Candidate Method for Selecting Design Flood Events for Faro Creek and Vangorda Creek Closure Diversions

Introduction

One or both of these diversions may become key components of the overall closure plan for the Anvil Range Mining Complex. If the decision is made to retain one or both diversions, a method will be required to provide a rational basis for selecting appropriate design floods for the upgrading of the diversions. In other words, it will be necessary to decide what event the diversions will be designed to convey, be it the 200-year flood, the 500-year flood, the probable maximum flood or some other extreme event. The method for finally selecting a suitable event will most likely take the form of a risk assessment. This memorandum outlines a potential means of selecting the return period of the design flood, and involves a type of risk assessment that examines the consequences of the diversions being breached.

The Faro Creek and Vangorda Creek Diversions share the identical configuration: an open channel running around the perimeter of a large open pit. Indeed, both diversions were constructed to facilitate the development of the orebodies that existed along the original routes of the two streams. This configuration can potentially lead to significant consequences if the diversions were to develop a breach, namely the release of contaminated water from the pits to the receiving environment. However, this configuration also offers the opportunity to mitigate the effects of such a breach. The open pits can be maintained in a drawn-down state, thus creating an empty buffer storage that would capture some or all of the water released by a breach. Similar to what is currently done during the care and maintenance of the mine development, an adequate amount of water would be pumped annually from each pit and treated to prevent the pit lake from rising up into the storage reserved for dealing with diversion breaches. If the buffer storage can be made large enough and/or the breach of a diversion can be repaired in a timely manner, the existence of a buffer storage has the potential of completely negating or significantly limiting the effect of a breach on the downstream receiving environment.

The method outlined in this memorandum examines the potential benefits of maintaining buffer storages in each of the two pits. If the buffer storages can be shown to be large relative to the amount of water that could flow through a diversion breach, then it may be acceptable to design the diversions for a flood event less extreme than the probable maximum flood. The development of the method entailed two broad steps: i) estimation of the flood hydrology of the two diversions; and ii) estimation of the time required to fill buffer storage in the pits in the event of a breach. These two steps are described below under separate headings.

Flood Hydrology of Diversions

The design of the upgraded diversions will eventually require estimates of two characteristics of the local flood hydrology: i) the instantaneous peak of some selected design flood event; and ii) the volume of water associated with that design event. Only the latter characteristic is of interest in the present study. The method outlined here for helping to select a suitable return period for the design event is based on estimating the time required to fill a buffer storage and, accordingly, depends on a knowledge of flood volumes. Determination of the instantaneous peak flow is not required to apply the method but will eventually be required to size the channel and to determine appropriate erosion protection.

The volume characteristics of local floods were estimated using a technique known as Regional Analysis. This technique involved transposing the flood data from regional streamflow gauging stations to the outlets of the two diversions. Application of the Regional Analysis entailed four steps.

The first step was the assembly of regional data. Emphasis was placed on finding streamflow gauging stations that had long periods of record and that were located on small drainage areas. To maximize the amount of data available from which to choose, a search was made of the networks of streamflow gauging stations operated by three government agencies: Water Survey of Canada (WSC), Environment Yukon (EY) and United States Geological Survey (USGS). The search for data in the WSC and EY networks extended over the entire Yukon Territory south of latitude 65^{o}. The search within the USGS network was limited to the eastern central region of Alaska. Examination of the three networks revealed a total of 15 stations that could potentially be useful in characterizing the flood hydrology of the diversion channels. Table 1 provides details of these stations, including length of record, drainage area, mean annual runoff and the name of the authority that operated the station.

The second step entailed a statistical analysis of the assembled records. From each streamflow record, a total of three annual series were extracted. All of the series had one characteristic in common: they contained a list of the highest discharge in each water year. The water year was defined as the period October 1 to September 30. The differences in the three annual series related to the period over which the highest discharge was defined. These periods were 1, 10 and 30 consecutive days. Each of these annual series was fitted to a theoretical frequency distribution to estimate the average flood flow rates for return periods of 2, 100 and 200 years. This meant a total of 45 fittings were undertaken (i.e., 15 stations x 3 annual series per station). Table 1 summarizes the results obtained from performing this step. To facilitate comparison of the floods generated by the differently sized catchments, the flood values in Table 1 are expressed as unit discharges in units of $L/s/km^2$ (i.e., the absolute flood discharge was divided by the contributing catchment area).

The third step involved examining the data for scale effects. For peak instantaneous floods, there is a tendency for the unit flood discharge to exhibit an inverse relationship with catchment area (i.e., unit flood discharge increases with decreasing catchment area). It was suspected that this inverse relationship may also apply to daily average flows and perhaps even longer durations. Figure 1 was prepared to examine the flood data for potential scale effects. Three plots are shown, each showing the average unit flow during a particular flood event versus catchment area. The flood event examined in the top plot is the average flow during the highest single day of the 200-year flood. The event in the middle plot is the average flow during the highest 10 consecutive days of the 200-year flood. Finally, the bottom plot examines the average flow during the highest 30 consecutive days of the 200-year flood. All the data points on these three graphs were extracted from Table 1. Examination of the plots reveals that the unit flood values are virtually independent of catchment area, at least over the range of catchment areas examined in the analysis (13.7 km^2 to 7250 km^2). Based on this observation, it was determined that the flood data for some of the larger catchments could be used to characterize the flood regimes of the Faro and Vangorda diversion channels without any adjustments for scale effects.

The fourth step involved using trends identified in Step 3 to estimate the flood regimes of the two diversions. Originally, this was going to be done using empirical equations that related flood discharge to catchment area. The empirical equations would have been derived by fitting power regressions to data sets like those plotted in Figure 1. However, the main finding of Step 3 (i.e., unit flood values are virtually independent of catchment area) meant that the empirical equations could be dispensed with. Instead, the analysis could be significantly simplified by using the flood data from only a single station to infer the flood regimes of the two stations. The station selected for this purpose was USGS Station 1548400, located on the Salcha River near Fairbanks, Alaska. This station was selected because it: i) experienced larger unit floods than most of the other stations listed in Table 1; and ii) possessed the longest period of record of all the stations (56 years). Table 2 shows the estimated flood magnitudes at this station for a much more extensive range of durations and return periods than presented in Table 1 (i.e., durations of 1 day to 365 days and return periods of 2 years to 1000 years). Flood estimates for the diversions can be made by multiplying the unit flood values in Table 2 by the catchment areas controlled by the diversions. If the Faro Creek Diversion were to breach, the total drainage area contributing to the Faro Main Pit would be about 17.6 km^2, including the pit wall areas and the pit lake surface area. A breach of the Vangorda Creek Diversion would result in an area of about 20.9 km^2 reporting to the Vangorda Pit, again including pit walls and lake surface.

Time to Fill Open Pits after Breach of Diversion

After a breach has occurred, the buffer storage may provide sufficient time for a work crew to be mobilized to repair the diversion. The amount of time available depends on the amount of buffer storage that can be reserved within the pit and the amount of water that subsequently pours through the breach. The size of the buffer storage within each pit will, in turn, depend on the closure measures that are ultimately selected for the mine development (e.g., relocation of tailings from Down Valley Tailings Impoundment to the Faro Pit and/or construction of a plug dam in an old access ramp of the Faro Pit). Table 3 lists estimates of the size of buffer storage that could potentially be reserved in each of the two open pits. A much larger buffer storage could probably be set aside within the Faro Pit than the Vangorda Pit (8 million m^3 vs. 3 million m^3).

Using the buffer storages listed in Table 3, the unit floods presented in Table 2 and the catchment areas listed in the previous section, calculations were done to determine the time that it would take to fill the buffer storages following the occurrence of a breach. Table 4 shows the results of the calculations for a range of floods from the 2-year event to the 1000-year event. If a breach were to occur in the Faro Creek Diversion Channel during the 100-year flood event, then the pit would take an estimated 179 days to fill. The estimated time span under similar conditions at the Vangorda Pit would be much less at 16 days.

The time estimates presented in Table 4 are associated with a number of assumptions. Some of these assumptions would result in an underestimation of the actual amount of time available to repair a breach. The following two assumptions have that effect.

- The breach is assumed to occur in the early stages of the flood event. In reality, a large proportion of the flood waters would likely have been successfully conveyed around the open pit before the breach actually developed.

- Upon development of the breach, the full flow of the stream is assumed to report to the open pit. However, the diversion may still be partially functional and continue to convey a portion of the flood waters around the open pit.

The following two assumptions could potentially result in an overestimation of the time available to repair the diversions.

- The sample of floods provided by the Salcha River streamflow record were assumed to be a good representation of the overall population of floods that could potentially occur in the region of the mine. However, it is possible that the true population is more skewed than suggested by the 56 years of data collected at the USGS station. This would result in true flood volumes that are greater than estimated in Table 2, particularly for the return periods of 500 and 1000 years.

- The flood volumes were assumed to be relatively insensitive to a stream's long-term mean annual runoff (MAR). This is probably a good assumption for the shorter durations (say up to 7 days). However, for the longer durations the flood volumes probably show some relationship with MAR. The Salcha River catchment is somewhat drier than the catchments controlled by the diversions (261 mm vs. approx. 350 mm). Thus, the flood volumes presented in Table 2 for the longer durations may underestimate the true amount of water that would be generated by the diversion catchments. This effect is expected to be relatively small.

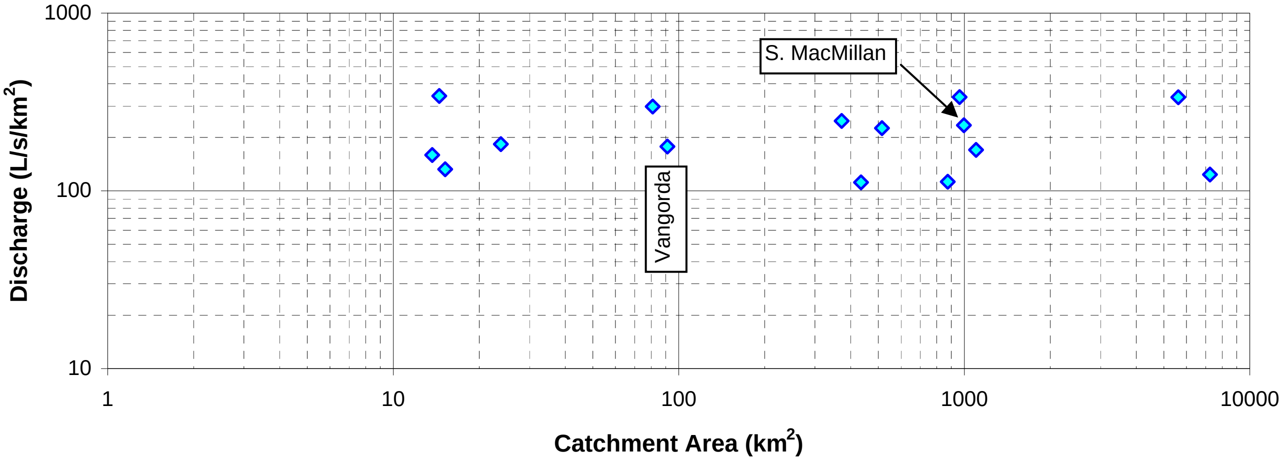
Summary

The analyses presented herein compare the storage available in the Faro and Vangorda pits to the volumes of water that could flow through breaches of the respective diversions.

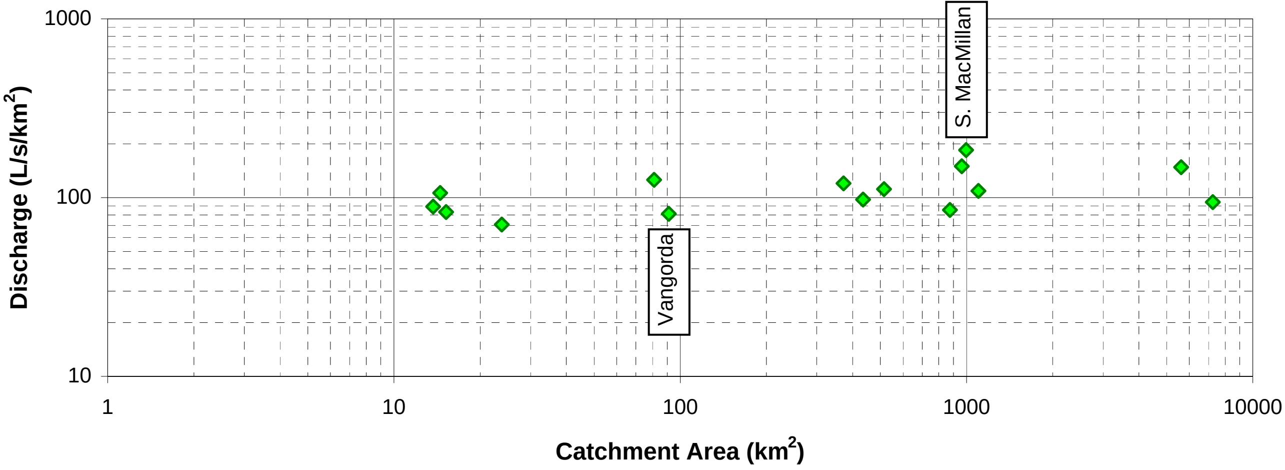
The Faro Pit was assumed to have about 8 million m^3 of storage, and the results in Table 4 indicate that it would take 93 days to fill that storage even during a 1000-year flood. It is difficult to imagine a situation where a breach of the diversion would go un-noticed and un-repaired for 93 days. Therefore, maintaining the available storage available in the pit would mitigate much of the risk associated with a failure of the Faro Creek Diversion. In such a case, it would be reasonable to design the Faro Creek Diversion for a relatively low return-period event.

In contrast, Table 4 shows that the Vangorda Pit, with an assumed storage of 3 million m^3, would fill within 7 days during a 1000-year flood and within 16 days during a 100-year flood. In this case, the pit would provide some mitigation of the risk associated with a breach of the Vangorda Creek Diversion, but only if there is a commitment to repair a breach within 1-2 weeks. It is possible to imagine many situations where such a prompt response would not happen. It is therefore reasonable to expect that the Vangorda Creek Diversion be designed to a higher standard and that a system of monitoring and alarms be in place to ensure that any breaches are repaired as rapidly as possible.

Average flow during highest single day of 200-year flood



Average flow during highest 10 consecutive days of 200-year flood



Average flow during highest 30 consecutive days of 200-year flood

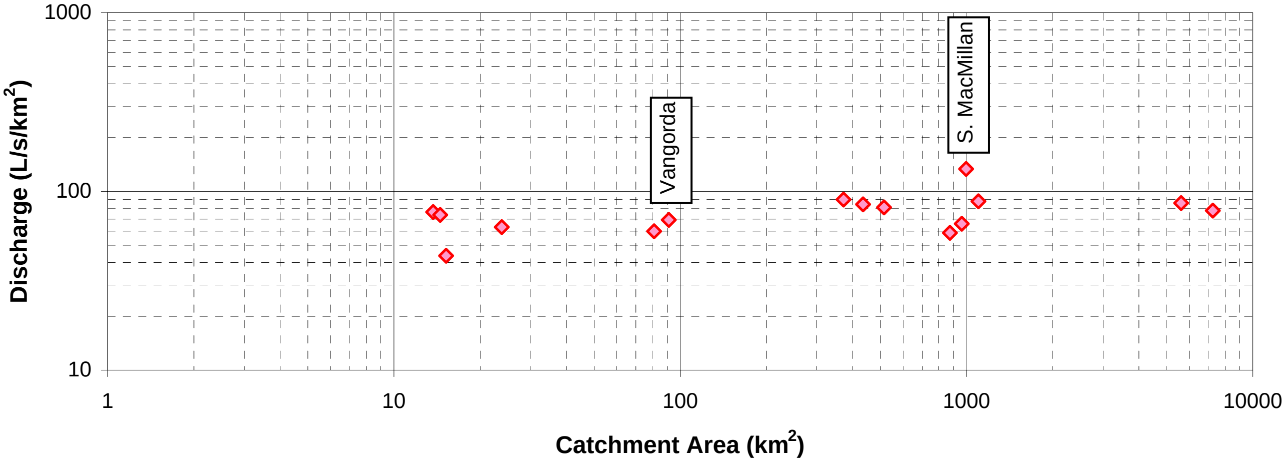


Figure 1: Scale Effects in Regional Flood Data

Table 1 Estimated Long-Duration Flood Flows at Regional Streamflow Gauging Stations

Streamflow Gauging Station		Length of Record	Drainage Area	Mean Annual Runoff	Authority	Average flow in L/s/km^2 during highest single day of flood with return period of:			Average flow in L/s/km^2 during highest 10 consecutive days of flood with return period of:			Average flow in L/s/km^2 during highest 30 consecutive days of flood with return period of:		
ID No.	**Name**	**(years)**	**(km^2)**	**(mm)**		**2 years**	**100 years**	**200 years**	**2 years**	**100 years**	**200 years**	**2 years**	**100 years**	**200 years**
10AB003	King Creek at km 20.9 Nahanni Range Road	12	13.7	290	WSC	82	150	159	54	86	89	39	72	77
29AB006	Upper Wolf Creek	9	14.5	179	EY	109	325	342	47	103	106	23	68	74
15344000	King Creek near Dome Creek	7	15.2	100	USGS	61	105	132	26	73	83	18	41	44
15535000	Caribou Creek near Chatanika	15	23.8	200	USGS	64	169	183	36	69	71	22	58	63
15439800	Boulder Creek near Central	20	81.0	131	USGS	64	257	298	36	112	126	25	56	60
29BC003	Vangorda Creek at Faro Townsite Road	22	91.2	235	EY	40	148	178	27	71	81	21	60	69
09AD002	Sidney Creek at km 46 South Canol Road	11	372	350	WSC	102	231	247	71	116	120	51	86	90
10AA002	Tom Creek at km 34.9 Robert Campbell Highway	18	435	218	WSC	43	105	112	33	90	97	25	76	85
09AG003	South Big Salmon River below Livingstone Creek	14	515	246	WSC	57	198	225	37	100	111	28	72	81
09AA012	Wheaton River near Carcross	37	875	285	WSC	60	107	113	46	81	85	35	56	59
15511000	Little Chena River near Fairbanks	37	963	199	USGS	43	256	337	28	123	150	20	58	66
09BB001	South MacMillan River at km 407 Canol Road	22	997	624	WSC	119	216	234	95	169	185	82	126	133
09EA004	North Klondike River near the mouth	28	1100	379	WSC	84	161	170	62	105	109	46	83	88
15484000	Salcha River near Salchaket	56	5618	261	USGS	68	285	336	41	131	148	27	77	86
09BA001	Ross River at Ross River	41	7250	293	WSC	53	113	124	45	88	94	36	72	78

Table 2 Estimated Extreme Floods at Outlets of Faro Creek and Vangorda Creek Diversions

Return Period (years)	Average discharge in L/s/km^2 for the following number of consecutive days:											
	1	**2**	**3**	**5**	**7**	**10**	**15**	**30**	**60**	**90**	**183**	**365**
2	68	61	57	49	45	41	35	27	22	19	13	8
100	285	239	217	179	152	131	107	77	52	44	29	15
200	336	278	252	208	174	148	121	86	57	48	32	17
500	408	335	303	247	204	172	140	99	63	53	35	18
1000	469	381	345	280	228	192	155	109	69	57	38	19

Table 3 Estimated Size of Buffer Storage Available to Capture Flows from Diversion Breach

Pit Name	Lower limit of storage (masl)	Upper limit of storage (masl)	Available storage between two limits (10^6 m^3)
Faro	1145 (assumed maximum operating level)	1158 (2 m below a plug dam with crest at 1160 m)	8.0
Vangorda	1092 (assumed maximum operating level)	1122.5 m (estimated low point on pit perimeter)	3.0