INVESTIGATION OF ANVIL RANGE MINING CORPORATION (FARO) WASTE DUMP WATER BALANCE

AVERAGE AND LOW PRECIPITATION YEAR WATER BALANCE

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Investigation of Anvil Range Mining Corporation (Faro) Waste Dump Water Balance - Final Water Balance

Executive Summary

The overall objective of the study is to provide improved estimates of the amount of water infiltrating the waste rock dumps. The improved estimates are required to support the assessment of methods to control or remediate acidic drainage from the dumps. The project was initiated in fall of 2003, with the installation of two meteorological stations at the mine site. A preliminary water balance was provided for the waste rock dumps using meteorological information that was transferred from other areas (Janowicz et al., 2004).

Phase 2 of the study was carried out during 2004, with objectives to carry out waste dump characterization studies, including soil moisture, infiltration and snow surveys, and, to develop dump water balance estimates based on site meteorological data using the Cold Regions Hydrological Model (CRHM) (Janowicz et al., 2005).

Phase 3 of the study focused on developing a water balance for a complete water year using site meteorological data. The findings of Janowicz et al. (2006) indicated that the 2004/05 water year was the wettest year in the 26 year record of the Faro Airport meteorological station.

Consequently it was determined that the study results would not be indicative of normal conditions, further work was initiated to assess waste rock dump water balance during average and dry conditions. This report presents the findings of the final phase of the study. Summary results are as follow:

- For a given precipitation scenario snow accumulation amounts are similar for all HRUs with greater amounts at the Grum and Vangorda dump sites
- Evaporation patterns between the three dump sites are similar; however, significantly differing cumulative amounts of evaporation are simulated for the six HRUs
- Evaporation amounts of 141, 126 and 133 mm, were simulated for the three precipitation scenarios, which represents 36, 41 and 81 percent of combined snowmelt and rainfall
- Rainfall infiltration is twice snowmelt infiltration during wet years, with the ratio increasing significantly in average and low years
- Snowmelt runoff is three times greater during wet years, while rainfall runoff dominates during average and wet years (as there is no snowmelt runoff simulated)
- Total soil and groundwater recharge was calculated to be 208, 175 and 31 mm for the wet, average and dry years, which represents 53, 58 and 19 percent of combined snowmelt and rainfall respectively for the Faro dump, with similar trends for the Grum and Vangorda dump sites.

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1 INTRODUCTION

Yukon Water Resources was contracted by SRK Consulting Inc., on behalf of Deloitte & Touche Inc., the Interim Receiver for Anvil Range Mining Corporation (ARMC) and the Faro Mine Closure Planning Office, to carry out investigations of the hydrology and water balances of the waste dumps at the Faro, Vangorda and Grum mine sites. The overall objective of the study is to provide improved estimates of the amount of water infiltrating the waste rock dumps. The improved estimates are required to support the assessment of methods to control or remediate acidic drainage from the dumps. Environment Canada's National Water Research Institute was subcontracted to participate in the project. The overall project was initiated in the fall of 2003, with the installation of two meteorological stations on the ARMC site. A preliminary historical water balance was provided for the dumps using meteorological information that was transferred from other areas. The results of the preliminary assessment are summarized by Janowicz et al. (2004).

Phase 2 of the study was carried out during 2004, utilizing partial site meteorological data for the period December 2003 to August 2004. Data for the period September 2003 to December 2003 was reconstructed using Faro Airport data. Janowicz et al. (2005) summarizes phase 2 of the study. The primary objectives of phase 2 were to carry out waste dump characterization studies, including soil moisture, infiltration and snow surveys, and, to develop dump water balance estimates based on site meteorological data using the Cold Regions Hydrological Model (CRHM) (Granger et al., 2002).

Phase 3 of the study was carried out during the 2005/06 period. The primary objective of phase 3 was to develop a water balance for the Faro, Grum and Vangorda waste rock dumps utilizing site meteorological data, for the period December 2003 to September 2005. The focus of analyses was on the September 1, 2004 to August 31, 2005 water year, which was the first complete water year of the study. The findings of phase 3 of the study are summarized by Janowicz et al. (2006). A review of the Faro Airport meteorological station data indicated that the 2004/05 water year was the wettest year in the 29 year record. Consequently it was determined that the study results would not be indicative of normal conditions, and, further work was initiated to assess waste rock dump water balance during average and dry conditions. This report summarizes the findings of the final phase of the project. The approved study proposal is presented in Appendix A.

2 STUDY AREA AND SETTING

The Anvil Range Mining Complex (ARMC) is located 200 km northeast of Whitehorse, YT near the community of Faro, YT (Figure 1). The Faro mine and its associated waste rock dumps are located approximately 14 km north of the Faro town site. Elevations of the dumps range from 1100 to 1300 m, with a mean elevation of 1200 m. The Grum and Vangorda Mines and their waste rock dumps are approximately 8 km northeast of the town site, with elevations ranging from 1130 to 1320 m and 1120 to 1180 m, with mean elevations of 1250 and 1150 m, respectively. Approximately 800 m separate the Grum and Vangorda dumps, while the Faro dump is approximately 14 km to the northwest. Detailed information on waste rock dump characteristics are provided by Janowicz et al. (2004; 2006).

3 METEOROLOGICAL CONDITIONS

3.1 ARMC Meteorological Stations (December 2003 – August 2006)

Two meteorological stations were established in December 2003, at the Faro and Grum dump sites (Figure 1). The Grum location was selected to represent meteorological conditions at both the Grum and Vangorda dumps, and as such, is referred to as the VanGrum station. Detailed information on the metrological stations is provided by Janowicz et al. (2004). A comparison of selected mean monthly meteorological parameters observed at the Faro and VanGrum stations is presented in Table 1. On an annual basis, Faro temperatures are slightly higher than VanGrum, though VanGrum values are slightly lower in the winter and higher in the summer. Relative humidity is generally higher at the VanGrum station on an annual basis, as is the wind speed, especially during the winter. Incoming solar radiation is generally greater at the VanGrum site, especially during the summer months. Monthly rainfall amounts are slightly higher at the VanGrum meteorological station, while winter snow surveys indicate that snowpack is significantly greater at the Grum and Vangorda dump sites, as compared to the Faro dump. An electronic copy of the meteorological data is provided with the final report.

3.2 Faro Airport Historical Precipitation Summary (1978 – 2006)

Monthly precipitation data for the Faro Airport meteorological station was assessed to determine where the 2004 - 2006 study period fell in terms of the historical precipitation trend. Table 2 provides a summary of summer, winter and annual water year (September to August) precipitation amounts for the Faro Airport station. Precipitation amounts during the September 2004 to August 2005 study period were quite high, with the 420 mm annual amount representing the maximum of the 29 year record. The precipitation total of 297 mm for the September 2005 to August 2006 study period was closer to the mean annual water year amount of 316 mm.

Table 1: Monthly average relative humidity, wind speed, incoming solar radiation, air temperature, and precipitation – Faro and VanGrum meteorological stations (2004/05; 2005/06)

	2004-2005					2005-2006				
FARO	RH (%)	Wind (m/s)	Solar (w/m^2)	Temp (^{0} C)	Precip (mm)	RH (%)	Wind (m/s)	Solar (w/m^2)	Temp (^{0}C)	Precip (mm)
Sep	72.4	2.5	85.9	1.8	60.7	76.4	2.1	86.6	4.8	32.8
Oct	79.2	2.0	45.4	-3.4	36.6	75.9	2.1	44.7	-1.8	13.0
Nov	76.8	2.2	18.2	-6.9	14.2	78.4	2.3	9.8	-9.1	30.1
Dec	80.5	2.0	4.3	-11.9	26.2	79.2	1.7	7.1	-8.5	10.8
Jan	79.0	1.5	10.5	-16.7	10.7	84.5	0.9	9.3	-15.8	10.8
Feb	76.3	1.9	36.1	-11.6	13.0	68.4	2.2	45.6	-11.2	6.2
Mar	63.1	3.1	106.9	-4.9	0.0	63.8	2.0	104.5	-12.1	12.4
Apr	59.8	2.3	184.7	0.3	15.8	61.5	2.7	163.1	-2.2	10.6
May	55.6	2.3	221.4	8.1	36.1	61.6	2.5	197.9	4.0	44.0
Jun	56.8	2.4	237.9	10.9	51.1	50.1	2.6	245.9	11.2	47.0
Jul	66.5	1.9	172.9	10.8	76.7	59.9	2.3	209.1	12.6	38.6
Aug	66.1	2.3	154.8	10.7	26.7	70.7	2.2	147.5	8.7	46.5
VANGRUM										
Sep	74.0	2.5	90.5	1.7	62.2	76.7	2.4	92.1	4.9	39.4
Oct	80.7	2.5	46.9	-3.6	44.2	78.2	2.8	48.2	-1.9	13.0
Nov	79.6	2.7	18.7	-7.4	11.2	79.6	2.7	11.8	-9.2	30.1
Dec	82.4	2.6	3.5	-12.3	26.2	80.5	2.6	7.0	-8.4	10.8
Jan	79.9	2.4	8.7	-17.1	4.3	85.9	1.7	9.2	-15.4	10.8
Feb	78.1	2.4	35.9	-12.2	18.5	70.3	2.9	46.3	-11.5	6.2
Mar	64.1	3.4	106.0	-5.2	0.0	64.8	3.0	106.0	-12.2	12.4
Apr	61.2	2.5	182.7	0.2	14.0	60.7	2.6	164.4	-2.0	10.6
May	55.4	2.5	227.1	8.2	48.3	61.9	2.4	193.2	4.1	44.0
Jun	56.5	2.5	237.7	11.1	34.0	50.8	2.5	253.5	11.2	59.9
Jul	65.8	2.2	192.0	11.0	77.0	60.1	2.3	221.8	12.8	49.0
Aug	66.8	2.4	158.6	10.7	33.0	70.4	2.4	152.6	8.8	56.9

Table 2: Faro Airport Precipitation (September – August Water Year)

	Summer May-Sep (mm)	Winter Oct-Apr (mm)	Annual Sep-Aug (mm)
1978	126	126	281
1979	161	105	268
1980	197	73	234
1981	156	86	266
1982	185	122	360
1983	212	92	280
1984	173	107	302
1985	235	129	382
1986	252	74	365
1987	277	93	322
1988	242	109	280
1989	158	152	346
1990	229	132	399
1991	249	204	380
1992	176	90	369
1993	282	142	301
1994	154	114	341
1995	210	116	313
1996	223	97	326
1997	192	66	171
1998	110	94	305
1999	217	111	356
2000	321	65	308
2001	183	123	305
2002	176	84	269
2003	177	157	289
2004	150	150	420
2005	259	94	297
2006	193		
Mean	**203**	**111**	**316**
Min	**110**	**65**	**171**
Max	**321**	**204**	**420**

Historically, the mean annual precipitation (water year) for the period ranged from 171 to 420 mm with an average value of 316 mm. Summer (May to August) and winter (October to April) precipitation during the 2004/05 study period were likewise high, with values of 259 and 150 mm, respectively, in comparison to the overall period mean values of 203 and 111 mm. Summer and winter precipitation values of 193 and 94 were closer to mean values, during the 2005/06 study period.

Peak and drought frequency analyses were carried out with the annual water year precipitation amounts. The analyses, which are summarized in Figures 2 and 3, suggest that the 2004/05 study period precipitation represents a 65 year return period, while the 2005/06 study year precipitation is less than a 2 year return period. The 1997/98 study year precipitation was in the order of a 100 year drought event.

4 WATER BALANCE DERIVATION

4.1 Cold Regions Hydrological Model Overview

The preliminary water balance was developed using the Cold Regions Hydrological Model (CRHM). Written in C++, the CRHM model is a spatially distributed, modular, numerical modelling system created from recent process-based hydrology research including state of the art research carried out in the Wolf Creek Research Basin near Whitehorse, Yukon. Modules represent algorithms which transform input data, interpret basin characteristics and represent physically-based hydrological processes. These modules include blowing snow, interception, sublimation, snowmelt, soil freezing, frozen soil infiltration, evapotranspiration, infiltration, soil moisture balance, routing and runoff algorithms, which are linked and compiled by CRHM into a customized simulation package. The model uses standard land use and basin characteristics, and climate data, for the process algorithms to calculate and graphically display hydrological parameters of interest. Simulations are carried out for distinct Hydrological Response Units (HRU) which represent sub-basins of hydrologically homogeneous characteristics, such as land cover, slope, aspect and soil type. Time series meteorological data requirements include air temperature, relative humidity, wind speed, precipitation and incoming solar radiation. Detailed information on the CRHM process modules is provided by Janowicz et al. (2004).

4.2 Model Data Assembly

4.2.1 Meteorological Data

Hourly data from the Faro and VanGrum dump meteorological stations were used for the analyses. For accounting purposes, the model runs on the hydrological year, September 1 to August 31, using air temperature, relative humidity, wind speed, incoming solar radiation and precipitation data. The 2004/05 study period was determined to be the wettest year on record; therefore, was determined to be likely not representative of normal conditions. The primary objective of this phase of the study is to assess waste rock dump water balance for average and low precipitation years. The 2005/06 study year was used to represent average precipitation conditions, since according to Faro Airport records, precipitation was close to (94 percent of) the mean annual water year precipitation for the period of record. Minimum water year precipitation was observed at the Faro Airport meteorological station in 1997/98. Since the ARMC meteorological stations were only established in December 2003, it was necessary to synthesize a low precipitation year. A value of 0.54, which represents the ratio of the minimum observed precipitation in 1997/98 (171 mm) and the calculated mean precipitation (316 mm) was used to adjust the observed 2005/06 hourly Faro precipitation to represent a low precipitation year. Other model input data (air temperature, relative humidity, wind velocity and solar radiation) was not synthesized, and, the observed 2005/06 ARMC meteorological station data was used directly.

4.2.2 Physical Data

The Faro, Grum and Vangorda waste dumps were subdivided into six HRUs for the water balance calculations: flat surfaces, push over slopes differentiated by aspect (north, south, east and west), and bubble dumps. Table 3 lists the specified physical parameters for the three waste rock dumps.

Table 3: HRU Physical Parameters

	FLAT	*SLOPE (N,S,E,W)*	*BUBBLE*
Latitude (deg)	62.33	62.33	62.33
Elevation (m)	1150	1175	1220
Slope Angle (deg)	0	20,40,40,40	0
Roughness Ht (m)	0.01	0.05	1.5
Fall Soil Saturation (%)	50	30,8,15,15	0.6
Albedo	0.24	0.24,0.20,0.20,0.20	0.22

5 SIMULATION OUTPUT

The water balance simulations for the 2004/05 and 2005/06 water years, and the synthesized "dry" year, were carried out at 1 hour intervals using meteorological data and physical parameters as specified. Detailed descriptions of the simulated water balance components for the 2004/05 study year are provided by Janowicz et al. (2006). The annual water balance for each of the three precipitation conditions are summarized in Tables 4 to 6 for the Faro waste rock dump, using the following relationship:

$$R_e = S + R - E - R_s - R_r$$

where R_e is soil and groundwater recharge (mm), S is snowmelt (mm), R is rainfall (mm) E is evaporation (mm), R_s is snowmelt runoff (mm), and Rr is rainfall runoff (mm).

Recharge represents the net change in soil and groundwater storage, and is the main component of subsurface storage. Infiltration during snowmelt and rainfall events is the primary mechanism for recharge.

Table 4: Faro Water Balance Summary - 2004/05 – Representative Wet Year

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	1.1	117	273	160	80	224	65	22	143
North	0.1	122	273	65	122	222	18	22	291
South	0.2	118	273	80	80	231	62	18	231
East	0.2	118	273	66	118	223	18	22	287
West	0.2	118	273	67	118	223	18	22	286
Bubble	1.6	122	273	159	122	262	11	0	225
Total	**3.4**	**120**	**273**	**141**	**105**	**242**	**32**	**11**	**208**

Table 5: Faro Water Balance Summary - 2005/06 – Representative Average Year

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	1.1	93	207	140	36	177	0.0	11	149
North	0.1	101	206	57	43	161	0.0	8.9	241
South	0.2	94	212	101	48	50	0.0	0.0	205
East	0.2	97	209	55	52	175	0.0	4.5	247
West	0.2	99	207	54	45	174	0.0	4.4	248
Bubble	1.6	102	205	141	55	188	0.0	0.0	166
Total	**3.4**	**98**	**206**	**126**	**47**	**174**	**0.0**	**4.3**	**175**

Table 6: Faro Water Balance Summary - Dry Year Scenario

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	1.1	48	112	148	0.0	111	0.0	0.5	12
North	0.1	56	111	61	0.0	111	0.0	0.3	106
South	0.2	52	114	103	0.0	114	0.0	0.0	63
East	0.2	54	113	58	0.0	113	0.0	0.0	109
West	0.2	55	112	58	0.0	112	0.0	0.0	109
Bubble	1.6	55	111	150	0.0	111	0.0	0.0	16
Total	**3.4**	**53**	**112**	**133**	**0.0**	**111**	**0.0**	**0.2**	**31**

Combined snowmelt and rainfall for the three precipitation scenarios is 393, 304 and 165 mm respectively. Annual evaporation is 141, 126 and 133 mm, which represents 36, 41, and 81 percent of available water respectively. Combined snowmelt and rainfall infiltration decreases significantly progressing through the three precipitation scenarios, with annual values of 347, 221 and 111 mm. Snowmelt runoff during wet years is 300 percent of rainfall runoff, with no snowmelt runoff during average and dry years, while there is some rainfall runoff from some HRUs.

Annual recharge was simulated to be 208, 175 and 31 mm, for the 2004/05 wet year, 2005/06 average year and the synthesized dry year respectively. In each of the three precipitation scenarios, flat HRUs were simulated to have the least recharge, largely due to the relatively impervious nature of the compacted surface, combined with relatively high rates of evaporation, which represent 41, 47 and 93 percent of combined snowmelt and rainfall. The greatest recharge occurred on the north, east and west facing HRUs, which have the lowest evaporation rates. South facing slopes have moderate amounts of recharge, in response to similarly moderate amounts of evaporation in the wet and average year scenarios. Because of relatively greater evaporation during the dry year, relative recharge is likewise less. Recharge to bubble surfaces is moderate for wet conditions, but progressively decreases moving from the wet to dry year scenarios, primarily in response to a likewise relative increase in evaporation and decrease in infiltration. Water balance summaries for the Grum and Vangorda waste rock dumps for wet, average and dry precipitation year scenarios are presented in Tables 7 to 12. The various water balance components are similar between the three waste rock dumps, as are the trends between the wet, average and precipitation scenarios.

Table 7: Grum Water Balance Summary - 2004/05 – Representative Wet Year

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	0.59	144	256	163	122	226	31	21	185
North	0.06	144	256	66	144	225	5	18	310
South	0.11	144	256	87	71	231	80	18	215
East	0.22	144	256	70	144	230	4	15	311
West	0.03	144	256	70	144	230	4	15	311
Bubble	0.59	146	256	162	146	249	7	0	232
Total	1.60	**145**	**256**	**139**	**132**	**235**	**21**	**12**	**229**

Table 8: Grum Water Balance Summary - 2005/06 – Representative Average Year

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	0.59	105	244	141	33	204	0.0	23	185
North	0.06	105	244	58	58	195	0.0	21	270
South	0.11	104	245	106	41	221	0.0	11	232
East	0.22	103	246	58	56	203	0.0	16	275
West	0.03	107	242	57	54	201	0.0	15	277
Bubble	0.59	106	243	143	55	226	0.0	0.0	206
Total	1.60	**105**	**244**	**123**	**46**	**213**	**0.0**	**13**	**213**

Table 9: Grum Water Balance Summary – Dry Year Scenario

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	0.59	56	146	157	16	142	0.0	3.7	41
North	0.06	57	146	62	36	130	0.0	2.9	138
South	0.11	56	146	116	14	146	0.0	0.0	86
East	0.22	56	147	62	44	138	0.0	0.9	140
West	0.03	58	145	62	45	137	0.0	0.8	140
Bubble	0.59	57	146	159	31	146	0.0	0.0	44
Total	1.60	**56**	**146**	**137**	**26**	**143**	**0.0**	**1.6**	**64**

Table 10: Vangorda Water Balance Summary - 2004/05 – Representative Wet Year

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	0.20	144	256	164	123	231	26	20	189
North	0.01	144	256	76	144	228	3	17	304
South	0.02	144	256	87	71	239	73	17	222
East	0.01	144	256	69	144	230	3	16	311
West	0.02	144	256	70	144	230	3	16	311
Bubble	0.46	145	256	164	141	249	11	0	226
Total	**0.71**	**145**	**256**	**158**	**134**	**242**	**17**	**7**	**219**

Table 11: Vangorda Water Balance Summary – 2005/06 – Representative Average Year

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	0.20	105	244	143	33	204	0.0	23	183
North	0.01	104	245	58	59	196	0.0	22	269
South	0.02	105	244	105	38	219	0.0	10	234
East	0.01	104	245	57	55	203	0.0	16	276
West	0.02	104	245	57	55	203	0.0	16	276
Bubble	0.46	105	244	144	55	227	0.0	0.0	205
Total	**0.71**	**105**	**244**	**139**	**48**	**219**	**0.0**	**7.5**	**202**

Table 12: Vangorda Water Balance Summary – Representative Low Year

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	0.20	56	146	158	16	142	0.0	3.7	40
North	0.01	57	146	62	36	130	0.0	2.9	138
South	0.02	57	146	116	14	146	0.0	0.0	87
East	0.01	57	147	62	46	138	0.0	0.9	141
West	0.02	57	146	62	45	138	0.0	0.9	140
Bubble	0.46	57	146	160	31	146	0.0	0.0	43
Total	**0.71**	**57**	**146**	**154**	**27**	**144**	**0.0**	**1.1**	**47**

6 DISCUSSION AND CONCLUSIONS

Water balance analyses were carried out for wet, average and dry precipitation scenarios, for the Faro, Grum and Vangorda waste rock dumps. The following relationship was used to calculate the annual water balance for the three dump sites:

$$R_e = S + R - E - R_s - R_r$$

where: R_e is soil and groundwater recharge, S is snowmelt, R is rainfall E is evaporation, R_s is snowmelt runoff, and Rr is rainfall runoff. Each of the components of the water balance was simulated using CRHM.

For a given precipitation scenario snow accumulation amounts are similar for all HRUs within the three waste rock dumps, with greater amounts at the Grum and Vangorda dump sites, as compared to the Faro dump. At the Faro dump, snowmelt patterns followed the observed meteorological station trend within the flat and bubble HRUs, with advanced melt within the south slope HRU, and progressively delayed melt within the east, west and north sloped HRUs.

Evaporation patterns between the three dump sites are similar; however, significantly differing cumulative amounts of evaporation are simulated for the six HRUs. The least amount of evaporation occurs from the north facing slope, while the greatest evaporation occurs from the bubble dumps. Slightly higher values of evaporation were simulated for the Vangorda site, as compared to Faro and Grum. The apparent higher evaporation for the dry year (compared to the average year) is the result of the fact that for the dry year scenario, only the precipitation values were adjusted. In an actual dry year, air temperature and relative humidity would be slightly higher and lower respectively, but unlike for precipitation, there is no appropriate relationship for adjusting these parameters. It is likely that in an actual dry year, evaporation would be somewhat lower, and subsequently, the recharge greater by a corresponding amount. These differences would not be large; however, and as such, the scenario demonstrates, with a reasonable degree of confidence, the anticipated trend in groundwater recharge for the range of precipitation inputs.

Simulated snowmelt infiltration, during high snowfall years, is generally lowest on south facing slopes due to rapid melt and runoff. Conversely, the north facing slopes have the most infiltration, due to the slowest melt and greatest infiltration opportunity time. Similar patterns and amounts of rainfall infiltration were simulated for the three dump sites. This pattern is not as strong during average snowfall years, and, no snowmelt infiltration is simulated during low snowfall years.

The simulated amount of snowmelt runoff on south facing HRUs is high during high snowfall years, with a pattern that is the inverse of snowmelt infiltration. Snowmelt runoff from flat HRUs is likewise high in comparison to the other HRUs, because of the relatively low permeability on the compacted horizontal surfaces. Snowmelt runoff is simulated to not occur during average and low snowfall years.

Moderate summer runoff was simulated for all HRUs during high rainfall years, except bubble surfaces, which is generally very low, with small amounts of runoff along the margins. Rainfall runoff is simulated to be low to nonexistent during average and low rainfall years.

Combined snowmelt and rainfall for the 2004/05 wet, 2005/06 average and synthesized low years was 393, 304, and 165 mm respectively. Evaporation amounts of 141, 126 and 133 mm, were simulated for the three precipitation scenarios, which represent 36, 41 and 81 percent of combined snowmelt and rainfall. Combined simulated snowmelt and rainfall infiltration was 347, 221, and 111 mm, for the wet, average and low precipitation scenarios respectively, while combined snowmelt and rainfall runoff was 43, 4.3 and 0.2 mm respectively. Total soil and groundwater recharge was calculated to be 208, 175 and 31 mm for the wet, average and dry years, which represents 53, 58 and 19 percent of combined snowmelt and rainfall respectively.

Simulated water balance components calculated for the Grum and Vangorda waste rock dumps exhibit similar trends for the wet, average and dry precipitation scenarios.

7 RECOMMENDATIONS FOR FURTHER WORK

Verification and refinement of the water balance could be achieved with additional years of data collection and study. Long term monitoring of seepage discharge would contribute to the verification and refinement procedure. It is recommended that the two meteorological stations be maintained for the long term, and the data archived for continuity purposes. It is also recommended that weighing precipitation gauges suitable for the Faro environment be installed. Possible options for carrying out this work include using ARMC staff, contract workers, or establishing an arrangement with Yukon Environment or another government agency.

8 REFERENCES

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Janowicz, J.R., N.R. Hedstrom and R.J. Granger. 2005. Investigation of Anvil Range Mining Corporation (Faro) Waste Dump Water Balances – 2003/04 Water Year - Preliminary Water Balance. Report prepared for SRK Consulting Inc. on behalf of Deloitte & Touche Inc. March 2005.

Janowicz, J.R., N.R. Hedstrom and R.J. Granger. 2006. Investigation of Anvil Range Mining Corporation (Faro) Waste Dump Water Balances – Final Water Balance. Report prepared for SRK Consulting Inc. on behalf of Deloitte & Touche Inc.August 2006.

FIGURES

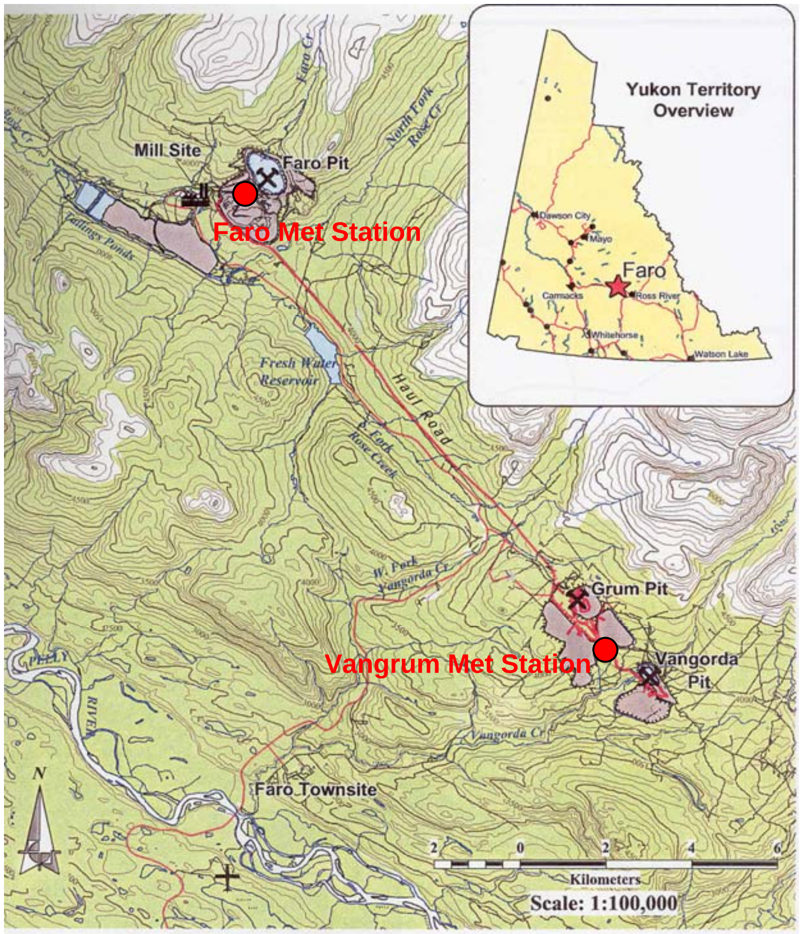
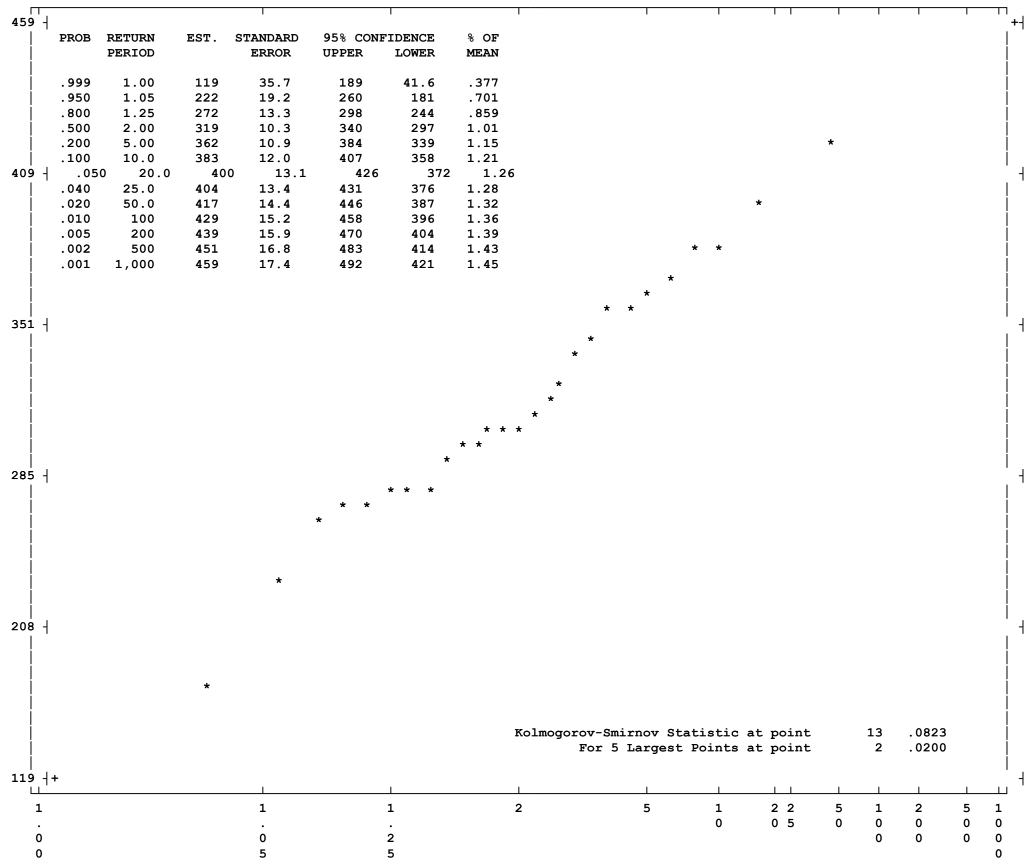


Figure 1: Location Plan (from Gartner Lee Ltd., 2002)

THREE PARAMETER LOG-NORMAL distribution

Upper bound by Moments 753.802
Upper bound by Maximum Likelihood 778.930
Log Statistics: Mean 6.1307
Standard Dev. 0.11688
Skew Coef. -0.27594E-02

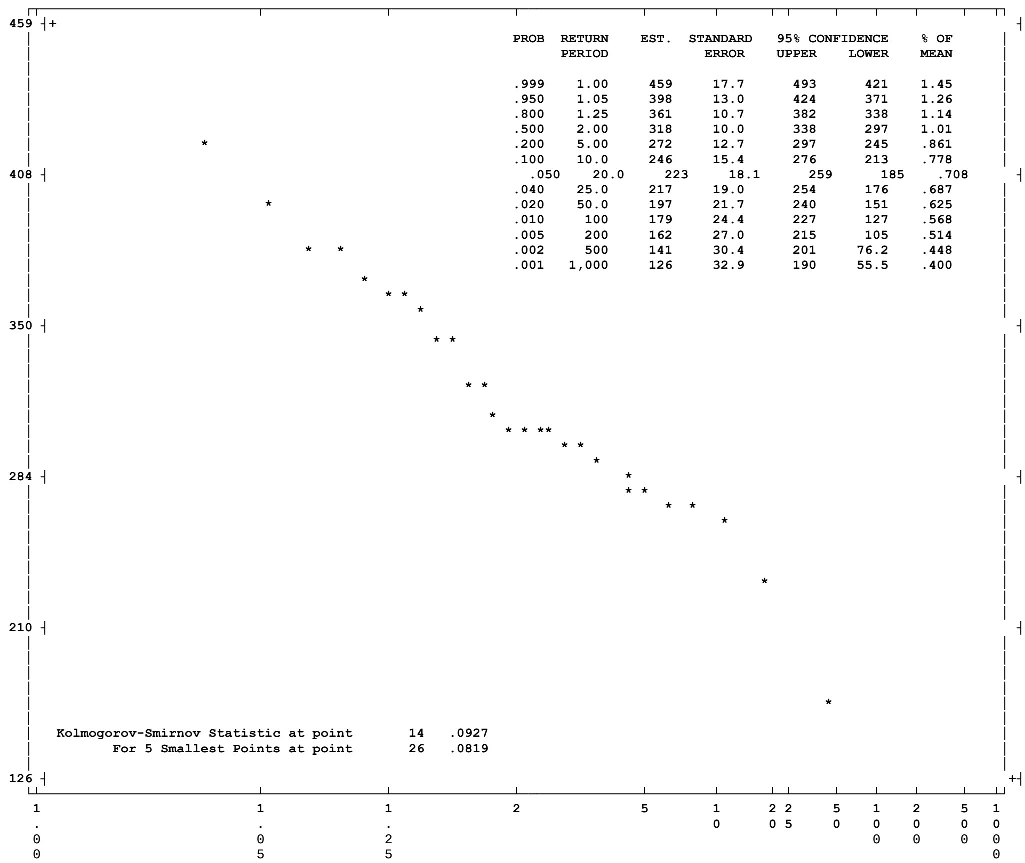


PROB	RETURN PERIOD	EST.	STANDARD ERROR	95% CONFIDENCE UPPER	LOWER	% OF MEAN
.999	1.00	119	35.7	189	41.6	.377
.950	1.05	222	19.2	260	181	.701
.800	1.25	272	13.3	298	244	.859
.500	2.00	319	10.3	340	297	1.01
.200	5.00	362	10.9	384	339	1.15
.100	10.0	383	12.0	407	358	1.21
.050	20.0	400	13.1	426	372	1.26
.040	25.0	404	13.4	431	376	1.28
.020	50.0	417	14.4	446	387	1.32
.010	100	429	15.2	458	396	1.36
.005	200	439	15.9	470	404	1.39
.002	500	451	16.8	483	414	1.43
.001	1,000	459	17.4	492	421	1.45

Figure 2: Annual (Water Year) Precipitation Peak Frequency Analysis - Faro Airport

THREE PARAMETER LOG-NORMAL distribution

Upper bound by Moments	788.215
Upper bound by Maximum Likelihood	845.067
Log Statistics: Mean	6.2671
Standard Dev.	0.10054
Skew Coef.	0.10849E-02



PROB	RETURN PERIOD	EST.	STANDARD ERROR	95% CONFIDENCE UPPER	LOWER	% OF MEAN
.999	1.00	459	17.7	493	421	1.45
.950	1.05	398	13.0	424	371	1.26
.800	1.25	361	10.7	382	338	1.14
.500	2.00	318	10.0	338	297	1.01
.200	5.00	272	12.7	297	245	.861
.100	10.0	246	15.4	276	213	.778
.050	20.0	223	18.1	259	185	.708
.040	25.0	217	19.0	254	176	.687
.020	50.0	197	21.7	240	151	.625
.010	100	179	24.4	227	127	.568
.005	200	162	27.0	215	105	.514
.002	500	141	30.4	201	76.2	.448
.001	1,000	126	32.9	190	55.5	.400

Kolmogorov-Smirnov Statistic at point 14 .0927
For 5 Smallest Points at point 26 .0819

Figure 3: Annual (Water Year) Precipitation Drought Frequency Analysis - Faro Airport

Appendix A

INVESTIGATION OF ANVIL RANGE MINING CORPORATION (FARO) WASTE DUMP WATER BALANCES – 2006/07

Task 1: Develop waste dump water balance scenarios for average, wet and dry conditions for existing dump surfaces

1.1 Transfer necessary CRHM input data from other locations using site meteorological station data for correlation purposes

1.2 Develop dump water balance estimates based on transferred data and use of CHRM model

Task 2: Design and carry out program to collect hydrometeorological data for developing water balance estimates for various cover configurations and types

2.1 Maintain meteorological stations

2.2 Upgrade precipitation instrumentation[1]

2.3 Consider maintaining recording station at V30 weir and monitor flows at V31, and V32 weirs[2]

2.4 Carry out summer infiltration studies

2.5 Carry out pre-freeze up soil moisture surveys

2.6 Consider carrying out winter and spring snow surveys[3]

Task 3: Develop dump water balance estimates for various cover configurations and types

3.1: Develop dump water balance estimates based on site meteorological data and use of CHRM model

Task 4: Final Report

4.1: Write draft final report

4.2: Make modifications to final report based on review comments

[1]Upgrading the precipitation instrumentation is expensive ($10,000) and perhaps should be considered separately

[2]Did not make too much use of the weir data but since V30 is below the cover plots it might be worthwhile putting some more effort into the project

[3]If the project continues through the winter it would be worthwhile carrying out snow surveys

Appendix B

Data from the Faro and Vangrum Meteorological Stations (Dec. 2003 to Sept. 2007)

Electronic Copy Available On Attached CD