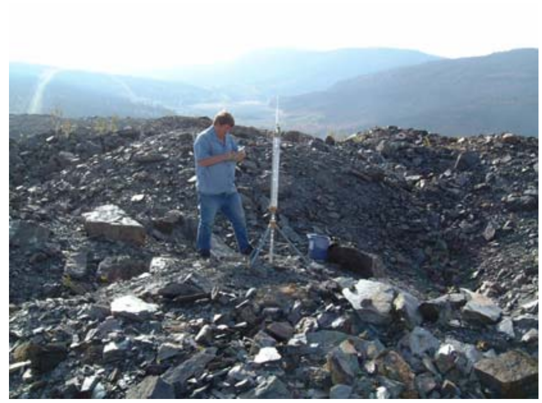
INVESTIGATION OF ANVIL RANGE MINING CORPORATION (FARO) WASTE DUMP WATER BALANCES – 2003/04 WATER YEAR

PRELIMINARY WATER BALANCE



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Prepared for
SRK Consulting Inc. on behalf of Deloitte & Touche Inc.
Interim Receiver of Anvil Range Mining Corporation

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EXECUTIVE SUMMARY

Yukon Water Resources was contracted by SRK Consulting Inc., on behalf of Deloitte & Touche Inc., the Interim Receiver for Anvil Range Mining Corporation, 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. The project was initiated in fall of 2003, with the installation of two meteorological stations at the minesite. A preliminary water balance was provided for the waste rock dumps using meteorological information that was transferred from other areas. The results of the preliminary assessment are summarized by Janowicz et al, 2004. This report summarizes phase 2 of the study, the primary objectives of which are 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).

The developed water balance for the Faro and combined Grum and Vangorda dump sites (VanGrum) provided reasonable results on a seasonal basis. Simulated infiltration and runoff during the snowmelt period was generally good, with combined infiltration and runoff approximating observed snowmelt for both Faro and VanGrum sites. The greatest difference between simulated and observed values occurred for the VanGrum site. The snowmelt budget indicates that there is a storage surplus in every

dump surface, within both the Faro and VanGrum waste sites. Based on available storage and computed infiltration, there is generally little seepage from beneath either the Faro and VanGrum dump surfaces during the snowmelt period. The summer water balance is significantly more complex since evaporation has a significant role. Simulated evaporation rates are generally high with respect to rainfall amounts within both waste dumps, with evaporation rates close to 140 percent of observed rainfall. The exception is from sloped surfaces, and specifically north facing slopes, with evaporation rates at 30 percent of observed rainfall. The rainfall budget indicates that there are storage deficits in flat and bubble surfaces, within both the Faro and VanGrum waste rock dumps. Based on available storage and computed infiltration, there is a potential for significant seepage below all dump surfaces.

One additional year of data collection and study, for the 2004/05 water year (September, 2004 to August, 2005), is recommended to finalize the water balance. Because of the timing of the initiation of the study (December, 2003), much of required site data was not available for the present analyses. Specifically:

- The present analyses were carried out with an 8 month period of site meteorological data, instead of 12 months for which the CRHM model was developed (the missing data was estimated using the much lower elevation Faro Airport station)
- The precipitation gauge was not functioning properly until April, 2004
- It was not possible to install the soil moisture and soil temperature sensors until June, 2004
- It was too late in the season to obtain the necessary pre-freeze-up soil moisture data for the snowmelt infiltration component

- It was not possible to carry out 2003/04 snow surveys on steep slopes due to avalanche conditions (a series of remotely accessible transects have since been installed which will permit the safe survey of sloped surfaces)
- Double ring infiltrometer and Guelph permeameter surveys were carried out during September, 2004, and it would be useful to extend these surveys through another season.
- A seepage monitoring station was established in July, 2004, and the study would benefit from a full season of data.
- The CRHM model will be modified to better suit conditions at the ARMC site - Specific modifications include:
    - adapting the evaporation modules for application to steeply sloped surfaces
    - modification of the Green-Ampt infiltration for use with coarse surface materials

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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, 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 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. This report summarizes phase 2 of the study, the primary objectives of which are 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). 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 m asl. 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 are noted 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 dumps are 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 form -30 in January to 20 ^{0}C in July. There is a strong seasonal variation in temperature which is further accentuated by elevation difference. 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 as well as possible , 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, outgoing and net 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, therefore, this data is sparse for the 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. The relative variation between respective meteorological parameters at the two stations vary between parameters. Patterns of air temperature are similar, with VanGrum values being 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 (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, while rainfall patterns can vary significantly as illustrated by comparing the hyetographs for the June 7 to 9, 2004 storm event (Figure 3). A comparison of snowpack accumulation and depletion is provided by Figure 4, which illustrates recorded snow depth at the respective stations.

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

	RH (%)	Wind (m/s)	Solar (W/m^2)	Temp (^oC)	Rainfall (mm)
FARO					
Dec	79.8	2.3	3.5	-10.1	0.0
Jan	81.5	1.0	8.8	-19.6	0.0
Feb	77.0	2.3	36.7	-6.6	0.0
Mar	73.9	2.6	89.6	-9.5	0.0
Apr	59.4	2.6	193.7	-0.8	0.0
May	54.6	2.5	225.3	5.6	14.7
Jun	49.5	2.4	230.0	15.1	50.8
Jul	57.7	2.4	186.3	13.3	31.8
Aug	59.9	1.9	164.5	12.0	20.1
VANGRUM					
Dec	81.7	3.3	4.7	-10.4	0.0
Jan	82.5	2.6	11.3	-19.4	0.0
Feb	80.0	2.7	38.0	-7.0	0.0
Mar	75.3	3.0	96.3	-9.7	0.0
Apr	59.6	2.7	197.1	-0.9	0.0
May	56.2	2.7	217.1	5.3	28.7
Jun	49.9	2.5	245.6	15.3	50.8
Jul	58.0	2.4	196.5	13.5	30.7
Aug	59.8	2.2	171.5	12.2	27.4

3.2 Snow Surveys

Extensive snow surveys were carried out at various locations across the ARMC site during March, 2004 (Photos 3 and 4). The objective of the surveys was to develop representative relationships between snow depth and snow water equivalent (SWE) for characteristic surfaces at the three waste rock dumps. Figures 5 and 6 illustrate the relationship between snow water equivalent and snow depth for flat and bubble surfaces respectively. The relationships clearly demonstrate that the snowpack is significantly greater at the Grum and Vangorda dump sites. Figure 7 shows the relationship between snow density and snow depth for north, south, east and west facing slopes for each of the dumps. 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 will provide the ability to estimate snowpack characteristics on dump slopes without carrying out physical surveys (Photo 5).

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 6). Figure 8 illustrates the variations in seepage discharge volume as a function of rainfall amount.

3.4 Infiltration Studies

Field studies were carried out in September 2004 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 7 and 8). Better success in acquiring absolute rates of infiltration was obtained with the Guelph permeameter, though the double ring infiltrometer was useful in providing infiltration trends across the dumps. Most tests were conducted on the flat surfaces; however, some useable information was obtained from the bubble dump surfaces. It was not possible to apply these techniques on sloped surfaces. Additional work is required to refine the utility of these methods at the waste dump sites since they were developed for use with finer agricultural soils.

4 WASTE ROCK DUMP CHARACTERIZATION

The waste rock dumps were developed between 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 2 to 3 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 of up to 60 degrees. Coarser material accumulates near the bottom of these steep 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, though 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 9 to 11.

Surficial materials weather over time resulting in finer texture. As would be expected, the flat traffic surfaces consist of more fines than other surfaces, and because of compaction by the heavy equipment, and tend to be denser. Table 2 summarizes the surface area of the various dump surface types.

Table 2: Estimated Dump Type Surface Area in hectares

	FARO	VANGORDA	GRUM
BUBBLE	160	46	59
FLAT	107	20	59
SLOPE	67	5	42
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. The model can select from a number of library modules those most applicable to the given situation. Figure 12 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 represents 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 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 recently installed meteorological stations were used for the analyses. The model runs on the hydrological year, September 1 to August 31, using air temperature, relative humidity, wind speed, incoming radiation and precipitation data. Because the station was not established until December, 2003, the necessary data for the beginning of the hydrological year were not available. The model uses hourly precipitation for its snowpack accumulation and snowmelt modules. Precipitation data from the Faro Airport, was adjusted, to provide the necessary precipitation data for the missing period. Winter precipitation was also not available for the entire winter period, due to instrumentation problems. It was possible to reconstruct winter precipitation for the period, after the station was established, using the available continuous snow depth data, supplemented by numerous snow course surveys.

5.2.2 Physical Data

The Faro, Grum and Vangorda waste dumps were subdivided into six HRUs each for the preliminary water balance calculations: flat surfaces, push over slopes differentiated by aspect (north, south, east and west), and bubble dumps. The preliminary analyses were carried out for the Faro and combined VanGrum waste dumps in keeping with the available meteorological data, using standardized physical parameters. Table 3 lists the specified physical parameters.

Table 3: HRU Physical Parameters

	FLAT	*SLOPE (N,S,E,W)*	*BUBBLE*
Latitude (deg)	62.33	62.33	62.33
Elevation (m)	1150	1175	1200
Slope Angle (deg)	0	40	0
Roughness Ht (m)	0.01	0.05	1.0
Fall Soil Saturation(%)	70	60,15,30,30	15
Albedo	0.21	0.21	0.14

6 SIMULATION OUTPUT

6.1 2003/04 Water Year

The water balance simulation for the partial 2003/04 water year was carried out at 1 hour step intervals using meteorological data and physical parameters as specified. The precipitation distributions for the Faro and VanGrum sites are presented in Figure 13. The simulated snow water equivalent (SWE) for the winter season is presented in Figures 14 and 15, for the Faro and VanGrum sites respectively. The plots illustrate both accumulation and ablation for the 6 HRU's, and are the products of blowing snow, sublimation, and snowmelt routines. The energy budget (ebsm) routine was used to generate snowmelt for the flat, south slope and bubble HRUs; while, the temperature index option was used for the north slope, east slope and west slope HRUs.

Snow accumulation amounts were slightly greater for the VanGrum sites, as indicated by the observed snow depth. Within the respective dumps, snow accumulation is basically similar for all HRUs, with only slight variations due to wind losses (sublimation and drift). Snowmelt patterns followed the observed trend within the flat HRU, which corresponds to station location, with advanced melt within the south slope HRU, and progressively delayed melt within the east slope and west slope, bubble and north slope HRUs respectively. While snowmelt commenced within a day of each other within the respective dumps, the cessation of melt was five days later within the VanGrum sites.

The estimated cumulative sublimation loss for each of the six HRUs within the Faro and VanGrum sites is illustrated in Figures 16 and 17 respectively. Sublimation and wind transport (drift) are simulated using the Prairie Blowing Snow Module, (pbsm) based on wind speed, air temperature, relative humidity and roughness height. Simulated sublimation is low within all Faro HRUs, with cumulative annual values ranging from 0 to 5 mm. Simulated sublimation loss within the VanGrum waste dumps is generally smaller within all HRUs, with values of approximately 1 for the flat HRU and less for the other HRUs. Simulated wind transport (drift) from both the Faro and VanGrum sites is insignificant as illustrated by Figures 18 and 19.

Simulated cumulative evaporation is illustrated in Figures 20 and 21 for the post-snowmelt period through to the fall. The Granger evaporation module (evap) was used to calculate evaporative flux, using a combination aerodynamic and energy budget approach, based on the procedure used by Penman. The procedure uses 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, ground heat flux, and solar radiation.

Evaporation commences after snowmelt, peaks with the available energy (solar radiation) in June and continues into the early fall. Evaporation patterns between Faro and VanGrum are similar; however, significantly differing cumulative amounts of evaporation are simulated for the 6 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 VanGrum sites.

The estimated cumulative infiltration is illustrated in figures 22 and 23 for the Faro and VanGrum dumps respectively. Snowmelt infiltration was calculated using the frozen soil infiltration module (crack) which uses pre-melt soil moisture (liquid + frozen) and available meltwater (SWE) to simulate infiltration (Janowicz et al., 2003). Summer infiltration is determined using the Green-Ampt module which is based on Darcy's law. The module 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 sand to clay. Input parameters include initial and maximum soil moisture, and soil type.

Though simulated volumes of infiltration were slightly greater at the VanGrum dumps than at Faro, similar patterns of infiltration simulated for both the snowmelt and summer periods. 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. The flat HRU is most impervious resulting in the lowest infiltration. Summer infiltration was least for the flat and north facing slopes, as these are most impervious and have the highest soil moisture. Infiltration was higher for the other four HRUs primarily due to greater permeability.

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 being conveyed to lower layers. Excess water from both layers goes to groundwater before being discharged as subsurface flow. Input parameters include cover type, soil type, initial and maximum soil moisture for both recharge and lower soil layers and the maximum amount of soil water excess that is routed to groundwater each day. The observed pattern of snowmelt runoff is the inverse of snowmelt infiltration, which can largely be explained by infiltration opportunity time on the slopes, and permeability on the horizontal surfaces. Summer runoff is more erratic and does not exhibit a similar pattern. Little summer runoff was simulated for south facing slopes and bubble surfaces within both the Faro and VanGrum dumps, while significant runoff was observed from the flat HRUs. Simulated cumulative runoff for Faro and VanGrum is illustrated in Figures 24 and 25.

The monthly and annual water balance for each of the 6 HRUs is summarized in Tables 4 to 9 for the Faro and VanGrum sites using the equation:

$$dS = P - E - S - R \pm e$$

where dS is change in storage (mm), P is precipitation (mm), E is evaporation (mm), S is sublimation (mm), R is runoff (mm) and e is the residual error term (mm). Surface infiltration during snowmelt and rainfall events is a primary component of ground storage, with potential lateral groundwater inflows from outside the dump areas, and, outflows as seepage, and is described using the equation:

$$dS = I \pm G \pm e$$

where I is infiltration (mm), G is groundwater flow (mm) and e (mm) is the residual error term.

Table 4: Monthly Water Balance Summary – Flat HRU

Faro	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOTAL
Rainfall	3								15	55	34	21	128
Snowfall	1	2	6	9	23	10	35	2					88
Precipitation	4	2	6	9	23	10	35	2	15	55	34	21	216
Evaporation	2								43	56	47	27	175
Sublimation				0.17	0.04	0.05	5	0.07	0.01				5
Runoff	1							8	76	40	25	6	156
Storage + error	1	2	6	9	23	10	30	-6	-104	-41	-38	-12	-120
Infiltration	1							12	2	14	9	7	45
Vangrum													
Rainfall	4								29	51	32	27	143
Snowfall	3	5	2	9	25	10	35	3					102
Precipitation	7	5	2	9	25	10	35	3	29	51	32	19	245
Evaporation	2								44	59	49	28	182
Sublimation				0.2	0.1	0	0.1	0	0.04				0
Runoff	1							54	45	39	19	3	161
Storage + error	4	5	9	52	25	10	35	-51	-60	-47	-36	-12	-106
Infiltration	1							7	43	17	14	8	90

Table 5: Monthly Water Balance Summary – North HRU

Faro	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOTAL
Rainfall	3								15	55	34	21	128
Snowfall	1	2	6	9	23	10	35	2					88
Precipitation	4	2	6	9	23	10	35	2	15	55	34	21	216
Evaporation	0								5	23	13		41
Sublimation							5	0.07	0.02				5
Runoff	1							7	5	30	20	3	66
Storage + error	2	2	6	9	23	10	30	-5	5	2	1	18	103
Infiltration	2							4	78	24	14	10	132
Vangrum													
Rainfall	4								29	51	32	27	143
Snowfall	3	5	2	9	25	10	35	3					102
Precipitation	7	5	2	9	25	10	35	3	29	51	32	19	245
Evaporation	0								5	24	13		42
Sublimation							0.1		0.04				0
Runoff	1							8	12	25	13	1	61
Storage + error	35	18	46	52	25	10	35	-5	12	2	6	18	142
Infiltration	2								96	60	21	10	184

Table 6: Monthly Water Balance Summary – South HRU

Faro	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**TOTAL**
Rainfall	3								15	55	34	21	128
Snowfall	1	2	6	9	23	10	35	2					88
Precipitation	4	2	6	9	23	10	35	2	15	55	34	21	216
Evaporation	2								27	38	26	17	110
Sublimation							5	0.1					5
Runoff	1							57			7		65
Storage + error	1	2	6	9	23	10	30	-55	-12	17	1	4	36
Infiltration	1							31	2	54	27	13	128
Vangrum													
Rainfall	4								29	51	32	27	143
Snowfall	3	5	2	9	25	10	35	3					102
Precipitation	7	5	2	9	25	10	35	3	29	51	32	19	245
Evaporation	2								28	42	29	18	119
Sublimation							0.1						0
Runoff	1							52	27		2		82
Storage + error	4	5	12	9	25	10	35	-49	-26	9	1	1	44
Infiltration	1							18	48	55	32	11	165

Table 7: Monthly Water Balance Summary – East HRU

Faro	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOTAL
Rainfall	3								15	55	34	21	128
Snowfall	1	2	6	9	23	10	35	2					88
Precipitation	4	2	6	9	23	10	35	2	15	55	34	21	216
Evaporation	2								28	39	29	18	116
Sublimation							5						5
Runoff	1							12	1	9	11		34
Storage + error	1	2	6	9	23	10	30	-10	-14	7	-6	3	61
Infiltration	1							7	71	45	23	13	160
Vangrum													
Rainfall	4								29	51	32	27	143
Snowfall	3	5	2	9	25	10	35	3					102
Precipitation	7	5	2	9	25	10	35	3	29	51	32	19	245
Evaporation	2								28	43	31	19	123
Sublimation							0.1		0.04				0
Runoff	1							7	4	2	6		20
Storage + error	4	5	2	9	25	10	35	-4	-3	6	-5	0	102
Infiltration	1							7	129	54	28	11	230

Table 8: Monthly Water Balance Summary –West HRU

Faro	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOTAL
Rainfall	3								15	55	34	21	128
Snowfall	1	2	6	9	23	10	35	2					88
Precipitation	4	2	6	9	23	10	35	2	15	55	34	21	216
Evaporation	2								28	39	29	18	116
Sublimation							5						5
Runoff	1							12	1	9	11		34
Storage + error	1	2	6	9	23	10	30	-10	-14	7	-6	3	61
Infiltration	1							7	71	45	23	13	160
Vangrum													
Rainfall	4								29	51	32	27	143
Snowfall	3	5	2	9	25	10	35	3					102
Precipitation	7	5	2	9	25	10	35	3	29	51	32	19	245
Evaporation	2								28	43	31	19	123
Sublimation							0.1		0.04				0
Runoff	1							7	4	2	6		20
Storage + error	4	5	2	9	25	10	35	-4	-3	6	-5	0	102
Infiltration	1							7	129	54	28	11	230

Table 9: Monthly Water Balance Summary –Bubble HRU

Faro	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOTAL
Rainfall	3								15	55	34	21	128
Snowfall	1	2	6	9	23	10	35	2					88
Precipitation	4	2	6	9	23	10	35	2	15	55	34	21	216
Evaporation	2								48	65	54	33	202
Sublimation													0
Runoff								5			3		8
Storage + error	2	2	6	9	23	10	35	-3	-33	-10	-23	-12	6
Infiltration	4							88	2	55	29	13	191
Vangrum													
Rainfall	4								29	51	32	27	143
Snowfall	3	5	2	9	25	10	35	3					102
Precipitation	7	5	2	9	25	10	35	3	29	51	32	19	245
Evaporation	2								49	69	56	34	210
Sublimation													0
Runoff								7	2	1	4		14
Storage + error	5	5	2	9	25	10	35	-4	-22	-19	-28	-15	21
Infiltration	4							54	85	56	32	11	242

Since the meteorological stations were not established until December 2003, monthly budget components for September to November were estimated using Faro Airport Data. Computed snowmelt tracked the observed snowmelt (meteorological stations located in flat HRU) very well, with melt on the southern slopes preceding the flat and other HRUs following the flat. Wind transport (drift) was negligible in all cases and is perhaps being underestimated. Sublimation is quite low and may also be underestimated. The annual budget indicates that there is a storage surplus in every in every Hru, within both the Faro and VanGrum waste rock dumps, with the exception of flat surfaces. Generally greater surpluses were simulated for the VanGrum dumps due to greater amounts of precipitation. An annual summary of storage, computed infiltration and the residual groundwater flow, which includes the error factor, is presented in table 10.

Table 10: Annual Storage Summary (mm)

		Flat	North	South	East	West	Bubble
FARO	**Storage + error**	-120	103	36	61	61	6
	Infiltration	45	132	128	160	160	191
	Groundwater Flow*	-165	-29	-92	-99	-99	-185
VANGRUM	**Storage + error**	-106	142	44	102	102	21
	Infiltration	90	184	165	230	230	242
	Groundwater Flow*	-196	-42	-121	-128	-128	-221

*G = S – I +/- e

Table 10 indicates that based on available storage and computed infiltration, there is potential for seepage below all HRU surfaces at both dumps. Practically, subsurface flows beneath specific HRU surfaces within the individual dumps would follow preferential flow paths, likely converging and exiting the dumps at the common seepage locations.

The following sections consider the water budget on a seasonal basis. From a water balance dynamics viewpoint, most activity occurs during the spring snowmelt period and subsequent summer period, since evaporation is insignificant during the remainder of the year.

6.1.1 Snowmelt Period

Simulated infiltration and runoff during the snowmelt period were generally good. Infiltration during this period is to frozen soil and evaporation losses during this period are negligible. The flat and bubble dump surfaces are likely most representative of "normal" field conditions for which the CRHM model was developed for. Within the flat HRU, winter precipitation totaled 88 and 102 mm for Faro and VanGrum respectively, with simulated snowmelt infiltration and runoff at 6 and 76 mm for Faro and 33 and 82 mm for VanGrum. The partitioning between infiltration and runoff is reasonable, given the impervious nature of the flat HRU surface, with estimated combined snowmelt infiltration and runoff approximating winter precipitation for both the Faro and VanGrum dumps. The partitioning trend was reversed for the bubble HRU, with 100 and 92 percent of winter precipitation infiltrating the surface.

The extreme angles of the slope HRUs place these landscape types outside of the design limits of the CRHM. On the north facing slopes, simulated infiltration and runoff were 72 and 7, and, 102 and 12 mm respectively for the Faro and VanGrum dumps respectively. The partitioning of runoff and infiltration makes sense, with the greater portion of infiltration resulting from the slow snowmelt process due to little energy availability. Partitioning of infiltration and runoff is reversed on south facing slopes, with significantly greater portions of runoff due to the rapid melt process. Simulated infiltration and runoff from east and west HRUs is identical, since these slopes receive similar amounts of radiation. Combined amounts of infiltration and runoff are within 15 percent of winter precipitation at both Faro and VanGrum.

A summary of the seasonal water balance components, with storage and residual groundwater flow, is presented in Table 11 for the snowmelt season. The snowmelt budget indicates that there is a storage surplus in every HRU, within both the Faro and VanGrum waste rock dumps. Generally greater surpluses were simulated for the VanGrum dumps due to greater amounts of precipitation. Table 11 indicates that based on available storage and computed infiltration, there is generally little seepage from beneath either the Faro and VanGrum dump surfaces during the snowmelt period.

Table 11: Snowmelt Storage Summary (mm)

		Flat	North	South	East	West	Bubble
FARO	**Precipitation**	88	88	88	88	88	88
	Sublimation	5	5	5	5	5	0
	Runoff	76	7	57	12	12	5
	Storage + error	7	76	26	71	71	83
	Infiltration	6	72	11	64	64	90
	Groundwater Flow*	1	4	15	7	7	-7
VANGRUM	**Precipitation**	102	102	102	102	102	102
	Sublimation	0	0	0	0	0	0
	Runoff	82	12	79	10	10	8
	Storage + error	20	90	23	92	92	94
	Infiltration	33	102	35	104	104	94
	Groundwater Flow*	-13	-12	-12	-12	-12	0

*G = S – I +/- e

6.1.2 Summer Period

The summer water balance is significantly more complex, since evaporation also plays a significant part. Simulated evaporation rates are generally high with respect to rainfall amounts within both Faro and VanGrum waste dumps, and from all HRUs, with exception of north facing slopes. Within the flat HRU, evaporation is simulated to be close to 140 percent of observed rainfall for both Faro and VanGrum dumps. Combined infiltration and runoff volumes are close to that of observed rainfall, indicating the presence of a water balance deficit. Partitioning between infiltration and runoff is reasonable, given the impervious nature of the surface, with runoff representing 70 and 60 percent of the combined total from the Faro and VanGrum sites respectively. Within the bubble HRU, simulated evaporation is 160 and 150 percent of observed rainfall at the Faro and VanGrum dumps respectively, while combined infiltration and runoff are approximately 80 and 100 percent of observed rainfall for the Faro and VanGrum dumps respectively. A water balance deficit situation exists for flat and bubble surfaces with a potential soil moisture withdrawal scenario in place.

The water balance dynamics are quite different on for the slope HRUs. On north facing slopes the water balance is almost in check with simulated evaporation representing approximately 30 percent of rainfall for both the Faro and VanGrum dumps, while combined infiltration and runoff represent close to 100 percent of rainfall for both dumps. Infiltration and runoff are partitioned equally at Faro, with 75 percent infiltration at VanGrum. On South facing slopes evaporation is about 90 percent of rainfall at both dumps, while combined infiltration and runoff is 95 percent. The water balance dynamics of east and west slope HRUs are similar to south slope HRUs with slightly more runoff at approximately 10 percent of combined infiltration and runoff.

A summary of storage, computed infiltration and the residual groundwater flow is presented in Table 12 for the rainfall season.

Table 12: Rainfall Storage Summary (mm)

		Flat	North	South	East	West	Bubble
FARO	**Precipitation**	128	128	128	128	128	128
	Evaporation	175	41	110	116	116	202
	Runoff	80	67	8	22	22	3
	Storage + error	-127	27	10	-10	-10	-77
	Infiltration	39	60	117	160	96	101
	Groundwater Flow*	-166	-33	-107	-106	-106	-178
VANGRUM	**Precipitation**	143	143	143	143	143	143
	Evaporation	190	42	119	123	123	210
	Runoff	79	49	3	10	10	6
	Storage + error	-126	52	21	10	10	-73
	Infiltration	57	87	136	126	126	148
	Groundwater Flow*	-183	-35	-115	-116	-116	-261

*G = S – I +/- e

The rainfall budget indicates that there are storage deficits in flat and bubble HRU surfaces, within both the Faro and VanGrum waste rock dumps. Table 12 indicates that based on available storage and computed infiltration, there is a potential for significant seepage below all HRU surfaces.

7 DISCUSSION AND CONCLUSIONS

A preliminary water balance was carried out for the Faro and combined VanGrum waste rock dumps with reasonable results. On a seasonal basis, simulated infiltration and runoff during the snowmelt period was generally good, with combined amounts of infiltration and runoff approximating observed snowmelt for both Faro and VanGrum dumps and all HRUs. The greatest difference between simulated and observed values occurred for the VanGrum dump.

The summer water balance is significantly more complex since evaporation has a significant role. Simulated evaporation rates are generally high with respect to rainfall amounts, within both waste dumps and from all HRUs, except north facing HRUs, with evaporation rates close to 140 percent of observed rainfall. Because of small amounts of available energy, north facing slopes have evaporation rates which are 30 percent of observed rainfall.

The snowmelt budget indicates that there is a storage surplus in every in every HRU, within both the Faro and VanGrum waste rock dumps. Based on available storage and computed infiltration, there is generally little seepage from beneath either the Faro and VanGrum dump surfaces. The rainfall budget indicates that there are storage deficits in flat and bubble HRU surfaces, within both the Faro and VanGrum waste rock dumps. Based on available storage and computed infiltration, there is a potential for significant seepage from beneath all HRU surfaces.

8 RECOMMENDATIONS FOR FURTHER WORK

It would be valuable to carry out a water balance with a full year of data for the 2004/05 water year (September, 2004 to August, 2005). The present analyses were carried out with an 8 month period of data. The CRHM was developed to run with 12 months of data for a given water year. Since the meteorological stations were established in December, 2003, it was necessary to estimate the previous 3 months of Faro and VanGrum data using the much lower elevation Faro Airport station. Problems were also encountered with the initial start up of the meteorological stations. The station was also not fully operational over the 2003/04 winter period. The precipitation gauge was not functioning properly until April, 2004, and, it was not possible to install the soil moisture and temperature sensors until the summer. Also the frozen soil infiltration component requires measurements of pre-freeze-up soil moisture status, to represent conditions during melt. Since the study was not initiated until the winter of 2003, it was too late to obtain this information for the present water balance exercise, and the required information was estimated. Pre-freeze-up soil moisture has been assessed for the three waste rock dumps during the September, 2004, and is available for the 2004/05 water balance year. Though extensive snow surveys were carried out during the 2003/04 winter and spring season, it was not possible to survey the steep slopes due to avalanche conditions. A series of remotely accessible transects have been installed which will permit the safe survey of sloped surfaces. Double ring infiltrometer and Guelph permeameter surveys were carried out during September, 2004, and it would be useful to extend these surveys through another season. Likewise soil moisture transect surveys were carried out, and a material sampling program established which would benefit from another season, as would the seepage monitoring station. Some additional consideration of soil moisture distribution between upper and lower soil layers is also required. This additional information will likely result in partitioning the dumps into a greater number of representative HRUs.

Plans are in place and funds are available to modify the CRHM model to better suit conditions at the ARMC site. Specific modifications include adapting the evaporation modules for application to steeply sloped surfaces, modification of the Green-Ampt infiltration for use with course surface materials and modifications to the soil water balance modules.

9 REFERENCES

Gartner Lee Limited. 2002. Anvil Range Mine Complex – 2002 baseline environmental information, prepared for Deloitte & Touche, Inc., Whitehorse.

Granger, R.J. and D.M. Gray. 1989. Evaporation from natural non-saturated surfaces. J. Hydrology, 111:21-29.

Granger, R.J., N. Hedstrom and T. Brown. 2002. Impact of land use on water balance and river discharge. National Water Research Institute Technical Report on NREI Project 13, Saskatoon, SK.

Janowicz, J.R., D.M. Gray and J.W. Pomeroy. 2003. Spatial variability of fall soil moisture and spring snow water equivalent within a mountainous sub-arctic watershed. Proceedings of 60th Eastern Snow Conference, June 4 – 6, 2003. Sherbrooke, PQ.

Janowicz, J.R., N.R. Hedstrom and R.J. Granger. 2004. Investigation of Anvil Range Mining Corporation (Faro) Waste Dump Water Balances – Preliminary Water Balance. Report prepared for SRK Consulting Inc. on behalf of Deloitte & Touche Inc. January, 2004.

M.D. Haug and Associates ltd. 2003. Grain size distribution, sample SRK-03-C08, July 10, 2003, prepared for SRK Consultants.

Robertson Geoconsultants Inc. 1996. Anvil Range Mining Complex – integrated comprehensive abandonment plan – volume 1 – Background, Report no. 033001/3, prepared for: Anvil Range Mining Corporation, Vancouver.

Rawls, W.J., D.L. Brakensiek, and B. Soni. 1983. Agricultural management of soil water properties: Part I - Soil water retention and Green-ampt infiltration parameters. Trans., Amer. Soc. of Agric. Engin. 26(6):1752-1753.

Smith, C.A.S., J.C. Meikle and C.F. Roots. 2004. Ecoregions of the Yukon Territory: Biophysical properties of Yukon Landscapes. Agriculture and Agri-Foods Canada, PARC Technical Bulletin No, 04-01, Summerland, British Columbia, 313 p.

Wahl, H.E., D.B. Fraser, R.C. Harvey and J.B. Maxwell, 1987. Climate of Yukon. Environment Canada, Atmospheric Environment Service, Climatological Studies Number 40, Ottawa.

FIGURES

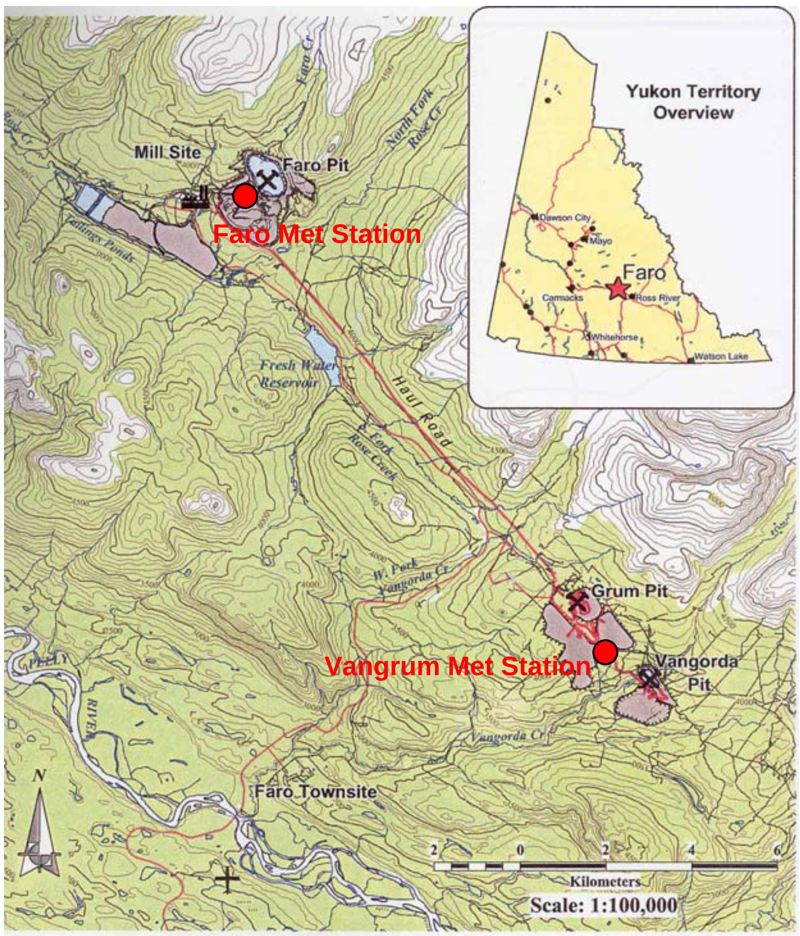

Figure 1: Location Plan (from Gartner Lee Ltd., 2002)

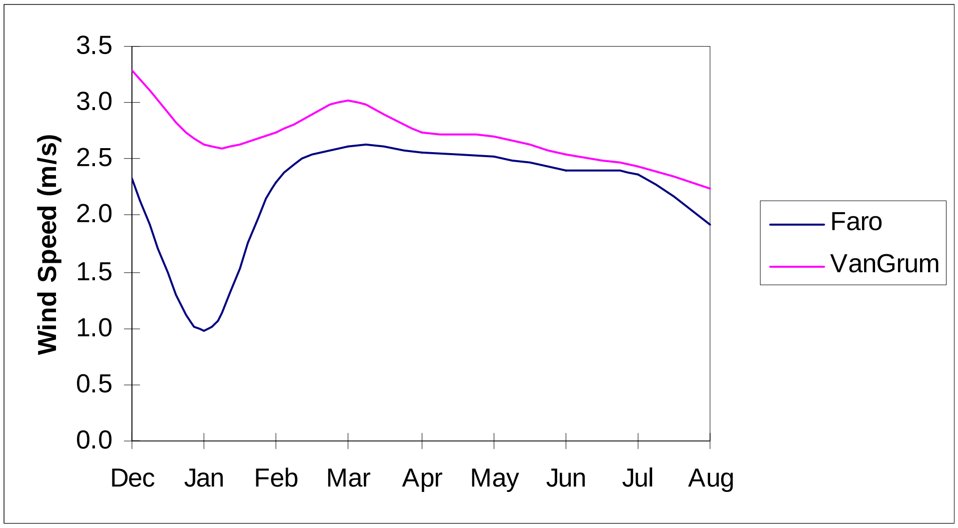

Figure 2: Monthly Wind Speed – 2003/04

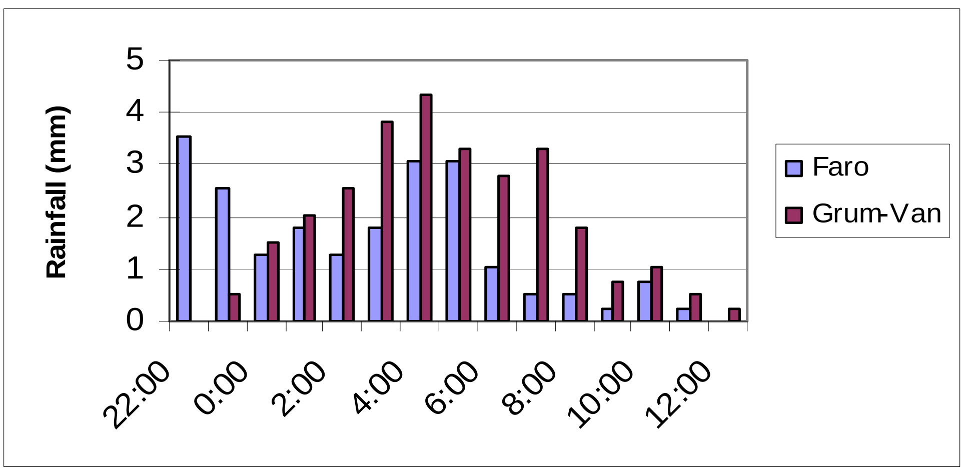

Figure 3: ARMC Rainfall – June 7 – 8, 2004

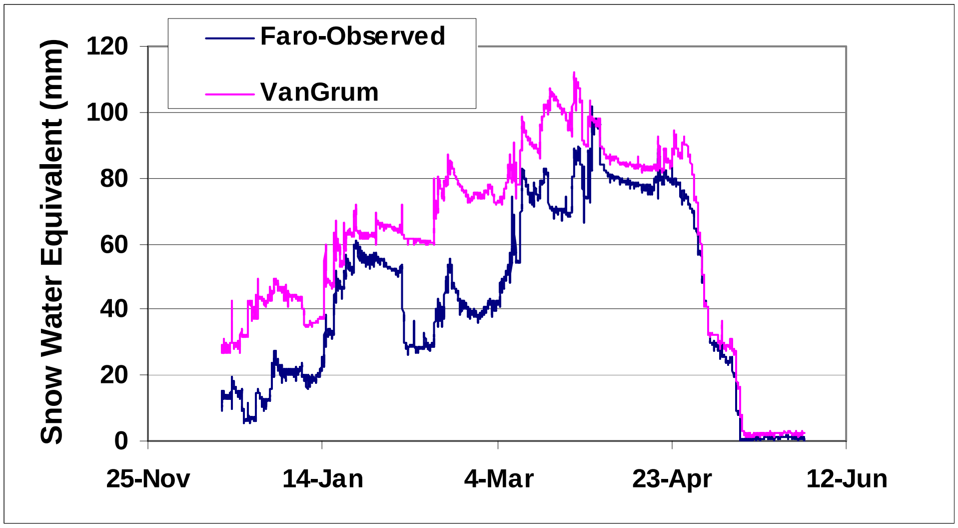

Figure 4: Faro and Vangrum Snow Water Equivalent – 2003/04

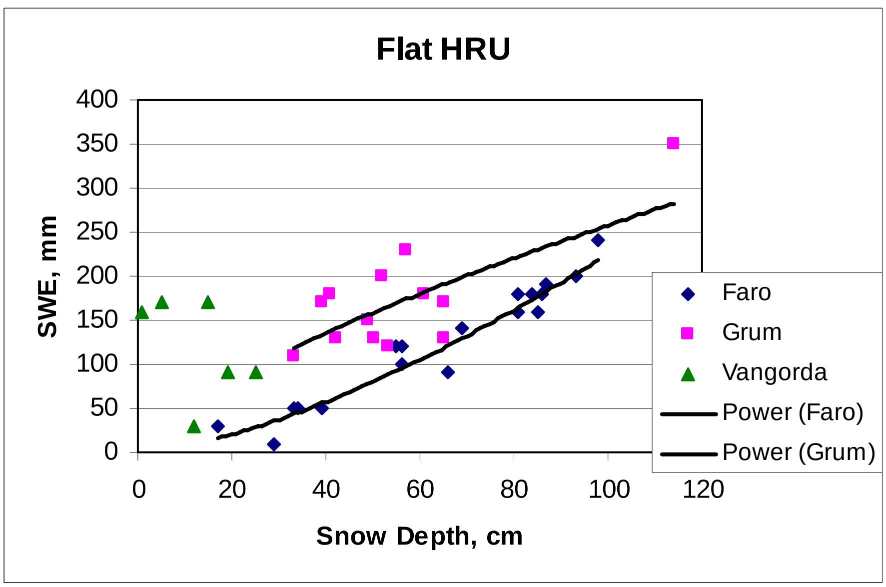

Figure 5: Snow Water Equivalent vs Snow Depth for Flat HRUs

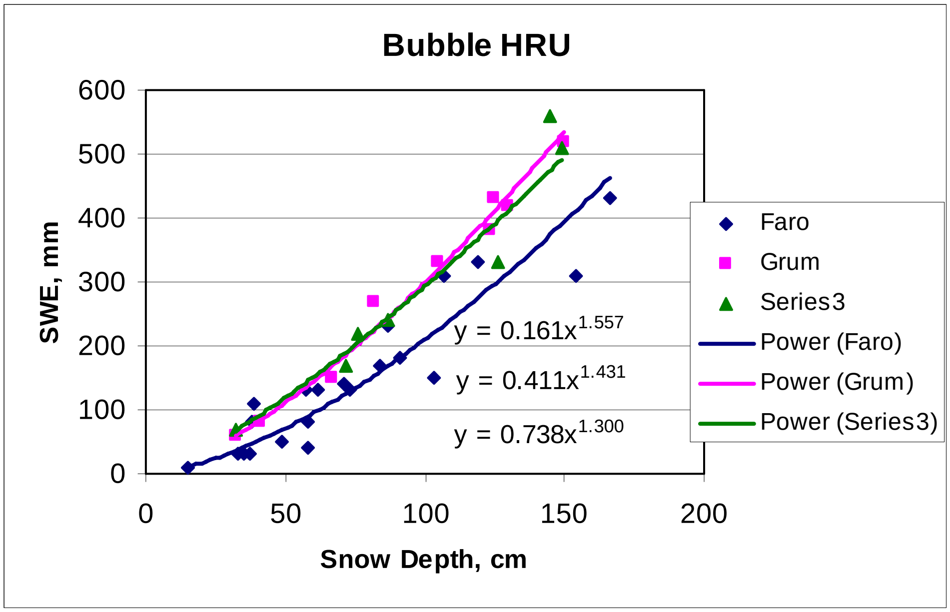

Figure 6: Snow Water Equivalent vs Snow for Bubble HRUs

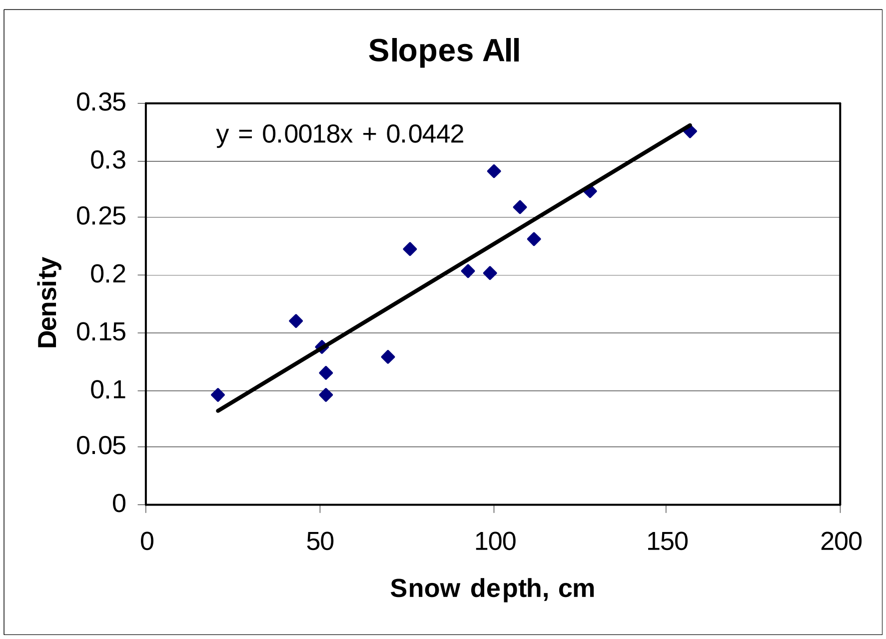

Figure 7: Snow Density vs Snow Depth for Slope HRUs

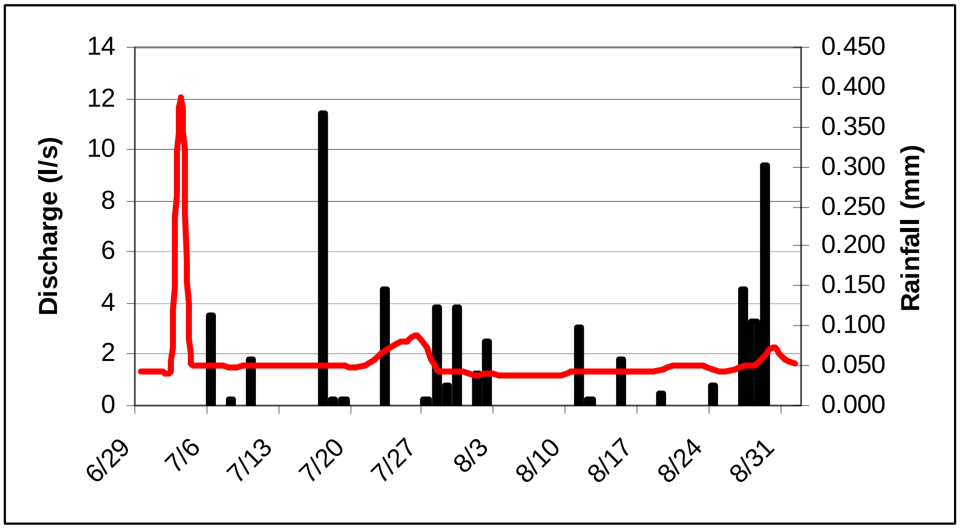

Figure 8: Vangorda Seepage Weir Hydrograph and Rainfall – 2004

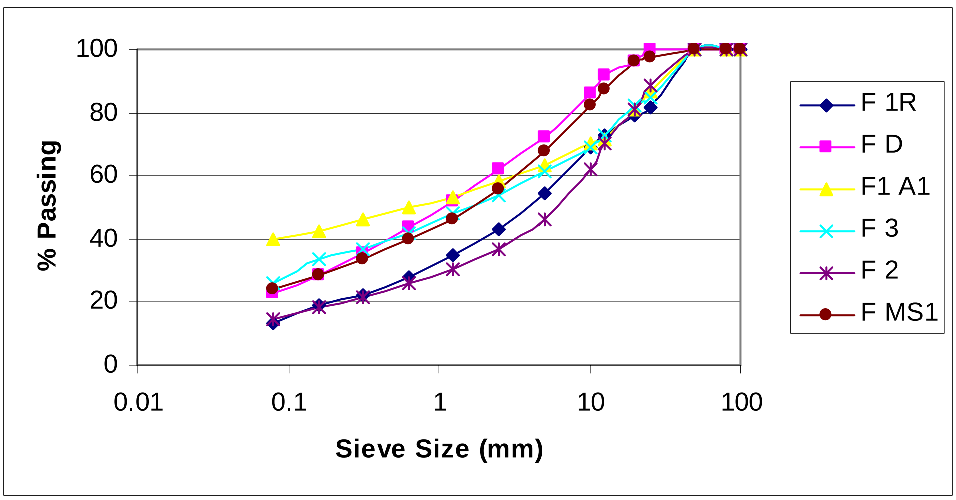

Figure 9: Waste Dump Material Size Distribution - Faro

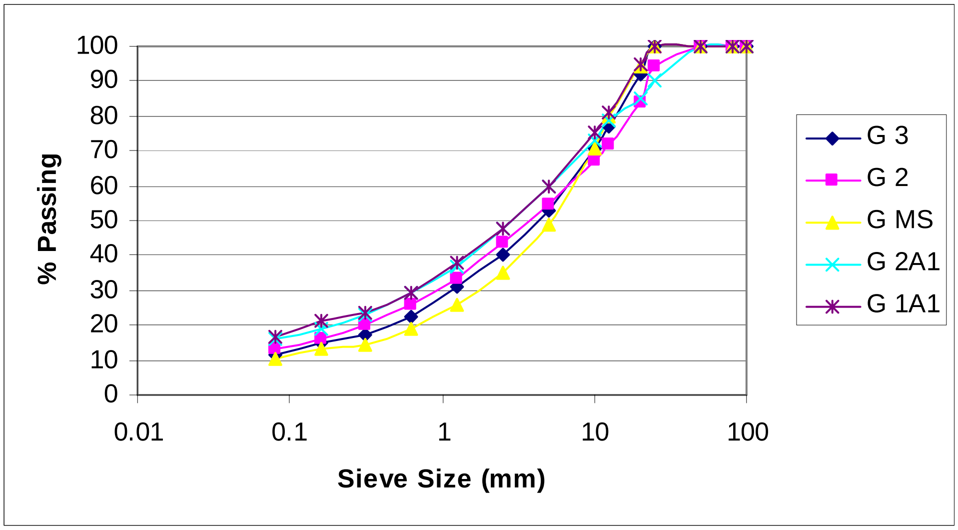

Figure 10: Waste Dump Material Size Distribution – Grum

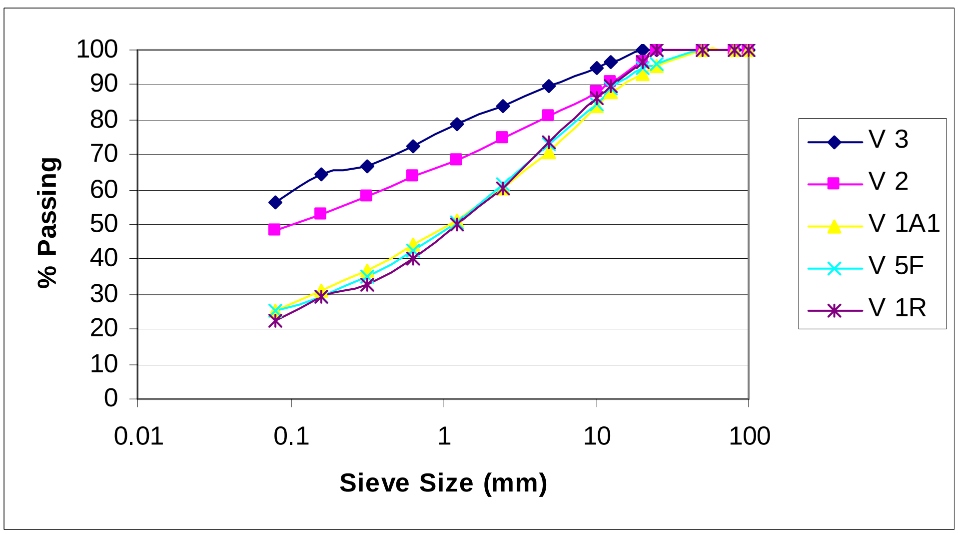

Figure 11: Waste Dump Material Distribution - Vangorda

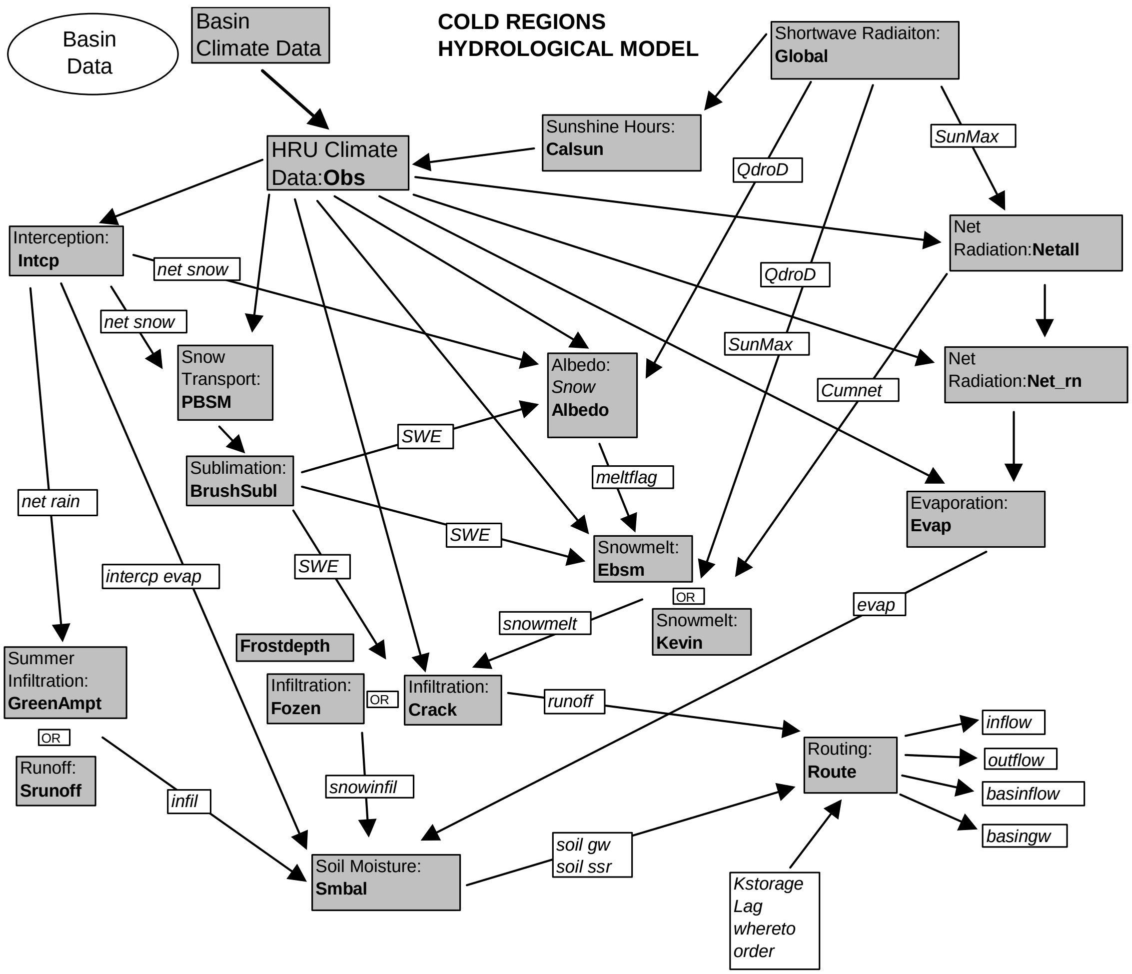

Figure 12: Cold Regions Hydrological Model Relational Flowchart (from Granger et al., 2002)

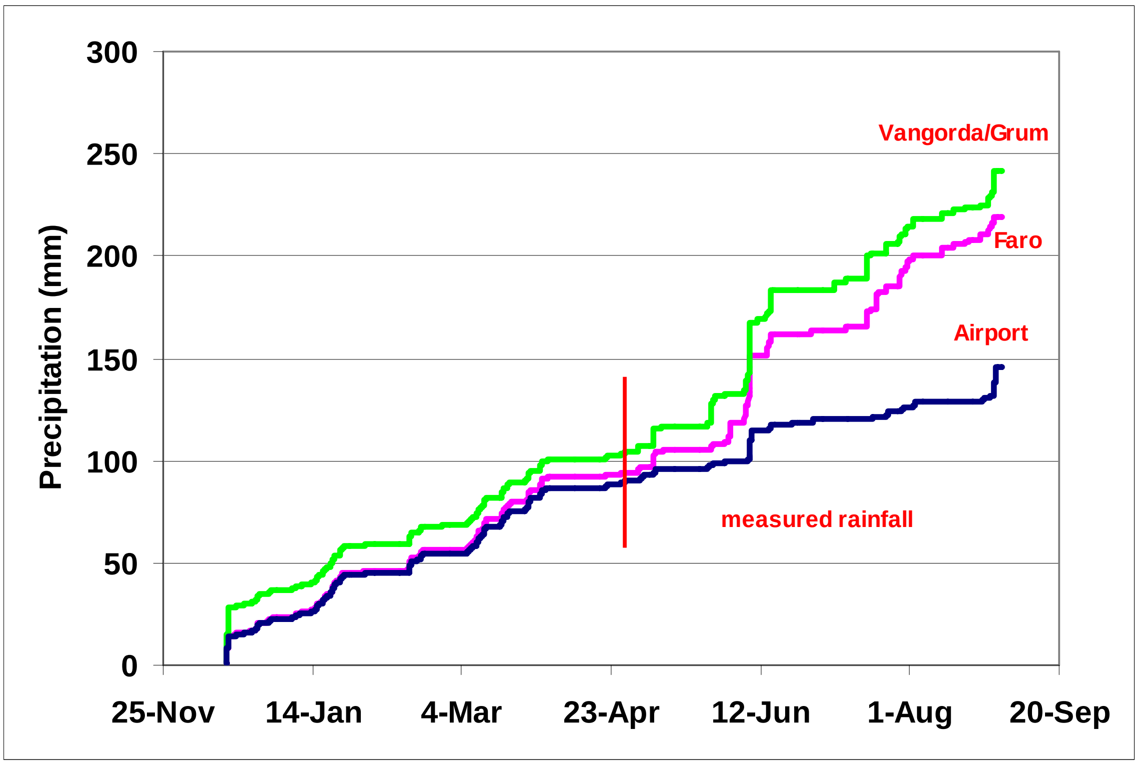

Figure 13: Faro VanGrum Cumulative Precipitation – 2003/04

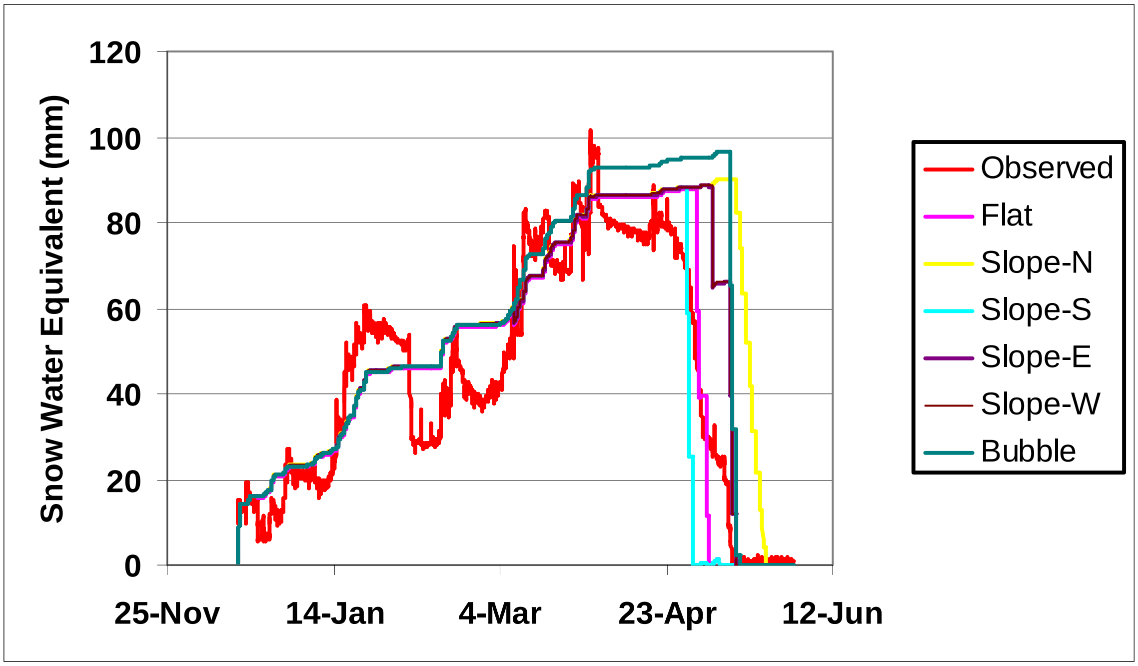

Figure 14: Faro Snow Water Equivalent – 2003/04

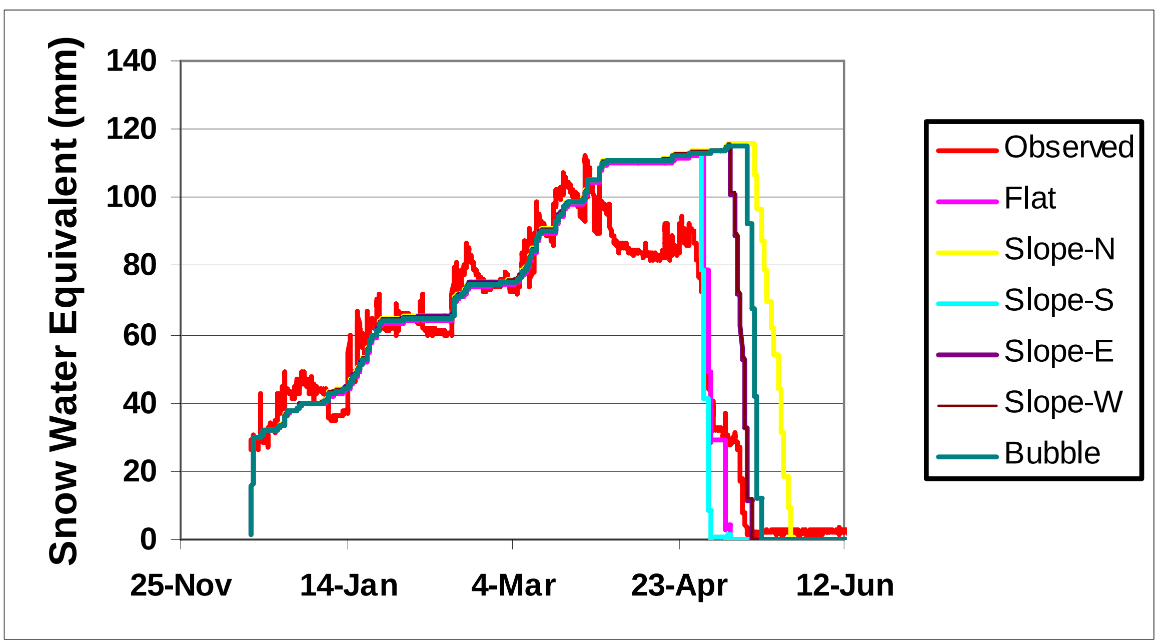

Figure 15: VanGrum Snow Water Equivalent – 2003/04

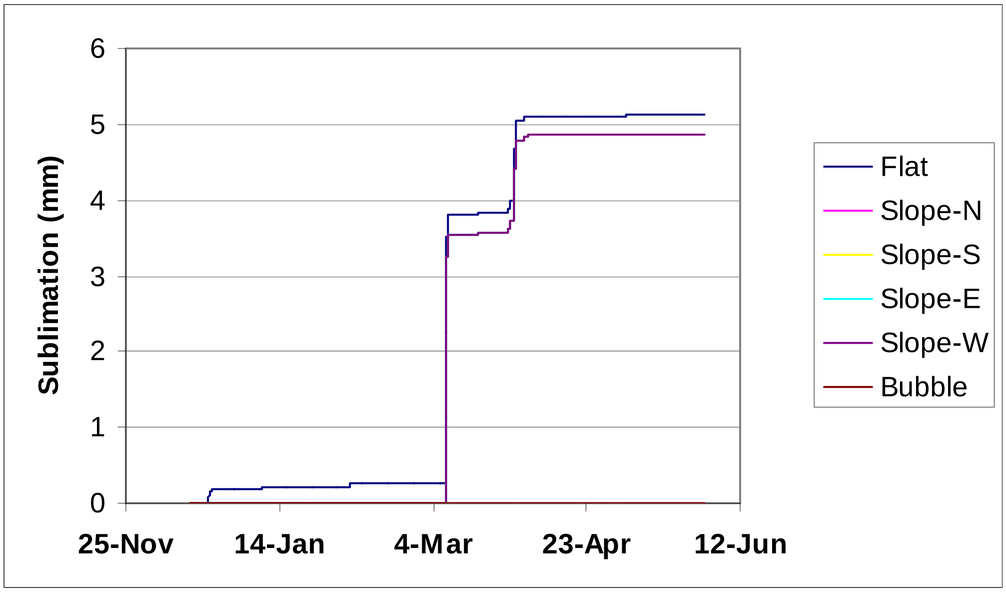

Figure 16: Cumulative Faro Sublimation – 2003/04

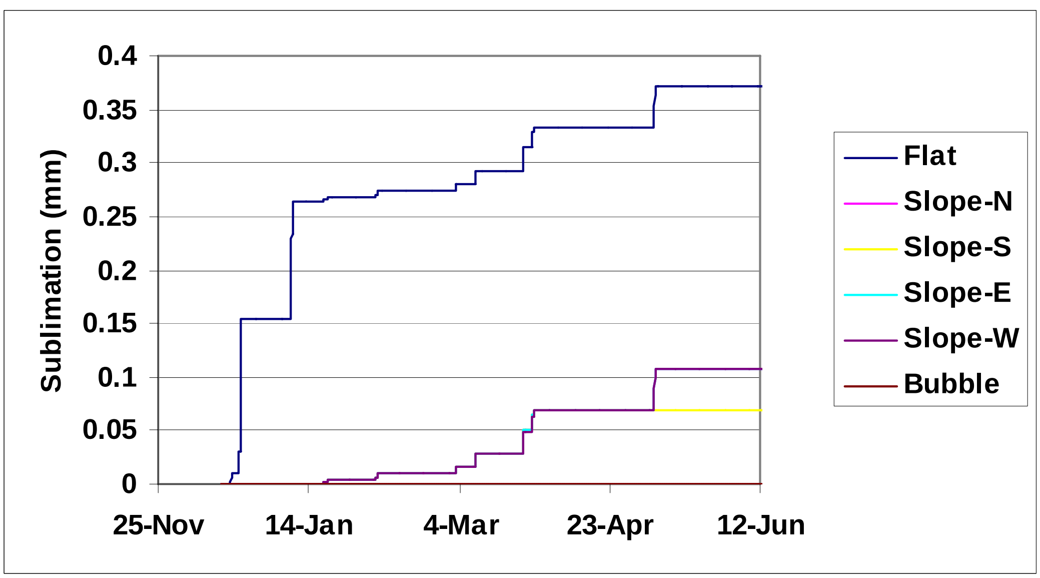

Figure 17: Cumulative VanGrum Sublimation – 2003/04

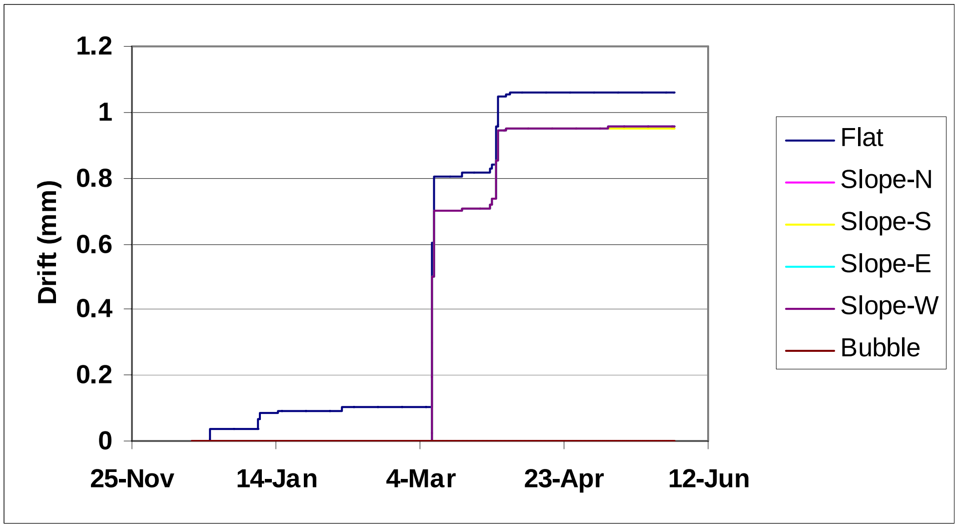

Figure 18: Cumulative Faro Drift (wind transport) – 2003/04

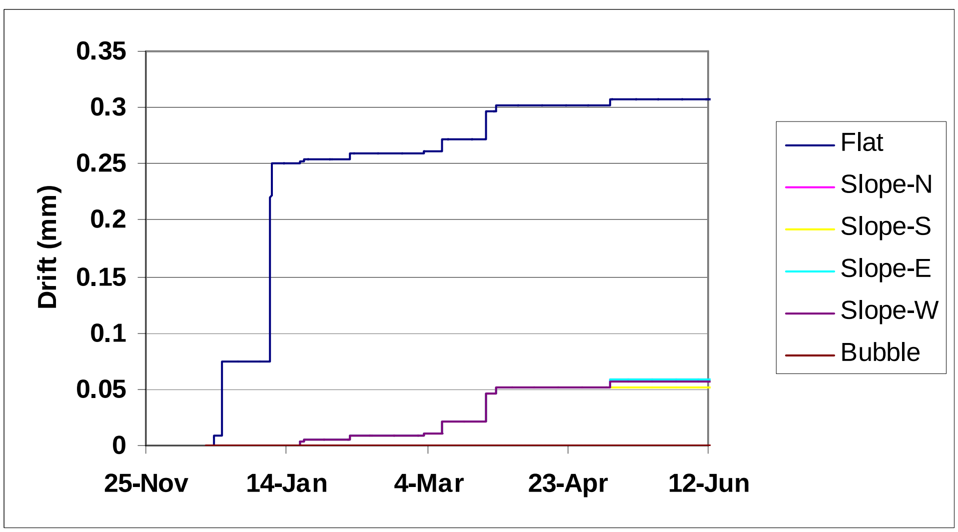

Figure 19: Cumulative VanGrum Drift (wind transport) – 2003/04

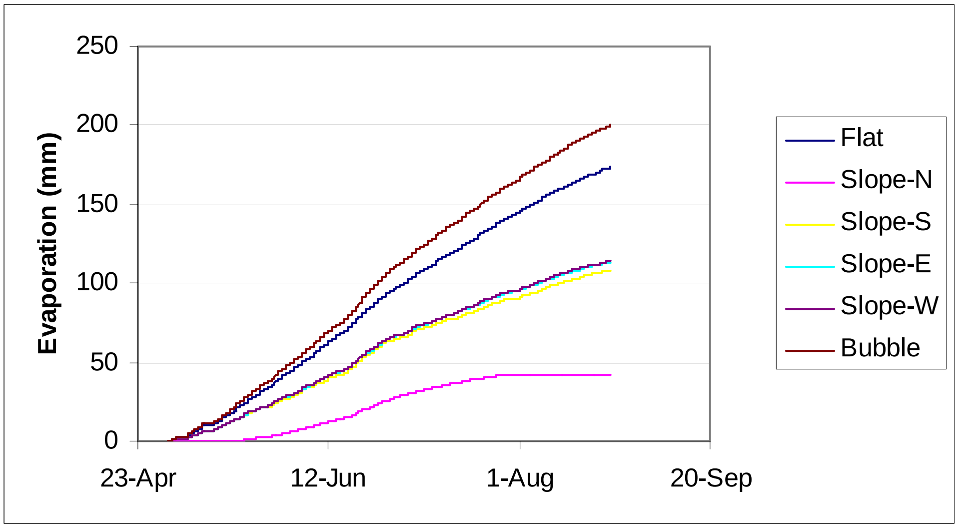

Figure 20: Cumulative Faro Evaporation – 2003/04

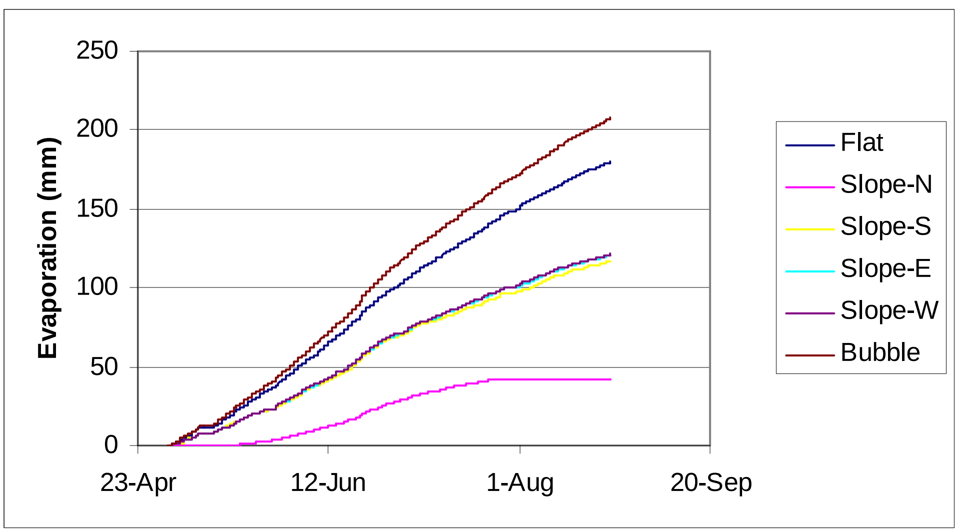

Figure 21: Cumulative Grum / Vangorda Evaporation – 2003/04

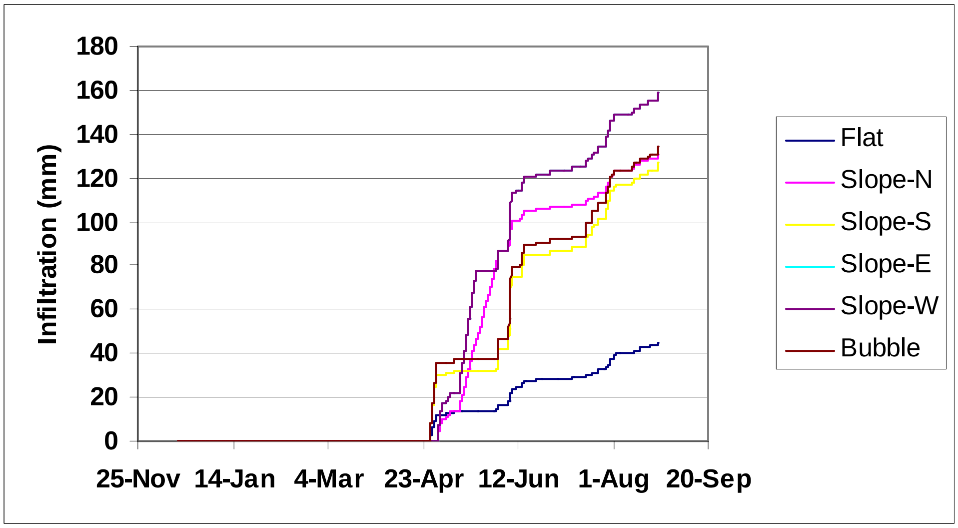

Figure 22: Cumulative Faro Infiltration – 2003/04

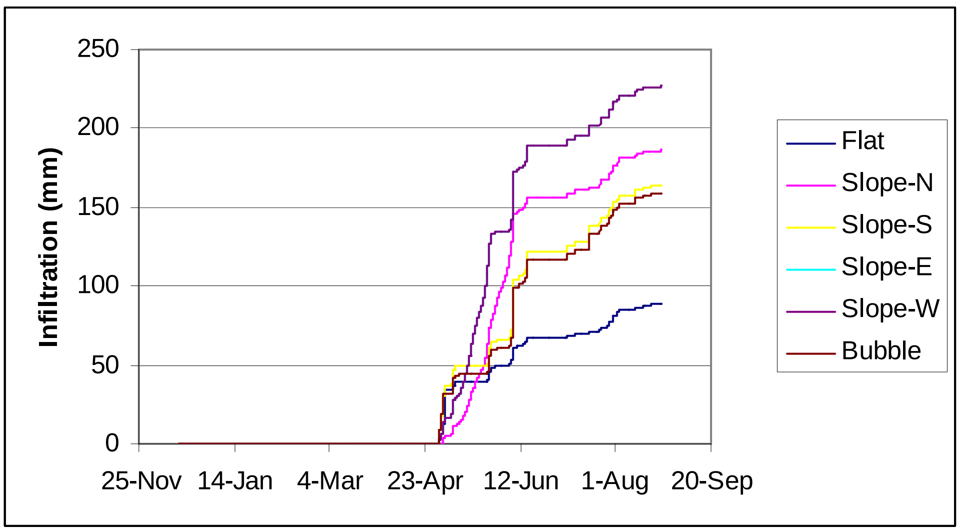

Figure 23: Cumulative VanGrum Infiltration – 2003/04

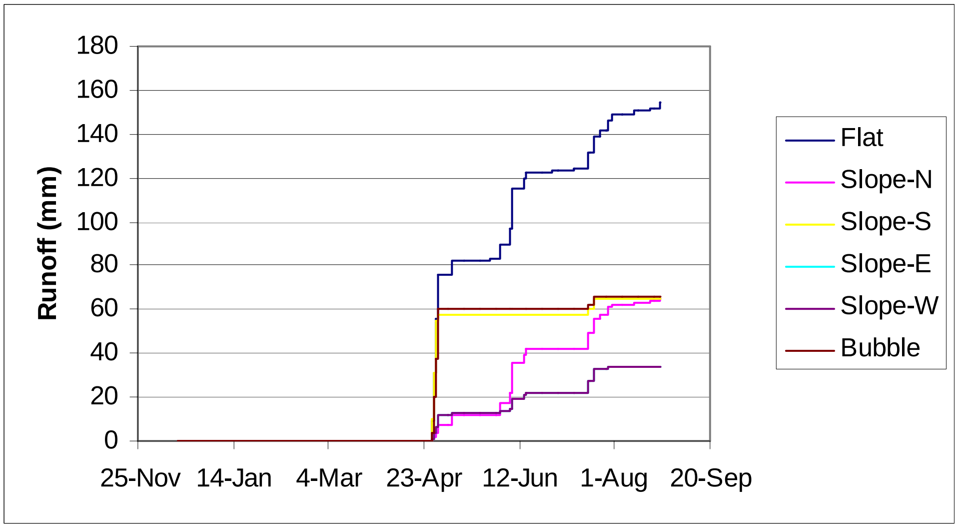

Figure 24: Cumulative Faro Runoff – 2003/04

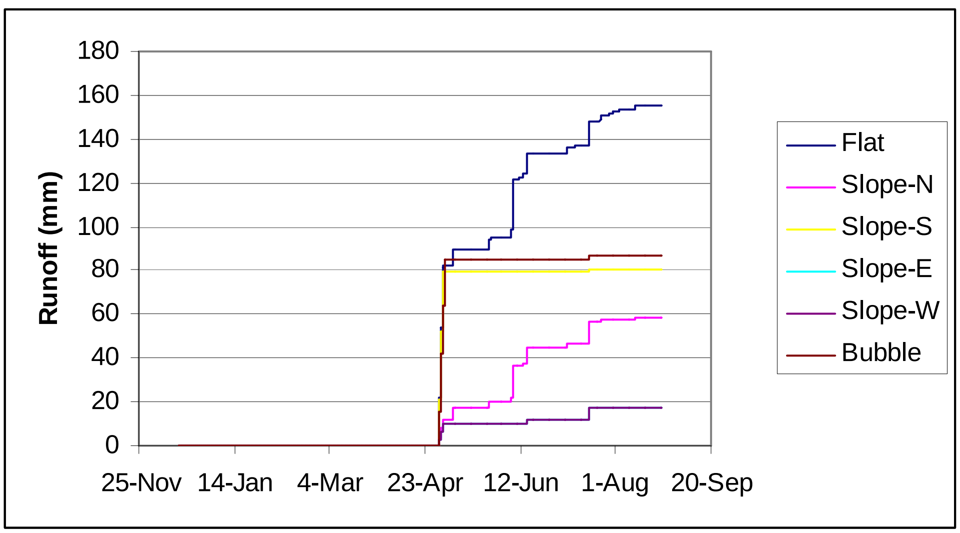

Figure 25: Cumulative VanGrum Runoff – 2003/04

PHOTOGRAPHS

Photo 1: Faro Meteorological Station

Photo 2: Grum Meteorological Station

Photo 3: Grum Snow Surveys

Photo 4: Slope Survey - Note Avalanche

Photo 5: Slope Snow Measurement Stakes

Photo 6: Vangorda Weir #3 with Data Logger

Photo 7: Guelph Permeameter Measurements at Vangrum Meteorological Station

Photo 8: Double Ring Infiltrometer Measurements at Faro Dump

Appendix A

INVESTIGATION OF ANVIL RANGE MINING CORPORATION (FARO) WASTE DUMP WATER BALANCES – 2004/05

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

- 1.1 Maintain meteorological stations
- 1.2 Work with Total North Communications and mine manager to develop telemetry plan for meteorological stations
- 1.3 Assess data and site characteristics to determine need for secondary meteorological instrumentation at other dump locations
- 1.4 Carry out site inspection during and immediately after snowmelt and significant rainfall events to identify surface runoff and seepage locations
- 1.5 Install new and / or upgrade existing weir(s) to measure surface runoff and seepage flows (based on results of task 1.4)
- 1.6 Consider developing program to monitor surface flows and pit water levels
- 1.7 Develop program for site staff to record hydrometeorological observations from weirs and other locations
- 1.8 Carry out summer infiltration studies
- 1.9 Carry out pre-freeze up soil moisture survey
- 1.10 Carry out winter and spring snow survey
  - 1.10.1 Install series of staff gauge transects on dump slopes

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: Refine water balance using site hydrometeorological data (task 1)

3.2.1 Reconstruct water balance for previous years by establishing relationship between locally measured meteorological parameters and those observed at Faro Airport and Williams Creek

- 3.3: Assess possibility that dumps are still reaching residual saturation

Task 4: Final Report

4.1: Write draft final report with possible recommendations for continuation of the monitoring program for 2005/06

4.2: Make modifications to final report based on review comments.