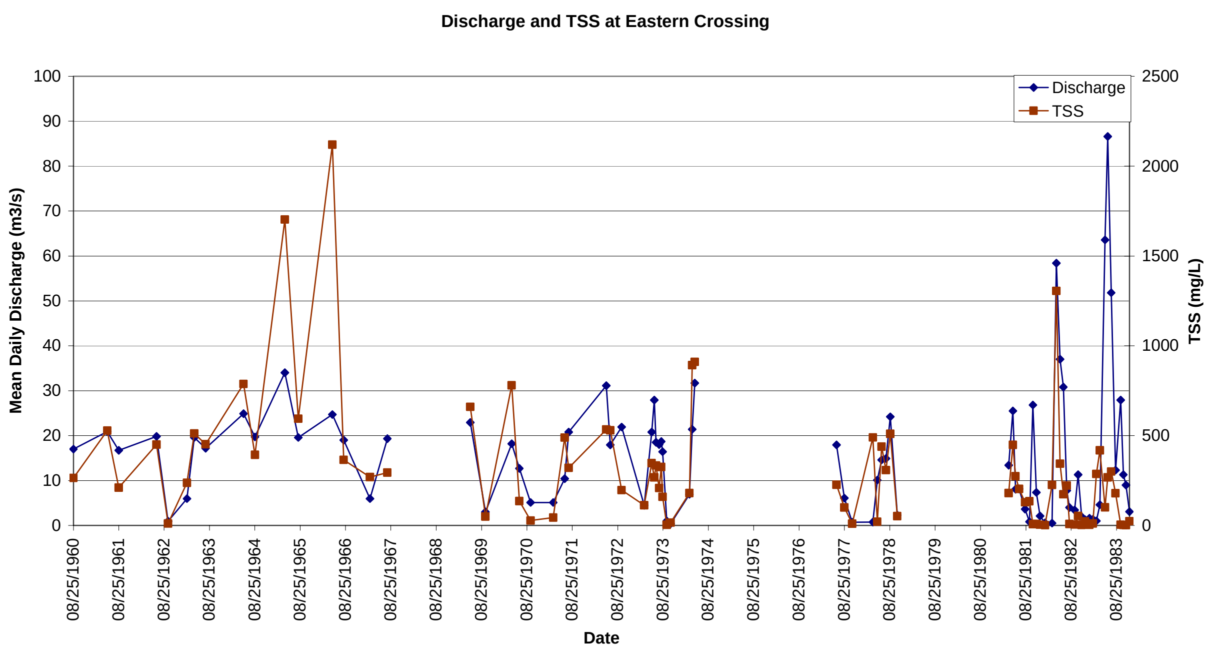


Figure 4.16 Regression Analysis of TSS Concentration and Daily Mean Discharge for the Station at the Western Crossing (AL11AA0002)

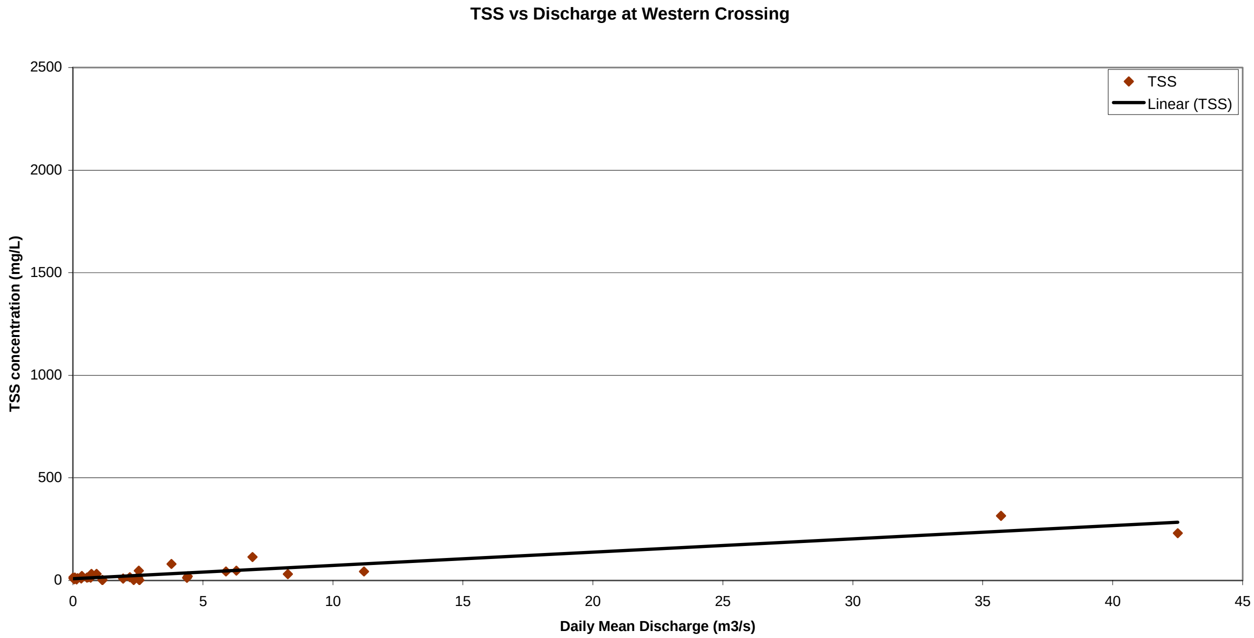
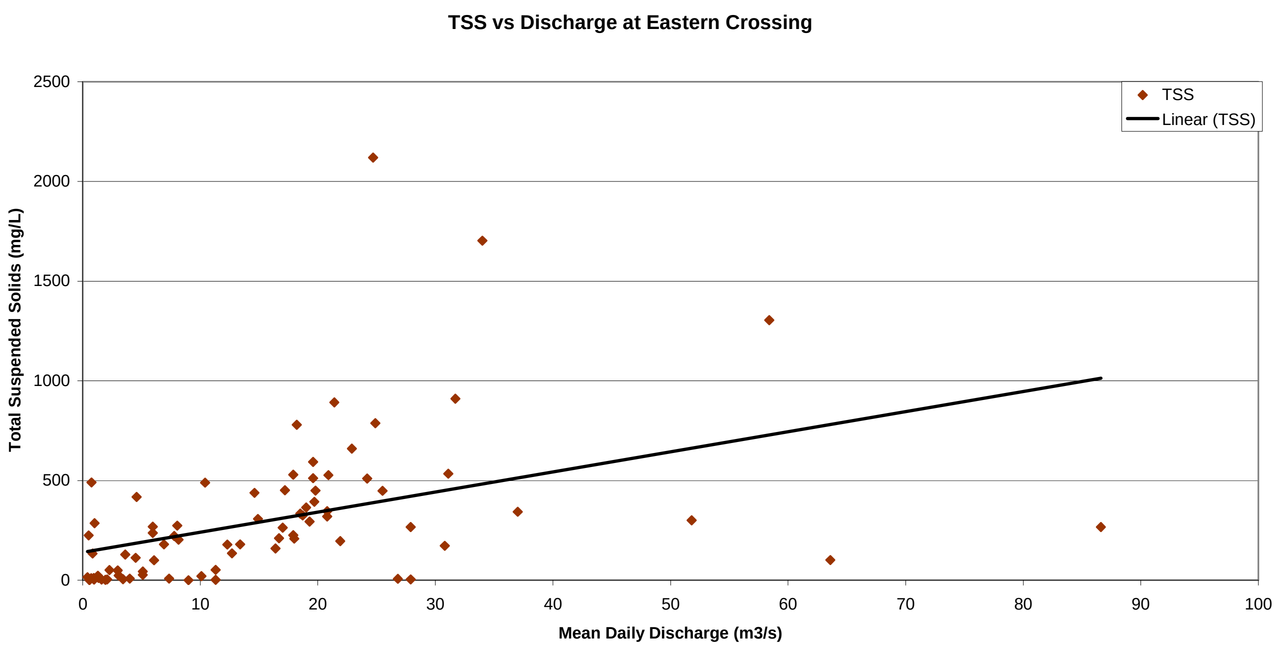


Figure 4.17 Regression Analysis of TSS Concentration and Daily Mean Discharge for the Station at the Eastern Crossing (AL11AA0003)



Time-series plots for discharge and TKN for the two stations are shown in **Figures 4.18 and 4.19**. There appears to be a relationship between these parameters, but regression analyses show weak relationships ($r^2 = 0.17$ for the western crossing station and $r^2 = 0.39$ for the eastern crossing station).

Figure 4.18 Discharge and TKN Time-Series for the Station at the Western Crossing (AL11AA0002)

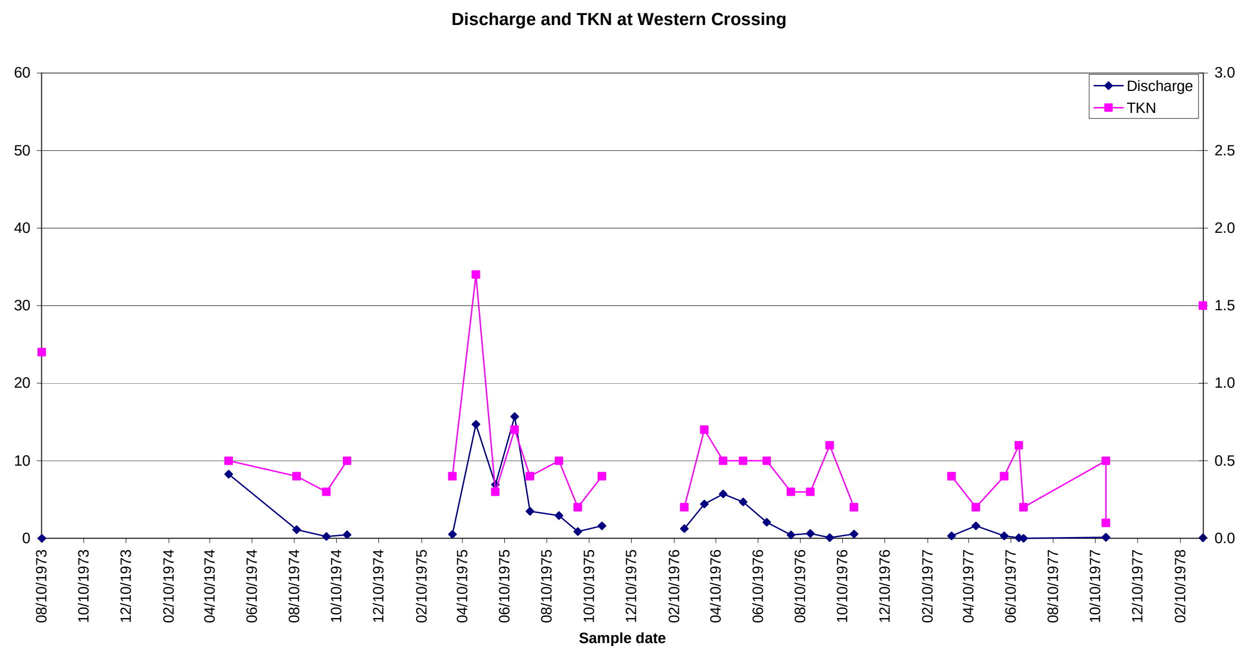
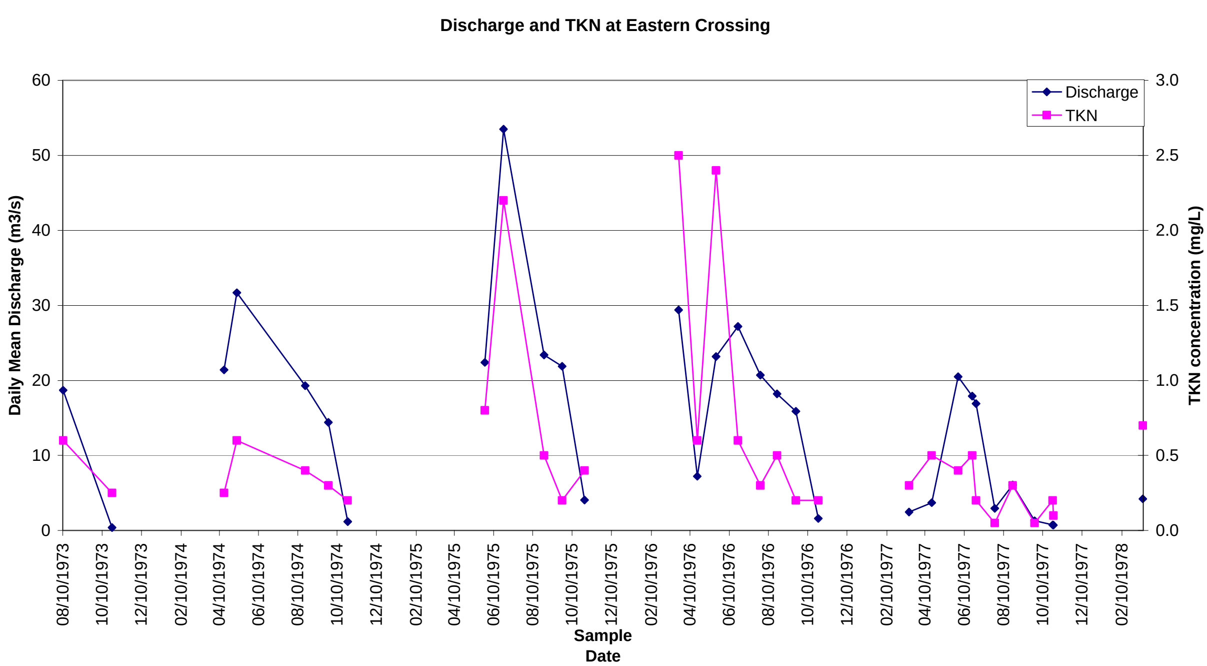


Figure 4.19 Discharge and TKN Time-Series for the Station at the Eastern Crossing (AL11AA0003)



Time-series plots for discharge and TP for the two stations are shown in **Figures 4.20 and 4.21**. TP shows a similar pattern as TKN, indicating a relationship in the time-series plots, but the regression analyses show weak relationships (r^2 = 0.17 for the western crossing station and r^2 = 0.39 for the eastern crossing station).

Figure 4.20 Discharge and TP Time-Series for the Station at the Western Crossing (AL11AA0002)

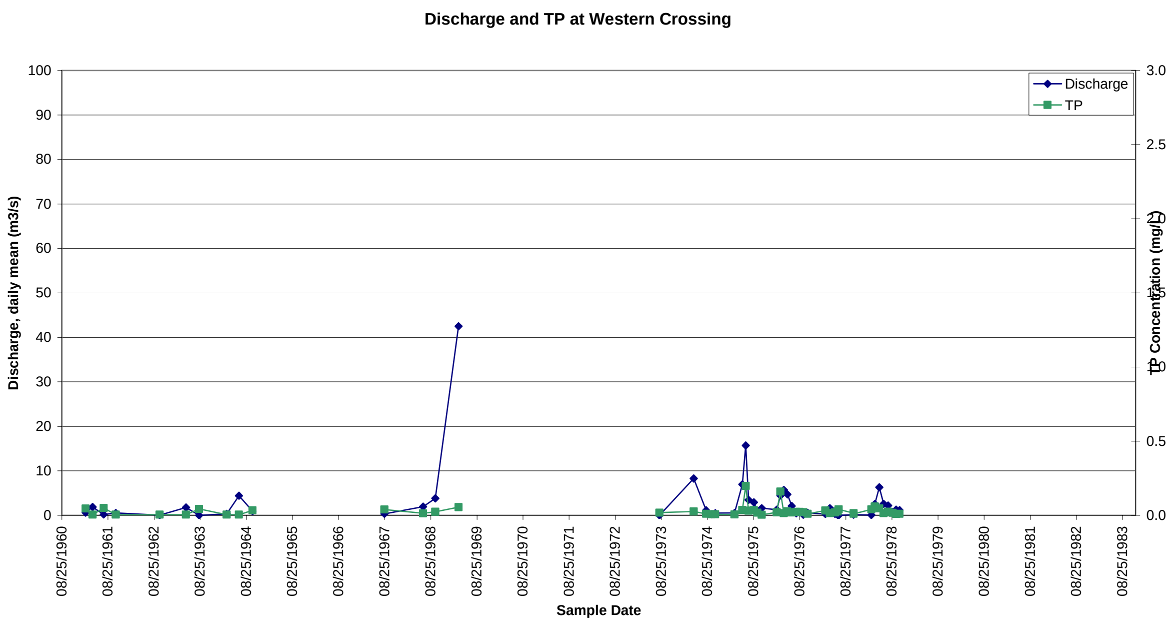
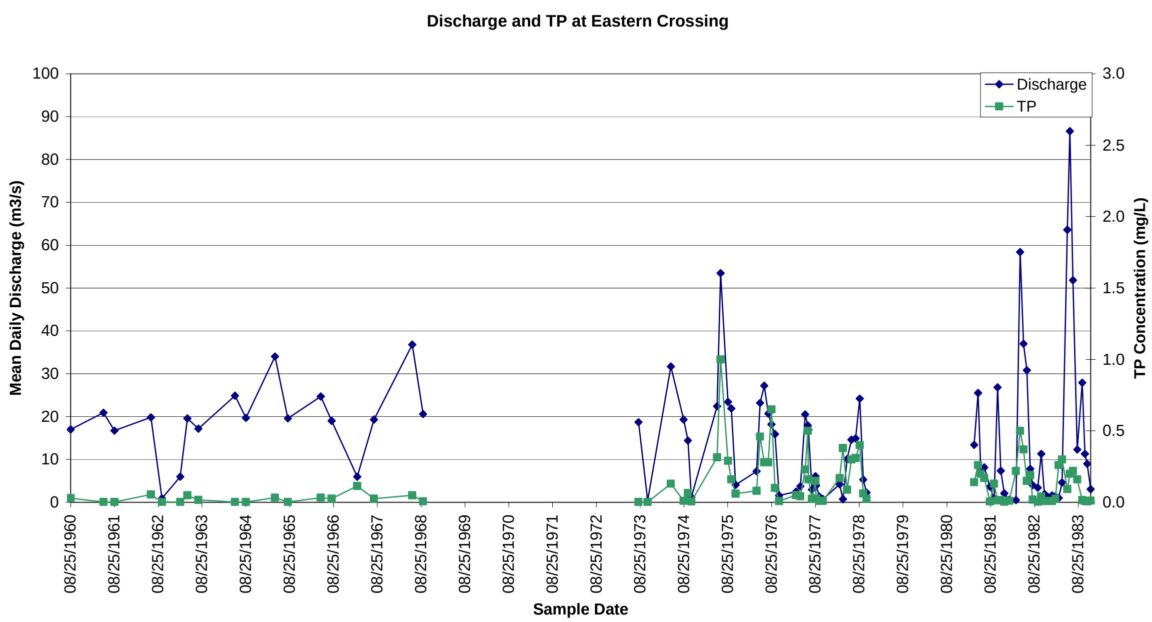


Figure 4.21 Discharge and TP Time-Series for the Station at the Eastern Crossing (AL11AA0003)



AENV and MRWCC Data

The data collected by MRWCC in their monitoring program was combined with historical data from AENV. This data set was analyzed as it provided more recent water quality data that had good spatial coverage. Four sites were selected for analysis:

- AB11AA00270 – North Milk River near the international boundary, upstream of Highway 501. This site represents water quality in the North Milk River after receiving water from the St Mary Diversion Canal and prior to its confluence with the Milk River.
- AB11AA00280 – Milk River near western boundary at Highway 501. This site represents water quality in the Milk River prior to the confluence with the North Milk River, including the water from the St. Mary Diversion Canal. This site is also the closest to the EC station at the western crossing.
- AB11AA0150 – Milk River upstream of the Town of Milk River. This site represents water quality after the confluence of the North Milk River and the south fork of the Milk River.
- AB11AA0320 – Milk River near eastern boundary at Pinhorn Grazing Reserve. This site is the most downstream sampling location, prior to the Milk River entering the United States again. This site is also the closest to the EC station at the eastern crossing.

As discharge data was not provided, TSS data was plotted along with the nutrient data.

<u>TSS and TKN</u>

Both time-series plots and regression analyses of TSS and TKN data at the four selected sites did not reveal any significant relationships between these parameters.

<u>TSS and TP</u>

The time-series and regression analyses for TSS and TP data at the upstream sites (on the North Milk River and the south fork of the Milk River near the international boundary on the west) did not reveal any significant relationships between these parameters. However, the downstream sites (at Milk River upstream of the Town of Milk River and at the furthest downstream station at Pinhorn Grazing Reserve) indicated a relationship as can be seen in the time-series plots (**Figures 4.22 and 4.23**) and the regression analyses (**Figures 4.24 and 4.25**). These figures show a strong positive relationship between TSS and TP, which supports the conclusion drawn in the MRWCC report which indicated that TP is mainly found in a particulate form associated with suspended sediments.

Figure 4.22 TSS and TP Time-Series for the Station Located Upstream of the Town of Milk River Crossing (AB11AA0150)

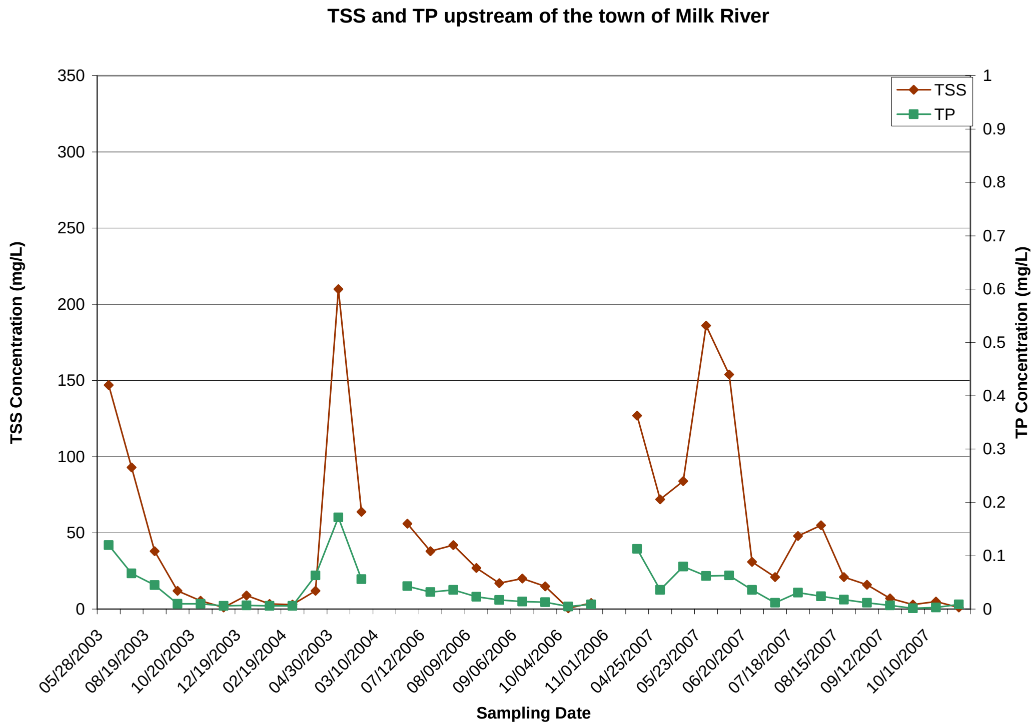


Figure 4.23 TSS and TP Time-Series for the Furthest Downstream Station Located on the Pinhorn Grazing Reserve (AB11AA0320)

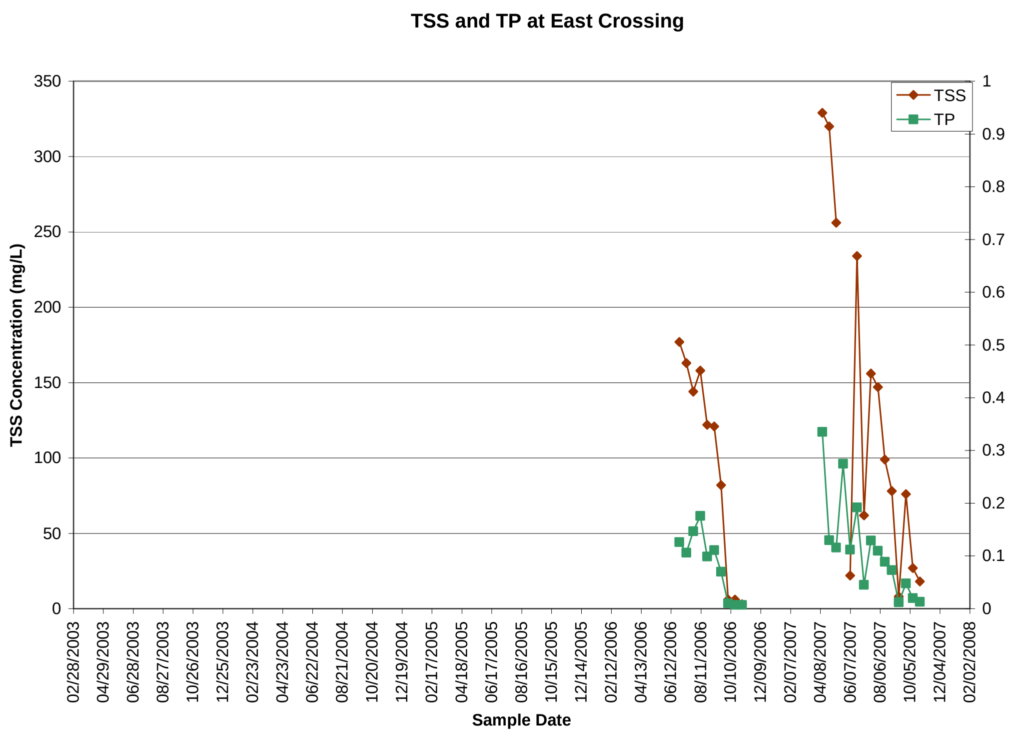


Figure 4.24 Regression analysis of TP and TSS Concentrations for the Station Located Upstream of the Town of Milk River Crossing (AB11AA0150)

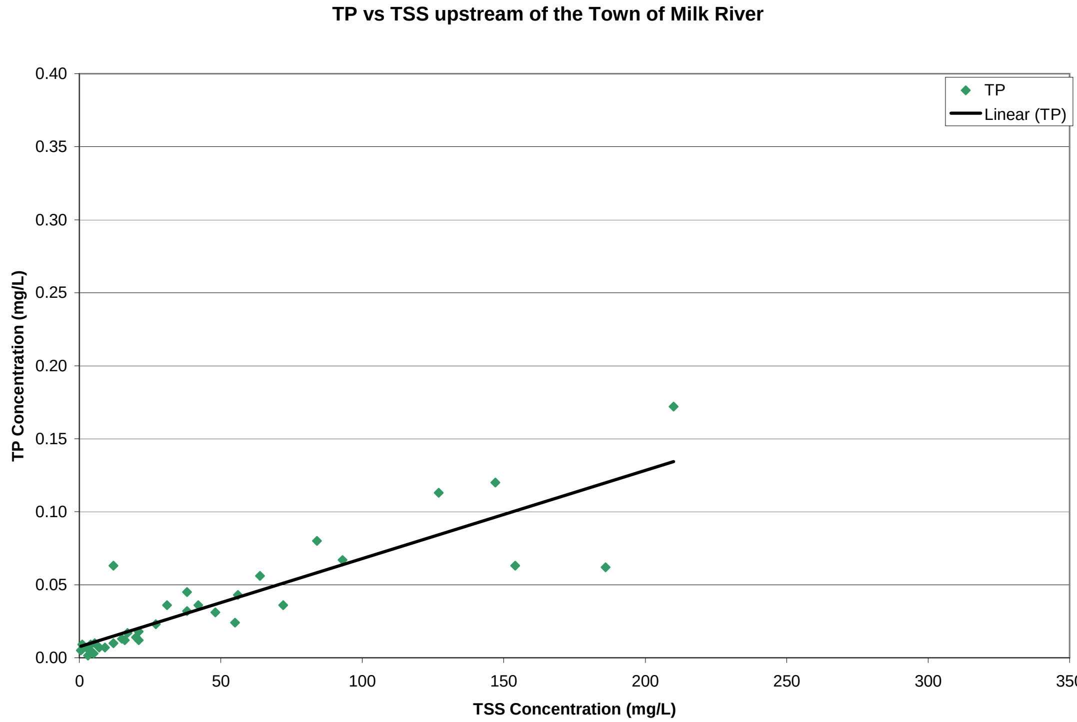
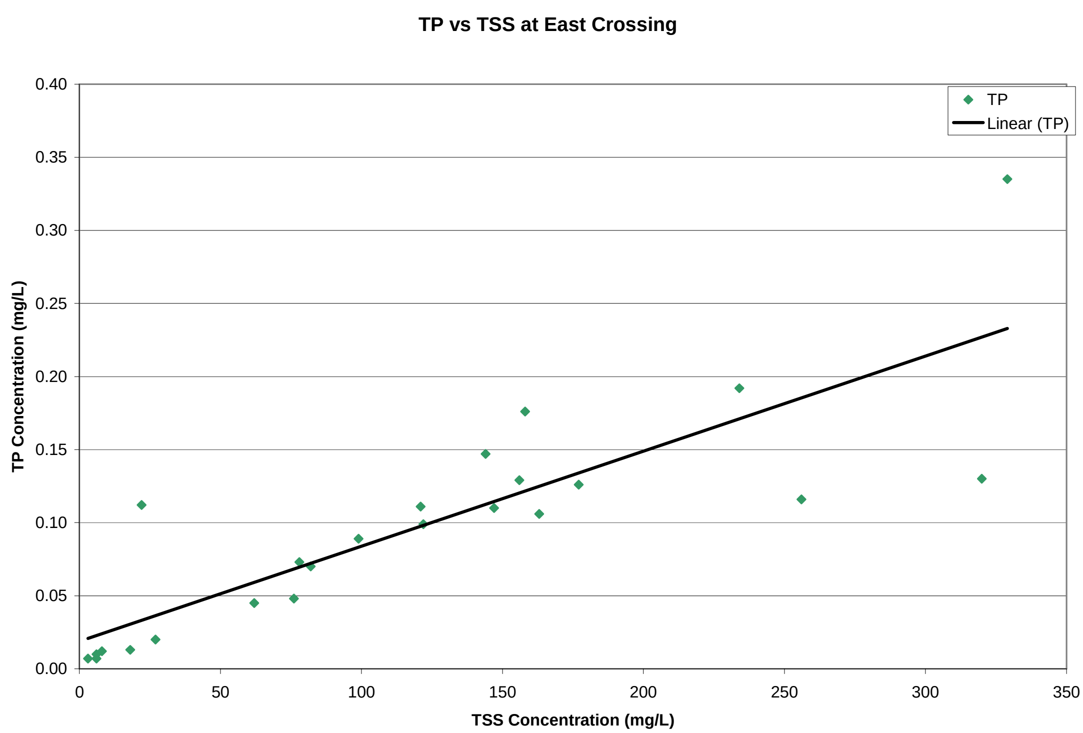


Figure 4.25 Regression Analysis of TP and TSS Concentrations for the Furthest Downstream Station Located on the Pinhorn Grazing Reserve (AB11AA0320)



4.4.1.4 Potential Effect of Increased Discharge

In summary, the analyses above revealed two positive relationships:

- TSS increased as discharge increased; and,
- TP increased as TSS increased.

The analysis was conducted under the current condition with diversion flows of 600 to 800 cfs. If flows were to increase to 1000 to 1200 cfs, that is a potential increase of 25% to 75%. Without implementing any new mitigation or management measures, there is the potential for TSS and TP concentrations to increase by the same factor (25% to 75%).

4.4.2 Conclusions and Recommendations

A review of existing water quality data in the Milk River watershed revealed that although there were many stations monitored by many different agencies, a comprehensive (both in terms of spatial coverage and analysis of parameters) continuous data set was not available. The most complete data set was provided by EC at both the western and eastern crossings of the Milk River. Unfortunately, this data set did not include information on the North Milk River, which is the reach that receives water from the St. Mary Diversion Canal.

A new monitoring program initiated in 2006 and extended into 2007 by the MRWCC has addressed the need for sufficient spatial coverage and a comprehensive list of analyzed parameters. Analysis of preliminary results from this program has already indicated the effect of the St. Mary Diversion on some water quality parameters, particularly how the increased flows improves parameters, such as nitrogen and salts, and degrades other parameters such as phosphorus. These changes appear to depend on whether a substance is bound to sediments in a particulate phase or exists in a dissolved form. Changes in suspended solids transport will appear if parameters are associated with a particulate phase and might not experience appreciable effects if only the dissolved component is involved.

Analysis of the most complete data sets from the two stations monitored by EC was conducted by time-series analysis and regression plots for discharge as compared to temperature, TSS, TKN and TP. Observations made on the relationships between parameters based on the analyses include the following:

- There appears to be a time-lag relationship between discharge and temperature, with discharge values peaking first. A regression analysis does not show a strong relationship, which is likely related to the time-lag.
- There is a positive relationship between discharge and TSS, particularly at the upstream site at the western crossing. The regression analysis indicates how TSS concentration increased as discharge increased. The lack of a strong correlation at the downstream site is likely due to the input of sediment from the badlands areas bordering the river during a rainstorm event which are not directly related to the river flow.
- Although the time-series plots indicate a relationship between discharge and the two nutrients, TKN and TP, the relationships were weakly positive.

Analysis of the most recent data collected by MRWCC by time-series plots and regression analysis has shown that TP and TSS have a positive relationship (i.e. TP concentrations increased when TSS concentrations increased). This relationship is not apparent in the upstream stations, but is revealed in analysis of the data from the stations downstream of the confluence of the North Milk River and the south fork of the Milk River. This is consistent with the observations made in the MRWCC report which indicated that phosphorus is mainly present in the particulate form and associated with suspended sediments.

Proposed Mitigation

The analysis revealed two positive relationships between discharge and TSS, and TSS and TP. Increases in TSS and TP concentrations deteriorate water quality; therefore, reducing erosion along the banks of the Milk River would maintain or improve water quality, particularly if there is an increase in flows from the diversion. Potential mitigation measures include bank armouring measures, such as riprap or bioengineering solutions, and instream flow diversion measures such as rootwads or rock veins.

Proposed Monitoring Program

AMEC proposes that the diversion effects monitoring in the future include several spatial and temporal surveys in accordance with the following schedule and scope:

- Spatially – two or three representative sites before and after diversion should be selected. Site selection in an after-diversion section of the river should take into account erosion studies.
- Temporally – at least two surveys should be conducted at the above mentioned sites: one prior to the start of the release of flow from the diversion (a week before) and one after the beginning of the release of flow (a week after). Surveys conducted for temporal analysis should be repeated in the middle of the diversion period, a week prior to the end of the diversion period, and within one, two, and three weeks after diversion has stopped.
- Water quality surveys will be accompanied with flow measurements. This will provide information for substance loadings assessment, meaningful regression, and analysis for flow-water quality relationships.
- Water quality parameters will include a set of in-situ measurements (temperature, pH, dissolved oxygen, conductivity) and laboratory analysis of samples for total, dissolved, and particulate total nitrogen and phosphorus, total dissolved solids, and potentially metals (e.g. aluminium and copper). The list of parameters may be revised as surveys progress.

Survey results analysis will include descriptive statistics in order to represent variability of water quality parameters within different temporal snapshots and spatially. Regression will be used to find if relationships do exist between flows and water quality parameters (total, dissolved, and particulate phases).

There is a potential in increase of TSS concentrations, particulate phase of nutrients and organic matter deposited in sediments. The effect can be caused by resuspension of bottom sediments in a result of increases in flow, which may be not typical for some reaches. Such effects usually have a temporal pattern and occur at the diversion start up but the duration depends on amount of available sediments previously deposited at the reach. There is no information currently available in order to track such effects but a special water quality and hydrologic survey can be designed to address and quantify the issue.

Changes in substance loadings, once they are calculated from water quality and related flows at above selected sites, will provide input information for mass balance calculations and mass balance modelling.

4.5 Fisheries Resources and Aquatic Habitat

This section provides an overview of fisheries resources, aquatic habitat and a qualitative evaluation of potential effects on fisheries resources and aquatic habitat from increased water diversions into the Milk River. For the purpose of this study, the distribution of fisheries resources and aquatic habitat is further described according to the three distinct river reaches; a) the North Milk River reach, b) gravel dominated Milk River reach, and the c) sand dominated Milk River reach. Following the review of existing information, key sport-fish and special status species were selected to evaluate the potential effects of increased diversions on these species. Habitat requirements and life history strategies of these fish species were then reviewed to assist in identifying potential effects linkages.

This approach provided a means of identifying effects linkages and primary risks to the fisheries resources and aquatic habitat, and a basis for developing broad high-level recommendations that should be considered during future planning. These risks to fisheries resources and aquatic habitat are expected to range both spatially and temporally following increased diversions, and in some instances are specific to certain fish guilds or species depending on habitat and/or life history requirements.

For the purpose of this study, fisheries resources and aquatic habitat, and potential effects from the increased diversions are described from the North Milk River at the western crossing of the international boundary to the Milk River at the eastern crossing of the international border. This overview evaluation does not include reaches upstream of the St. Mary River diversion outlet structure or downstream reaches south of the international border or the Fresno Reservoir.

4.5.1 Existing Conditions

4.5.1.1 Background Information Sources

Fisheries resources and aquatic habitat in the Milk River have been extensively studied in relation to the irrigation diversion, feasibility studies for a previously proposed storage dam on the Milk River and more recent investigations of several fish species that have been designated '*At Risk*' by Alberta Sustainable Resource Development (ASRD) or '*Threatened*' under federal jurisdiction and the Canadian *Species at Risk Act*. Primary sources of published information on fisheries resources and aquatic habitat in the Milk River includes:

- Channel features and aquatic habitat distribution (McLean and Beckstead, 1981, 1987; Clayton and Ash 1980; R.L.&L. 1987, 2002; and Spitzer 1988);
- Information on the distribution and abundance of fish species in the Milk River (ASRD, 2003, 2004a, 2004b, 2005; Clayton and Ash 1980; R.L.&L. 1987, 2002; Quinlan R.W et al. 2003; Clayton and Sikina 2005; Henderson and Peter 1969; W.A Watkinson pers. comm.; J. Cooper 2007; and T. Clayton pers. comm.); and
- Habitat requirements and life history strategies of key fish species, ASRD, 2003, 2004a, 2004b; Clayton and Ash, 1980; R.L.&L., 1987, 2002, Scott and Crossman, 1973); Quist *et al.,* 2004; Nelson and Paetz 1992; Lee *et al.,* 1980; Houston, 1998; and Joynt and Sullivan, 2003).

Fisheries baseline information does not exist prior to the 1915 diversion and therefore no comparison can be done before and after the diversion. Therefore, the following information is based on data collected from the late 1960's and onward. Fisheries data has been collected by different groups for various purposes and does not provide any conclusive information on temporal changes during this period.

4.5.1.2 Aquatic Habitat in the Milk River

The three distinct river reaches of the Milk River are described below. Among the three reaches, stream gradient differences exist as well as differences in bank lithology. **Figure 3.1** illustrates the gradient changes among the three reaches (see **Section 3.2**). Alluvial deposition dominates the bank material along most of the river reaches except at Writing-on-Stone Provincial Park and the sections of the North Milk River where erosion-resistant sandstone cliffs abut the river. All three prairie system reaches are subjected to natural variability in seasonal flows and fluctuations in temperature, salinity and dissolved oxygen concentration Quist, M.C. *et al.* (2004). Peak seasonal flows occur from June to August and minimum flows occur from December to February RL&L (1987).

North Milk River Reach

The North Milk River reach is approximately 80 kilometres long and is distinguished by its dominant boulder and cobble substrate. The reach has a moderate to steep stream gradient (RL&L, 1987) and begins at the western international boundary and ends at the confluence to the south stem of the Milk River.

The banks of the North Milk River are mainly composed of unconsolidated alluvial material except for those areas where the channel abuts the valley wall (sandstone). Due to the high stream gradient of 0.003m/m (**Figure 3.1**), the North Milk River reach has high stream flow energy resulting in the deposition of coarser channel substrate material such as boulders and gravel. These materials create good cover and riffle habitat for fish species. As well, the North Milk River is characterized as having low turbidity and increased turbidity in a downstream direction (RL&L, 1987). RL&L (1987) found that the North Milk River reach was characterized by predominantly run, riffle and pool habitats with low velocity areas (stream margins and pools) receiving a large amount of sediment accumulation.

Aquatic macrophytes are sparse but are found in the upstream portion of the North Milk River in the mouths of tributaries, flooded areas and shallow, low velocity pools. The higher turbidity found further downstream in the North Milk River is thought to limit the distribution of aquatic macrophytes (RL&L, 1987). Typically this reach receives more rainfall than the other downstream reaches (ASRD, 2004b) and is glacier fed from the St. Mary River thus maintaining lower temperatures than the other downstream reaches. This characteristic makes habitat more suitable for coldwater species (i.e. salmonids) in comparison to other reaches.

Milk River Reach (Gravel)
This reach begins at the confluence of the North Milk River and the south stem of the Milk River and ends approximately 10 kilometres upstream of Writing-on-Stone Provincial Park. This highly erosional reach has a moderate overall stream gradient (slope= 0.0013 m/m to 0.0019 m/m) (**Figure 3.1**) and consequently is dominated by gravel and cobble substrate.

RL&L (1987) found this reach was mainly dominated by good quality run habitats (R1 and R2[1]), depositional pools and few flat habitats. Slight changes in stream gradient along this reach determine the distribution of different habitat types. High quality holding areas (R1 and P1) are more frequent in the mid and to a lesser extent in the upper sections of this reach. Shallow habitat types (R3 and P3) are most common in the lower section of the reach. RL&L (1987) concluded this reach had the most habitat diversity compared to the other two reaches.

Milk River Reach (Sand)
The lower reach begins 10 km upstream of Writing-on-Stone Provincial Park and ends at the eastern crossing of the international boundary. The lithology of stream banks is dominated by unconsolidated alluvial materials except when the stream flows through Writing-on-Stone Provincial Park, where the banks are harder consisting of more erosion-resistant sandstone.

This reach has a low stream gradient and is highly depositional in nature. RL&L (1987) concluded this reach has the lowest habitat diversity and is mainly dominated by flat and low quality run habitats (R3) and lacks high quality holding areas. This reach is considered the most turbid and has the highest temperatures due to receiving the least amount of rainfall and exposure to higher ambient air temperatures, compared to the other two reaches. Fish species composition is dominated by cool water species that have higher tolerances to elevated turbidity levels and temperatures.

Due to the shallow and depositional nature of this reach, it is more susceptible to habitat changes and possible habitat fragmentation caused from variability in natural and anthropogenic flow regimes. This reach experiences the most sediment accumulation compared to the other two reaches and has consequently reduced the storage capacity of the downstream Fresno Reservoir in Montana (U.S. Department of the Interior, 1984).

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[1] Habitat definitions are described in RL&L 1987.

4.5.1.3 Fish Community Structure and Distribution

There are a total of 27 fish species documented in the Canadian section of the Milk River and North Milk River since the late 1960s. The distribution of these species along the North Milk River and the mainstem Milk River are dependent on a number of factors including substrate composition, turbidity, water temperature, predation pressures, cover type and the presence of aquatic macrophytes. Fathead minnow, longnose dace, longnose sucker, flathead chub and mountain sucker are the most common and widely distributed species in the North Milk River and the mainstem Milk River. Special status species (provincially and federally) commonly found in the Milk River system include the western silvery minnow, eastslope sculpin, sauger and stonecat. **Table 4.14** lists the distribution, abundance and status of fish species found in the Milk River system.

Very rare species with incidental occurrences in the Milk River system were not included in the table (walleye, finescale dace, cutthroat trout, brown trout, rainbow trout, bull trout and lake whitefish). One walleye was captured at the Aden Bridge in 2006 but this is the only representation of walleye in the Milk River system to date (pers. comm., T. Clayton). There has only been one finescale dace recorded in the North Milk River and according to Terry Clayton from the ASRD, it may have been misidentified. Excluding mountain whitefish, the Salmonidae family is poorly represented in the Milk River system. One cutthroat (Willock, 1968) and brown trout (Quinlan, R.W *et al.,* 2003) have been caught in the North Milk River since the late 1960s and on very rare occasions, rainbow and bull trout have entered the system at the St. Mary Canal inlet near Babb, (Quinlan, R.W. *et al.* 2003). Lake whitefish have been recorded in the mainstem Milk River but only on very rare occasions (Quinlan, R.W *et al*., 2003).

TABLE 4.14
The Distribution, Abundance and Status of Fish Species in the North Milk River and Mainstem Milk River

Common Name	Scientific Name	Species Code[1]	Fish Species Distribution[2]			General Abundance[3]	Regional Importance	Special Status	
			North Milk River Reach	Milk River Reach (Gravel)	Milk River Reach (Sand)			Provincial[4]	Federal[5]
brassy minnow	*Hybopsis gracilis*	BRMN	U	•	•	R	Ecological	Undetermined	
brook stickleback	*Culaea inconstans*	BRST		•	•	R	Ecological	Secure	
burbot	*Lota lota*	BURB		•	•	C	Sport-Fish	Secure	
fathead minnow	*Pimephales promelas*	FTMN	•	•	•	A	Ecological	Secure	
flathead chub	*Platygobio gracilis*	FLCH	•	•	•	A	Ecological	Secure	
Iowa darter	*Etheostoma exile*	IWDR			•	R	Ecological	Secure	
lake chub	*Couesius plumbeus*	LKCH	•	•	•	A	Ecological	Secure	
longnose dace	*Rhinichthys cataractae*	LNDC	•	•	•	A	Ecological	Secure	
longnose sucker	*Catostomus catostomus*	LNSC	•	•	•	A	Ecological	Secure	
mountain sucker	*Catostomus platyrhynchus*	MNSC		•	•	A	Ecological	Secure	Not at Risk
mountain whitefish	*Prosopium williamsoni*	MNWH	•	•		C	Sport-Fish	Secure	
northern pike	*Esox lucius*	NRPK	•	•	•	C	Sport-Fish	Secure	
northern redbelly dace	*Phoxinus eos*	NRDC	•			R	Ecological	Sensitive	
sauger	*Sander canadensis*	SAUG			•	C	Sport-Fish	Sensitive	
eastslope sculpin	*Cottus bairdi punctulatus*	SHSC	•	•		R	Ecological	Threatened	At Risk[6]
stonecat	*Noturus flavus*	STON	U	•	•	C	Ecological	Threatened	
trout perch	*Percopsis omiscomaycus*	TRPR		•	•	R	Ecological	Secure	
western silvery minnow	*Hybognathus argyritis*	WSMN			•	C	Ecological	Threatened	Threatened
white sucker	*Catostomus commersoni*	WHSC		•	•	A	Ecological	Secure	
yellow perch	*Perca flavescens*	YLPR		•	•	R	Sport-Fish	Secure	

Notes:

1. MacKay et al., 1980.
2. Fisheries distribution information for the Milk River obtained from ASRD, 2004a; 2004b; R.L&L.,1980, 1987, 2002; Quinlan R.W et al., 2003; Watkinson W.A, 2007; J. Cooper pers. comm. and T. Clayton pers. comm. U-Unknown.
3. Information on general fish abundance in the Milk River is subjective and obtained from Clayton and Ash, 1980; and R.L&L., 1987. A-Abundant, C-Common, R-Rare.
4. Provincial fish species ranking based on *The General Status of Wild Species in Alberta* (ASRD, 2005).
5. Federal fish species ranking based on *Canadian Species at Risk, September 2007* (COSEWIC, 2007).
6. Proposed as “Threatened” and is currently under review (COSEWIC, 2007).

4.5.1.4 Habitat Requirements and Life History Strategies of Selected Species

Key fish species were selected based on their general abundance, regional importance, and potential for the species to be effected by increased diversions. Sport-fish species that are considered uncommon migrants that enter the Milk River through the diversion system (i.e. salmonids) or migrate upstream from the Fresno Reservoir (i.e. walleye, lake whitefish) were not selected. Common small and large-bodied forage fish and other fish species that are well represented throughout the Milk River system and generally well adaptive to a wide range of physical and biological conditions were also not selected.

Habitat requirements and life history strategies are described for three sport-fish and three special status species as follows: mountain whitefish, northern pike, sauger, eastslope sculpin, stonecat and western silvery minnow. **Table 4.15** outlines habitat requirements and life history strategies of these fish species. Habitat requirements and life history strategies vary considerably between the fish species selected. The discussion on the potential effects of increased diversions focuses on these species, although in some instances there are references to other species in the system.

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TABLE 4.15
Summary of Habitat Requirements and Life History Strategies of
Selected Fish Species Found in the North Milk River and the Milk River Mainstem

Fish Species	Distribution	Spawning	Rearing & Feeding	Overwintering
Sport-Fish Species				
Mountain Whitefish (*Prosopium williamsoni)*	• Mountain whitefish are the most abundant salmonid species found in the Milk River assemblage (RL&L, 1987) and has been recorded in the North Milk River and as far downstream, yet rare, as the Town of Milk River (Quinlan, R.W *et al.,* 2003). • They are year round residents in the North Milk River and according to RL&L (1987), their downstream distribution is limited by summer water temperatures and turbidity.	• Late September to early November (Nelson & Paetz, 1992) in riffles over gravel substrate. • Preferred areas with greater depth and lower velocities than adjacent or surrounding riffle habitat. • Eggs have been predominantly found in run habitats primarily in R2 habitats (RL&L, 1987). • Spawning habitats are often found immediately downstream of high velocity areas (R.L & L, 1987). • Prefer coarse and very coarse gravel substrate for spawning (RL&L, 1987).	• Past studies have shown the North Milk River does not provide good rearing habitat for young of the year (RL&L 1970, 1987) despite the high amount of spawning habitat. This may be due to erratic temperature patterns (Chinooks) the Milk River watershed is subjected to throughout the winter months. • These temperature fluctuations could cause eggs to prematurely hatch and the young of the year, who feed on drift organisms, may not be able to get enough food to survive causing high young-of-the-year mortality (R.L&L, 1987).	• Little is know of overwintering habitat for mountain whitefish in the North Milk River. • There are adequate overwintering pools along the North Milk River (RL&L, 1987) but approximately 5% of the surface water available in July was available in March (RL&L, 2002). Therefore, dissolved oxygen levels may also be a limiting factor for adequate overwintering habitat.
Northern Pike (*Esox lucius)*	• Northern Pike have been captured in the North Milk River and the mainstem Milk River (Quinlan, R.W *et al.,* 2003). • They exhibit a localized distribution pattern along the North Milk River and Milk River and are mainly found in backwaters, creek mouths, and large pool habitats. As these three habitat types are irregularly found on the North Milk River and the Milk River, this may explain the northern pike's irregular distribution and occurrence in the Milk River system.	• Early spring in water between 4-11C and normally under ice (D.S. Lee *et al.,* 1980) or immediately after spring break-up in April and May. • Small demersal adhesive eggs are attached to aquatic macrophytes, which in the Milk River system, are fairly limited. Aquatic macrophytes are predominantly found in flooded oxbows and lower reaches of tributaries to the Milk River and it is likely these are good spawning habitats as well (R.L&L, 1987).	• Northern Pike are not strong swimmers and will seek sluggish or standing water where they will expend little energy swimming. • Young-of-the-year will inhabit rocky slow moving pools, backwaters and/or standing water where ample prey can be found (sucker and minnow species)	• RL&L (1987) conducted telemetry on northern pike in 1986 to provide information on movement and overwintering habitat. Northern Pike were found to be overwintering in the few deep (1>1.5 m) runs or pools that exist. Natural seasonal flow variations will affect the overwintering habitats and could limit the survival of northern pike in the Milk River system.
Sauger (*Sander canadensis)*	• In the Milk River system, Saugers have been captured from the confluence of the North Milk River downstream to the International Eastern Boundary. • Saugers are typically in turbid, free-flowing streams, generally tolerant of turbid conditions (Quinlan, R.W *et al.,* 2003)	• Spawn in the spring when water temperatures are approximately 6°C, on gravel or coarse gravel substrate (Nelson & Paetz, 1992). • Since saugers are know to spawn on coarse substrate, the North Milk River and upper portion of the mainstem Milk River have adequate spawning habitat.	• RL&L (1987) captured juvenile saugers in the lower reach of the Milk River where the habitat is predominantly composed of soft sediment, flats and slow runs with numerous backwater areas.	• Saugers will overwinter in deep pool and runs, where adequate depth exists. • RL&L (1987) suggests saugers may overwinter in downstream reaches of the Milk River in the United States.
Special Status Species				
Eastslope sculpin (*Cottus bairdi punctulatus)*	• Found only in the St. Mary and Milk River systems. • RL&L (2002) found the eastslope sculpin's distribution to be limited to the North Milk River and the mid and upper portions of the Milk River as far downstream as Deer Creek Bridge. • Prefer the cooler water temperatures and the increased water clarity of the upper reaches and the North Milk River.	• Spawning begins in mid-May and eggs are laid in cracks between rocks or ledges (Nelson & Paetz, 1992). • The male makes the nest and once the female lays the eggs, the male will fan oxygenated water onto the eggs. • Eggs hatch three to four weeks later (Nelson & Paetz, 1992).	• A benthic, nocturnal forager (ASRD, 2004). • Hid in cracks between boulders during daylight hours and remain on the bottom camouflaged with the substrate. • Feed on aquatic invertebrates.	• While overwintering, the Eastslope sculpin will remain hiding amongst boulders camouflaged from piscavores • The greatest threat to the Eastslope sculpin is variability in flow regimes which may reduce the availability of overwintering habitat (ASRD, 2004).
Stonecat (*Noturus flavus)*	• Alberta's only catfish specie and within the Milk River system, is distributed from the lower North Milk River to the International Boundary. • Occupy slow moving waters in deep pools with boulder, gravel and/or silt substrate. • Tolerable to turbid conditions (Scott and Crossman, 1973).	• Spawning occurs in late spring and early summer on boulder or coarse substrate habitats in slow, stagnant pools (Scott and Crossman, 1973). • Eggs are deposited in nests below the rocks and usually the male guards the nest until hatching occurs 7-9 days later (Joynt & Sullivan, 2003).	• Occupy slow moving pools with boulder or silt substrate. • Feed on aquatic insect larvae and occasionally other fish. • Feed at night and use their long barbels to locate food.	• Overwinter in coarse substrate pools using boulders and turbidity for cover. • The ASRD (2004b) concluded the key limiting factor of stonecat abundance was overwintering survival.
Western Silvery Minnow (*Hybognathus argyritis)*	• Considered a turbid-river cyprinid (Quist *et al.,* 2004). • Limited to the mid and lower portions of the Milk River dominated by shallow, flat, run and backwater habitats.	• Preferred spawning areas are in slow moving backwaters or at the mouth of tributaries. • Non-adhesive, partially buoyant eggs are laid in late May and early June (Watkinson, pers. comm.).	• Rearing occurs in quiet shallow backwaters and tributary mouths where there are low velocities. • Watkinson (pers. comm.) found they feed primarily on algal detritus, rotifers and zooplankton.	• According to RL&L (1987), western silvery minnow has been found to overwinter along the eastern crossing of the international boundary in moderately deep pools. • T. Clayton observed, in November, large schools of western silvery minnow in deep pools near the Deer Creek Bridge. This may suggest western silvery minnows move upstream to overwinter in areas with deeper pools than found in the downstream sand reach.

4.5.2 Current Data Gaps

There are several data gaps that still exist for fisheries resources and aquatic habitat in the Milk River system in order to ensure that impacts are predicable and minimized through management. More recent studies have concentrated on characterizing the distribution of special status fish, habitat use and requirements, and life history strategies. Similar studies have investigated these attributes for sport-fish species in the Milk River, but are relatively outdated occurring in the early 1980's. Additional information should be obtained to fill in the data gaps on certain species and input on these data gaps should be provided by regional stakeholder groups, such as ASRD Fish and Wildlife and Fisheries and Oceans Canada (DFO). Important data gaps that have been identified are below:

- Comprehensive data on habitat use and requirements, fish movement and life history strategies for select sport-fish species in the Milk River system;
- Population size estimate data for select species in the Milk River system;
- Critical habitat data (overwintering, spawning, rearing and holding) for the Milk River focusing on areas of bank erosion identified within this study;
- Studies to determine the potential effects of increased suspended solids on fish health in the Milk River; and
- Studies to evaluate potential changes temperature variability and nutrient concentrations on select species.

4.5.3 Potential Effects of Increased Diversion Flows

Information on the effects of the St. Mary diversion that commenced in 1917 is poorly understood, since no fisheries and aquatic habitat data exists prior to this period. There is limited research that has investigated the response of fisheries resources and aquatic habitat to changes from increased diversion flows. Similar to channel stability, fisheries resources and aquatic habitat in the Milk River may undergo a period of change following increased diversion flows until some level of channel stability equilibrium is established.

To better understand the potential effects of increased diversion flows, limiting factors affecting the fish species assemblage in the Milk River should be considered. Some limiting factors that have been identified in the Milk River (RL&L, 2002), include low winter flows; high suspended sediment levels; high siltation of the substrate; low winter dissolved oxygen concentrations; limited availability of deep water refugia; limited benthic invertebrate community; and limited availability of aquatic macrophytes. These limiting factors adversely affect fish assemblages in the Milk River over the long term and vary on a year-to-year basis depending upon seasonal flow regimes.

The potential effects from increased diversions are based on the predicted changes to erosion and sediment processes, which further interact with other physical and biological processes. These potential effects are described in relation to the limiting factors that effect fish assemblages in the Milk River, and more specifically to the selected fish species.

4.5.3.1 Changes to River Flows and Channel Hydraulics

Increased diversion flows may in the short-term alter channel hydraulics and change stream velocities and depths. Riverine fish utilize different microhabitats (i.e. depth, velocity, substrate) for different portions of their life cycles. The abundance and distribution of microhabitats may shift when diversion flows are increased, which could lead to changes in fish community structure until a channel stability equilibrium is reached.

For example, the eastslope sculpin prefer slow moving stream margin habitats (ASRD, 2004b), and localized increases in stream velocity, depth and/or sedimentation could change or alter the quality of these habitat types (i.e. reduce spawning or rearing habitat quality). Rapid increases in stream velocities may affect the egg and fry success of the western silvery minnow. The western silvery minnow lay partially buoyant eggs in May to early June (Watkinson, pers. comm.) and the increased flows may carry a greater number of eggs into lentic or less preferable habitat such as the Fresno Reservoir possibly affecting egg and fry survivorship. Mountain whitefish have preferred stream velocities and water depths for spawning. Any changes could affect the suitability of existing spawning habitat, but may increase the suitability of other areas.

4.5.3.2 Changes to Water Quality

<u>Turbidity and Suspended Sediment</u>
There was determined to be a positive relationship between increased diversion flows and suspended solids in the Milk River. Increases in turbidity and suspended sediment can have a number of direct and indirect effects on fisheries resources and aquatic habitat. These effects depend on the severity ranging from behavioural, sub lethal, and lethal responses, and include other indirect responses such as reduced feeding rates and success, siltation of spawning gravels, increased egg mortality, reduction in pool quality, abundance and diversity of aquatic macrophytes, and changes to benthic invertebrate communities.

Different fish species are more tolerant to increases in turbidity and suspended sediments than others. The western silvery minnow is tolerant to turbid waters (Quist *et al.,* 2004), while salmonid species and other coldwater species are less tolerant to turbid water (Jensen & Newcombe, 1996). Mountain whitefish are year round residents in the North Milk River and according to (RL&L, 1987) summer water temperatures and turbidity limit their downstream distribution. Increased suspended sediment may further restrict the movement of the mountain whitefish in the North Milk River, limiting the amount of forage, rearing and holding habitats in the summer.

Increased turbidity is generally inversely related to the abundance of aquatic macrophytes. In highly turbid water, aquatic macrophytes and algae do not have enough sunlight to properly photosynthesize and thus cannot be productive. When a system has a rapid increase in turbid water for an extended period of time, aquatic macrophytes and algae may die off and decay. This can provide food for some species of fish in the short-term but will also severely limit spawning habitat for species that spawn in or attach eggs to macrophytes, such as the western silvery minnow and northern pike.

Increased suspended sediment may have an adverse effect on benthic invertebrate productivity and community diversity. High levels of suspended sediment may decrease respiration among some species of benthic invertebrates, thus decreasing or eliminating the benthic invertebrate community. The increased levels of suspended sediment may provide protection for benthic invertebrates and zooplankton from visual predators, such as young-of-the-year mountain whitefish, northern pike and eastslope sculpin. As a result, food availability may become scarcer for young-of-the-year and growth rates reduced.

Nutrients

Potential changes in nutrient concentrations from increased diversion flows can cause elevated nitrogen and salts, but reduced levels of phosphorus. These changes are generally dependent on whether parameters occur in the particulate phase and can bind to suspended sediments (see Water Quality Section). Total kjeldahl nitrogen (TKN) and total phosphorus (TP) have a weak positive relationship with increased flows. Increases or decreases in nutrient concentrations could have an affect on the abundance and distribution of aquatic macrophytes and benthic invertebrates. This could indirectly affect the amount of food, cover, and spawning opportunities for species that rely on aquatic macrophyte growth (i.e. northern pike). Aquatic macrophyte decomposition can cause dissolved oxygen levels to deplete in winter months, and if significant, negatively affect overwintering by fish.

Temperature

There is time-lag relationship between elevated discharge and increases in water temperature in the Milk River. Changes in temperature as a result of increased diversion flows may cause a minor shift in the transition zone between cold and cool water environments affecting the distribution of fish. For example, the stonecat prefers slightly warmer water where as the western silvery minnow prefers slightly colder water, yet the two coexist in a transitional zone. Changes in temperature may shift this transition zone in the Milk River and affect the population of one species through competition.

Temperature changes can affect spawning success and distribution. Rapid fluctuating temperatures can disrupt spawning causing premature hatching or resulting in sporadic spawning over a longer period of time. When temperatures remain fairly constant, spawning occurs in a shorter interval (Nelson & Paetz, 1992). Temperature changes can also cause premature spawning and may cause starvation of fry.

4.5.3.3 Changes to Channel Morphology and Habitat Quality

Increased diversion flows could result in short-term effects to channel morphology and habitat quality. Increased bank erosion, channel cut-off activity, sediment transport and deposition could lead to reduced habitat complexity and quality. Deposition environments would probably be most vulnerable, particularly near areas of bank erosion or within the Milk River (sand) reach where aggradation is possible.

The abundance of high quality pool habitat could be reduced through deposition and infilling effecting deep water areas used for holding, overwintering, and refugia during low flow conditions. Overwintering habitat is limited along all sections of the North Milk River and the mainstem Milk River (RL&L, 1987). RL&L (1987) found that depth of water beneath the ice at all sampled overwintering sites to be less than one metre. The increased siltation may also affect spawning areas by causing high mortality, starvation of fry and slowed maturation (Jensen and Newcombe, 1996). Increased deposition also causes infilling of interstitial spaces in spawning gravels, limiting the available oxygen to the eggs. This may reduce the survival of the eggs and possibly reduce the survival of the young-of-the-year (Jensen & Newcombe, 1996). This could affect all species that lay eggs on coarse substrate (eastslope sculpin, stonecat, suckers, salmonids and mountain whitefish).

Changes in sediment transport and deposition could also affect the distribution and abundance of aquatic macrophytes and benthic invertebrates. This could affect feeding and spawning for species that rely on aquatic macrophytes (i.e. northern pike).

4.5.3.4 Changes to Habitat Quantity

Two potential increased diversion flow scenarios, Scen 1000 and Scen 1200, were modeled and discussed in **Section 3.6.4**. For both diversion scenarios, the combined estimated increases in channel widths are:

1. 20 to 30% (7 to 11m) for the North Milk River;
2. 10 to 20% (6 to 12m) for the Milk River (gravel) and;
3. 15 to 25% (14 to 23m) for the Milk River (sand).

Increased channel width in these reaches results in greater habitat available for fish, although productivity in the short-term (until channel conditions obtain equilibrium) will not increase unless habitat quality was equivalent. Net increases in habitat quantity will be greatest in the Milk River (sand) reach compared to the other two reaches. In the long-term increases in channel area would be expected to have positive effects on productivity.

4.5.4 Recommendations

For the proposed increase of flow diversion in the Milk River, further fisheries information should be obtained before and after the increased flows in order to compare fish assemblage and community structure. Data gaps in baseline fisheries information are described in **Section 4.5.2** and should be considered in order to gain a further understanding into the potential effects of increased diversion flows. ASRD Fish and Wildlife, DFO, the MRWCC, local universities and other relevant stakeholders should collaborate to further assess data gaps and direct research on the potential effects of increased diversion flows on selected species in the Milk River. In particular, these studies should focus on studying areas of bank erosion that have been identified.

In combination with bank protection strategies, it is also recommended that stakeholders evaluate potential options for habitat maintenance, enhancement and restoration work in the Milk River. There may be opportunities to mitigate the potential effects on fisheries resources and aquatic habitat or restoration may be possible in the Milk River system. For example, where sedimentation may be an issue in areas of overwintering structures such as bendway weirs, V-weirs and/or other log structures may be useful in maintaining habitat. In some areas, bank stability and riparian function may be increased by re-introducing cottonwood stands. Options may exist to open oxbows and allow access for spawning northern pike.

5.0 CONCLUSIONS

The following conclusions have been reached based on the work presented in the foregoing discussion.

1. An assessment undertaken of the hydrological effects of increasing the magnitude of the St. Mary River diversion discharge to the Milk River watershed from the existing 600 cfs (historical) to 1000 cfs (Scen. 1000) and to 1200 cfs (Scen. 1200) concluded that seasonal and peak flood discharges will increase. It is projected that there would be a significant increase over historical flows (recorded flows) along the entire length of the river within Canada in 20 % to 30% of the weeks. Flood discharges could increase by as much as 65% beyond present values (for the 50% event on the North Milk River) as a result of increased diversion discharges. The effects on flood frequencies diminish for greater return period events and for locations further downstream.

2. Geomorphological changes to the river area are expected to occur as a result of increased diversion discharges. An increase in the diversion discharge to 1000 cfs and to 1200 cfs is expected to have the following effects:

a) For the North Milk River, increased diversion discharges are expected to result in a mean river width increase from 20% to 30% (7 m to 11 m). In the intermediate time-frame (say several decades), the potential increase in slope is expected to be less than the 10% 'recorded' change that has occurred historically. No change in depth is anticipated, as the cobble/boulder bed is resistant to erosion.

b) For the Milk River Gravel Reach, increased diversion discharges could result in a mean river width increase from 10% to 20% (6 m to 12 m). No significant change in depth or slope is estimated since there weren't any 'recorded' changes in bed levels.

c) For the downstream Milk River Sand Bed reach, increased diversion discharges are expected to result in a mean river width increase from 15% to 25% (14 m to 23 m). The potential increase in depth is expected to be less than the 0.2 m 'recorded' increase. The impact on channel slope is expected to be less than the 10% 'recorded' decrease in slope.

3. The existing diversion to the Milk River has resulted in channel widening, increased channel sinuosity, and an increase in cut-off activity immediately following the initiation of the diversion (McLean and Beckstead, 1981, 1987). A comparison of previous river survey information from 1915 and 1979/1980 with the information from river channel cross-section surveys obtained for this study in 2007 indicates that the channel is still widening, some 90 years after the diversion was initiated.

4. Sediment resulting from erosion will be transported downstream. As the channel continuously and gradually adjusts towards a new dynamic equilibrium, sediment eroded from the upstream banks will be deposited to form point bars or deposited on the floodplain and in oxbow lakes during periods of overbank flooding. In-channel sediment will continue to move downstream and sediment deposited above bankfull level will be liberated when bank erosion occurs or cut-off channels are created.

5. Ice jam activity along the Milk River is a regular occurrence. It is known that the annual maximum flows in the river occur during the ice-affected period more than 20% of the time. The specific effects of the St. Mary Diversion during this period were not examined however.

6. It is not possible to make a general conclusion on future trends in the frequency of ice jam occurrence. All other factors being equal, increased flow rates increase the hydrodynamic forces acting on an ice cover. Where conditions are favourable for the development of a break-up ice jam accumulation, an increase in the magnitude-of-discharge rates are expected to result in higher water levels and thicker accumulations than for discharge rates of lesser magnitude. This suggests that future diversion activities will result in an incremental increase in the rate of erosion due to ice jam activity. Sufficient information is not available to provide estimates on current erosion rates or incremental changes in erosion rates due to diversion activity.
7. The vegetation types that occur within the three typical reaches of the North Milk and Milk rivers are listed in **Table 4.5**. **Table 4.6** lists rare plants along the North Milk River and Milk River. An increased diversion will result in the river channel widening by erosion processes. Riparian vegetation losses of up to about 10% from existing values may result from increased diversion discharges. The potential increased diversion could cause higher discharges, causing increased flooding, which potentially could lead to point bar formation as well as overbank flooding. If the conditions are right (flooding and seed dispersal), plains cottonwood regeneration is favoured.
8. Water quality analyses were hampered by a lack of continuous long-term water quality data for the North Milk and Milk Rivers. The recent short-term data available from MRWCC provided useful information to supplement the available data from provincial and federal sources. The following preliminary conclusions were drawn from the available data:
   a) Increased flows improves parameters, such as nitrogen and salts, and degrades other parameters, such as phosphorus.
   b) There appears to be a time-lag relationship between discharge and temperature, with discharge values peaking first.
   c) There is a positive relationship between discharge and TSS, particularly at the upstream site at the western crossing. The regression analysis indicates how TSS concentration increased as discharge increased. The lack of a strong correlation at the downstream site is likely due to the input of sediment from the badlands areas bordering the river during rainstorm events which are not directly related to the river flow.

d) There is a strong positive relationship between TSS and TP, as TP is mainly found in a particulate form associated with suspended sediments).

9. Data gaps have been identified, as listed below.
   a) Data on documented ice jam events is not sufficient to provide estimates on the potential impacts of diversion activities on the frequency of ice jam occurrence.
   b) On the North Milk River, there is a lack of historical water quality data; monitoring programs have been fragmented resulting in no continuous data set.
   c) There are spatial data gaps with respect to vegetation surveys along portions of the North Milk and Milk Rivers, as illustrated by the map on **Figure 4.9**.

6.0 RECOMMENDATIONS

6.1 Monitoring

The following sections provide recommendations regarding monitoring activities. The purposes of the monitoring are briefly discussed, whether to fill data gaps identified or to provide a better understanding of the effects of increased diversion discharges on the riparian habitat.

6.1.1 Monitoring of Erosion and Flow Characteristics

Long-term flow monitoring should be maintained at representative sites to aid in further assessment of flow characteristics and erosion. Flow monitoring is presently undertaken by Environment Canada and the US Geological Survey at long-term stations along the Milk River system.

The MRWCC should maintain a close working relationship with agencies investigating flows in the Milk River system, such as Environment Canada and Alberta Environment.

The MRWCC should investigate the potential for federal and provincial funding of monitoring programs.

Additional work should be undertaken to characterize historical river erosion patterns and erosion rates along the entire length of the North Milk and Milk rivers.

Information on existing or proposed facilities and infrastructure should be compared to historical and potential river bank locations to prioritize sites for investigation.

Erosion monitoring should be undertaken at locations that are representative of average conditions within each of the three characteristic river reaches. In addition, specific monitoring programs may target vulnerable sites identified by landowner responses or from information obtained through examination of historical river movement in relation to existing or proposed facilities and infrastructure.

6.1.2 Monitoring of Effects of Increased Diversion Discharges

6.1.2.1 Vegetation Monitoring

To fill in an identified data gap regarding baseline vegetation along the river, a vegetation monitoring program should be developed. The program should initially provide a vegetation map which can then be used to plan and locate the long-term sampling locations that will provide the data necessary to directly measure the effects of increased diversion flows.

6.1.2.2 Water Quality Monitoring

Water quality monitoring along the North Milk and Milk Rivers should be expanded spatially and temporally so that necessary baseline information can be obtained to facilitate assessment of the effects of increased diversion flows on water quality.

6.1.2.3 Fisheries Monitoring

For the proposed diversion, further fisheries information should be obtained prior to and following the diversion, in order to compare fish assemblage and community structure for selected species (sensitive species such as SARA listed species and sauger, sucker species and sport fish).

6.2 Erosion Mitigation

Where facilities or infrastructure are potentially threatened due to channel widening or shifting, a range of options including erosion protection, channel re-alignment and moving the facility to a new location are available. Evaluating erosion mitigation options on a site-by-site basis will ensure that the optimum solution for each site is obtained and that potential detrimental effects at neighbouring locations are minimized or eliminated.

6.2.1 Management Options

The following recommendations are made to provide advice on actions the MRWCC can consider to potentially mitigate effects of the exiting or potential future increased diversion flows and manage information concerning the Milk River.

1. It is recommended that the MRWCC should consider the following as management objectives to reduce the potential effects of increased diversion flows on the Milk River and its riparian ecosystem:
   a) Diversion flows should be controlled to the period following break-up on the North Milk and Milk rivers. By scheduling the diversion to commence after break-up, the effects of the increased flows in promoting channel switching through overland flows, and physically eroding the banks, may be effectively negated.
   b) It is recommended that a task force be established to investigate potential options for habitat enhancement and restoration work.
2. In addition to the monitoring recommendations provided in **Section 6.1**, it is recommended that other information and data gaps be filled. For example, to complete an examination of the role of the diversion during break-up, the available hydrometric records should be analyzed further to determine if the St. Mary River diversion was operating at the time peak discharges referenced in **Table 4.3** occurred.
3. It is recommended that MRWCC make provisions to obtain, organize and catalogue available relevant information concerning the Milk River and the effects of the St. Mary diversion on the river. AMEC has assembled information provided by Environment Canada regarding the Milk River. Included in that information is a set of images of the 1915 river survey plans. Environment Canada scanned a hard copy of the rolls of maps provided by Alberta Environment originally provided by Environment Canada. The images are not catalogued and in many cases there are duplicate images of each portion of the map (the map was often scanned in two directions along the top and bottom edge of the original). In some cases portions of the river are missing from the images. Correspondence from Environment Canada indicates they may have other paper copies of the maps and/or cross-sections. This should be investigated further; otherwise, this important historical resource may be lost.

Environment Canada also provided images of aerial photos (c. 1980). The location of individual photos is unknown. If the MRWCC deems this imagery to be useful, the flight lines should be obtained and the locations of the individual photos identified and geo-referenced. Other information available from Environment Canada includes ground photos and the sections surveyed and flow measurements from a 2007 flow measurement program.

7.0 CLOSURE

This report has been prepared for the exclusive use of Milk River Watershed Council Canada. This report is based on, and limited by, the interpretation of data, circumstances, and conditions available at the time of completion of the work as referenced throughout the report. It has been prepared in accordance with generally accepted engineering practices. No other warranty, express or implied, is made.

Yours truly,

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