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

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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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. Environment Canada's National Water Research Institute was subcontracted to participate in the project. The 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 approved study proposal is presented in Appendix A. This report summarizes the work carried out under Task 6: *develop interim dump water balance estimates based on regional information and use of the CHRM model*.

STUDY AREA AND METHODOLGY

Study Area

The Anvil Range Mining Complex (ARMC) is located 200 km northeast of Whitehorse near the community of Faro. The mine site is located in the Anvil Range Mountains within the Macmillan Highlands of Yukon Plateau-North ecoregion (Smith et al., 2002). 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 1200 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 and 1120 to 1180 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.

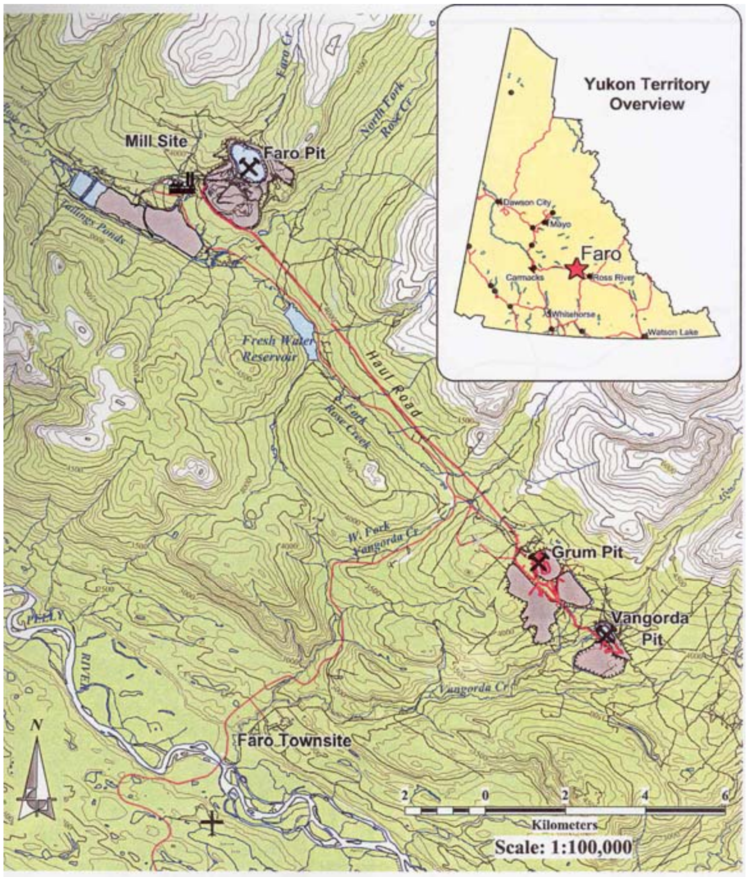

Figure 1: Location Plan (from Gartner Lee Ltd., 2002)

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 temperature of the area is approximately -5 ^{0}C with a range of mean monthly temperatures from -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 ^{0} 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).

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. Tables A1 and A2 (from Robertson Geoconsultants Inc. (1996)) of Appendix B characterize the Faro dumps by their physical dimensions and rock type. Sulphides make up 13% of the total waste. Although attempts were made to isolate the sulphide material from other waste rock, most of the Faro dumps contain significant proportions of reactive sulphide material. The Vangorda dumps were developed between 1990 and 1994. The two main rock types include sulphides and phylites in proportions of 19 and 81 % respectively. The sulphide material was segregated by encapsulation with glacial till from the overburden dump. The remainder of the dumps; however, include significant amounts of reactive sulphides. In 1994, Public Works Canada, undertook a project to reslope and cap a portion of the dump. A 2 m thick cover of glacial till was placed on half of the resloped area. The Grum dumps, which were the last to be constructed, include a sizable overburden till dump which was completed in 1995. The two main rock types in the other dumps are sulphides and phylites in proportions of 4 and 96 % respectively. In this case, the segregation of sulphide materials appears to have been better implemented, and the Grum "sulphide cell" contains most of the sulphide rock. Portions of the southwest slope of the Grum main dump is mantled with glacial till, with thickness varying from 0.1 to 6.7 m. This material is covered with fluvial sand and gravel and a thin organic soil layer.

Three types of surfaces can be distinguished: bubble dumps, flat surfaces and push over slopes. Bubble dumps are hummocky areas of alternate mound and depression features created by the successive end dumping of waste material by large dump trucks. The mounds are 3 to 4 m high, while the depressions are 2 to 3 m deep. Flat surfaces have been created by the redistribution of bubble dump material by heavy equipment. These surfaces are typically smooth, packed surfaces which tend to be driven upon such as roadways, 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. The predominate classes are gravel and sand (M.D. Haug & Associates Ltd, 2003). Surficial materials weather over time resulting in finer texture. As would be expected the flat traffic surfaces consist of more fines than other surfaces because of abrasion by the heavy equipment, and tend to be denser. Table 1 summarizes the surface area of the various dump surface types.

Table 1: 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)

WATER BALANCE DERIVATION

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 2 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 radiation. Hourly or half hourly time steps can be specified. Detailed information on the CHRM process modules is provided in Appendix C.

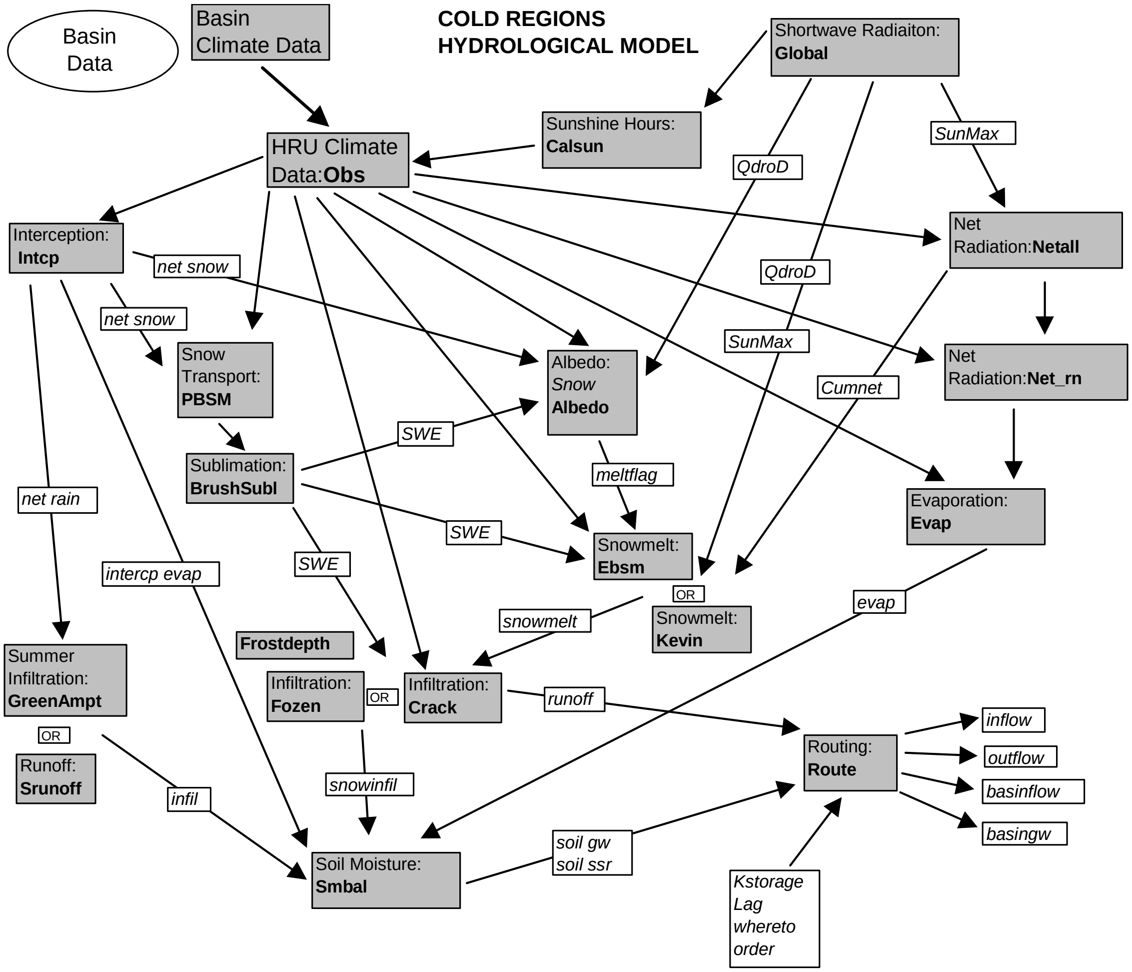

Figure 2: Cold Regions Hydrological Model relational flowchart (from Granger et al., 2002)

Model Data Assembly

Meteorological Data

The only historical meteorological data for the ARMC area was provided by the Anvil station which operated from 1971 to 1977. This station was located within the mine complex area at an elevation of 1158 m. The station was moved to the Faro Airport, at an elevation of 691 m, in 1978 where it continues to operate. Of the necessary model input parameters (air temperature, humidity, wind speed, precipitation and radiation) neither station has the historical radiation data, and this parameter is not routinely monitored by Environment Canada. There are a few stations operated by Yukon Water Resources which do monitor radiation. The closest such station is located at Williams Creek mining property 35 km northwest of Carmacks (175 km west of the ARMC area) which was established in 1994. Though the physiography of the William’s Creek property is similar to the ARMC, its elevation is lower at 850 m. Since no other radiation data is available, direct use of this data is only available option for the development of a preliminary water balance. In addition since daily air temperatures only are available for the Anvil and Faro stations (hourly records with significant missing records are available for Faro and a project is underway to reconstruct this record), hourly values were extracted from the Williams Creek record. Because simultaneous records are not available for Williams Creek and Anvil, the Faro station was selected to provide the balance of necessary input data for modeling purposes. Hourly humidity and wind speed are available for Faro; however, daily values of precipitation are available only. To accommodate the necessary hourly format, daily precipitation was distributed evenly throughout the day.

A five year composite record (1994 to 2000) of hourly meteorological data was prepared for the development of the preliminary ARMC waste rock dumps water balance. Annual precipitation values ranged from 171 mm in 1997/98 to 345 mm in 1994/95. This report summarizes the results of preliminary water balance development for the 1994/95 wet year. Usin regional trends, monthly and annual precipitation data were adjusted for elevation, yielding a annual value of 442 mm. The input data set is attached as Appendix D.

Transferring Meteorological Data

A discussion is warranted on the impact of using data sets transferred from other landscapes or regions on the quality of the model simulations. Most of the model algorithms rely on the use of accurate representative data; this is particularly true of the evapotranspiration routine. Most of the meteorological parameters are affected by elevation and by the surface over which they are measured.

Air temperature generally decreases with elevation; this is clearly reflected in monthly mean values. However, developing relationships on daily or hourly time scales proves to be more difficult. There are situations in mountainous regions where cold air drainage causes an inversion such that higher elevations can at times be relatively warmer. Air temperature is a significant parameter in the calculation of snowmelt (and consequently infiltration and runoff) and evapotranspiration.

Humidity of the air is used particularly in the evapotranspiration algorithm, where it is a critical parameter. Humidity, particularly at standard measurement height of 1.5 m, is strongly influenced by the evaporative process occurring at the ground surface. This feedback mechanism makes it difficult to transpose humidity data with reliability for the purpose of calculating evapotranspiration, especially where estimates are required for specific landscapes.

Wind speed generally increases with height (elevation) in the atmospheric boundary layer. However wind speeds are also greatly affected by landcover (forest cover) and by landforms. Mountainous regions represent very complex landforms, and are characterized by very complex wind regimes. Wind speed is an important parameter in the calculation of snow accumulation in that it controls drifting and sublimation of snow; it also comes into play in the calculation of evaporation. Use of valley bottom measurements of wind speed will adversely affect the quality of the SWE estimates, and consequently the melt, infiltration and runoff estimates. It also does not allow for the adequate differentiation in snow accumulation between the various HRUs. The current model runs did not incorporate a wind flow module for complex terrain.

Solar radiation is affected mostly by cloud cover and varies with latitude; the effect of elevation differences as experienced between the observation sites is not likely to be significant. The major limitation in the transposition of solar radiation data then, is the difference in the cloud cover regimes experienced. Cloud cover information with which to correct or adjust this parameter was unavailable. Solar radiation is used in the calculation of the net allwave radiation which governs the snow melt and evaporation; it represents, in both cases, the driving force for the processes. The net allwave radiation is sometimes measured directly. Net radiation data are more difficult to transpose because they are affected by the underlying surface; the albedo or reflectivity of the surface governs the fraction of incoming energy that is reflected back to the atmosphere.

Precipitation generally increases with elevation in response to orographic lifting of an air mass to ascend a mountain slope. Small scale topographic effects are not as obvious and may be significant. In rugged terrain, precipitation is not only related to elevation, but to aspect, slope, distance from moisture source, temperature and wind characteristics. Windward slopes may exhibit a well defined pattern of increasing precipitation with elevation; however, this relationship would not be apparent on leeward slopes and sheltered valleys. There are also significant differences between rainfall and snowfall patterns in mountainous terrain. The transposition of rainfall, snowfall and SWE from one site to another can be difficult, especially to areas devoid of vegetation such as the ARMC area. The greatest short duration rainfall intensities occur during convective storms, which are associated with relatively small air mass cells which produce isolated patterns of rainfall. Convective events of this nature would not generally be subject to elevation effects. Snowfall over an area tends to be more uniform than rainfall, but its accumulation and retention tends to be highly variable. In addition to physiographic and meteorological parameters, vegetation patterns have a significant effect on snowpack accumulation and redistribution. In mountainous areas, snowpack generally increases with elevation; however, this pattern can be reversed above the tree line, where snow transport and sublimation rates are significant as a result of high wind velocities. Snow tends to be eroded from vegetation free areas and deposited in vegetated areas. Also windward slopes tend to be wind scoured with deposition and drift formation on leeward slopes.

Physical Data

The ARMC waste dumps were subdivided into six HRUs 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 general ARMC area as opposed to the individual waste dumps, with simulated unit area outputs. Physical data required for modeling purposes was selected to represent average ARMC parameters. Because the available meteorological input data set represents approximate ARMC conditions only, precise individual physical parameter values are unwarranted. Table 2 lists the specified physical parameters.

Table2: 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

SIMULATION OUTPUT

1994/95 Water Year

The water balance simulation for the 1994/95 water year was carried out at 1 hour step intervals using meteorological data and physical parameters as specified. The precipitation distribution is presented in Figure 3. For these preliminary calculations, a single precipitation regime was assumed across the entire complex, whereas, in reality the precipitation distribution varies over the complex, with the Vangorda/Grum area being considerably wetter than the Faro area. The estimated snow water equivalent (SWE) for the winter season is presented in Figure 4. The plot illustrates both accumulation and ablation for the 6 HRU's, and is the product of blowing snow, sublimation, and snowmelt routines. The energy budget (ebsm) routine was used to generate snowmelt for the flat,

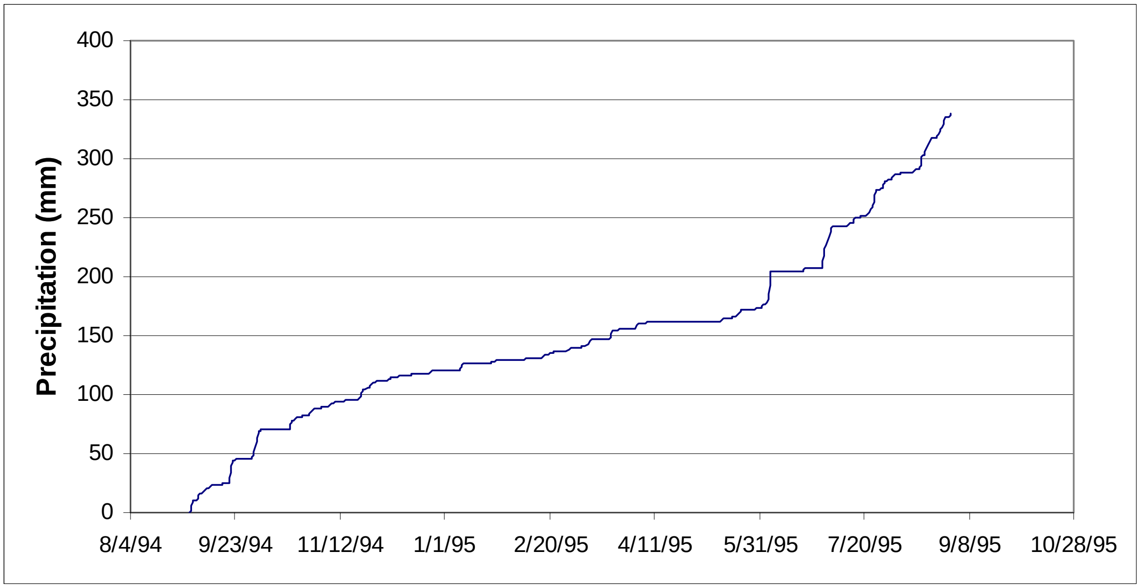

Figure 3: ARMC Cumulative Precipitation – 1994/95

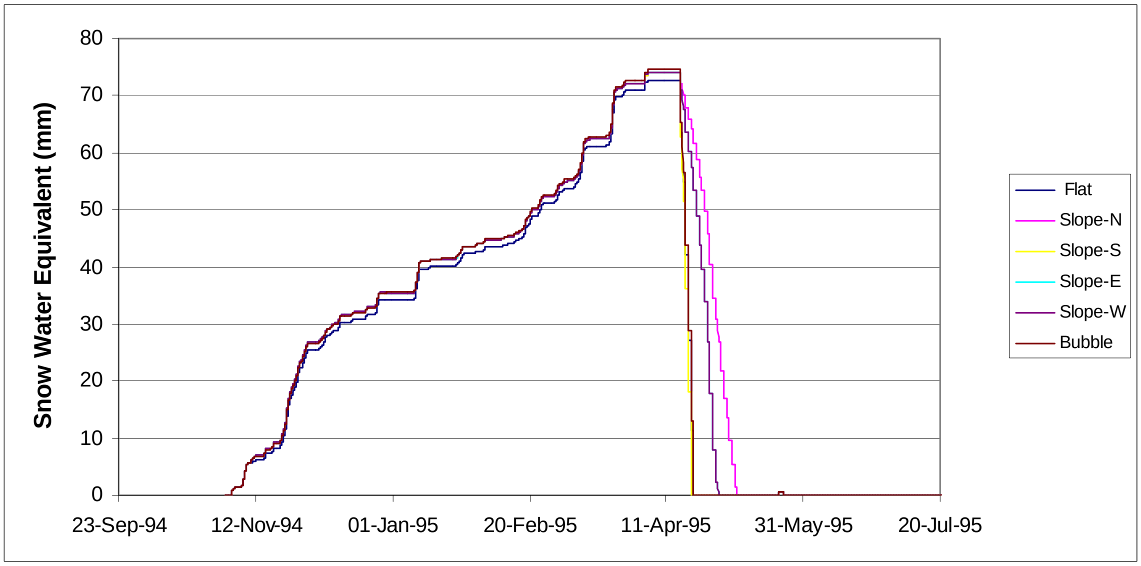

Figure 4: ARMC Snow Water Equivalent – 1994/95

slope-s and bubble HRUs; while, the temperature index option was used for the slope-n, slope-e and slope-w HRUs.

Snow accumulation is basically similar for all HRUs, with only slight variations due to wind losses (sublimation + transport). The snowmelt process was simulated to commence around April 16 within all HRUs, while the snowpack was depleted on April 21 within the flat, slope-s and bubble HRUs, May 1 within the slope-e and slope-w HRUs and May 9 with the slope-n HRU.

The estimated cumulative snow loss by wind for the six HRUs is illustrated in Figure 5. Sublimation and wind transport is simulated using the Prairie Blowing Snow Module, (pbsm) based on wind speed, air temperature, relative humidity and roughness height.

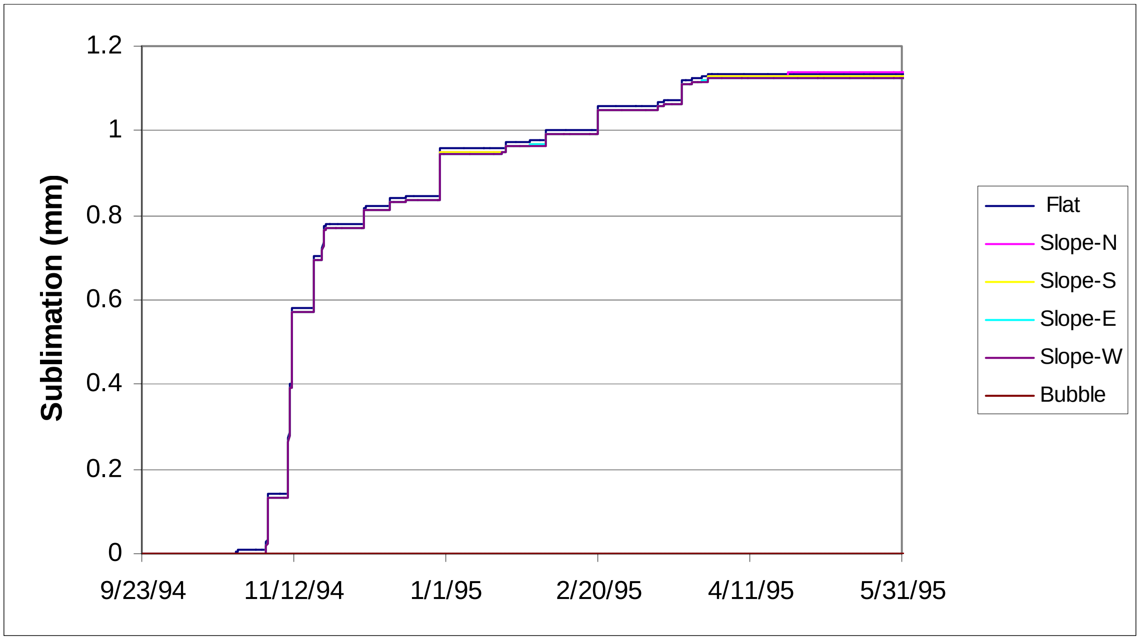

Figure 5: ARMC Cumulative Sublimation – 1994/95

Snow ablation is simulated to be similar within all HRUs, with a cumulative annual value of about 1 mm. These plots illustrate the importance of wind speed which, for simulation purposes is relatively low and consistent between HRUs. Actual ARMC wind speeds are known to be higher; therefore, would result in greater wind loss.

Estimated cumulative evaporation is illustrated in figure 6 from after the snowmelt period through to the fall. The 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.

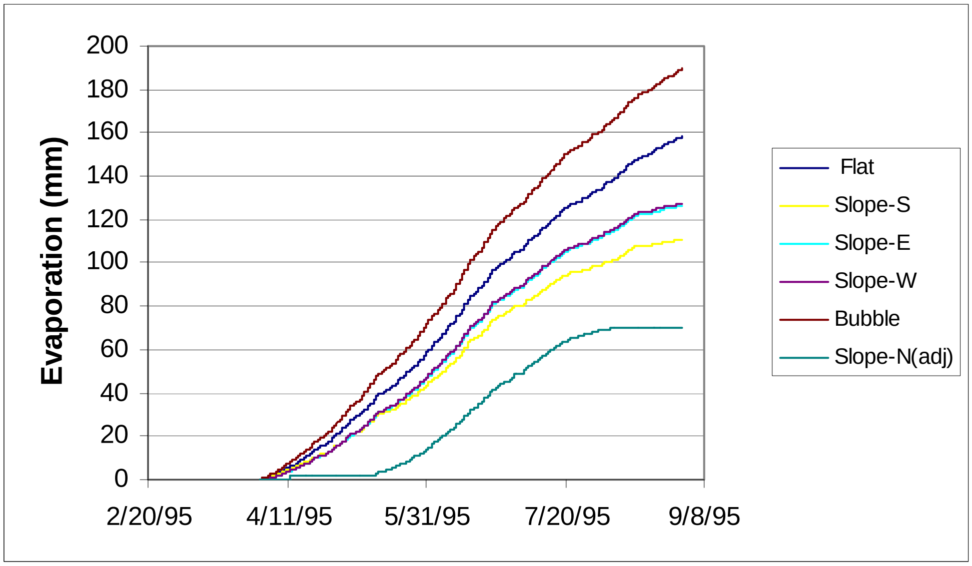

Figure 6: ARMC Cumulative Evaporation – 1994/95

Evaporation commences after snowmelt, peaks with the available energy (solar radiation) in June and continues into the early fall. Significantly differing cumulative amounts of evapotranspiration are simulated for the 6 HRUs with 70 mm from the north facing slope, which has the least available energy for the process, to 190 mm from the bubble dumps which has both significant amounts of energy and available soil moisture.

The estimated cumulative infiltration is illustrated in figure 7. Snowmelt infiltration was calculated using the CRACK module which uses pre-melt soil moisture (liquid + frozen) and available meltwater (SWE) to simulate infiltration (Janowicz et al., 2003).

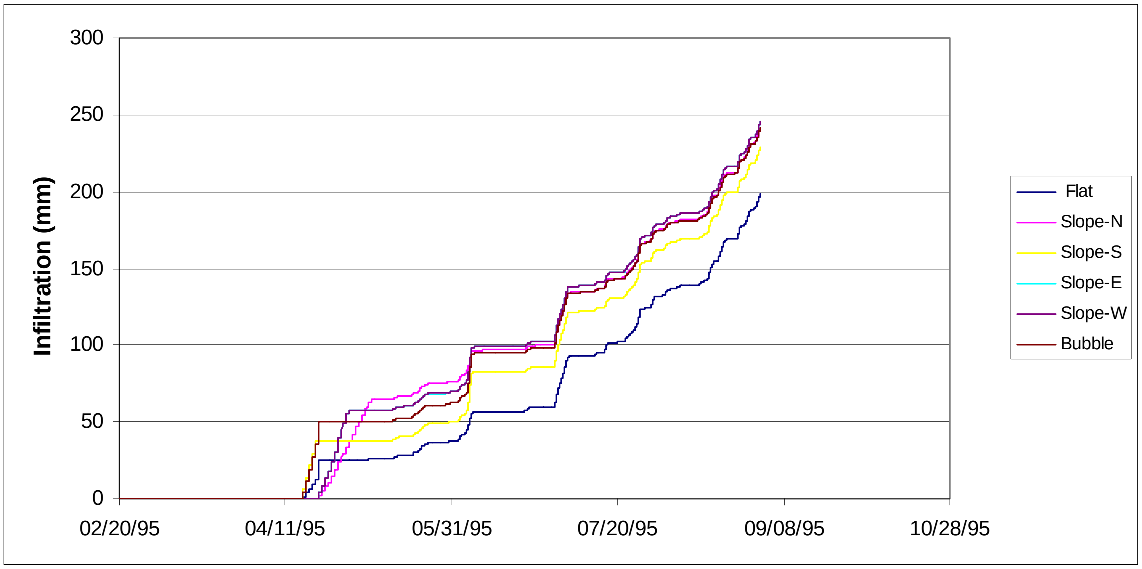

Figure 7: ARMC Cumulative Infiltration – 1994/95

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 from capillary pressure and hydraulic conductivity (Rawls et al., 1983). These parameters are a function of soil texture, and are provided for 11 soil classes ranging from sand to clay. Input parameters include initial soil moisture, and maximum soil moisture, and soil type. Infiltration during the snowmelt period ranges from 25 mm for the flat HRU to 64 mm for the north facing HRU. This progression is inversely related to infiltration opportunity time on the sloped surfaces. 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 sloping slope as these are most impervious and have the highest soil moisture. Infiltration was higher for the other four HRUs primarily due to greater permeability.

Estimated cumulative runoff is illustrated in figure 8. Runoff is generated by the SMBAL module 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, while evaporation is taken from the entire soil cross section. Surface infiltration first satisfies the recharge layer before being conveyed

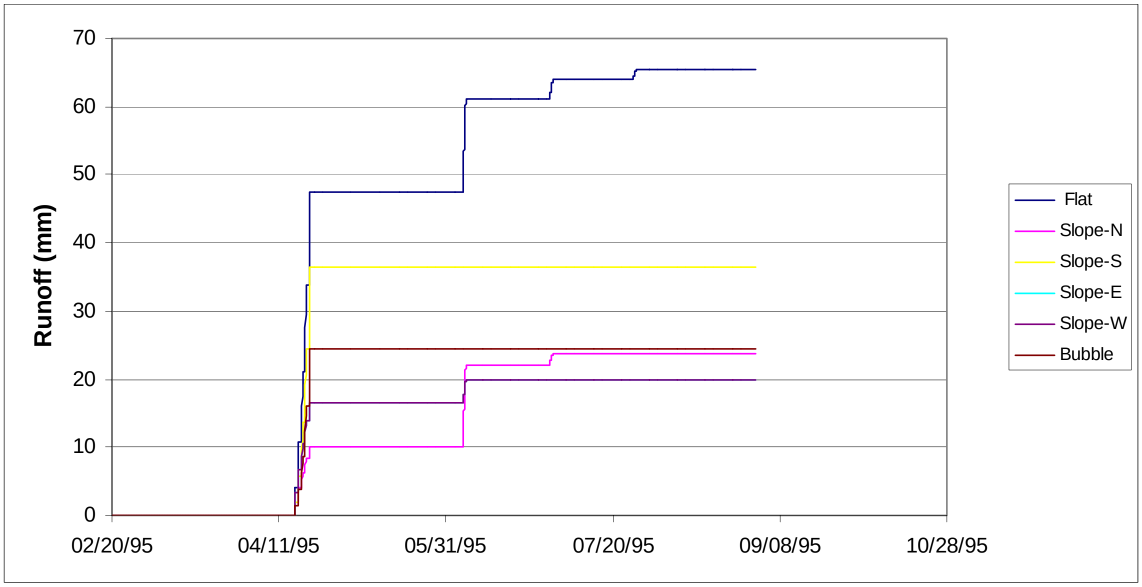

Figure 8: ARMC Cumulative Runoff – 1994/95

to low 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. Snowmelt runoff varies from 10 mm on the north facing slope to 48 mm on the flat surface. The observed pattern 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 did not exhibit a similar pattern. No summer runoff was simulated for the south facing slope and bubble surface, while runoff was observed from three summer events within the flat HRU. Runoff was simulated for one summer event within the east and west HRUs and two events within the north HRU.

The monthly and annual water balance for each of the 6 HRUs is summarized in Table 3.

The annual budget indicates that there is storage surplus in every HRU with values ranging from 13 mm in the bubble HRU to 107 mm in slope-n HRU. The bubble dump conditions are likely most representative of “normal” field conditions which the CHRM was developed for. The relatively tight annual balance, with a storage surplus of 13 mm, indicates the model performed reasonably well for this HRU. Monthly winter SWE totaled 80 mm, with simulated snowmelt and infiltration amounts of 50 and 25 mm respectively in April. Simulated sublimation amounts are insignificant with actual amounts being likely greater. Monthly summer precipitation ranges from 15 to 97 mm with a total of 231 mm. Infiltration amounts follows a similar pattern with values ranging from 12 to 76 mm with a total of 191 mm. No runoff from the bubble dumps is

Table3: Monthly Water Balance Summary

Flat HRU

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOT
Precip	60	55	32	11	11	11	25	7	15	45	97	74	442
Evap	-	-	-	-	-	-	-	-	36	44	31	25	137
Sub	-	.01	.77	.18	.02	.08	.08	-	-	-	-	-	1.14
SWE	-	-	30	8.8	8.5	8.4	23	-79	-	-	-	-	73
Inf	-	-	-	-	-	-	-	25	12	22	72	67	199
Run	-	-	-	-	-	-	-	48	-	14	4.3	-	65
Stor								+6	-33	-33	-10	-18	+40

Slope-N HRU

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOT
Precip	60	55	32	11	11	11	25	7	15	45	97	74	442
Evap	-	-	-	-	-	-	-	-	12	32	22	1.3	68
Sub	-	.01	.77	.18	.02	.08	.08	.01	-	-	-	-	1.14
SWE	-	-	27	8.8	8.8	8.4	20	-45	-27	-	-	-	74
Inf	-	-	-	-	-	-	-	37	39	24	75	67	242
Run	-	-	-	-	-	-	-	10	-	12	1.6	-	24
Stor								+2	-36	-23	-2	+6	+107

Slope-S HRU

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOT
Precip	60	55	32	11	11	11	25	7	15	45	97	74	442
Evap	-	-	-	-	-	-	-	-	27	35	20	12	94
Sub	-	.01	.77	.18	.02	.08	.08	-	-	-	-	-	1.14
SWE	-	-	27	8.8	8.5	8.4	20	-72	-	-	-	-	74
Inf	-	-	-	-	-	-	-	38	12	36	76	67	229
Run	-	-	-	-	-	-	-	36	-	-	-	-	36
Stor								+2	-24	-26	+1	-5	+82

Slope-E HRU

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOT
Precip	60	55	32	11	11	11	25	7	15	45	97	74	442
Evap	-	-	-	-	-	-	-	-	30	39	25	16	110
Sub	-	.01	.77	.18	.02	.08	.08	-	-	-	-	-	1.14
SWE	-	-	27	8.8	8.5	8.4	20	-72	-	-	-	-	74
Inf	-	-	-	-	-	-	-	57	12	33	76	67	245
Run	-	-	-	-	-	-	-	17	-	3.1	-	-	20
Stor								+2	-27	-30	+4	+9	+66

Table3: Monthly Water Balance Summary (con'd)

Slope-W HRU

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOT
Precip	60	55	32	11	11	11	25	7	15	45	97	74	442
Evap	-	-	-	-	-	-	-	-	31	39	25	16	110
Sub	-	.01	.77	.18	.02	.08	.08	-	-	-	-	-	1.14
SWE	-	-	27	8.8	8.5	8.4	20	-72	-	-	-	-	74
Inf	-	-	-	-	-	-	-	57	12	33	76	67	245
Run	-	-	-	-	-	-	-	17	-	3.1	-	-	20
Stor								+2	-28	-30	+4	+9	+66

Bubble HRU

	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	TOT
Precip	60	55	32	11	11	11	25	7	15	45	97	74	442
Evap	-	-	-	-	-	-	-	-	44	51	37	30	162
Sub	-	.01	.77	.18	.02	.08	.08	-	-	-	-	-	1.14
SWE	-	-	30	9.1	8.6	8.7	23	-80	-	-	-	-	74
Inf	-	-	-	-	-	-	-	50	12	36	76	67	241
Run	-	-	-	-	-	-	-	25	-	-	-	-	25
Stor								+5	-41	-42	-16	-23	+13

simulated by the model, which seems reasonable. Summer evaporation values range from 30 to 51 mm which is perhaps on the high side, resulting in summer monthly storage deficits ranging from 16 to 42 mm.

The annual water balance on the flat HRU was the next tightest with an annual storage surplus of 40 mm. The landscape type represented by this HRU fits within the design limits of CRHM. Monthly winter SWE totaled 79 mm, with 25 and 48 mm simulated infiltration and runoff respectively leaving a monthly storage surplus of 6 mm. Monthly summer precipitation ranged from 25 to 44 mm, with a summer total of 136 mm. The simulated pattern of infiltration and runoff was different than the bubble HRU due to the more impervious nature of the landscape type. Monthly infiltration ranged from 12 to 72 mm, closely following the monthly precipitation pattern. Simulated infiltration may be high for this HRU because of the relatively impervious surface. Runoff was simulated during the months of June and July. Monthly evaporation was simulated to range from 25 to 44 mm. Summer monthly storage deficits ranged from 10 to 33 mm.

The extreme angles of the slope HRUs place these landscape types outside of the design limits of the CRHM. Even so simulated water balances appear to be reasonable, especially for the snowmelt component of the simulation where storage surpluses of 2 mm were simulated for all slopes. Similar infiltration amounts of 37 and 38 mm were simulated on the north and south slopes respectively, while, 10 and 36 mm or runoff were simulated which seems reasonable. Values of 57 and 17 mm of infiltration and runoff respectively were simulated for both east and west facing slopes.

Identical rainfall regimes were assumed given for all slopes. All slopes had similar summer infiltration, with the exception of the north facing slope which included some residual snowmelt in May. The greatest summer runoff was simulated to occur from the north facing slope, while no runoff was simulated from the south facing slope and only a small amount from the east and west facing slope. Summer evaporation amounts of 68, 94 and 110 mm were simulated for the north, south and east/west facing slopes respectively, which seems reasonable from an energy and water availability viewpoint. Summer storage within the sloped HRUs ranged from a monthly deficit of 30 mm to a surplus of 9 mm.

DISCUSSION AND CONCLUSIONS

A preliminary water balance was carried out for the ARMC waste rock dumps with reasonable results given that all meteorological data was transposed from other locations. The analyses were carried out for the 1994/95 water year which is considered a “wet” year. Positive annual water budgets were simulated in each of the six HRUs indicating that storage surplus conditions exist in each HRU. The tightest annual water balances were simulated for the bubble and flat HRUs which are most representative of normal field conditions for which the CRHM was developed. The extreme angles of the sloped HRUs are outside the application limits of the model, yet reasonable water budgets were simulated. The snowmelt components of the simulations were generally better than the summer regimes.

The greatest improvements to the simulations will be through the use of site specific ARMC meteorological data. Two meteorological stations were installed at the site in December, 2003, and data will be collected for at least one full year before the next round of water balance calculations is undertaken. Other improvements will be realized by carrying out extensive snow surveys through the dump sites and by comprehensive soil moisture sampling of the upper soil layer. 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. Additional work will be carried out on the CRHM model to make it more applicable to ARMC conditions.

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