Supporting Document G1

Giant Mine Flood Hydrology
(SRK, 2004)

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Technical Memorandum

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Subject:	**Giant Mine Flood Hydrology**	**Project #:**	1CI001.12.B5

1 Introduction

This memorandum summarizes two studies that were undertaken to characterize the flood hydrology of the Giant mine site. The purpose of the first study was to examine the behaviour of the mine's tailings impoundments during an extremely large and rare flood known as the Probable Maximum Flood (PMF). The second study was aimed at developing a general method for estimating the magnitude of more common floods at ungauged locations around the mine site.

2 PMF Estimates for Tailings Impoundments

Two tailings impoundments were developed at the Giant Mine, namely: the Original Tailings Area and the Northwest Pond. Studies are underway to identify a suitable set of measures to permanently close these facilities. One necessary measure will be the provision of a spillway at each impoundment. The design flood event for these spillways has yet to be selected but a likely candidate is the PMF, which is defined as "the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin under study" (USACE, 1999).

This study examines the implications of adopting the PMF as the design basis for the spillways. The estimated magnitude of the PMF for a small catchment in northern Canada tends to be an order of magnitude larger than the largest floods that have thus far been measured in the region. Based on its sheer size relative to common flood events, the PMF probably has a return period measured in the thousands of years.

The estimation of the PMF for each tailings impoundment involved four broad steps. These are described below under separate headings.

2.1 Spillway Hydraulics and Available Storage

Both tailings impoundments have considerable unused storage capacity behind their dams. This storage can be exploited to significantly reduce the magnitude of the flood discharges that would have to be passed by the spillways during the occurrence of the PMF. A portion of the incoming flood waters would be temporarily stored in the impoundment for subsequent release after the peak of the flood-producing storm has passed. A potentially large reduction in the flood peak is possible because the available storages are large relative to the catchment areas controlled by the tailings impoundments.

Two pieces of information were required to establish how effective the storage in the tailings impoundment would be at reducing flood peaks. The first was a relationship between elevation and discharge over the spillway (i.e., the so-called rating curve of the spillway). The second was a relationship between elevation and available storage in the impoundment above the tailings surface.

Figure 1 shows these two relationships for the Northwest Pond. The top plot presents the rating curve for the proposed spillway. The spillway was assumed to have a trapezoidal shape with a basewidth of 2 m, sideslopes of 1H:1V and a crest elevation of 192.0 m (UTM NAD83) which is equivalent to 6089.1 ft (mine datum). Steep sideslopes were selected because the spillway will likely be cut in bedrock. The spillway crest elevation was selected on basis of information provided by Golder which outlines minimum freeboard requirements for the Northwest Pond. The rating curve for the spillway was derived using the discharge equation for a broad-crested trapezoidal weir.

The bottom plot on Figure 1 shows the storage available in the impoundment above the tailings surface. Not all of this storage would be useful in dealing with flood waters. The storage of greatest value is that in the one or two metre vertical increment immediately above the spillway crest. At the preferred elevation of 192.0 m (6089.1 ft), this incremental storage is significant. The pond surface at this elevation is about 0.15 km^2. In the one metre vertical interval above the preferred crest elevation, the available storage is 223,000 m^3.

Figure 2 presents the spillway rating curve and height-storage relationship for the Original Tailings Area. This impoundment comprises three cells: the South, Central and North Ponds. The spillway will be located in the North Pond, or the lowest of the three cells. Three different options were examined for the geometry of the proposed spillway. In Option 1, the spillway was assumed to have a 2 m basewidth, 2H:1V sideslopes and a crest elevation of 175.0 m (6033.4 ft). The selected sideslope is milder than in the case of the Northwest Pond because the spillway will likely be constructed in soil. The spillway crest elevation was selected on the basis of information provided by Golder and reflects dam stability concerns.

In Option 2, the spillway geometry would be identical to that of Option 1 except the crest elevation would be raised by 1.7 m to the 176.7 m (6039 ft) level. The adoption of this higher crest elevation would likely require measures to increase the stability of the dams. The advantage of a higher crest elevation is the flood reduction capacity of the North Pond could be significantly improved. At the preferred crest elevation of 175.0 m (6033.4 ft), the pond surface is 0.064 km^2. By raising the crest to 176.7 m (6039 ft), the pond surface almost doubles to 0.124 km^2.

Option 3 is the same as Option 2 except the basewidth is reduced from 2 m to 0 m (i.e., the spillway would have a triangular shape). This reduction in basewidth would further decrease the peak of the outflow flood by forcing a greater proportion of the incoming flood waters to be temporarily stored in the impoundment.

The bottom plot on Figure 2 presents the available storage in the North Pond above the deposited tailings surface as a function of elevation. In the one metre increment above the 175.0 m (6033.4 ft) level, the pond has a storage volume of 76,000 m^3, or substantially less than available for the Northwest Pond. By increasing the crest elevation to 176.7 m (6039 ft), the storage in the first one metre increment would increase to 129,000 m^3.

2.2 Meteorological Conditions Assumed to Generate PMF

The PMF's for the two impoundments were assumed to be generated by an extreme rainfall storm falling on a ripe snowpack that, in the days preceding the storm, was experiencing an unusually high melt rate. The storm was assumed to have a duration of 24 hours and possess rainfall intensities at a level known as the Probable Maximum Precipitation (PMP). The PMP is "the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location during a certain time of the year" (USACE, 1999).

The magnitude of the PMP event was estimated using the Hershfield Method, a statistical procedure based on several hundred thousand station-years of rainfall data from many countries (Hogg and Carr, 1985 and WMO, 1986). The method requires an understanding of how variable short-duration rainfall amounts are at the site of interest. To obtain this understanding for the Giant mine site, reference was made to the intensity-duration-frequency curve for the Yellowknife Airport (AES, 1991). The estimated rainfall depths for various durations within the PMP storm are provided in Table 1. The total rainfall depth over 24 hours is estimated to be 318 mm. About 31% of this total would fall during the most intense hour of the storm. The estimated 24-hour PMP for the Giant Mine is small on the world scale, being only about 17% of the largest daily rainfall ever recorded (Linsley et al., 1986).

Table 1 Estimated Rainfall Depths for Various Periods Within 24-hour PMP Storm

Duration (hours)	Rainfall Depth (mm) [1]	Percentage of World Record [2]
1	100	24
2	129	22
3	150	21
6	195	20
12	248	18
24	318	17

Notes: 1) Based on applying the Hershfield Method to the short-duration rainfall data measured at the Yellowknife Airport.

2) Based on envelope curve of world's greatest observed point rainfalls (Linsley, Kohler and Paulhus, 1986).

The 24-hour PMP total was compared with record precipitation depths at regional climate stations within a 400 km radius of the Giant Mine. Table 2 presents the largest daily precipitation values measured at these regional stations, all of which are operated by the Meteorological Service of Canada. The single largest event was 86.4 mm and occurred at Fort Simpson. This event is 27% of the estimated PMP at Giant Mine. The record daily precipitation at Yellowknife Airport is 82.8 mm.

Table 2 Historical Maximum Daily Precipitation at Climate Stations within 400 km Radius of Giant Mine

MSC Climate Station		Period of Record	Completeness of Record (%)	Maximum Daily Precipitation of Record	
ID	Name			Depth (mm)	Date
3071330	Caribou Mtn Lo	1976 - 1990	23.9	81.3	Jun 8, 1977
2300850	Contwoyto Lake	1959 - 1981	99.9	48.8	Sep 28, 1967
307JRN0	Crowe Tower	1984 - 1990	27.0	72.0	Jul 6, 1988
2201800	Fort Providence	1943 - 1982	69.2	77.7	Jun 3, 1945
2201900	Fort Reliance	1948 - 1991	96.0	39.9	Jul 10, 1963
2201998	Fort Resolution	1911 - 1936	83.2	50.8	May 8, 1916
2202000	Fort Resolution A	1930 - 2002	80.6	76.7	Nov 20, 1947
2202100	Fort Simpson	1895 - 1963	89.9	**86.4**	Jul 24, 1935
2202101	Fort Simpson A	1963 - 2002	97.4	85.8	Jun 30, 1988
2202198	Fort Smith	1928 - 1946	88.5	63.0	Aug 21, 1930
2202200	Fort Smith A	1943 - 2002	97.7	66.5	Jul 2, 1962
2202398	Hay River	1893 - 1943	68.9	52.1	Jun 8, 1921
2202400	Hay River A	1943 - 2002	98.4	59.9	Sep 13, 1991
2202405	Hay River Paradise Gdns	1962 - 2002	85.6	72.0	Jul 13, 1990
3073655	Klewi Tower	1978 - 1990	25.9	67.8	Aug 15, 1989
23026HN	Lupin A	1982 - 2002	99.2	41.8	Jul 9, 1983
3074999	Parson Lake Tower	1968 - 1990	24.1	53.3	Jun 8, 1977
307NM9J	Rees Tower	1986 - 1990	20.8	81.7	Jun 20, 1986
2203700	Snare Rapids	1947 - 2000	36.4	40.1	Aug 7, 1974
3076108	Steen Lo	1964 - 2002	31.7	75.0	Jun 9, 1988
3077498	Whitesand Afs	1996 - 2002	28.5	54.3	Jul 31, 1997
3077500	Whitesand Lo	1968 - 1996	27.3	55.8	Jul 17, 1977
3077678	Yates Lo	1969 - 2002	29.4	62.2	May 23, 1975
2204100	Yellowknife A	1942 - 2002	98.8	82.8	Aug 15, 1973
2204200	Yellowknife Hydro	1943 - 2000	86.0	42.7	Oct 11, 1967

Note: This table only lists stations with a record daily precipitation greater than 50 mm, unless the station has more than 20 years of record.

As indicated above, the PMP was assumed to coincide with the rapid melt of a snowpack. To represent this condition, the catchments controlled by the two tailings impoundments were assumed to be nearly impervious (i.e., minimal retention of the falling rainfall in surface depressions or soil moisture for subsequent evaporation or slow release to the tailings pond).

In addition to causing low rainfall retention on the catchments, a rapid melting snowpack would also result in high outflows from the two tailings impoundments even before the PMP storm hit. The magnitude of this high outflow rate was estimated assuming that, in the days preceding the PMP storm, the snowpack had been melting at a rate of 40 mm/d, which is near the maximum possible rate on a clear day (Church, 1988). Since the Northwest Pond and the Original Tailings Area have almost identical catchment areas of 0.691 km^2 and 0.682 km^2, respectively, the 40 mm/d melt rate corresponds with a daily average flow of 0.32 m^3/s for both impoundments.

The assumed pre-storm flow of 0.32 m^3/s was compared against the maximum observed daily flows from small catchments throughout the Northwest Territories, Nunavut and northern Alberta. Table 3 shows the record daily floods at all stations in the Water Survey of Canada (WSC) database with catchment areas less than 2000 km^2 in the Northwest Territories and Nunavut. Table 4 provides the same information for stations in northern Alberta (north of 57^o latitude). To facilitate comparison of the flows from the differently sized catchment areas, the flood values have been expressed as unit discharges in units of m^3/s/km^2 (i.e., the absolute flood value has been divided by the contributing catchment area). The 0.32 m^3/s flow for the two tailings impoundments converts to a unit discharge of 0.46 $m^3/s/km^2$. Examination of Tables 3 and 4 reveals that, of the 84 WSC stations, only five stations have ever recorded a higher unit daily discharge rate. Thus, the assumed antecedent conditions prior to the occurrence of the PMP storm already represent an unusually high flow rate in the North.

Table 3 Historical Maximum Flood Discharges at WSC Stations in Northwest Territories and Nunavut with Small Catchment Areas

WSC Streamflow Gauging Station		**Period of Record**	**Catchment Area**	**Maximum Peak Daily Flood of Record**		**Maximum Peak Instantaneous Flood of Record**	
ID	**Name**		**(km^2)**	**(m^3/s)**	**($m^3/s/km^2$)**	**(m^3/s)**	**($m^3/s/km^2$)**
06MA004	Akkutuak Creek near Baker Lake	1978 - 1990	15	7	0.47	7 +	0.47
10VC001	Allen River near the mouth	1971 - 1979	448	105	0.23	130	0.29
10UH002	Apex River at Apex	1973 - 1994	58.5	11.8	0.20	21.4	0.37
10PC002	Atitok Creek near Dismal Lakes	1980 - 1990	217	72.1	0.33	105	0.48
07SB013	Baker Creek at outlet of Lower Martin Lake	1983 - 2001	121	8.35	0.07	8.45	0.07
07SB009	Baker Creek near Yellowknife	1968 - 1982	126	4.16	0.03	4.19	0.03
10HC003	Big Smith Creek near Highway No. 1	1974 - 1994	964	170	0.18	170 +	0.18
10ED003	Birch River at Highway No. 7	1975 - 2001	542	304	0.56	390	0.72
10LC010	Boot Creek near Inuvik	1981 - 1990	28.2	4.59	0.16	4.59 +	0.16
10KA003	Bosworth Creek at Norman Wells	1976 - 1979	122	7.31	0.06	7.31 +	0.06
10KA007	Bosworth Creek near Norman Wells	1980 - 1994	109	19.7	0.18	23.5	0.22
10LC009	Cabin Creek above Highway No. 8	1984 - 1995	133	20.7	0.16	24.1	0.18
10LC007	Caribou Creek above Highway No. 8	1975 - 2001	625	65	0.10	67.2	0.11
06NC001	Diana River near Rankin Inlet	1989 - 1995	1460	102	0.07	102 +	0.07
10UF001	Duval River near Pangnirtung	1977 - 1983	95.5	22.3	0.23	39.7	0.42
10VH001	Falls River near D'Iberville Fiord	1975	32.6	4.28	0.13	4.28 +	0.13
06OA003	Far Creek at Far Lake outlet	1978 - 1981	0.21	0.113	0.54	0.134	0.64
10EA002	Flat River at Cantung Camp	1974 - 1987	155	22.6	0.15	24.9	0.16
10EA004	Flat River at Tungsten Airstrip	1988 - 1992	171	26.8	0.16	27.5	0.16
10TF001	Freshwater Creek near Cambridge Bay	1975 - 2001	1490	74	0.05	76	0.05
10QC002	Gordon River near the mouth	1978 - 1994	1530	221	0.14	228	0.15
10ND004	Hans Creek above Eskimo Lakes	1988 - 2001	329	28.5	0.09	28.5 +	0.09
10ND001	Hans Creek near Inuvik	1977 - 1987	337	87	0.26	87 +	0.26
10GC002	Harris River near the mouth	1973 - 1995	701	62.3	0.09	66.7	0.10
10LC017	Havikpak Creek near Inuvik	1995 - 2001	15.2	4.65	0.31	4.65 +	0.31
07SA004	Indin River above Chalco Lake	1978 - 2001	1520	105	0.07	106	0.07
10PB002	Izok Lake inflow	1993 - 1994	313	23.6	0.08	23.6 +	0.08
10LD002	Jackfish Creek near Fort Good Hope	1982 - 1986	62.9	4.98	0.08	4.98 +	0.08
10FB005	Jean-Marie River at Highway No. 1	1973 - 2001	1310	211	0.16	216	0.16
10KA006	Jungle Ridge Creek near the mouth	1980 - 1993	41.3	12.3	0.30	12.3 +	0.30
10EB003	Lened Creek above Little Nahanni River	1983 - 1992	34.3	5.88	0.17	6.51	0.19
10EB002	Mac Creek near the mouth	1978 - 1992	216	59.3	0.27	66.4	0.31
10UB001	Marcil Creek near Arctic Bay	1978 - 1981	139	17.6	0.13	23.7	0.17
07QC004	Marten River above Thoa River	1977 - 1989	738	42.9	0.06	43.3	0.06
06OA002	Meadow Creek above Saqvaqjuac Inlet	1978 - 1981	0.16	0.069	0.43	0.076	0.48
10VC002	Mecham River near Resolute	1972 - 1979	86.8	27	0.31	63.1	**0.73**
10GB005	Metahdali Creek above Willowlake River	1977 - 1987	344	64.4	0.19	73.3	0.21
06OA004	P/N Lake outlet	1978 - 1981	0.36	0.094	0.26	0.102	0.28
10FC001	Plateau Creek near Willow Lake	1979 - 1985	69.9	13.2	0.19	13.2 +	0.19
10EC002	Prairie Creek at Cadillac Mine	1975 - 1990	495	127	0.26	187	0.38
06MA002	Qinguq Creek near Baker Lake	1970 - 1994	432	96	0.22	96 +	0.22
10ED006	Rabbit Creek at Highway No. 7	1984 - 1990	92.7	19.8	0.21	21.3	0.23
10ED004	Rabbit Creek below Highway No. 7	1978 - 1983	105	24.4	0.23	28.1	0.27
10MC007	Rat River near Fort McPherson	1981 - 1990	1260	152	0.12	177	0.14
10LC003	Rengleng River below Highway No. 8	1976 - 2001	1310	152	0.12	170	0.13
10GC005	Sahndaa Creek at Highway No. 1	1982 - 1990	251	115	0.46	149	0.59
06OA005	Saqvaqjuac River above Saqvaqjuac Inlet	1979 - 1981	607	79.4	0.13	85.4	0.14
10ED009	Scotty Creek at Highway No. 7	1995 - 2001	202	7.39	0.04	7.56	0.04
10KA005	Seepage Creek at Norman Wells	1975 - 1978	30.8	8.47	0.28	8.47 +	0.28
10HB004	Silverberry River near Little Dal Lake	1981 - 1990	1420	229	0.16	278	0.20
06LC003	Siuraq Creek near outlet to Kazan River	1980 - 1990	1480	450	0.30	450 +	0.30
10VC013	Snowbird Creek near Bradford Island	1976	87	7.48	0.09	7.48 +	0.09
07RC001	Thonokied River near the mouth	1981 - 1990	1780	168	0.09	174	0.10
10ND002	Trail Valley Creek near Inuvik	1977 - 2001	68.3	45.9	**0.67**	45.9 +	0.67
10HA002	Tsichu River at Canol Road	1976 - 1992	219	50.9	0.23	55.5	0.25
10UE001	Tulugak River on Broughton Island	1982	27.4	6.6	0.24	8.51	0.31
07SC002	Waldron River near the mouth	1979 - 1994	1830	75.3	0.04	75.5	0.04
10LA004	Weldon Creek near the mouth	1978 - 1990	852	150	0.18	150 +	0.18
10HB003	Wrigley River near the mouth	1978 - 1987	1230	478	0.39	889	0.72
10ND003	Zed Creek near Inuvik	1978 - 1982	401	4.42	0.01	4.42 +	0.01

Note: For 20 stations in this table, the instantaneous peak of the station's largest flood was not measured. In these cases, the instantaneous peak was estimated to equal the daily flood peak. These estimates are flagged with a plus ("+") sign.

Table 4 Historical Maximum Flood Discharges at WSC Stations in Northern Alberta with Small Catchment Areas

WSC Streamflow Gauging Station		Period of Record	Catchment Area	Maximum Peak Daily Flood of Record		Maximum Peak Instantaneous Flood of Record	
ID	Name		(km^2)	(m^3/s)	($m^3/s/km^2$)	(m^3/s)	($m^3/s/km^2$)
07DA012	Asphalt Creek near Fort Mackay	1976 - 1977	148	3.6	0.02	3.6 +	0.02
07DA005	Beaver River near Fort Mackay	1973 - 1975	454	54.1	0.12	54.1 +	0.12
07NB006	Bench Mark Creek near Fort Smith	1968 - 1983	43	2.0	0.05	2.29	0.05
07JF004	Boyer River near Paddle Prairie	1979 - 2003	94.3	16.9	0.18	21.4	0.23
07DA014	Calumet River near Fort Mackay	1976 - 1977	183	3.71	0.02	3.71 +	0.02
07DB002	Dover River near the mouth	1976 - 1977	963	24.6	0.03	24.6 +	0.03
07DA010	Ells River below Gardiner Lakes	1976 - 1978	1380	21	0.02	21.6	0.02
07DA009	Hartley Creek near Fort Mackay	1975 - 1993	358	17.2	0.05	18.7	0.05
07OB007	Hutch Lake tributary near High Level	1977 - 1986	103	2.28	0.02	2.31	0.02
07JD003	Jackpine Creek at Wadlin Lake Road	1972 - 2003	582	60.7	0.10	61.5	0.11
07DA016	Joslyn Creek near Fort Mackay	1976 - 1993	257	40	0.16	40.0 +	0.16
07HF002	Keg River at Highway No. 35	1972 - 2003	667	142	**0.21**	154	**0.23**
07JC001	Lafond Creek near Red Earth Creek	1976 - 2003	491	26.5	0.05	30.2	0.06
07OB006	Lutose Creek near Steen River	1978 - 2003	292	18.5	0.06	19.5	0.07
07OB005	Meander River at outlet Hutch Lake	1976 - 1995	507	19.3	0.04	19.5	0.04
07DA008	Muskeg River near Fort Mackay	1974 - 2003	1460	66.1	0.05	66.4	0.05
07DA013	Pierre River near Fort Mackay	1976 - 1977	123	1.57	0.01	2.72	0.02
07NB007	Salt River below Peace Point Highway	1973 - 1980	1060	39.4	0.04	39.4 +	0.04
07OA001	Sousa Creek near High Level	1971 - 2003	819	71.4	0.09	78.7	0.10
07DA006	Steepbank River near Fort McMurray	1974 - 2003	1320	81	0.06	92	0.07
07DA015	Tar River near Fort Mackay	1976 - 1977	301	14.5	0.05	14.5 +	0.05
07DA019	Tar River near Fort Mackay (Upper Station)	1977	103	1.76	0.02	1.81	0.02
07JD004	Teepee Creek near La Crete	1981 - 2003	136	20.8	0.15	23.4	0.17
07DA011	Unnamed Creek near Fort Mackay	1976 - 1993	274	16.7	0.06	18.7	0.07

Note: For 7 stations in this table, the instantaneous peak of the station's largest flood was not measured. In these cases, the instantaneous peak was estimated to equal the daily flood peak. These estimates are flagged with a plus ("+") sign.

2.3 Modelling of PMF Hydrographs

Two types of modelling work were required to complete the estimation of the PMF's for the Northwest Pond and the Original Tailings Area. The first type involved transforming the rainfall on the catchments of the tailings impoundments into flood hydrographs, while the second entailed routing the resulting flood hydrographs through the respective tailings ponds. Both types of modelling were undertaken using a computer model developed by the U.S. Corps of Engineers known as HEC-HMS (USACE, 2001). The setups of the model for the two tailings impoundments are documented in Table 5.

Table 5 Adopted Inputs for HEC-HMS Model to Simulate Probable Maximum Floods at the Giant Mine Tailings Impoundments

Item	Original Tailings Area	Northwest Pond	Comment
Version of HEC-HMS model	2.2.2	2.2.2	Released May 28, 2003.
Model time step (minutes)	5	5	
Precipitation model	Frequency Storm	Frequency Storm	The PMP rainfall event was constructed with a 5-minute increment and a 24-hour duration. The storm was assumed to have a symmetrical shape in which the rainfall intensity steadily increased through the first 12 hours of the storm and then steadily decreased through the remaining 12 hours.
Rainfall loss method	SCS Curve No. = 80 and impervious area = 10%	SCS Curve No. = 80 and impervious area = 25%	The model was set up in such a manner that virtually all of the storm's rainfall was assumed to be rapidly shed from the catchment to form the flood hydrograph. Allowance was made for only a small retention of rainfall for subsequent evaporation or slow release to the catchment's streams. The pond surface was represented as an impervious surface (i.e., no retention of rainfall). The remainder of the catchment was assumed to behave as a highly saturated surface (SCS Curve No. = 80 with no initial interception losses).
Transformation method	Clark Unit Hydrograph	Clark Unit Hydrograph	This was adopted method for transforming the storm's excess rainfall into surface runoff.
Time of concentration (hours)	0.69	0.53	Estimated using an empirical prediction equation developed in northeastern U.S.A (Straub et al., 2000). The U.S.A. catchments used to develop the equation likely have a faster response time than the TCA catchment. Accordingly, the use of the empirical equation likely underestimates the true time of concentration of the TCA catchment, which leads to an overestimation of the true PMF peak.
Storage coefficient (hours)	1.3	1.3	Estimated using an empirical prediction equation developed in northeastern U.S.A. (Straub et al., 2000). Similar to above, the U.S.A. catchments likely have lower storage capacities than the TCA catchment. Accordingly, the use of the empirical equation likely underestimates the true storage coefficient of the TCA catchment, which leads to an overestimation of the true PMF peak.
Baseflow method	Recession with initial flow of 0.32 m^3/s	Recession with initial flow of 0.32 m^3/s	The PMP storm was assumed to fall on a ripe snowpack that, in the days preceding the storm, was experiencing an extremely high snowmelt rate of 40 mm/d. To approximate the effect of these conditions, the initial inflow to and outflow from the TCA were both set to the average flow generated by 40 mm of melt over one day (assuming no losses). The contribution from snowmelt was assumed to decay subsequent to the storm's arrival.
Drainage area (km^2)	0.682	0.691	
Simulation period	4 days in June	4 days in June	The PMP was assumed to hit on the first day of the simulation. The simulation was extended beyond the storm to examine the time required for the storm water to drain from the tailings pond via the spillway.

The results of applying the HEC-HMS model to the Northwest Pond are graphically illustrated in Figure 3. The simulated inflow hydrograph to the tailings impoundment has an instantaneous peak of almost 12 m^3/s. Storage within the tailings impoundment causes a substantial attenuation of this peak so that the outflow from the spillway peaks at 2.5 m^3/s. At the time of the peak outflow, the pond surface would have risen 0.68 m above the crest of the spillway and some 137,000 m^3 of the flood waters would be temporarily stored in the Northwest Pond. The large reduction in the peak of the PMF is due to the large storage available and the constricted spillway shape. This constricted shape (i.e., sideslopes of 1H:1V) is possible because it is anticipated that the spillway will be cut in bedrock. If the spillway is constructed in soil, then milder sideslopes will be required and the impoundment's capacity to attenuate floods will be reduced somewhat.

Figure 4 presents the model results for the Original Tailings Area. The simulated inflow hydrograph peaks at just over 11 m^3/s. The three spillway options outlined in Section 2.1 have varying capacities to reduce the magnitude of this peak. For Option 1, the peak of the outflow hydrograph is 5.4 m^3/s, or roughly half the peak of the inflow hydrograph. Option 2 has a greater available storage above the spillway crest and, as a result, would reduce the peak of the PMF to
3.8 m^3/s at the spillway. Option 3, with its constricted outflow capacity, would result in an outflow peak of 3.3 m^3/s. Details on the amount of water temporarily stored in the North Pond during passage of the PMF are given in Figure 4. The results of the modelling work indicate significant improvements could be achieved in the pond's capacity to reduce flood peaks by raising the crest elevation of the spillway above the preferred level and/or reducing the basewidth of the spillway.

2.4 Validation of PMF Estimates

The PMF estimates for the Giant Mine tailings impoundments were checked for reasonableness using the Canadian envelope curve of maximum observed floods. The most up-to-date and comprehensive version of the Canadian envelope curve appears to be the one contained in the publication entitled “Hydrology of Floods in Canada: A Guide to Planning and Design” (NRCC, 1989). The authors of this publication assembled a list of 22 of the highest known floods to have ever been experienced in Canada. The top plot on Figure 5 shows the 22 flood values on a logarithmic graph of unit discharge vs. catchment area. Superimposed on this graph is an envelope curve that bounds all of the flood data. The equation for this envelope curve is known as the “Creager Equation” and takes the form of a double exponential. The Creager Equation is an empirical relationship that provides a simple means of comparing floods in different regions and on different sizes of catchment. The relationship is consistent with the observed behaviour that unit flood discharge decreases as drainage area increases. The positioning of the Creager Equation on a logarithmic plot is dictated by a single constant known as the “Creager Constant”. The magnitude of the Creager Constant may be used as a measure of the flood-producing characteristics of a region. The higher the constant, the more severe is the flood regime. A Creager Curve with a Creager Constant of 44 envelopes all of the known extreme floods experienced in Canada.

The bottom plot on Figure 5 compares the estimated PMF values for the two tailings impoundments against the Canadian envelope curve. The peaks of the inflow and outflow hydrographs for the Northwest Pond have unit discharges of 16.9 $m^3/s/km^2$ and 3.6 $m^3/s/km^2$, respectively. The peak of the inflow hydrograph for the Original Tailings Area has a unit discharge of 16.4 $m^3/s/km^2$. The various proposed options for providing a spillway at this second impoundment would result in unit discharges ranging from 4.8 $m^3/s/km^2$ to 7.9 $m^3/s/km^2$. For both impoundments, the peaks of the inflow hydrographs fall just below the Canadian envelope curve, while the outflow peaks fall well below the envelope curve.

As an additional check on the PMF estimates, the bottom plot shows the record peak instantaneous floods observed at all WSC stations in the Northwest Territories, Nunavut and northern Alberta with catchment areas less than 2,000 km^2 (see Tables 3 and 4). All of the observed record floods have unit discharges less than 1.0 $m^3/s/km^2$ and fall well below the simulated outflow peaks for the Northwest Pond and the Original Tailings Area.

3 Flood Estimation Method for Ungauged Locations

This section describes the development of a method for estimating the 2-, 10-, 100- and 200-year peak instantaneous discharges at ungauged locations around the mine site. The adopted estimation technique is known as Regional Analysis. In essence, this technique provides a means of inferring the flood hydrology of an ungauged location from the streamflow records of measured streams in the region. The data from the measured streams are transposed to the ungauged location by way of empirical equations that relate flood magnitude to the physiographic characteristics of the catchment that generates the flood. The development of the Regional Analysis involved four steps, as outlined below.

3.1 Data Assembly

The first step entailed data gathering. The network of streamflow gauging stations operated by the Water Survey of Canada (WSC) was searched to find suitable data for developing the Regional Analysis. The emphasis of the search was to identify stations that: i) had long periods of record; ii) were in reasonably close proximity to the mine site; and iii) measured flows from a wide range of catchment areas. Table 6 provides details of the 36 stations that were identified in the search. From the streamflow record of each of these stations, an annual series of flood peaks was extracted.

The set of selected WSC stations included two stations that were operated on Baker Creek just upstream of the mine development (07SB009 and 07SB013). The first station operated from 1968 to 1982 and was then replaced by the other station, which continues to operate. Owing to their close proximity on the same stream, the records from these two stations could be combined to provide a single, longer flood series. The opportunity to create extended flood series was also available on three other streams in the region (viz., Bosworth Creek, Rabbit Creek and Snare River). After combining records, a total of 32 annual series of flood values were available to characterize the flood regime of the region. The length of these annual series ranged from 7 to 38 years, with an average of 21 years.

3.2 Statistical Analysis

The second step involved a statistical analysis of the assembled data. For each station, the annual series of flood peaks was fitted to a theoretical frequency distribution (Generalized Extreme Value) to provide estimates of the 2-, 10-, 100- and 200-year return period floods. All fittings were done using Version 3.1 of the CFA program (Environment Canada, 1993). Table 6 presents the estimated flood peaks for the 32 flood records.

3.3 Identify Trends for Extrapolating Data to Mine Site

The third step entailed transposing the estimated floods at the regional stations to the mine site catchments. This was done by exploiting a well-known observation that flood discharge is correlated with catchment area. The most useful way of examining this correlation was to prepare a logarithmic plot of "unit" discharge versus catchment area. Unit discharge means the flood peak is expressed as a flow rate per unit area (i.e., the absolute flood value is divided by the contributing catchment area). The unit discharge was expressed in units of L/s/km^2. Figures 6 and 7 show the plots used to examine the relationship between unit discharge and catchment area for the four return periods of interest (viz., 2, 10, 100 and 200 years). The plots for the more common flood events are on Figure 6 while the other two are on Figure 7.

The data provided by the 32 regional flood records were plotted on the four plots. Examination of each plot revealed two observations about the data. Firstly, the unit flood values exhibit an inverse trend between unit discharge and catchment area (i.e., as catchment area decreases, the unit flood values increase). Secondly, the data exhibit a wide scatter about this identified trend. This last observation revealed that catchment area could not be used alone to explain variations in flood hydrology within the region. One or more additional variables were required to improve the accuracy of the Regional Analysis.

To help identify one or more suitable variables, the catchment areas for the regional WSC stations were plotted on 1:1,000,000 scale topographic maps (not shown). Examination of these maps revealed that the scatter could be, at least partially, explained by the slope of the main channel. As expected, the unit flood discharge tended to increase with an increase in the channel slope. Based on this observation, the 32 regional flood records were separated into two groups, one for mild-sloped channels and the other for moderate-sloped channels. These groupings are identified on Figures 6 and 7 with symbols. An open square signifies flood data for a mild stream while a solid square denotes data for a steeper stream.

3.4 Develop Flood-Prediction Equations

Flood estimates can be made for the mine site by reading information directly from the plots on Figures 6 and 7. However, it is more convenient to capture this information in the form of equations. To do this, two curves were fitted to the data of each plot, one for mild-sloped streams and the other for moderate-sloped streams. The curve for the mild-sloped streams was obtained by fitting a power regression to the data.

The use of regression analysis was not a valid approach for deriving the equations for the moderate-sloped streams. The data for five WSC stations in this grouping would have significantly biased the results of a regression analysis. Four of the stations (Birch River, Martin River, Sahndaa Creek and Wrigley River) have short records that contain an extreme flood (i.e., a high outlier). This makes the distribution of floods at the four gauging stations appear to have a much greater skew than is actually the case (i.e., the skew of the sample is a poor representation of the skew of the overall population of floods). This, in turn, means the estimated flood magnitudes, especially for the 100- and 200-year events, are probably overestimated, possibly by a large margin. The fifth problematic data point is for a stream that drains the Mackenzie Mountains (Carcajou River). The flood peaks for this stream would be enhanced by orographic effects that do not occur in vicinity of the mine.

Without access to regression, the curves for the moderate-sloped streams were essentially fitted by eye. For all four return periods, the fitted curves were assumed to have the same slope as the curves for mild-sloped streams. In the case of the 2 and 10 year events, the curves were placed such that an equal number of data points fell above and below the curve. For the 100 and 200 year floods, the curve was made to envelope all flood values except for the five problematic ones mentioned above. The envelope curve approach was adopted for the more extreme flood events to provide a degree of conservatism in flood estimates based on the Regional Analysis.

Text boxes are provided on Figures 6 and 7 that present the adopted equations for predicting the unit flood discharges at the Giant Mine site for various return periods. These equations can be altered to predict absolute flood discharges by multiplying both sides of each equation by catchment area. The resulting equations are:

$$Q_2 = 0.15\ A^{0.877}$$
$$Q_{10} = 0.45\ A^{0.832}$$
$$Q_{100} = 1.53\ A^{0.785}$$
$$Q_{200} = 1.93\ A^{0.771}$$

where: Q_2 = peak instantaneous flood for return period of 2 years (m^3/s);
Q_{10} = peak instantaneous flood for return period of 10 years (m^3/s);
Q_{100} = peak instantaneous flood for return period of 100 years (m^3/s);
Q_{200} = peak instantaneous flood for return period of 200 years (m^3/s); and,
A = catchment area (km^2).

These equations represent the flood regime of the moderate-sloped streams in the region. They should generally be used for making flood estimates at the Giant Mine, unless the catchment in question can be confidently characterized as behaving like the mild-sloped streams. If this is the case, then the required unit flood discharge could be read off the appropriate plot in either Figure 6 or 7.

It should be noted that the flood estimates provided by the above equation represent the <u>instantaneous</u> maximum discharge that the flood event attains, and not the lower value associated with the so-called maximum <u>daily</u> discharge (i.e., the average discharge experienced over an entire day).

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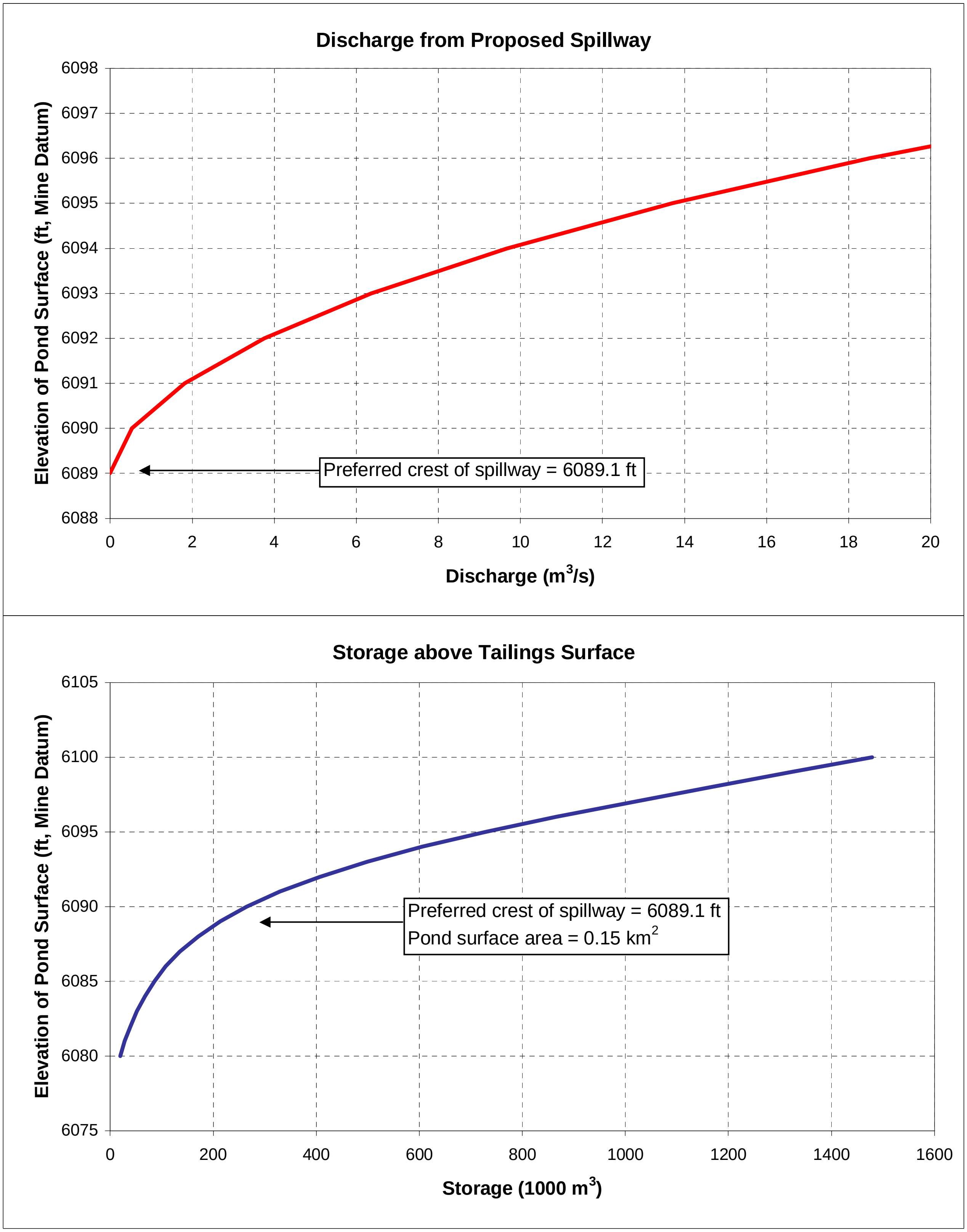


Figure 1: Elevation-Storage-Discharge Relationship for Northwest Pond

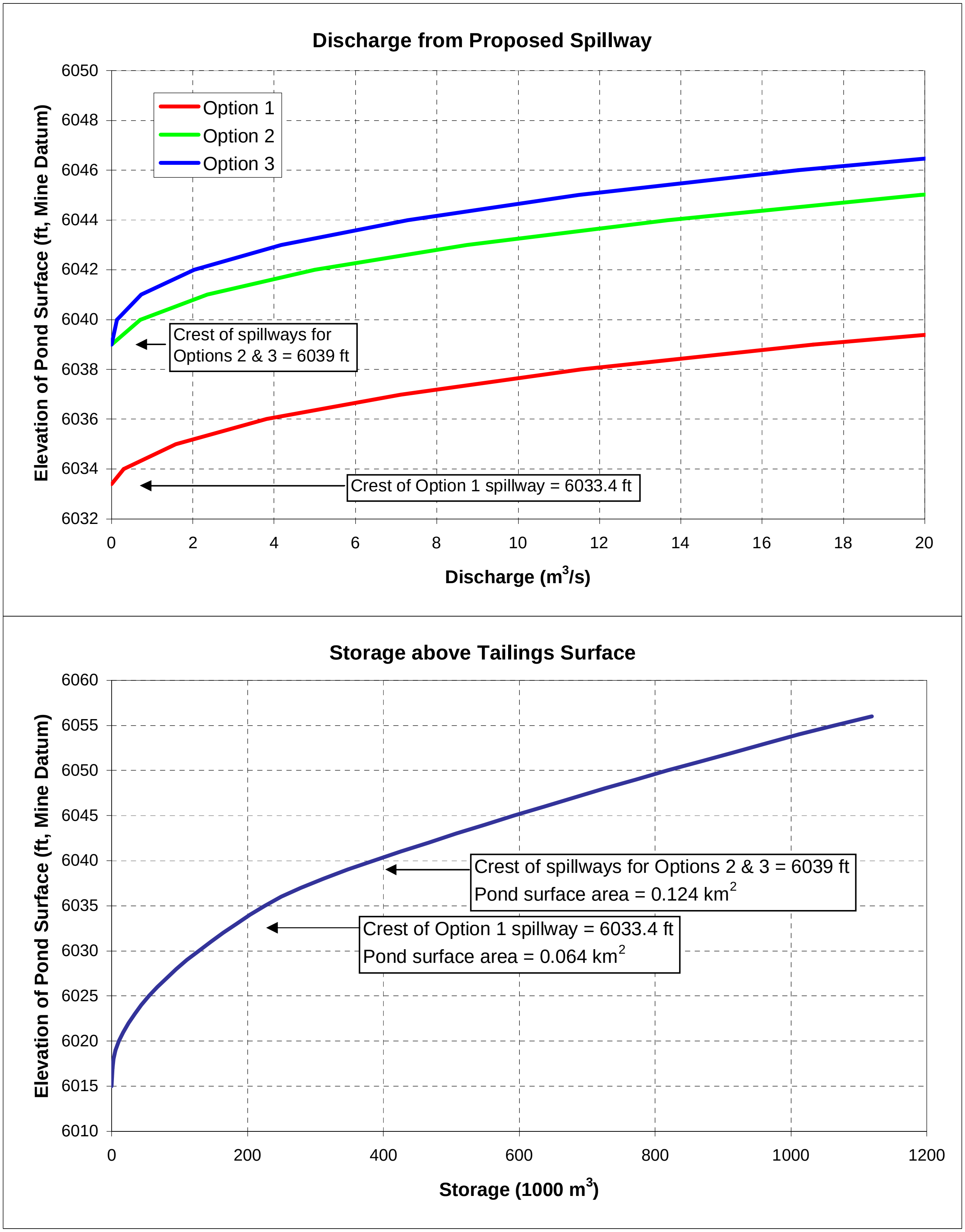
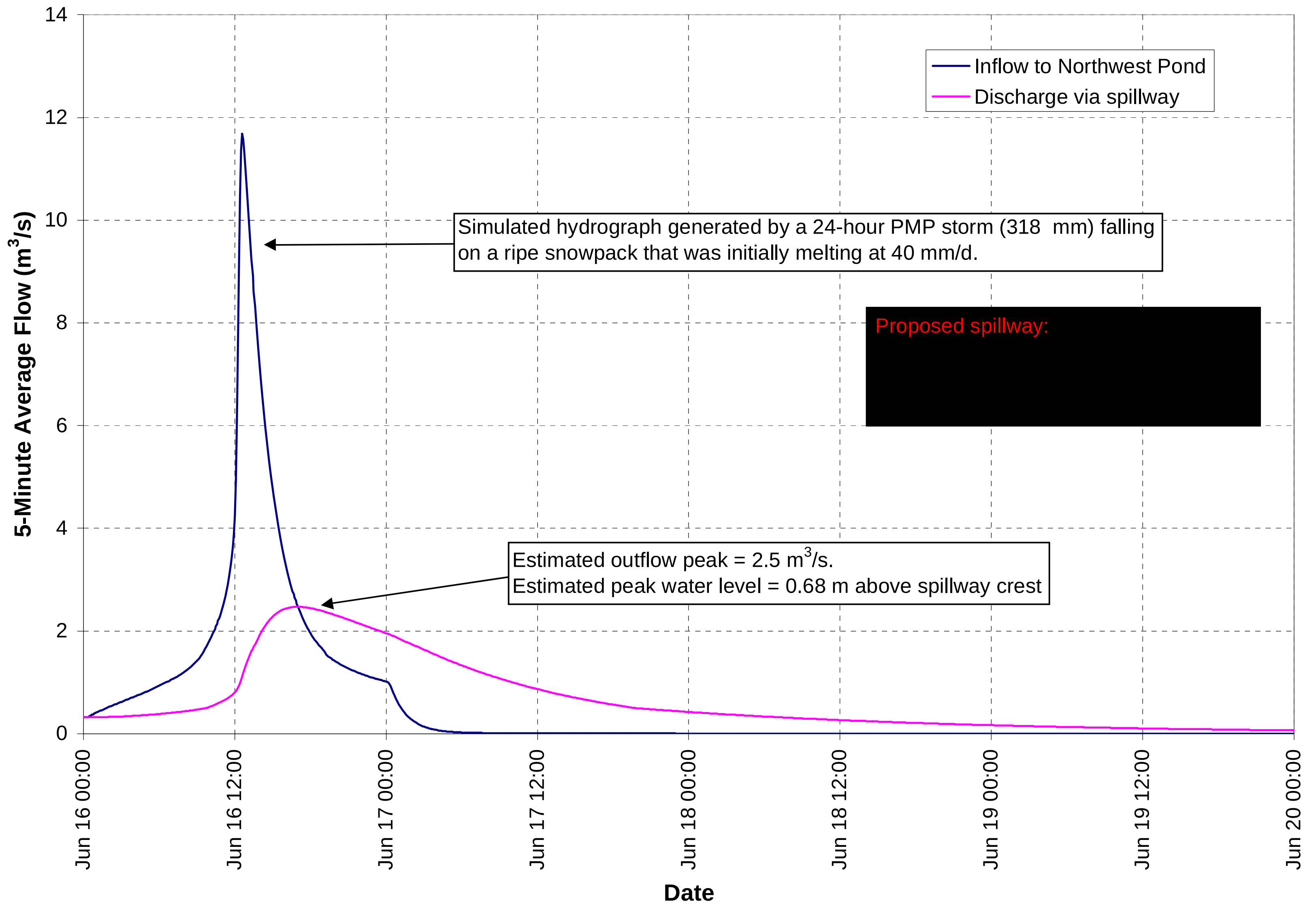


Figure 2: Elevation-Storage-Discharge Relationship for Original Tailings Area



Simulated hydrograph generated by a 24-hour PMP storm (318 mm) falling on a ripe snowpack that was initially melting at 40 mm/d.

Estimated outflow peak = 2.5 m^3/s.
Estimated peak water level = 0.68 m above spillway crest

Figure 3: Simulated Inflow to and Outflow from the Northwest Pond During the PMF Event

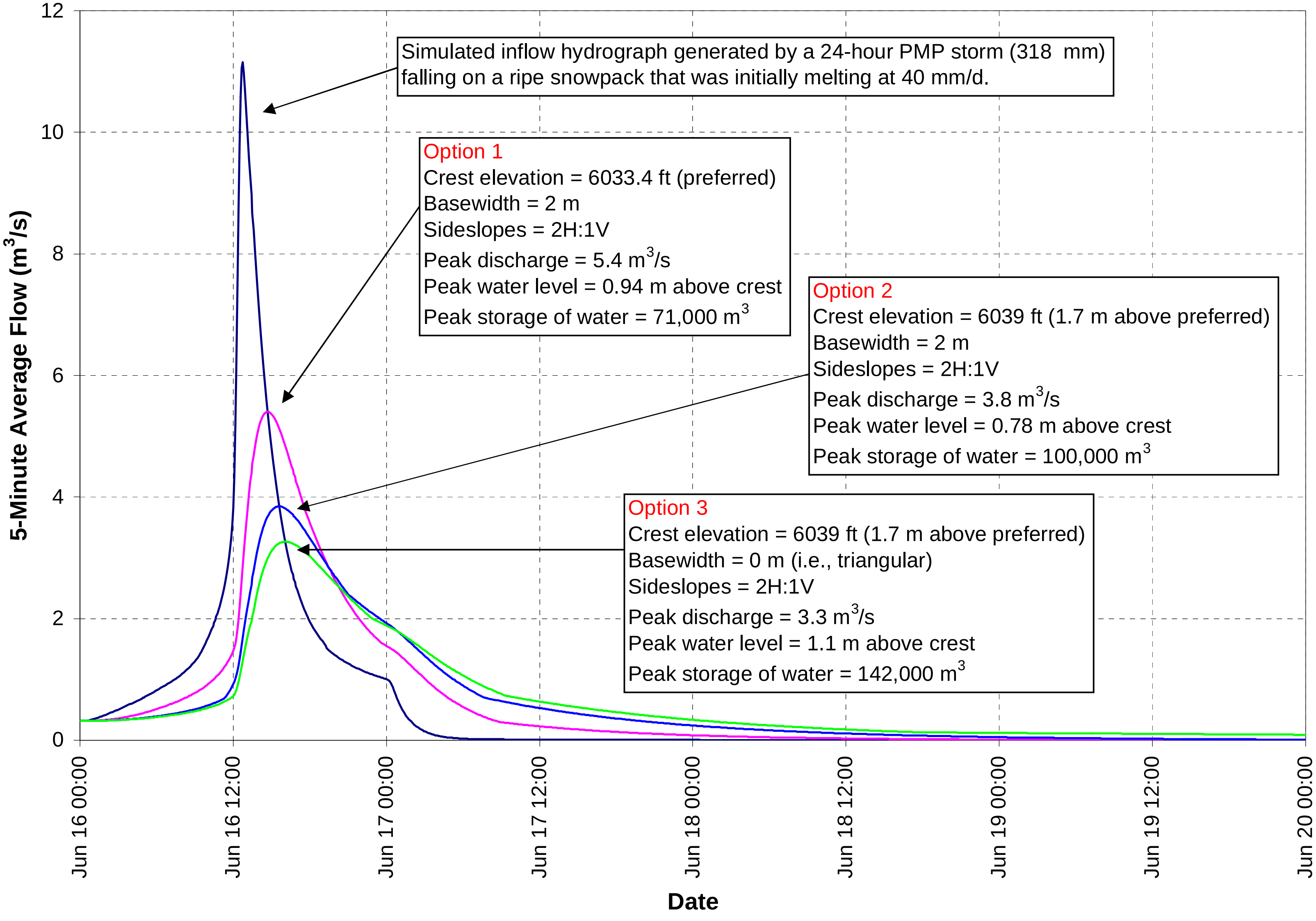


Figure 4: Simulated Inflow to and Outflow from the Original Tailings Area During the PMF Event

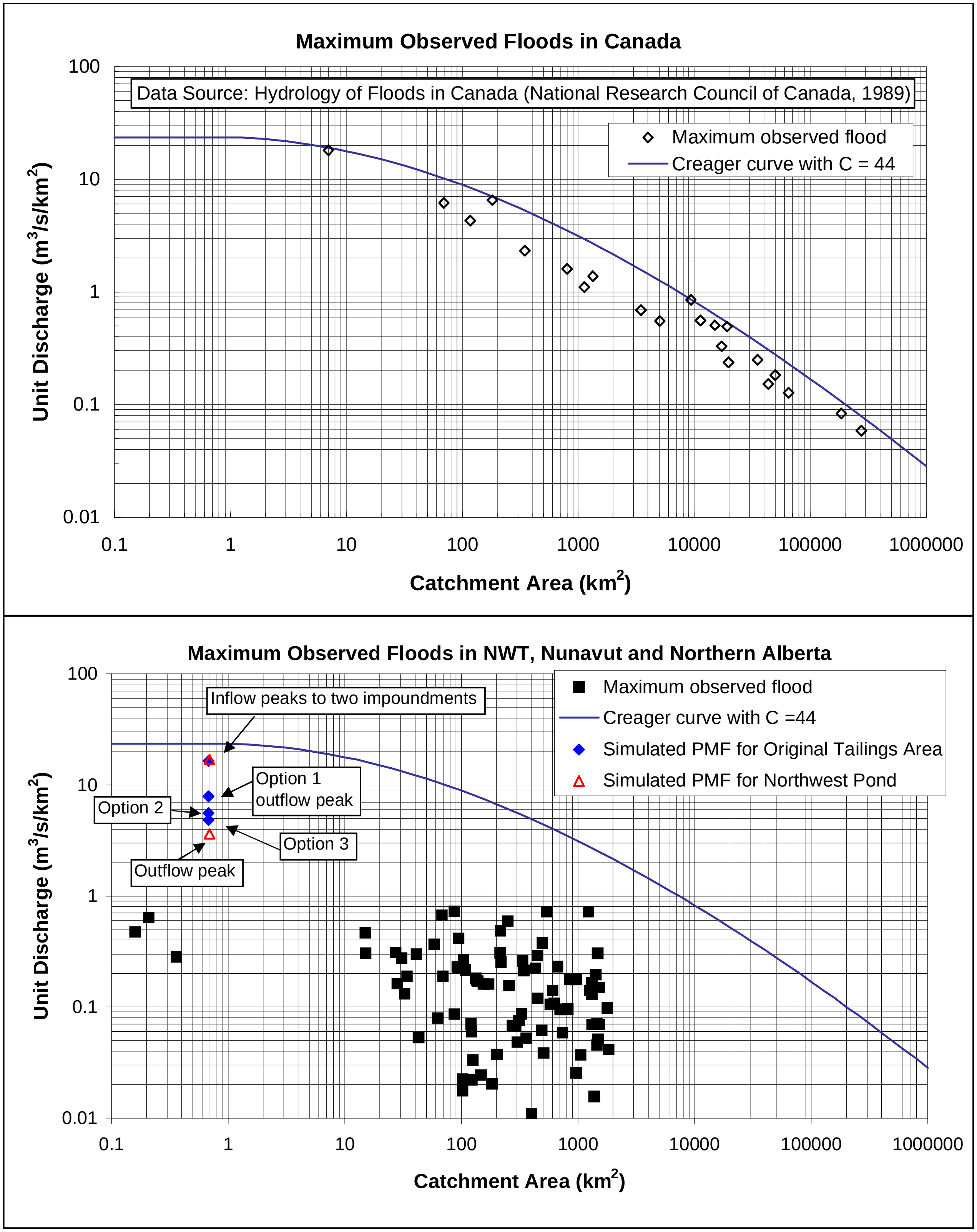


Figure 5: Comparison of PMF Estimates with Maximum Observed Floods in the North and in Canada

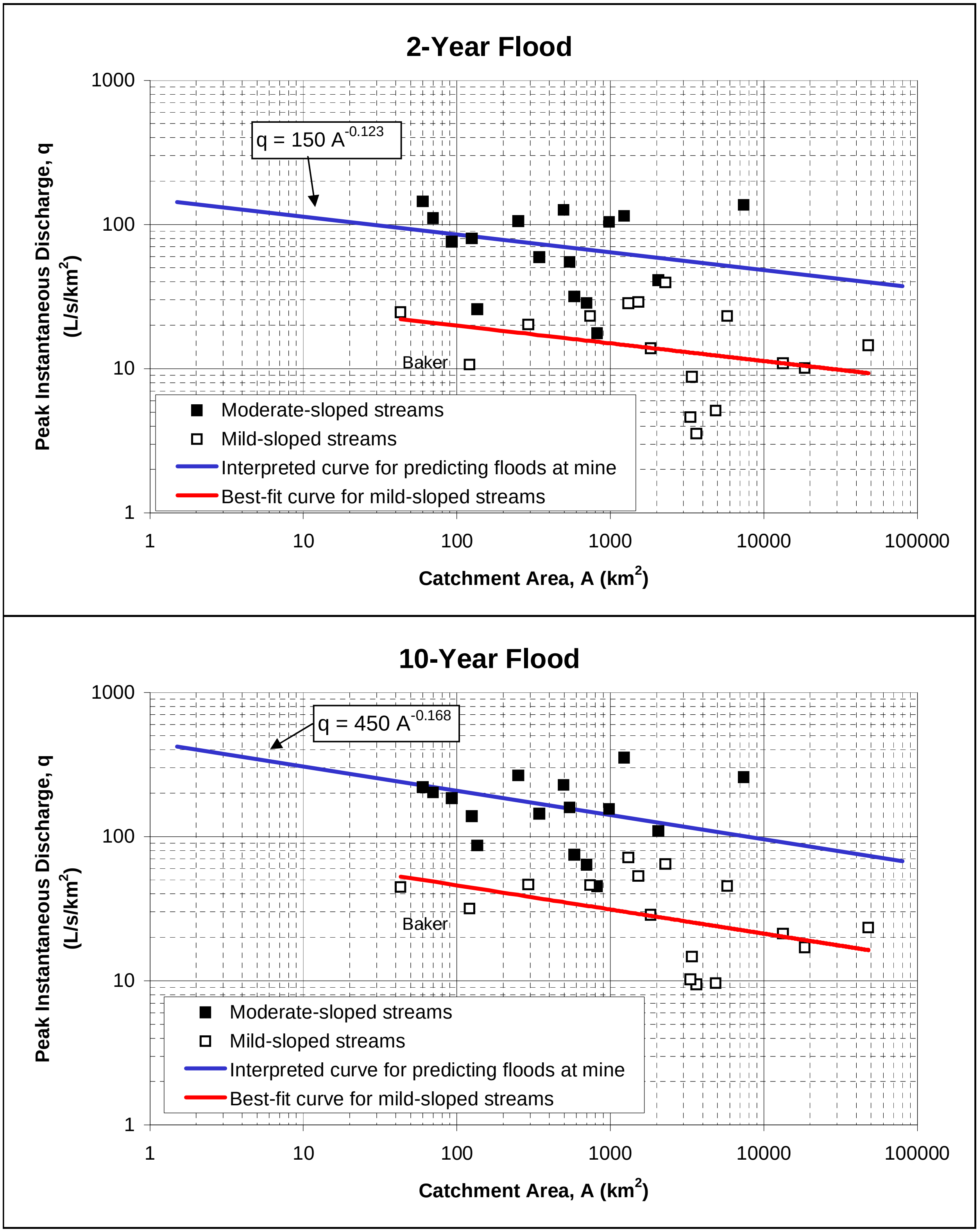
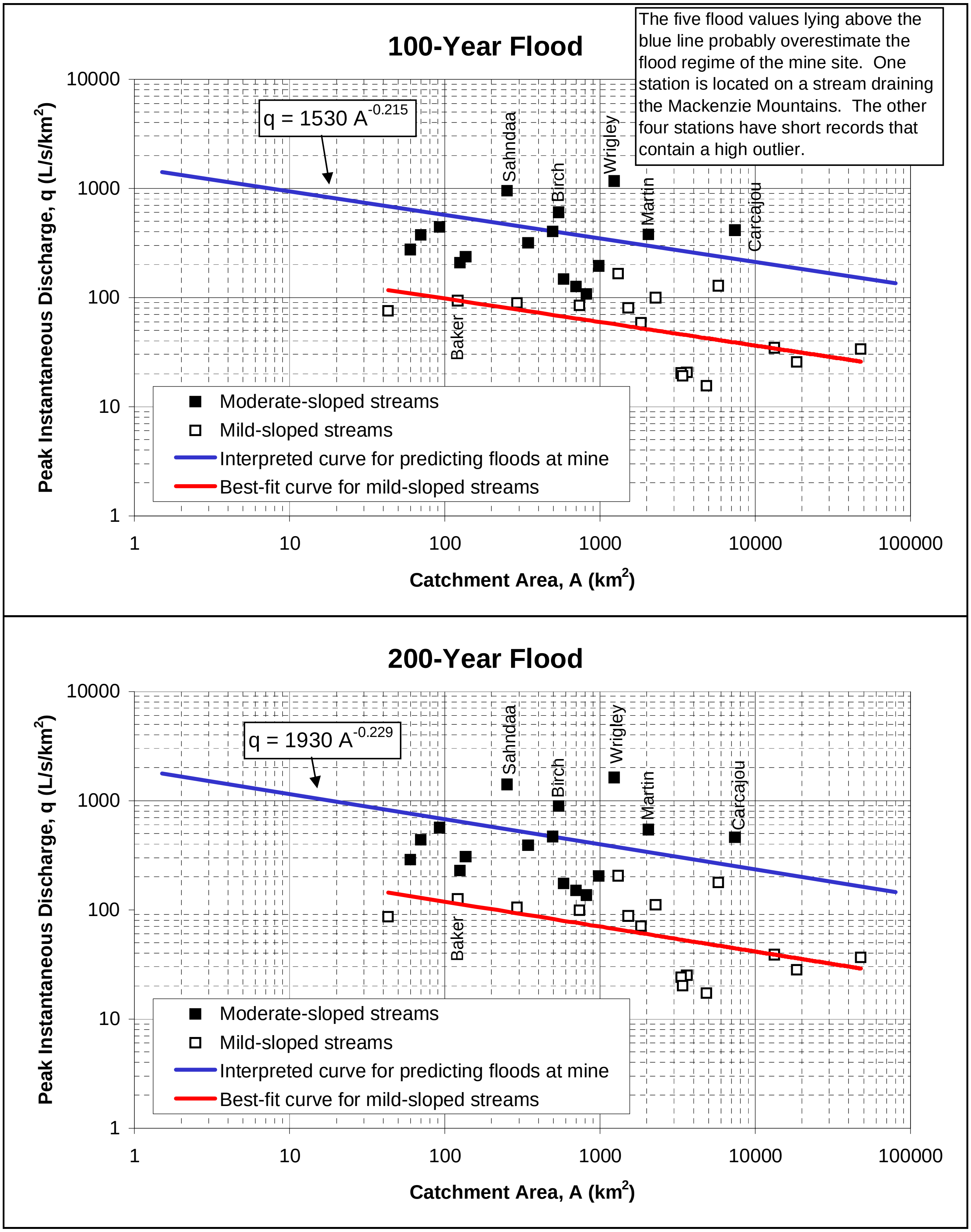


Figure 6: Extrapolation of Regional Flood Data to Giant Mine Site (2- and 10-Year Floods)



The five flood values lying above the blue line probably overestimate the flood regime of the mine site. One station is located on a stream draining the Mackenzie Mountains. The other four stations have short records that contain a high outlier.

Figure 7: Extrapolation of Regional Flood Data to Giant Mine Site (100- and 200-Year Floods)