

--- Minesite Access
 — Northern Access Road
 — Watershed Boundary

1:280,000
 0 5 10
 Kilometres
 Projection: UTM12, NAD83

Overview of Scud River Basin

FIGURE 3.6-10

**Table 3.6-7
Summary Characteristics of Scud River Basin
and Selected Tributaries**

Watershed	Area (km²)	% Glacier Cover	Median Basin Elevation (m)	Estimated Annual Runoff - 2005 (mm)
Galore Creek	145	31	1300	2130
Reference Creek	213	63	1620	1870
Contact Creek	23.5	9	980	2870
Scud River just upstream of Galore Creek	575	47	1500	2100
Scud River at mouth	1130	21	1400	2050

Flow hydrographs for each of the stations for 2005 are given in Figure 3.6-11. The pattern of flow at REF-2 was very similar to Gwm8. Flow fluctuated throughout the summer season, and flows were high from June to early September. The highest flows occurred in August, during a period of prolonged rainfall. In contrast the flow hydrograph for Contact Creek is very different in form; with peak flow occurring during early June with flows generally decreasing steadily through the year thereafter. There are some variations in flow during the summer and fall in response to rainfall but these are on a smaller scale than early season flows. A similar pattern of flow occurred in 2004, except that fall rain events produced higher flows. The differences in the flow hydrographs are thought to result from the lower elevations and lack of glaciated areas in Contact Creek producing earlier snowmelt than Galore or Reference Creeks. By summer much of the snow in Contact Creek has melted and flows decrease, with little supplementary flow from glaciated areas. In contrast flows in Galore Creek and Reference Creek are supported by snow and glacier-melt into the late summer.

Basin yield is compared in Figure 3.6-11 and monthly flows are summarised in Table 3.6-4. Both datasets confirm the differences in hydrological response between Contact Creek and the two larger watersheds. The highest yields are observed in Contact Creek during freshet, with yield dropping in the summer months. This pattern of flows is quite similar to the GAL-1A watershed in Galore Creek, a basin with lower elevations when compared to the rest of Galore Creek and with only small headwater glaciers. In contrast the yield and monthly flows in Reference Creek closely follow the values for Gwm6 and Gwm8, watersheds dominated by runoff from upland, glaciated regions.

Annual runoff totals for each watershed are shown in Table 3.6-7. Runoff values for 2005 are similar for Galore Creek and Reference Creek (Gwm8 2131 mm; Reference Creek 1865 mm), but were substantially higher for Contact Creek (2867 mm). A similar pattern of higher flows in Contact Creek was also observed in 2004. Runoff values for Contact Creek are higher than might be anticipated and values for Reference Creek are possibly lower than might be expected. There are a number of reasons for this including uncertainties in the runoff calculations and the difference in the size of the watersheds and different hydrological responses of the watersheds (different bedrock types, local slope, gradients, timing of snowmelt). However, the difference in response may also reflect the location of each watershed within the regional precipitation gradient, with more precipitation falling on Contact Creek, the most westerly basin and less on Reference Creek, the most easterly basin.

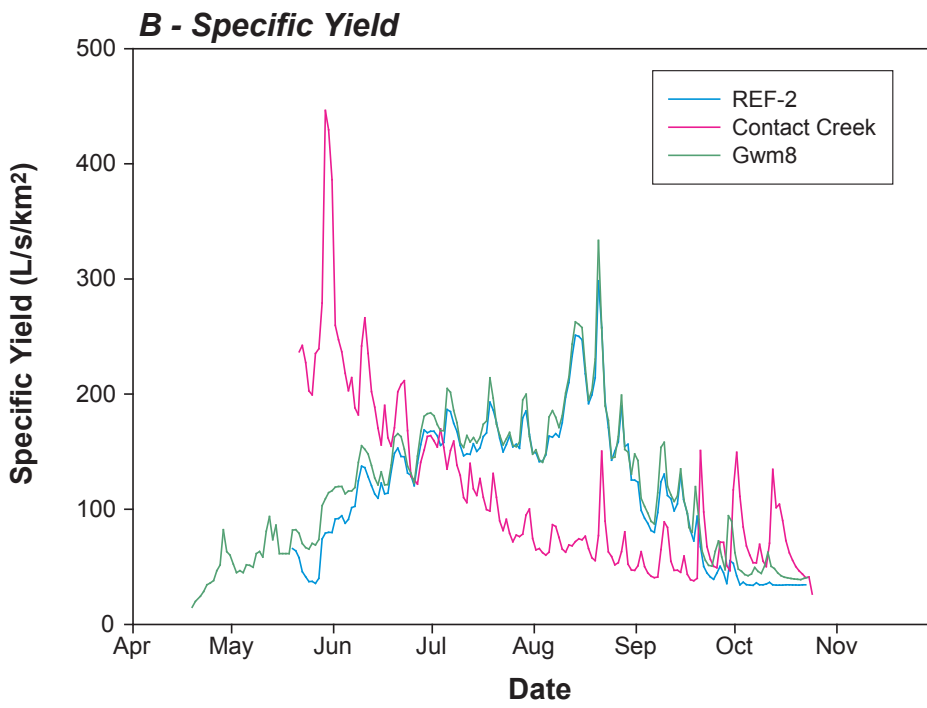
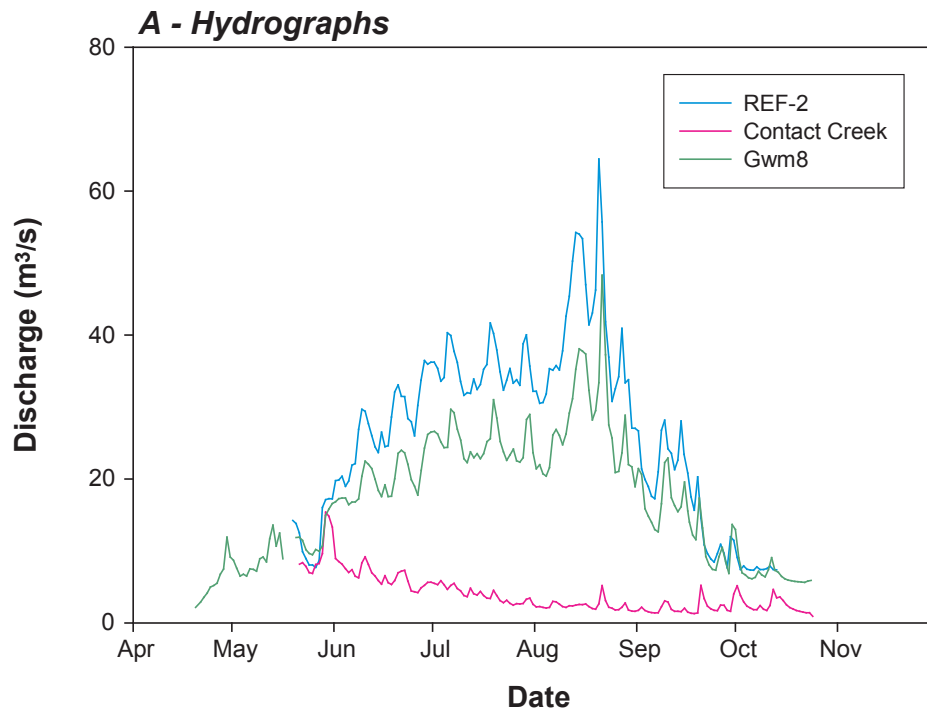


FIGURE 3.6-11



Contact Creek and REF-2 Hydrographs and Specific Yield, 2005

Using the available data estimates were made of flows in the Scud River during 2005. Estimates are summarised in Tables 3.6-7 to 3.6-9. Runoff estimates for the Scud River were based on comparing basin characteristics (watershed area, median elevation, glaciated area) for the whole watershed with those for Galore Creek, Reference Creek and Contact Creek data. Just upstream of the confluence with Galore Creek, the Scud River has a watershed area of 575 km². Hence, at the confluence Galore Creek is 20 % (145 km²) of the total watershed area at that point. Annual runoff for the Scud watershed upstream of Galore Creek is estimated to be 2100 mm and monthly flows are calculated based on the monthly proportion of flow seen at Galore Creek in 2005.

**Table 3.6-8
Summary of Estimated Annual and Monthly Runoff Characteristics for the Scud River and Sub-basins**

Station	Watershed Area (km ²)	Annual Runoff 2005 (mm)	Estimated Monthly Runoff (mm)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gwm8	144.9	2131	22	22	22	63	196	369	458	514	241	117	65	43
Contact Creek	34.5	2867	29	29	29	117	789	651	398	251	232	198	86	58
Reference Creek	216	1865	17	17	17	33	124	334	437	494	205	92	57	38
Scud River just upstream of Galore Creek	575	2100	20	20	20	49	167	370	472	532	234	109	64	42
Scud River upstream of Stikine River	1130	2050	20	20	20	48	163	361	460	519	228	107	62	41

**Table 3.6-9
Summary of Estimated Annual and Monthly Flow Characteristics for the Scud River and Sub-basins, 2005**

Station	Watershed Area (km ²)	Mean Annual Flow (m ³ /s)	Estimated Monthly Average Flow (m ³ /s)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gwm8	145	9.8	1.2	1.2	1.2	3.4	10.6	20.0	24.8	27.8	13.0	6.3	3.5	2.3
Contact Creek	34.5	2.3	1.1	1.1	1.1	4.6	31.1	25.6	15.6	9.9	9.2	7.8	3.4	2.3
Reference Creek	216	12.8	0.9	0.9	0.9	1.8	6.7	18.1	23.6	26.7	11.1	5.0	3.1	2.0
Scud River just upstream of Galore Creek	575	38.3	4.5	4.5	4.5	10.9	37.0	82.1	104.6	118.0	51.9	24.3	14.1	9.4
Scud River upstream of Stikine River	1130	73.5	8.7	8.7	8.7	21.0	70.9	157.5	200.8	226.3	99.5	46.6	27.1	18.1

The total area of the Scud watershed at its mouth is 1130 km², such that Galore Creek comprises 13 % of the area. Results of the regional analysis undertaken in Section 4 indicated that runoff at the mouth of the Scud might be around 3 % less than at Galore Creek. Hence, the estimated runoff for the Scud in 2005 was taken as 2050 mm, and monthly flows are calculated based on the monthly proportion of flow seen at Galore Creek in 2005.

At its confluence with the Scud River, the Stikine River has an upstream area of approximately 37,000 km². Hence at the confluence, the Scud is approximately 3%, and Galore Creek is less than 0.5%, of the area of the Stikine watershed.

3.6.6 Iskut River Basin; More Creek and Ball Creek

More Creek is a tributary of the Iskut River, which has a drainage area of 9,400 km² and is a major tributary of the Stikine River.

At the point where More Creek enters the Iskut, the upstream watershed area is 3,810 km². Hence, More Creek is 22% of the total area of Iskut at the confluence. The WSC conducts active monitoring of flow on the Iskut River below Johnson River, located just upstream of the confluence of the Iskut and Stikine Rivers. At the gauging station, the Iskut River has a drainage area of 9,350 km². In addition, flow monitoring was undertaken during 2004 and 2005 at Ball Creek, another tributary of the Iskut, located to the north of More Creek. Ball Creek flows in a westerly direction and is slightly less than half the size of More Creek.

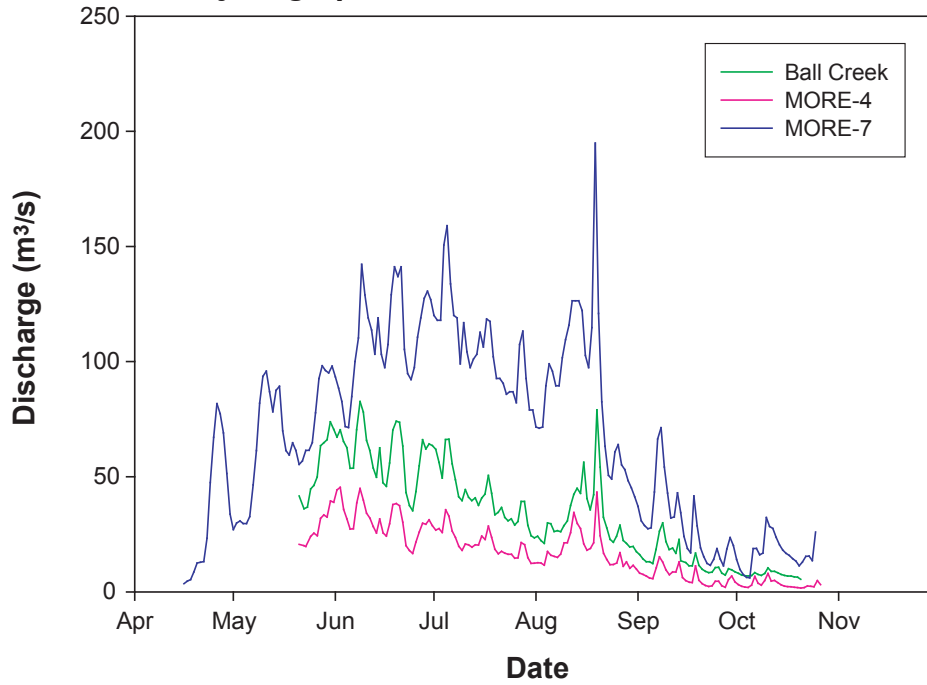
Figure 3.6-12 compares flow hydrographs for Ball Creek and More Creek stations. Yield curves for these stations are also given in Figure 3.6-12. The Ball Creek hydrograph is similar in shape to those for the More Creek stations, indicating a similar hydrological response. Daily discharge values and watershed yield in Ball Creek falls between the observed values for MORE-4 and MORE-7, consistent with the relative watershed areas of upstream of each monitoring station. Annual runoff totals for Ball Creek are summarised in Table 3.6-2. For 2004 the observed runoff at Ball Creek was substantially less than in More Creek and in 2005 runoff was similar to MORE-7. Lower runoff might be expected in Ball Creek, as much of the watershed is located further east than the headwaters of More Creek, resulting in lower precipitation in upstream reaches.

Flow hydrographs for the Iskut-Johnson WSC station were obtained for 2004 and 2005 and the data are shown in Figure 3.6-13. In both years, the Iskut River hydrograph has a very similar shape to that at More Creek. In 2004, there is a dominant snow-melt freshet, and peak flow occurs during this period. High flows also occur during rainfall events in the fall. In 2005, flows are variable throughout the summer, and there is no dominant snow-melt peak. Peak discharge occurs during August at the same time as the peak flow observed in More, Galore and Sphaler Creeks. The fact that high flows occurred at all locations at the same time indicates that a high intensity rainfall event occurred over a large geographic area, covering the entire study area.

Annual runoff at the Iskut River station was 1770 mm in 2004, and is predicted to be approximately 1400 mm in 2005. The average annual runoff at the site is 1525 mm (calculated from flow data from 1959 to 2004), and the observed range is from 1215 mm to 1855 mm. Therefore, 2004 appears to be fairly wet year, and 2005 a dry year for the Iskut Watershed. This is similar to the patterns that were observed at most of the monitoring stations in the study area.

A comparison of yields between the Iskut River and More Creek hydrostations is given in Figure 3.6-14. Specific yield typically decreases with increasing drainage area. During the earlier

A - Hydrographs



B - Specific Yield

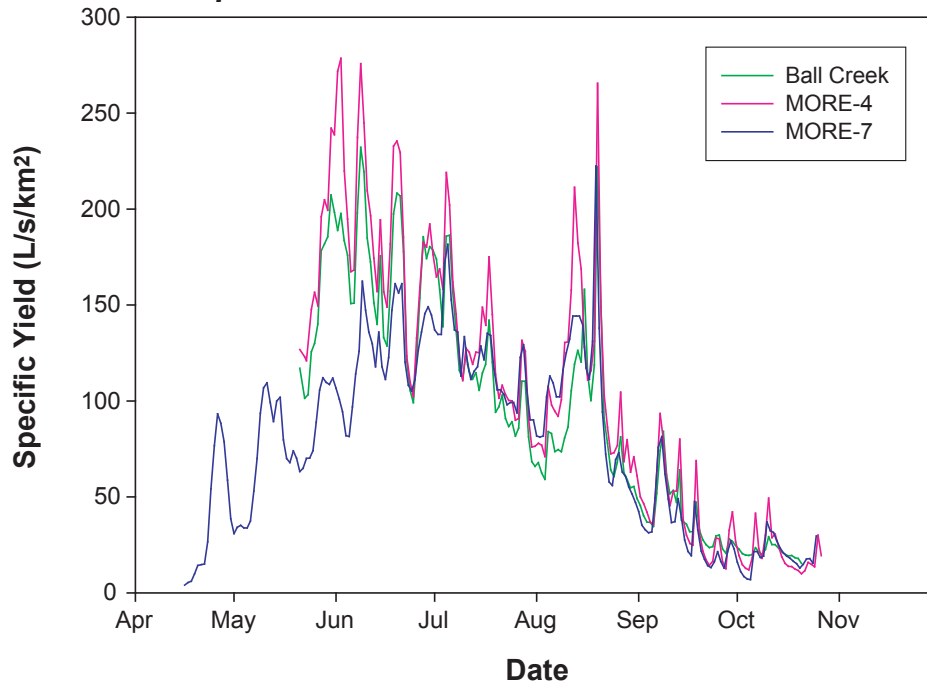
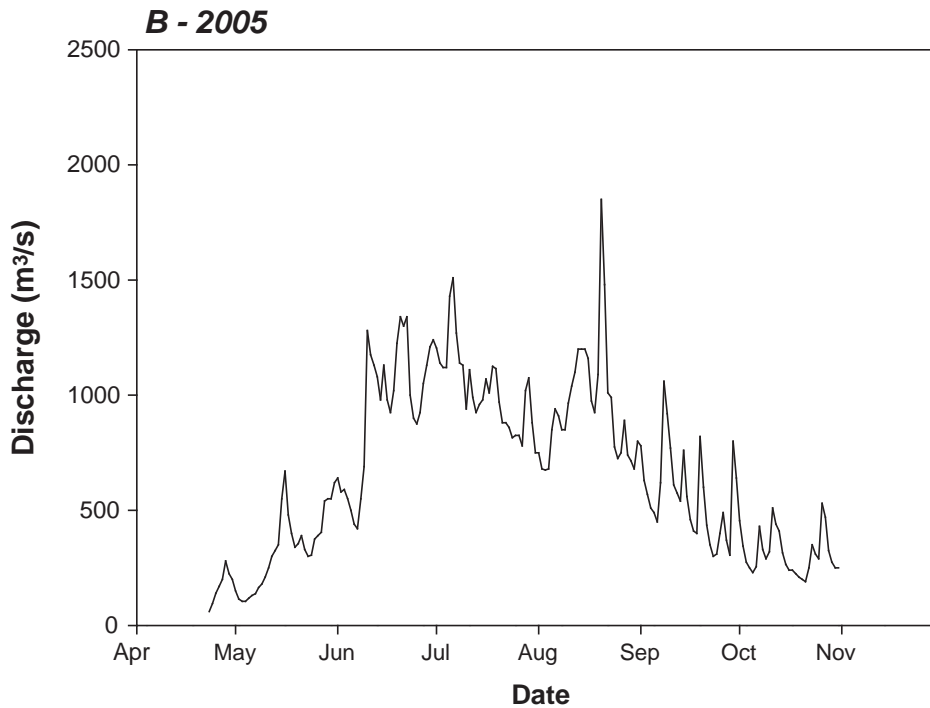
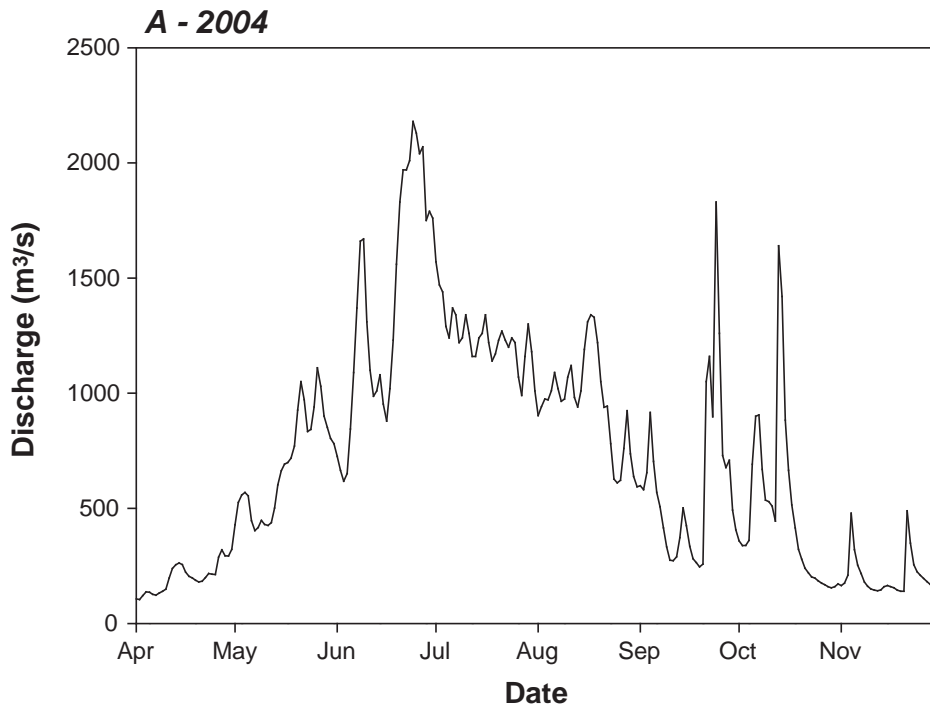


FIGURE 3.6-12



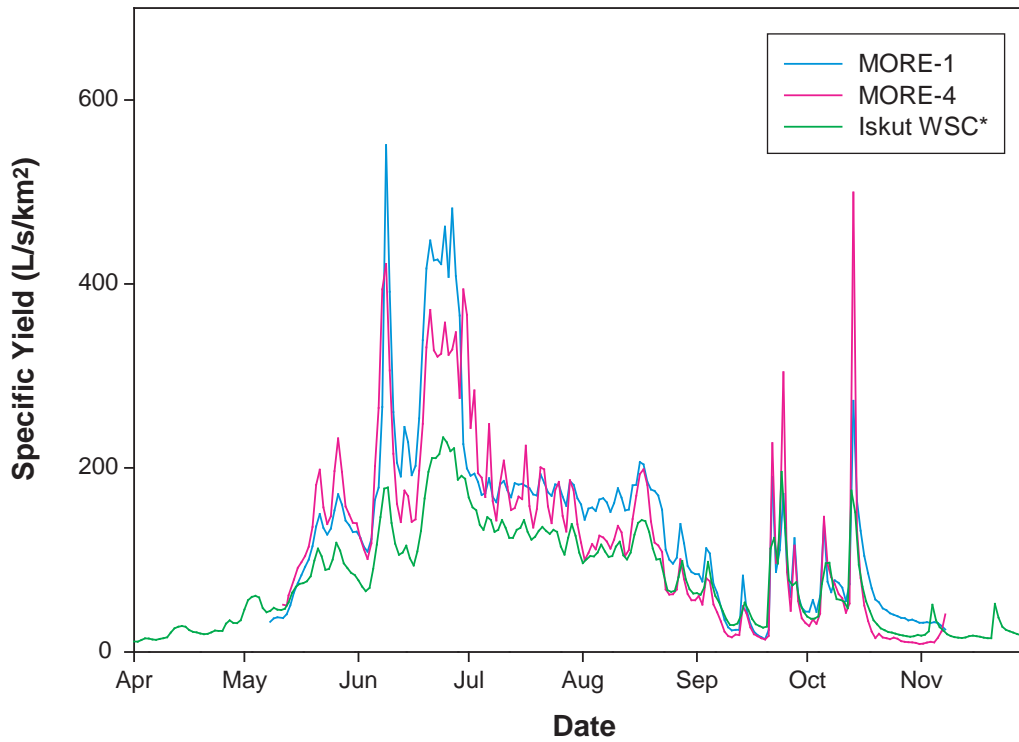
Ball Creek and More Creek Hydrographs and Specific Yield, 2005



*Note: Data are based on uncorrected real-time measurements, and have not been reviewed or assessed by Environment Canada for accuracy. This data may therefore be subject to change.
Source: Environment Canada, 2005*

FIGURE 3.6-13





*Source: Environment Canada, 2005

FIGURE 3.6-14

Specific Yield from Iskut River and More Creek Hydrostations 2004

portion of the season, there are differences in yield between the stations, and later in the year, the yield curves converge. Overall, the hydrological response (*i.e.*, shape of the curve) at all the stations is very similar which is surprising given that drainage areas range over four orders of magnitude (10 to 10,000 km²).

In terms of flow volume More Creek provided an estimated 12% of flow at the mouth of the Iskut in 2004 and 10% in 2005, consistent with its watershed area (9%). Monthly flows for the Iskut River are given in Table 3.6-10.

3.6.7 Porcupine River Basin

Sphaler Creek is a tributary of the Porcupine River, which is itself a tributary of the Stikine River. The Porcupine River joins the Stikine downstream from the Scud River. The Porcupine River has a drainage area of approximately 740 km² with Sphaler Creek contributing 45% of the basin area.

Scotsimpson Creek is also tributary of the Porcupine River which will be impacted by the proposed mine access road. It is a small tributary (49km²) that joins the Porcupine just downstream of Sphaler Creek.

Due to the morphology of the Porcupine River, it was not possible to establish a monitoring station on the river. Only a single manual flow measurement was able to taken in the river at a location upstream of Sphaler Creek (drainage area of 270 km²) during bank-full discharge conditions in July 2005. The measured flow was 75 m³/s. Flow conditions at the mouth of the Porcupine River for 2005 are estimated based on flows in Sphaler Creek. Estimated annual and monthly runoff and flow estimates for the Porcupine River are given in Table 3.6-12 and 3.6-13 respectively. Estimates were based on runoff at Sphaler-2 and LS-1, scaled to the area of the Porcupine watershed. Annual runoff for the Porcupine River during 2005 is estimated to be 1950 mm.

However, runoff is difficult to predict for the Porcupine River because of variability in precipitation throughout the basin. The Porcupine River basin lies across a strong gradient in precipitation from a wet coastal climate near the mouth, to a drier interior climate at the headwaters. Observed precipitation (October 2004 to September 2005) at the mouth of the Porcupine River was 3415 mm, and at the headwaters (*i.e.*, West More Creek meteorological station) was 1607 mm. A meteorological station was installed in July 2005 at the Porcupine River airstrip, which is located near the mouth of Sphaler Creek. During the period of simultaneous operation of the two Porcupine River meteorological stations, precipitation at the airstrip was 67% of precipitation observed at the mouth.

Table 3.6-10
Summary of Estimated Annual and Monthly Runoff Characteristics for the Iskut River below Johnson River WSC Station

Station	Year	Watershed Area (km ²)	Mean Annual Runoff (mm)	Estimated Monthly Runoff (mm)											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Iskut River below Johnson River	2004	9350	1771	27	23	24	56	191	388	344	264	166	132	57	67
	2005 ^a	9350	1386	29	29	29	32	94	261	294	272	156	90	57	43
	Average (1951-2004)		1525	22	19	19	39	133	283	322	263	184	134	60	31

^a Note: Data for 2005 is preliminary based on real-time monitoring by the Water Survey of Canada. This data has not been verified by the WSC, and is subject to change.

Table 3.6-11
Summary of Estimated Annual and Monthly Flow Characteristics for the Iskut River below Johnson River WSC Station

Station	Year	Watershed Area (km ²)	Mean Annual Flow (m ³ /s)	Estimated Monthly Average Flow (m ³ /s)											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Iskut River below Johnson River	2004	9350	525	99	83	88	201	688	1400	1240	954	600	476	207	240
	2005 ^a	9350	411	103	103	103	115	340	940	1062	982	565	324	207	155
	Average (1951-2004)		452	78	68	68	139	481	1020	1160	950	662	485	215	113

^a Note: Data for 2005 is preliminary based on real-time monitoring by the Water Survey of Canada. This data has not been verified by the WSC, and is subject to change.

Table 3.6-12
Summary of Estimated Annual and Monthly Runoff
for the Porcupine River and Sub-basins

Station	Watershed Area (km ²)	Annual Runoff 2005 (mm)	Monthly Runoff (mm)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sphaler-2	142	2196	23	23	23	67	260	440	480	520	240	53	37	38
LS-1	306	2073	21	21	21	64	240	380	460	520	230	50	35	35
Porcupine River	740	1950	20	20	20	60	230	390	420	460	220	47	33	33

Table 3.6-13
Summary of Estimated Annual and Monthly Flow Characteristics for
the Porcupine River and Sub-basins

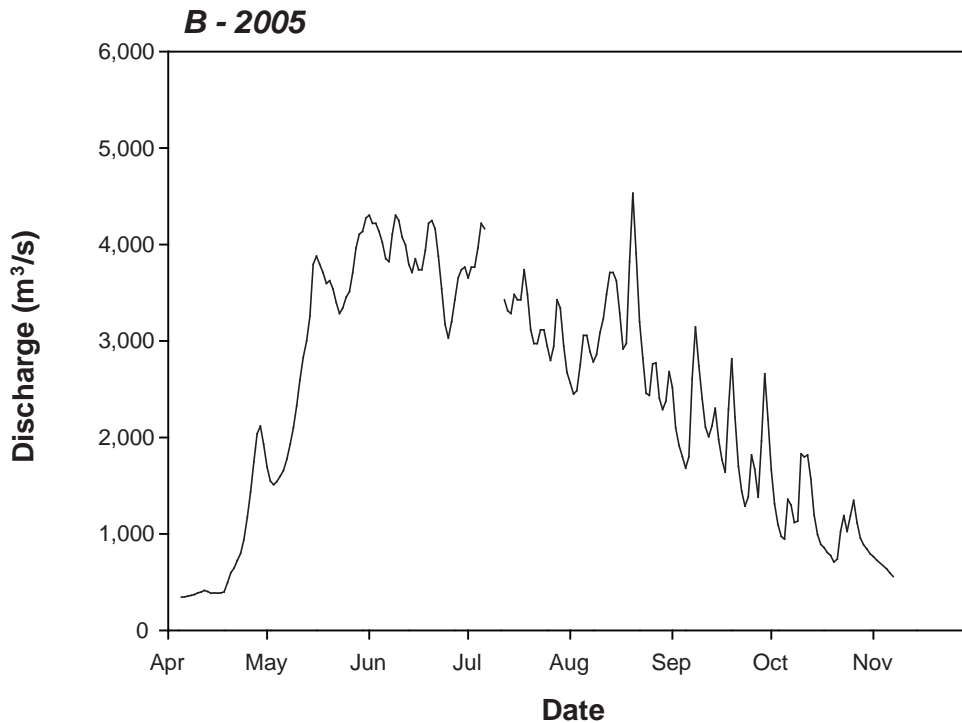
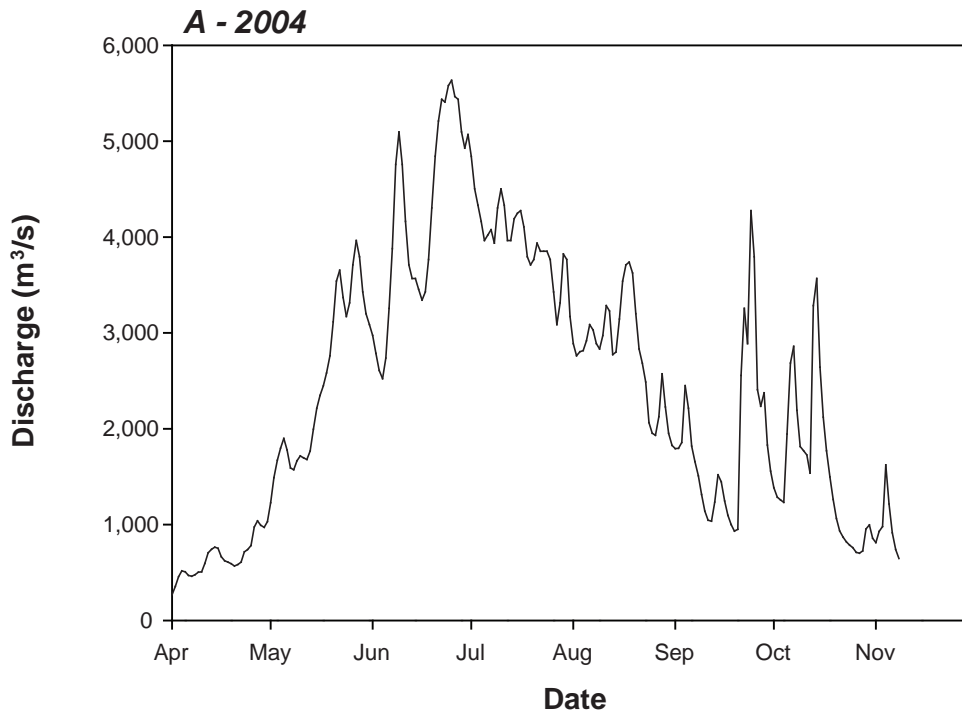
Station	Watershed Area (km ²)	Mean Annual Flow (m ³ /s)	Monthly Average Flow (m ³ /s)											
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sphaler-2	142	9.9	1.2	1.2	1.2	3.7	14	24	26	28	13	2.9	2.1	2.1
LS-1	306	20.1	2.5	2.5	2.5	7.5	29	45	54	61	27	5.9	4.2	4.2
Porcupine River	740	45.8	5.7	5.7	5.7	17	65.3	110	120	130	62	14	9.5	9.5

This suggests that locally within the Porcupine River basin, high variability exists in precipitation. Sphaler Creek comprises a large proportion of the total Porcupine River, and represents hydrological conditions within the area. Therefore, runoff and flow estimates for the Porcupine River based on Sphaler Creek observations should capture the effects of this transition from wet coastal to drier interior climates. However, flows may be under-estimated if the high precipitation total measured at the mouth of the river impacts a large area of the downstream portion of the watershed.

3.6.8 Stikine River Basin

The Stikine River is the major river system within the region. The Stikine River drains approximately 51600 km² from its headwaters around Spatsizi Plateau to its mouth near Wrangell, Alaska. Galore Creek, More Creek, the Porcupine River, and the Iskut River are all tributaries of the Stikine River, and therefore all components of the Galore Creek Project are contained within the greater Stikine River watershed. Galore Creek represents 0.3% of the drainage area of the Stikine River.

The USGS conducts active monitoring of flow on the Stikine River at the mouth near Wrangell. Flow hydrographs for the Stikine near Wrangell USGS station were obtained for 2004 and 2005 and the data are shown in Figure 3.6-15. In both years, the Stikine River hydrographs are similar, and are dominated by a snow-melt freshet from June to August. In 2004, peak flows from snow-melt are more pronounced than in 2005 had similar flows throughout the melt season. Sporadic high flows also occur during rainfall events in the fall, however, these tend to produce



Source: United States Geological Survey, 2006
Note: Data is provisional based on uncorrected real-time measurements, and has not been reviewed by the USGS to assess accuracy. This data, therefore, may be subject to change.

FIGURE 3.6-15

**Stikine River Near Wrangell (USGS),
2004 and 2005**

less extreme flows than during snow-melt. Peak flows in 2005 occurred from combined snow-melt and rain in late-August. This is the same event which was observed at other sites (e.g. Galore Creek, Iskut River) which suggests that high intensity rainfall events can affect flows over very large areas.

Annual runoff and average flow conditions for the Stikine River USGS station are given in Table 3.6-14 and 3.6-15, respectively. Annual runoff is near average for 2004 and 2005. Slightly wetter conditions were observed in 2005, which is different than observations of drier conditions in 2005 at other sites. This may be due to variation within the region in either snow-pack or later season precipitation.

3.7 Summary

The results from the on-site hydrological monitoring program allowed a characterization of the hydrological regime in study area. The important conclusions that can be drawn from on-site monitoring are:

- Annual runoff varies greatly between watersheds, and within sub-catchments of the same watersheds. For the 2005 season, annual runoff varied from 1400 to 3300 mm. Figure 3.7-1 plots annual runoff totals for all watersheds >10 km² in size, against four basin characteristics: median elevation; watershed area; percent glacier coverage; and latitude. The results reveal the complexity of the different influences controlling runoff in the study area.
- Throughout the region there is no strong relationship between runoff and median elevation (Figure 3.7-1b), although within individual watersheds (e.g., More Creek) the pattern was more clearly defined;
- In general, runoff decreased with increasing drainage area (Figure 3.7-1a).
- There is a trend for increased annual runoff with increased glacier coverage.
- A clear trend was visible relating longitude and annual runoff, with higher runoff in the west and runoff decreasing towards the east (Figure 3.7-1d). Longitude represents a measure of the distance across the Coast Mountains from the coast and reflects the observed spatial trend in annual precipitation totals and the transition from a wetter climate in the west and drier climate in the east.
- Monthly flow patterns varied depending on watershed size and amount of glacier coverage. In small to medium sized, heavily glacierized basins (e.g., Galore Creek, Sphaler Creek) monthly flows were relatively constant through June, July and August. In contrast small watersheds without a large glacier component (e.g., Mwm2, Contact Creek) typically had a snow-melt dominated hydrograph with high flows in late-May and June, and then lower flows throughout the summer and fall season. Larger watersheds, such as More Creek, had a relatively even spread of flow throughout the summer, but with a high portion of flow during freshet when compared to watersheds such as Galore Creek or Sphaler Creek.

Table 3.6-10
Summary of Estimated Annual and Monthly Runoff Characteristics for the Iskut River below Johnson River WSC Station

Station	Year	Watershed Area (km ²)	Mean Annual Runoff (mm)	Estimated Monthly Runoff (mm)											
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Iskut River below Johnson River	2004	9350	1771	27	23	24	56	191	388	344	264	166	132	57	67
	2005 ^a	9350	1386	29	29	29	32	94	261	294	272	156	90	57	43
	Average (1951-2004)		1525	22	19	19	39	133	283	322	263	184	134	60	31

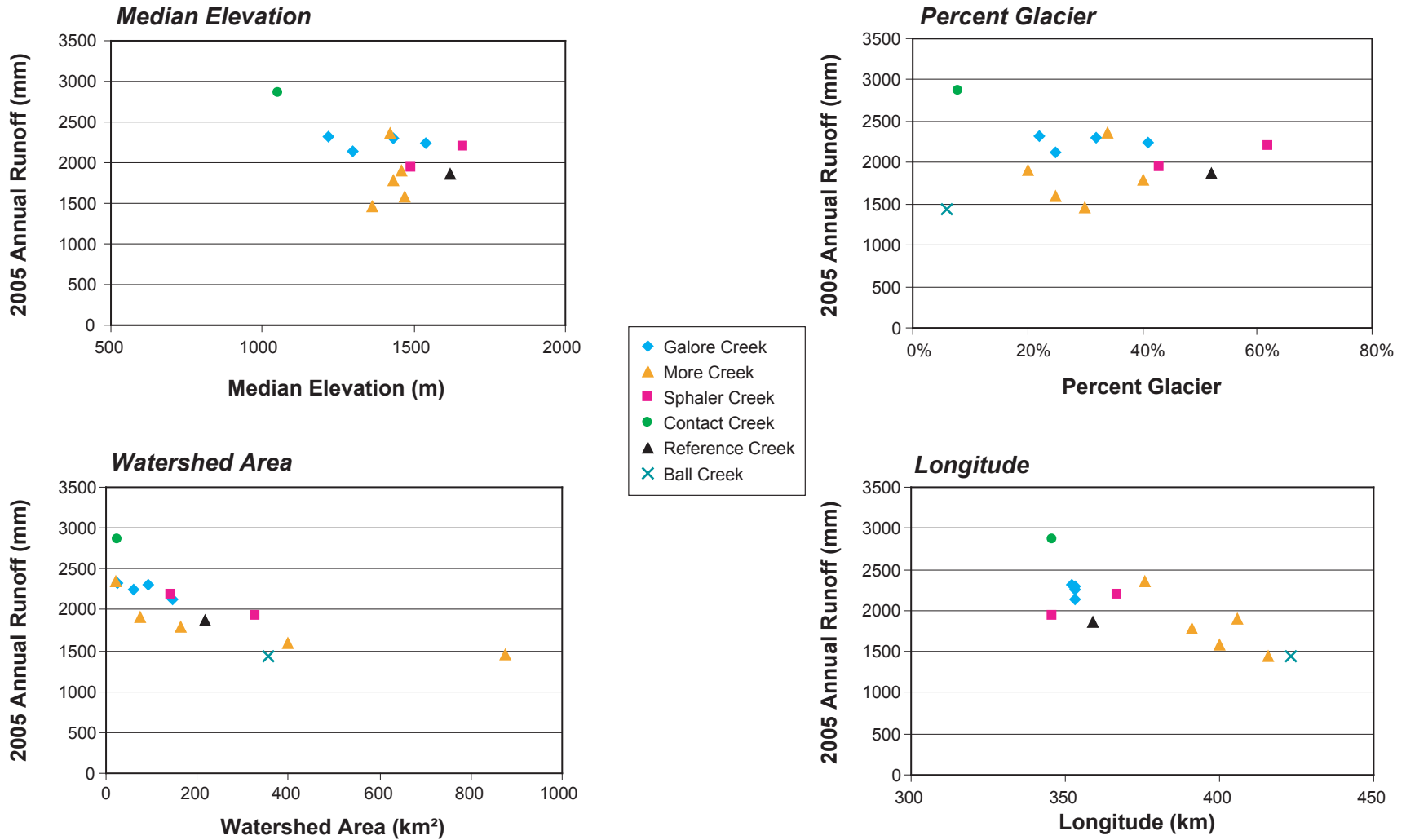
^a Note: Data for 2005 is preliminary based on real-time monitoring by the Water Survey of Canada. This data has not been verified by the WSC, and is subject to change.

Table 3.6-11
Summary of Estimated Annual and Monthly Flow Characteristics for the Iskut River below Johnson River WSC Station

Station	Year	Watershed Area (km ²)	Mean Annual Flow (m ³ /s)	Estimated Monthly Average Flow (m ³ /s)											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Iskut River below Johnson River	2004	9350	525	99	83	88	201	688	1400	1240	954	600	476	207	240
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	Average (1951-2004)		452	78	68	68	139	481	1020	1160	950	662	485	215	113

^a Note: Data for 2005 is preliminary based on real-time monitoring by the Water Survey of Canada. This data has not been verified by the WSC, and is subject to change.

- Drier conditions were generally observed in 2005, when compared to 2004. However, this pattern was reversed for watersheds to the west of the study area (*e.g.*, Sphaler-2 and GAL-1A) highlighting the potential for local variability within this region.
- The shape of flow hydrographs varied between 2004 and 2005. In both years spring snowmelt began around mid-April. In 2004, peak flows occurred during freshet and there was a dominant snow-melt runoff peak within the flow hydrograph. However, in 2005, there was no strong snow-melt peak, and flows were high and variable throughout the summer season. Peak flows occurred in August as a result of a large rainfall event.
- UBC Watershed modelling allowed for an examination of the contribution of runoff from different sources (*e.g.*, snow-melt, rainfall, *etc.*). Snow-melt dominates runoff during the summer period. The proportion of runoff from rainfall is dependent on the occurrence and amount of rainfall. The contribution of runoff from glaciers varied between watersheds. In Galore Creek, a large snow pack fed runoff throughout the summer period and glacial melt was less. In More Creek, where snow-pack was less, flows were maintained by glacial melt during the summer period. Groundwater also provided an important baseflow component through summer and fall.



Comparison of Observed Annual Runoff versus Selected Basin Characteristics

FIGURE 3.7-1

4. ESTIMATION OF KEY HYDROLOGICAL PARAMETERS

4. Estimation of Key Hydrological Parameters

4.1 Introduction

The previous section described the field data collected within the study area during 2004 and 2005. While these data allowed a detailed assessment of hydrological conditions during the period of measurement, they only provide an indication of the possible range of flows within the study area. Estimates of a number of key hydrological parameters, such as average annual runoff, average and extreme monthly flow rates, and mean annual flood are required as inputs for mine site development, for engineering design and for the EIA process. In order to make robust estimates of these parameters long-term flow records are required. Within the three watersheds directly impacted by mine development More Creek is the only location with a WSC flow monitoring station which has long-term flow records. However, there are other WSC stations in watersheds close to the study area, as outlined in Section 2. A regional hydrological assessment involves the analysis of data from nearby monitoring stations and the extrapolation of this data to the sites of interest.

In this section available regional hydrological data sets are analyzed and used to estimate average and extreme hydrological conditions within the study area. These predictions are then compared to field data obtained during 2004 and 2005. In addition, methodologies are described that can be used to calculate hydrological parameters for the key watersheds and sub-watersheds in the study area. The key parameters considered in the study are:

- Annual runoff totals;
- Monthly runoff totals;
- High flows; and
- Low flows.

All variables are estimated for a range of return periods (see Section 3 for definition). Values are calculated for selected locations within the study area (the mouths of Galore Creek, More Creek, Sphaler Creek, Scud River, Iskut River, Porcupine River and Stikine River), however, methodologies are outlined to allow the calculation of values for all parameters for other locations such as sub-watersheds within the main study watersheds.

It should be noted that there are a limited number of hydrological monitoring stations in northern British Columbia when compared to regions in the south of British Columbia. This lack of data increases the uncertainty associated with the results of any regional hydrological assessment.

Analysis of available meteorological data is also a key component of any regional analysis. More information on the analysis of meteorological data relevant to the study area is provided in the Meteorology, Air Quality and Noise Baseline Report. However, key meteorological data are discussed in the following sections where required.

4.2 Selection of Regional Hydrological Monitoring Stations

A key requirement of any regional hydrological analysis is that the stations used in the assessment are located in watersheds that are hydrologically similar to the sites of interest. In British Columbia there have been a number of studies that attempted to divide the province into regions of hydrological similarity. Coulson and Obedkoff (1998) analysed data from over 400 WSC hydrology stations throughout British Columbia and identified 17 hydrological zones within the province. This work updated previous estimates made in the Provincial Hydrologic Zone Map 1995. Obedkoff (2001) then considered northwestern British Columbia in more detail and re-defined the hydrological zones in the Skeena area on the basis of a more thorough analysis of available hydrological data. Figure 4.2-1 illustrates the hydrological sub-zones defined by Obedkoff (2001). The figure also shows the location of the WSC hydrology stations used in the Obedkoff hydrological assessment. The Galore Creek study area is located within sub-zone 's'. The locations of the sub-zones are reasonably consistent with regional precipitation patterns described in Section 3.6-1.

Additional regional analyses have been conducted by Eaton *et al.* (2002), who examined flood scaling relationships in British Columbia, and Curran *et al.* (2003), who examined flood flows in Alaska, including the Iskut and Stikine Rivers.

This study draws from these previous sources, but supplements the information presented in these studies with additional analyses of WSC and USGS data. For each hydrological parameter slightly different groupings of stations are used in the analyses, reflecting differing controls on annual runoff, monthly flow distributions, flood flows and low flows, as follows;

- Annual runoff totals are strongly controlled by spatial variations in annual precipitation. The Obedkoff (2001) analysis produced hydrological zones that are broadly consistent with the regional pattern of annual precipitation. Hence, the regional analysis is based on Obedkoff's (2001) sub-zone 's'.
- Monthly flow distribution is controlled by a number of factors, including precipitation, elevation, presence of glaciers and latitude. Latitude is seen to have a strong control on the timing of the onset of freshet. The regional analysis was based on Obedkoff's sub-zone 's', but included additional stations lying within 2 degrees of latitude of the study area. This resulted in the exclusion of some stations in sub-zone 's' that are located to the south of the study area.
- Flood flows can be produced by rapid snowmelt, extreme precipitation events and rain on snow events. The flood frequency analysis presented in this study is primarily based on stations lying within Obedkoff's sub-zone 's', however, some stations in Alaska are included in the analysis as they had flood statistics similar to stations close to the study area.
- Low flows are influenced by local groundwater conditions, annual precipitation, latitude, presence of glaciers and amount of precipitation during fall. Consistent with the discussion in Obedkoff (2001), the low flow analysis is based on stations covering a wider area than for the other analyses described above. Stations considered in the analysis are based on Zone 9 of Coulson and Obedkoff (1998).

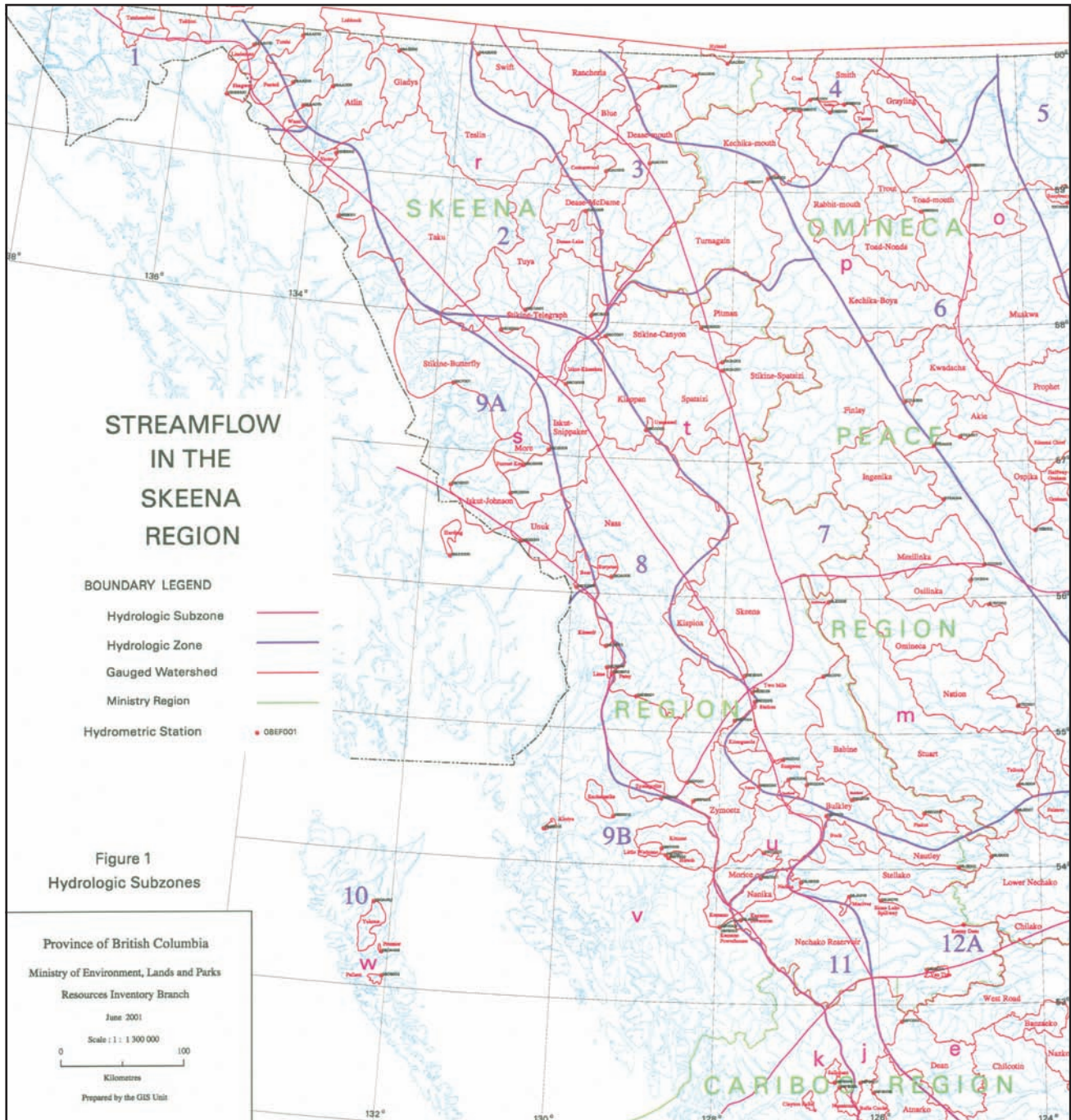


FIGURE 4.2-1

Map Showing Hydrological Zones of Obedkoff (2001)



Estimation of Key Hydrological Parameters

A list of hydrology stations considered in the regional assessment is provided in Table 4.2-1.

**Table 4.2-1
Summary of Regional Hydrometric Stations**

Station Name	Monitoring Organization	Station ID	Watershed		Used for Annual Flows	Used for Monthly Flows	Used for Flood Flows	Used for Low Flows
			Area (km ²)	Years of Operation				
Bear	WSC	08DC006	289	1976 - present	√	√	√	√
Forrest Kerr	WSC	08CG006	312	1972 - 1994	√	√	√	√
Iskut below Johnston	WSC	08CG001	9,350	1959 - present	√	√	√	√
Iskut above Snippaker	WSC	08CG004	7,230	1966 - 1995	√	√	√	√
Iskut at Kinaskan	WSC	08CG003	1,250	1964 - 1996	√	√		
Kispiox	WSC	08EB004	1,870	1963 - present	√			
Klappan	WSC	08CC001	3,540	1962 - 1996		√		
Lime	WSC	08DB010	39.8	1976 - present	√			
Lindeman	WSC	09AA010	250	1954 - 1993	√	√		
More	WSC	08CG005	844	1971 - 1994	√	√	√	√
Nass	WSC	08DB001	18,500	1949 - present	√	√		
Patsy	WSC	08DB012	5.86	1987 - present	√			
Sloko	WSC	08BB002	427	1954 - 1979				√
Stikine above Butterfly	WSC	08CF001	36,000	1971 - 1995		√		√
Stikine at Telegraph Creek	WSC	08CE001	29,300	1954 - present		√		
Surprise	WSC	08DA005	220	1967 - present	√	√	√	
Unuk	WSC	08DD001	1,480	1957 - present	√	√	√	√
Cascade	USGS	15026000	60	1917 - 1973			√	
Farragut	USGS	15028300	391	1977 - 1994			√	
Harding	USGS	15022000	175	1951 - 2002			√	√
Skagway	USGS	15056100	376	1963 - 1986	√	√		

4.3 Estimation of Annual Runoff

Annual runoff (mm) is a measure of the hydrological response of a watershed. It is presented as runoff depth, in mm, over an entire watershed, allowing direct comparison with precipitation totals. Runoff is calculated by dividing the total flow volume (m³) observed at a monitoring station with the drainage area (m²) upstream of the site. The variation in runoff across northwestern British Columbia is strongly controlled by spatial patterns of precipitation. As discussed in Section 3, a strong gradient in precipitation exists from west to east across the study area reflecting the change from a wet coastal to a dry interior climate. In addition, precipitation varies with elevation, with an increase in precipitation of up to 7% per 100 m in elevation for the mountainous watersheds in the study area.

The field data presented in Section 3 illustrated how runoff varied within and between watersheds in the study area. The geographical location of the watershed, in terms of longitude, was seen as a key factor influencing annual runoff totals; with higher runoff in watersheds located in the west of the study area when compared to those in the east. Higher runoff can also

be measured in watersheds at higher elevations, reflecting the increase in precipitation with height. In addition, runoff is influenced by other factors such as watershed area, presence of glaciers, land cover (*e.g.*, degree of forestation) and bedrock geology. Observed runoff can also exceed precipitation in some cases (*e.g.*, More Creek in 2005) due to contributions from glacier melt.

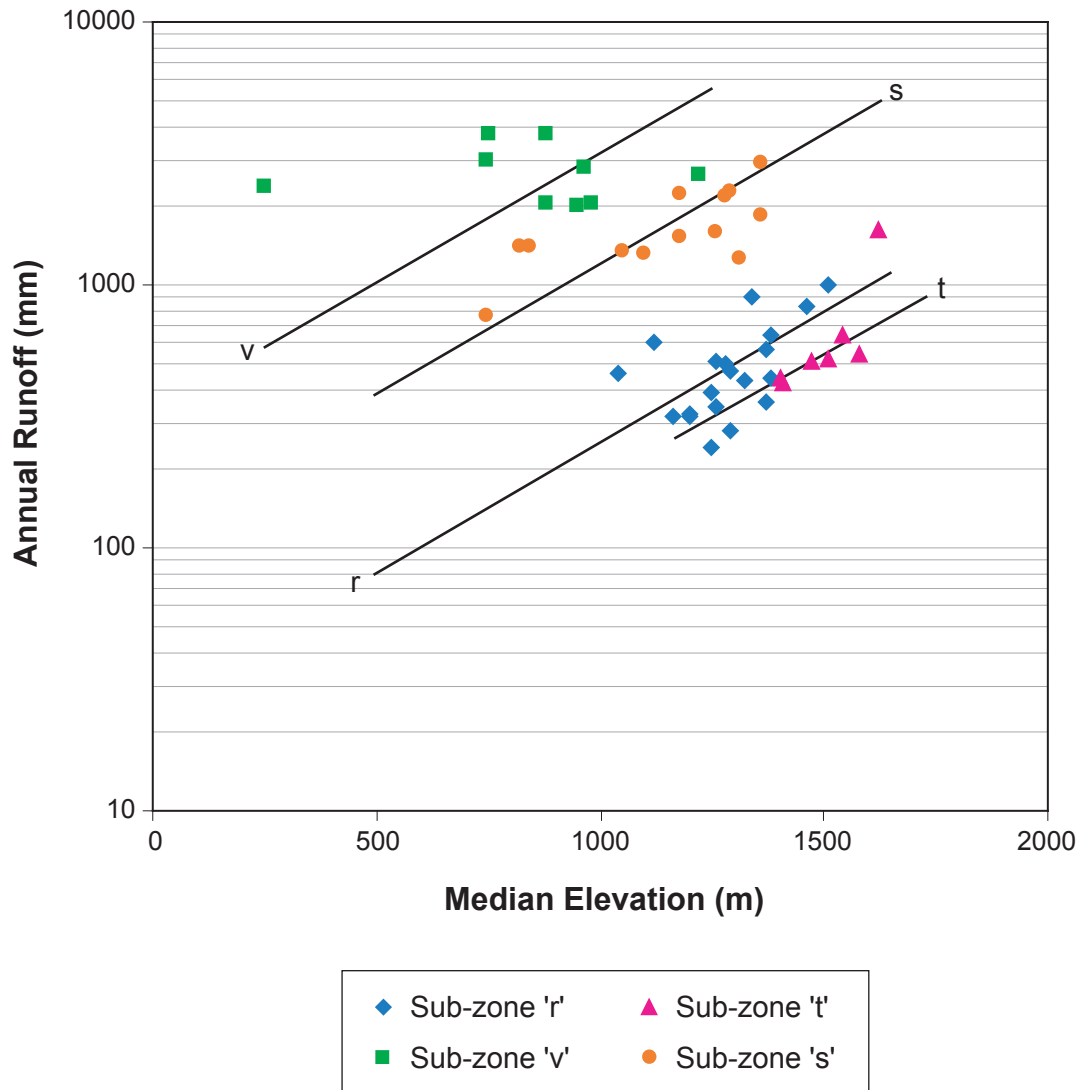
4.3.1 Annual Average Runoff

Estimates of average annual runoff and return period runoff totals for key watersheds in the study area are made using the results of an analysis of annual runoff data from regional hydrology stations.

Obedkoff (2001) related annual runoff totals for WSC stations in northern British Columbia to the median elevation of the watershed lying upstream of the gauging station. The median elevation is the elevation within a watershed which half of the basin area lies above and half lies below. The results of the analysis are shown in Figure 4.3-1. The graph illustrates the impact of median elevation and geographical location on annual runoff totals. The data presented relate to four hydrological sub-zones close to the study area. Sub-zone 'v' is located to the south of the Galore area and closer to the coast. It has the highest runoff values, indicating heavier rainfall and a coastal climate. In contrast sub-zones 'r' and 't' are located to the east of Galore and have substantially less runoff, consistent with a drier interior climate. Stations at the coast can have an order of magnitude more runoff than stations in the interior. Sub-zone 's' contains the study area and data for this zone lie between the other data series reflecting the position of the Galore Creek area in a transition zone between a wet coastal climate and a drier interior. Within each sub-zone there is a clear pattern of increasing annual runoff with median basin elevation, reflecting the expected increase in precipitation with elevation.

Figures 4.3-2a and b provide detailed views of the stations within sub-zone 's'. Figure 4.3-2a plots annual runoff against median elevation and Figure 4.3-2b plots annual runoff against longitude. Also plotted on Figure 4.3-2 are average annual runoff totals for key hydrological monitoring stations in the study area. The median elevations for these watersheds were calculated from DEM's based on TRIM data. The data plotted on the figure is summarised in Table 4.3-1. Best-fit lines are shown on each graph. The quality of the fit in both cases is poor, although the curves do reveal the underlying trend of increasing runoff with median elevation and geographical location. Estimates of average annual runoff can be made using two separate methods; the relationship between annual runoff and median elevation and that between annual runoff and longitude.

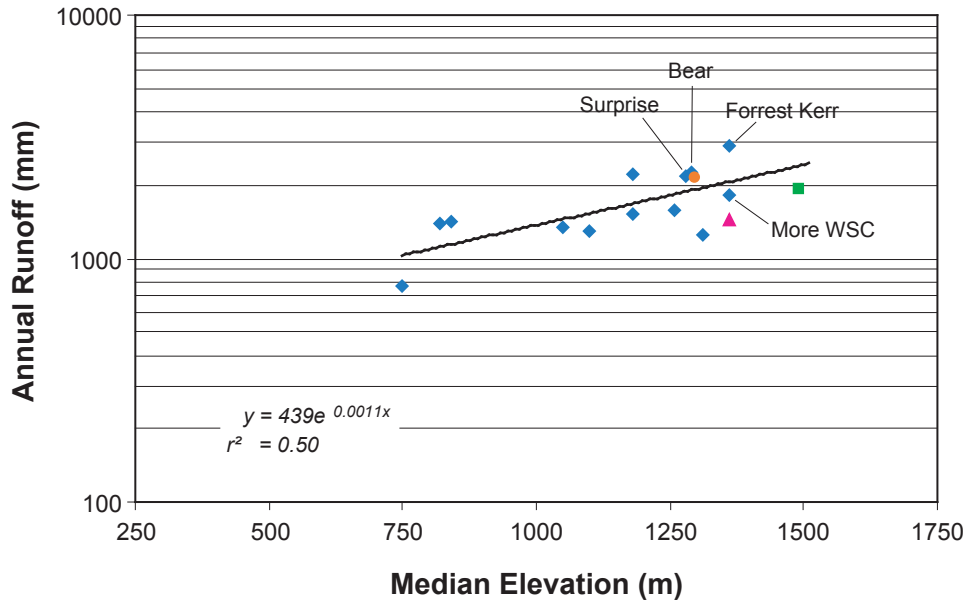
In Figure 4.3-2a observed runoff data for Galore Creek (Gwm8 monitoring station) plots above the regional regression line. However, meteorological data would indicate that 2005 was a drier than average year suggesting that the regional regression line does not describe runoff conditions at Galore Creek.



Comparison of Average Annual Runoff Against Median Watershed Elevation for Selected Water Survey of Canada Gauging Stations

FIGURE 4.3-1





- ◆ WSC stations in sub-zone 's'
- Galore Creek observed
- ▲ More Creek observed
- Sphaler Creek observed

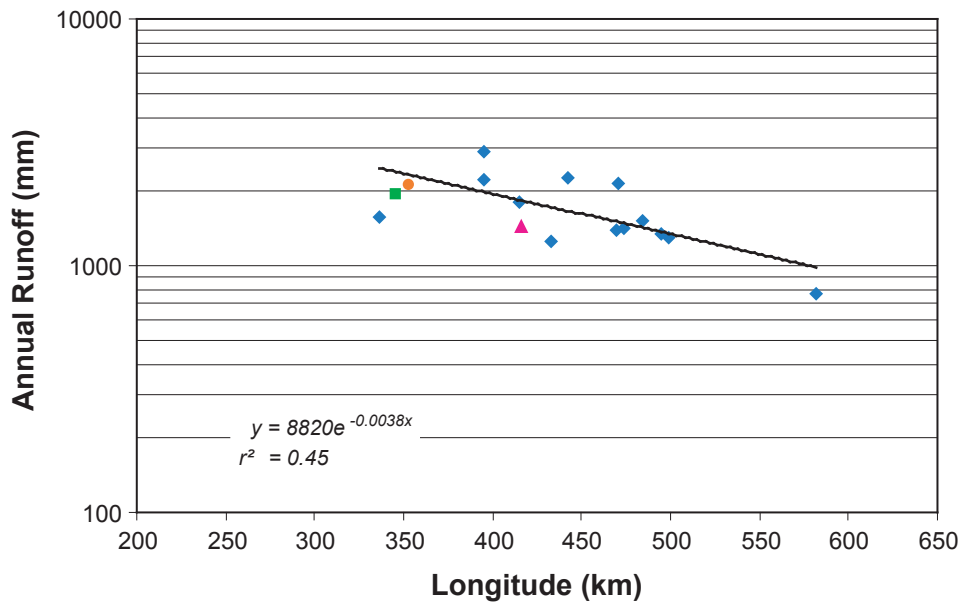


FIGURE 4.3-2

Calculation of Relationship Between Average Annual Runoff and Median Elevation for Sub-Zone's of Obedkoff (2001)



Estimation of Key Hydrological Parameters

**Table 4.3-1
Summary of Data Plotted on Figure 4.3-2**

Station	Period of Operation	Median Elevation (m)	Watershed Area (km ²)	Average Annual Runoff (mm)	Average Annual Flow (m ³ /s)
WSC stations					
Bear	1976 - 1999	1290	289	2270	25.2
Forrest Kerr	1972 - 1994	1360	312	2880	28.4
Iskut - Snippaker	1966 - 1995	1310	7,230	1260	274
Iskut - Johnson	1959 - 2004	1260	9,350	1580	467
Kispiox	1963 - 2003	750	1,870	767	45.5
Lime	1976 - 1996	820	39.8	1400	1.74
Lindeman	1954 - 1993	1100	250	1300	10.3
More	1971 - 1994	1360	844	1820	48.7
Nass	1949 - 2003	1050	18,500	1350	790
Patsy	1987 - 1996	840	5.86	1410	0.21
Skagway	1963 - 1986	1180	376	1520	18.1
Surprise	1967 - 2003	1280	220	2170	15.2
Unuk	1957 - 1995	1180	1,480	2230	141
On-site data					
Gwm8	2005	1300	145	2130	9.79
MORE-7	2005	1360	876	1453	40.4
LS-1	2005	1490	327	2070	20.1

The Galore Creek data plots close to that for Surprise Creek and Bear Creek, and Forest Kerr Creek, three other small, glacierized watersheds. As 2005 was seen as a slightly dry year, the position of the Gwm8 data just below the average runoff values for these WSC stations is consistent. These watersheds were identified as being the most suitable for comparison with Galore Creek and the long-term average runoff at the mouth of Galore Creek is predicted using data from these three stations, providing an estimate of average annual runoff of 2360 mm. The observed runoff data for More Creek plots close to the average value from the More Creek WSC station. The 2005 data is below the long-term average for the WSC station, but this is expected given that 2005 was considered a dry year. The long-term average runoff for More Creek is less than that predicted for Galore Creek, consistent with the 2005 field data. Annual average runoff for More Creek is calculated using the More Creek WSC data, giving a value of 1820 mm. The observed data for Sphaler Creek plots below the regional regression line and does not plot close to any of the regional hydrological stations. Hence, annual average runoff is estimated from the regional runoff/elevation curve, which gives a value of 2260 mm.

In Figure 4.3-2b the data from the monitoring stations all plot below the regional runoff/longitude curve, consistent with observations that 2005 was drier than average. Average annual runoff estimates are made for each watershed based on the regional curve, giving values of 2310 mm for Galore Creek; 1820 mm for More Creek and 2370 mm for Sphaler Creek.

The results are summarized in Table 4.3-2. Estimates using both methods are within 10% of one another for all three watersheds. Final estimates of average annual runoff are taken as the

Estimation of Key Hydrological Parameters

average of the two estimates, as outlined in Table 4.3-2. As an additional check, the runoff total for Galore Creek can be calculated by converting average basin average precipitation for the valley to runoff using a runoff coefficient. The 2005 data indicated that a runoff coefficient of 0.8 was not unreasonable for Galore Valley. Annual average precipitation at an elevation of 761 m is 2241 mm. This converts to a basin average precipitation of 3000 mm at the mouth of Galore Creek, calculated using DEM of the basin and results of UBC Watershed models. Hence, using the runoff coefficient this relates to an average annual runoff of 2400 mm. This value is within 10% of the runoff values estimated using the regional hydrological datasets.

**Table 4.3-2
Estimated Average Annual Runoff
for Key Watersheds in the Study Area**

Station	Estimated Average Annual Runoff – from Median Elevation (mm)	Estimated Average Annual Runoff – from Longitude (mm)	Average Annual Runoff (mm)
Galore Creek – average for watershed (Gwm8)	2360	2310	2340
More Creek – average for watershed (MORE-7)	1820	1820	1820
Sphaler Creek – average for watershed	2260	2370	2320

Table 4.3-2 provides estimates of mean annual runoff at the mouths of each of the main watersheds of interest. Runoff estimates may also be required for sub-watersheds within these catchments. Field data from 2005 indicated that runoff from sub-watersheds of Galore Creek appeared to be relatively constant throughout the basin although higher runoff was observed in small (<5 km²) headwater streams. Field observations and modelling suggested that additional precipitation falling on the western side of the watershed compensated for the higher runoff expected from the eastern tributary produced by glacier melt. Given the available data, it is recommended that the same runoff be applied for all sub-watersheds in the Galore Valley; however, for small (<5 km²) headwater canyons additional runoff could be considered, taking the Gwm5 gauging station as a reference. In More Creek runoff was seen to decrease downstream with increasing watershed area. It is recommended that annual average runoff estimates for sub-watersheds in More Valley should be made by multiplying the average annual runoff estimated for the mouth of More Creek (1820 mm) by a scaling factor, that is the ratio of the observed 2005 runoff from a similar sized watershed in More Creek with observed runoff at the mouth. Similar scaling approach should be used for sub-watersheds in Sphaler Creek.

For the other larger watersheds (*i.e.*, Iskut, Scud, Porcupine and Stikine) annual runoff estimates are outlined in Table 4.3-3. For Iskut River annual average runoff is calculated using the historical data at the WSC gauging station at Iskut-Johnson. For the Scud River and Porcupine River estimates are made using the regional regression curves. Stikine River estimates are calculated from the historical data at the USGS Stikine River near Wrangell station.

Estimation of Key Hydrological Parameters

There is uncertainty associated with all the estimates provided in Tables 4.3-2 and 4.3-3, although, given the limited amount of data it is difficult to accurately quantify the uncertainty. It is likely to be at least $\pm 20\%$. However, the estimates were made using best-available data, following a detailed regional assessment.

Table 4.3-3
Estimated Average Annual Runoff
for Key Watersheds in the Study Area

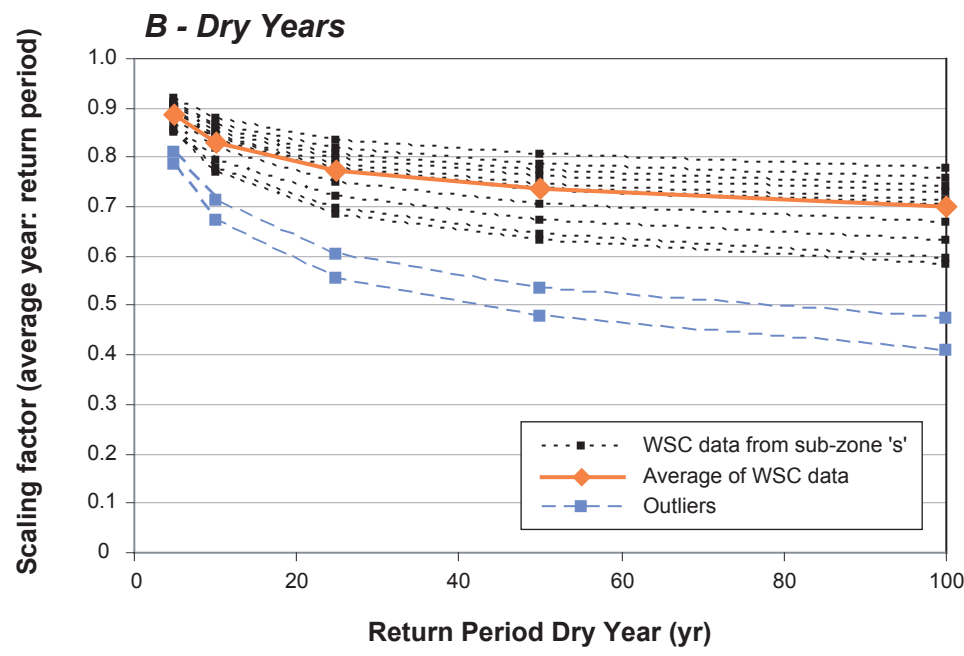
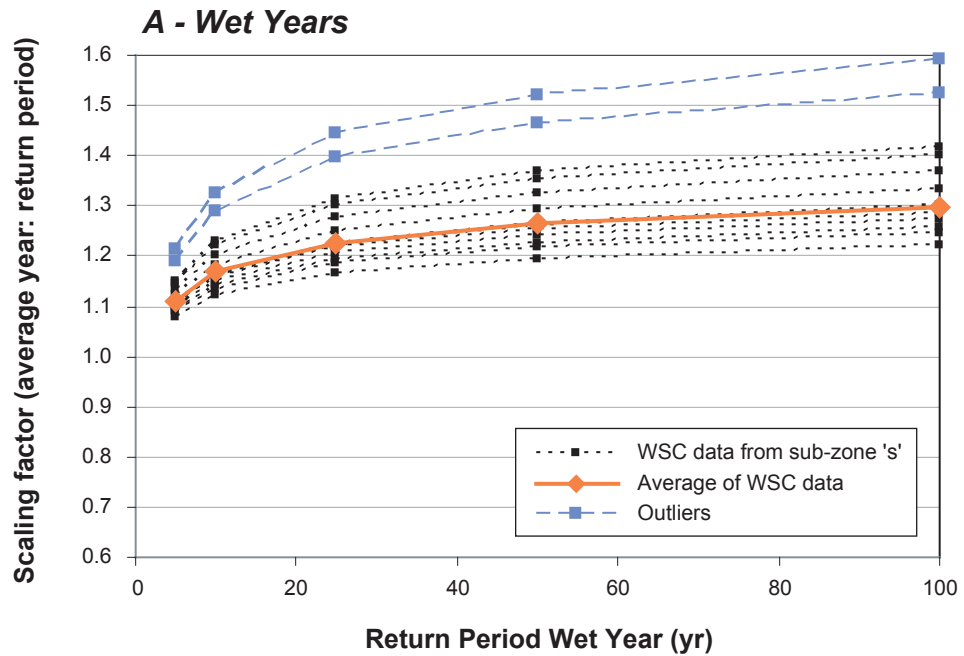
Station	Estimated Average Annual Runoff – from Median Elevation (mm)	Estimated Average Annual Runoff – from Longitude (mm)	Average Annual Runoff (mm)
Iskut River	-	-	1585
Scud River	2050	2480	2270
Porcupine River	1990	2531	2260
Stikine River	-	-	960

4.3.2 Return Period Annual Runoff Totals

Return period estimates of annual runoff totals were calculated using scaling factors calculated through statistical analysis of annual runoff totals for WSC stations in sub-zone 's'. Regional growth curves were calculated for annual runoff based on return period assessments of annual runoff totals for each of the gauging stations. For each station the 5-year, 10-year, 25-year, 50-year and 100-year dry and wet annual runoff totals were estimated assuming that the historical data is part of a normal probability distribution. Other distributions (*e.g.*, log normal, Log Pearson III) were considered but neither gave a better fit to the data than the normal distribution. The return period runoff totals for each station were divided by that station's 2-year (average) runoff to give a scaling factor for each return period. The scaling factors for all WSC stations in sub-zone 's' are shown in Figure 4.3-3. The curves for most stations lie closely grouped together except for the Lime and Skagway watersheds. These outliers were removed from the data set and regional average scaling factors were calculated for each return period.

For the Galore Creek watershed the scaling factors were based on the average values for the Surprise Creek, Bear Creek and Forrest Kerr Creek watersheds; stations identified as having similar basin characteristics (*e.g.*, area, elevation, presence of glaciers) to Galore Creek. For More Creek scaling factors were based on the More Creek WSC data set. For Sphaler Creek scaling factors were based on the regional average data. For other larger watersheds, data for both the Scud River and the Porcupine River were based on regional values; factors calculated for the WSC station at Iskut-Johnson were used for the Iskut River, and factors for the USGS station at Stikine near Wrangell were used for the Stikine River.

Estimates of return periods are provided in Table 4.3-4. For sub-watersheds the average annual runoff can be calculated using the methodologies outlined above and return period estimates made using the scaling factors relevant for that watershed.



Scaling Relationships For Return Period Annual Runoff - Wet and Dry Years

FIGURE 4.3-3



4.4 Estimation of Monthly Flow Distribution

An assessment of the average monthly flow distribution for a watershed (the percent of the annual flow that occurs during each month) provides an indication of the seasonal variation in flows at a site. These values can be combined with annual runoff totals to estimate monthly runoff totals and average monthly flows associated with different annual runoff totals.

**Table 4.3-4
Estimated Annual Runoff Return Periods for Study Area**

Return Period	Galore Creek at the Mouth		More Creek at the Mouth		Regional Scaling Factor ²	Sphaler Creek at the Mouth;	Porcupine River;	Scud River;	Iskut River		Stikine River
	Scaling Factor ¹	Runoff (mm)	Scaling Factor	Runoff (mm)		Runoff (mm)	Runoff (mm)	Runoff (mm)	Scaling Factor	Runoff (mm)	Runoff (mm)
1 in 100 dry year	0.68	1590	0.76	1380	0.70	1620	1580	1590	0.67	1060	730
1 in 50 dry year	0.71	1660	0.78	1420	0.74	1720	1670	1680	0.71	1120	760
1 in 20 dry year	0.76	1780	0.82	1490	0.78	1810	1760	1770	0.75	1180	800
1 in 10 dry year	0.82	1920	0.87	1580	0.83	1930	1880	1880	0.82	1290	830
1 in 5 dry year	0.88	2060	0.91	1660	0.89	2060	2010	2020	0.88	1390	880
Average	-	2340	-	1820	-	2320	2260	2270	-	1580	960
1 in 5 wet year	1.12	2620	1.09	1980	1.11	2580	2510	2520	1.12	1760	1040
1 in 10 wet year	1.18	2760	1.13	2060	1.17	2710	2640	2650	1.18	1860	1090
1 in 20 wet year	1.24	2900	1.18	2150	1.22	2830	2760	2770	1.25	1970	1120
1 in 50 wet year	1.29	3020	1.22	2220	1.26	2920	2850	2860	1.29	2030	1160
1 in 100 wet year	1.32	3090	1.24	2260	1.30	3020	2940	2950	1.33	2090	1190

¹Scaling Factor is the ratio of the return period runoff value to the average value. The scaling factor can be used to calculate return period estimates using other annual average runoff values

²Regional average for stations in sub-zone 's' is applied to Sphaler Creek, Scud River and Porcupine River

Table 4.4-1 shows the average percentage of the annual runoff occurring in each month of record for WSC stations in sub-zone 's' and for selected stations in other sub-zones that lie at a similar latitude to Galore Creek. The latitude of a watershed has a strong influence on the timing of freshet flows. Lime, Patsy and Kispiox WSC gauging stations are the most southerly stations in sub-zone 's'. At these stations the highest freshet flow volumes typically occur in May, while at the other stations in sub-zone 's' the largest flow volumes are in June or July. Data for these three southerly stations were excluded when calculating average monthly flow distributions for the region. However, values for the stations in nearby sub-zones and at the same latitude as Galore Creek were added to the assessment. Although these stations will have different annual runoff totals the monthly distribution of flow is thought to reflect conditions within the study area.

Estimation of Key Hydrological Parameters

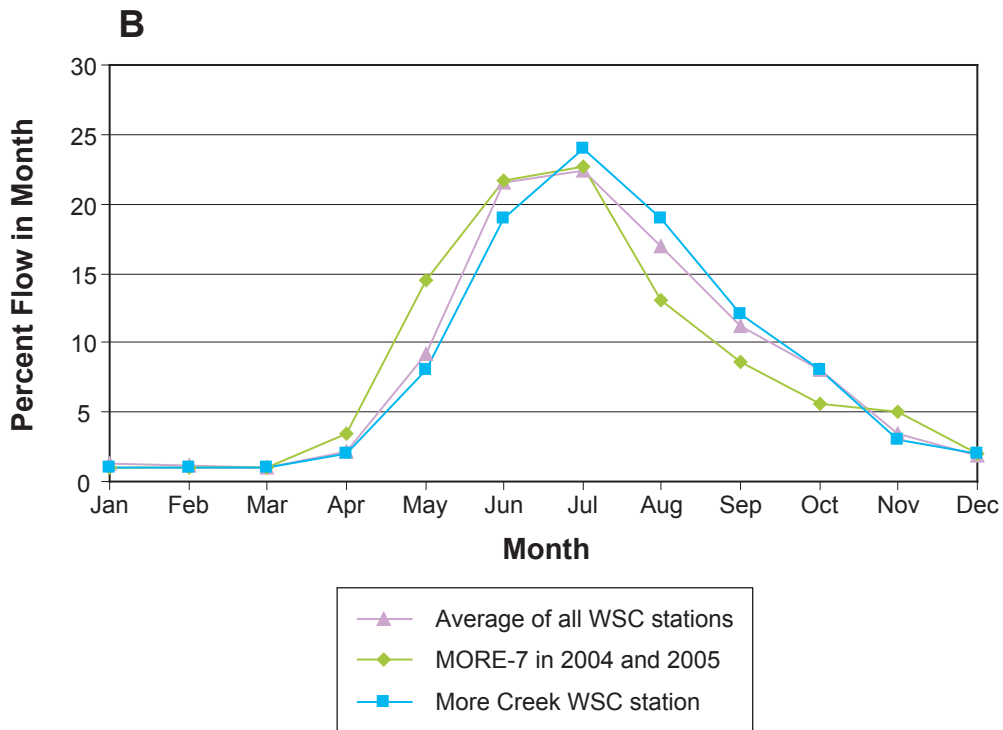
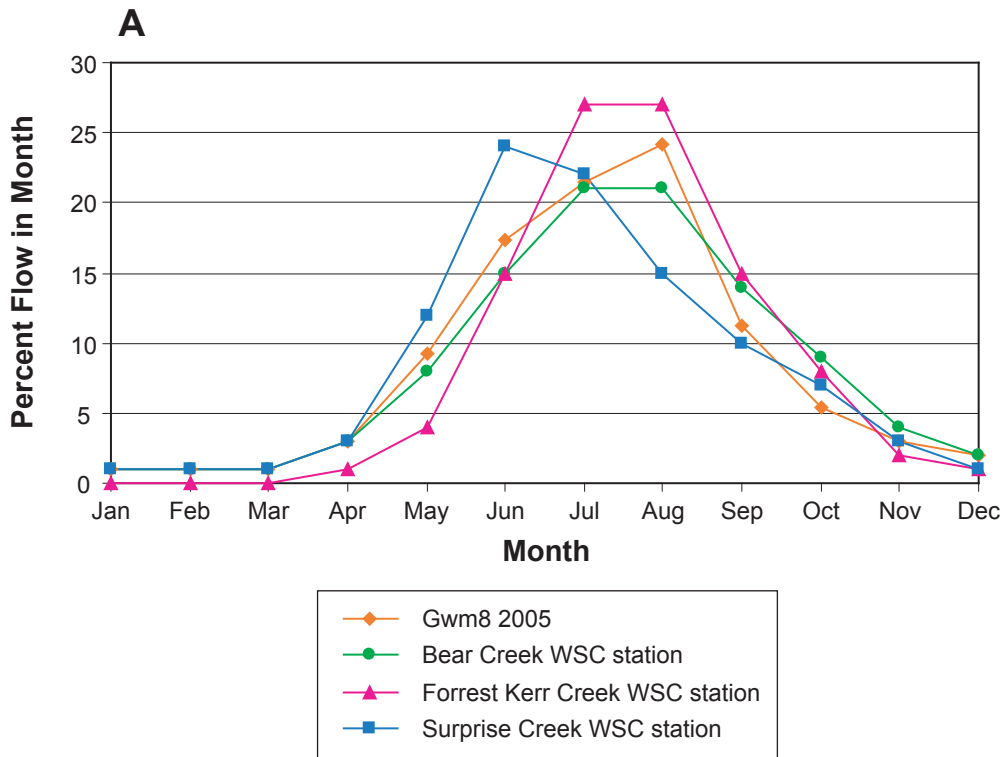
Table 4.4-1
Monthly Flow Distribution for Regional WSC/USGS Gauging Stations

Station Information		Percentage of Annual Flow Occurring in Each Month (%)											
Name	Watershed Area (km ²)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bear	289	1	1	1	3	8	15	21	21	14	9	4	2
Forrest Kerr	312	0	0	0	1	4	15	27	27	15	8	2	1
Iskut - Snippaker	7,230	1	1	1	2	9	21	23	17	11	8	4	2
Iskut - Johnson	9,350	1	1	1	3	9	19	21	18	12	9	4	2
¹ Kispiox	1,870	1	1	1	6	19	24	15	7	7	10	5	2
¹ Lime	39.8	3	3	3	9	21	18	9	5	8	13	7	3
Lindeman	250	1	1	1	1	9	25	24	16	11	7	3	1
More	844	1	1	1	2	8	19	24	19	12	8	3	2
Nass	18,500	2	1	1	4	14	22	18	13	9	9	5	2
¹ Patsy	5.86	2	2	2	10	29	16	3	3	8	14	7	4
Skagway	376	1	1	1	1	7	22	26	19	12	7	2	1
Surprise	220	1	1	1	3	12	24	22	15	10	7	3	1
Unuk	1,480	2	2	1	3	9	17	20	18	13	9	4	2
Stikine Butterfly	36,000	2	1	1	2	12	25	21	13	10	8	3	2
Stikine/Telegraph	29,300	2	1	1	2	13	29	20	11	9	7	3	2
Stikine/Wrangell	51,600	2	1	2	3	11	20	21	16	12	8	3	2
Iskut/Kinaskan	1,250	2	2	2	2	6	21	23	15	10	9	5	3
Klappan	3,540	1	1	1	2	9	26	24	15	9	7	3	2
Regional Average		1	1	1	2	9	21	22	17	11	8	3	2
On-site data													
Gwm8	145	1	1	1	3	9	17	21	24	11	5	3	2
MORE-7	876	1	1	1	5	14	22	22	19	6	3	3	2
LS-1	327	1	1	1	3	12	18	22	25	11	2	2	2

¹ Stations not used in calculation of regional average

The data shows that flow is concentrated in the non-winter/open-water months (May to October) with only around 8 to 10% of the annual flow occurring from November to April. During the open water season (*i.e.*, ice free months) the distribution of flow depends on the timing of freshet and also the balance between the volume of water released during freshet with water resulting from autumn rainfall or glacier melt. Smaller watersheds with glaciers (*e.g.*, Forrest Kerr Creek, Bear Creek) show a higher proportion of flow occurring during July and August when compared to larger watersheds. Such a pattern was also seen in the 2004 and 2005 field data for Galore Creek and Sphaler Creek, and reflects the influence of glacier melt and the melting of snow retained at higher elevations in the watershed into late summer. However, Surprise Creek, another small watershed with high glacier coverage does not follow the same pattern, reflecting the high degree of uncertainty in watershed response for glaciated watersheds. In Figure 4.4-1 data for Galore Creek is compared to data from Forrest Kerr, Bear Creek and Surprise Creek.

The monthly flow distribution from the long-term flow records at More Creek WSC station is similar to the regional average of all stations. The 2004 and 2005 data collected at MORE-7, at the mouth of More Creek, show a similar pattern to the regional average although the 2004 and



Comparison of Monthly Flow Distributions for Key Watersheds

FIGURE 4.4-1



Estimation of Key Hydrological Parameters

2005 data had higher flows earlier in the year compared to the long-term average, in Figure 4.4-1. It is difficult to draw any conclusions from one or two year's worth of data and the difference may reflect warm conditions during spring in these two years. However, a trend of earlier freshet conditions is predicted from potential climate change and is discussed in more detail in Appendix 2.

Table 4.4-2 summarises the values that are recommended to be used in hydrological assessments of the study area. Values for Galore Creek and Sphaler Creek are based on the average of long-term records at Forrest Kerr, Bear Creek and Surprise Creek. Values for More Creek are based on the average of long-term records at the More Creek WSC station. Monthly flow distributions for the Iskut are based on data from the WSC station at Iskut-Johnson, and for the Scud and Porcupine Rivers, regional average values are used. It is recommended that the monthly flow distributions selected for the mouth of the watershed are used for sub-watersheds. However, for headwater streams it is likely that runoff during winter months will tend to zero. In such cases winter flows may be redistributed to other months during the open water season.

Return period monthly flows can be estimated by taking return period annual runoff totals and dividing by the monthly percentage values given in Table 4.4-2. Estimates of return period average monthly flows can also be obtained through direct analysis of average monthly flow data for WSC stations (*i.e.*, from a return period assessment of average monthly flows for each site). Results of such an analysis are not provided in this report. Such data may be required for the EIA and analysis will be undertaken if required. For the purpose of describing Baseline conditions and providing estimates of monthly flows for most hydrological analyses, an assessment of monthly percentage flows is thought to be sufficient.

**Table 4.4-2
Estimates of Monthly Flow Distribution for Selected Watersheds**

	Percentage of Annual Flow Occurring in Each Month (%)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average for Regional WSC stations	1	1	1	2	9	21	22	17	11	8	3	2
¹ Galore Creek at the mouth	1	1	1	2	8	18	23	21	13	8	3	1
² More Creek at the mouth	1	1	1	2	8	19	24	19	12	8	3	2
³ Sphaler Creek at the mouth	1	1	1	2	8	18	23	21	13	8	3	1
Iskut River at the mouth	1	1	1	3	9	19	21	18	12	9	4	2
Scud River at the mouth	1	1	1	2	9	21	22	17	11	8	3	2
Porcupine River at the mouth	1	1	1	2	9	21	22	17	11	8	3	2
⁴ Stikine River at the mouth	2	1	2	3	11	20	21	16	12	8	3	2
⁵ Precipitation	12	11	6	7	4	2	3	5	12	14	12	12

Notes:

- ¹Galore Creek data based on long-term average from small, glaciated watersheds (Forrest Kerr, Bear, Surprise Creek)
- ²More Creek data based on long-term average at More Creek WSC station
- ³Sphaler Creek data based on long-term average from small, glaciated watersheds (Forrest Kerr, Bear, Surprise Creek)
- ⁴Stikine River data based on average at Stikine River-Wrangell USGS station.
- ⁵From historical Galore Creek meteorological data and on-site data collected in 2004 and 2005. See Meteorology, Air Quality and Noise Baseline Report for more details.

4.5 Estimation of High Flows

Floods in northwest British Columbia are produced by three main mechanisms;

1. Rapid snowmelt – during freshet conditions in June or July
2. Rain falling on melting snow– during freshet conditions in June or July, or during early winter in November and December
3. Heavy rainfall – during September or October

In the Coast Mountains, the largest floods are typically caused by mechanisms 2 and 3.

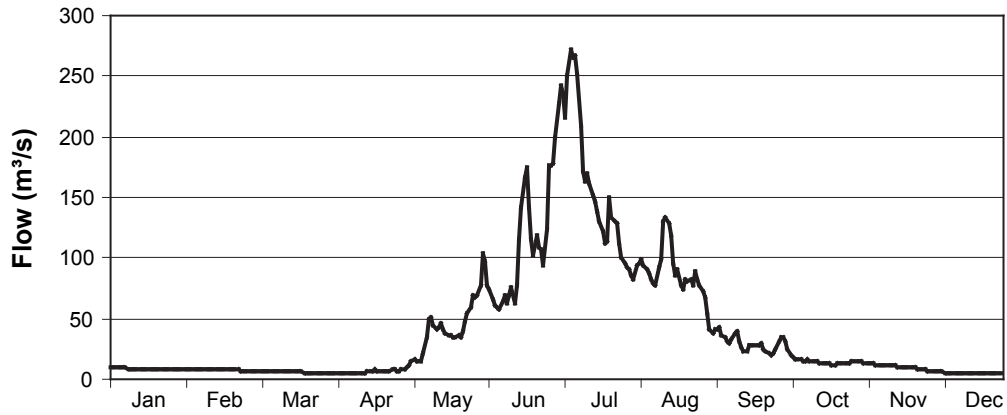
Examples of these three different flood generating mechanisms can be seen in Figure 4.5-1, using data from the More Creek WSC gauging station. The upper graph illustrates a flood peak generated by rain falling during snowmelt; the middle graph shows a year with a series of small flood peaks as a result of snowmelt, rain on snow and rainfall. Finally, the lower graph illustrates a large flood event occurring due to rainfall in early October. There are clear differences in the shape of the flood hydrographs associated with different flood mechanisms. Rainfall generated floods in September and October typical have a ‘peakier’ form with steep rising and falling limbs. Flood events in June and July have broader peaks with the flood superimposed on top of a flow component comprised of snowmelt or glacier melt.

Figure 4.5-2 considers the More Creek WSC data in more detail. For each year the annual instantaneous peak flow is recorded by WSC and is provided as an annual peak series. Figure 4.5-2a shows how these annual peak flows are distributed through the year. Approximately half of the annual flood peaks occur in September and October and the other half in the preceding three months. Figure 4.5-2b shows that floods occurring in September and October have, on average, larger peaks than those occurring during freshet. The two largest floods on record both occurred during fall. Figure 4.5-2c illustrates that the distribution of flood peak discharges for More Creek is skewed, with a cluster of floods with discharge less than 400 m³/s and two outliers greater than 1000 m³/s. This degree of skew is typical of other stations in northern BC and has a strong impact on predicted floods at high return periods (*e.g.*, greater than 1 in 50 year flood). More detailed discussions of the impact of skewness within the data and flood-generating mechanisms on flood frequency analysis are provided in Appendix 6.

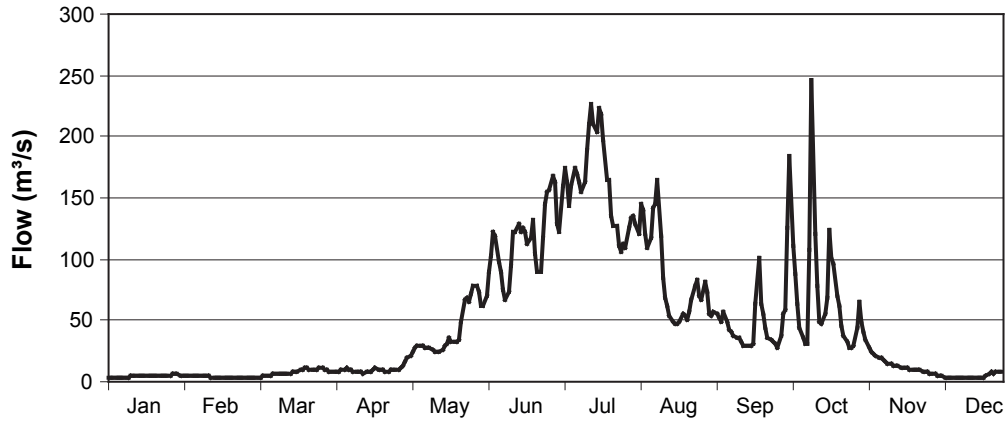
The purpose of a flood frequency analysis is to predict river flood flows for different return periods. The return period refers to the probability of occurrence of the flood event. A 1-in-100 year return period (Q_{100}) event is the magnitude of flow that has a 1% chance of being equalled or exceeded in a given year. Similarly a Q_{50} has a 2% chance of being exceeded in a year. The mean annual flood is generally defined as the Q_2 (*i.e.* a 50% probability of being equalled or exceeded in a given year). The probability of exceeding a flood of return period t within n years is $1-(1-(1/t))^n$ (Chow, 1981).

A number of methods of estimating the magnitude and frequency of flood events have been applied to rivers in British Columbia. These include:

A



B



C

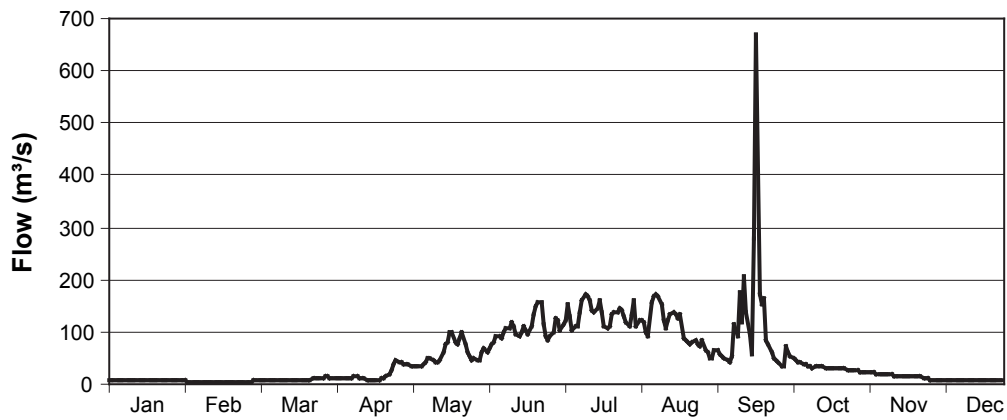


FIGURE 4.5-1

**Examples of Annual Peak Floods at More Creek
WSC Gauging Station**



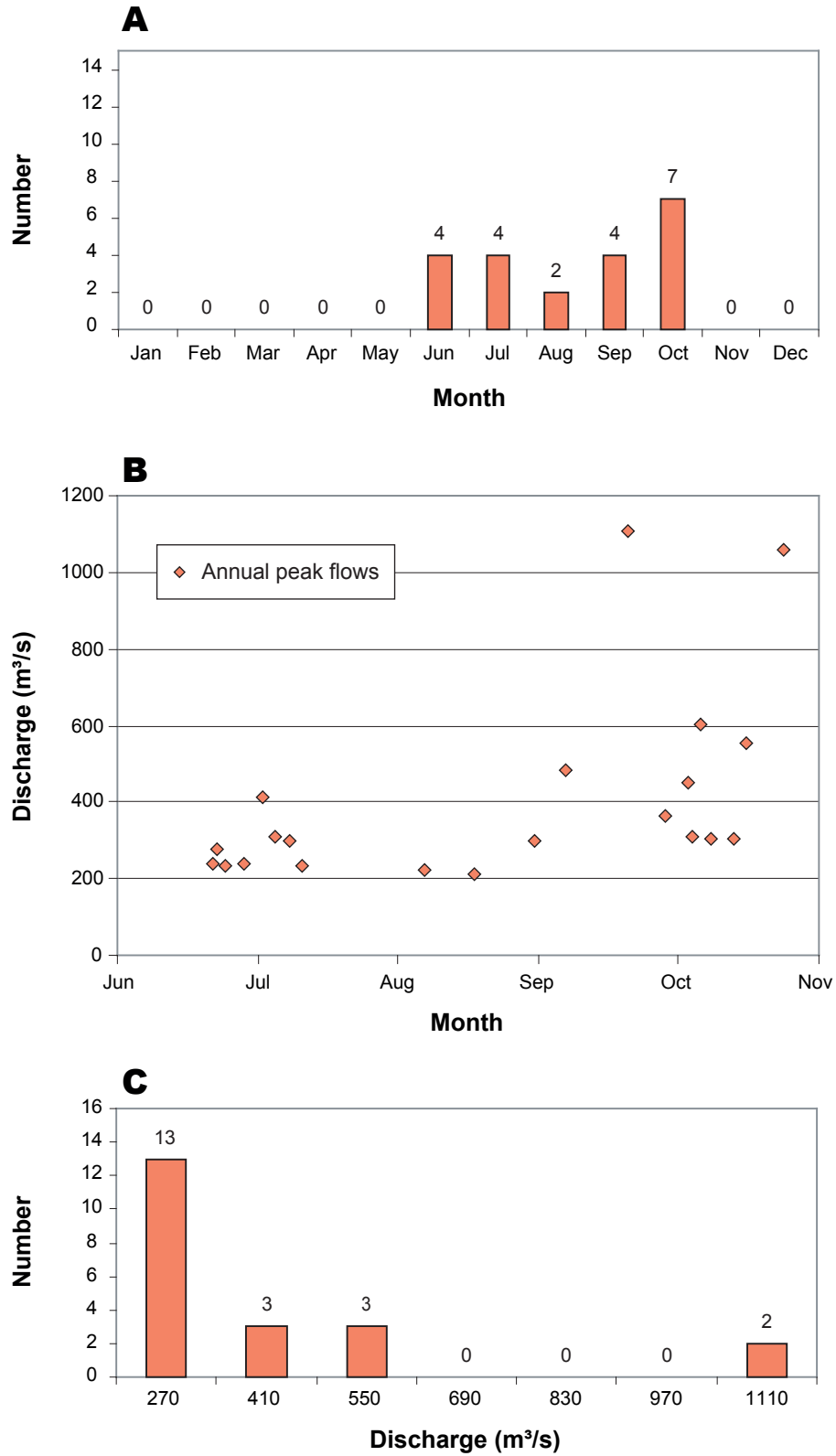


FIGURE 4.5-2



Distribution of Annual Peak Flows at More Creek WSC Gauge

- Single site flood frequency analysis;
- Regional analysis;
- Hydrological modeling, including the rational method; and
- Channel geometry approaches.

There are no standard methodologies for use in British Columbia, although guidance is offered in Coulson (1991). Each of the methods listed above have advantages and limitations. When selecting an appropriate methodology a number of factors need to be considered, including the availability of meteorological and hydrological datasets (from the site or from neighbouring or hydrologically similar watersheds) and the size of the watershed.

Different methodologies are typically used for watersheds of different sizes. There are very few long-term flow monitoring stations on watersheds smaller than 25 to 50 km², hence methods (single-site analysis, regional analysis) developed using regional flow datasets are usually suitable for larger watersheds only. For small watersheds hydrological modeling and channel geometry approaches are more commonly used. In this study we suggest the use of different approaches for large and small watersheds, with large watersheds defined as being > 25 km² and small < 25 km² in size.

In the following sections a range of methodologies are discussed in more detail.

4.5.1 Approaches for Large Watersheds

4.5.1.1 Single-Site Flood Frequency Analysis

On gauged rivers, a single-site flood frequency analysis is the most commonly used method for predicting extreme peak flows (*e.g.*, Chow 1981). The method requires the fitting of statistical probability distributions to observed annual peak flow time series data taken from the flow records at a gauging station. The approach identifies the peak discharge event that occurred in each year of record, and creates a frequency-magnitude plot for those events. Observed peak-flows are ranked based on their magnitude, and assigned a probability of occurrence, or frequency. An extreme-value statistical distribution is then fit to the frequency-magnitude data; the most common extreme-value distributions used are log-normal, Gumbel, Pearson Type III, and log-Pearson Type III.

The main limitation of the single-site approach is that for most gauging stations the period of record at the station is less than the return period event of interest (*e.g.*, 1-in-100 year flood). For example, most WSC stations close to the study area have records that are shorter than 40 years. When the period of record at the gauge site is longer than the return period, the return period peak flow can be interpolated from the existing data, providing a robust estimate of the flood flow. Where the period of record is shorter than the return period, flow estimates have to be extrapolated from the fitted extreme-value distribution. This results in flood flow estimates with a higher degree of uncertainty.

Other issues to be considered include the presence of outliers (*i.e.*, extremely high annual peak flows) in the data that can skew return period flow estimates. In addition, at sites where there are

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more than one peak-flow generating process (*e.g.*, snowmelt or rainfall), the mixing of flood event data generated from the two processes can also skew the return period estimates. Both these issues are relevant to the study area and are discussed in Appendix 6.

Despite the limitations of the method, at any site with a flow gauging station the use of a single site analysis is invariably the most appropriate method for a flood frequency analysis. However, it is very uncommon for there to be a gauging station with long-term flow records exactly at the site of interest. If the site of interest lies in the same watershed, or in close proximity to the gauge then the flood-frequency relationships for one station can be used as a surrogate for the ungauged site. However, in most cases a regional assessment approach is used, which combines data from several stations within a region. Such an approach is often more appropriate since it accounts for regional variability in hydrology processes and conditions. Regional analysis approaches used within British Columbia are discussed in the next section.

There are WSC/USGS gauging stations on a number of rivers considered in this report. Long-term flow records are available for More Creek, the Iskut River (at the Iskut-Johnson and Iskut-Snippaker sites), and the Stikine River (near Wrangell). Details of single-site analyses of these stations are summarized in Table 4.5-1 and are discussed in more detail in Appendix 6.

**Table 4.5-1
Results of Single-Site Analyses for Selected Stations**

Station	Code	Watershed Area (km ²)	Q ₂ (m ³ /s)	Q ₁₀ (m ³ /s)	Q ₁₀₀ (m ³ /s)
More Creek	08CG005	844	320	640	1630
Iskut- Johnson	08CG001	9350	2620	4130	9150
Iskut-Snippaker	08CG004	7230	1790	2570	6320
Stikine-Wrangell	08CF003	51600	5880	7710	10600

4.5.1.2 Regional Flood-Frequency Analysis

A regional flood-frequency analysis uses results of single-site analyses from a number of gauging stations to develop relationships or regression equations that allow return period flows to be predicted at ungauged sites. Typically, different relationships are developed for different geographical regions, selected based on climate, topography and geographical proximity. The regression equations are only considered valid for watersheds of a size that is represented within the flow dataset used to generate the equations.

Several methods have been used to conduct regional analysis of flood-frequency in northwest British Columbia. In this section we discuss approaches based on simple and multiple regression equations.

Simple Regression Equations

In British Columbia a number of studies have developed simple regression equations relating peak flows to watershed area (*e.g.*, Government of British Columbia 1996, Coulson and Obedkoff 1998, Church 1997, Obedkoff 2001, Eaton *et al.* 2002). The equations take the form;

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$$Q = kA^x$$

Where Q is the flow (m^3/s), x is a scaling coefficient usually assumed to be between 0.6 and 1.0 and k is a constant related to flood frequency-magnitude relationships. Different k values exist (e.g., k_2 , k_{50} , k_{100} , etc.) for each return period event (e.g., Q_2 , Q_{50} , Q_{100} , etc.).

In the most recent study, Eaton et al. (2002) developed values for k at individual WSC gauged rivers throughout British Columbia, and combined these values to create regional patterns of k . Based on an assessment of scaling relationships from other areas they set the value of $x = 0.75$ and then calculated k values from the results of single-site flood frequency analyses at each gauging station. An alternative approach is to calculate values of k and x by curve fitting. Data for each gauging station is plotted on log graph paper and a best fit line is drawn through the data. Obedkoff (2001) used this approach for data within northern British Columbia.

The regional dataset used for this study included WSC stations within ± 2 degrees of latitude of the Galore Creek and which were within the Coast Mountains. The grouping was similar to sub-zone 's' from Obedkoff (2001), but 4 stations located south of the study area were removed from the set of stations used by Obedkoff. In addition, data from 3 USGS stations located on the same latitude as the study area were incorporated into the study. Although these stations were closer to the coast and might expect to have higher overall precipitation, the flood statistics of the stations were similar to stations near the study area. In addition, Sphaler Creek flows to the west and is likely to be impacted by coastal weather patterns to a greater degree than More Creek or other watersheds further to the east. It should also be noted that the Obedkoff groupings were based primarily on annual runoff totals and not flood flows. Details of each of the stations are provided in Table 4.5-2.

**Table 4.5-2
Mean Annual Floods for Regional WSC and USGS Stations**

Station Name	Code	Watershed Area (km ²)	Mean Annual Flood (m ³ /s)	Mean Annual Flood (L/s/km ²)	Number of Points	Skewness
Harding River Creek - USGS	15022000	175	186	1064	51	-
Cascade River Creek - USGS	15026000	60	45	751	66	-
Farragut River - USGS	15028300	391	390	998	17	-
Bear Creek - WSC	08DC006	289	173	599	30	0.8
Forrest Kerr Creek - WSC	08CG006	312	164	526	22	1.1
Iskut - Snippaker - WSC	08CG004	7230	1450	248	25	3.3
Iskut - Johnson - WSC	08CG001	9350	2620	280	41	2.3
More Creek - WSC	08CG005	844	321	477	21	2.1
Surprise Creek - WSC	08DA005	220	109	495	31	2.5
Unuk River - WSC	08DD001	1480	755	510	29	0.4

¹ Data not available on WSC Hydat CD. Mean annual flood data for WSC stations from Obedkoff (2001).

The calculated k -values for each regional hydrology station are given in Table 4.5-3. The average regional k -value for the Q_{100} flood is 7.26, but it should be noted that values for

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individual sites ranges from 3.50 to 10.41 and the highest value is for the More Creek gauging station. Values for the Iskut River are also higher than the regional average indicating that the ratio of the estimated Q_{100} to the Q_2 for these watersheds is larger than for other watersheds in the region. This may reflect hydrological conditions in these watersheds or the available flood record at the monitoring status. The flood records for More Creek and the Iskut River are discussed in more detail in Appendix 6.

Figure 4.5-3 presents results of the curve fitting method using data for each of the stations outlined in Table 4.5-2.

**Table 4.5-3
K-Factor Values for Regional WSC and USGS Hydrology Stations**

Station Name	Watershed Area (km ²)	k ₂	k ₁₀	k ₁₀₀	k ₂₀₀	Scaling Factor (k ₁₀₀ /k ₂)
Harding River - USGS	175	3.87	6.35	9.67	10.06	2.50
Cascade Creek – USGS	60	2.09	3.30	4.92	5.100	2.35
Farragut River - USGS	391	4.44	5.57	9.14	9.62	2.06
Bear Creek - WSC	289	2.28	3.61	5.42	5.99	2.38
Forrest Kerr Creek - WSC	312	2.16	2.83	3.53	3.70	1.64
Iskut- Johnston - WSC	9350	2.41	4.34	9.62	12.30	4.00
Iskut-Snipaker - WSC	7230	1.85	3.28	8.06	10.76	4.36
More Creek - WSC	844	2.05	4.11	10.41	13.86	5.08
Surprise Creek - WSC	220	1.74	2.89	4.95	5.76	2.84
Unuk River - WSC	1480	2.99	4.82	6.91	7.46	2.31
Regional Average		2.59	4.11	7.26	8.46	2.95

There is a wide scatter in the data, but there is a relationship between drainage area and Q_{100} flow. The regression line through the data was fit using least squares regression.

A regional approach is suitable for estimating flood frequency data for Galore Creek and Sphaler Creek as neither of these watersheds have long-term flow records. Return period flow predictions for Galore Creek and Sphaler Creek using the two methods outlined above are provided in Table 4.5-4. The predictions made using the two methods are seen to be similar, although, the estimates made using the k-factor method are higher.

The two approaches described above can provide useful estimates of flood magnitude, though there are limitations. The k-values and regression equations have been derived from a fairly limited number of WSC gauging stations. Almost all of these stations are on rivers with large drainage areas (>200 km²), and therefore extrapolation to smaller streams needs to be done with caution. In addition, the study area lies within a transition zone between a wetter, mountainous coastal region and a drier interior.