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

FINAL WATER BALANCE

JR Janowicz[1], NR Hedstrom[2], RJ Granger[2]

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SRK Consulting Inc. on behalf of Deloitte & Touche Inc.
Interim Receiver of Anvil Range Mining Corporation and Faro Mine Closure Planning Office

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[1]Water Resources, Yukon Department of Environment, Whitehorse, YT
[2]National Water Research Institute, Environment Canada, Saskatoon, SK

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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).

This report summarizes the findings of the final phase of the project. A water balance for the Faro, Grum and Vangorda waste rock dumps, utilizing site meteorological data, for the period December 2003 to September 2005 was carried out. Summary results are as follow:

- Snow accumulation is greater at the Grum and Vangorda dump sites, as compared to the Faro dump,
- Slightly higher values of evaporation were simulated for the Vangorda site, as compared to Faro and Grum,
- Rainfall infiltration exceeded snowmelt infiltration by close to twice as much,
- Snowmelt infiltration at the Faro dump was simulated to be approximately 80 percent of the Grum and Vangorda dump sites,
- Simulated snowmelt runoff on south facing and flat HRUs is high in comparison to other HRU surfaces,
- Annual recharge was 208, 229 and 219 mm for Faro, Grum and Vangorda, respectively,
- The historical precipitation and temperature data indicate that the 2004/05 study period was significantly wetter and warmer than normal, suggesting that the 2004/05 water balance is not indicative of normal conditions, with groundwater recharge likely higher during the study period as compared to historical rates.

Because the 2004 study period (September to August water year) was the wettest in the 26 year Faro Airport record, it is recommended that a following study be initiated to determine waste rock dump recharge: 1) during average and dry conditions; and, 2) with various cover scenarios. It is further recommended that the two meteorological stations be maintained, with the addition of a more robust weighing precipitation gauge, and the data archived for continuity purposes.

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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 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).

This report summarizes the findings of the final phase of the project. A water balance for the Faro, Grum and Vangorda waste rock dumps was developed utilizing site meteorological data, for the period December 2003 to September 2005. The approved study proposal is presented in Appendix A.

2 STUDY AREA

The Anvil Range Mining Complex (ARMC) is located 200 km northeast of Whitehorse, YT near the community of Faro, YT. The mine site is located in the Anvil Range Mountains within the Macmillan Highlands of Yukon Plateau-North ecoregion (Smith et al., 2004). The topography consists of broad valleys which separate rounded mountains of moderate relief ranging from 800 to 2000 masl. The Anvil Range Mining Complex is situated at the southern bases of Mount Aho and Mount Mye within the Rose and Vangorda Creek drainages of the Pelly River. The location of the mine waste dumps is shown in 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.

The climate is characterized as sub-arctic continental, with a large annual range in temperature and relatively moderate amounts of annual precipitation. The mean annual air temperature of the area is approximately -5 ^{0}C with a range of mean monthly temperatures from -30^{0}C in January to 20 ^{0}C in July. There is a strong seasonal variation in temperature which is further accentuated by elevation differences. Winter temperatures can be 10 degrees lower in valley bottoms as compared to upland areas, due to temperature inversions. Summer temperatures adhere more closely to the environmental lapse rate with valley bottom temperatures higher than upland areas (Wahl et al., 1987).

3 DATA COLLECTION PROGRAM

3.1 Meteorological Stations

Two meteorological stations were established in December 2003 (Figure 1), at the Faro and Grum dump sites (Photos 1 and 2). 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. Meteorological parameters monitored at the site include air temperature, relative humidity, incoming and outgoing short-wave radiation, net all-wave radiation, wind speed and direction, rainfall, snowfall, snow depth, soil moisture and temperature and soil heat flux. The stations generally performed well, producing a continuous data set to present. Problems were encountered, however, with the winter precipitation instrumentation during the first winter of operation, therefore, this data is incomplete for the 2003/04 winter period. Because the meteorological stations were established during the winter period, it was not initially possible to install the soil moisture and soil temperature sensors. This instrumentation was installed in July 2004 and has been functioning well since that time. 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

Table 1: Monthly average relative humidity, wind speed, incoming solar radiation, air temperature, and precipitation – Faro and VanGrum meteorological stations (2003/04; 2004/05)

	2003-2004					2004-2005				
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
Oct						79.2	2.0	45.4	-3.4	36.6
Nov						76.8	2.2	18.2	-6.9	14.2
Dec						80.5	2.0	4.3	-11.9	26.2
Jan	81.5	1.0	8.8	-19.6	-	79.0	1.5	10.5	-16.7	10.7
Feb	77.0	2.3	36.7	-6.6	-	76.3	1.9	36.1	-11.6	13.0
Mar	73.9	2.6	89.6	-9.5	-	63.1	3.1	106.9	-4.9	0.0
Apr	59.4	2.6	193.7	-0.8	-	59.8	2.3	184.7	0.3	15.8
May	54.6	2.5	225.3	5.6	14.7	55.6	2.3	221.4	8.1	36.1
Jun	49.5	2.4	230.0	15.1	50.8	56.8	2.4	237.9	10.9	51.1
Jul	57.7	2.4	186.3	13.3	31.8	66.5	1.9	172.9	10.8	76.7
Aug	59.9	1.9	164.5	12.0	20.1	66.1	2.3	154.8	10.7	26.7
VANGRUM										
Sep						74.0	2.5	90.5	1.7	62.2
Oct						80.7	2.5	46.9	-3.6	44.2
Nov						79.6	2.7	18.7	-7.4	11.2
Dec						82.4	2.6	3.5	-12.3	26.2
Jan	82.5	2.6	11.3	-19.4	-	79.9	2.4	8.7	-17.1	4.3
Feb	80.0	2.7	38.0	-7.0	-	78.1	2.4	35.9	-12.2	18.5
Mar	75.3	3.0	96.3	-9.7	-	64.1	3.4	106.0	-5.2	0.0
Apr	59.6	2.7	197.1	-0.9	-	61.2	2.5	182.7	0.2	14.0
May	56.2	2.7	217.1	5.3	28.7	55.4	2.5	227.1	8.2	48.3
Jun	49.9	2.5	245.6	15.3	50.8	56.5	2.5	237.7	11.1	34.0
Jul	58.0	2.4	196.5	13.5	30.7	65.8	2.2	192.0	11.0	77.0
Aug	59.8	2.2	171.5	12.2	27.4	66.8	2.4	158.6	10.7	33.0

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 (Figure 2). Incoming solar radiation is generally greater at the VanGrum site, especially during the summer months. Monthly rainfall amounts are slightly higher at the VanGrum site. A comparison of snowpack accumulation and depletion is provided by Figure 3, which illustrates recorded snow depth at the respective stations for the two seasons of operation.

The relationship demonstrates that the snowpack is significantly greater at the Grum and Vangorda dump sites, as compared to the Faro site. An electronic copy of the meteorological data is provided with the final report.

3.2 Snow Surveys

Extensive snow surveys were carried out at various locations across the ARMC site during March 2004, and, February and April 2005. Representative relationships between snow depth and snow water equivalent (SWE) for characteristic surfaces at the three waste rock dumps were developed. Due to the hazard associated with snow sampling on steep slopes, insufficient data were collected to differentiate between snowpack characteristics on dump slope surfaces at the three sites. A number of snow survey transects were installed in September 2004, which provide estimates of snowpack characteristics on dump slopes without carrying out physical surveys (Photo 3). Detailed information on the snow surveys is provided in Janowicz et al. (2005).

3.3 Seepage Weir

An existing 90 degree V-notch weir at the southern base of the Vangorda waste rock dump (drain #3) was reconditioned and a data logger was installed to provide a continuous record of weir pond water level (Photo 4). Figure 8 illustrates the variations in seepage discharge volume as a function of rainfall amount for the 2004 season. The 2005 seepage weir monitoring program was not entirely effective in describing the relationship between inputs and seepage discharge. Due to stilling well intake blockage, the early snowmelt period was missed. The installation was repaired on May 19. Weir data during the latter part of the season is also questionable due to leaf matter in the weir pond affecting water level instrument malfunction, Spot discharge measurements taken between May 19 and September 20, 2005, vary by a factor of 1.7 (Table 2).

Table 2: Vangorda Seepage Weir Discharge - 2005

Date	Discharge (l/s)
May 19	0.077
Jun 3	0.067
Jun 22	0.058
Jul 19	0.051
Aug 6	0.045
Sep 2	0.058
Sept 20	0.063

3.4 Infiltration Studies

Field studies were carried out in September 2004 and August 2005 to characterize the variation of infiltration across the three waste dump areas. A Guelph permeameter and double ring infiltrometer were used to assess permeability (Photos 5 and 6). Better success in acquiring absolute rates of infiltration was obtained with the Guelph permeameter, although the double ring infiltrometer was useful in providing infiltration trends across the dumps. Most tests were conducted on the flat surfaces; however, there was some limited success with the application to the bubble dump surfaces. It was not possible to apply these techniques on sloped surfaces. Though these methods were developed for use with finer agricultural soils, and are not directly applicable to the waste dump sites, some useful information was obtained. Hydraulic conductivity values obtained using the Guelph permeameter and corresponding Green-Ampt soil classes are summarized in Table 3.

Table 3: Hydraulic conductivity and Green-Ampt soil class values

	Faro 1		Faro 2		Grum	
Date	**K (cm/s)**	**Soil Class**	**K (cm/s)**	**Soil Class**	**K (cm/s)**	**Soil Class**
Sep 16/04	2.51E-05	7 to 8	7.60E-04	2	1.40E-04	4 to 5
Aug 16/05	7.55E-05	5 to 6	6.30E-04	2	1.46E-03	1 to 2

The double ring infiltrometer results are presented in Appendix B. High volume percolation tests were carried out at several bubble dump locations using a water truck with a volume of 1000 litres. A water application rate of approximately 200 litres/min to the bubble depressions produced insignificant ponding, and a near instantaneous infiltration rate.

4 WASTE ROCK DUMP CHARACTERIZATION

The waste rock dumps were developed from 1968 to 1995 with some subsequent modification for mine rehabilitation purposes. The Faro waste rock dumps were developed over the 1968 to 1992 mining period, with waste rock depositions occurring at several dumps at the same time. Dump physical dimensions and composition are summarized by Janowicz et al., 2004.

Three types of dump surfaces can be distinguished: bubble dumps, flat surfaces and push-over slopes. Bubble dumps are hummocky areas of alternate mound and depression features with relief of 1 to 2 m, created by the successive end dumping of waste material by large dump trucks. Flat surfaces have been created by the redistribution of bubble dump material by heavy equipment. These surfaces are typically smooth, hard packed surfaces, which receive heavy driving traffic and are often used as staging area and storage lots. Push-over slopes are located along dump edges and peripheries of successive dump lifts. These features were created by haul trucks directly dumping material over lift edges, or by dozers pushing material that was end dumped by the trucks. They tend to be 20 to 80 m in length with angles up to 60 degrees. Coarser material accumulates near the bottom of these slopes.

Because of the nature of the deposition process, dump material tends to be variable in texture with grain size distribution classes ranging from boulders to silt. According to M.D. Haug & Associates Ltd (2003), the predominate material classes are gravel and sand. Grain size distribution analyses carried out for the present study indicate that each waste rock dump, although all on the coarser end of the scale, consists of unique textural classes with Grum having the most coarse surface material and Vangorda with the least coarse material. The predominant textural class descriptions are:

- Faro – Silty gravel with sand
- Grum – Gravel with sand and silt
- Vangorda – Silty sand with gravel.

Selected grain size distribution analyses are presented in Figures 5 to 7. The surficial materials weather over time resulting in finer texture. As would be expected, the flat higher traffic surfaces consist of more fines than the other surfaces because of compaction by heavy equipment and the material tends to be denser. Table 4 summarizes the surface area of the various dump surface types.

Table 4: Estimated Dump Type Surface Area in hectares

	FARO	VANGORDA	GRUM
Flat	107	20	59
North Slope	10	0.8	6.3
South Slope	20	2.1	11.3
East Slope	20	0.5	21.5
West Slope	20	1.6	2.9
Bubble	163	46	59
TOTAL	334*	71	160

*from Robertson Geoconsultants Inc (1996)

5 WATER BALANCE DERIVATION

5.1 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. CRHM contains a library of physically-based modules from which a user selects the most applicable to the given hydrological scenario. Figure 8 presents a relational flowchart which shows the linkages between algorithms and their outputs.

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. Hourly or half hourly time steps can be specified. Detailed information on the CRHM process modules is provided by Janowicz et al., 2004.

5.2 Model Data Assembly

5.2.1 Meteorological Data

Hourly data from the dump site 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. Because the station was not established until December 2003, the necessary data for the beginning of the 2003/04 hydrological year were unavailable. Separate model runs were carried out for 2004/05 hydrological year and the entire period of available record, December 2003 to September 2005.

5.2.2 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 5 lists the specified physical parameters for the three waste rock dumps.

Table 5: 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

6 SIMULATION OUTPUT

6.1 2004/05 Water Year

The water balance simulation for the 2004/05 water year was carried out at 1 hour intervals using meteorological data and physical parameters as specified. For illustrative purposes the simulated Faro snow water equivalent (SWE) for the winter season is presented in Figure 9 along with the observed SWE. The plots illustrate both accumulation and ablation for the six HRUs, and are the products of the precipitation and of the blowing snow, sublimation, and snowmelt routines. Patterns of simulated SWE for the Grum and Vangorda dumps are similar, although total amounts of SWE are greater at the latter dump sites as shown in Figure 3 which illustrates observed snow depth at the two sites..

Sublimation and wind transport (drift) are simulated using the Prairie Blowing Snow Module, (pbsm) which uses wind speed, air temperature, relative humidity and roughness height as key input variables. Both simulated sublimation and drift are low within all HRUs at the three dumps. A threshold value of wind velocity to initiate both sublimation and drift is approximately 6 m/s (Li and Pomeroy, 1997). There were few sustained periods of wind velocity above this threshold, as illustrated in Figure 10, which explains the insignificant sublimation and wind transport.

The energy budget (ebsm) routine was used to generate snowmelt for all HRUs. Snow accumulation is similar for all HRUs, with slight variations due to sublimation and drifting. Snowmelt patterns followed the observed trend within the flat HRU, which corresponds to station location, and the bubble HRU; within the south slope HRU the smowmelt was advanced, and the melt was progressively delayed within the east and west slopes, and the north slope HRUs respectively.

Simulated evaporation for the flat HRU at the Faro dump is illustrated in Figure 11 for the 2003/04 and 2004/05 summer periods. Patterns of evaporation were similar for the two years, while annual amounts were slightly greater during 2003/04. The Granger evaporation module (evap2) was used to calculate evaporative flux. The method is based on the combination aerodynamic and energy budget approach, developed by Penman (1948) for saturated surfaces. The non-saturated situation is parameterized using a relationship between relative evaporation and relative drying power (a function of wind speed, saturation vapour pressure and actual vapour pressure, net radiation and ground heat flux) (Granger and Gray, 1989). Input variables include air temperature and humidity, wind speed, net radiation or solar radiation and soil heat flux.

Simulated cumulative evaporation for the six HRUs at the Faro dump site is illustrated in Figure 12. Evaporation commences after snowmelt, peaks with the available energy (solar radiation) in June and continues into the early fall. 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, which has the least available energy for the process. The greatest evaporation occurs from the bubble dumps which have both significant amounts of energy and available soil moisture. Slightly higher values of evaporation were simulated for the Vangorda site, than Faro and Grum.

Infiltration was calculated using the "greencrack" module, which is a hybrid routine utilizing combined frozen soil and summer infiltration models for snowmelt and rainfall respectively. The snowmelt infiltration component uses pre-melt soil moisture (liquid + frozen) and available meltwater to simulate infiltration (Janowicz et al., 2003). Summer infiltration is determined using the Green-Ampt model which is based on Darcy's law. The model describes the infiltration of ponded water based on total porosity, effective porosity, wetted capillary pressure and hydraulic conductivity (Rawls et al., 1983). These parameters are a function of soil texture, of which CRHM has 11 soil classes ranging from water to clay. Input parameters include initial and maximum soil moisture, and soil type. Simulated cumulative infiltration for the six HRUs at the Faro dump site for the 2004/05 water year is illustrated in Figure 13. Rainfall infiltration exceeded snowmelt infiltration by close to twice as much overall. Significant infiltration occurred during September 2004, consisting of a combination of rainfall and snowmelt. Simulated spring snowmelt, during May 2005, was least on south facing slopes due to rapid melt and runoff. The south slope has the most rapid melt, therefore, the shortest "opportunity time" to infiltrate. Conversely, the north facing slope has 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. Faro snowmelt infiltration was simulated to be approximately 80 percent of the Grum and Vangorda dump sites.

Runoff is generated by the soil moisture balance module (smbal) which handles soil moisture accounting for the model. The soil is separated into two layers, with the top layer treated as the recharge layer. Evaporation can only occur from the recharge layer. Surface infiltration first satisfies the recharge layer before water can be conveyed to lower layers. Excess water from both layers goes to groundwater before being discharged as subsurface flow. Input parameters for "smbal" include cover and soil type, initial and maximum soil moisture amounts for both recharge and lower soil layers and the maximum amount of soil water excess that is routed to groundwater each day. Simulated cumulative runoff for the six HRUs at the Faro dump site, for the 2004/05 water year is illustrated in Figure 14. The simulated amount of snowmelt runoff on south facing HRUs is relatively large, with a pattern inverse of the 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. Moderate summer runoff was simulated for all HRUs except for the bubble surfaces, for which runoff is generally very low, with only small amounts of runoff along the margins.

The annual water balance for each of the six HRUs is summarized in Tables 6 to 8 for the Faro, Grum and Vangorda waste rock dumps 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

Table 6: Faro Water Balance Summary - 2004/05

	Area (km^2)	Snowmelt (mm)	Rainfall (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
Flat	1.10	117	273	160	80	224	65	22	143
North	0.10	122	273	65	122	222	18	22	291
South	0.20	118	273	80	80	231	62	18	231
East	0.20	118	273	66	118	223	18	22	287
West	0.20	118	273	67	118	223	18	22	286
Bubble	1.60	122	273	159	122	262	11	0	225
Total	**3.40**	**120**	**273**	**141**	**105**	**242**	**32**	**11**	**208**

Table 7: Grum Water Balance Summary - 2004/05

	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: Vangorda Water Balance Summary - 2004/05

	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**

primary mechanism for recharge. Annual recharge was 208, 229 and 219 mm for Faro, Grum and Vangorda respectively. In each of the three dumps, Flat HRUs were simulated to have the least recharge, largely due to the relatively impervious nature of the compacted surface, combined with high rates of evaporation. The greatest recharge occurred on the north, east and west facing HRUs, which have the lowest evaporation rates. The south facing slope and bubble surface have moderate amounts of recharge because of rapid snowmelt runoff and high rates of evaporation.

Subsurface flows within the waste rock dumps likely follow preferential flow paths, which converge and exit the dumps at the common seepage locations. There may also be some lateral groundwater inflows from outside the dump areas, which likely follow preferential flow paths to the seepage outlets as well.

Figure 15 illustrates the accuracy of the modelling exercise in estimating waste rock dump recharge. Figure 15 shows a close association between calculated and observed soil moisture variation in response to rainfall inputs for the Faro meteorological station location. Calculated soil water is a function of rainfall, infiltration and evaporation and the close association between observed and calculated values indicates that estimated evaporation is also reasonable.

6.2 Historical Water Balance Assessment

Monthly precipitation and temperature data for the Faro Airport meteorological station was assessed to determine where the 2004/05 study period was in terms of the historical precipitation and temperature trends. Table 9 provides a summary of summer, winter and annual water year (September to August) precipitation amounts for the Faro

Airport station. Precipitation amounts during the study period were quite high, with the 420 mm annual amount representing the maximum of the 28 year record.

Table 9: 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		
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 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. It is interesting to note that the 2004 summer was the 3rd driest on record with 150 mm, but the annual total was a record wet year. A frequency analysis was carried out with the annual water year precipitation amounts. The analysis, which is summarized in Figure 16, suggests that the 2004/05 study period precipitation represents a 65 year return period.

Table 10 provides a summary of summer, winter and annual water year (September to August) air temperatures for the Faro Airport station. Similar to precipitation, air temperature during the study period were quite high. The mean annual temperature for the water year was -1.2^0 C, the 4th warmest in the 28 year record. The mean annual temperature for the period ranged from -0.3°C to -4.7^0 C with a mean value of -2.2^0 C. Summer and winter temperatures were also high, with mean values of 11.8 and -10.0 ^{0} C respectively, in comparison to the overall period mean values of 10.9 and -11.5 ^{0} C.

The historical precipitation and temperature data indicate that the 2004/05 study period was significantly wetter and warmer than normal, suggesting that the 2004/05 water balance is not representative of normal conditions. Both winter snowfall and associated snowmelt, and summer rainfall was greater than over the last 28 years, potentially resulting in both greater infiltration and runoff. Generalizing on historical evaporation is not as simple, because of the complexity of feedback mechanisms. For conditions of equal radiant energy input, particularly over a surface with sparse vegetation, a lower air temperature would mean a greater evaporation rate, because a

Table10: Faro Airport Temperature (September - August Water Year)

	Summer May-Sep (mm)	Winter Oct-Apr (mm)	Annual (mm)
1978	11.4	-14.0	-3.5
1979	11.2	-10.3	-1.2
1980	10.8	-10.3	-1.5
1981	10.8	-15.5	-4.7
1982	11.0	-12.5	-2.8
1983	10.1	-11.1	-2.5
1984	9.9	-12.1	-3.1
1985	9.5	-11.7	-2.6
1986	10.2	-9.8	-1.3
1987	10.6	-8.3	-0.3
1988	10.8	-12.8	-2.5
1989	12.2	-11.9	-2.1
1990	11.8	-12.8	-2.8
1991	10.9	-9.7	-1.2
1992	9.4	-11.0	-2.3
1993	11.1	-10.9	-1.4
1994	11.6	-11.4	-2.0
1995	12.0	-14.6	-4.1
1996	9.8	-13.9	-3.4
1997	11.7	-9.9	-0.8
1998	11.5	-11.9	-2.4
1999	11.1	-8.6	-0.7
2000	9.8		
2001	11.0	-12.8	-3.1
2002	10.5	-10.0	-1.3
2003	10.4	-10.9	-1.4
2004	11.8	-10.0	-1.2
2005	11.6		
Mean	10.9	-11.5	-2.2
Min	9.4	-15.5	-4.7
Max	12.2	-8.3	-0.3

greater portion of the available energy has been partitioned to the latent heat process. The distribution of summer rainfall would also effect evaporation. Although the evaporation is governed by the available energy, the amount of actual evaporation is also function of the period of water availability near the surface. A number of small rainfall events would likely result in a greater evaporative loss, than a smaller number of large, persistent rain events which would produce greater infiltration amounts. In terms of groundwater recharge it is likely that historical rates over the last 26 years were lower than those simulated during the study period. Unfortunately, there is insufficient historical data on seepage discharge rates to develop any rigorous estimates of residual saturation of the waste rock dump cores.

7 DISCUSSION AND CONCLUSIONS

A water balance was carried out for the Faro, Grum and Vangorda waste rock dumps with reasonable results. 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.

Snow accumulation is similar for all HRUs, 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.

Rainfall infiltration exceeded snowmelt infiltration at the Faro dump site by close to twice as much overall. Simulated spring snowmelt during May 2005, was least on south facing slopes due to rapid melt and runoff. Conversely, the north facing slopes simulations 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. Faro dump snowmelt infiltration was simulated to be approximately 80 percent of the Grum and Vangorda dump sites.

The simulated amount of snowmelt runoff on south facing HRUs is high, 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. Moderate summer runoff was simulated for all HRUs, except bubble surfaces, which is generally very low, with small amounts of runoff along the margins.

Annual recharge was 208, 229 and 219 mm for Faro, Grum and Vangorda waste rock dumps, respectively. In each of the three dumps, flat HRUs were simulated to have the least recharge, largely due to the relatively impervious nature of the compacted surface, combined with high rates of evaporation. The greatest recharge occurred on the north, east and west facing HRUs, which have the lowest evaporation rates. South facing slopes and bubble surfaces have moderate amounts of recharge because of rapid snowmelt runoff and high rates of evaporation for the former and latter HRUs, respectively.

A comparison was made between calculated and observed soil moisture variation in response to rainfall inputs for the Faro meteorological station location. The close association between observed and calculated values indicates the model is generally performing well, and that the estimated evaporation is also reasonable. Monthly precipitation and temperature data for the Faro Airport meteorological station was assessed to determine where the 2004/05 study period was in terms of the historical precipitation and temperature patterns. Precipitation amounts during the study period were quite high, with the 2004/05 water year amount representing the maximum of the 28 year record. A frequency analysis of the data indicated that the 2004/05 data represented a 65 year return period. The air temperature data during the study period was also found to be quite high. The historical precipitation and temperature data indicate that the 2004/05 study period was significantly wetter and warmer than normal, suggesting that the 2004/05 water year was not a typical year. In terms of groundwater recharge it is likely that historical rates over the last 26 years were lower than those simulated for during the study period.

8 RECOMMENDATIONS FOR FURTHER WORK

Given the available data limitations, the ARMC waste rock dump water balance is as complete and no further data is required. 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. The 2004 study period (September to August water year) was the wettest in the 26 year Faro Airport record. It is recommended that a following study be initiated to determine waste rock dump recharge: 1) during average and dry conditions; and, 2) with various cover scenarios. Regardless of decisions pertaining to future study, it is recommended that the two meteorological stations be maintained, 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.

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FIGURES

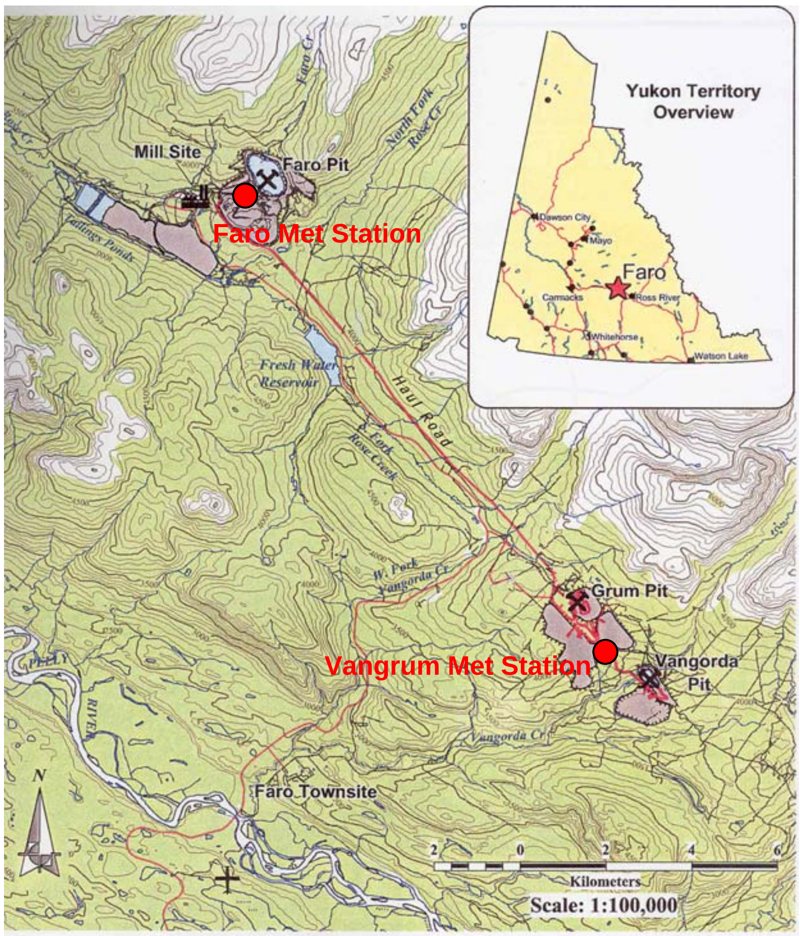


Figure 1: Location Plan (from Gartner Lee Ltd., 2002)

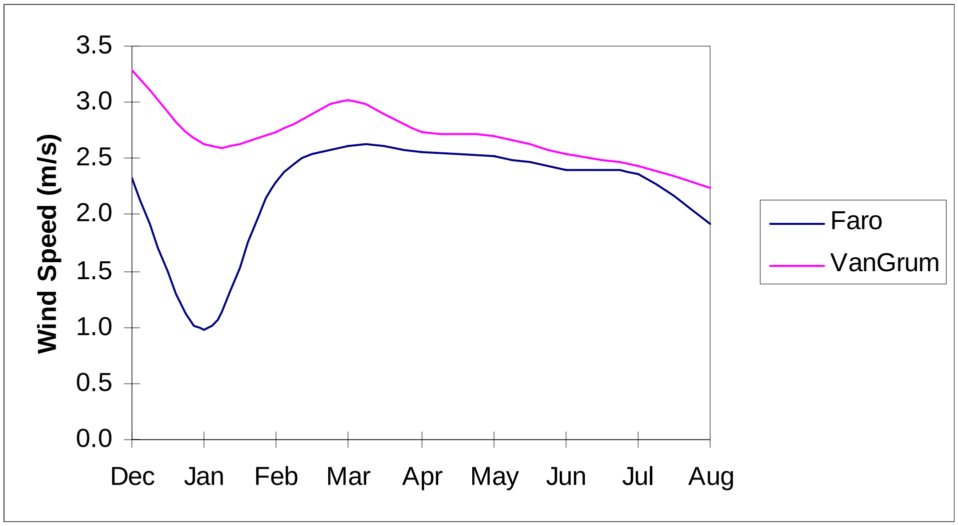


Figure 2: Monthly Wind Speed – 2003/04

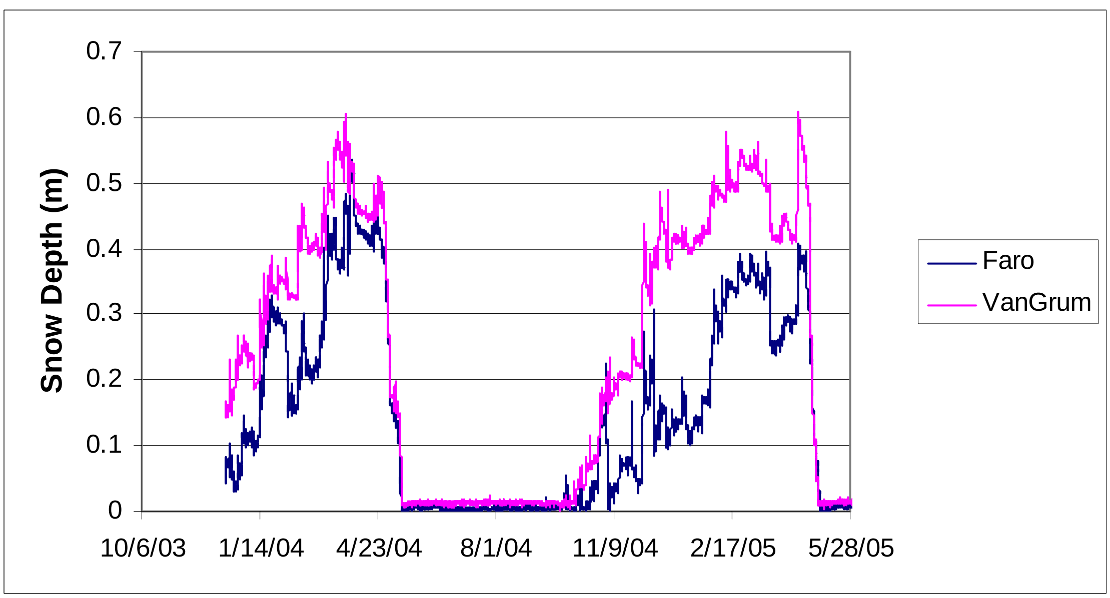


Figure 3: Faro and VanGrum Snow Depth - 2003/05

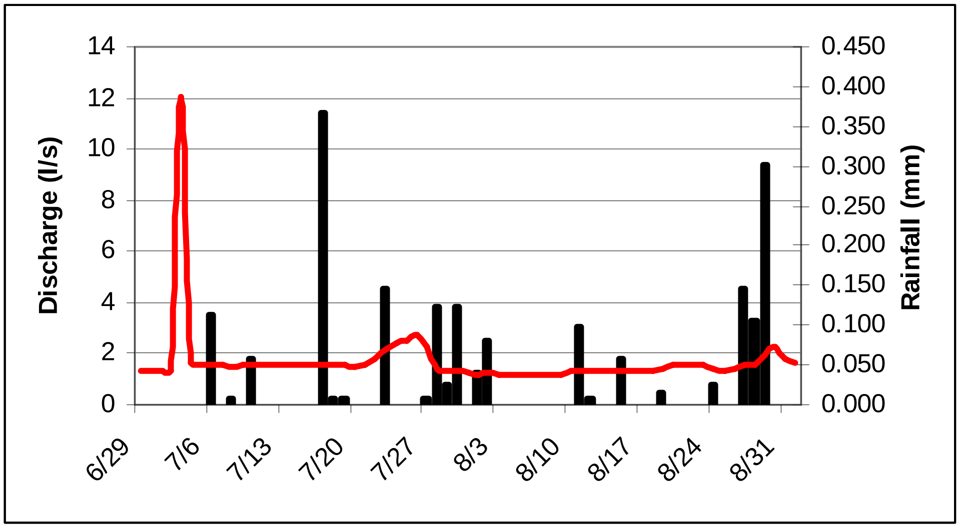


Figure 4: Vangorda Seepage Weir Hydrograph and Rainfall – 2004

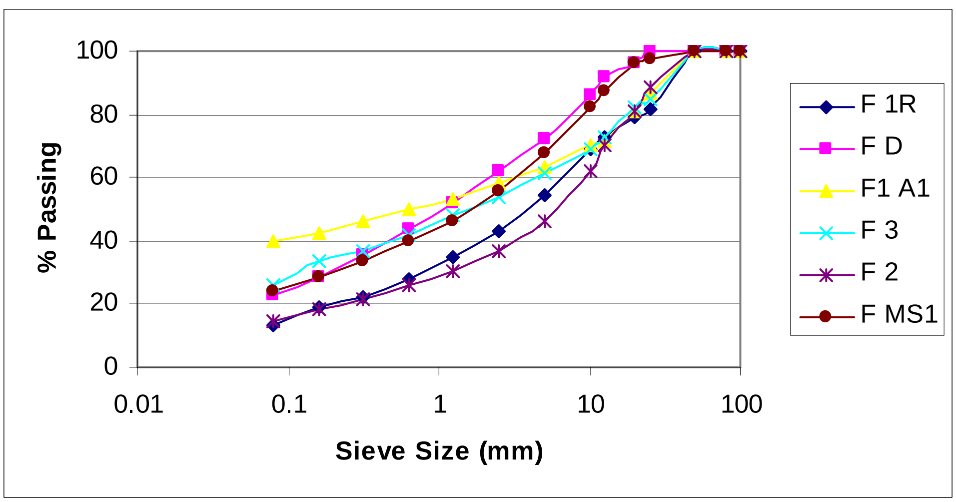


Figure 5: Waste Dump Material Size Distribution - Faro

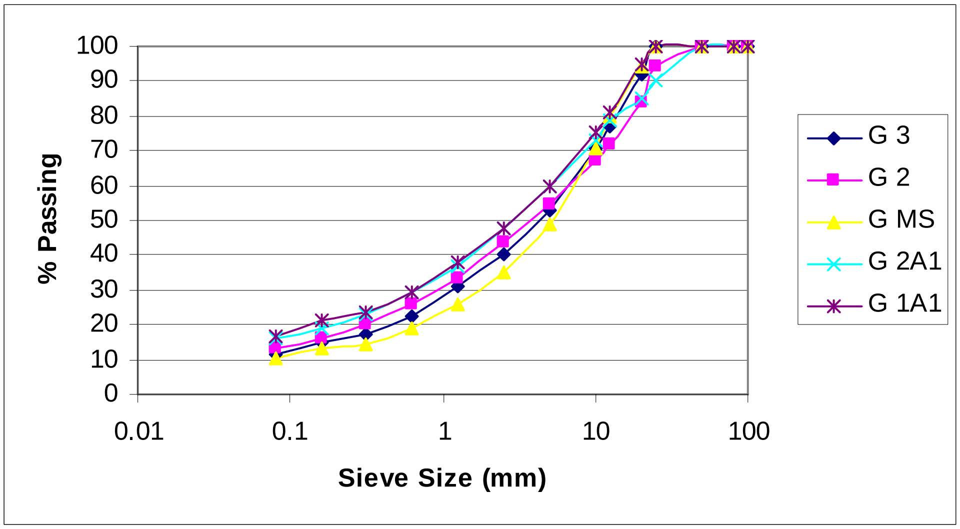


Figure 6: Waste Dump Material Size Distribution – Grum

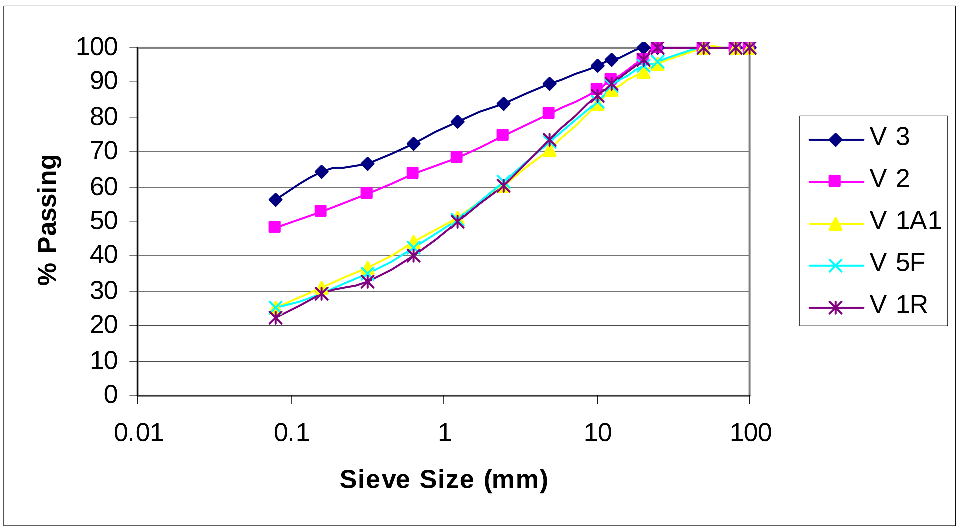


Figure 7: Waste Dump Material Distribution - Vangorda

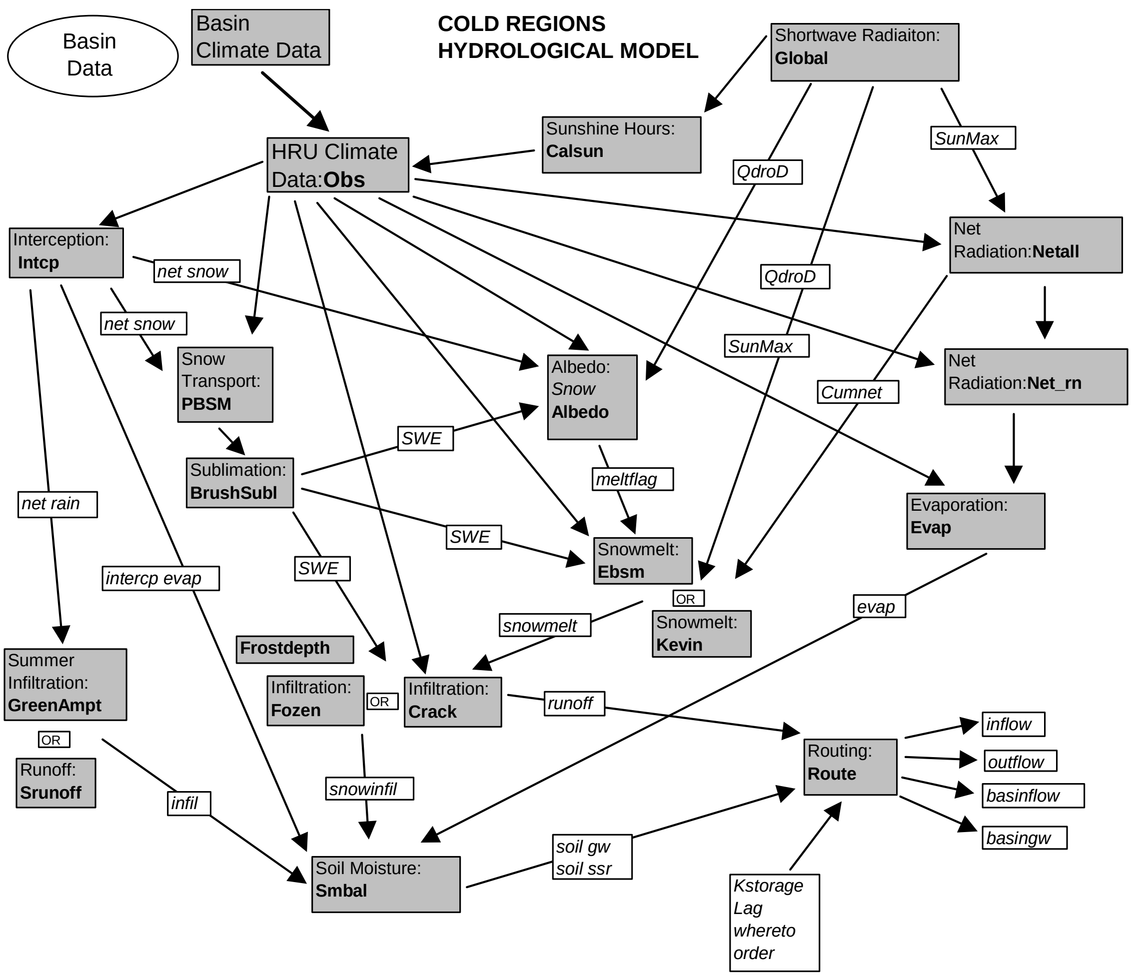


Figure 8: Cold Regions Hydrological Model Relational Flowchart (from Granger et al., 2002)

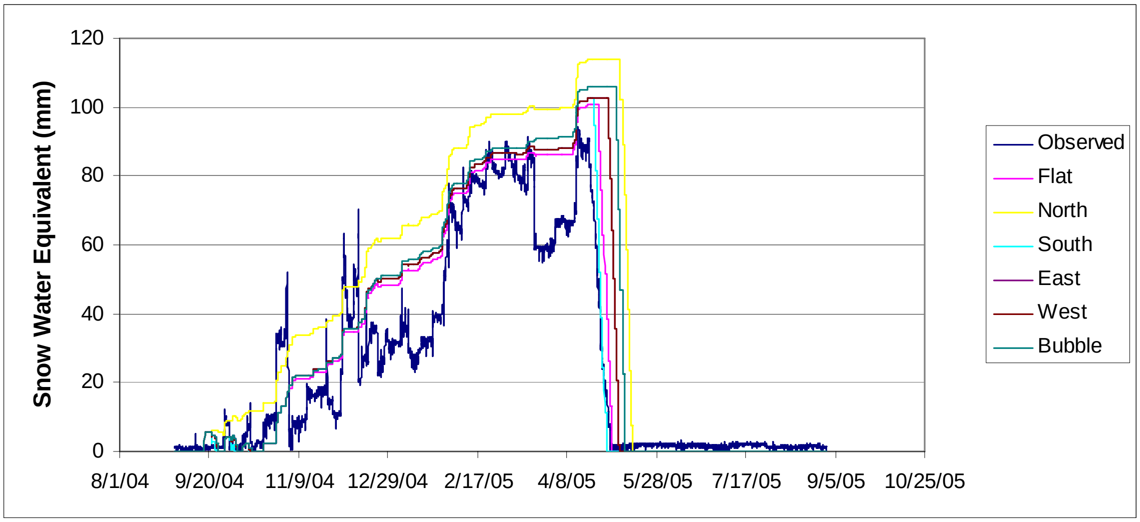


Figure 9: Faro Snow Water Equivalent – 2004/05

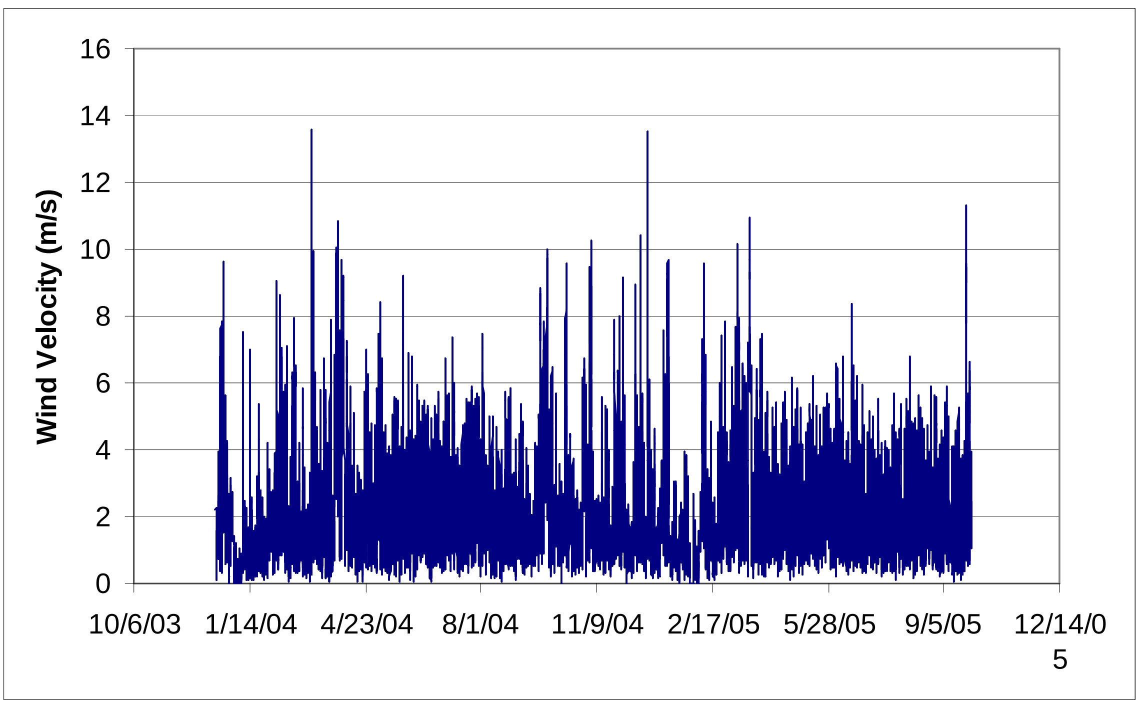


Figure 10: Faro Wind Velocity – 2005/05

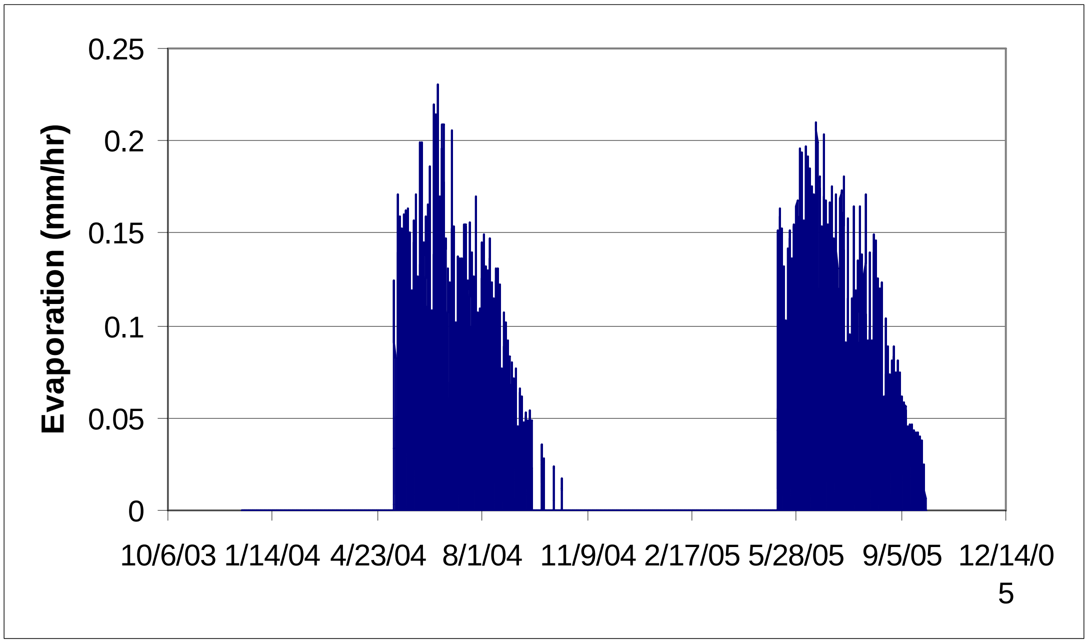


Figure 11: Faro Evaporation - 2003/5

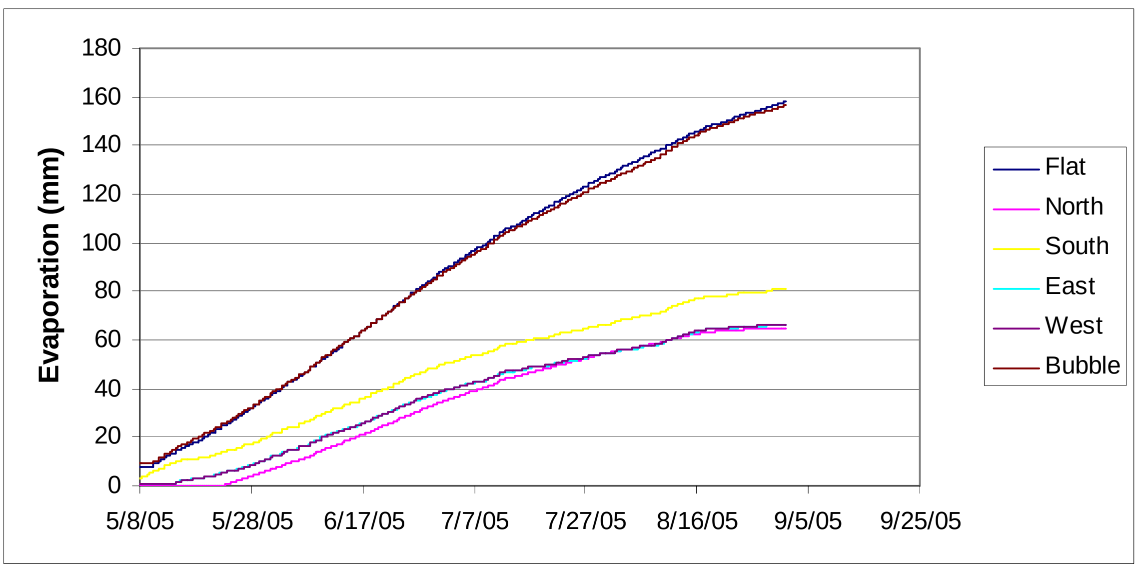


Figure 12: Faro Cumulative Evaporation – 2004/05

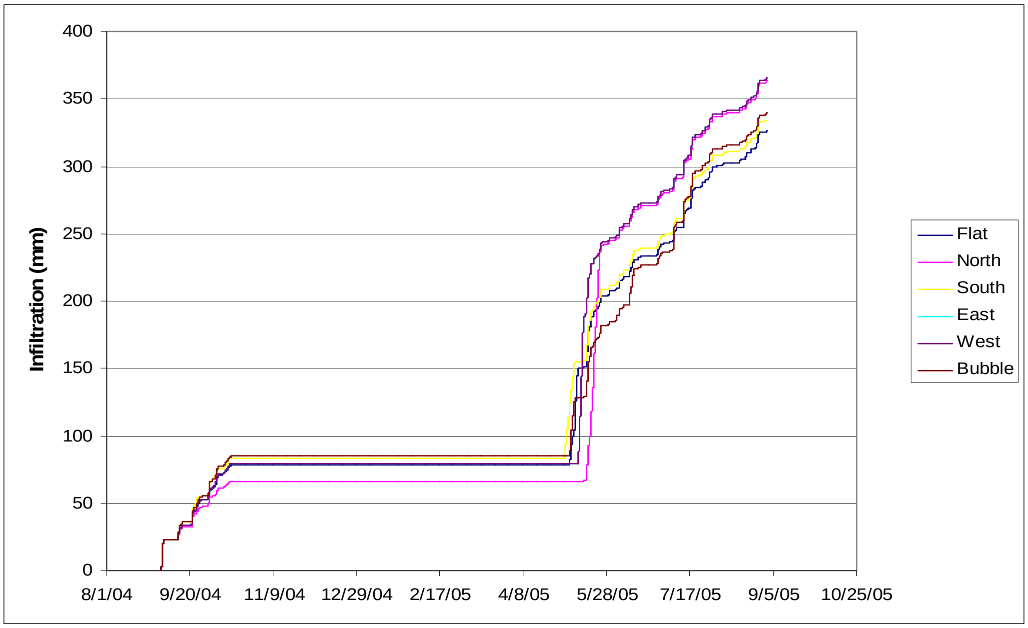


Figure 13: Cumulative Faro Infiltration - 2004/05

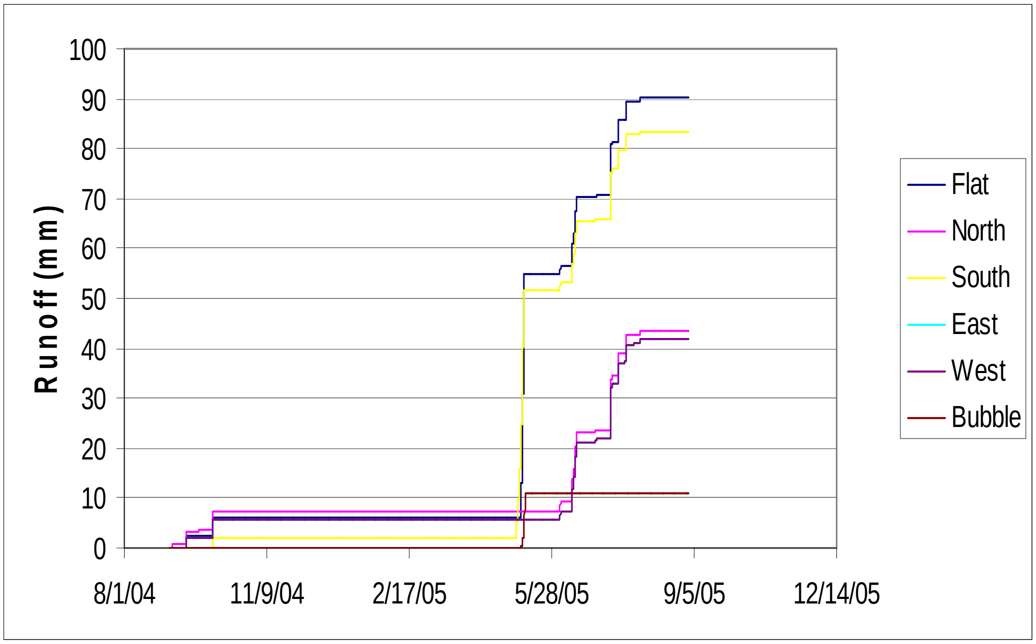


Figure 14: Cumulative Faro Runoff – 2004/05

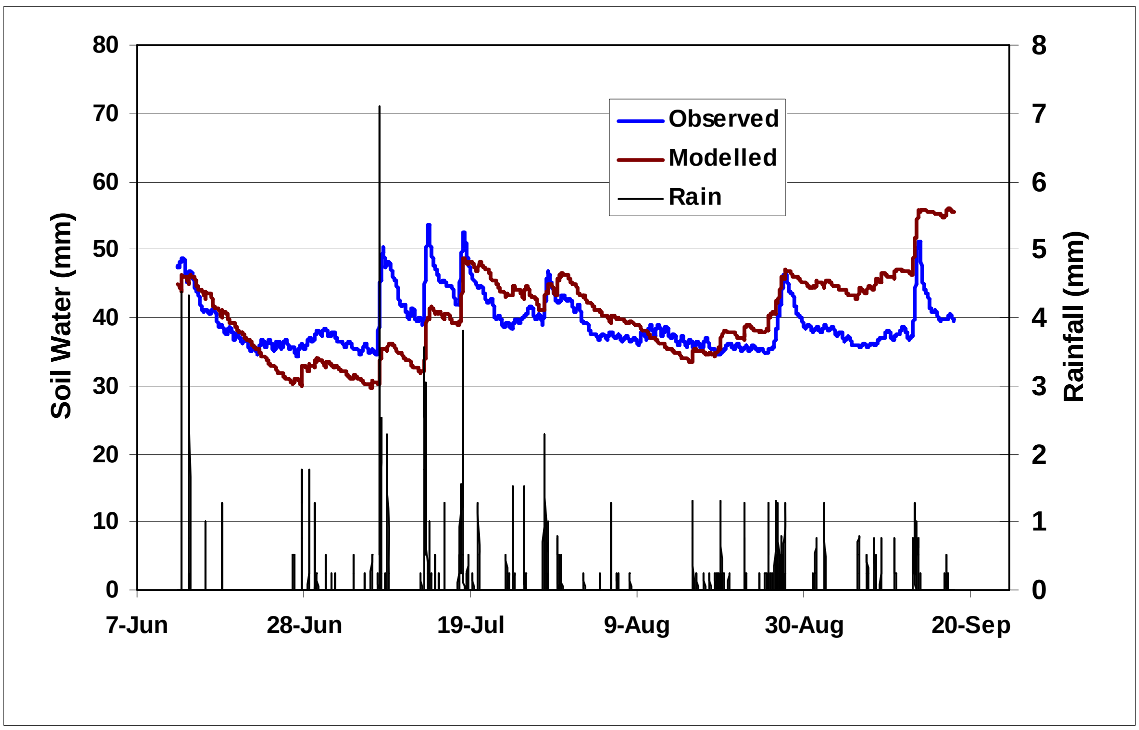


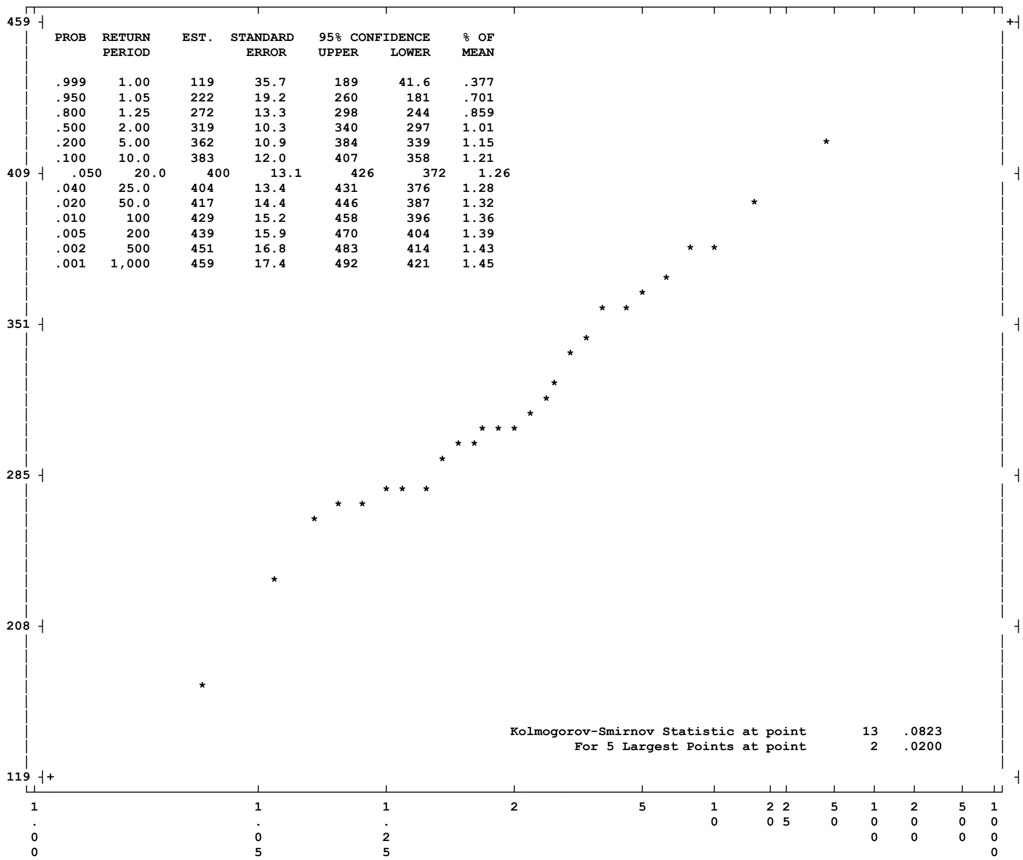
Figure 15: Faro Modelled and Measured Soil Moisture in the Upper Soil Layer - 2005

Figure 16: Annual (Water Year) Precipitation Frequency Analysis - Faro Airport

FARO AIRPORT PRECIPITATION - SEPT-AUG WATER YEAR   Frequency Analysis January 26, 19:6   Page 2

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	95% CONFIDENCE 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

PHOTOGRAPHS

Photo 2: Faro Meteorological Station

Photo 2: VanGrum Meteorological Station

Photo 3: Slope Snow Measurement Stakes

Photo 4: Vangorda Weir #3 with Data Logger

Photo 5: Guelph Permeameter Measurements at VanGrum Meteorological Station

Appendix A

WORKPLAN FOR INVESTIGATION OF ANVIL RANGE MINING CORPORATION (FARO) WASTE DUMP WATER BALANCES – 2005/06

Task 1: Design and carry out program to collect hydrometeorological data for developing water balance

- 1.1 Maintain meteorological stations
- 1.2 Carry out site inspection during and immediately after snowmelt and significant rainfall events to identify surface runoff and seepage locations
- 1.3 Maintain recording station at V30 weir and monitor flows at V31, V32 and X23 weirs
- 1.4 Consider developing program to monitor surface flows and pit water levels
- 1.5 Carry out summer infiltration studies
- 1.6 Carry out pre-freeze up soil moisture survey
- 1.7 Consider carrying out winter and spring snow surveys

Task 2: Refine characterization of dump surfaces

- 2.1 Subdivide dump surfaces into finer (or more appropriate) scale hydrologic response units (HRUs)

Task 3: Develop dump water balance estimates

- 3.1: Develop dump water balance estimates based on site meteorological data and use of CHRM model
- 3.2: Assess possibility that dumps are still reaching residual saturation

Task 4: Final Report

- 4.1: Write draft final report
- 4.2: Make modifications to final report based on review comments
    - 4.21 Meet with SRK

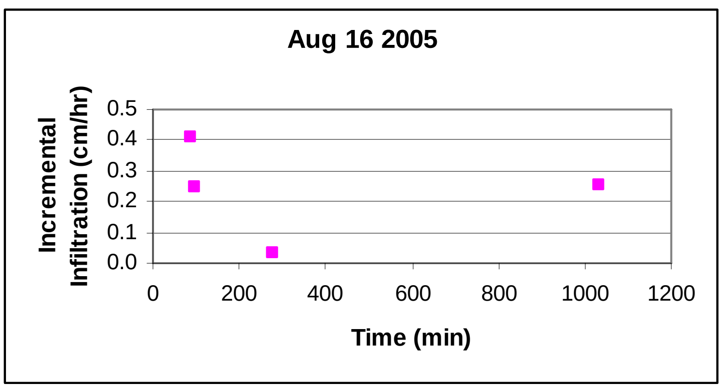
Appendix B

DOUBLE RING INFILTROMETER DATA

Faro Dump 8 in / 15 in Double Ring Infiltrometer

	Tstart	Tfin	Time (min)	Telapse (min)	Vol add (ml)	Depth (cm)	InfRate (cm/hr)
16-Aug-05	1400	1530	90	90	200	0.62	0.41
		1705	95	185	125	0.39	0.24
17-Aug-05		1020	1035	1220	1400	4.32	0.25
		1500	280	1500	50	0.15	0.03

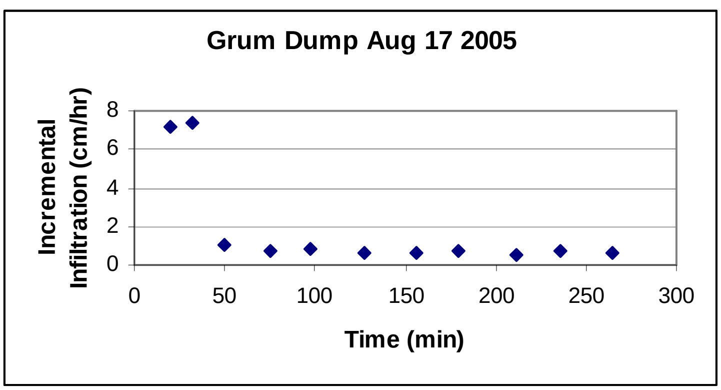
Inter Ring Area 8"= 324.1 cm^2



Grum Dump 6.5 in / 10 in Double Ring Infiltrometer

	Tstart	Tfin	Time (min)	Telapse (min)	Vol add (ml)	Depth (cm)	InfRate (cm/hr)
Aug 17/05	1100	1120	20	20	400	2.37	7.12
		1132	12	32	250	1.48	7.42
		1150	18	50	50	0.30	0.99
		1215	25	75	50	0.30	0.71
		1237	22	97	50	0.30	0.81
		1307	30	127	50	0.30	0.59
		1336	29	156	50	0.30	0.61
		1359	23	179	50	0.30	0.77
		1401	32	211	50	0.30	0.56
		1426	25	236	50	0.30	0.71
		1455	29	265	50	0.30	0.61

inter ring area 6.5" = 168.5 cm^2



Vangorda Dump 6.5 in / 10 in Double Ring Infiltrometer

	Tstart	Tfin	Time (min)	Telapse (min)	Vol add (ml)	Depth (cm)	InfRate (cm/hr)
Sep 16/04	1500	1501	1	1	100	0.59	35.61
		1504	3	4	100	0.59	11.87
		1511	7	11	100	0.59	5.09
		1531	20	31	50	0.30	0.89
		1556	25	56	50	0.30	0.71
		1624	28	84	50	0.30	0.64
		1647	23	107	50	0.30	0.77
		1719	32	139	50	0.30	0.56
		1744	25	164	50	0.30	0.71
		1814	30	194	50	0.30	0.59
		1839	25	219	50	0.30	0.71
		1904	25	244	50	0.30	0.71

inter ring area 6.5 " = 168.5 cm^2