8.0 CHANNEL MAINTENANCE INSTREAM FLOW NEEDS

8.1 Background - Channel Maintenance Flows

The objective of this section is to define the flow regime needed to maintain the channels of the South Saskatchewan River Basin study reaches. This flow is referred to as the Channel Maintenance Flow (CMF). In the literature terms such as Regime Flow and Channel Forming Flow have also been used for this type of flow.

In the Regime Theory of self-formed channels (Blench 1967), channel maintenance flow is defined as a steady flow that will maintain a channel in the same hydraulic regime (i.e. same average width, depth and slope) over a long period of time. The channels are referred to as alluvial channels, meaning they flow in deposits of unconsolidated or partially consolidated river laid material, in a stream valley. The basic assumption in Regime Theory is that the channels are free to adjust the hydraulic variables (width, depth and slope) in response to imposed variables of discharge (Q), sediment load (Q_S) and bed material (D_S).

Flushing Flows is the term used to describe flows with velocities that will move fines (silt, sand) out of coarser riverbed materials and keep them in motion. Such flows do not have enough power to remove gravels (Milhous 1990). Flushing flows are important for reducing silt build-up in the coarse bed material habitats used for the spawning and incubation life stages of many fish species. Coarse bed materials also provide cover habitat for many species of fish and a variety of benthic invertebrate species.

Bed mobilization or channel maintenance flows are of a greater magnitude than flushing flows and are sufficient to initiate general bed material transport. Bed mobility flows result in the formation and movement of physical habitat features such as riffles, pools, runs, point bars.

McNamara et al. (2000) provide the following definition for Channel Maintenance Flow:

> *"… Instream Flow that is intended to maintain the physical characteristics of the channel so that the ability of the channel to convey stream flow and bed load sediment is maintained. These flows are initiated only during periods of high stream flow and are required to accomplish channel maintenance – it is assumed that channel maintenance flow would at the same time provide adequate flows to sustain riparian vegetation".*

Andrews and Nankervis (1995) provide another definition for Channel Maintenance Flow:

> *"…dimensions, morphology and other physical characteristics of… gravel-bed rivers are primarily determined by a well-defined relatively narrow range of discharges… these results establish the basis for forming a regime of stream flows which will substantially maintain the existing physical characteristics of… river channels when natural flows are appreciably altered."*

The above definitions convey the concept that, under natural conditions, the bed of a stream channel becomes mobilized over a certain range of flows and that there are reasons to favour maintaining this regime under regulated conditions. Decreasing the natural extent, frequency and duration of mobile bed conditions could result in encroachment of vegetation into the channel, reduced channel widths, self-armouring of bed surfaces, and reduced channel capacity.

Milhous (1980) applied single case methods for determining flushing flows that had previously been suggested by various authors. He obtained a six-fold range of recommended discharges; evidence that there was no generally agreed upon concept or definition of flushing flows. Milhous suggested defining the term on the basis of specific values of the Shields (Mobility) Number, as calculated from hydraulic and sediment parameters.

Andrews and Nankervis (1995) proposed a procedure to establish an effective discharge (ED) as part of determining the CMF for a gravel bed river. It was argued:

> *"…The relationship between discharge and the characteristics of a channel is complex. Thus one must consider a range and frequency of occurrence for the Channel Forming Flows rather than a single (or dominant) discharge".*

They incorporated a concept by Wolman and Miller (1960) that essentially states that most of the sediment transported over a period of years is associated with an intermediate range of discharges. Andrews and Nankervis (1995) point out however, that most researchers had applied this concept to suspended load and that their results were more applicable to problems like the impact of deforestation in a basin. They went on to suggest that an effective discharge for maintaining the bed load regime (magnitude and frequency) in a river would be more related to the Channel Forming Discharge. They computed rates and durations of bed load transport for 17 reaches using a bed load function by Parker. Based on the results, the following conclusions were drawn:

> *"On the average, those flows that transported the modal 80 percent of the long-term bed-material load ranged from 0.8 to 1.6…bank full discharge…"*
>
> *" The bank full discharge of 17 gravel-bed rivers are in excellent agreement with the interval of discharge that carries the largest quantity of bed material over the period of record…it was concluded that the range of effective bed-material transporting discharge are flows which construct and maintain these channels over time."*
>
> *"A substantial majority of channel maintenance flows, both number of days and volume, would occur during large runoff years. Little or no maintenance flows would occur during years with below average runoff."*
>
> *"Commonly in gravel-bed streams, the bed is active only 5% to 10% of the time. With appropriate selection of flow conditions when diversion is allowed, up to 60% of natural flow volume can be diverted without reducing channel capacity and channel maintenance flows."*

Annear et al. (2002) state that the structure and function of riverine systems are based on five riverine components: hydrology, biology, geomorphology, water quality, and connectivity. Therefore, the objective of an instream flow prescription should be to sustain the intra- and inter-annual variability of the natural flow regime as closely as possible. Flow regimes must address both instream and out-of-stream needs and integrate biotic and abiotic processes. For these reasons, inter- and intra-annual instream flow prescriptions are needed to preserve the ecological health of a river.

Flows in the range between overbank flows and those that initiate the movement and suspension of the smallest particles provide a number of ecosystem functions, including hydraulic habitat for riverine organisms and the support of floodplain vegetation. As detailed in Section 7.1, high flows are essential to the survival of riparian cottonwood seedlings. The magnitude, duration and seasonal timing of peak and overbank flows all affect the success or failure of annual seeding events. Changes to any of these characteristics of peak flows can reduce seedling recruitment and lead to gradual deterioration of riparian forests.

Hydraulic habitat is related to the shape of the channel, the bed and bank sediments, and the water that flows through and sometimes over the channel. As such, instream flow determinations must not focus solely on habitat-discharge relationships. Rather, they must also address the dynamic nature of alluvial channels and sustain the processes that define the channel.

It is important to recognize that the physical habitat essential to aquatic and riparian communities is dependent on periodic disturbance that in the short term may be detrimental to individual organisms. High flows reset the system by forming new channels, scouring vegetation, abandoning side channels, and creating habitat beneficial for some species over the long term. Such a resetting of the system is an essential and naturally occurring process. Any comprehensive instream flow analysis must account for these kinds of changes by prescribing the flows necessary to maintain the dynamic nature of an alluvial channel.

Channel form has been described as a direct result of interactions among eight variables: discharge, sediment supply, sediment size, channel width, depth, velocity, slope, and roughness of channel materials (Leopold et al. 1964, Heede 1992, Leopold 1994). For many alluvial streams, the channel exists in a state of dynamic equilibrium in which the sediment load is balanced with the stream's transport capacity over time (Bovee et al. 1998). When sediment load exceeds transport capacity, aggradation and alteration of the channel form will occur. When transport capacity exceeds sediment load, as is often the case below a storage reservoir, the channel may adjust by degrading the bed. Clearly, alteration of flow regimes (Schumm 1969), sediment loads (Komura and Simmons 1967), and riparian vegetation will cause changes in the morphology of stream channels (Johnson 1998).

Bankfull flows are important for forming and maintaining stream channel cross-sectional area and habitat in alluvial streams (Leopold et al. 1964). Bankfull stage is generally defined as the height of the floodplain surface or the flow that "just fills the stream to its banks" (Gordon et al. 1992), or the stage at which water starts to flow over the floodplain (Dunne and Leopold 1978). The floodplain is the relatively flat depositional area adjacent to the river that is formed by the river under current climatic and hydrologic conditions (USFS 1995). Bankfull flow is subject to minimum flow resistance (Petts and Foster 1985) and transports the most sediment over time (Inglis 1949, Richards 1982, Andrew and Nankervis 1995). Bankfull events have been determined to have a recurrence interval of approximately 1.5 to 3.0 years (Leopold et al. 1964, Mosley 1981), but in streams with sharp peak flows and accentuated low flows, the channel capacity may be more influenced by less frequent, greater magnitude events (Gregory and Walling 1973). Studies by Smith (1973) of Alberta rivers found an average bankfull recurrence interval of 16.7 years, varying between 2.4 to 45 years. Smith hypothesized this was due to high channel capacity. He proposed ice jamming as the mechanism for channel enlargement (Smith 1973). Aquatic habitat is also related to bankfull flows because scour in pools and deposition of bedload in riffles and bars is most predominant at bankfull flow (Leopold et al. 1964).

Determination of the bankfull flow condition through field observation is difficult and subjective (Johnson and Heil 1996). Floodplains may not be obvious along all stream channels. They are most noticeable along low gradient streams. In steep gradient channels, floodplains may be intermittent, on alternate sides of meander bends, or completely absent. It is also important not to confuse the level of a low terrace, located up to several metres above the present streambed, with that of the floodplain, and to be able to recognize disturbed and incised channels (USFS 1995). The use of regional relations between bankfull discharge and channel characteristics, such as those found in Dunne and Leopold (1978), can be helpful for determining where to look for the floodplain and bankfull stage in specific geographic regions of the country. In severely altered systems, the bankfull discharge concept may be too simplistic. In these cases, site-specific studies of bedload relations and transport capacity may be needed (Rosgen 1996).

Geomorphological considerations require more than providing bankfull flows. It is also important to accommodate channel migration, sediment transport, scour and deposition, bank erosion, and vegetation encroachment in determining channel maintenance flows. Changes in bed profile, bed material distribution, instream cover, overhead cover, velocity patterns, island or bar formation and removal, among others, should be considered (Annear et al. 2002).

One of the most difficult challenges that must be addressed in an IFN study, is to determine the entire range of channel maintenance flows, with magnitude, frequency of occurrence, and duration similar to the natural flow regime (Andrews and Nankervis 1995). Producing only flushing flows will not maintain, in perpetuity, the hydraulic characteristics of the channel, or the habitats of the stream dwelling organisms that rely upon them. What is needed to maintain the channel regime is a description of an instream flow requirement based on the naturally-occurring frequency of discharges within the natural range of flow variability. The objective of specifying channel maintenance instream flow needs is to maintain the hydraulic characteristics of the river channel, an important component in providing for the protection of the aquatic ecosystem.

8.2 Review of Methods

The following principles, as outlined by Wolman and Miller (1960), form a reasonable basis for reviewing various methods available for calculating the channel maintenance flows:

- Channel maintenance flows are needed in the range between streamflows that begin to mobilize bedload materials and the highest natural flow on record.
- Incrementally higher percentages of flow are needed as flow approaches bankfull, because that is when the river does most of its work in transporting sediment and maintaining fish habitat.
- Ideally, a range of flows is needed (as opposed to a single, specified high flow). Though higher discharges move more sediment, they occur less frequently, so that over the long-term, they move less bedload than more frequent, lesser discharges.

The Technical Team reviewed several well-documented sediment transport models that can be used to determine flows that move bed material. These included, among others:

- HEC-6 (US Army Corps of Engineers 2001a);
- Bed Material Transport Methodology (Reiser et al. 1988);
- Incipient Motion Methodology based on the Meyer-Peter Mueller formula (Meyer-Peter and Mueller 1948, Reiser et al. 1988); and
- Rosgen geomorphic stream classification system (Rosgen 1985, 1994, 1996).

The Instream Flow Council suggests all these methods are acceptable for determining channel maintenance flows (Annear et al. 2002). In addition to the above methods, an approach used by the U.S Forest Service (Gordon 1995), and an approach used by the State of Wyoming, (Annear and Day 2000) were reviewed. These appeared to be promising in that they take into account the pattern of natural flow variability (i.e. duration, frequency, magnitude and timing).

All the methods are useful and if properly applied, should provide meaningful guidance. Some will provide channel maintenance instream flow recommendations. The Rosgen geomorphic stream classification system is a classification system rather than a method to define site specific instream flow recommendations. From the review it was found that some of the methods are data intensive. As directed by the SSRB Steering Committee, no additional data could be collected for this study. Therefore, the HEC-6 model could not be used. Data did exist from previous studies, however, that allowed for the use of a type of sediment transport model. The application of this approach is described in detail in Section 8.3.

The Wyoming Fish and Game Department (Annear and Day 2000) developed a channel structure flow model based on the one developed by Leopold, as described by the U.S. Forest Service (1994) and Gordon (1995). The original model used the average annual flow as the flow at which bed-material movement begins. Emmett (1975) recorded movement of fine sediment (silt and sand) at the mean annual flow, which related to 0.25 of bankfull discharge, for the Snake River, Idaho. Other studies have defined the channel maintenance flow where coarse particles begin to move to be in the range of 0.5 to 0.6 times the bankfull discharge (Ryan 1996, Leopold 1994, Andrews and Nankervis 1995). The average annual flow term in the model was re-defined by the Wyoming Fish and Game Department as the bed material mobilization flow and was assigned a value of 0.5 times bankfull flow.

In a recent study in Alberta, the Wyoming model was investigated as a possible tool to define channel maintenance flows for the Highwood River. Clipperton et al. (2002) reported that, as a general rule, the movement of bed material in east slope streams in Alberta, such as the Highwood River, begins at flows that are greater than average annual flows. Therefore, certain parameters were modified and at the study site in question, 28.3 m^3/s was used for the bed material mobilization flow parameter and 152.9 m^3/s was used as the bankfull flow (Alberta Environment 1993). These parameters were used in the following modified version of the Wyoming model:

$$Q_{cs} = \left\{ (Q_n) \bullet \left[\frac{(Q_n - Q_m)}{(Q_b - Q_m)} \right]^{0.1} \right\}$$

<u>Equation 8.1</u>

Where: Q_{cs} = Recommended channel maintenance flow

Q_n = Natural streamflow (Mean Weekly Flow in Highwood Study)

Q_m = Bed-material mobilization flow

Q_b = Bankfull flow

For this approach, the instream need for flows in the range between bankfull and the 25 year recurrence flow are set to the actual flow that maintains floodplain function and stream channel form (Annear and Day 2000, U.S. Forest Service 1994). On the basis of the Wyoming analysis, all flows between bankfull and the 25 year flood flow (509.7 m^3/s) are required as an instream flow need for channel maintenance. At flows greater than the 25 year flood flow, only the 25 year flood flow is needed. An example of the channel maintenance instream flow needs, as determined with the modified Wyoming model, are illustrated, and compared with the natural flows for Week 21 in Study Site 4 of the Highwood River, as shown in Figure 8.1

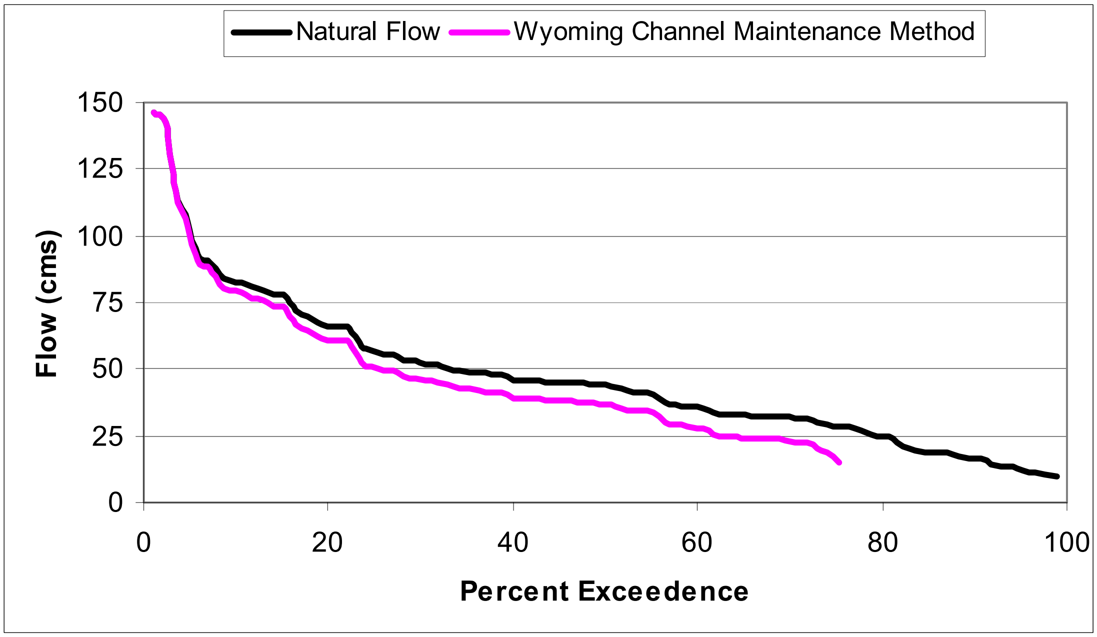

Figure 8.1. Example of channel maintenance instream flow needs, determined using the modified Wyoming Model, for Week 21 in Study Site 4 of the Highwood River Channel (Source: Clipperton et al. 2002).

8.3 Calculating a Channel Maintenance Flow (CMF), Shields Method

Although each of the reviewed methods holds promise for use in the SSRB, the more detailed methods could not be used due to data requirement limitations. It was therefore decided to adopt a sediment transport model similar to the one used in a recent study on the Highwood River (Clipperton et al. 2002). In that study, channel maintenance flow recommendations were based on a channel maintenance flow method as outlined in a report prepared by Northwest Hydraulics (Neill and Yaremko 2001). As stated in this reference,

> *"Quantification of bed mobility is fundamental to consideration of channel maintenance. Understanding how bed load and suspended loads of sediment behave naturally allows the investigator to make rational assessment of the potential impact of changes in hydraulic parameters".*

The study used an incipient motion method based on the Shields entrainment function (S_N) (Shields 1936). The Shields equation is:

$$S_N = hS/(s-1)D \qquad \text{Equation 8.2}$$

Where: S_N = Shields Number

h = mean depth of flow

S = Hydraulic gradient (Channel Slope x 0.85)

s = Dry density of bed material

D = D_{50} of the bed material size distribution

Values for D_{50}, h, S, s and Q (discharge) for each reach in the SSRB are provided in Appendix F. Appendix F also shows the calculation of S_N for different discharges for each reach. It is acknowledged that the absolute initiation of motion is difficult to define, even in a laboratory setting. The following values of S_N are generally accepted as indicators of different levels of bed activity:

$S_N = 0.03$	Occasional grain movement
$S_N = 0.045$	Effective beginning of transport
$S_N = 0.06$	General transport of all sizes

For each reach, hydraulic data parameters (hydraulic gradient, mean depth of flow) were obtained from either an existing hydraulic database, a flood risk study, or in some cases, from sources such as Kellerhals et al. (1972). The bed material data were mostly taken from Shaw and Kellerhals (1982).

Calculation of the Shields equation is straightforward for wide, straight and uniform channels with flat beds. In these cases, the hydraulic resistance is derived from the roughness of the gravel surface and the slope is taken as the channel slope (energy gradient). In natural rivers, additional sources of resistance, such as bends, cross sectional and profile irregularities, and bed forms, consume additional energy. Therefore, in these cases "S" is taken as a portion of the total slope for effective bed movement. In this analysis, effective slope was taken as 0.85 of the channel slope.

The S_N values are mainly influenced by D_{50} values and by the effective reach slope (0.85 x S). Therefore, reliable D_{50} values are needed to accurately calculate S_N values. Most of the available data used in this analysis is based on localized reach values (S and D_{50}), usually near a Water Survey of Canada gauge site. However, these sites may not be representative of the whole reach under consideration. Detailed reach surveys are required to capture the variability of the hydraulic parameters (h, S, D_{50}) to incorporate in the determination of channel maintenance flows.

To provide a measure of bed mobility, the Shields Number was calculated for a range of flows at each cross-section, using 0.85 of the average reach slope as described above. Results are shown in Figures 8.2 – 8.5. These plots show the relationship between the calculated Shields Number and discharge for the Red Deer, Bow, Oldman, and South Saskatchewan rivers respectively. The plots show the variability of the S_N values with discharge for different reaches of each river. Horizontal lines are drawn on these plots to show different levels of bed material movement.

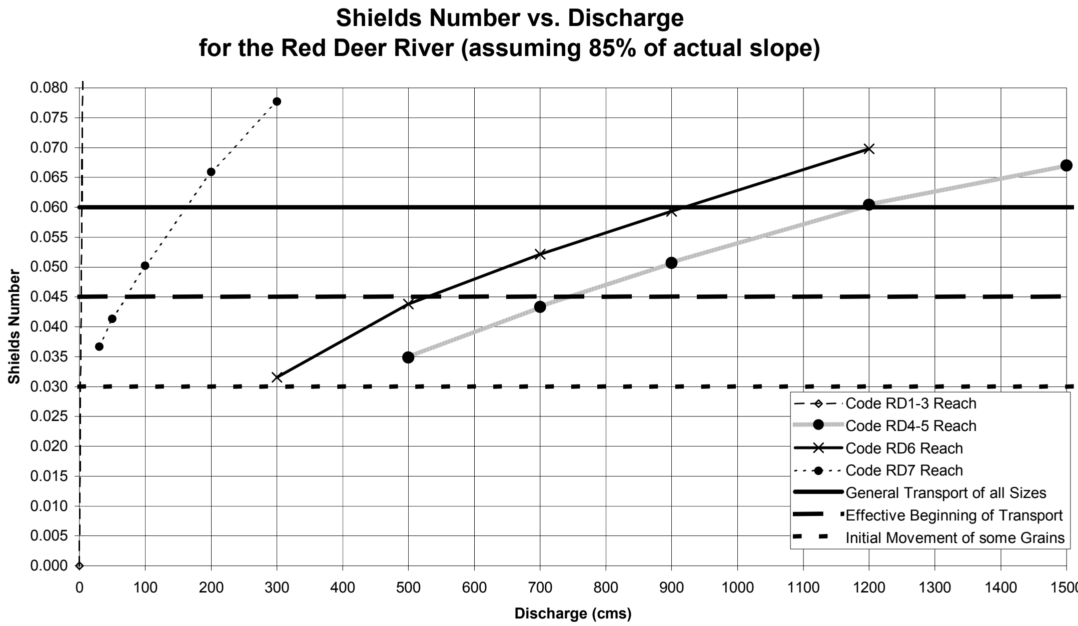

Figure 8.2. Shields number versus discharge relationship for the Red Deer River.

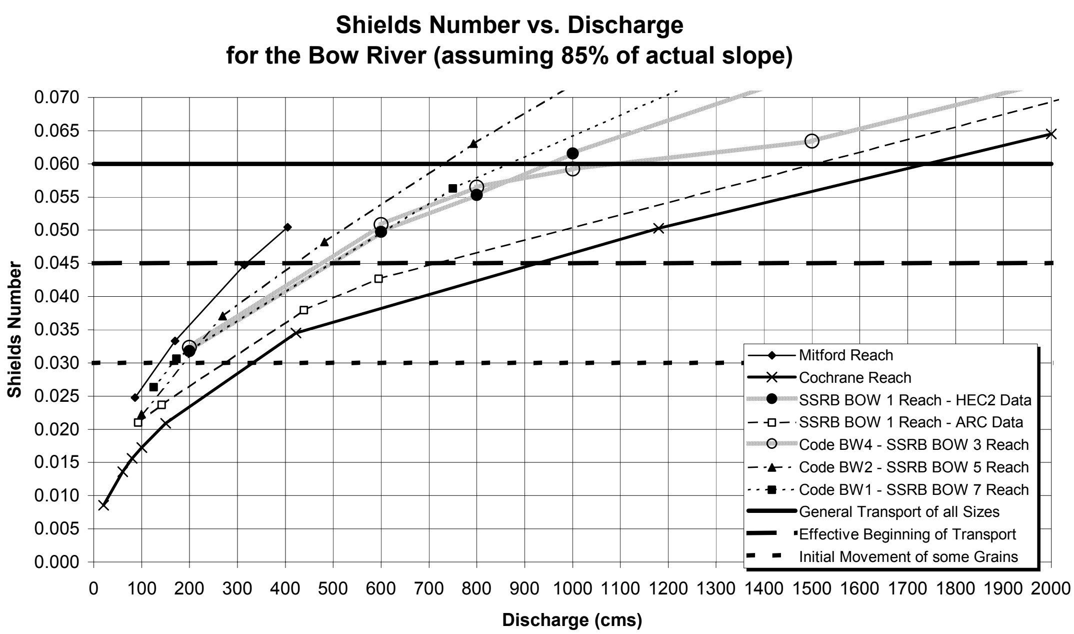

Figure 8.3. Shields number versus discharge relationship for the Bow River.

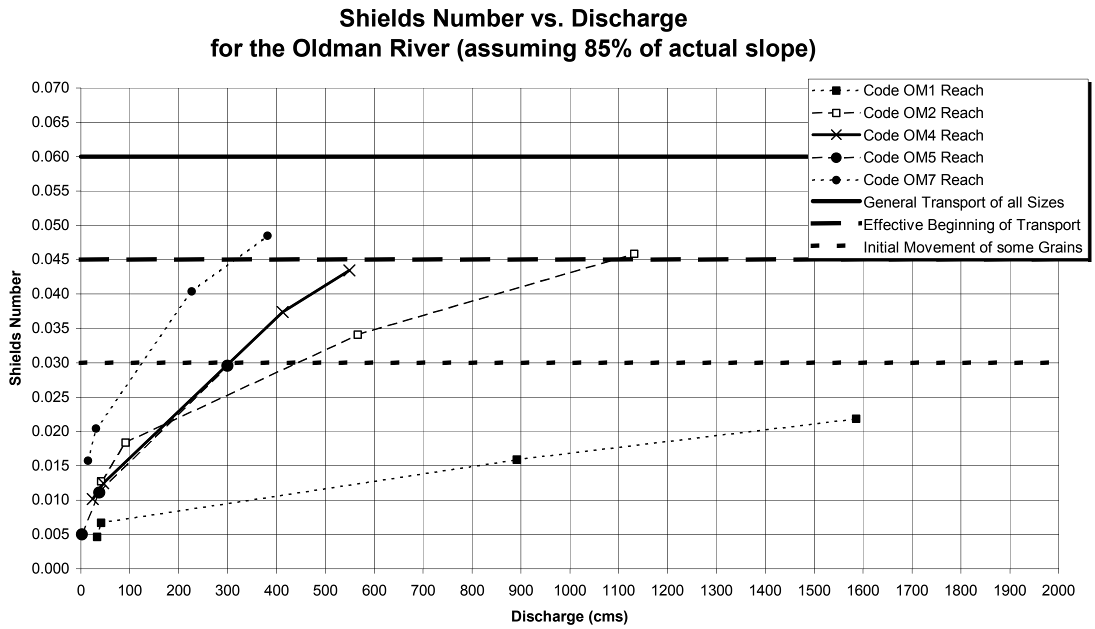

Figure 8.4. Shields number versus discharge relationship for the Oldman River.

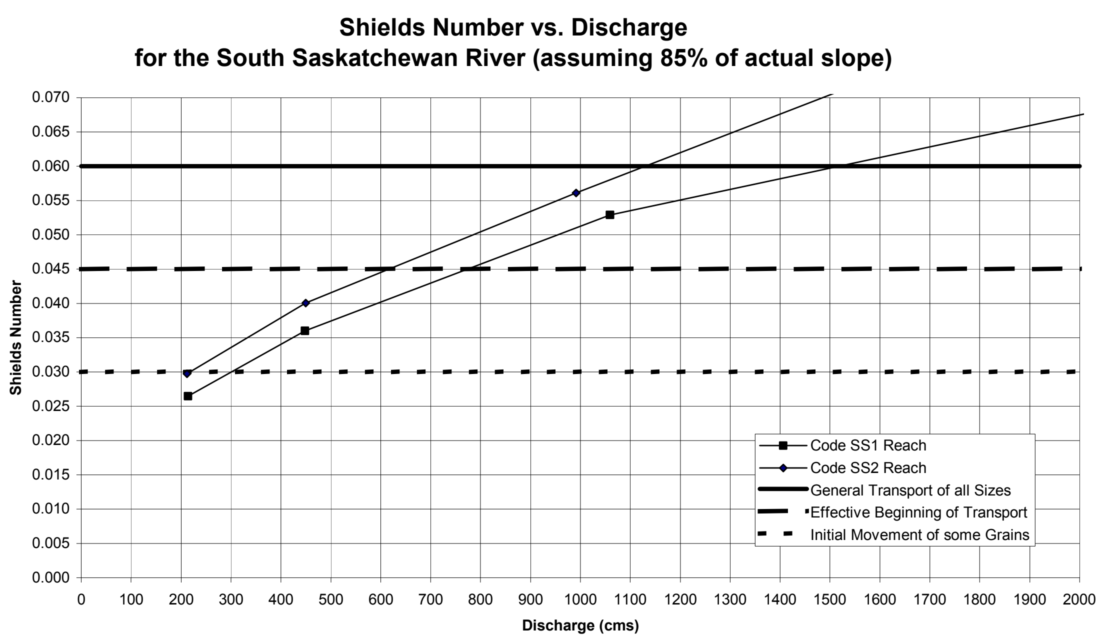

Figure 8.5. Shields number versus discharge relationship for the South Saskatchewan River.

8.4 Summary of Channel Maintenance Flows for SSRB Reaches

The Shields Equation generates a flow magnitude, but does not stipulate the timing or duration of the needed flow. The frequency of the calculated CMF values was approximated from the nearest flood frequency curves (Kellerhals et al. 1972). These frequency curves are based on maximum instantaneous flows, whereas the flow duration curves used in IFN are based on weekly flows. The required duration of the channel maintenance flow was not calculated in this study, due to the lack of daily flow data. In the literature reviewed (Neill and Yaremko 2001), it has been suggested that the natural duration of the CMF should be maintained. Therefore, it is recommended that the natural duration of the prescribed CMF flows be determined before any implementation of IFN determinations is initiated.

The discharges corresponding to S_N values of 0.045 (beginning of transport) and 0.06 (general bed movement) were derived from the plots in Figures 8.2 to 8.5 and are summarized in Table 8.1. The lesser flow values related to S_N = 0.045 and the higher flow values related to S_N = 0.06 are given as the CMF flow range in Table 8.1. From a review of Table 8.1, it is not possible to establish any general relationship between the S_N values and the flood frequencies (2- and 5-year return interval flows). The only exception is the Bow River, where the initiation of motion (S_N=0.045) closely relates to the one in two year flow. A number of factors contribute to this discrepancy, especially the lack of general reach hydraulic data (h, S, D_{50}). Flood frequencies are also localized (WSC gauge site) and based on flow records only up to 1972 (Kellerhals et al. 1972). Re-assessment of the flood return intervals, after updating flow data files to include the most recent flows, may help clarify these relationships.

As shown in Table 8.1 and illustrated in Figure 8.6, the data for the Belly, St. Mary and the Waterton rivers were insufficient to calculate channel maintenance flows. Therefore, an estimate for the CMF flows was made using the 5 year return interval flow as the bankfull flow, from the nearest gauge data available (Kellerhals et. al., 1972). This was based on the assumption that in this case, the bankfull flow will provide a close approximation of CMF.

8.4.1 Overbank Flows Needed for Geomorphic Activity

Overbank flooding is vital to sustain channel meandering and overbank processes. The data in the current study are not detailed enough to determine the bankfull flows accurately and specify a level of overbank flow that will maintain the overbank processes. From a review of the literature, and from general observation, a flow equivalent to 125% of the bankfull flow is considered sufficient to maintain the overbank processes. Experience from a number of floods in Alberta shows that once a flood is overbank, channel meandering, bank erosion, channel cutoffs, and overbank deposition of silts and sands become prominent. The Technical Team believes 125% of bankfull maintains the erosion and deposition processes needed to support the long term viability of cottonwood forests (Section 7.1).

Table 8.1. Recommended channel maintenance flows (CMF).

REACH DESCRIPTION	Reach Codes	CMF Range* (m^3/s)	2 Year Return Flow (m^3/s)	5 Year Return Flow (m^3/s)	COMMENTS
Red Deer River					
Dickson to Medicine River	RD7	70-160	266	505	
Medicine River to Blindman River	RD6	530-920	284	552	
Red Deer to Drumheller	RD4 & 5	750-1200	431	793	
Drumheller to border	RD1 - 3	679			Sand bed, based on 1 in 5 year flow
Bow River					
WID to Highwood	BW4	460-1050	413	821	
Highwood River to Carseland	BW3				No D_{50} data for BW3
Carseland to Bassano Dam	BW2	410-730	481	792	
Bassano to Mouth	BW1	490-860	750		
Oldman River					
Dam to Pincher Creek	OM7	320-590	226	382	
Pincher Creek to LNID	OM6				No data
LNID to Willow Creek	OM5	530-?	300	577	
Willow Creek to Belly River	OM4	549-?	413	549	
Belly River to St. Mary River	OM3				No data
St. Mary River to Little Bow River	OM2	450-?	566	1132	
Little Bow to Grand Forks	OM1	580-?	891	1582	
Belly River					
St. Mary Canal to Mouth	BL1, 2 & 3	100		100	Poor Hydraulic data. CMF based on 5 Year flow
St. Mary River					
Reservoir to Mouth	SM1 & SM2	175		175	Poor Hydraulic data. CMF based on 5 Year flow
Waterton River					
Reservoir to Mouth	W1 & W2	153		153	Poor Hydraulic data. CMF based on 5 Year flow
South Saskatchewan River					
Grand Forks to Medicine Hat	SS2	620-1140	1085	2265	Riverbed material is fine (D_{50}~0.25mm).
Medicine Hat to Red Deer Confluence	SS1	770-1340	991	2123	

Notes: * FLOW RANGE – Flows needed for initiation of motion to fully developed in-depth bed movement, based on Shield's Number range of 0.045-0.060.

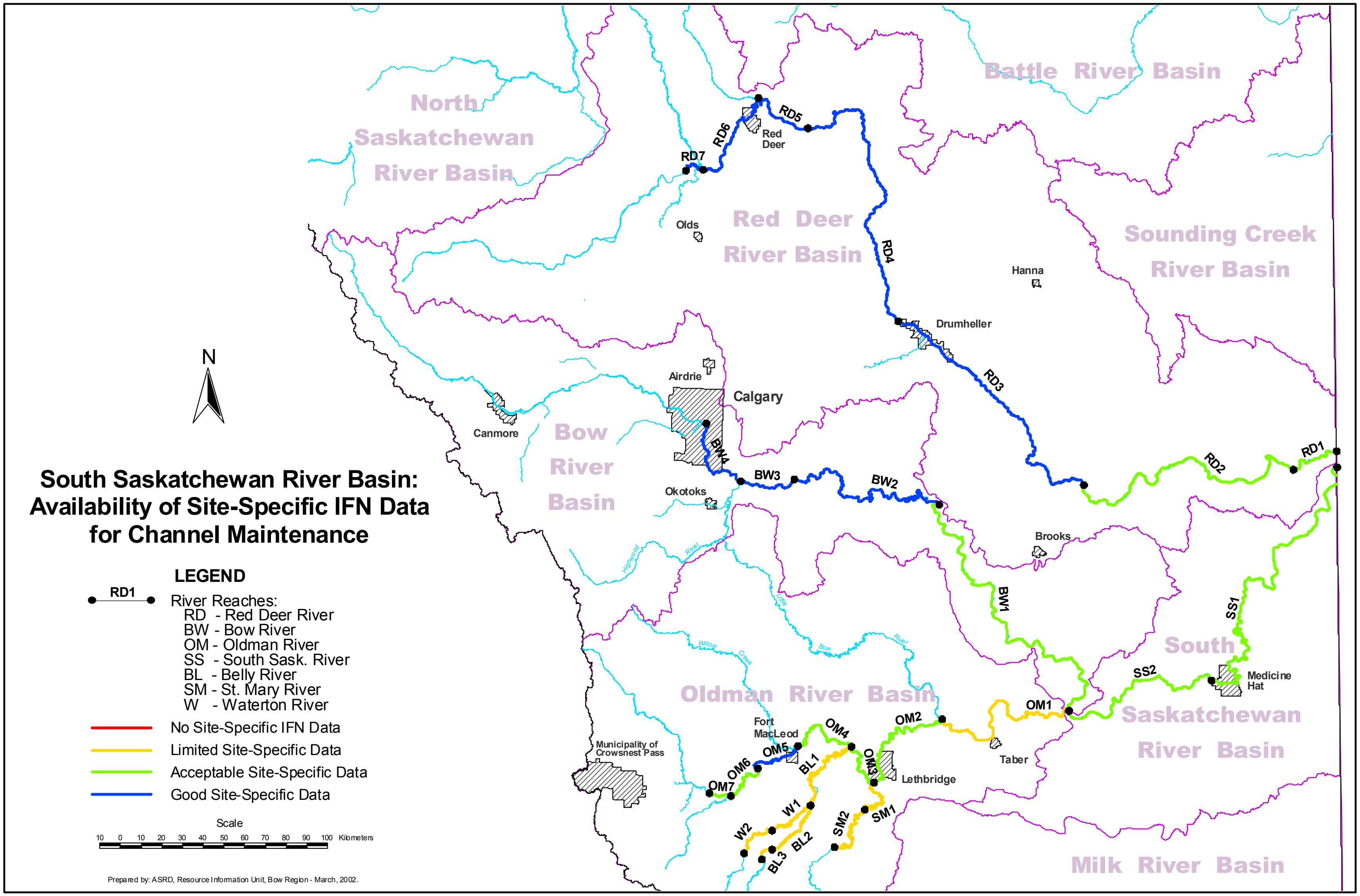

Figure 8.6. Availability of site-specific data required for the Shield's equation to calculate the channel maintenance flows.

8.5 Conclusion and Recommendations

For the purpose of this study, the channel maintenance flow was defined as the flow that maintains the physical characteristics of the channel so that the ability of the channel to convey streamflow and bedload is maintained.

Shields bed mobility criteria were adopted to determine the channel maintenance flows for the reaches of the SSRB study. This decision was based on the fact that insufficient hydraulic reach data (cross-sections, slope, and bed material size data) were available to implement more detailed procedures for the study reaches. The data used in the analysis were extracted from isolated reach studies and were assumed to apply to the full reach length under study.

The CMF values given in Table 8.1 specify a range of flows between the beginning of sediment transport and general bedload transport. These values represent the range between flushing flows and channel maintenance flows referred to in the literature. The higher flow value is the prescribed CMF for each reach considered.

The CMF values in Table 8.1 show no consistent correlation with either the 2 year or 5 year return flow. A lack of reach specific hydraulic and flow data is considered to be one of the main reasons for the lack of correlation. The data in Table 8.1 show that the 5 year return flow approximately covers the upper range of the calculated CMF. Therefore, the 5 year return interval flow is the recommended criterion for CMF when insufficient data are available to calculate the CMF using the Shields method.

No analysis was done to determine the duration and frequency of the CMF calculated. It is recommended that natural duration of the calculated flows should be maintained until a comprehensive analysis can be completed.

A flow equivalent to 125% of bankfull flow is recommended to maintain overbank geomorphic activity.

It is recommended that detailed hydraulic and hydrologic data be collected for all study reaches. The collected data should then be used to:

- Enable determination of CMFs for all study reaches within the SSRB;
- Improve our understanding of the correlation between CMF determinations and the 2 and 5 year return interval flows;
- Allow the implementation of more rigorous methods for making CMF determinations;
- Facilitate an analysis of the high flow requirement (125% bankfull) to support fluvial geomorphic activity;
- Permit investigation of the frequency and duration characteristics of CMFs that need to be met; and
- Clarify the relationship between instantaneous CMF values and those proposed for modelling on a weekly time step.