IMPACTS OF FLOW AUGMENTATION ON RIVER CHANNEL PROCESSES AND RIPARIAN VEGETATION

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Abstract

The Little Bow River Project was implemented in 2003 and includes Alberta's newest dam. The Project involves tripling the diversion of water from the Highwood River to the Little Bow River and subsequently storing the water in the Twin Valley Reservoir. This MSc Thesis provided part of the environmental monitoring for that Project and particularly investigated the impacts of augmented flows on the river channel and riparian vegetation along the upper reach of the Little Bow River. An initial component of the long-term study was to determine the existing associations between fluvial geomorphic characteristics and riparian plant communities. Poplar (*Populus balsamifera* L.), willow (*Salix bebbiana* Sargent and *S. exigua* Nutt.) and wolf-willow (*Elaeagnus commutata* Bernh.) communities were located along the upper section of the river, where the channel had a steeper gradient and was narrower and more sinuous. Cattail (*Typha latifolia* L.) and grass (grasses and sedges) communities were generally located along the lower section of the river that was shallower in gradient, wider and straighter. Plant community distribution also reflected impacts from cattle grazing. Initial channel and vegetation responses in the first two years following the increase in flow augmentation were slight and included bank slumping, sediment scour and inundation of flooded zones. The initial responses are consistent with the primary prediction of channel widening and this will probably be associated with some changes in the adjacent riparian plant communities.

Acknowledgements

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CHAPTER 1 - INTRODUCTION: UNDERSTANDING FLOW AUGMENTATION AND RIPARIAN VEGETATION ALONG THE UPPER LITTLE BOW RIVER

1.1 Thesis Structure

This thesis is composed of four chapters including an introduction and three body chapters. Chapter 1, “Understanding flow augmentation and riparian vegetation along the upper Little Bow River”, provides background and basic concepts of river science. It reviews the current literature on flow augmentation, provides background on fluvial geomorphology and information about the upper Little Bow River and the unique opportunity to study the effects of flow augmentation.

Chapter 2, “Hydrogeomorphic associations of riparian plant communities along the upper Little Bow River”, provides a stand-alone research paper describing the associations between different physical parameters and the five dominant riparian plant communities along the upper Little Bow River. This study also relates these associations to current management practices.

Chapter 3, “Initial channel and vegetation responses along the upper Little Bow River”, provides results and discussion on the initial channel and vegetation responses following the implementation of the increased flow regime. This chapter is intended to provide a baseline for follow-up research.

Chapter 4, “Predicted future responses along the upper Little Bow River”, is a conceptual analysis that combines previous findings, general predictions and observations from

Chapter 2 and 3 to predict future channel and vegetation responses. Additionally Appendix A contains a figure illustrating the original slope along the upper Little Bow River and Appendix B includes figures that expand on the findings from sediment cores taken along the upper Little Bow River.

1.2 Introduction

1.2.1 Flow augmentation

Rivers provide freshwater resources for irrigation and industrial and domestic needs and have been extensively dammed and diverted for human use (Postel and Richter 2003). Water storage and transport are primary components of this water management. Water transport changes the flow regime and alters river ecosystems that depend on the natural flow pattern.

While flow diversion removes water from a system and often degrades river and floodplain ecosystems, the opposite perturbation, flow augmentation, is less common and the environmental consequences are poorly understood (Stromberg and Patten 1992). Flow augmentation can alter the seasonal pattern of a river's flow regime and can change stream flow pattern from intermittent to perennial. It can also stabilize the natural variation between annual flow patterns.

There has been limited research investigating the consequences of flow augmentation. Some scientific studies have utilized a temporal approach and analyzed impacts following years or decades of initial changes to flow regime using aerial photo interpretation. Others have used a spatial assessment and compared augmented and non-augmented reaches. The common result in these studies was an increase in channel width (Bradley and Smith 1984, Church 1995, Dominick and O'Neill 1998, Kellerhals et al. 1979). However, some channels also became deeper and straighter following flow augmentation (Stromberg and Patten 1992). These channel changes also influence density, distribution and growth response of riparian vegetation (Stromberg and Patten 1992). Species composition may adapt to include more flood tolerant species (Henszey et al. 1991) and the riparian zone may expand (Stromberg 1993). Alterations to flow not only change channel characteristics but also alter the ecological nature of the riparian zone.

1.2.2 Fluvial Geomorphology

A river channel represents a function of the water flow, the quantity and character of the sediment moving through the reach, and the composition of materials (including the substrate and vegetation) that make up the banks along the channel (Leopold 1994). Channel morphology is defined by the disposition of these components and altered by entrainment, transport and deposition of sediment during moderate and peak flow events (Richards 1982). The geomorphic effectiveness, expressed in terms of sediment transported and modification of the channel surface, of a specific discharge involves the frequency of occurrence and the magnitude (Wolman and Miller 1960). The channel-forming discharge is thus a product of stream competence and flow exceedance (Rood et al. 2002). Competence is the capacity to erode, suspend and transport sediments and exceedance relates to the frequency of occurrence. High flows are very competent, however they are rare and therefore their net impact on channel form is limited.

Conversely, low flows occur often but have low competence and also have limited impact on channel form. Moderate flows balance competence and frequency and their cumulative impact becomes the dominant channel-forming discharge (Leopold 1994, Rood et al. 2002). Channel-forming discharge is also referred to as bankfull discharge (Leopold 1994) and is contained within the channel capacity without over-topping the banks.

The natural channel migrates laterally by erosion of one bank and deposition along the opposite bank to maintain equilibrium between erosion and deposition (Leopold 1994). These sediment dynamics are a function of the resistance of the bed and bank materials. This process promotes the channel to laterally migrate across the valley while maintaining a relatively consistent width. The channel and thalweg, or thread of deepest water, tends to wander in a sinuous course with a wavelength that relates to channel width (Leopold 1994).

Channel pattern can vary within and among streams and is a measure of a stream's planimetric form. Streams are classified as straight, meandering, braided or anastomosing, and are distinguished on the basis of channel multiplicity and sinuosity (Gordon et al. 2004). A meandering stream maintains a single channel that has definite geometric shape. Sinuosity is a measure of curviness and the sinuosity index (SI) is calculated by dividing the river channel length (thalweg) by river valley length. A straight reach would have a SI of 1 and an intricately meandering reach would have a SI of up to about 4 (Gordon et al. 2004).

Classification systems have been established based on particular combinations of channel slope (gradient), bed material, ratio of width and depth, amount or degree of meandering as defined by sinuosity, and degree of confinement or constraint to lateral movement (Leopold 1994). Different combinations of parameters are associated to different local environments. These hydrogeomorphic parameters or characteristics represent the physical conditions relative to water and land (especially sediments).

1.2.3 Riparian Vegetation

Riparian zones provide the link between terrestrial and aquatic ecosystems (Malanson 1993); they are transitional areas that are regularly influenced by fresh water (Naiman et al. 2005). In semi-arid ecoregions these zones are easily identified as the green zone that surrounds the stream network often in contrast to the dryer upland environment. The semi-arid regions of western North America are characterized by relatively low annual rainfall and generally lack native trees except in riparian areas (Rood and Mahoney 1995). Riparian ecosystems in these regions are dependent on supplemental water, from the alluvial aquifer (Pattern 1998) which provides ground water storage (Newson 1994).

Riparian woodlands provide valuable aesthetic, recreational and environmental resources (Rood and Mahoney 1995) and also stabilize stream banks, trap sediment, improve water quality and help modulate hydrologic processes (Patten 1998). Riparian ecosystems influence many hydrologic and geomorphic conditions; they are also a product of these conditions and are controlled by interacting hydrologic and geomorphic processes. The distribution of riparian vegetation is partially determined by flood processes and landforms that are shaped by floods. It is particularly sensitive to the variation in the hydrological cycle and serves as a good indicator of environmental change (Nilsson and Berggren 2000).

Riparian plant species can be described as either obligate riparian or facultative riparian plants. Obligate riparian species such as willows (*Salix sp.*) and cottonwoods (*Populus sp.*) are generally phreatophytes and are restricted to floodplains and especially dependant on groundwater as a moisture source (Busch et al. 1992, Rood et al. 2003c). Facultative riparian species are not dependent upon the water table even though these plants prosper within the riparian zone due to increased water availability. Examples along the Little Bow River include wolf-willow (*Elaeagnus commutata*) and other shrubs, as well as some grass species.

River valley cottonwoods obtain moisture from the riparian ground water table (Busch et al. 1992, Rood et al. 2003a, Rood et al. 2003c), a saturated zone that extends more or less horizontally from the river and fluctuates with the river stage (level or height of water) (Rood et al. 1995). Cottonwoods are adapted to natural variations in the level of the water table caused by seasonal fluctuations in flow. Cottonwoods are ecologically valued trees and the only native tree occurring in Alberta's semi-arid prairie landscape. Cottonwoods and poplars require particular hydrologic and geomorphic conditions for seedling recruitment, establishment and survival (Mahoney and Rood 1998).

Riparian systems occur along spatial and temporal gradients (Patten 1998). Vegetation transitions can occur along the longitudinal stream corridor as ecoregions and other biophysical variables change (Samuelson and Rood 2004). Distribution may be related to geographic elevation, climate and precipitation patterns. The distribution of plant communities can also extend horizontally from the stream and reflect natural elevation zones. For example, inundation-tolerant species occupy the lower elevations adjacent to the stream while intolerant species are located farther from the stream. Amlin and Rood (2001) established that sandbar willow (*Salix exigua*) typically occurs in the lowest zone, closest to the stream and is especially flood tolerant whereas cottonwoods occur at higher positions along the floodplain.

Wetland plants possess various characteristics that enable them to survive and function in intermittently flooded wetland environments (Li et al. 2004). Cattail (*Typha latifolia*) is an emergent plant that is established along the fringe of some streams. These wetland species are morphologically and physiologically adapted to tolerate saturated soils (Wetzel 1993). Cattails are competitive dominants under a variety of hydrologic regimes, especially when nutrients are abundant such as in agricultural landscapes (Kercher and Zedler 2004).

1.3 Study Region

A rare study opportunity exists along the Little Bow River in southern Alberta, where flow has been augmented since the 1890s (NRCB/CEAA 1998). At that time the Little Bow Canal in the Town of High River was excavated to divert water from the Highwood River into the Little Bow River (Figure 1-1). The Little Bow River formerly had an intermittent flow regime and became perennial following the augmentation from the Highwood River (Rood et al. 2002). This change in flow regime promoted the establishment of riparian trees and shrubs. Currently there are scattered riparian woodlands along the upper reach consisting of a few willows, balsam poplar and occasionally, trembling aspen (Rood et al. 2002).

Increased irrigation from the Little Bow River has increased demand for diversion from the Highwood River. The Highwood River is the primary spawning tributary for the Bow River trout fishery and retaining favourable flow patterns along the Highwood River is vital in maintaining that fishery (NRCB/CEAA 1998). To meet these two demands, the Little Bow/Highwood Rivers Project proposal was implemented. This included expansion of the Little Bow Canal in the Town of High River and construction of the new Twin Valley Dam on the Little Bow River downstream from the inflow of Mosquito Creek (Figure 1-1). The Highwood Diversion Plan includes tripling the flow diverted from the Highwood River into the Little Bow River during the high spring flows. These flows would then be stored in the new reservoir for release during the irrigation season (NRCB/CEAA 1998). This would avoid increasing flow diversion from the Highwood River through the irrigation season that would result in reduced flows along the Highwood River and increased water temperatures.

Canal and dam construction was completed in 2003 and subsequent spring diversion has increased from about 2.8 m^3/s to about 8.5 m^3/s (NRCB/CEAA 1998). Consequently, the upper Little Bow River now conveys three times the discharge it had during the spring months prior to the project. The reach impacted by the change in flow regime begins downstream from the Little Bow Canal and continues to the upper end of the Twin Valley reservoir. There are no other major tributaries along this reach that contribute to flow, providing a unique opportunity to study the river system response to specific hydrologic alteration and also to utilize flow regulation as a tool for environmental conservation. It is anticipated that the channel will accommodate the new flow regime and establish a new dynamic equilibrium but the duration for change is uncertain (Rood et al. 2002).

To predict riparian vegetation response to the changing flow regime and river channel, we must understand the processes underlying riparian vegetation distribution and pattern. Subsequently, investigating hydrogeomorphic parameters, the physical conditions imposed by water and land, associated with different plant communities (Hupp and Osterkamp 1996). An understanding of the current pattern of vegetation distribution along the upper Little Bow River in conjunction with analysis of changing channel cross-sections will enable predictions about the future conditions of the study reach. Continued monitoring of geomorphic and ecologic responses along the upper Little Bow River will provide scientific understanding and facilitate adaptive flow management intended for environmental conservation.

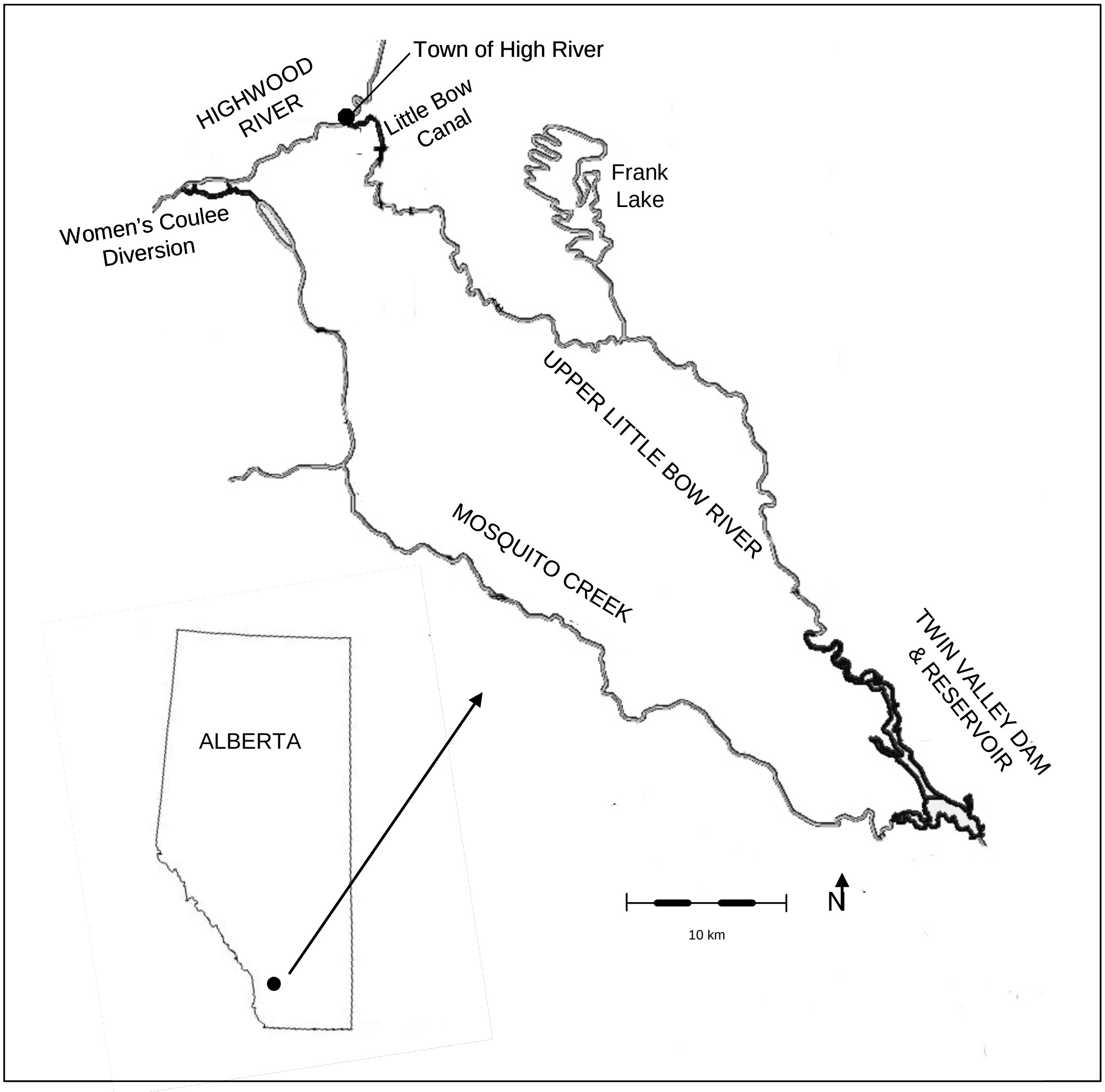

Figure 1-1 Map of the upper Little Bow River in southern Alberta, from the Highwood River to the Twin Valley Dam and Reservoir and the adjacent Mosquito Creek; including the two Highwood River diversions, Women's Coulee and the Little Bow Canal.

CHAPTER 2 - HYDROGEOMORPHIC ASSOCIATIONS OF RIPARIAN PLANT COMMUNITIES ALONG THE UPPER LITTLE BOW RIVER

2.1 Introduction

Water management is a primary concern in southern Alberta where river damming and water diversion have proceeded for a century (NRCB/CEAA 1998). This region is the national focus for irrigation agriculture in Canada and associated with this, almost all of the rivers in the South Saskatchewan River Basin have been dammed (Alberta Environment 2004). In most cases river damming has been accompanied by offstream water diversion and consequently most river reaches have had instream flows reduced. This has harmed aquatic and riparian ecosystems with the severity generally correlated with the extent of diversion (Golder 2003).

Changes in the instream flow regime can modify riparian (streamside) composition and processes, often leading to the degradation of the riparian ecosystem. In order to conserve remaining river reaches and restore impacted reaches we need a better understanding of the physical and biological consequences of altered river flows (Poff et al. 1997). A required study for this understanding includes investigation of the principal physical and biological processes and their associations to provide a foundation for analyzing the consequences of instream flow alteration.

While river flows are generally reduced following river damming an unusual opportunity with an opposite pattern exists with the Little Bow River in southwestern Alberta. Rather than experiencing reduced flows, instream flows along this river have been augmented (increased) as this natural river channel is used to convey irrigation water from the Highwood River to the region of irrigation that occurs downstream. This unusual system creates an opportunity to investigate the impact of augmented flows on the river channel and on riparian vegetation. Associated with this intriguing study system, an initial step is to analyze associations between instream flow patterns, river channel conditions and riparian plant communities. This study will thus categorize the existing physical and biological conditions associated with different channel patterns. Following this analysis, an understanding of the relationships between riparian plant communities and their physical habitats may allow predictive capabilities relative to prospective future conditions along a successional pathway (Hudak and Ketcheson 1991).

The Little Bow River is located in the semi-arid prairie ecoregion of southern Alberta, which is characterized by low annual rainfall. Flow has been diverted from the Highwood River to the Little Bow River since 1898 (NRCB/CEAA 1998, Golder Associates 1995). Prior to diversion the Little Bow River had an intermittent flow regime and did not naturally support riparian cottonwoods, as evidenced by the woodland survey of Dawson and McConnell (1884). Accompanying demand of water for domestic needs and for irrigation, the Little Bow Canal was constructed at the Town of High River to transport water from the Highwood River to the Little Bow River (NRCB/CEAA 1998, Golder Associates 1995). Following this flow augmentation, the flow regime of the Little Bow River became perennial resulting in the establishment of riparian shrubs and trees through the twentieth century (Rood et al. 2002). The upper Little Bow River is an alluvial, losing system where channel form is predominantly controlled by stream flow and adjacent groundwater is recharged by the stream (Gordon et al. 2004). Outside of the riparian zone, regional vegetation is primarily limited by precipitation and temperature.

Poplars and cottonwoods (*Populus* species) are the only native riparian trees on the floodplains of perennial streams within the semi-arid ecosystems of southern Alberta (Rood and Mahoney 1991, Floate 2003). These trees require the supplemental ground-water provided by the adjacent stream and consequently the health and reproduction of these riparian cottonwoods are tightly coordinated with patterns of instream flows (Rood et al. 2003a). Poplars in this region are generally limited to river floodplains where a dependable source of water is available (Rood and Mahoney 1990). As phreatophytes, they are dependent on a permanent water table (Busch et al. 1992, Mahoney and Rood 1991).

Increasing demand for irrigation along the Little Bow River resulted in the Little Bow/Highwood Rivers Project that involved an increase in the capacity of the Little Bow Canal, a change in the pattern of instream flow regulation and the construction of the Twin Valley Dam and Reservoir (NRCB/CEAA 1998). This Dam is located downstream from the junction of the Little Bow River and Mosquito Creek and was completed in 2003. Flow operations for the Project included increasing the water diverted from the Highwood River during the high spring flow period and storing the water in the Twin Valley Reservoir (NRCB/CEAA 1998). The stored water will subsequently be released for use through the irrigation season which extends through the summer (Rood et al. 2002). The upper reach of the Little Bow River, the zone between the Little Bow Canal and the Twin Valley Reservoir, will convey spring flow of approximately 8.5 m^3/s, a three-fold increase from the previous diversion and bankfull discharge (Q_{bf}) of 2.85 m^3/s (MSA 2001).

An investigation of the present channel conditions and distribution of riparian vegetation along the study reach was used to provide a foundation to predict the changes that may follow the increase in flow augmentation. Thus, in this study we investigated associations between hydrogeomorphic characteristics and different riparian plant communities along the upper Little Bow River. Hydrogeomorphic associations represent the physical conditions relative to water and land (especially sediments) and largely define riparian plant species distributions (Hupp and Osterkamp 1996). The present study further considered the context of land management and particularly influences of livestock.

The physical characteristics associated with hydrogeomorphic parameters that were used in this study included longitudinal gradient (channel slope), bankfull channel width and sinuosity. These channel parameters are interrelated (Leopold 1994) and variations of these parameters create different local environments. Baker (1989) recognized that drainage basin variables such as hydrology, sedimentology and morphology of the basin have the principal influence on vegetation composition. These variables directly relate to channel characteristics such as channel width, gradient, sinuosity and meander length, which have been correlated with vegetation transitions. Different characteristics have been documented to have varying degrees of influence on vegetation distribution. Shifts in stream gradient can have profound effects on the presence and character of fluvial landforms and the supported bottomland vegetation (Hupp 1982).

The physical conditions of the study reach reflect a historic bankfull discharge (Q_{bf}) of about 2.85 m^3/s (Rood et al. 2002), although this conveyance capacity increases progressively downstream as surface flow contributes to river discharge especially during snowmelt and heavy spring rains. Vannote et al. (1980) describes this dominant longitudinal physical variation as enabling a continuous gradient of ecological conditions along a river resulting in a continuum of aquatic or riparian communities.

2.2 Materials and Methods

With funding from Alberta Transportation, false-color infra-red aerial photographs of the upper Little Bow River at a scale of 1:10,000 were acquired in May 2001. These photos show river conditions of the full diversion before 2003 with discharges (Q) between 2.6 and 2.9 m^3/s. Mack, Slack and Associates (MSA) ortho-rectified these photos to provide true geometric-scale photographs for mapping and environmental assessment.

The orthophotos were also calibrated with topographic map overlays. The resulting orthophoto mosaic was compiled at a scale of 1:2,500 with topographic contours at 1 m vertical intervals and stations designated at 100 m intervals along the river length (Figure 2-1). These ortho-rectified aerial photos (‘orthophotos’) provided the basis for measurements of channel characteristics and provided base maps for plotting the distributions of riparian plant communities.

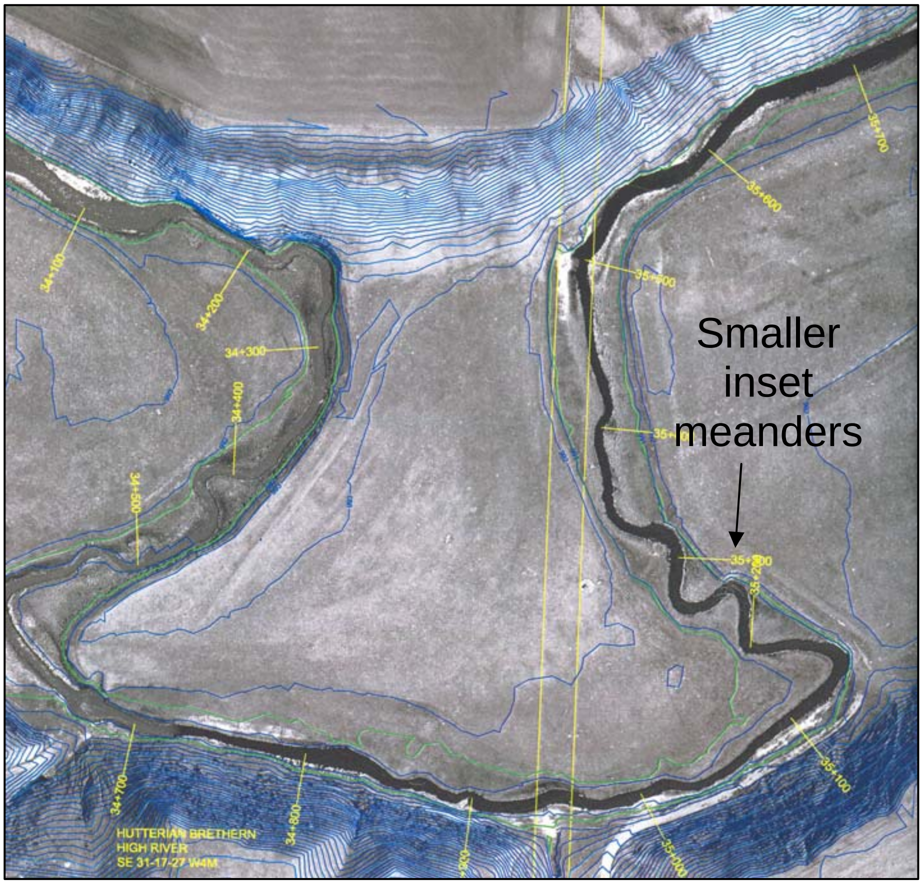

Figure 2-1 Ortho-rectified aerial photograph with topographic contours and river stations (100 m intervals) along the upper Little Bow River showing inset meanders within a larger meander (position 34.1 km (left) to 35.7 km (right)).

2.2.1 Longitudinal Profile

The orthophotos with topographic contours provided elevations along the 57.5 km reach of the upper Little Bow River from the inflow of the Little Bow Canal to the upstream end of the Twin Valley Reservoir behind the new Twin Valley Dam. To determine the longitudinal profile, the positions of the 1 m contours were recorded to the nearest 50 m. The longitudinal slope (gradient) was then derived from the plot of this longitudinal profile.

2.2.2 Channel Width

The aerial photographs were taken at discharges slightly below bankfull discharge (Q_{bf}) and therefore the wetted widths were considered to represent the bankfull channel widths. The apparent wetted width was measured at 100 m intervals along the orthophoto mosaic for the 57.5 km reach of the upper Little Bow River.

2.2.3 Sinuosity Index

Sinuosity provides a measure of river curvature. The most commonly used measure is sinuosity index (SI) which is calculated as the ratio of river channel distance to river valley distance. The SI provides a sinuosity metric with the length of the measurement interval influencing the values. The upper Little Bow River is somewhat unusual since it includes both large meanders, that probably reflect a flow regime prior to 1900, and inset meanders that are consistent with the recent artificial flow pattern of the late twentieth century (Figure 2-1). Due to this complex channel form, SI was calculated at two different scales to reflect both meander forms.

The segment length used for each SI scale was two meander wavelengths (i.e. 2 inset meanders or 2 large meanders). This length was considered appropriate because it was sufficient to determine the sinuosity of different segments along the reach and short enough to discriminate the two meander scales. Two methods were used to calculate the reach length for the small meander scale. Leopold (1994) concluded that one wavelength typically averages 11 channel widths and is usually between 10 to14 channel widths. The average channel width for the upper Little Bow River was determined to be 18.7 m. One wavelength was consequently estimated as 18.7 m x 11 = 205.7 m. A segment length of 411.4 m was determined to represent two wavelengths. The second, independent method measured wavelengths for 10 randomly chosen inset meanders and produced a mean of 205 m ± 90 m (Std. Dev.). These two approaches provide very consistent values and consequently the two wavelength segment length used to calculate SI for the smaller inset meanders was 400 m.

The large meanders were probably created by an ancient and much larger flow regime and consequently current bank width does not provide a basis for determining meander wavelength for segment length. The average wavelength calculated from 10 random meanders was 1050 m ± 443 m. Consequently, the two wavelength segment length used to determine SI for the large meanders was 2000 m.

For both meander scales the 400 m and 2000 m river segments were determined from the 100 m stations on the orthophotos. The corresponding valley distance or straight line distance was then measured and the river distance was divided by valley distance to produce the SI.

2.2.4 Vegetation mapping

Five dominant plant communities were recognized along the upper Little Bow River. These different plant communities were initially identified by aerial photo interpretation and then verified by low elevation aerial observation and a complete field inventory by boat. The plant community types were then mapped on the orthophotos along the study reach. For each 100 m position the most prominent plant community was recorded for each side of the bank. The number of occurrences of each plant community was then compiled for a series of 5 consecutive positions into proportions of the total frequency of occurrence along the 57.5 km of river.

2.2.5 Physical conditions and plant communities

A χ^2 (Chi-square goodness-of-fit) analysis (Microsoft Excel 2003) was used to examine associations between different plant communities and the different channel characteristics. At each 100 m position along the river, the value for each particular channel characteristic was determined, along with the corresponding plant community type. The number of positions used in the comparison was twice the positional distance because plant communities were classified for both sides of the river.

For longitudinal analysis, the study reach was separated into three equal segments referred to as the upper, middle and lower sections of the upper Little Bow River. River slope ranged from 0.01 to 0.5 % and was separated into six bin ranges. Channel width was separated into four bin ranges between 1 and 60 m. The small and large meander scales were separated into eight and four SI ranges respectfully. Bins were designated to provide groups that contained similar numbers of positions within each range, as indicated in the table of categories (Tables 2-2 to 2-6) in the Results section.

A χ^2 analysis was used to investigate the expected distribution of the different plant community types across each range for each characteristic. The expected random values for each range of channel characteristics was derived by the total number of occurrences of the different plant community types multiplied by the proportion of positions within each range.

2.2.6 Land management

To determine if different land management regimes reflected plant community distribution, the study reach was separated into different sections delineated by fence lines crossing the river. The positions of river boundaries for each property were arranged as longitudinal river distance. The number of occurrences per plant community type was recorded for each riparian land parcel and used to calculate the frequency of each plant community, for both left and right banks. The average bankfull channel width was also calculated for each parcel of land.

2.3 Results

2.3.1 Channel characteristics and riparian vegetation

The physical parameters measured in this study were the longitudinal gradient, channel width and sinuosity. The upper reach of the Little Bow River extends from 1032 to 967 m above sea level (Figure 2-2), extending from the Rocky Mountain foothills through the western prairies. It has a progressively diminishing gradient that deviated slightly from a straight line and closely fitted a quadratic equation (Figure 2-2). Specific segments were slightly steeper or shallower than the overall profile. The gradient of 100 m intervals (Figure 2-3) ranged from 0.05 to 0.5 % and averaged 0.15 % or a tan slope of 0.08˚.

The channel width reflects a bankfull (Q_{bf}) or channel-forming discharge (Q_{cf}) of approximately 2.85 m^3/s (Rood et al. 2002). The bankfull channel width (Figure 2-4) was locally variable from less than 10 m wide to greater than 45 m wide. The width averaged 18.7 m and increased by about 0.23 m/km along the study reach. Some wider channel segments near the lower end of the study reach are pond areas.

The Little Bow River has a complex meandering pattern that includes a combination of large meanders (Figure 2-5) that remain from a flow regime prior to 1900 and inset meanders that reflect the artificial flow regime of the twentieth century (Figure 2-6). Sinuosity varied along the 57.5 km study reach with a range of straight (SI about 1.2) sections and very sinuous (SI > 2.0) sections. The large and small sinuosity patterns were similar in profile and the most difference occurred in the lower section of the study reach. The sinuosity index was proportionally low or straight for the small meander scale whereas the large meanders were more evenly distributed between straight and very sinuous reaches.

The running average of bank width over twenty-one positions (position = 100 m intervals) was plotted with the inverse running average of slope over seven positions. Twenty-one positions for bank width and seven positions for slope were used for the comparison because they created smoother profiles. Some correspondence between bank width and the inverse slope was evident (Figure 2-7).

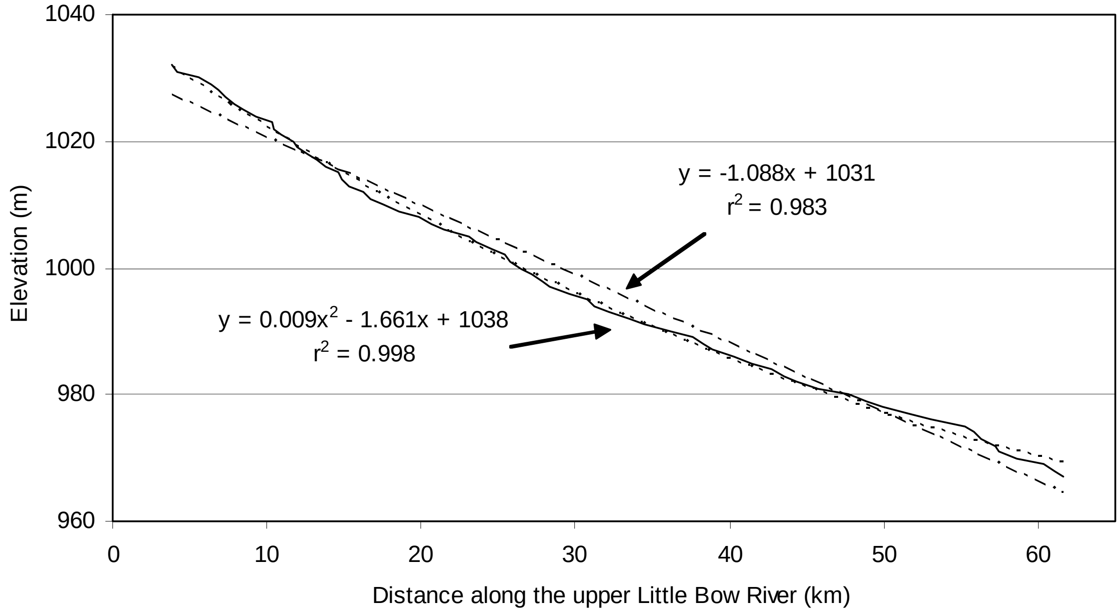

Figure 2-2 The longitudinal profile of the upper Little Bow River.

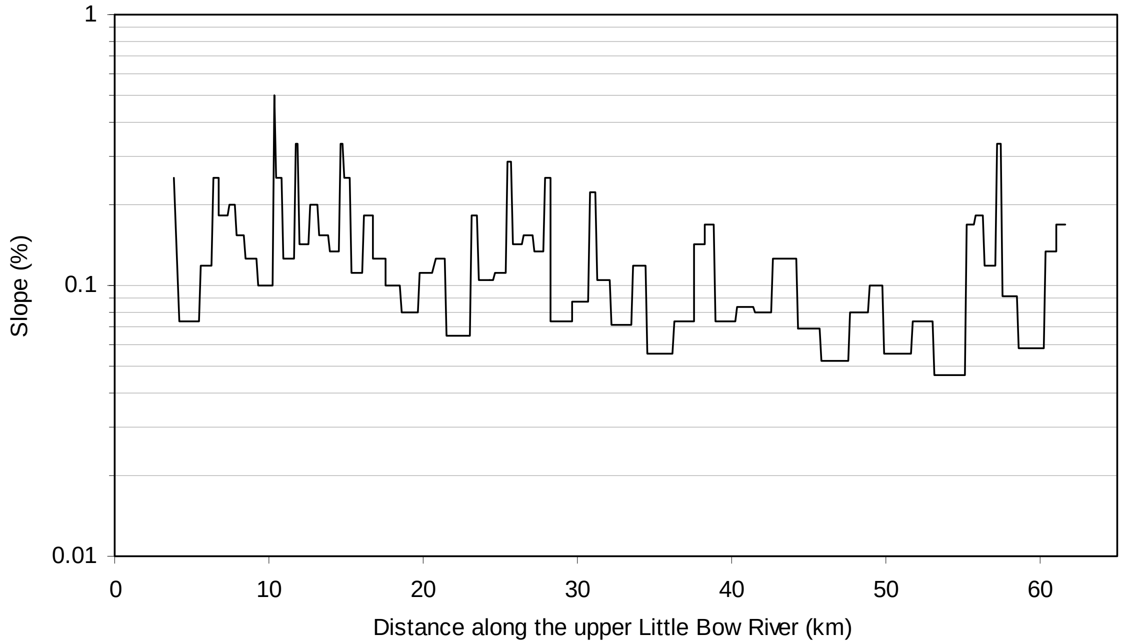

Figure 2-3 Average slope (log) for 100 m intervals along the upper Little Bow River. The average percent slope is 0.15 % or a tan slope of 0.08˚.

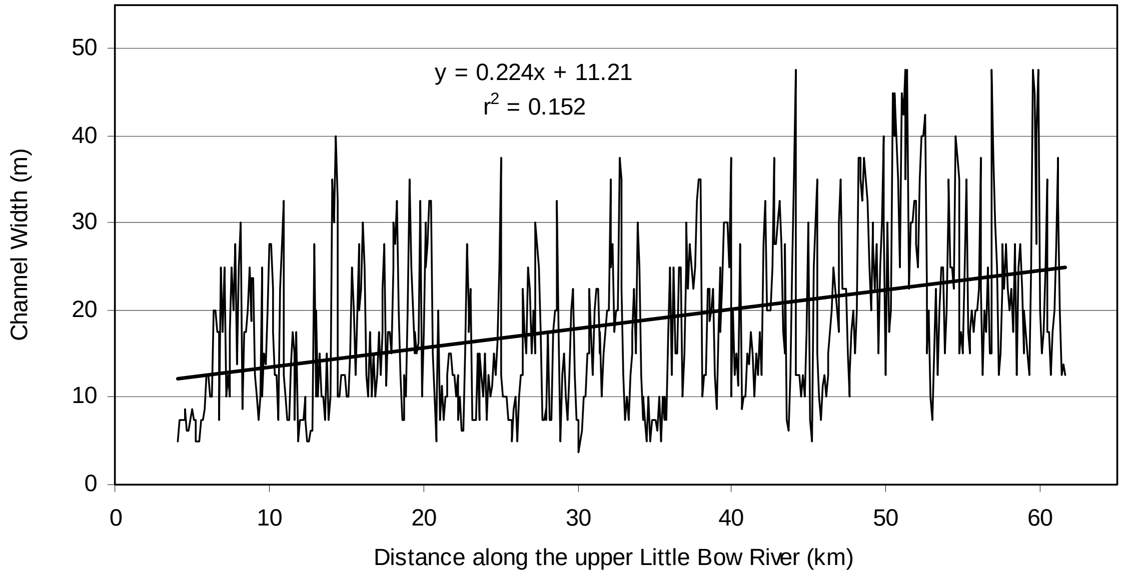

Figure 2-4 Bankfull channel width measured at 100 m intervals along the upper Little Bow River.

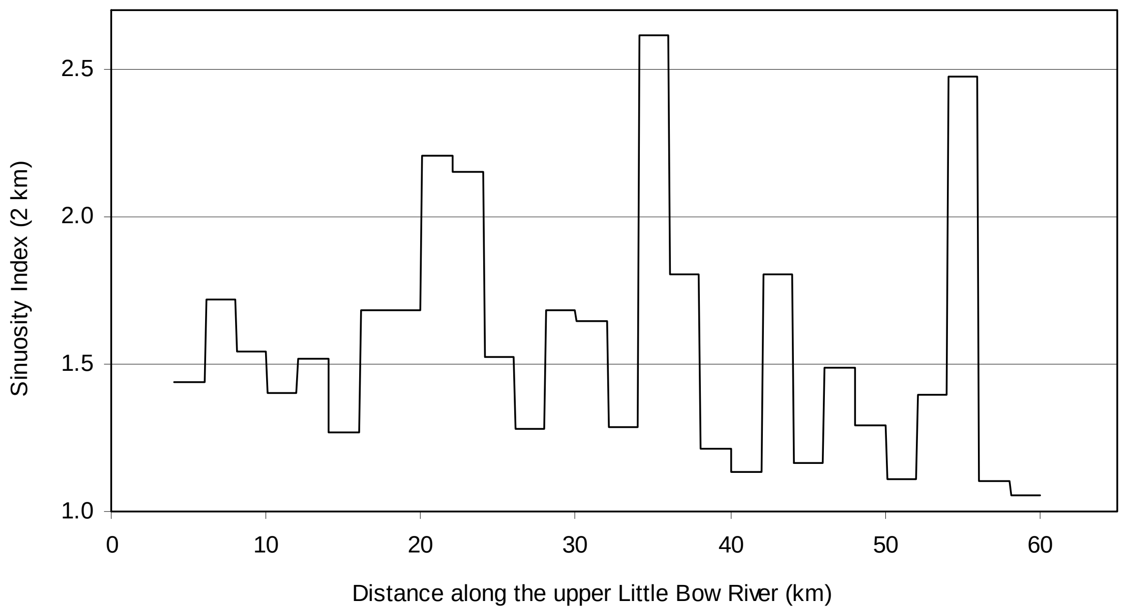

Figure 2-5 Sinuosity index measured at 2000 m (2 km) intervals for large meanders along the upper Little Bow River.

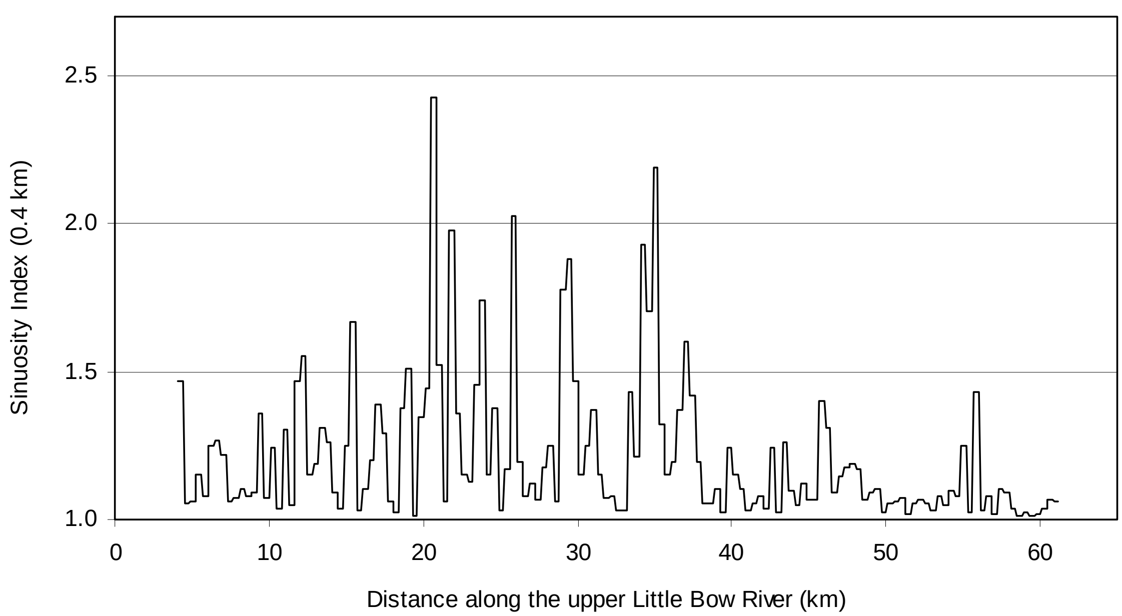

Figure 2-6 Sinuosity index measured at 400 m (0.4 km) intervals for small meanders along the upper Little Bow River.

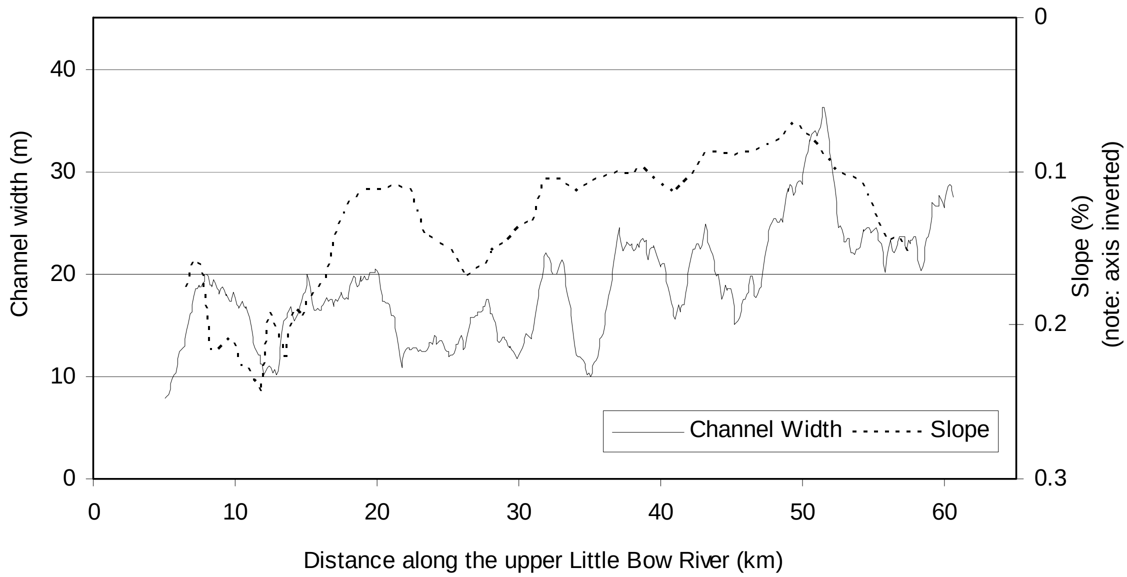

Figure 2-7 Running average of channel width over 21 positions (positions = 100 m intervals) and slope over 7 positions (positions = 100 m intervals) along the upper Little Bow River. Note: The axis for the slope profile has been inverted to allow for visual coordination.

Five dominant plant community types along the upper Little Bow River were identified based on field inventory and aerial observation. Plant communities were designated by dominant species. The obligate riparian tree group was dominated by balsam poplar (*Populus balsamifera* L.) but also included trembling aspen (*Populus tremuloides* Michx.). Two shrub groups were distinguished, containing either obligate or facultative riparian species. The obligate riparian shrubs were the willow species *Salix exigua* Nutt. and *Salix bebbiana* Sarg., and the facultative riparian shrub was primarily wolf-willow (*Elaeagnus commutata* Bernh.) but also included wild rose (*Rosa woodsii* Lindl.), saskatoon (*Amelanchier alnifolia* Nutt.), choke cherry (*Prunus virginiana* L.), western snowberry (*Symphoricarpos occidentalis*) and sage (*Artemisia* sp.). The fourth community was the common cattail (*Typha latifolia* L.), an emergent plant. The fifth group was the graminoids and represented grass-like species, particularly grasses and sedges (*Carex* sp.).

The poplar, willow, wolf-willow, cattail and graminoid communities were all progressively distributed along the study reach (Figure 2-8). The poplar community was predominantly located at the upstream end of the study reach with a few occurrences downstream. It was the least common community along the study reach and dominated at less than 2 % of the positions assessed (Table 2-1). The willow communities along the upper Little Bow River followed a similar pattern as the poplars and were also primarily located in the upstream end of the study reach with some occurrences extending downstream (Figure 2-8). Only 7 % willow (Table 2-1) occurred along the study positions of the upper Little Bow River. Wolf-willow was generally located along the upper half of the study reach with a small proportion of occurrences extending downstream. Wolf-willow constituted 15 % (Table 2-1) of the total positions examined. The cattail community was more prominent through the middle and lower portions of the study reach. Although it extended upstream, it did not overlap with the poplar communities. This emergent community was the second most abundant, comprising 22 % (Table 2-1) of all the positions. Grasses and sedges are the predominant vegetation cover along the upper Little Bow River occurring 53 % (Table 2-1) of the total positions analysed. The graminoids were dispersed along the entire study reach (Figure 2-8).

Table 2-1 Percent occurrence of five plant communities along the upper Little Bow River for 100 m intervals along both sides of the bank (n = 1146).

Poplar	Willow	Wolf-willow	Cattail	Grass
1.66%	7.07%	15.45%	22.43%	53.40%

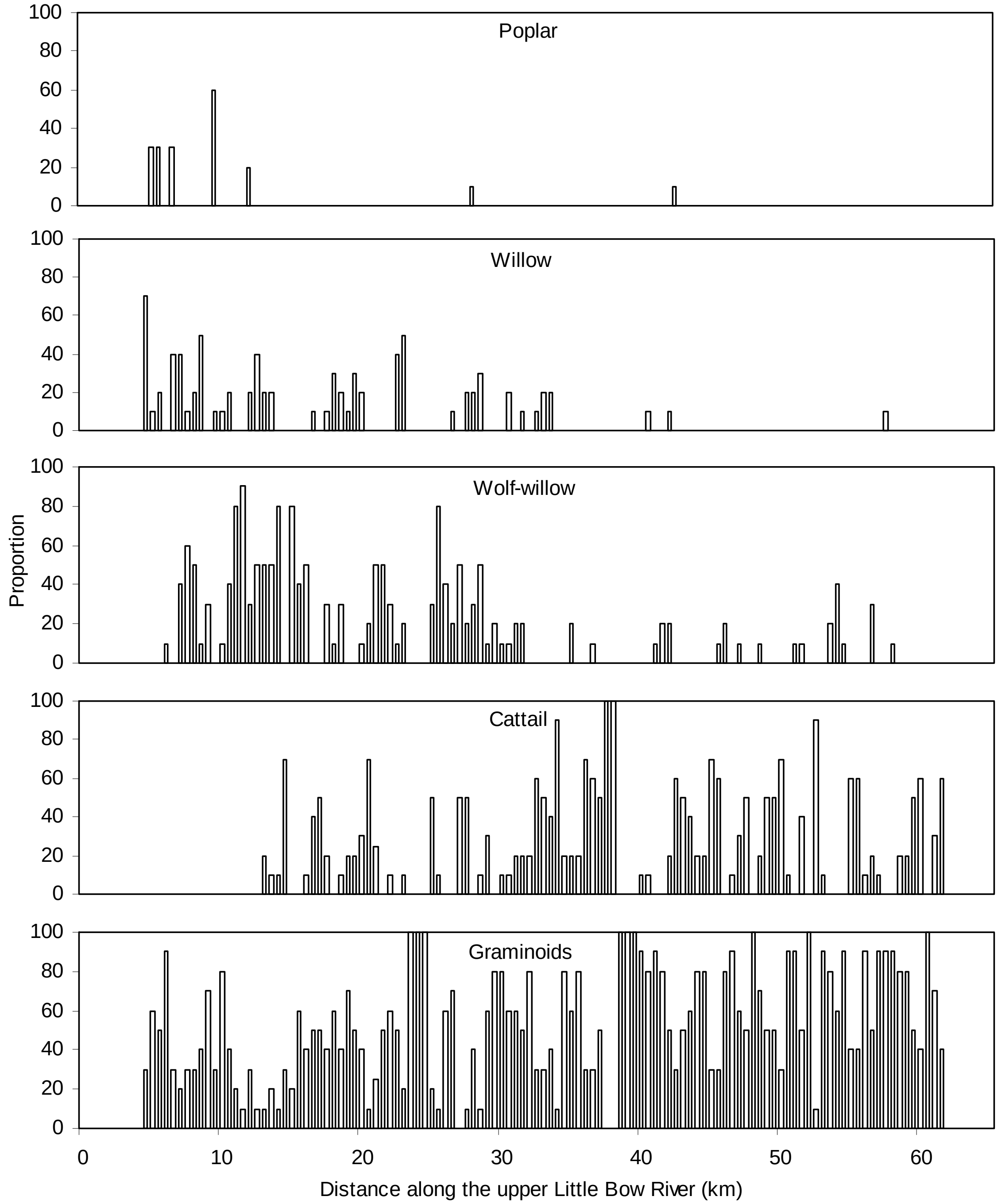

Figure 2-8 Plant community distribution along the upper Little Bow River. At each 100 m interval the most prominent plant community was recorded for each side of the bank. The number of occurrences of each plant community within 500 m intervals was then calculated along 57.5 km of river.

2.3.2 Physical conditions and plant communities

Distribution of the five different plant communities along the upper Little Bow River was compared with each of the physical characteristics. Different variations of each of the channel characteristics defined the distribution of each plant community. Each of the five plant communities had a different distribution along the longitudinal profile and was either distributed evenly or unevenly throughout different sinuosities, channel slopes and channel widths.

Distribution of each plant community was not uniform between the upper, middle and lower sections the study reach according to a χ^2 analysis (Table 2-2). The poplar communities were predominantly located in the upper section. The majority of the willow and wolf-willow communities were also located in the upper reach. Cattails and grasses, the non-woody communities, were located primarily in the middle and lower sections. The poplar, willow and wolf-willow communities were located closer to the foothills region whereas the cattails and graminoids were located within the prairie region, although the graminoid vegetation type was the most prominent along the study reach and appeared to be dispersed throughout.

Each plant community was not evenly distributed along channel gradient except for the poplar community (Table 2-3). The limited amount of poplar appeared to be equally distributed along different channel slopes. The willow community did not occur in the shallower slopes and was primarily located in the middle slope ranges and although wolf-willow occurred in all the slope ranges, it was primarily located in the steeper slopes. The cattail and graminoid communities occurred in all slope ranges but were more prominent in the lower slopes.

Four of the five plant communities had a significantly different distribution across the different channel width ranges (Table 2-4). More poplar and willow communities occurred between channel widths of 1 and 10 m than would be expected if they were evenly distributed throughout. This is similar for the wolf-willow community that primarily occurred between 1 and 30 m. Additional cattail communities occurred at channel widths between 21 and 50 m than would of, if they were evenly dispersed. Although the graminoid community appeared to be dispersed throughout all channel width ranges, a few more communities occurred at channel widths between 11 and 20 m and less communities at 21 and 30 m than expected. Only three community types, wolf-willow, cattail and graminoid, occurred in channel widths greater than 30 m.

The graminoid community was the only plant community evenly distributed throughout the sinuosity ranges at the large meander scale (Table 2-5). There were fewer occurrences for the each of the poplar, willow and wolf-willow communities at the straighter large meanders than expected if uniformly distributed. In contrast there were more occurrences at the straighter sections for the cattail community than expected. There were significant differences for willow, cattail and graminoid distribution at different sinuosity ranges for the small meander scales (Table 2-6). Willow communities occurred more at sinuous sections than straight sections and cattail and grass occurred more at straight section than sinuous sections. Distributions of the poplar and wolf-willow communities were evenly dispersed across SI at the small meander scale.

Table 2-2 Statistical analysis (χ^2) comparing longitudinal distribution of five plant communities along the upper, middle and lower sections of the upper Little Bow River (E = expected, O = observed).

	Poplar		Willow		Wolf-willow		Cattail		Grass	
	n = 19	(1.7 %)	n = 81	(7.1 %)	n = 177	(15.5 %)	n = 257	(22.4 %)	n = 612	(53.4 %)
Longitudinal Segment	E	O	E	O	E	O	E	O	E	O
Upper (n = 382)	6.3	17	27	62	59	110	85.6	42	204	151
Middle (n = 382)	6.3	1	27	18	59	49	85.6	106	204	208
Lower (n = 382)	6.3	1	27	1	59	18	85.6	109	204	253
Total n = 1146	χ^2=	26.95		73.41		74.27		33.44		25.62
df = 2	Prob.	< 0.0001		< 0.0001		< 0.0001		< 0.0001		< 0.0001

Table 2-3 Statistical analysis (χ^2) comparing the distribution of five different plant communities and slope along the upper Little Bow River (E = expected, O = observed).

	Poplar		Willow		Wolf willow		Cattail		Grass	
	n = 19	(1.7 %)	n = 81	(7.1 %)	n = 177	(15.5 %)	n = 257	(22.4 %)	n = 614	(53.5 %)
Slope (%)	E	O	E	O	E	O	E	O	E	O
0.00-0.06 (n = 186)	3.1	0	13.1	0	28.7	13	41.6	52	99.5	121
0.061-0.079 (n = 228)	3.8	6	16.1	23	35.2	16	51.0	63	121.9	120
0.08-0.10 (n = 200)	3.3	5	14.1	18	30.8	16	44.8	34	107.0	127
0.105-0.13 (n = 234)	3.9	5	16.5	6	36.1	47	52.4	53	125.2	123
0.131-0.19 (n = 208)	3.4	1	14.7	23	32.1	40	46.6	49	111.3	95
≥ 0.20 (n = 92)	1.5	2	6.5	11	14.2	45	20.6	6	49.2	28
Total n = 1148	χ^2=	7.47		31.71		98.36		18.45		19.99
df = 5	Prob.	0.19		< 0.0001		< 0.0001		< 0.01		< 0.01

Table 2-4 Statistical analysis (χ^2) comparing the distribution of five different plant communities and channel width along the upper Little Bow River (E = expected, O = observed).

	Poplar		Willow		Wolf-willow		Cattail		Grass	
	n = 19	(1.7 %)	n = 81	(7.1 %)	n = 177	(15.5 %)	n = 257	(22.4 %)	n = 614	(53.5 %)
Channel Width (m)	E	O	E	O	E	O	E	O	E	O
1 - 10 (n = 302)	5.0	16	21.3	32	46.6	66	67.6	22	161.5	166
11 - 20 (n = 440)	7.3	2	31.1	34	67.8	76	98.5	65	235.3	273
21 - 30 (n = 264)	4.4	1	18.6	15	40.7	30	59.1	101	141.2	117
31 - 50 (n = 142)	2.4	0	10.0	0	21.9	5	31.8	69	76.0	58
Total n = 1148	χ^2=	33.00		16.37		24.95		128.35		9.56
df = 3	Prob.	< 0.0001		< 0.001		< 0.0001		< 0.0001		0.01

Table 2-5 Statistical analysis (χ^2) comparing the distribution of five different plant communities and sinuosity of large meanders (reach length 2 km) along the upper Little Bow River (E = expected, O = observed).

	Poplar		Willow		Wolf-willow		Cattail		Grass	
	n = 19	(1.7 %)	n = 81	(7.3 %)	n = 177	(15.9 %)	n = 248	(22.4 %)	n = 591	(53.0 %)
Sinuosity (2 km)	E	O	E	O	E	O	E	O	E	O
1.00 - 1.29 (n = 400)	6.8	1	29.0	13	63.4	44	88.9	103	211.8	239
1.3-1.59 (n = 280)	4.8	14	20.3	29	44.4	75	62.2	29	148.3	133
1.60-1.99 (n= 280)	4.8	4	20.3	30	44.4	38	62.2	79	148.3	129
≥ 2.00 (n = 156)	2.7	0	11.3	9	24.7	20	34.7	37	82.6	90
N = 1116	χ^2=	22.96		17.17		27.96		24.50		7.57
df = 3	Prob.	< 0.0001		< 0.001		< 0.0001		< 0.0001		0.06

Table 2-6 Statistical analysis (χ^2) comparing the distribution of five different plant communities and sinuosity of small meanders (reach length 400 m) along the upper Little Bow River (E = expected, O = observed).

	Poplar		Willow		Wolf-willow		Cattail		Grass	
	n = 19	(1.7 %)	n = 81	(7.1 %)	n = 177	(15.5 %)	n = 255	(22.4%)	n = 608	(53.3 %)
Sinuosity (400 m)	E	O	E	O	E	O	E	O	E	O
1.00 -1.04 (n = 216)	3.6	0	15.4	10	33.5	36	48.3	57	115.2	113
1.05 - 1.09 (n = 312)	5.2	6	22.2	15	48.4	37	69.8	64	166.4	190
1.10 - 1.14 (n = 80)	1.3	0	5.7	8	12.4	5	17.9	22	42.7	45
1.15 - 1.19 (n = 136)	2.3	3	9.7	14	21.1	23	30.4	30	72.5	66
1.20 - 1.29 (n = 120)	2.0	4	8.5	16	18.6	26	26.8	29	64.0	45
1.30 - 1.39 (n = 96)	1.6	4	6.8	7	14.9	18	21.5	16	51.2	51
1.40 - 1.59 (n = 96)	1.6	2	6.8	11	14.9	15	21.5	21	51.2	47
≥ 1.60 (n = 84)	1.4	0	6.0	0	13.0	7	18.8	4	44.8	11
Total n = 1140	χ^2=	12.39		22.16		13.84		16.21		35.59
df = 7	Prob.	0.09		< 0.01		0.05		0.02		< 0.0001

2.3.3 Land management

The occurrence of the five plant communities sometimes differed abruptly between different fenced parcels of land (Figure 2-9), indicating that different management practices may influence species distribution along the upper Little Bow River. This was also observed along the float in June 2005, where abrupt changes in vegetation occurred across fence lines. Figure 2-10 illustrates the continuing change of the dominant plant community across fence lines within the same local environment. This was primarily noticed in the upper and middle sections, where there is a more diverse distribution of plant communities. Figure 2-11 illustrates that average bankfull channel width was consistent from parcel to parcel, although some sharp changes were observed with the different management regimes.

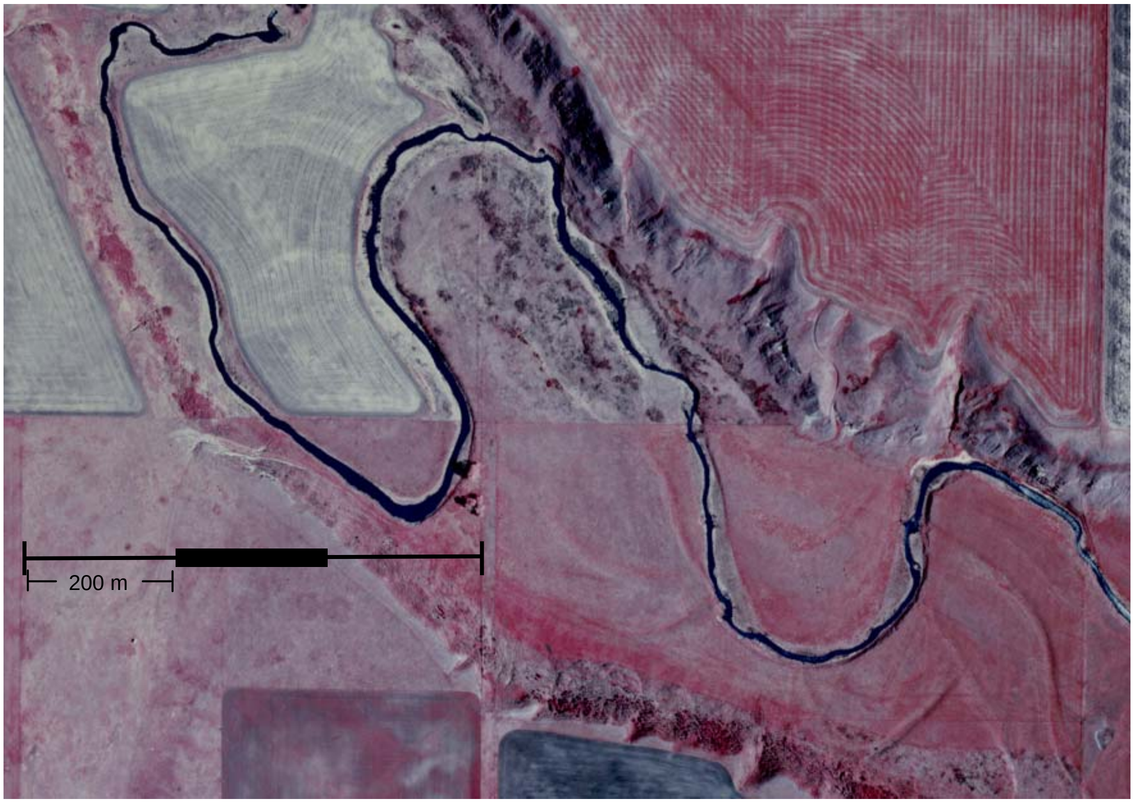

Figure 2-9 An aerial photograph taken on May 22nd, 2001 at a daily discharge of 2.9 m^3/s. The mid-point of the photo is located at N 50 ° 30.75 and W 113° 47.33. The figure also includes positions 20.8 to 24.2 km along the upper Little Bow River mapped on the MSA orthophotos. Note: (1) The direction of flow is from left to right and (2) the difference in vegetation on either side of the fence line is shown running across the center of the photo.

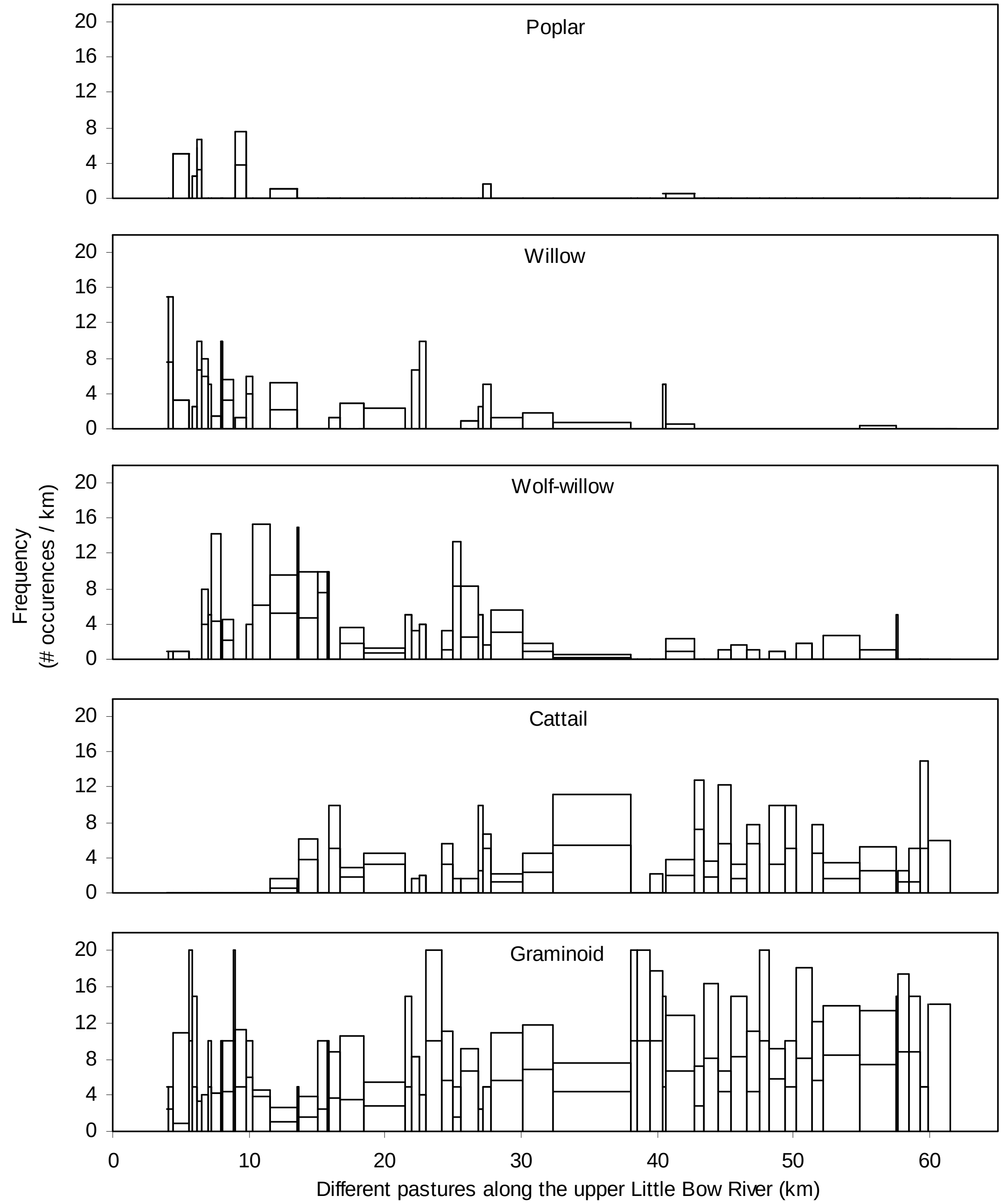

Figure 2-10 Distribution of the five different plant communities within different fenced parcels of land or pastures along both banks of the upper Little Bow River (right bank is above left bank). At each 100 m the most prominent plant community was recorded. The frequency of occurrence or counts per km of each plant community was then calculated for each parcel of land along 57.5 km of river.

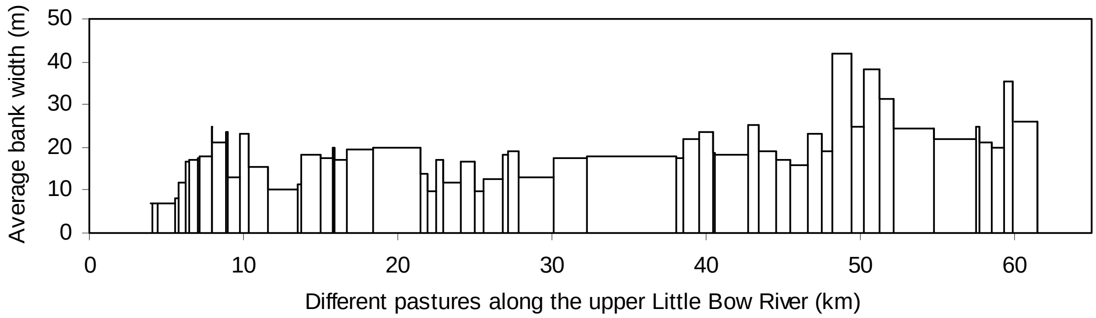

Figure 2-11 Average channel width calculated for different fenced parcels of land along the upper Little Bow River.

2.4 Discussion

2.4.1 Channel characteristics and riparian vegetation

The upper Little Bow River (LBR) is an underfit system as the river is much smaller than the wide valley it resides in. Consequently the channel should readily accommodate an increased flow regime as it is not restricted by a narrow valley. The LBR does not have any major tributaries until the inflow of Mosquito Creek at the Twin Valley Reservoir. Without inflowing tributaries the upper LBR provides a relatively constant study system. The LBR is situated within an agricultural zone and is impacted by livestock grazing and cropland management practices. It is also subject to other artificial impacts such as the construction of roads, bridges and pipelines particularly along the upper reach.

Channel characteristics are dynamic and depend on the hydrology and sedimentology of the drainage basin (Baker 1989). The inter-relationships typically exhibited between different stream characteristics (Leopold 1994) were generally observed along the upper LBR. The longitudinal profile demonstrated a few positions where a change in gradient existed (Figure 2-2), otherwise the channel gradient generally decreased along the study reach (Figure 2-3). The channel width progressively increased along the LBR and corresponded to an increase in local runoff as discharge would increase along with an increase in drainage area (Gordon et al. 2004). The channel width peaked in the lower section and then slightly decreased (Figure 2-4). The peak in channel width corresponded to a depression in channel slope and it appeared that gradient was inversely related to channel width along the LBR (Figure 2-7).

Channel width was measured at 100 m intervals along the study reach without reference to the morphological shape of the channel. Channel shape may vary at different positions along the meander such as at the apex or inflection point of the meander (Leopold 1994) and such variation is reflected in the measurements along the Little Bow River. A running average reduced the localized variation while maintaining the general pattern of longitudinal channel width. A running average over twenty-one positions (position = 100 m intervals) was used for comparison with slope (Figure 2-7). The value for channel slope was not acquired for every 100 m but instead at varying intervals, defined by a 1 m drop in topographical elevation (See Appendix A for original data). A running average of the inverse slope has a similar pattern to channel width. However, other components may also influence the channel width.

There was coordination of SI between the two scales of sinuosity, although SI of the small inset meanders was smaller in magnitude (Figure 2-5 and 2-6). Sinuosity measures the curvature of a water course (Gordon 2004) and is determined by wavelength distance. A common relationship exists between wavelength and channel width (Leopold 1994). A wider channel corresponds to longer wavelengths or straighter channels. This relationship can be observed around the 50 km position where the gradient was low, channel width was high and sinuosity for both meander scales was low. This supports observations made by Leopold (1994) and others (Richards 1982, Rosgen 1996) regarding the interrelationship between channel characteristics.

Occurrence of the five pant communities was not constant along the upper Little Bow River. The poplar and willow communities were the least common along the study reach (Table 2-1). This is atypical for rivers and streams in semi-arid southern Alberta where willows and cottonwoods are extensive and principal streamside shrubs and trees (Amlin and Rood 2002). Cattail and wolf-willow communities were the second and third most abundant plant communities along the study reach and graminoids provided the predominant vegetation cover type. A gradient among plant communities was observed and many variables may combine to cause this pattern. An evaluation of the communities recognized possible factors that may compromise the typical association between hydrogeomorphic characteristics and plant communities.

Some of the poplar and willow communities had clearly been planted or were associated with human influences and some of these were not included in the study. Although communities might have been established artificially, some were determined to have become naturalized.

A naturalized community, as defined by Richardson (2000) is one that establishes a new self-perpetuating population and becomes incorporated within the ecosystem. We classified a naturalized community based on pattern of establishment, age structure and diversity of species. This classification was not exclusive since communities with diminished population dynamics and diversity may also be impacted by flow and land management. Due to this complexity, some poplar communities were eliminated from the study based on systematic pattern and anthropogenic evidence, such as structures, buildings, fences and other domestic remnants.

Similar to the poplars, the complexity of naturalized communities existed for Bebb willow and one community was eliminated from the study. These poplar and willow communities were replaced with a graminoid classification as it was also present. There was also some confusion in the interpretation or distinction of sandbar willow and identification was verified during the float in June 2005.

All poplar and willow communities included in the study were evaluated and determined to be naturalized, regardless of origin. Although initial recruitment of poplar and willow communities may be artificial, the long-term survival could be attributed to hydrogeomorphic conditions. The maintenance of riparian cottonwoods and poplars relies on periodic recruitment to compensate for ongoing mortality (Mahoney and Rood 1998). Recruitment can be through either seedlings or clonal processes (Rood et al. 1994). Seedling recruitment is contingent on particular hydrogeomorphic conditions. Flood events enable cottonwood seedling recruitment through direct geomorphic and hydrologic patterns (Rood and Mahoney 1990, Scott et al. 1996). These flood events drive the erosional and depositional processes associated with the creation of barren nursery sites and provide a pattern of stream flow and stage that is suitable for seedling establishment (Mahoney and Rood 1998). The upper Little Bow River is regulated and flow operations may not provide suitable flows for poplar establishment or large enough flows to promote lateral channel migration that would create barren sites for recruitment. Other impacts such as streamside grazing or beaver browse may also eliminate young saplings and other vegetation.

2.4.2 Physical conditions and plant communities

The interaction between riparian vegetation and hydrologic and geomorphic processes demonstrates a strong synergy that makes understanding riparian ecosystem processes a complex task (Patten 1998). Different river types and drainage basins are associated with different riparian ecosystems and the physical parameters along an individual river may also play a role in determining the distribution of riparian vegetation (Baker 1989, Patten 1998). A continuous gradient of physical conditions within a stream system usually result in a predictable structuring of biological communities (Vannote et al. 1980).

Dominated by balsam poplar, the poplar community was significantly associated with higher elevations, narrow channel widths and moderately sinuous large meanders (Table 2-2 to 2-5). It was uniformly distributed along the various slope ranges and SI for the small inset meanders.

The poplar community was predominantly located in the upper reach of the study region near the edge of the foothills with an upper elevation of 1032 m. In contrast, the downstream reach dissects the prairies and has a lower elevation of 967 m. Differences in elevation corresponded to differences in climate and precipitation. The upstream section tends to be cooler and wetter and the downstream section tends to be warmer and dryer according to Environment Canada's climate normals for High River (1219.2 m) and Carmangay (939.4 m) from 1971 - 2000. The wetter environment favours poplar survival and poplar forests are abundant along the Highwood River near the upper reach. In contrast, poplars are scarce along Mosquito Creek. Mosquito Creek is the most comparable river system to the Little Bow River as it is a tributary subject to similar climatic conditions, land management practices and flow regime history. Mosquito Creek also had an intermittent flow prior to augmentation. Although one study has found elevation to be the most significantly correlated variable to vegetation gradients (Baker 1989), another study recognized the establishment of cottonwoods and poplars along adjacent rivers in warmer and dryer climates (Floate 2004). Climate is a major factor controlling stream flow patterns and shaping landforms and vegetation communities (Gordon et al. 2004) but it may not be the underlying factor along the regulated upper Little Bow River.

Poplars were apparently associated with narrow channel widths. This association may be less reliable due to the history of channel modification along the upper section. Further, the association of poplar communities with narrow channel widths supports research that has found riparian woodlands to be bank stabilizers which would deter channel widening (Patten 1998).

In this study poplars occurred along moderately sinuous large meanders. However, due to artificial impacts along the upper reach, that segment may not be representative of the large meanders that occur downstream. Occurrence of poplars at different gradients and sinuosity for the small meanders could be a result of the slight variation within these parameters. These parameters represent a low stream gradient and straighter channels and may not have the magnitude to limit poplar distribution. Although Hupp and Osterkamp (1996) believe channel gradient is the most important factor affecting fluvial landforms and associated processes, the limited distribution of the poplar community, artificial location and degree of magnitude within the parameters, make it difficult to assess the extent of association existing between poplar distribution and channel characteristics.

Other variables may play role in the distribution of the poplar plant community. Poplar distribution along the upper Little Bow River could have been limited by inadequate flow patterns that were unable to provide the ecological requirements for poplar germination, establishment, growth and long-term survival. Woody riparian vegetation in semi-arid regions of North America is dependant on adequate moisture (Rood and Mahoney 1990, Scott et al. 1993). The extent, density and species composition of riparian vegetation are dependent on timing, magnitude and pattern of stream flows (Stromberg 1993, Stromberg and Patten 1996, Scott et al. 1993).

Riparian vegetation also relies on flow variability that is not usually observed along regulated streams. This variability provides episodic flood events that facilitate cottonwood seedling recruitment through both geomorphic impacts and hydrologic patterns. Large floods scour the floodplain and provide necessary barren sites for seedling recruitment (Barnes 1985, Braatne et al. 1996, Friedman and Lewis 1995, Rood et al. 1999, Scott et al. 1997). Coincident with high spring flows, poplars and cottonwoods disperse their seeds in late May and June. Following a flood, gradually decreasing flows would maintain moist deposition zones as the seedlings establish roots (Rood and Mahoney 1990). The poplar sites in the upstream reach were located near abandoned excavation sites, disturbed sites suitable for seedling recruitment.

As with other phreatophytes, long-term maintenance and survival of poplar populations is dependant on a recharged water table (Rood et al. 2003c). Augmented stream flows in July and August can provide favourable flows for established cottonwoods and poplars by reducing drought stress (Rood and Mahoney 1995). Operational flow management may not provide a flow regime suitable for obligate riparian vegetation establishment and growth. This could be a flow regime that incorporates late timing of peak flow, double peaking, or a steep instead of gradual decline in ramping rates (Rood et al. 2003b).

A lack of seed source may also contribute to a low proportion of poplars along the Little Bow. Although there were some planted poplars in the downstream reach, they may not provide a sufficient seed source. Further, planted poplars are typically male to restrict seed production.

Another impact on the establishment and survival of young seedlings and saplings is land management practice. Grazing can severely diminish the successful establishment of young seedlings and saplings by either trampling or browsing (Samuelson and Rood 2004, Scott et al. 1997). Grazing and other agricultural practices are common within the upper Little Bow River watershed as observed during the 2005 float and in aerial photographs from various years. Landowners have also observed evidence of beavers cutting down saplings along the middle reach.

Associated with other similarities between the obligate riparian species, the willow distribution was consistent with the poplar distribution but was associated with a broader range of characteristics. The willow communities were generally located at higher elevations, moderate slopes, narrower channel widths, straighter small meanders and moderate to sinuous large meanders (Table 2-2 to 2-5). This was consistent with other studies that have found Bebb willow located at higher elevations and low to moderate gradients, within narrow to moderate valley bottoms and typically on benches adjacent to streams (Manning and Padgett 1991). Sandbar willow is one of the most widespread willow species, occupying gradients that were very low to moderate and narrow to very broad valley bottoms (Manning and Padgett 1991). Although the willow communities extended further downstream than the poplar communities, they were associated with higher elevations and therefore a cooler and wetter climate. Elevation is one factor that influences the distribution of willow species, likely a response to temperature (Hudak and Ketcheson 1991).

Willows are associated with narrow channel widths. However, channel width is not the sole correlate of a vegetation gradient but is correlated with other variables (Baker 1989). Narrow widths tend to coincide with upper sections. A progressive increase in flow corresponds to wider channel widths in the lower reaches (Leopold 1994). As well riparian vegetation is considered to play an effective role in bank stability (Kovalchik and Elmore 1991).

Willows depend on stream stage (height) patterns for successful establishment of seedlings (Amlin and Rood 2001, Barnes 1985). They are also regarded as phreatophytes and rely on ground water that infiltrates from the adjacent stream (Busch et al. 1992). Sandbar willow forms dense thickets and is a major component in early successional riparian zones. Prolific clonal growth allows for long-term colonization of riparian zones and the balance between seedling establishment and clonal growth is based on the disturbance regime (Douhovnikoff et al. 2005). Willow seedlings establish more successfully on recently disturbed ground, which could either be newly deposited sediment or scoured banks (Hudak and Ketcheson 1991).

Most of the Bebb willow communities had been exposed to grazing but at an unknown intensity and although the species still exists, grazing could have hindered community expansion. Improper grazing can severely impact the stability of riparian zones especially those dominated by willows (Kovalchik and Elmore 1991). This may be similar for the sandbar willow along the upper LBR as it was only identified in apparently ungrazed areas. These sandbar willow communities appeared to be juvenile and research has found first year willow seedlings are very sensitive to grazing and mortality can be caused by browsing or trampling (Kovalchik and Elmore 1991). These observations were made during the float in June 2005 where the presence differed on either side of fences (Figure 2-9). This indicates that willow establishment was limited largely by land management instead of flow operations. Thus, distribution of the willow dominated communities may be primarily limited by livestock grazing along the middle section of the upper LBR.

Although wolf-willow was predominantly in the upper section, it was also found along the entire study reach. Wolf-willow is associated with higher elevations, steeper gradients, narrower bank widths and straighter channels at the large meander scale but occurs within each category for all parameters (Table 2-2 to 2-5). It does not appear to be as sensitive to the magnitude of variability within each parameter as the other woody species. It is a common shrub at lower elevations in southern Alberta (Kuijt 1982). Wolf-willow is a facultative riparian shrub and therefore does not rely on the stream allowing it to become established in drier environments. Not as limited by moisture as the poplar and willow communities, wolf-willow was located along the study reach and also inhabited the valley slopes. Aspect also influenced distribution, as the moister north and northeast facing slopes of the LBR were typically vegetated with facultative riparian shrubs whereas the south and southwest facing slopes were generally barren of shrubs.

The cattail community was associated with lower elevations, shallower slopes and wider channel widths along the upper LBR (Table 2-2 to 2-5). A common marsh plant found at low elevations in Alberta (Kuijt 1982), cattails are typical of wetland conditions with wide channels and shallow stream gradients. A flood-tolerant species that is morphologically and physiologically adapted to tolerate saturated soils (Wetzel 1993), common cattails are resilient under a variety of hydrologic patterns when nutrients are not limiting (Kercher and Zedler 2004, Li et al. 2004). The cattail community was distributed through the bottom portions of the study reach. Although it also extended upstream, it did not overlap with the poplar communities.

The graminoid community was dispersed along the entire study reach (Figure 2-8). Similar to the cattail and wolf-willow communities, it was found within all ranges of each hydrogeomorphic parameter. However, grass and grass-like species were more prominent in the lower sections, low to moderate gradients, narrow to moderate channel widths and straighter small meanders along the LBR (Table 2-2 to 2-5). It was the classification used when none of the other four communities were present because the graminoid community type was present at all positions along the study reach.

Grasses are the dominant upland species within the geographic region and are adapted to most environments. The LBR has a history of fluctuating flows and prior to augmentation may have been considered an intermittent or ephemeral stream. Ephemeral streams tend to be grass-dominated (Hupp and Osterkamp 1996). Distribution of different plant communities along the LBR may also be limited by species tolerance to drought or flooding, as seen with the cattail and graminoids.

The distribution of vegetation may be limited by species' tolerance for specific disturbance or stress regimes (Hupp and Osterkamp 1996) such as land management practices and excess nutrient loads. Observations along the float in 2005 recognized the large proportion of grasses to be the main vegetation throughout large areas. The prevalence of grasses could also reflect land management practices such as grazing that inhibit the establishment of other vegetation (Belsky et al, 1999). To assess the impact of different management regimes, plant community distribution was compiled according to different parcels of land. Figure 2-10 indicates that different management regimes had local affects on established vegetation and can be seen where the occurrence of a plant community existed in one pasture and not in the adjacent one. This is also illustrated in the aerial photograph (Figure 2-9) with an immediate change in the presence and absence of woody vegetation across fence lines. This vegetation transition from grazed to un-grazed zones was noticeable along the float in June 2005. The ungrazed areas were densely covered with a variety of species. The grazed areas had sparse, homogeneous grass type vegetation and showed evidence of pugging.

To assess the impact of different management regimes on channel width, bankfull channel widths were averaged according to different parcels of land. The consistent profile (Figure 2-11) has a rather dramatic increase in the lower section. Further investigation of the profile indicated that the increase in channel width in the lower section was inversely related to a decrease in gradient. Grazing practices have shown evidence of pugging which could further reduce bank stability and cause excess channel widening. Figure 2-10 also raised the issue of land-use fragmentation. Grazing and other agricultural practices may have different impacts depending upon the size of the pasture. Colonized farming, a common practice along the LBR, may have different impacts on plant community composition than spatially constrained segments.

No measurement was undertaken to determine the extent of impact caused from different management practices. The assessment of land management only implies that different practices, of unknown magnitude and duration, influence the distribution of different plant communities along the upper LBR. As well, the graminoid classification may or may not include invasive species, which would also provide another indicator of the severity of impact.

2.5 Conclusion

The Little Bow River is a regulated stream which was formerly managed with a relatively consistent flow regime instead of one with natural variability. The current channel characteristics reflect this flow pattern. Channel characteristics and the hydrological pattern are linked to the distribution of different plant communities. Associations were found between different channel characteristics and the distribution of plant communities along the upper Little Bow River. The obligate riparian poplars and willows were located near the upstream end of the study reach, while the facultative riparian species extended further downstream.

While other factors may also contribute to plant community establishment flow and land management have the most impact on vegetation at a local scale. The flow regime prior to the establishment of the Twin Valley Dam and Reservoir maintained flows throughout the irrigation period. These regulated flows were rather static and did not contain the variability needed for ecological requirements of riparian vegetation.

The longitudinal distribution of five dominant plant communities was assessed along the 57 km reach of the upper Little Bow River. The distribution of each plant community was not uniform along the reach and was associated with different physical characteristics of the river. Plant community distribution also reflected impacts related to land management practices, in particular livestock grazing.

CHAPTER 3 - INITIAL CHANNEL AND VEGETATION RESPONSES TO FLOW AUGMENTATION ALONG THE UPPER LITTLE BOW RIVER

3.1 Introduction

Water management in southern Alberta has involved many infrastructure projects that divert, transport and store water. Monitoring of the long term environmental impacts related to these projects has become a novel component of the recent developments, particularly those following the controversial Oldman River Dam Project. The present project represents part of the monitoring program for the Little Bow /Highwood Rivers Project which included (1) construction of the Twin Valley Dam and Reservoir, (2) expansion of the Highwood Diversion Head Works and Canal, and (3) implementation of the Highwood Diversion Plan (NRCB/CEAA 1998, MSA 2001).

The Twin Valley Dam is located near the confluence of the Little Bow River and Mosquito Creek. Construction of the onstream dam and filling of the reservoir was completed in 2003 and the project was officially implemented in 2004. The Highwood Diversion Plan was designed to increase the maximum water diversion from the Highwood River to the upper Little Bow River (LBR). Systematic monitoring and assessment will enable validation of environmental impacts and identification of operational refinements to minimize negative impacts on the environment and optimize water provision for consumptive use (HMP-PAC 2004). As a foundation for further study, various methods were used to describe pre-project conditions and to monitor initial changes caused by the increased flow regime along the upper Little Bow River. The LBR is unique in that it provides the opportunity for the long term investigation of the impacts related to flow augmentation or increase. This contrasts with water withdrawal that accompanies most water management projects in southern Alberta.

The Highwood River Diversion Plan was intended to triple diversion flows during the spring when river flows were high (Golder Associates 1995) and this was initially intended to reduce diversion from the Highwood River through low flow summer months when riverine ecosystems are prone to drought stress. Water from increased flows would be stored in the Twin Valley Reservoir for subsequent summer release downstream. Augmented flows along the upper Little Bow River would be increased from the prior bankfull discharge (Q_{bf}) of 2.85 m^3/s to about 8.5 m^3/s during approximately six weeks through May and June in most years (MSA 2001). Consequently, the channel must physically adjust to convey three times the flow of water than had been diverted in previous years (Rood et al. 2002).

The bankfull discharge (Q_{bf}) is also referred to as the channel-forming discharge (Q_{cf}) (Leopold 1997) and has particular impact on determining channel geometry and morphology, including channel width and depth, meander pattern and lateral migration rate (Leopold 1994, Rood et al. 2002). A river sculpts and maintains a channel form that is sufficient to contain discharges up to the flood level (Leopold 1994). Larger discharges exceed the channel capacity and overflow onto the floodplain. The Q_{cf} is the mathematical product of stream competence or erosion capacity and flow exceedance or frequency of occurrence (Wolman and Miller 1960). Larger flows have greater velocities with increased competence to erode, suspend and transport sediments. However, their recurrence or frequency of occurrence is rare. Moderate flows balance competence and exceedance and the cumulative effect becomes the dominant channel-forming discharge

(Rood et al. 2002). The channel shape, size and properties are altered by the processes of erosion and deposition of sediments (Leopold 1997). Sediment is eroded from cut-banks and deposited on meander lobes, other bars and adjacent floodplains. The aggradation or accretion of material on the point bar or convex bank, is compensated by the erosion of the concave bank. This process promotes lateral migration across the valley while maintaining a relatively constant channel width along a channel reach. If unimpaired by human alteration, sediment dynamics of erosion and deposition often maintain a balance referred to as dynamic equilibrium. A range of flows allow the channel to maintain its dynamic equilibrium by maintaining its morphologic form without significant aggradation or degradation, elevational increase or decrease (Leopold 1997).

Prior to the Little Bow Project, the Q_{cf} for the upper Little Bow River was consistently determined by a variety of methods to correspond to the Q_{bf} of slightly less than 3 m^3/s (MSA 2001, Rood et al. 2002), a discharge substantially less than the augmentation flow of 8.5 m^3/s. The upper LBR was consequently predicted to undergo changes in cross-sectional geometry to accommodate the increased flow regime. Other studies found the prominent response to augmentation was channel widening, as well as increased erosion and sediment yield, channel incision, decreased sinuosity and increased rate of meander migration (Kellerhals et al. 1979, Bradley and Smith 1984, Church 1995, Dominick and O’Neill 1998). Riparian vegetation also responded in a variety of ways to increased flows. Changes in plant community structure and composition and increased width and erosion of riparian vegetation have been recognized in prior studies (Henszey et al. 1991, Stromberg and Patten 1992, Stromberg 1993, Church 1995).

Associated with project implementation, a long-term study was established to investigate the environmental impacts on the river channel and riparian vegetation due to increased flow augmentation along the upper LBR. The reach primarily impacted extends approximately 57.5 km from the Little Bow Canal to the Twin Valley Reservoir. Pre-project channel cross sections and an inventory of vegetation from 2002 provided a basis for future comparison. Impacts to the channel and riparian vegetation are being investigated and monitoring will continue until the system has adapted to the increased flows and achieved a new semi-constant equilibrium.

Probably the least understood aspect of the response is the time frame. A time-scale for adjustment is influenced by the severity of the regulation, the development of vegetation communities and the redistribution of sediment (Church 1995). To provide further insight into the process and rate of channel adjustment continued monitoring of sediment dynamics has been started. Sampling sediment suspension and deposition may provide insight into the rate of change along the channel.

Channel bank composition may influence the rate of change along the channel as smaller sediment grain sizes such as clays and silts are more cohesive than sand. This cohesive tendency will have a stronger influence in stabilizing banks. A comparison of studies in Bradley and Smith (1984) illustrated that floodplains composed of coarser sediments such as sand rather than clay had higher migration rates. High migration rates would indicate that the substrate was more susceptible to erosion and channel adjustment would occur in less time. To test this principle, cores were collected to determine the sediment composition of the floodplain along the upper Little Bow River.

3.2 Methods

3.2.1 Re-survey of cross-sectional river riparian transects

During the summer of 2002, twenty-five permanent transects were established perpendicular to the river and extended from one side of the riparian vegetation through the river to the riparian zone on the opposite bank. Twenty-one of these cross-sectional transects were established at ten sites along the LBR upstream from the Twin Valley Reservoir (Figure 3-1). The ten sites were chosen to represent the five different plant community types; poplar (*Populus balsamifera* L.), willow (*Salix exigua* Nutt. and *Salix bebbiana* Sarg.), wolf-willow (*Elaeagnus commutata* Bernh.), cattail (*Typha latifolia* L.) and graminoids (grasses and sedges). At each site there were two transects established except for one poplar site that also included a willow transect. Species identification and percent cover were collected for tree, shrub and herbaceous species from quadrats placed in sequence along each transect. To provide a baseline topographic profile, each transect was surveyed before the increase in flow augmentation, that included channel edge and cross-sectional width and depth. These transects also provided the elevations of the different vegetation types relative to the river. During 2003 and 2004 the 21 transects were re-surveyed to investigate initial topographic changes following the increase in flow augmentation.

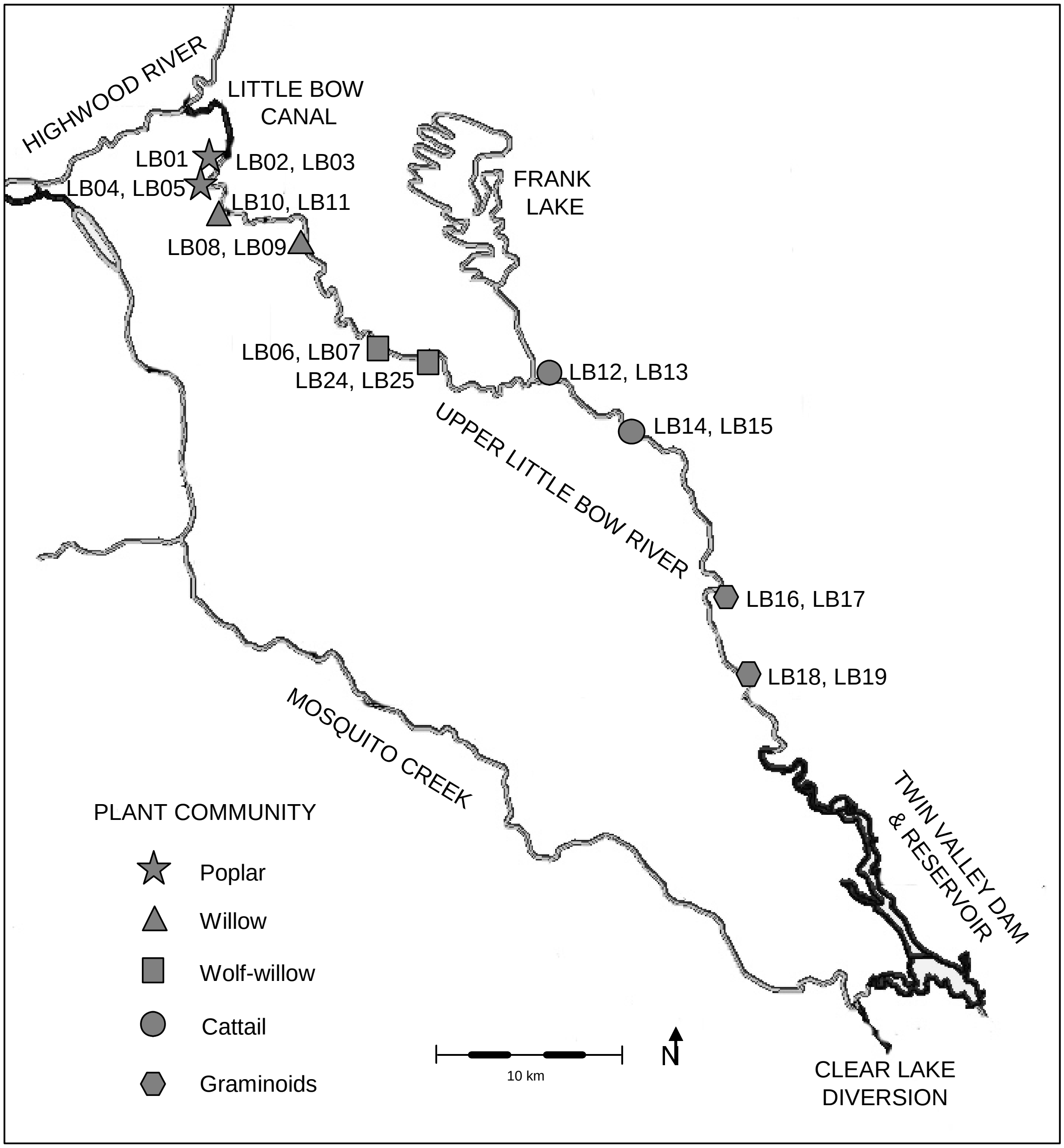

Figure 3-1 Map of permanent sampling sites with cross-sectional transects upstream of the reservoir, categorized by vegetation community type and including site designation.

3.2.2 Discharge and sediment sampling

Daily discharges were acquired from Alberta Environment for the Little Bow Canal (#05BL015) and Highway #533 (#05AC930) hydrometric gauges for 2004 and 2005. For comparative purposes the discharge at the Little Bow Canal was related to suspended sediment loads collected along the upper section and the gauge at Highway #533 was related to suspended sediment loads collected along the lower section of the study reach.

In 2004, suspended sediment samples were collected at two locations along the upper Little Bow River (Figure 3-2). One location was near the upstream end, at the site of transect LB01 and the other at the downstream end at Highway #533, approximately 2 km upstream from the Twin Valley Reservoir. Samples were taken twice weekly from May 17th to July 29th, 2004. Samples were also collected at a third location, along the Little Bow Canal near Highway #23 within the Town of High River twice weekly from June 18th to July 29th, 2004.

In 2005 suspended sediment samples were collected at six locations along the upper Little Bow River (Figure 3-2). Samples were collected from foot-bridges along the Little Bow Canal near Highway #23 and LB04/05, as well as from road bridges along Highway #2A, 658 Ave., Highway #534 and Highway #533. Samples were taken twice weekly from May 4th until June 8th. The discharge at the beginning of the sampling period was approximately 3 m^3/s. It then increased to vary around 7 m^3/s and 8 m^3/s. Sampling was then discontinued due to heavy rains and flooding in the region and along the Highwood River.

At all sampling locations, the inner channel was divided into five equal segments. The middle of each segment was marked and used as a sampling site. Samples were collected using a DH-59, a depth-integrating sampler designed to collect suspended sediment samples as it is submerged through a vertical column of flowing water (Tassone et al. 1992) (Federal Interagency Sedimentation Project (FISP), US-DH-59).

The sediment was then extracted from the sample by vacuum filtration, dried, weighed and the concentration (mg/L) determined. The five samples from each location were averaged to estimate the sediment load at that site.

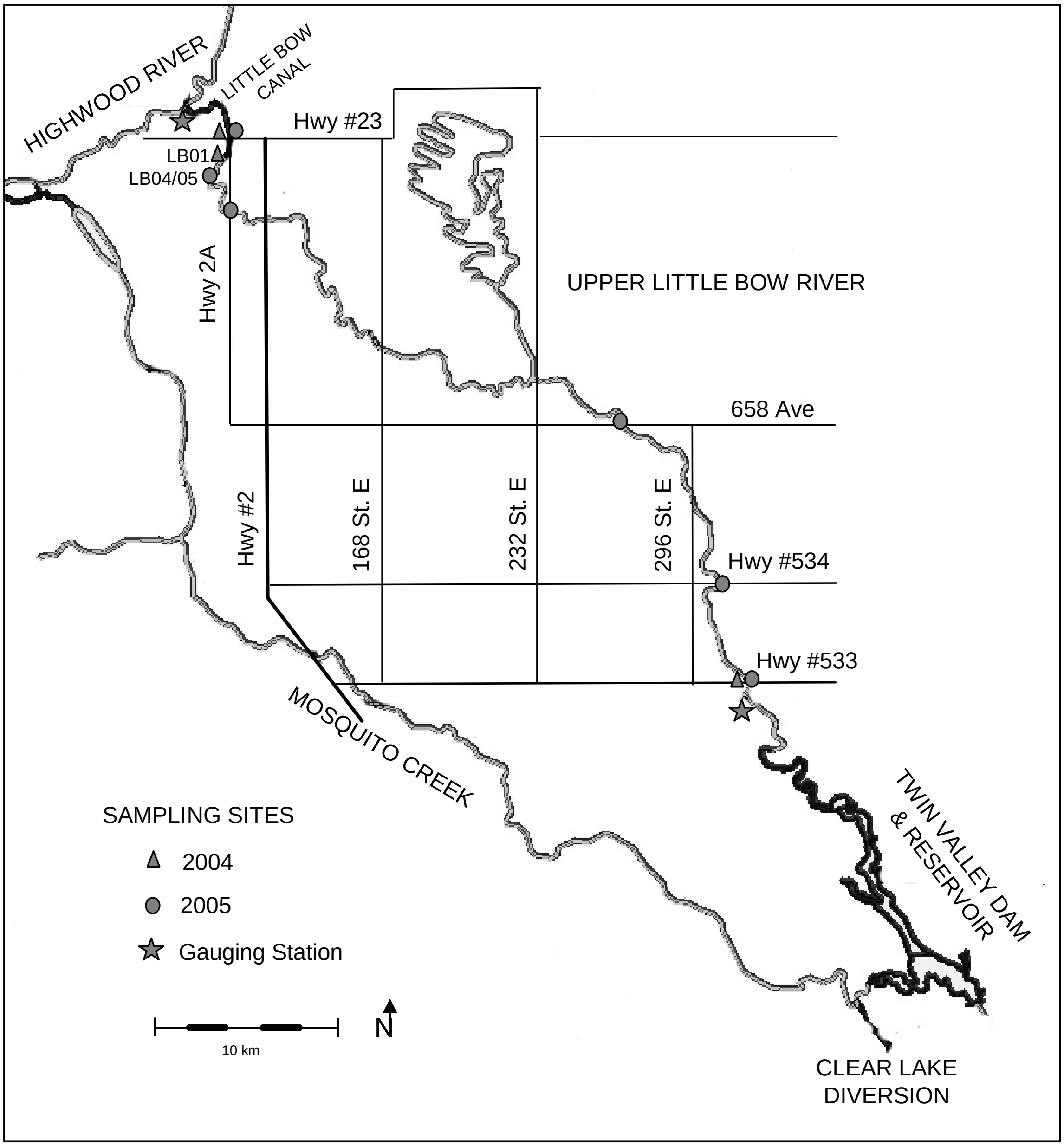

Figure 3-2 Map of suspended sediment sampling sites in 2004 and 2005 and gauging stations along the upper Little Bow River, including highway and secondary crossings.

Deposited sediment was collected at three locations along the upper LBR in 2004 (Figure 3-3). The upstream location was at the site of transect LB01, the middle location was at the site of transect LB14/15 and the downstream location at Highway #533. At each location five containers were placed along the channel within the flooded zone during high flow on May 28th, 2004. They were fastened to the ground with galvanized steel spikes so that traps remained stable throughout the sampling period. The containers were then recovered on June 28th, 2004 after the flooded areas were exposed.

Sediment was also collected in 2005 at ten locations along the upper LBR (Figure 3-3). In downstream order the locations included: the site of transects LB02, LB04/05, LB08/09, LB12/13, LB14/15, downstream from 296 St. E, 658 Ave, Highway #534 and Highway #533 and upstream from the Twin Valley Reservoir. The containers were positioned in the flooded zones on May 12th, 2005. Containers were then retrieved on June 13th, 2005 during the heavy rain sequence. Only 36 of the 50 containers were retrieved on the initial collection and 8 of the remaining 14 containers were collected on various dates; six were not recovered. All collected samples were subsequently dried and weighed.

Five sediment cores were extracted at two sites perpendicular to the river generating a cross-section of the valley that excluded the river. The two sites were selected because they met particular criteria: 1) correspondence with permanent transect locations, 2) downstream from human impacts such as roads and buildings, 3) permission from landowners and 4) no recent use of pesticides. Only four cores were augered at LB08/09 because one was located in a cultivated field near a vacant gravel pit and was very difficult to auger. Each sediment core was extracted with a hand auger and representative samples were collected at 25 cm intervals along the core. The samples were sieved to 1 mm and the smaller particles were prepared for laser particle size analysis using the Mastersizer 2000 (Ver. 5.21, Malvern Instruments Ltd., Malvern UK) at the University of Calgary. The remaining particles greater than 1 mm were sorted with a sieve shaker. The proportion of each particle size was then determined within each sample according to the grade scales in Table 3-1.

Table 3-1 Grade scales for particle size (Gordon et al. 2004).

Description	(mm)	(µm)
Fine gravel	8-4	8000-4000
Very fine gravel	4-2	4000-2000
Very coarse sand	2-1	2000-1002.4
Coarse sand	1-0.5	1002.4-502.4
Medium sand	0.5-0.25	502.4-251.8
Fine Sand	0.25-0.125	251.8-126.2
Very fine sand	0.125-0.0625	126.2-63.3
Coarse silt	0.0625-0.0312	63.3-31.7
Medium silt	0.0312-0.0156	31.7-15.9
Fine silt	0.0156-0.0078	15.9-7.9
Very fine silt	0.0078-0.0039	7.9-3.9
Coarse clay	0.0039-0.002	3.9-2.0
Medium clay	0.002-0.001	2.0-1.0
Fine clay	0.001-0.0005	1.0-0.50
Very fine clay	0.0005-0.00024	0.50-0.25
unknown	0.00024-0	0.25-0

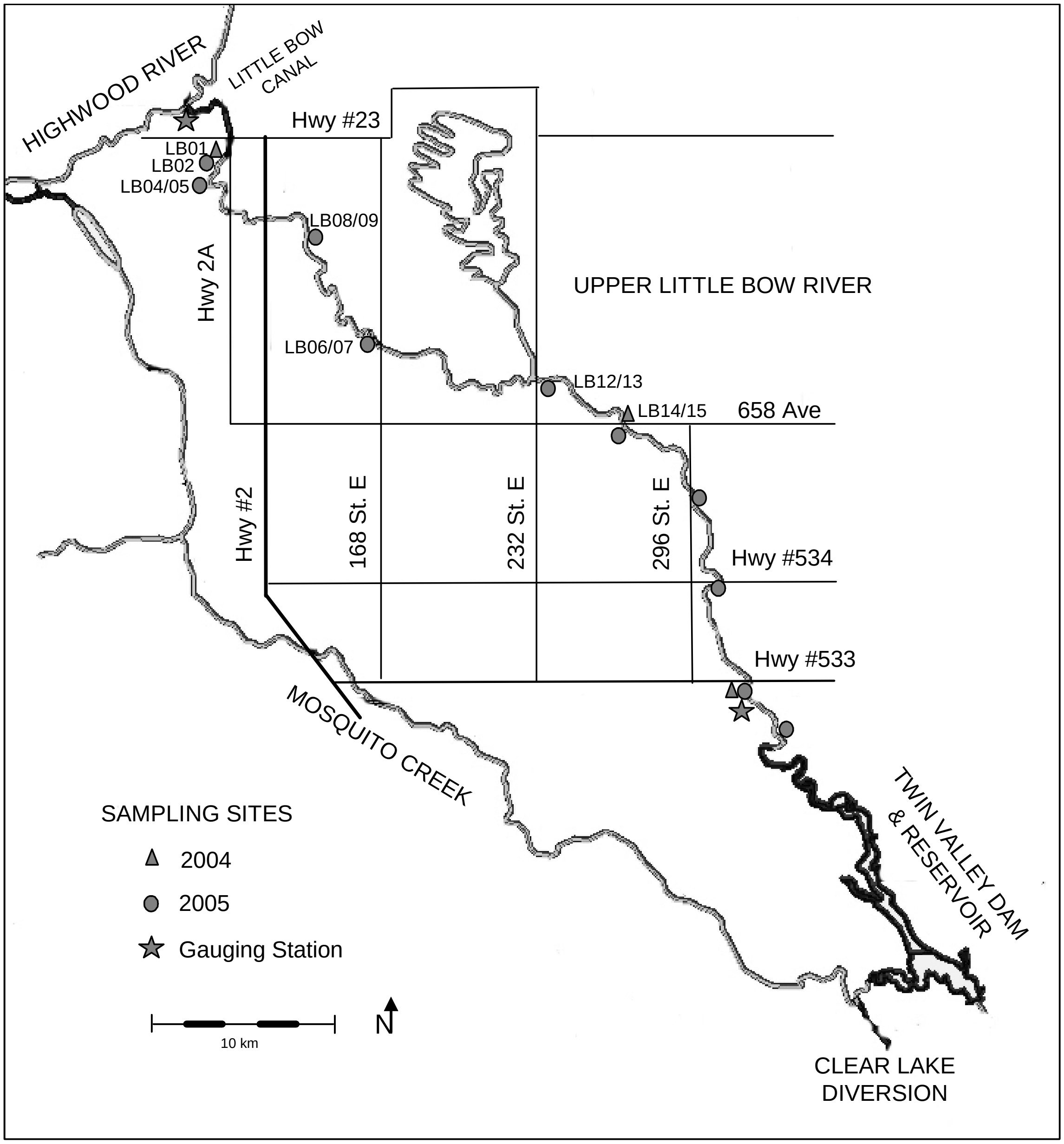

Figure 3-3 Map of sediment sampling sites in 2004 and 2005 and gauging stations along the upper Little Bow River, including highway and secondary crossings.

3.2.3 Observations and river float

Photographs were taken from eight bridge locations along the upper LBR (Figure 3-4) from 2001 to 2004 (Rood et al. 2002). The chronological sequence of photographs provided a comparison for monitoring the response of channel and vegetation impacts from the increased flows. Photos were also taken at each transect for every year surveyed. Other photos were also taken to record specific observations of effects induced by the increased flows. A longitudinal float survey by boat on June 11th and 12th, 2005 enabled additional photography and water level observations along the study reach.

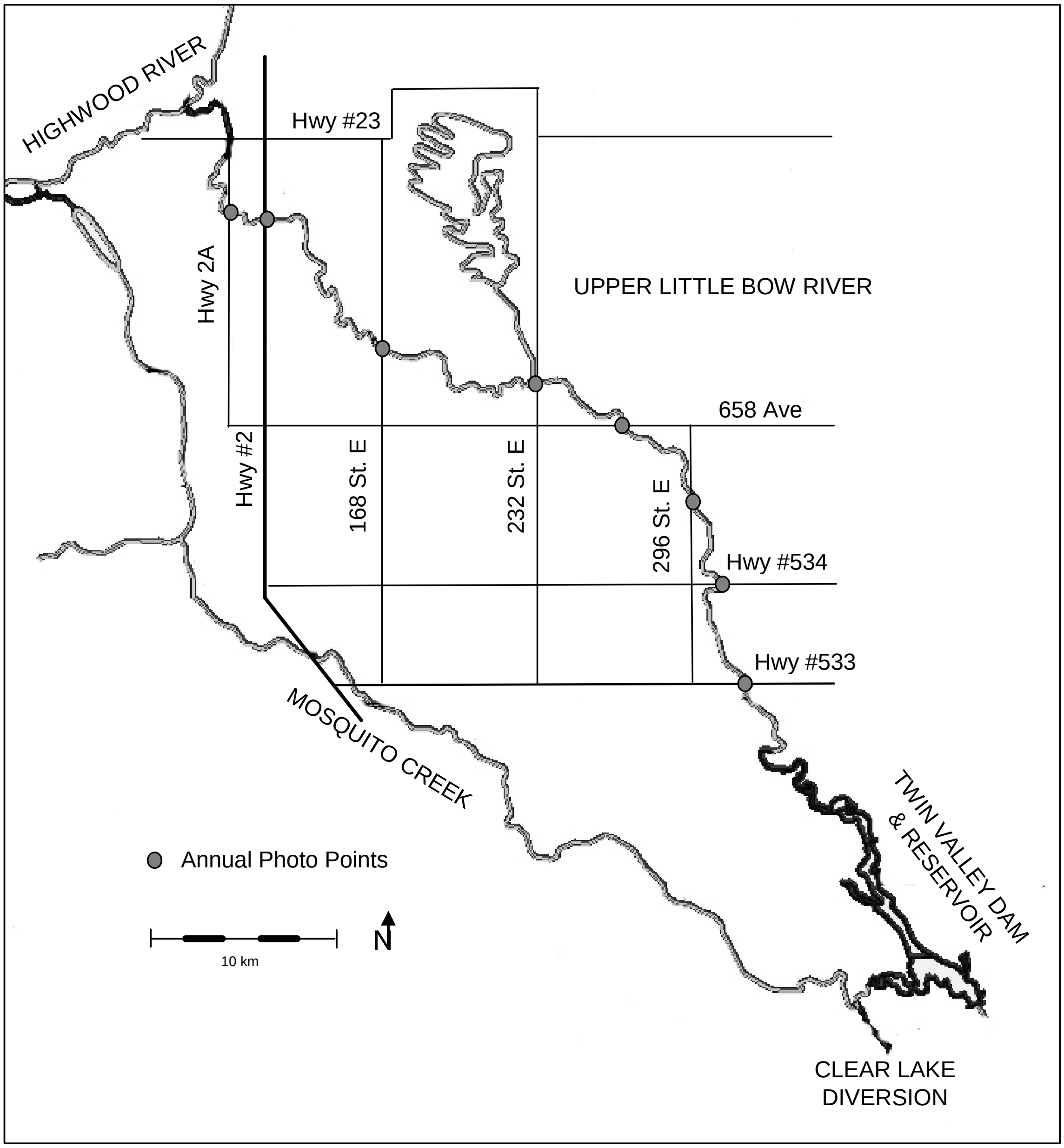

Figure 3-4 Map of annual photo points along the upper Little Bow River, including highway and secondary crossings.

The location of all sites used for cross-sectional river and riparian transects, sediment sampling and photos were converted to river distance, originating at the Little Bow Canal head gates along the Highwood River (Table 3-2).

Table 3-2 Corresponding features and river distance along the upper Little Bow River.

Feature	River Distance (km)
LB Gauge	0
LB Canal	3.4
LB01	4.7
LB02	4.95
LB03	5.25
LB04	6.25
LB05	6.3
LB11	8.2
LB10	8.5
Hwy 2A	9.1
Hwy 2	11.65
LB09	17.85
LB08	17.88
LB06	25.2
LB07	25.55
168 St.E	25.6

Feature	River Distance (km)
LB24	27.13
LB25	27.25
232 St. E	38.18
LB13	38.4
LB12	38.46
LB15	44.2
LB14	44.26
658 Ave.	44.5
296 St. E	49.45
Hwy 534	54.85
LB17	55.15
LB16	55.2
LB18	61.13
LB19	61.2
Hwy 533	61.55
533 Gauge	61.65

3.3 Results

3.3.1 Re-survey of cross-sectional river and riparian transects

The cross-sectional transects with the poplar communities (Figure 3-5) showed minimal differences between years. Both sites were located near the upper end of the study reach. Transects LB02 and LB03 (4.95 km and 5.25 km) were characterized by a slightly curved channel with a gradual point bar and poplar stand along the left bank. The right bank has a higher elevation and was adjacent to a cultivated field. Transects LB04 and LB05 (6.25 km and 6.3 km) were inhabited by poplars on both sides of the river even though elevational differences occurred. The channel bottom for both sites was composed of gravel and cobble and remained stable throughout 2003 and 2004. There is always variation re-locating survey points along transects and this imposes slight variation among re-surveys even without geomorphic change and could partly explain deviations in the profiles (Figure 3-5). All four transects were fenced and excluded from livestock.

The willow transect profiles were not as consistent as those of the poplar communities (Figure 3-6). LB01 (4.7 km) was the upstream transect and was located upstream from LB02 and LB03 (4.95 km and 5.25km). The profile of LB01 (4.7 km) shows minimal change and resembles the shape of the poplar transects. Slightly more variation is seen in LB08 and LB09 (17.88 km and 17.85 km). These transects were located on a meander lobe with sandbar willow established on the left bank. Records from 2002 indicated a heavy layer of fine sediment and abundant macrophytes along the bottom of the channel. Fine sediment was still found within the channel in 2004 but was less extensive. Both sites LB01 and LB08/09 (4.7 km and 17.88 km/ 17.85 km) were fenced or excluded from cattle. LB10 and LB11 (8.5 km and 8.2km) were both located along meander transitions within Bebb willow communities. Hummocks were recorded along the 2002 profile for LB10 (8.5 km) and both transects exhibited fine sediment and macrophytes within the channel. Livestock grazing was recognized by the presence of fresh fecal pads (‘cow pies’).

Topographic profiles within the wolf-willow sites slightly different responses to augmented flows (Figure 3-7). Transects LB06 and LB07 (25.2 km and 25.55 km) were located along a straight channel reach and showed some variation from the baseline transect, particularly for LB06 (25.2 km) that had widened by 2004. Both transects had gravel channel bottoms. The presence of livestock was not obvious and a well had been excavated a short distance from LB06 (25.2 km). The cross section for both transects dissected wolf-willow and surveying was difficult. Transects for both LB24 and LB25 (27.13 km and 27.25 km) showed minimal change. LB24 (27.13 km) was located along a straight river segment that was occupied by wolf-willow on the left bank. The riparian wolf-willow zone was fenced from livestock that were present within the rest of the valley zone. However, the right bank showed signs of grazing with pugging (substrate perforation by hooves) and fecal pads. LB25 (27.25 km) was fenced on both sides and was located after a sharp right curve that contained shrubs on the right convex bank. Gravel and sand were also observed within the channel bed.

Overall, transects located within the cattail communities showed the most change following the initial change in flow regime (Figure 3-8). LB16 and LB17 (55.2 km and 55.15 km) were located in an extensive cattail community along a large, gradual meander. Fine sediment was trapped within the matted layer where the cattails were present and formed a ledge at the edge of the open channel. The open channel had a cobble bottom that included pockets of fine sediment with aquatic vegetation or macrophytes, as well as scattered boulders up to 30 cm in diameter. Periods of rain in 2004 had caused flooding of the cattail zones and the re- survey for the channel cross-section of LB17 (55.15 km) was abandoned early due to deep mud zones along the downstream right cattail zone. Transects LB18 and LB19 (61.13 km and 61.2 km) revealed an increase in channel depth, contrary to prediction. LB19 (61.2 km) was situated along a right meander and cattails were more extensive on the right. LB18 (61.13 km) was positioned downstream and the cattails were more extensive on the left. Both of the profiles displayed extensive deposits of fine sediment and aquatic vegetation within the open channel in 2002. By 2004 the fine sediment had been reduced and boulders were exposed.

Only three of the four transects were relocated in 2003 and 2004 for the grass communities (Figure 3-9). The left bank of LB13 (38.4 km) was significantly altered by the removal of livestock yards and buildings and therefore the transect reference markers were removed. The remaining three transects had regions dominated by hummocks indicated in the profiles, particularly LB14 and LB15 (44.26 km and 44.2 km). LB12 (38.46 km) had cobble and aquatic vegetation within the channel in 2002; these observations were consistent through to 2004 but there was also accumulated fine sediment. The grass community transects LB14 and LB15 (44.26 km and 44.2 km) demonstrated some variation along the profiles and some changes were inconsistent across the surveys. The 2002 records indicated a build up of fine sediment along the stream edges and large boulders and aquatic vegetation along a gravel channel bed. In

2004 deposition along the bank was observed. All of the grass transects were exposed to some degree of livestock grazing.

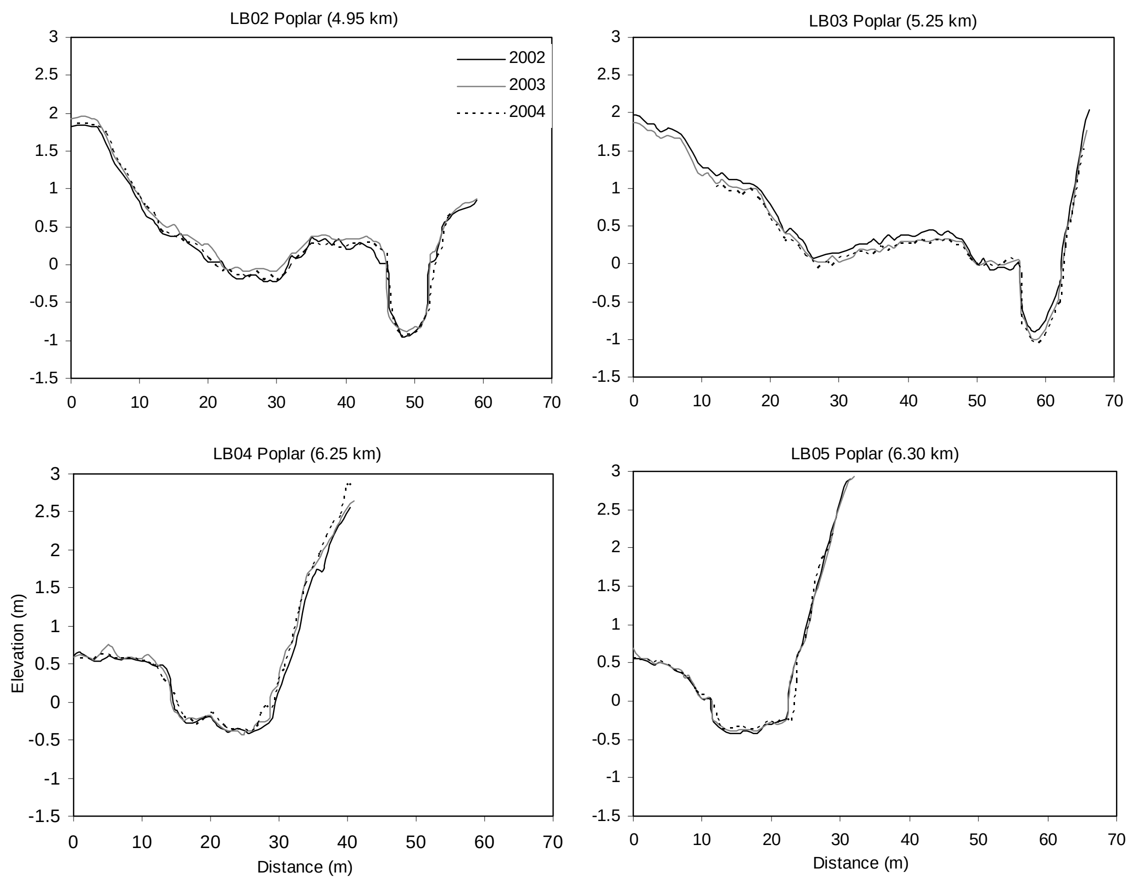

Figure 3-5 Repeated surveys of cross-sectional river and riparian transects in poplar plant communities along the upper Little Bow River. The figures display the cross-section in a downstream-facing perspective with the left bank near the y-axis.

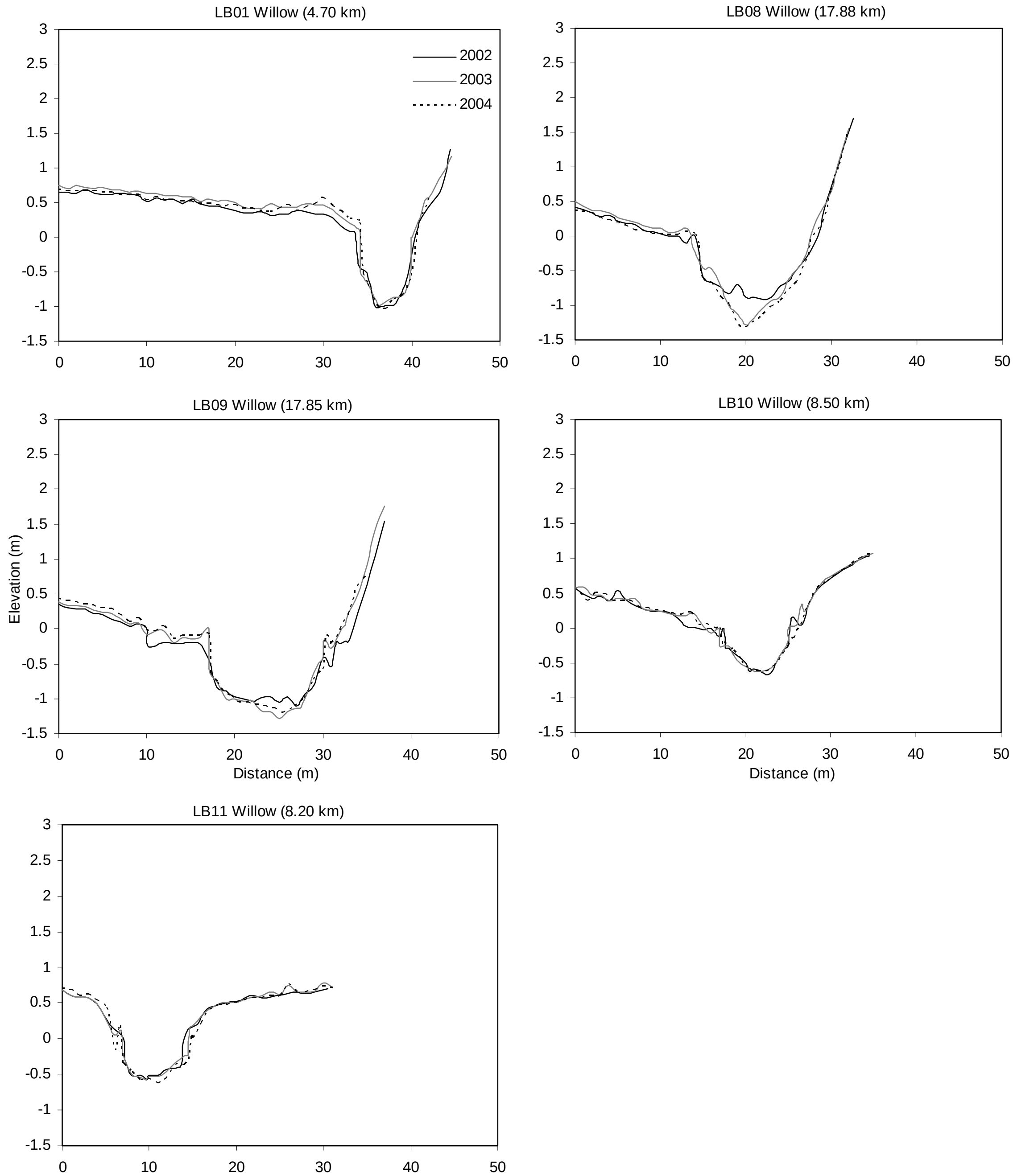

Figure 3-6 Repeated surveys of cross-sectional river and riparian transects in willow plant communities along the upper Little Bow River. The figures display the cross-section in a downstream-facing perspective with the left bank near the y-axis.

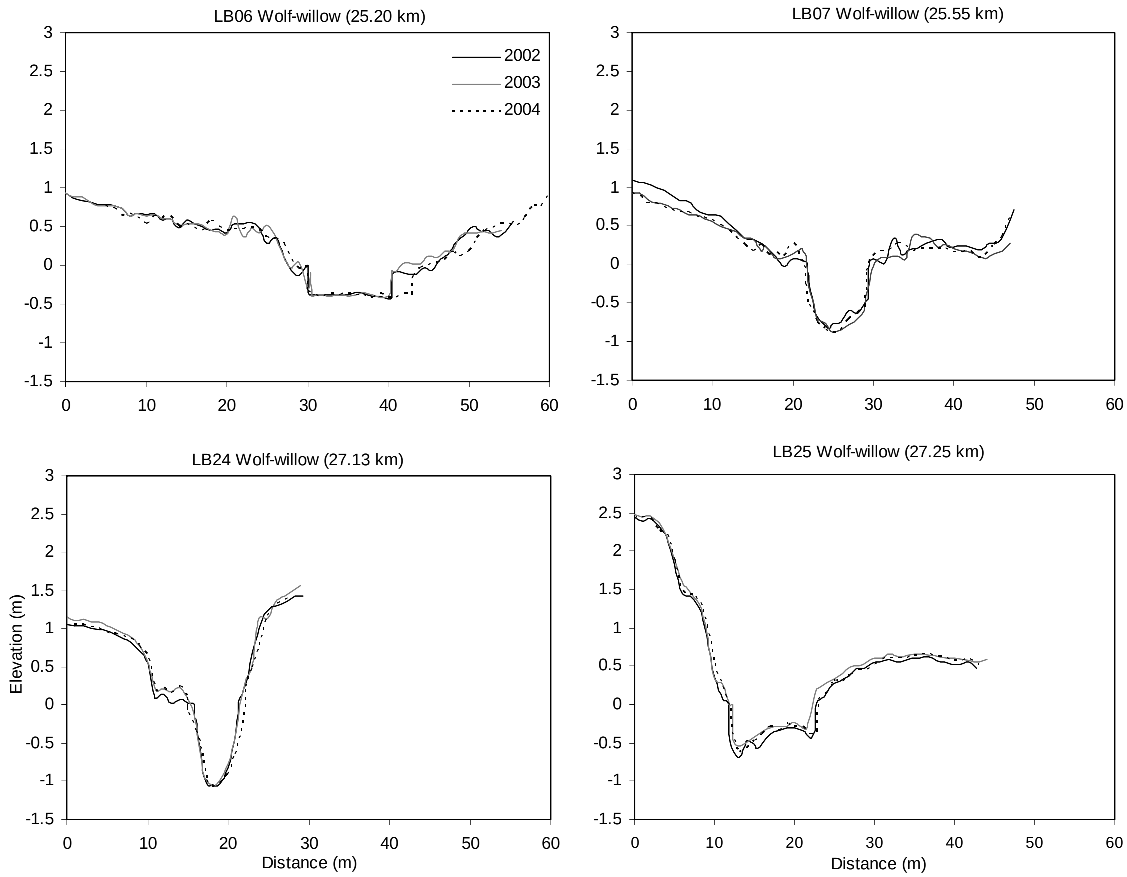

Figure 3-7 Repeated surveys of cross-sectional river and riparian transects in wolf-willow plant communities along the upper Little Bow River. The figures display the cross-section in a downstream-facing perspective with the left bank near the y-axis.

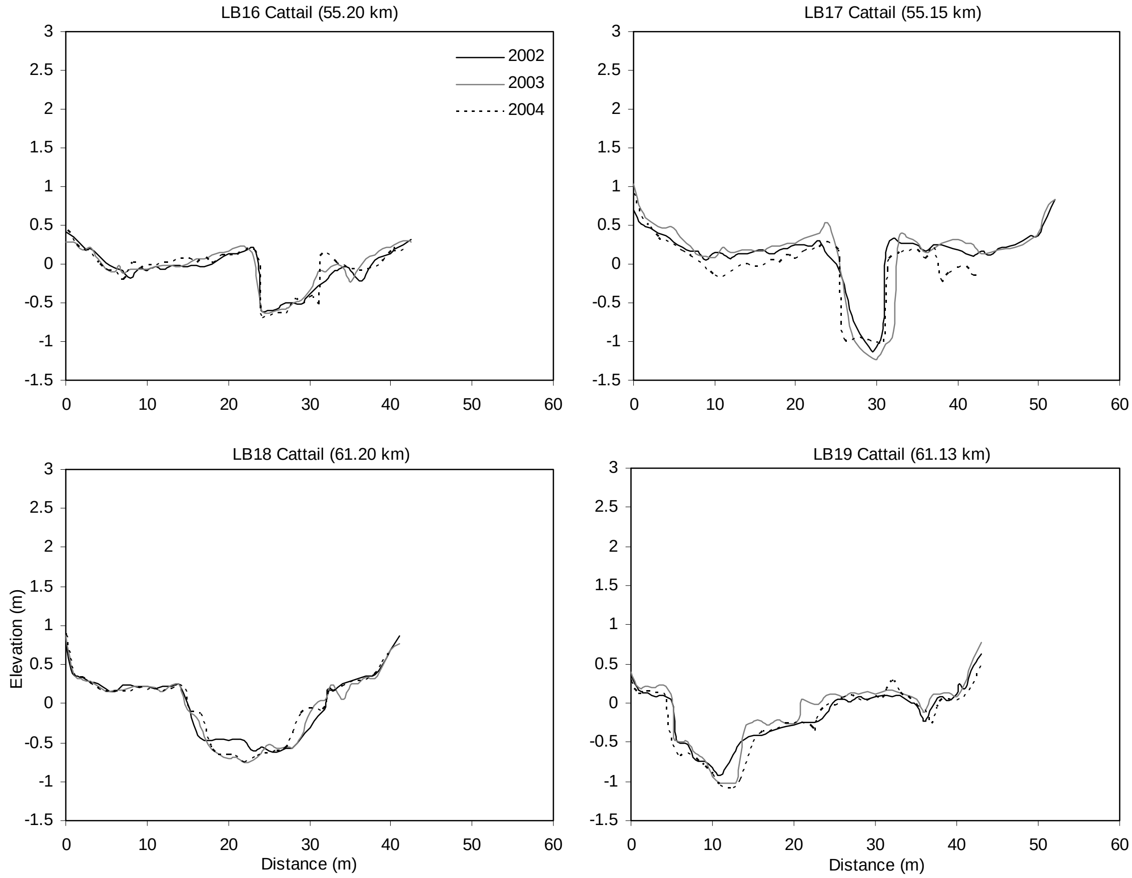

Figure 3-8 Repeated surveys of cross-sectional river and riparian transects in cattail plant communities along the upper Little Bow River. The figures display the cross-section in a downstream-facing perspective with the left bank near the y-axis.

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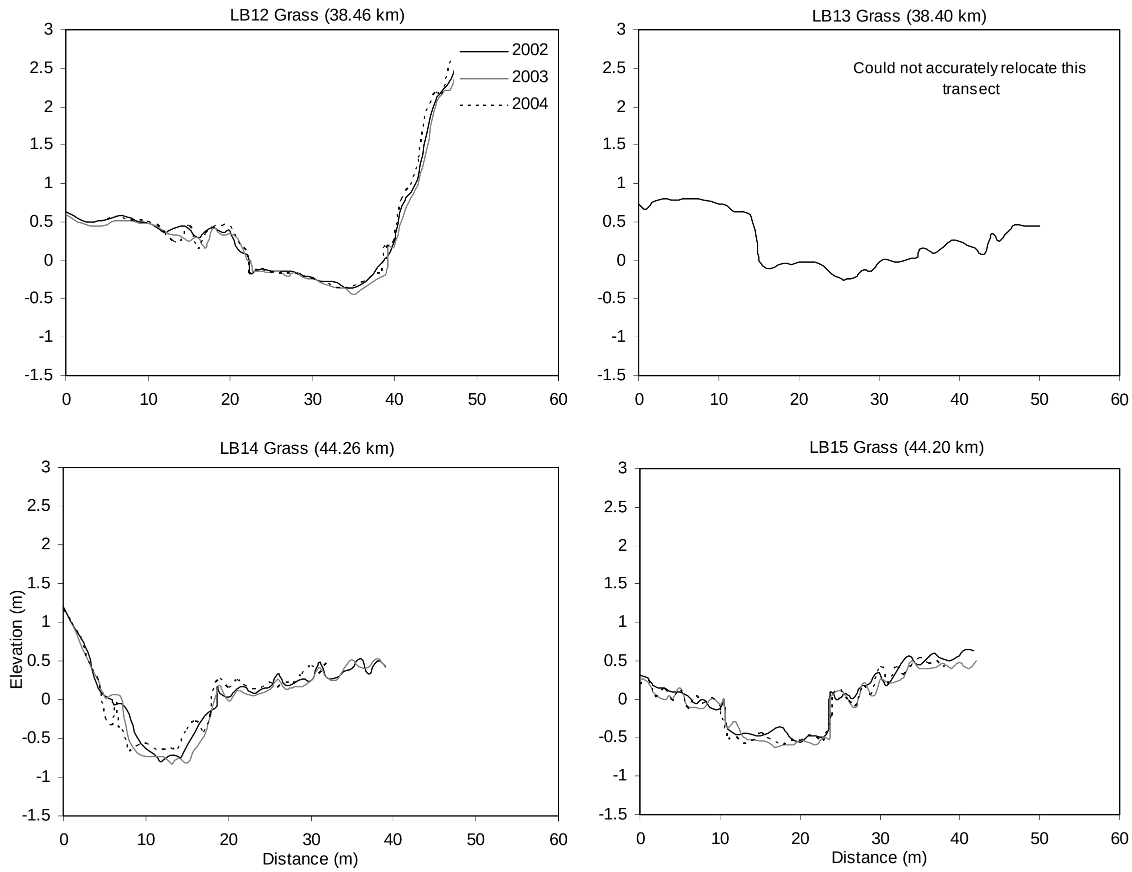

Figure 3-9 Repeated surveys of cross-sectional river and riparian transects in graminoid plant communities along the upper Little Bow River. The figures display the cross-section in a downstream-facing perspective with the left bank near the y-axis.

3.3.2 Discharge and sediment

Daily discharge in 2004 along the Little Bow Canal represented the new flow regime and varied between daily discharges of 7 and 8.5 m^3/s through most of May and June (Figure 3-10). After June 25th the discharge was ramped down to around 0.6 m^3/s. Flows then increased in mid-July to 3.5 m^3/s and were then ramped back down to the base flow of 0.6 m^3/s (MSA 2001). The discharge recorded at the Highway #533 gauge (61.65 km) illustrates an attenuated flow regime from the canal that is greater than 1 m^3/s in 2004 (Figure 3-10).

In 2005 discharge along the Little Bow Canal illustrated three dramatic shifts throughout the month of June (Figure 3-11). The gauge recorded daily flows up to 46 m^3/s, 33 m^3/s and 22.5 m^3/s. The peak flows resulted from rains that caused significant floods throughout the region. The gauge along the Little Bow Canal was located between two sets of head gates. The Highwood River had flooded over into the section between the gates. The second set of head gates upstream from the initial diversion gates were subsequently shut, preventing flood flows from entering the LBR. Consequently, gauge readings did not correspond to actual flows in the canal. Therefore, the June discharges represented in Figure 3-11 for 2005 for the canal gauge do not necessarily correspond to flows along the upper Little Bow River. The Highway #533 (61.65 km) flows in June were primarily due to increased runoff once the diversion from the Highwood River was closed. Augmentation along the upper Little Bow River was resumed following decline of the spring floods.

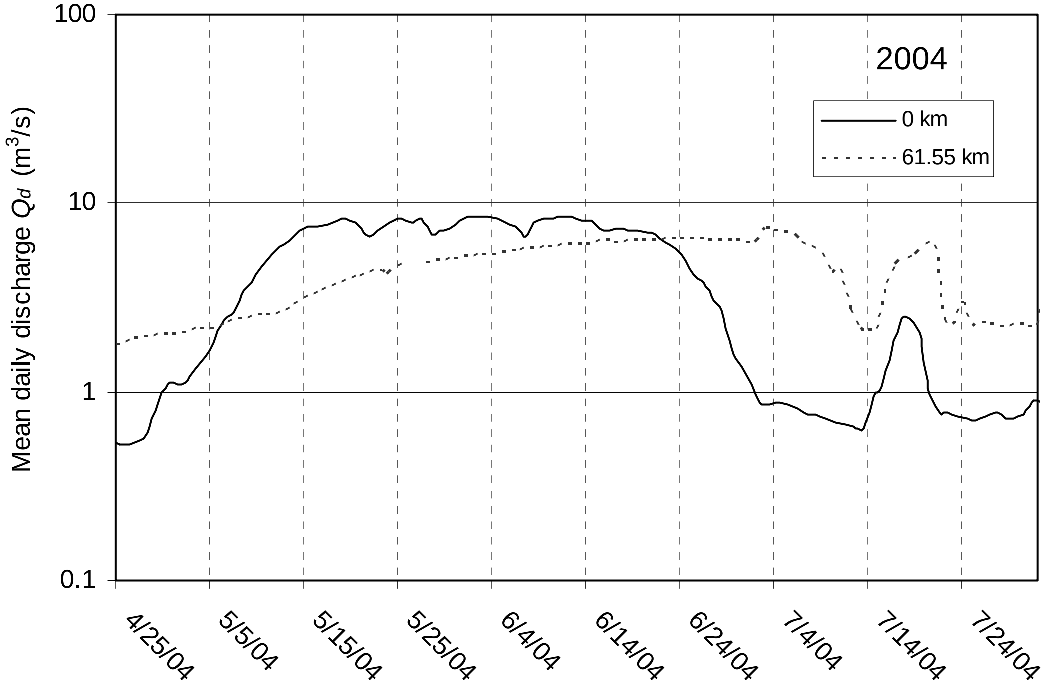

Figure 3-10 Discharge along the Little Bow Canal (0 km) and the Little Bow River at Highway #533 (61.55 km) from April 25th to August 1st, 2004.

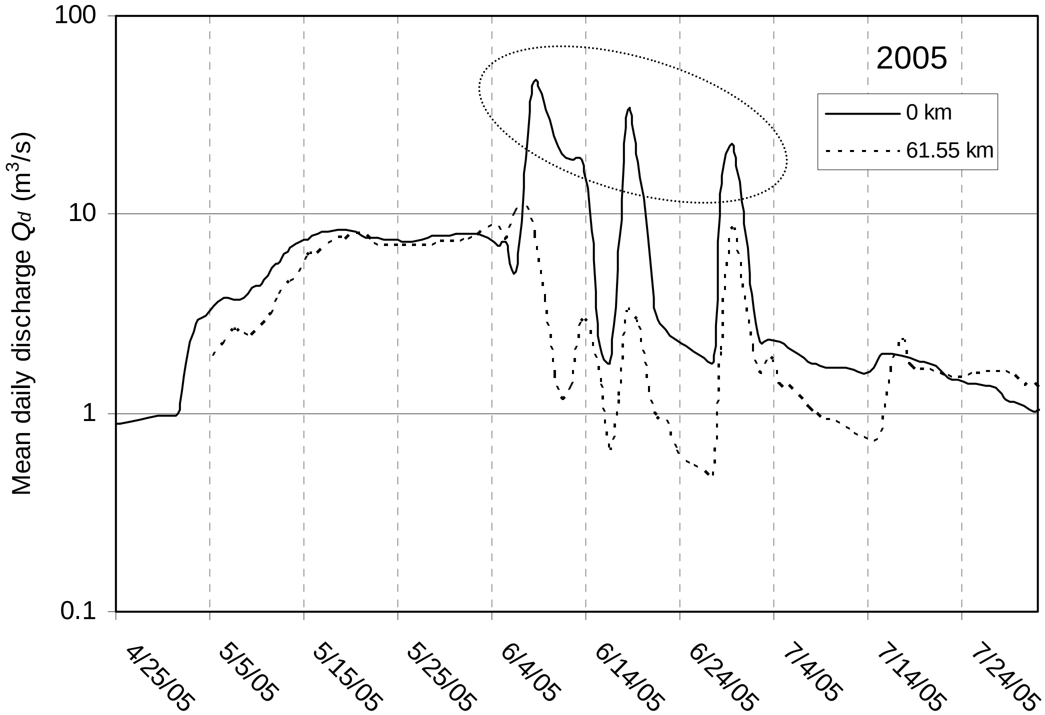

Figure 3-11 Discharge (log) along the Little Bow Canal (0 km) and the Little Bow River at Highway #533 (61.55 km) from April 25th to August 1st, 2005. Discharge from three peaks gauged along the Little Bow Canal was not all diverted into the Little Bow River but mostly returned to the Highwood River during flooding.

The suspended sediment load in the spring of 2004 (Figure 3-12) was correlated with daily discharge, demonstrating an association of increase and decrease. The sediment load was modest and remained below 100 mg/L throughout the sampling period. Sediment load was fairly consistent until discharge decreased and then more variation was observed among the sites. Suspended sediment concentration was elevated during the spring of 2005 and ranged between 10 and 1000 mg/L even though discharge was predominantly under 10 m^3/s (Figure 3-13). The relationship between sediment load and discharge in 2004 appeared to be positively correlated, where as the values in 2005 were higher and more dispersed (Figure 3-13).

Sediment was collected at three sites in 2004 and was greatest in the upper section (Figure 3-14). The average sediment deposited at LB01 (4.7 km) was six-fold greater than at Highway #533 (61.65 km), which was four times that of the sediment collected at LB14/15 (44.2 km). Sediment was collected at nine sites in 2005 and was substantially greater than in the previous year (Figure 3-15). The greatest sediment load was observed at LB08/09 (17.88 km) and then at Highway #533 (61.65 km).

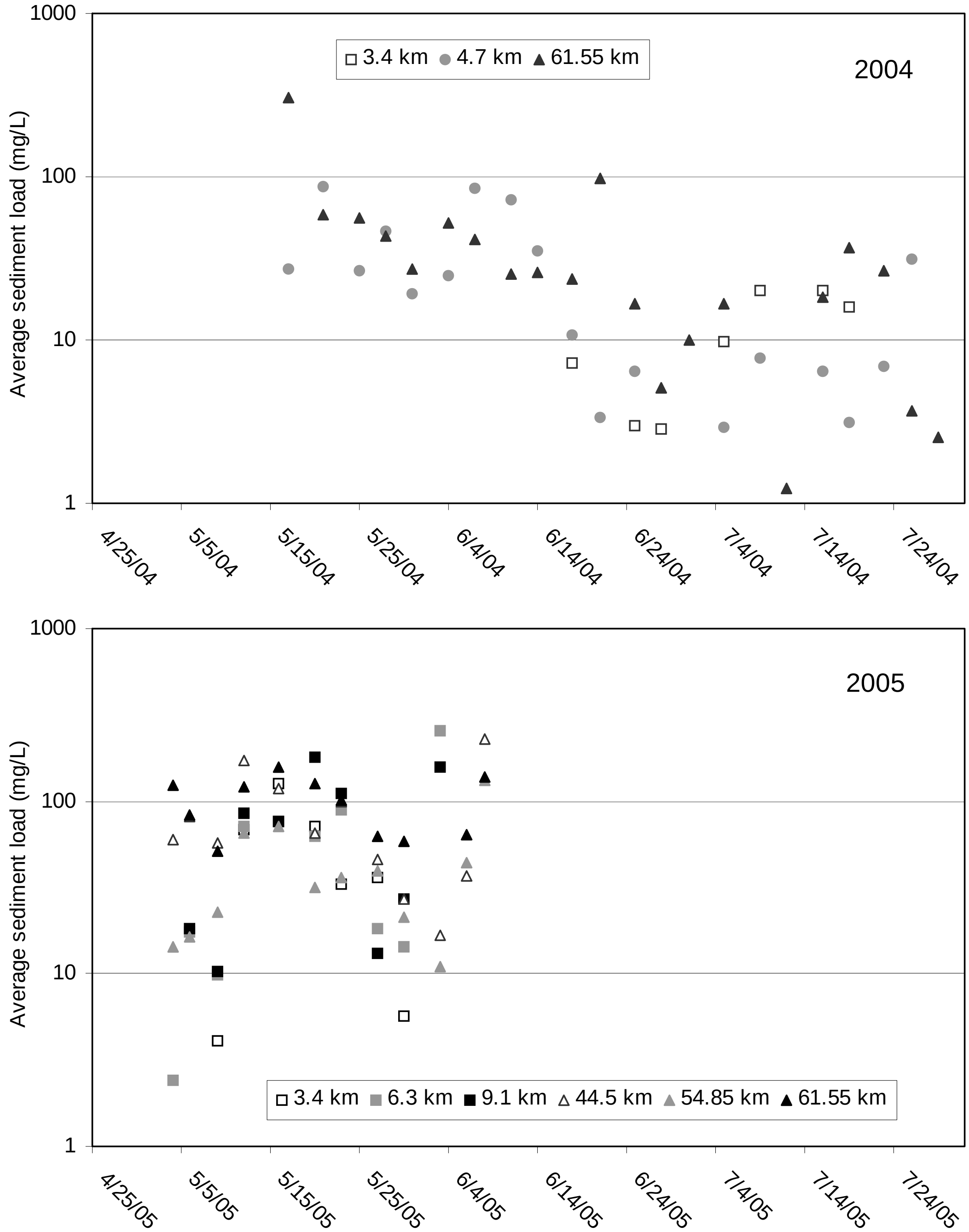

Figure 3-12 Suspended sediment loads (log) along the upper Little Bow River in 2004 and 2005.

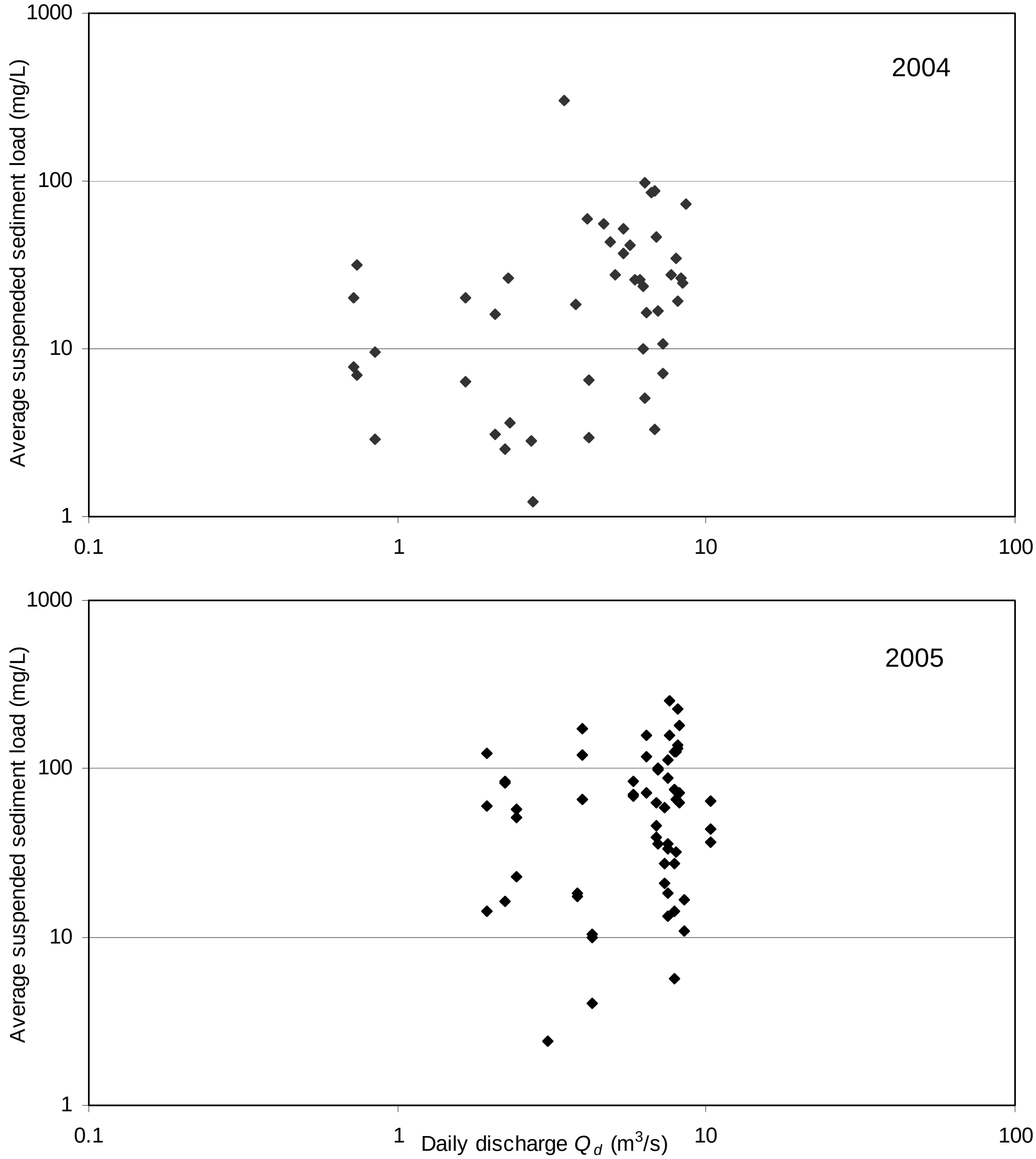

Figure 3-13 Relationship between suspended sediment loads (log) and daily discharge (log) along the upper Little Bow River during the spring months for 2004 and 2005.

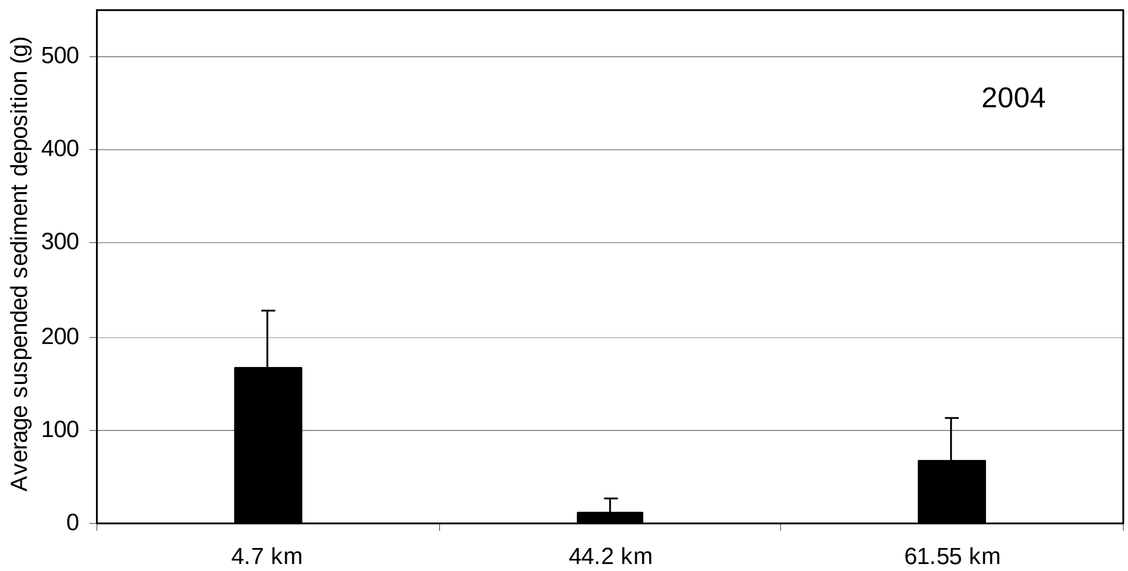

Figure 3-14 Average suspended sediment transport (+ SD) collected from May 28th to June 28th, 2004 along the upper Little Bow River.

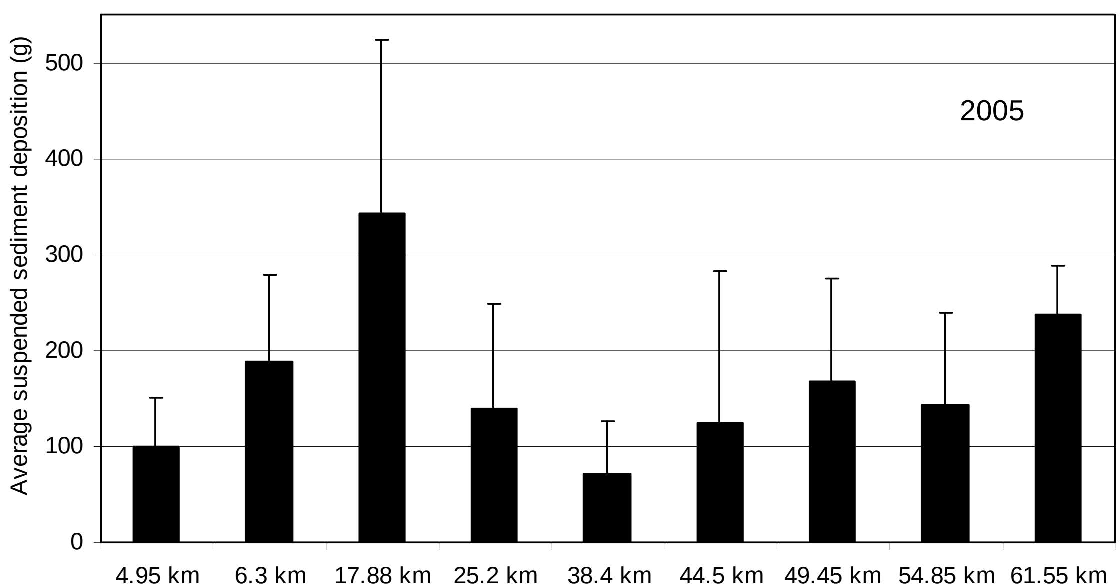

Figure 3-15 Average suspended sediment transport (+ SD) collected from May 12th to June 13th, 2005 along the upper Little Bow River.

The four cores located at LB08/09 (17.88 km) along the upper LBR had similar compositions (Figure 3-16). Particle size analysis of each core primarily ranged from medium sand to very fine silt. Standard deviation for each core represented the variation between different depths for each particle size. Medium sand to very fine sand showed the most deviation among the different depths in cores 1 and 4. The four cores characterize the substrate composition from valley wall to valley wall extending down to the gravel layer. Five cores were extracted at LB06/07 (25.2 km) and showed similar distribution of particle sizes as LB08/09 (17.88 km). Cores 1, 2 and 4 expressed variation at different depths (by larger standard error bars) for medium sand to very fine sand (Figure 3-17). One sample, core 5, also included fine gravels (See Appendix C for individual core data).

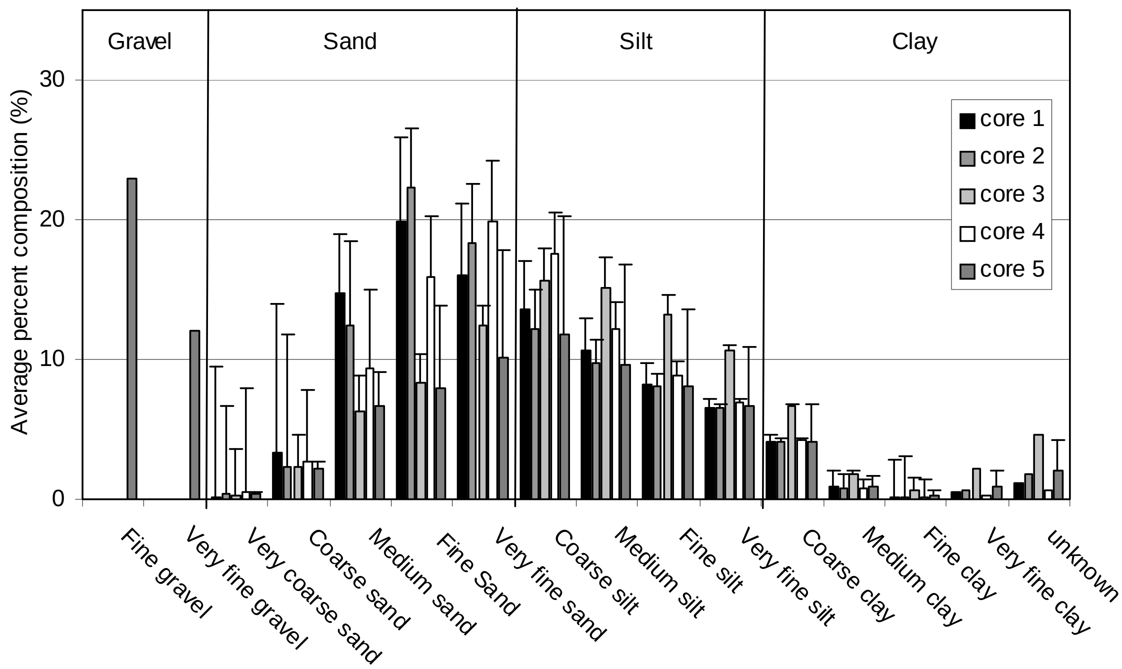

Figure 3-16 Average percent occurrence (+SD) of particle size for five different sediment cores at LB 08/09 (17.88 km) along the upper Little Bow River.

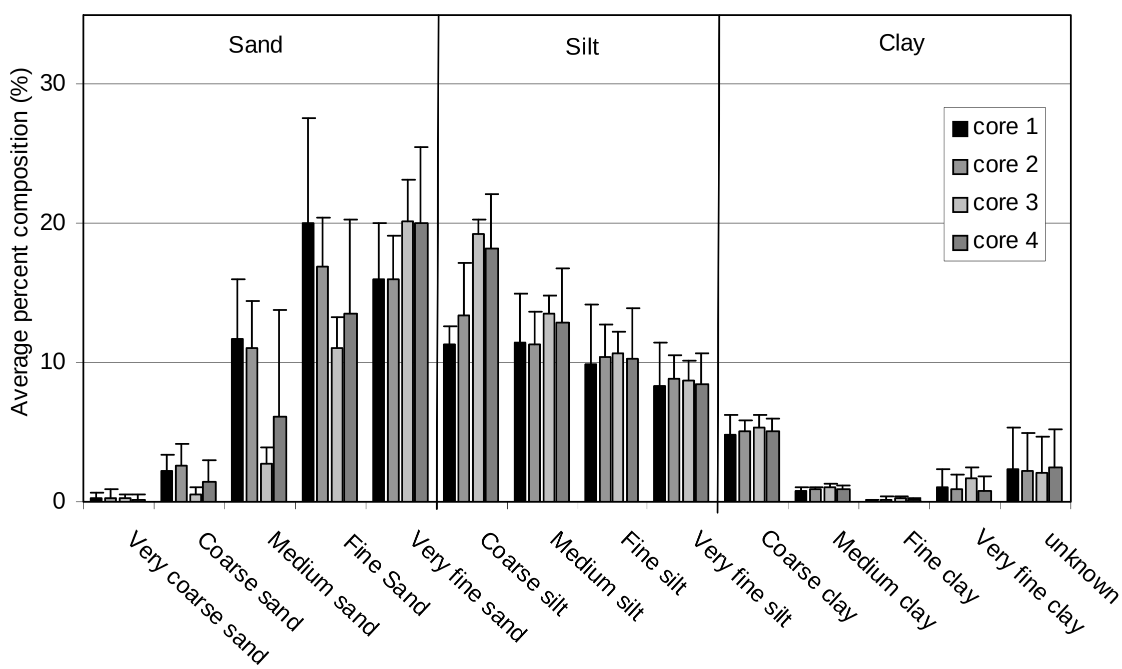

Figure 3-17 Average percent occurrence (+SD) of particle size for four different sediment cores at LB 06/07 (25.2 km) along the upper Little Bow River.

3.3.3 General observations

Photographs taken along the upper LBR in 2003, 2004 and 2005, illustrate the effect of increased flows. High velocities, flooding and bank slumping were observed during high flows. Initial implementation of increased flows in the spring of 2003 resulted in increased velocities especially at Q_{bf}. Figure 3-18 (8.2 km) illustrates high velocities along a section near the upper end of the study reach at a daily discharge of 8.05 m^3/s. Increased velocities were observed along the entire study reach. Flows exceeded channel capacity and inundated the willow and poplar floodplain directly downstream from the Little Bow Canal in 2003 (Figure 3-19 at 4.75 km). Low lying areas were inundated within all plant community types. Although inundated zones varied throughout the reach, localized flooding was a common occurrence during increased flows. Following the high flows, channel impacts also included bank slumping (Figure 3-20 at 8.2 km). The channel banks became unstable and vertical sheets of sediment collapsed into the channel.

In the spring of 2004 similar responses to increased flows were recognized. Figure 3-21 displays an inundated cattail zone at a distance of 55.15 km along the study reach when the daily discharge recorded at the #533 gauge (61.65 km) was only 4.65 m^3/s. Cattail zones were typically inundated and created a large amount of debris that was subsequently transported downstream. Debris consisted of fragmented remains of cattail stalks and rhizomes. In July of that year when flows had decreased (3.8 m^3/s at 61.65 km) deposition composed of fine sediment, was exposed just upstream from the cattail zone (Figure 3-21 at 55.15 km). Localized deposition zones were observed throughout the reach. Figure 3-22 (54.8 km) demonstrated the common practice of cattle grazing within the riparian zone. Figure 3-23 (at 32 km to 35.5 km) was taken from a low flying aircraft in September of 2004 and illustrates the middle portion of the study reach. Many attributes of the valley and channel can be recognized, especially a grass dominated landscape for a Bebb willow community along side the river. Extensive livestock grazing was also common throughout segments of the study reach.

For June of 2005 there was heavy rain within the region. Photos taken along a float on June 11th and 12th, 2005 revealed localized zones of major bank erosion and deposition. The discharge was unknown during this period due to flooding of the gauge along Little Bow Canal. Figure 3-24 (17.8 km) illustrates deposition of fine sediment and cattail debris along a point bar. Channel impacts included major bank slumping along concave banks (Figure 3-25 at 20.75 km) and further downstream, gravel bar deposition occurred. This observation was more common in areas dominated by grass (Figure 3-26 at 20.95 km). Recent erosion of concave banks revealed bank composition and formation, demonstrating the layered accumulation of gravels and finer sediments (Figure 3-27 at 27.6 km).

Figure 3-18 Increased velocities with increased flow on June 27th, 2003 at distance of 8.2 km along the upper Little Bow River (Q_d = 8.05 m^3/s) (S. Rood).

Figure 3-19 Inundation of the flood tolerant willow zone caused by increased flows on June 27th, 2003 at a distance of 4.75 km along the upper Little Bow River (Q_d = 8.05 m^3/s) (S. Rood).

Figure 3-20 Localized clump-erosion caused by increased flows on June 27th, 2003 at a distance of 8.2 km along the upper Little Bow River (Q_d = 8.05 m^3/s) (S. Rood).

Figure 3-21 Inundated cattails on May 25th, 2004 at a distance of 55.15 km along the upper Little Bow River (Q_d = 4.65 m^3/s) (S. Bigelow).

Figure 3-22 Livestock grazing and deposition on July 16th, 2004 at a distance of 54.8 km along the upper Little Bow River (Q_d = 3.8 m^3/s) (S. Bigelow).

Figure 3-23 The Little Bow Valley extending from 32 to 35.5 km along the upper Little Bow River on September 21st, 2004 (Q_d = 0.67 m^3/s) (S. Rood).

Figure 3-24 Deposition and debris on June 11th, 2005 at a distance of 17.8 km along the upper Little Bow River (Q_d = unknown) (S. Bigelow).

Figure 3-25 Bank slumping on June 11th, 2005 at a distance of 20.75 km along the upper Little Bow River (Q_d = unknown) (S. Bigelow).

Figure 3-26 Localized bank slumping and deposition of a gravel bar on June 11th, 2005 at a distance of 20.95 km along the upper Little Bow River (Q_d = unknown) (S. Bigelow).

Figure 3-27 Exposed stratified sediment layers along a concave cut-bank on June 11th, 2005 at 27.6 km along the upper Little Bow River (Q_d = unknown) (S. Bigelow).

3.4 Discussion

3.4.1 Re-survey of cross-sectional river and riparian transects

Aggradation and degradation processes can be monitored by repeating cross-sectional surveys at fixed transect sites (Gordon et al. 2004). Consecutive re-surveys along the upper LBR following the increased flow regime showed minimal change in comparison to the pre-project profile for 2002. The topographic profiles from 2003 and 2004 resembled similar patterns within each plant community. Riparian vegetation along the banks of a regulated channel provides an important element influencing the long-term width and pattern adjustment (Church 1995).

The poplar community transects were located near the upper end of the study reach and in close proximity to each other. Here, the channel was narrower and the increased flow would be proportionally greater than downstream. The channel bottom was composed of gravel and cobble (MSA 2003) which indicated armouring and resistance to scour. There was little evidence of livestock grazing both sites and the poplar communities included an under-story of dense shrubs. The cross-sectional transects indicated that the channel banks have apparently remained stable through to 2004 (Figure 3-5). Dense vegetation is known to provide bank stabilization (Patten 1998) and resistance to the increased velocities. However, poplars are not especially tolerant to inundation (Amlin and Rood 2001) and some poplar and willow zones in the upper reach were inundated at flows greater than 3 m^3/s (Samuelson and Rood 2003). Although the channel banks may remain stable with increased velocities, inundation stress may jeopardize survival and reduce bank stability.

The most upstream transect LB01 (4.7 km) was positioned within a willow community and subject to similar conditions as LB02 and LB03 (4.95 km and 5.25 km). Riparian willows, especially sandbar willow are more tolerant to inundation than riparian cottonwoods and poplars and are adapted to the lower-elevation streamside zones (Amlin and Rood 2001). The remaining transects residing in the willow communities demonstrated more variation within the profiles. Transects LB08 and LB09 (17.88 km and 17.85 km) existed in a location recognized in 2002 for large amounts of sediment deposition within the channel. Following the resurvey in 2003 and 2004, sediment appears to have been transported downstream, contributing to the increased channel depth observed in these two profiles (Figure 3-6). Rood et al. (2002) predicted the initial response to increased flow would primarily involve increased depth and velocity and subsequent adjustment would involve increased channel width. The profiles of LB10 and LB11 (8.5 km and 8.2 km) illustrated minimal change. However, livestock grazing and the presence of hummocks may contribute to local variations within the profiles across the years (Figure 3-6).

The channel bed along the wolf-willow transects remained stable throughout the monitoring period. The cross-section of LB06 (25.2 km) appeared to have widened, the predicted response to increased flows (Figure 3-7). Channel widening has been a common response to augmented flows (Kellerhals et al. 1979, Church 1995, Dominick and O'Neill 1998), especially in instances where channel beds are armoured (Bradley and Smith 1984). The profiles of LB24 and LB25 (27.13 km and 27.25 km) were fairly consistent throughout the monitoring period as indicated by minimal change (Figure 3-7).

The most visible impact was observed in the cattail communities, where increased flows and velocities produced scour and cattail removal which caused channel widening. The variation between years in the cattail profiles of LB16 and LB17 (55.2 km and 55.15 km) was most likely a result of modest bank erosion and slumping (Figure 3-8). During 2004 variation along the contour of the channel bottom was recognized as an accumulation of cattail debris that resulted from the cattail edge along the open channel collapsing and breaking away. Variation in the profiles of LB18 and LB19 (61.13 km and 61.2 km) were the result of different processes. These zones were prone to congestion from fine sediment deposition which had diminished by 2004 and was indicated in the cross-sections as channel deepening. Increased velocities caused an increase of debris along LB16 and LB17 (55.2 km and 55.15 km) and scoured fine material along LB18 and LB19 (61.13 km and 61.2 km).

The different responses probably reflect the different amount of fine sediment deposited along the two sites. The channel bed along LB16 and LB17 (55.2 km and 55.15 km) was a gravel bottom and channel widening is expected to be the primary result of increased flows. LB18 and LB19 (61.13 km and 61.2 km) are probably also restricted by the same gravel bed observed along all transects based on excavated samples taken from the channel bed that uniformly revealed thick deposits of gravel (MSA 2003). Provisional increase in depth along LB18 and LB19 (61.13 km and 61.2 km) is expected until the fine material is scoured revealing the resilient gravel channel bed. Although the initial response was greatest along the cattail sites, the long term outcome may not be as distinct. Cattails have the ability to thrive in flooded conditions but are also susceptible to periodic drought (Li et al. 2004). Conversely, their ability to adapt to fluctuating water levels allows them to dominate under a range of hydrologic conditions (Kercher and Zedler 2004).

Of the three re-surveyed graminoid sites, all were grazed and included regions with hummocks that may complicate the detailed transect profiles. LB12 (38.46 km) was the most consistent through the years surveyed and in 2003, LB12 (38.46 km) was the only transect without visible evidence of deposition (Samuelson and Rood 2003). The oscillating profiles of LB14 and LB15 (44.26 km and 44.2 km) are partly the result of extensive hummocks (Figure 3-9) and only minimal accumulation of sediment was observed in 2004. Transect LB13 (38.4 km) was not accurately relocated due to the removal of livestock yards and buildings and comprehensive reclamation along the left bank. Slight deviation along all profiles could be applicable for all transects as a result of relocation error of the permanent transects.

A definitive time frame expected for the channel to equilibrate and adjust to the new flow regime has not been determined. Monitoring up to 2004 indicated little change but multiple year effects may accumulate to later impact the stability of the channel. Church (1995) recognized three approaches to estimating the time-scale for adjustment of alluvial rivers. One approach considers the transport of sediments, another acknowledges the role played by riparian vegetation, and the most direct approach is by observation. Time-scale estimates are influenced by many variables and depend on the size of the river and the nature and severity of regulation (Church 1995). Unique to different systems, morphological adjustments of the sectional geometry may be relatively short, however, ecological changes and river pattern and gradient adjustment may take much longer (Church 1995). Since changes may not occur for a decade or more, re-survey of the cross-sections will not occur every year. Observations at comparative photo points determined that channel changes were small in 2005, therefore transects were not re-surveyed. The re-surveys of 2003 and 2004 did not include complementary plant inventory as these occur at longer intervals. Impacts on riparian vegetation have received less study (Henszey et al. 1991), probably because of the interpretation complexity and the time frame involved for adaptation.

Further potential influences that may deter the initial onset of channel change include instream aquatic plants, soil texture and land-use practices. There were aquatic macrophytes within the stream channel in the majority of the cross-sectional transects. Macrophytes increase frictional resistance to flow (Clarke 2002) and affect sediment and nutrient dynamics. Increased frictional resistance may reduce velocities and therefore reduce the impacts on the channel cross-section. Macrophyte beds also enhance deposition of fine sediment that would otherwise be eroded (Carpenter and Lodge 1986). Loss of accumulated fine sediments within the channel with the onset of increased velocities may be the cause of the slight deepening in some of the profiles.

Knowledge of materials that might be exposed to erosional processes is an essential prerequisite to an attempt at predicting the outcome of a diversion (Kellerhal et al. 1979). Consequently, the particle size of the substrate comprising the valley bottom floodplain was determined. Substrate primarily consisted of medium sand to very fine silt in all cores (Figure 3-16 and 3-17). Sand particles are non-cohesive and thus do not stick together. Silts exhibit more plasticity and cohesion and clay particles are particularly cohesive (Brady and Weil 2002). These are very small particles that have a high capacity to absorb water. There was little clay in the substrate and therefore floodplain composition was not considered a major influence on bank stability.

Grazing was observed along a number of transects and may have local impacts on channel stability within the reach. The deleterious effect of grazing on soil properties depends on stocking density, soil texture, and soil water and vegetation type (Chanasyk and Naeth 1995). As well, fine-textured soils are more susceptible to compaction. These variables differ along the study reach and may have caused additional impacts to local channel stability and sediment dynamics. The presence of cattle in streamside inundation zones was evidenced in 2003 by the effects of heavy grazing and pugging of vegetation and impacts were considerable in nine of the ten transects accessed by cattle (Samuelson and Rood 2003).

3.4.2 Discharge and sediment

Hydrographs for 2004 generally demonstrate the flow regime proposed by the new Highwood Diversion Plan. Augmented flows reached 8.5 m^3/s through May and June, an increase of almost three-fold over the previous Q_{bf} (Figure 3-10). Some fluctuation occurred along the hydrograph and was probably a combined result of precipitation events and flow management. Flow operations may vary further until the Highwood Diversion Plan is finalized. As a component of the Highwood Diversion Plan, an Interim Diversion Plan (IDP) was developed in 2004 and this will be effective until recommendation on a final Highwood Diversion Plan is made (HAP-PAC 2004). Several scenarios have been explored to define a Diversion Plan that will guide flow operations of the Little Bow Project.

In 2004, the hydrograph at Highway #533 (61.65 km) varied less abruptly than the canal (0 km) (Figure 3-10) and progressively increased to peak flow. This displayed a time lag as diverted flows travel downstream and Rood et al. (2002) determined it would take approximately one day for flow from the Little Bow Canal to reach the junction of the upper LBR and Mosquito Creek. In addition to augmented flows, run-off along the reach increases downstream, increasing flows along the lower sections. Vegetation cover and land-use within the basin will also influence the hydrograph shape. Since vegetation affects infiltration rates, its removal can increase direct run-off (Gordon et al. 2004). Near mid-July the flow regime fluctuates, a possible result of small rain events or run-off from irrigation.

Flows along the Little Bow Canal in 2005 were ramped up about 8 m^3/s in May. However, due to the complexity of two control gates, discharge along the LBR in June was unknown and did not correspond to the dramatic shifts shown in the hydrograph (Figure 3-11). Heavy rain in the region caused significant flooding along the Highwood River and subsequently augmentation along the LBR was postponed until flooding diminished.

Sediment was collected along the upper LBR in the spring of 2004 and 2005 to determine the quantity of sediment that was transported and deposited during the increased in flows. It was also intended to provide insight into sediment dynamics and rates of change. Sediment load varies from stream to stream and is affected by geology, soil forming processes, vegetation, and climatic regime (Leopold 1997). Frequent systematic sampling is an essential basis for understanding suspended sediment and solute transport (Richards 1982). Continued monitoring will provide the best foundation for understanding sediment dynamics along the upper LBR. In addition, suspended sediment is non-uniformly distributed with depth across the channel and a transverse and vertical integration is necessary (Richards1982). Therefore, five samples were equally distributed across the channel cross-section at each site and averaged to determine the sediment load.

Suspended sediment collected in 2004 primarily provided background on methods and appropriate samplers and locations. Sediment was sampled at only three locations and sampling was not initiated until after flows exceeded channel capacity due to difficulty accessing flow operation plans. However, the most substantial sediment transport occurs when discharge is increasing and corresponds to the rising limb of the hydrograph (Leopold 1994). Once flows exceed bankfull and inundate the floodplain, velocities decrease and sediment settles on the floodplain. The smaller particles remain in suspension longer than the larger particles and the rate at which they settle is determined by their weight (Leopold 1997). Therefore, the crucial period to determine suspended sediment was missed and Figure 3-12 does not an accurately represent the sediment load regime in 2004.

Sampling along the canal (3.4 km) was not initiated until later in the season. During that period the sediment load ranged between the load gathered at LB01 (4.7 km) and #533 (61.65 km). The concentration at LB01 (4.7 km) was less than the canal (3.4 km) and indicated that sediment transported from the canal was deposited prior to the LB01 (4.7 km) site. Therefore, sediment transported along the canal should not have provided a significant contribution to sediment load along the remainder of upper LBR as flows decreased from the 8.5 m^3/s peak flow.

The upstream sampling site (LB01 at 4.7 km) was located along a slight bend and appeared to trap excess sediments due to the confining nature of a bridge downstream. The location was not considered representative of the suspended sediment load and the corresponding discharge. The transport of solids is not controlled by stream discharge but by associated flow characteristics such as bed velocity, shear stress or stream velocity that vary along a stream of constant discharge to cause spatial variations in competence and discontinuous bedload movement (Richards 1982).

Sampling in 2005 occurred at more locations along the river to provide a more representative collection. Sampling was initiated prior to the increase in flows. However, the prospects for a standard data set were eliminated due to heavy rains in the region and a change in flow operations from the Highwood River. Further, the last few suspended sediment samples in collected in 2005 do not correspond to the discharge gauged along the Little Bow Canal. They were collected at an unknown discharge after the Highwood Diversion head gates were closed below the hydrometric gauge.

The sediment load in 2005 was generally higher than 2004 prior to the heavy rain (Figure 3-12) although sampling sites were not the same in 2004 and 2005, except 61.55 km. The substantial increase in sediment loads in 2005 indicates that the banks may have been more susceptible to erosion than in 2004. Although some rain occurred during the sampling of 2005, most of the suspended sediment samples were collected before the heavy rains and suspended sediment typically includes slope runoff and bank erosion (Richards1982). Precipitation has been widely understood to have a predominating influence on river and sediment discharges (Gupta and Chakrapani 2005).

There was not a substantial difference in sediment load from upstream to downstream and no longitudinal pattern existed. Even though sediment transport may increase downstream due to upstream erosion, this would also depend on bed and bank material and the competence of the increased flows (Bradley and Smith 1984).

The variation among the values from site to site may correspond to a number of variables such as streamside vegetation, adjacent land use and substrate composition. Vegetation intercepts runoff, providing a slower integration into the river and reducing the amount of sediment entering the river (Gordon et al. 2004). Localized areas adjacent to the river were barren due to intensive livestock operations and were more exposed to channel erosion. Variation of sediment loads among the different locations may also be determined by the presence of aquatic plants. The instream plants alter flow velocities within the channel and impact on sedimentation (Clarke 2002). Macrophyte beds enhance deposition of fine sediment that would otherwise be eroded and transported along the stream (Carpenter and Lodge 1986). Particle size was not accounted for in either year but was observed to be generally a mixture of fine particles with some sand.

Without historical records of sediment dynamics it is difficult to distinguish other factors that may cause variability in sediment loads and deposition, such as grazing. Temporal and spatial variations have been observed along other rivers and should be considered especially during extreme events such as the spring of 2005 (Gupta and Chakrapani 2005).

One particular site along Highway #2A (9.1 km) may not have provided typical readings. It was located downstream from an intensive livestock operation positioned directly adjacent to the channel. Samples were taken from the downstream side at which the bridge pillars created turbulence and swirled the sampling device and may influence vertical sampling through the column of water. This site should be reconsidered for future sampling.

The relationship between sediment load and discharge for 2004 and 2005 was illustrated in Figure 3-13 and corresponds to Figure 3-12. Suspended load corresponded to discharge in 2004, although some residual deviation was apparent and although the relationship was weak, there appears to be a positive correlation. A positive correlation between sediment load and discharge was the common result found in other studies (Chen et al. 2001, Day and Spitzer 1984, Gupta and Chakrapani 2005). The scatter observed could be accounted for by periodic increases in sediment load from bank slumping and channel flushing as well as external impacts, such as livestock. Although the correspondence was slight, the channel was strained and may be responding with small adjustments. The sediment load and discharge relationship along the Little Bow River was scattered in 2005 and probably resulted from increased bank erosion and bank slumping. Sediment load along the canal was also high and reflected suspended sediment in the water diverted from the Highwood River. Although stream flow integrated with sediment transport provides an estimate of sediment yields (King and Emmett 2004), further calculations to determine cumulative sediment loads were not undertaken due to the complexity from the extremely unusual conditions of 2005. Sediment deposition was evident in 2003 along the streamside inundation zones (Samuelson and Rood 2003). Deposition samples collected in 2004 and 2005 were incomplete but did provide future indication of sediment deposition. Two of the three sampling sites used in 2004 were relocated following further assessment (Figures 3-3 and 3-14). LB01 (4.7 km) was located upstream from a foot-bridge and was determined to collect excess sediment deposition. The location was moved downstream in 2005 to LB02 (4.95 km). LB14/15 (44.2 km) was located downstream from a cattail zone in 2004 that also functioned as a sediment trap. The location was subsequently moved downstream of 658 Ave (44.5 km) in 2005 and was situated within a cattail zone. The location of Highway #533 (61.65 km) was determined suitable and was not adjusted in 2005. The issue of positioning was resolved in 2005 and all locations were considered ideal. However, heavy rainfall and fluctuating water levels created saturated banks, heavy deposition and bank slumping and some of the containers were not recovered. Therefore, some locations were composed of only averages of three or four samples (Figure 3-15). Sediment in all samples in 2005 was higher than 2004 and may reflect the influence of heavy rain. The profile of Figure 3-15 was bimodal for reasons that are unclear. However, LB08/09 (17.88 km) had the highest deposition rate and complements observations made during the re-survey at that location. Accumulation of fine sediments at LB08/09 (17.88 km) was also observed along the float in 2005.

3.4.3 General observations

In general, the field observations were consistent with other findings. Following both the test flows in 2003 and the implementation flows in 2004, the channel was minimally altered although somebank slumping occurred. However, considerable channel impacts were recognized in localized areas in 2005. Observations were consistent with the expected sequence of adjustment resulting from the increased flows. Rood et al. (2002) predicted that the initial response to increased flow would primarily involve increased depth and velocity and subsequent restructuring of the channel cross-section would primarily involve increased channel width.

Velocity and channel area (width x depth) are a function of discharge (Leopold 1994). The channel area along the LBR has not yet expanded to accommodate the increased discharge and the velocity must increase with respect to discharge. An increase in velocity was a common observation along the study reach (Figure 3-18 at 8.2 km).

As discharge increases and exceeds the channel capacity, discharge over-tops the bank and inundates the floodplain. Flood events are considered physical disturbances and involve processes that particularly impact riparian vegetation (Amlin and Rood 2001). An increase in stream stage typically results in saturated substrates and partial or complete plant submergence. Over-bank flooding was commonly observed along the study reach and was restricted to low-lying zones, generally adjacent to the river channel (Figure 3-19 at 4.75 km and Figure 3-21 at 55.15 km). Following inundation, established vegetation is vulnerable to flood-induced mortality and displacement by more invasive species such as reed canary-grass (*Phalaris arundinacea* L.). Plant community response to inundation may vary and will largely be based upon flood tolerance of particular species.

High velocities potentially erode sediments and scour plants along the bank (Amlin and Rood 2001) and localized cases of bank slumping resulted (Figure 3-20 at 8.2 km). Increased velocities also increase the stream's physical competence to transport and deposit alluvial sediments and excess deposition was also observed along particular zones of the study reach (Figure 3-22 at 54.8 km). However, the predominant conclusion from the comparison of sequential photos following 2004 was that initial change was slight.

The presence of livestock grazing along the upper LBR was captured in various photos (Figure 3-22 at 54.8 km and Figure 3-23 at 32 to 35.5 km). Grazing can cause the breakdown of stream banks and increased erosion from trampling that reduces bank stability and resistance (Belsky et al. 1999), as well as increase sediment deposition and inhibit growth and survival of deep-rooted plants that anchor and stabilize channel banks.

June of 2005 was characterized by extreme rainfall and effects were seen along the majority of the study reach during the float. Zones of significant bank slumping and formation of gravel bars (Figure 3-26 at 20.95 km) were observed at various locations along the reach. Major erosion of concave banks was obvious from fence lines and sign-posts that had partially fallen into the channel (Figure 3-25 at 20.75 km). Eroded concave-banks exposed the vertical substrate profile and the gravel layer (Figure 3-27 at 27.6 km) that was recognized in the other monitoring methods. Cattail debris was also prominent in various sections along the study reach (Figure 3-24 at 17.8 km) and large boulders were observed in the downstream section. During the float it was apparent that the rain was a factor influencing channel change in 2005 because mud slides along the valley were observed and these would not have been impacted by stream flows. It was also evident that land management practices played a role in channel stability. Livestock grazing was observed to cause pugging and bank degradation, as well as significant impacts to dominant plant communities in the middle reach.

3.5 Conclusions

At this early stage in the long-term study, monitoring indicated a slight impact from increased flows diverted from the Highwood River. The current assessment indicates that the upper LBR system is in the adjustment phase and following the heavy precipitation of 2005 the future channel response might accelerate.

In other studies, channel widening was the predominant response to accommodate augmented flows (Bradley and Smith 1984, Kellerhals et al. 1979, Church 1995, Dominick and Neill 1998). Channel expansion has been minimal so far although localized areas have undergone major bank slumping and accumulation of sediments. Slight channel deepening has also occurred in areas characterized by fine sediment in 2002 (Samuelson and Rood 2003). This response is expected to be small based on the presence of a resistant cobble and gravel along the study reach.

Although general similarity was observed along cross-sectional profiles within the different plant communities over the years studied, species tolerance to flooding may determine survival and successional establishment. Riparian vegetation may play a substantial role in channel stability and the resulting communities along the study reach. Follow-up plant species inventories along each transect will distinguish changes within each community and continuous surveys will indicate varied vegetation and channel impacts among the different plant communities.

Other variables, macrophytes and livestock grazing may have local effects on channel and vegetation adjustment and fragment system response to increased flows.

Uncontrolled variables such as precipitation patterns may also have a substantial impact on the rate and intensity of change along the upper LBR. Extreme events will influence the time scale predicted for the channel and riparian vegetation to reach equilibrium.

Continued monitoring will provide a better understanding of vegetation and channel processes and sediment dynamics in response to augmented flows. As well, it will reveal the temporal sequence and associations of different processes along the upper Little Bow River.

CHAPTER 4 - PREDICTED FUTURE RESPONSES ALONG THE UPPER LITTLE BOW RIVER

The Little Bow River (LBR) is located in the semi-arid region of southern Alberta and flow has been augmented from the Highwood River since 1898 (NRCB/CEAA 1998). Prior to diversion from the Highwood River, the LBR had an intermittent flow regime, only flowing naturally with spring melt or heavy rains and/or with overflow from the Highwood (NRCB/CEAA 1998). Due to the irregular flow it did not naturally support riparian woodlands. Diversion facilities were constructed to augment flows to compensate for reduced flows during the summer months and to support irrigation demands. This artificial flow regime changed the LBR from an intermittent to a perennial stream that allowed for the establishment of riparian woodlands (Rood et al. 2002). Increased demand for irrigation from the LBR resulted in the Little Bow/ Highwood Rivers Project that expanded the conveyance capacity of the pre-existing facilities from 2.85 m^3/s to 8.5 m^3/s (MSA 2001). This tripling of diversion flows has substantially altered the hydrologic regime along the upper Little Bow River. In this thesis, the predicted impact to the channel and riparian vegetation from increased instream flows was reviewed and supplementary predictions were considered.

Flow augmentation is an uncommon form of flow manipulation (Stromberg and Patten 1992). Studying the effects related to flow augmentation on a case-by-case basis will provide better understanding for generalizations in relation to riparian community type, geomorphic type and the extent of manipulation. The predominant response to flow augmentation has been channel widening (Bradley and Smith 1984, Kellerhals et al. 1979, Church 1995, Dominick and Neill 1998). A ten percent and greater increase in channel width occurred over a thirty-five year period along the Milk River following substantial augmentation from the St. Mary River in Montana (Bradley and Smith 1984). An increase in mean flows along the Milk River has lead to increased erosion rates on meander bends and increased sediment loads and has apparently increased rates of lateral migration (Bradley and Smith 1984).

As a river channel adjusts to increased flows, over bank flooding occurs and inundates the floodplain. Augmented flows initially flood the streamside zone and result in standing and flowing water (Henszey et al. 1991). Comparison of an augmented reach and a control reach concluded that flow augmentation played a role in increased willow mortality along the upper Owens River in California (Stromberg and Patten 1992), a result from adverse physiological effects of inundation and from removal of streamside trees where flood flows caused bank slumping and erosion. That study also accounted for other factors that influenced willow abundance and determined that livestock grazing complicated the effects of flow augmentation from a negative correlation between cow dung and willow abundance.

As the channel accommodates the new flow regime, benefits may be observed in riparian vegetation resulting from an elevated water table and more water availability. Empirical evidence from a semi-arid watershed indicated that mixed deciduous riparian forests varied as a function of stream flow parameters. Species richness was greatest along streams with intermediate flood magnitudes (Stromberg 1993). Another study determined that stream flow augmentation elevated the natural ground water level along a river in southeastern Wyoming (Henszey et al. 1991).

Riparian trees and shrubs such as poplars and willows are native on the floodplains of perennial streams within the semi-arid ecosystems of southern Alberta (Floate 2004, Amlin and Rood 2002). These riparian plants depend on supplemental ground water that infiltrates from the stream (Amlin and Rood 2002). Both genera are extensively clonal, although seeds are the principal mechanism for dispersal (Mahoney and Rood 1998). Recruitment of cottonwoods and poplars is dependent on flood events that cause geomorphic impacts and particular hydrologic patterns (Rood and Mahoney 1990). Although there are many variables involved, seedlings require barren substrate and suitable flow conditions for recruitment and establishment.

Due to the long period predicted for channel adjustment and impact on riparian vegetation, riparian succession is apt to play a dominant role in the development of the new riverscape (Church 1995). Long-term monitoring will be important because response will vary over time and differ along successional stages. Different studies have been implemented at various stages and observations vary according to the spatial or temporal methodology. Studies comparing adjacent streams investigate spatial differences that may occur at a particular stage of stream adjustment, where as a study that compares changes along a stream over time provides a temporal scale.

The LBR previously had a bankfull discharge (Q_{bf}) that equalled the prior diversion flow of 2.85 m^3/s (MSA 2001, Rood et al. 2002). Commencing in 2004 the augmentation flow was nearly tripled to 8.5 m^3/s and occurs for an average of 6 weeks annually and will provide a major hydraulic disturbance (Rood et al. 2002). In response to this dramatic flow increase two contrasting predictions are offered regarding possible ecosystem responses.

1. Since water is a fundamental limitation in semi-arid environments, supplemental flow will enhance the aquatic and riparian conditions. The system will thus respond through progressive change without catastrophic consequence. Or conversely,

2. River ecosystems represent complex systems in which dynamic equilibria is gradually established. The dramatic flow augmentation represents a major perturbation that will severely disrupt the system. Thus, change will involve system break-down and then reestablishment of a new system. During break-down there will be increased vulnerability to stresses such as from livestock and exotic invasion.

The first prediction, gradual change without major impact, was made by previous investigators. These studies concluded that except for localized areas the upper LBR was capable of conveying the augmented flow of 8.5 m^3/s and occasional flooding would occur in narrow, low-lying areas (Yaremko and Adams 1992). That prediction was not challenged during the environmental impact assessment (NRCB/CEAA 1998) but with the undertaking of further hydraulic modeling, project engineers questioned the proposal. Subsequently, further analysis has lead to the second prediction; the system will break down and re-establish to accommodate the new instream flow regime (Rood et al. 2002).

The general steps and variables outlining the predicted response along the upper LBR are as follows:

(1) with the increase in flow (2.85 m^3/s to 8.5 m^3/s) there will be over-bank flooding and

(2) subsequent flood-induced vegetation mortality in the inundated riparian zone,

(3) allowing erosion and transport of underlying bank sediments,

(4) creating a wider, but not deeper, channel that will accommodate the augmented flow (Figure 4-1).

(5) As the channel widens, over-bank flooding will diminish, allowing recolonization through seedling recruitment in the barren, eroded zones.

(6)The nature of the new riparian vegetation will depend substantially upon the hydrologic regime provided by Alberta Environment and this could promote desirable native plants such as willows and balsam poplar, or undesirable invasive weeds such as foxtail barley (*Hordeum jubatum* L.).

(7) Increased spring and early summer flows may improve water quality for the aquatic ecosystem, including fish.

(8) However, land-use practices, and particularly cattle use in the river and riparian zone will influence all of the processes by accelerating vegetation removal and bank erosion, by retarding recolonization by native plants, and by degrading water quality and aquatic conditions.

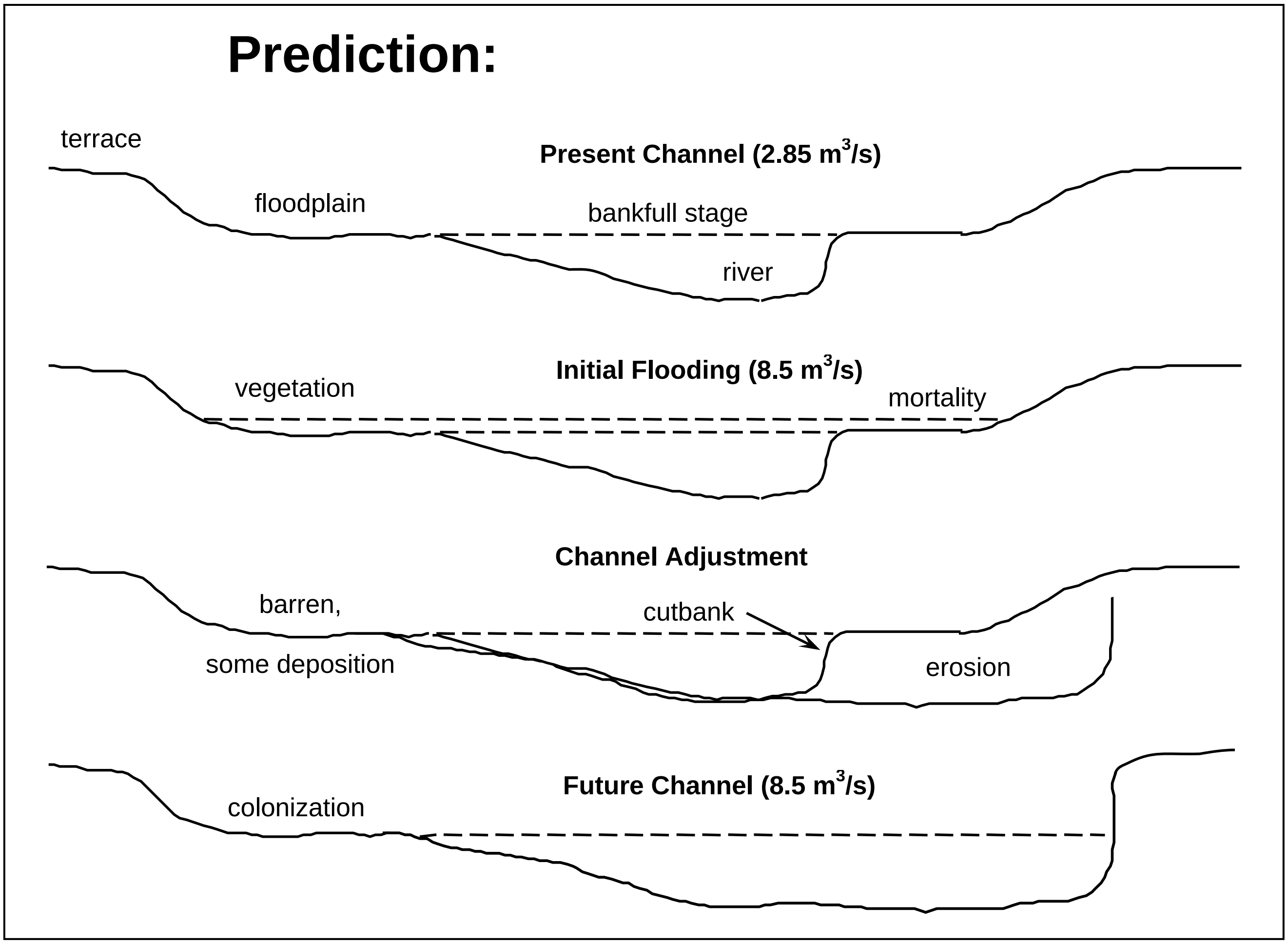

Figure 4-1 Cross-sectional representation of the predicted channel and vegetation responses along the upper Little Bow River, following a tripling of flow augmentation which commenced in 2004.

The Q_{bf} is defined as the discharge that is conveyed within the channel at full capacity (Leopold 1994). Once discharge exceeds Q_{bf} the river overtops its banks and inundates the floodplain. Based on recurrence or period augmentation the Q_{bf} will increase from 2.85 m^3/s to 8.5 m^3/s. The initial response will include over-bank flooding and inundation of the riparian zone (Figure 4-1). Inundation can inflict an anaerobic environment (Amlin and Rood 2001) on the established vegetation. Loss or mortality of riparian vegetation adjacent to the active channel is a common response to transbasin diversion practices (Dominick and O'Neil 1998). However, some plants can adapt to these conditions, for example, a study following two years of elevated surface and groundwater levels and shallow flooding, herbaceous vegetation shifted towards more water tolerant species (Henszey et al. 1991). Water and sediment may influence both mortality and natality rates of riparian species although it is unclear whether mortality results primarily from 1) the force of flowing water causing physical damage (uprooting) or 2) physiological intolerance of plants to anaerobic conditions (Baker 1989). The driving factor may depend largely on channel response and timing of channel adjustment.

Discharge is a function of cross-sectional area and velocity (Leopold 1974) and these variables must increase to compensate for an increase in discharge. Until the channel expands to accommodate the larger flows, the velocity will increase. A major increase in flow will eventually increase channel width and depth (Kellerhals et al. 1979). The primary predicted response is channel widening because a cobble/gravel channel bottom along the study reach (MSA 2003) will restrict any significant increase in channel depth. Some channel incision may occur in localized areas until fine material has been flushed, exposing the resistant layer. If increased depth is inhibited by the cobble/gravel bed, then increased velocity and channel width will compensate for the increased flows.

Ultimately the channel of the upper LBR would widen. Impact would be most significant along the upper section of the study reach as it is typically narrower. While depth can be variable throughout a stream, channel width tends to be a consistent channel feature that progressively increases downstream in response to a progressive increase in discharge. Following from calculations provided in Rood et al. (2002), the future channel along the upper LBR will be one-half to three-quarters wider than the current channel, although relative widening will progressively diminish downstream. The average channel width determined from 2001 orthophotos was 18.7 m yielding an expected increase in channel width of approximately 9.4 m to 14 m. Other geomorphic responses following increased flows include increased rate of meander migration as material is eroded and deposited (Bradley and Smith 1984). However the meander length will increase to accompany channel widening following the flow augmentation along the upper LBR (Rood et al. 2002) and the reflected channel straightening would display decreased sinuosity.

The likely sequence and associations of different processes is unclear. For example, it is unclear whether bank erosion will immediately follow flow augmentation and lead to undercutting, uprooting and loss of vegetation, or alternately whether vegetation mortality due to anoxic inundation will first occur and subsequently expose mobile bank sediments for erosion. Thus, the temporal sequence should reveal system ‘drivers’ and the rates of change will provide insight into process dynamics.

Two possible prospects for system response were considered. First, the rate of change will continue to be slight over time and thus the channel widening and adjustment of riparian vegetation may progress over many years and even a number of decades. Or second, there may be a threshold response whereby the riparian vegetation may survive inundation up to some point at which mortality would be abrupt. If this were accurate, in some future year(s) there will be extensive mortality of riparian vegetation that will subsequently allow more rapid sediment scour and channel widening.

With the modest responses following both the test flows of 2003 and the implementation flows of 2004, plant species tolerance to inundated conditions may dictate the response. The response was minimal and flooding conditions may prevail for several years. This indicates that flood tolerant species such as cattail and willow would dominate in areas undisturbed by land management practices. However, if bank slumping and erosion processes continue, species tolerance to inundated conditions may not be as critical in determining system response, whereas species ability to stabilize banks may be.

Scoured banks may provide a unique opportunity along the upper LBR suitable for seedling recruitment. However, willow establishment will not become abundant until the river floodplain system has re-equilibrated which may take decades (Leopold 1964, Stromberg and Patten 1992).

Sediment data was inadequate to make predictions regarding rates of erosion and deposition along the channel. Higher suspended load values in 2005 indicated that the channel is adjusting and sediments are eroding. However, the heavy rain in June 2005 may alter current predictions and accelerate the channel adjustment process. Localized channel response observed along the float in 2005 following the initial rain event included major bank slumping and gravel bar formation. Significant impacts in localized areas following the rain event could have been the result of a vulnerable system weakened by prior flows, and impacts were emphasized during the 2005 rains. Or system break-down has been accelerated and will be vulnerable to climatic controls in following years. However all conclusions are provisional and will be verified with future monitoring.

Two primary influences may have substantial impact on the channel and the structure and productivity of riparian vegetation. These variables are flow operation management and land management. In the process of channel adjustment the banks are eroded and will provide barren sites suitable for seedling recruitment and establishment of riparian cottonwoods and poplars. The flow conditions suitable to promote seedling survival are high flows that precede seed release, flow recession that permits establishment at appropriate streambank elevations, gradual flow decline for seedling survival and the absence of large floods in the following year (Rood et al. 1999). Typically, flow stabilization has led to channel stabilization and reduced cottonwood recruitment (Rood et al. 1999). Probable environmental impacts of different flow diversion scenarios have been reviewed by Rood et al. (2003b) to provide an assessment of different flow conditions and riparian vegetation.

Heavy grazing has a detrimental effect on the soil parameters of bulk density and penetration resistance (Chanasyk and Naeth 1995). Livestock grazing has been found to have negative impacts on stream channel morphology, hydrology, riparian zone soils, instream and streambank vegetation as well as other parameters and no positive environmental impacts were found (Belsky et al. 1999). Observation along a float in 2005 revealed that plant communities varied across fence lines and particularly that grasses dominated grazed areas and sandbar willow dominated ungrazed riparian zones along the middle section of the study reach. It appeared that if riparian zones along the middle section were fenced from cattle, the potentially dominating plant community would be sandbar willow especially in zones prone to saturation. Sandbar willow tends to be more tolerant to flood inundation than poplars and less tolerant to drought stress (Amlin and Rood 2001). However, land management practices may play a significant role in the establishment of present and future plant communities and inflict more stress on a vulnerable system and enhance overall impacts. With improved livestock grazing practices dramatic improvements in rangeland and riparian area conditions can be achieved (Oman 1998). Land management impacts could be minor with revised tactics.

Continued monitoring of changes occurring to the river channel and riparian vegetation will provide an understanding of the spatial and temporal sequence of processes along the upper Little Bow River and other augmented streams. Monitoring will also ultimately show whether response will be a continual gradient of change in physical parameters and established plant communities or step-wise variation representing threshold responses.

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APPENDIX A

Tan slope along the upper Little Bow River

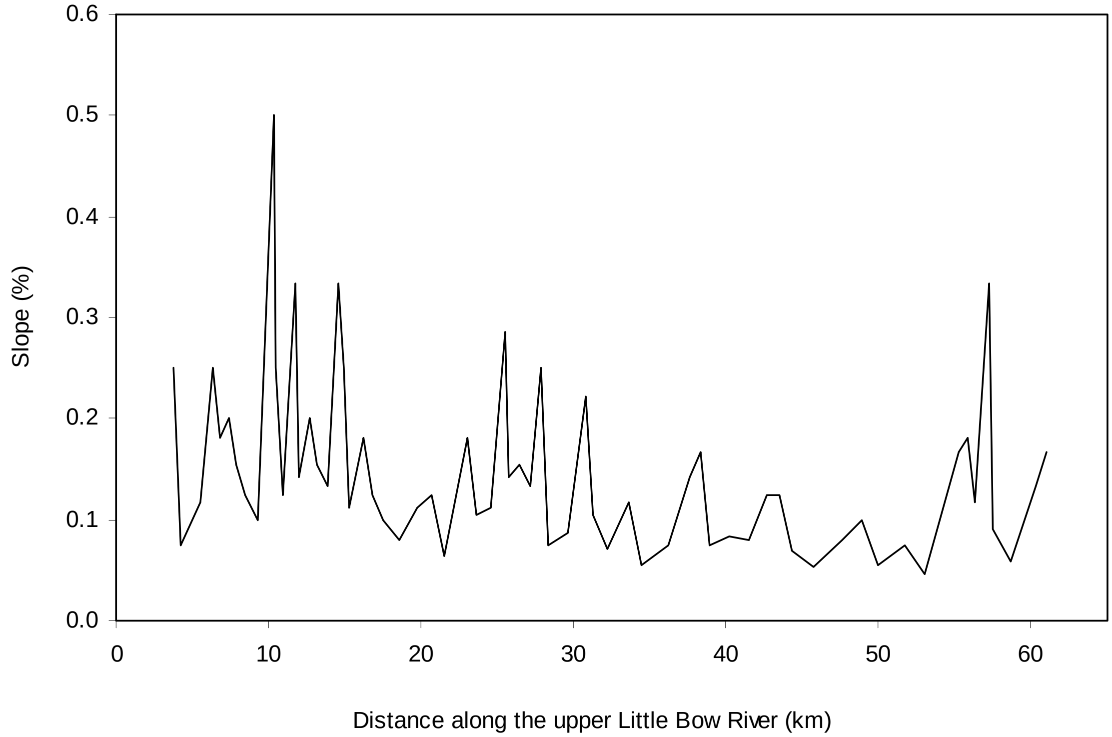

Figure A-1. Slope (channel gradient) along the upper Little Bow River.

APPENDIX B

Sediment core data

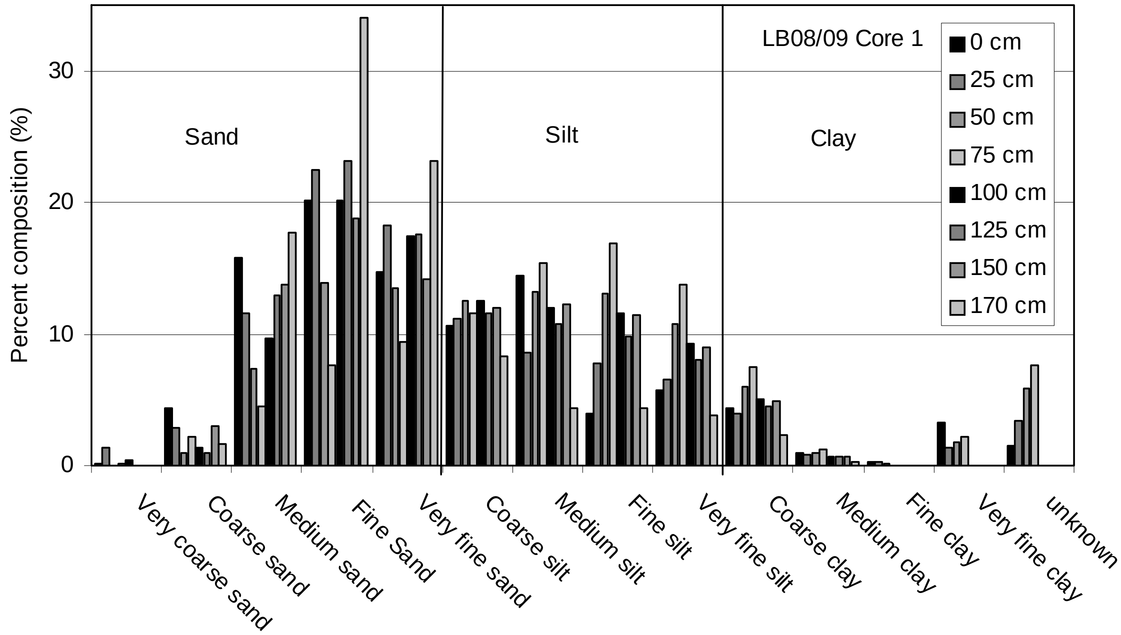

Figure B-1. Percent occurrence of particle size for sediment core 1 taken at LB08/09 (17.88 km) along the upper Little Bow River.

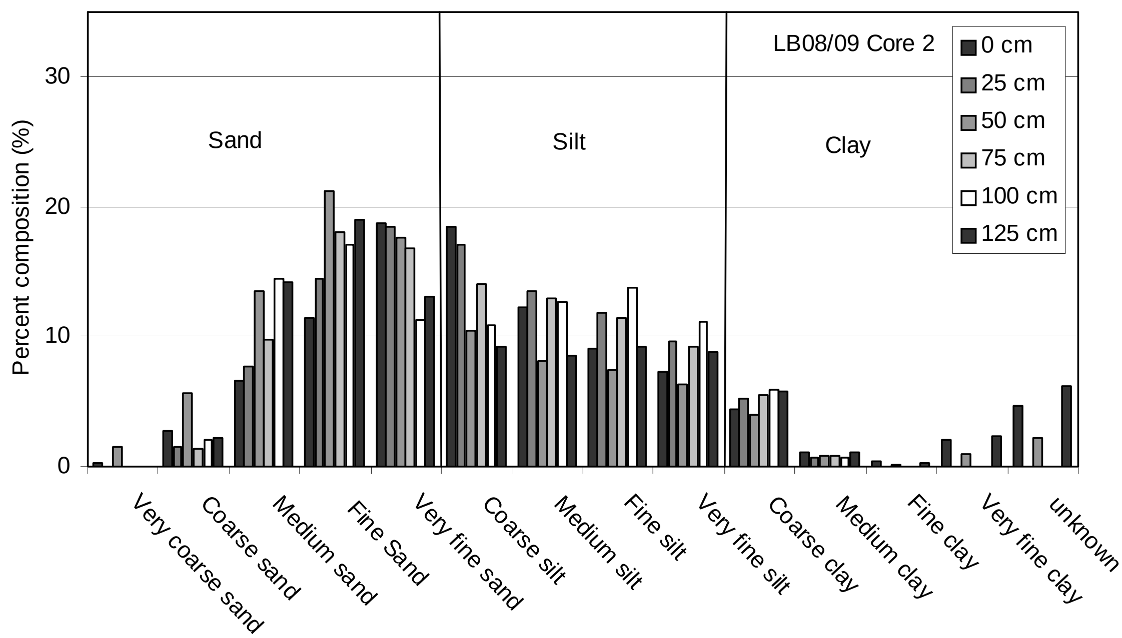

Figure B-2. Percent occurrence of particle size for sediment core 2 taken at LB08/09 (17.88 km) along the upper Little Bow River.

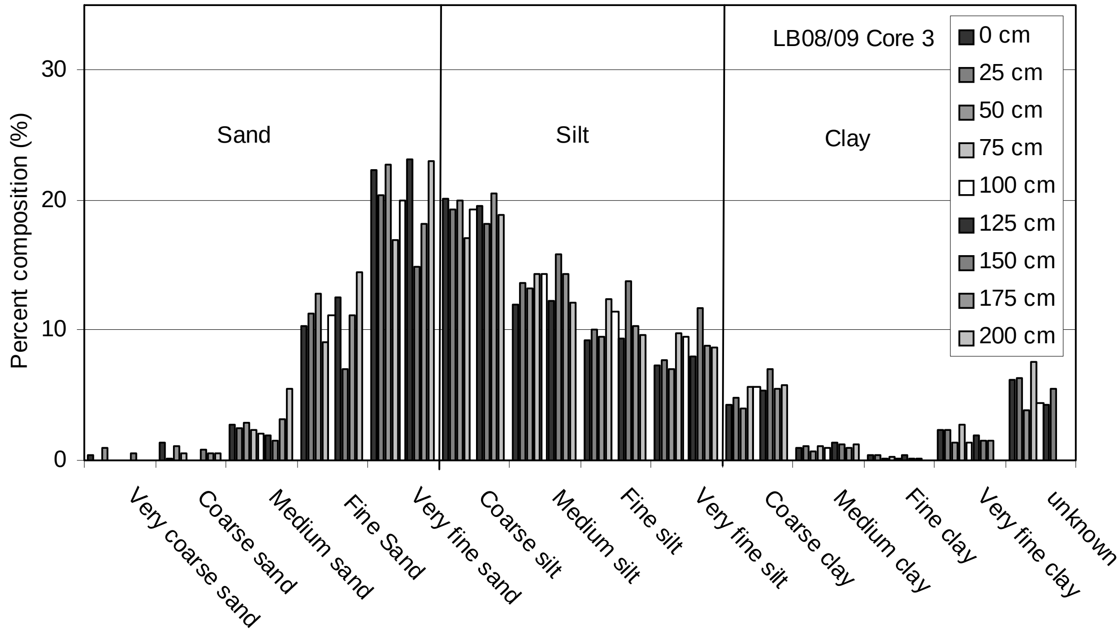

Figure B-3. Percent occurrence of particle size for sediment core 3 taken at LB08/09 (17.88 km) along the upper Little Bow River.

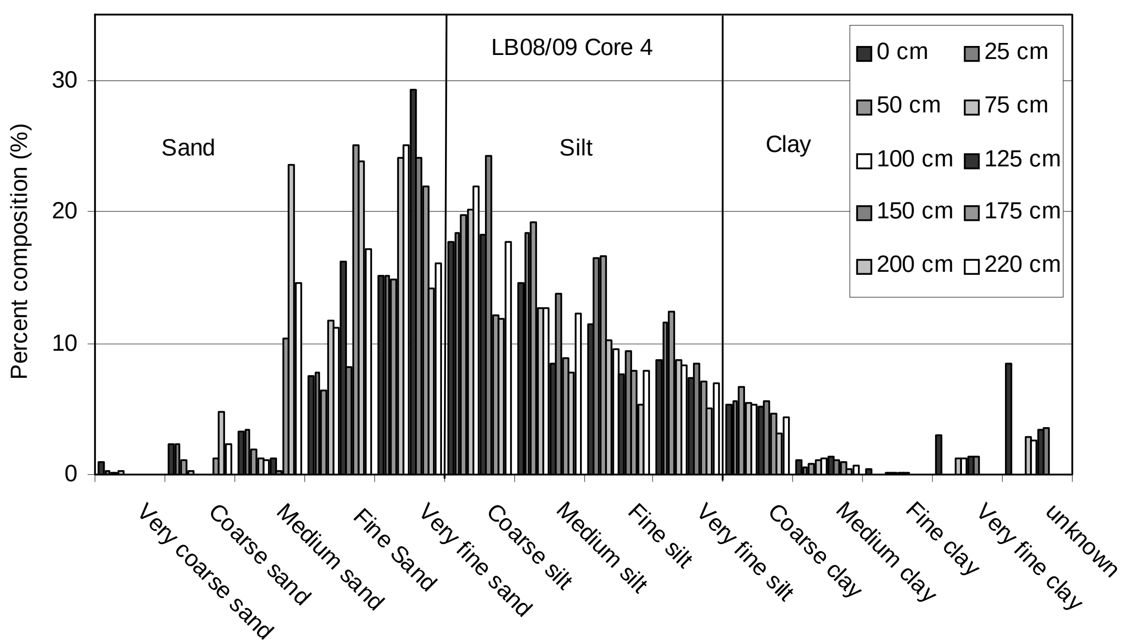

Figure B-4. Percent occurrence of particle size for sediment core 4 taken at LB08/09 (17.88 km) along the upper Little Bow River.

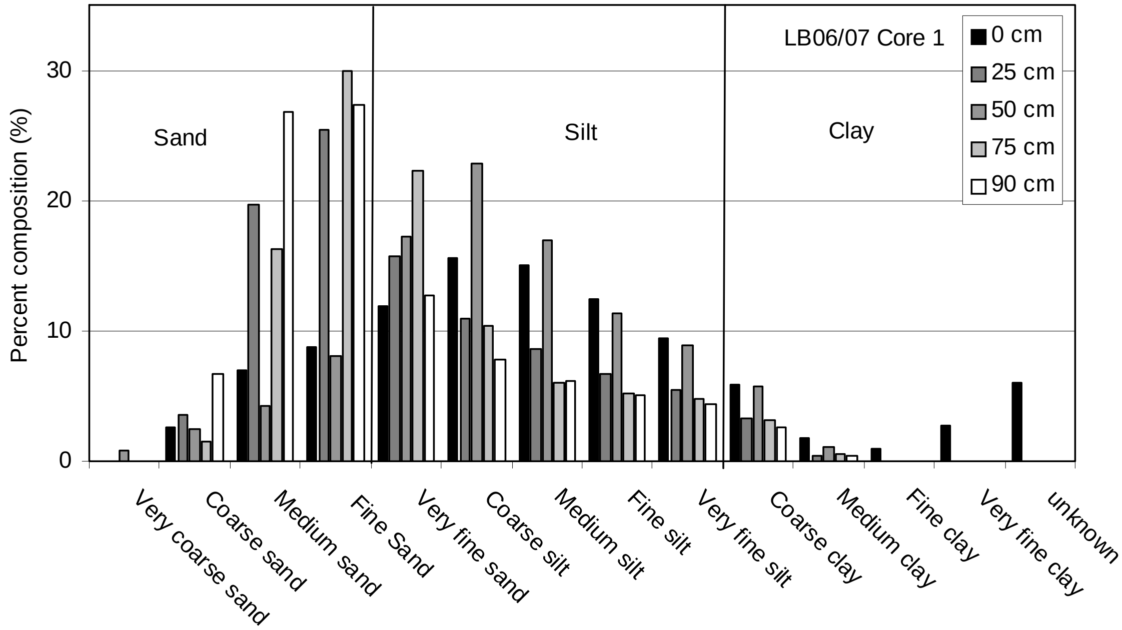

Figure B-5. Percent occurrence of particle size for sediment core 1 taken at LB06/07 (25.2 km) along the upper Little Bow River.

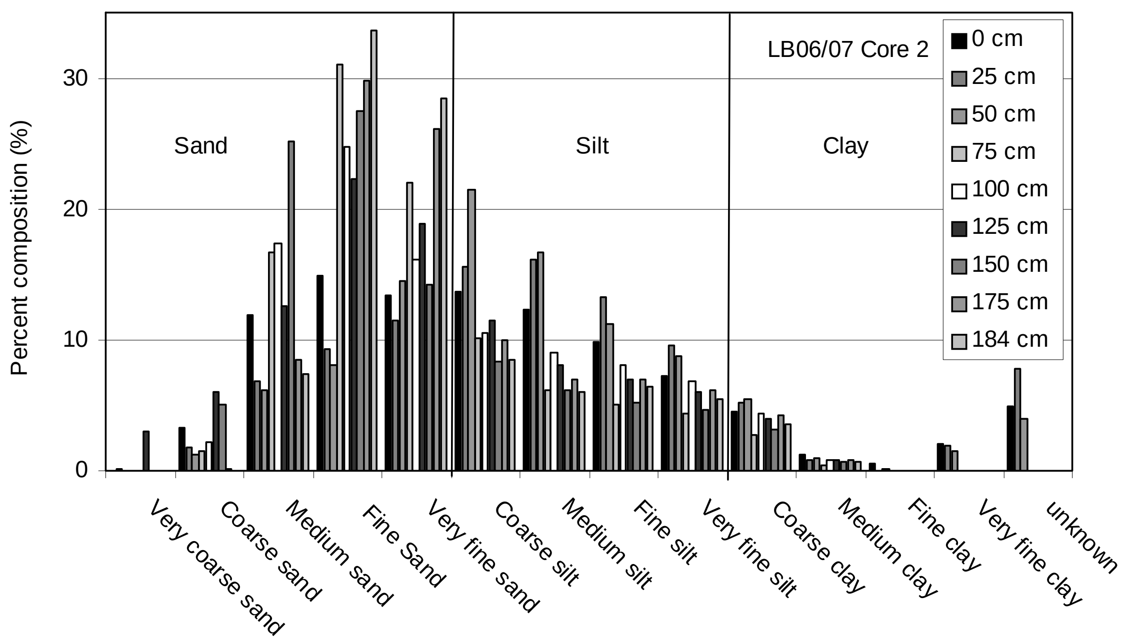

Figure B-6. Percent occurrence of particle size for sediment core 2 taken at LB06/07 (25.2 km) along the upper Little Bow River.

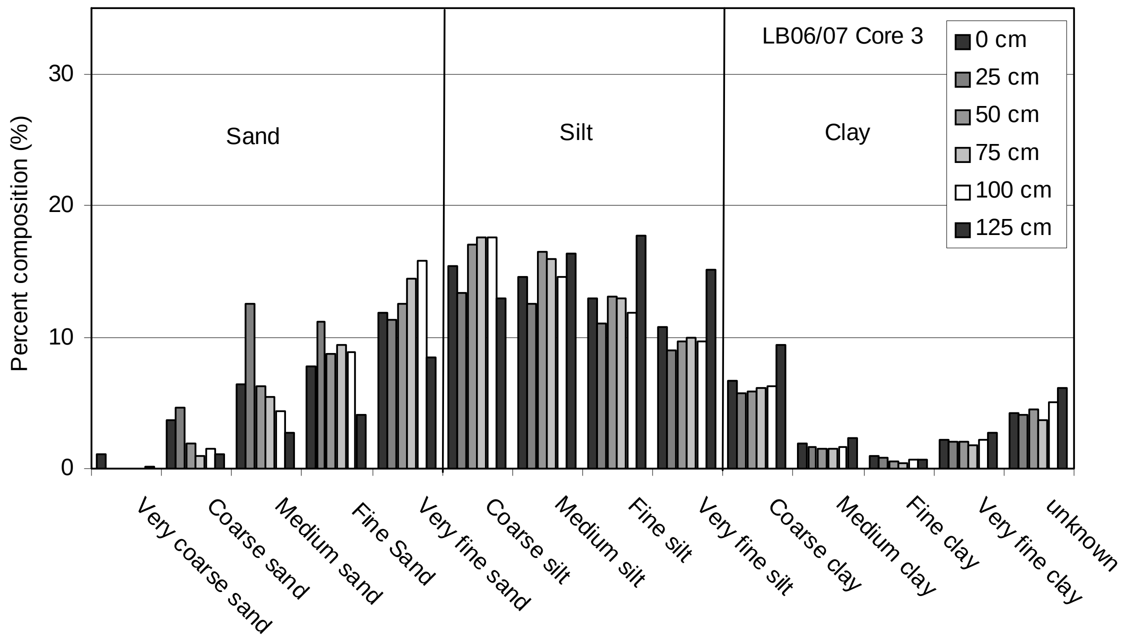

Figure B-7. Percent occurrence of particle size for sediment core 3 taken at LB06/07 (25.2 km) along the upper Little Bow River.

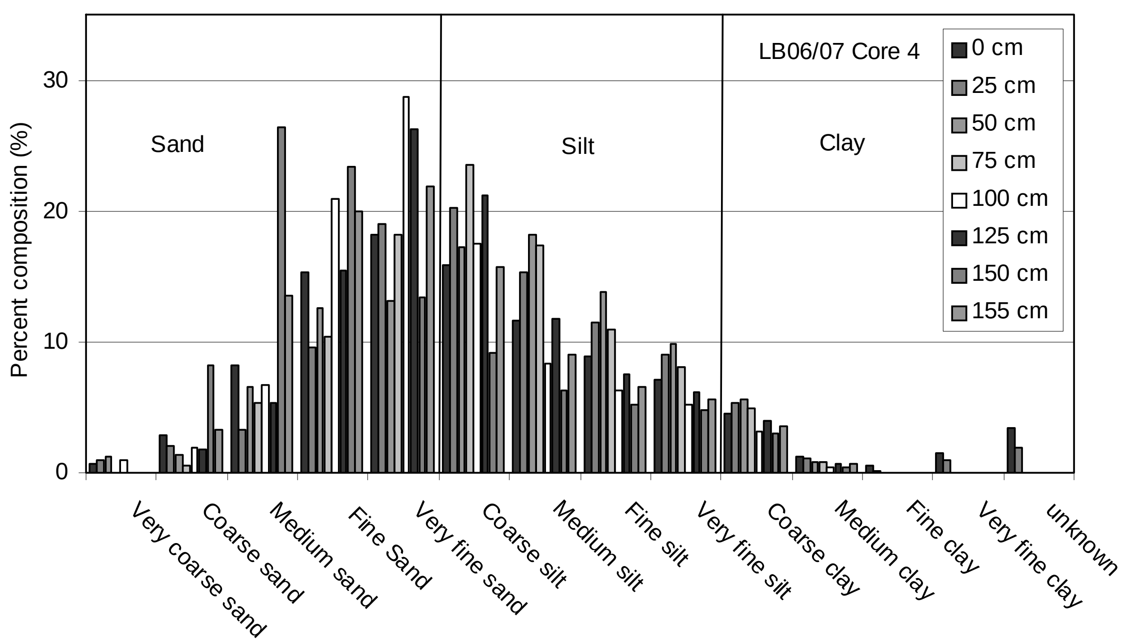

Figure B-8. Percent occurrence of particle size for sediment core 4 taken at LB06/07 (25.2 km) along the upper Little Bow River.

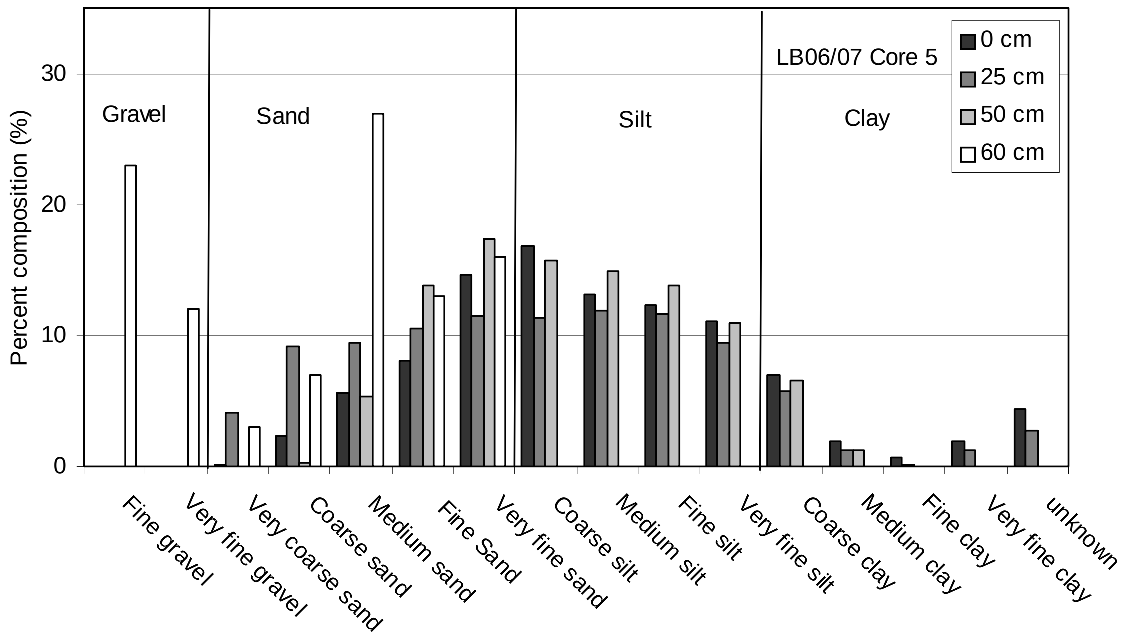

Figure B-9. Percent occurrence of particle size for sediment core 5 taken at LB06/07 (25.2 km) along the upper Little Bow River.