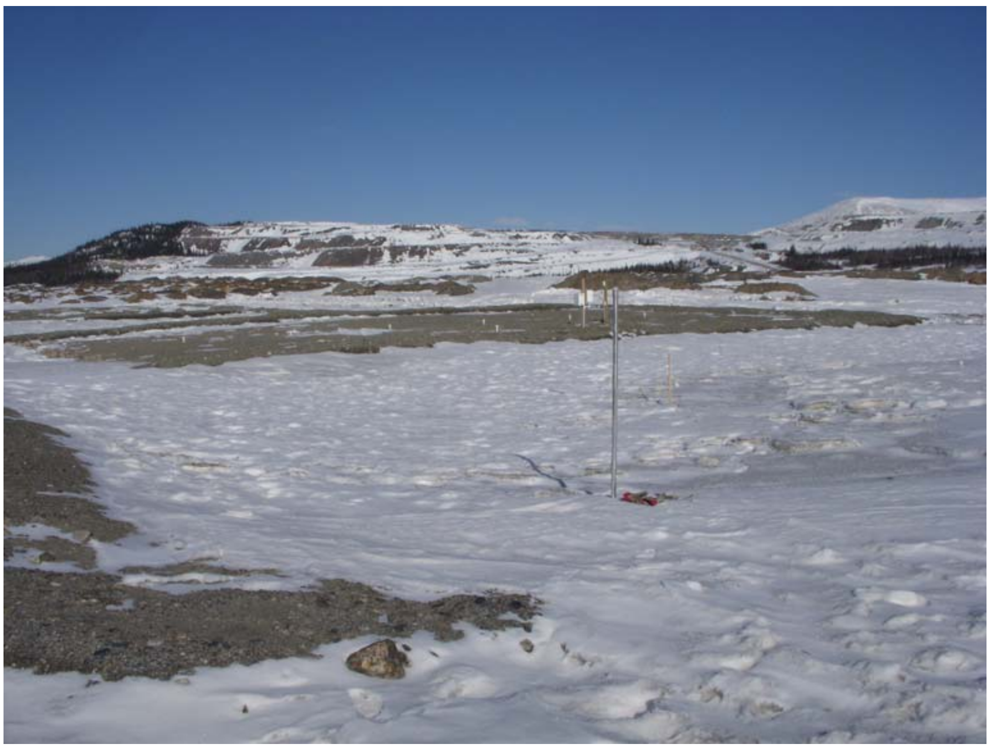
INVESTIGATION OF ANVIL RANGE MINING CORPORATION (FARO) WASTE DUMP WATER BALANCE

VANGORDA TRIAL COVERS WATER BALANCE



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Prepared for
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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Investigation of Anvil Range Mining Corporation (Faro) Waste Dump Water Balance – Vangorda Trial Covers Water Balance

Executive Summary

The overall objective of the study is to provide improved estimates of the amount of water infiltrating the waste rock dumps. The improved estimates are required to support the assessment of methods to control or remediate acidic drainage from the dumps. 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. Several phases of the project were carried out from 2003 to 2006. These are summarized by Janowicz et al. (2006; 2007a). Yukon Water Resources was also requested to conduct a water balance assessment of the recently constructed test covers at the Vangorda waste rock dump (Janowicz et al., 2007b). Since winter snow surveys were not a component of this study, a subsequent request was made to carry out a further assessment of the Vangorda trial waste rock dump covers for the 2008 snowmelt period which is summarized in this report. Summary results are as follows:

- Simulated rainfall and snowmelt for the study period are similar for the three test covers
- Evaporation is slightly greater for the sloped covers as compared to the horizontal covers
- Rainfall infiltration is significantly greater than snowmelt infiltration
- Infiltration to the sloped till and glacio-fluvial covers, is greater relative to the horizontal covers
- The greater recharge for the sloped surfaces appears to be directly related to grain size which is larger on the sloped covers due to the erosion of the fine material from the surface enhancing infiltration
- The large runoff values for the horizontal covers are anomalous, due to limitations of the model
- Recharge for the study period was simulated to be -17, 14 and 20 mm, for the horizontal till, sloped till and sloped glacio-fluvial covers, respectively
- The horizontal cover is simulated to have a negative recharge primarily due to the significant simulated runoff which, in reality, does not leave the HRU and will either evaporate or infiltrate

The simulated results represent a preliminary assessment of recharge to the Vangorda waste rock dump trial covers. In terms of cover performance it appears that at the Vangorda site snowmelt infiltration is significantly less than snowmelt runoff, and it is likely that infiltration on the sloped covers may be greater than horizontal covers.

At this time, it is not possible to validate the simulated results, since corresponding trial cover data are yet unavailable.

Table of Contents

List of Tables

List of Figures

List of Photographs

List of Appendices

1 INTRODUCTION

Yukon Water Resources was previously contracted by SRK Consulting (Canada) Inc. (SRK), 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 rock dumps at the Faro, Vangorda and Grum mine sites. The overall objective of the study was 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. Several phases of the project were carried out from 2003 to 2006. These are summarized by Janowicz et al. (2006; 2007a). Yukon Water Resources was also requested to conduct a water balance assessment of the recently constructed test covers at the Vangorda waste rock dump (Janowicz et al., 2007b). Since winter snow surveys were not a component of this study, a subsequent request was made to carry out a further assessment of the Vangorda trial waste rock dump covers for the 2008 snowmelt period which is summarized in this report. The approved study proposal is presented in Appendix A.

2 STUDY AREA AND SETTING

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

3 VANGORDA WASTE ROCK DUMP TRIAL COVERS

SRK Consulting (Canada) Inc. (SRK) was retained by Deloitte & Touche Inc. on behalf of the Faro Mine Closure Planning Office to assist in the development of a final closure and reclamation plan for the Anvil Range Mining Complex. A component of the plan is to develop a method of managing the acid generating waste rock dumps. One method of managing acid generating waste rock includes constructing physical material covers. SRK was tasked with developing a cover design which would reduce long-term infiltration using locally available till and glacio-fluvial materials (SRK, 2006). Six test covers were designed and constructed on the Vangorda waste rock dump in September 2004 (Figures 2 and 3). The covers have been designed to assess the performance of various configurations of the till and glacio-fluvial material in reducing infiltration. Instrumentation to measure various water balance components was installed in June 2005, and may be monitored for up to five years.

Significant work was carried out by SRK (2006) to characterize the test covers. Selected test cover characteristics are presented in Table 1.

Table 1: Vangorda Trial Cover Physical Properties

		Thickness (m)	Dry Density (kg/m^3)	Moisture* (%)	Standard Proctor Compaction (%)
CT#1	Uncompacted Till	1.8	2005	6.3	94.1
CT#2A	Uncompacted Till	1.11	2096	5.5	98.4
CT#2B	Uncompacted Till	0.75	1968	5	92.4
CT#3A	Glacio-fluvial - L1	0.45			
	Uncompacted Till - L2	1.05	1981	2.8	93
CT#3B	Glacio-fluvial - L1	0.5			
	Uncompacted Till - L2	0.6	1963	2.9	92.1
CT#4	Uncompacted Till - L1	1.79			
	Compacted Till - L2	0.5	2095	4.9	98.4

After SRK (2006) *tests carried out by EBA Engineering on August 5, 2005

Two relatively flat and horizontal covers were constructed on the top of the Vangorda dump, while four covers ware constructed on the southwestern facing graded slope. The horizontal covers, CT2A and CT2B, are 1.11 and 0.75 m thick, respectively, and consist of uncompacted till. The remaining four covers are on the graded slope, including CT1, which is 1.8 m thick and consists of uncompacted till, and CT4 which is 1.79 m thick, and consists of uncompacted till over a 0.5 m layer of compacted till. Covers CT3A and CT3B consist of glacio-fluvial material on top of a layer of uncompacted till.

Material samples were collected by Yukon Water Resources staff on September 26, 2007. Numerous samples were collected across the six test covers. The samples were integrated over 15 cm. In addition, the top 1 cm of material was sampled on covers CT2A and B. A summary of the material classification and gravimetric moisture content results are presented in Table 2.

Table 2: Vangorda Trial Cover Material Characterization

Sample #	Material Classification	[1] Moisture Content (%)
CT2A	Silty Sand	13.8
CT2As	Silty Sand	18.3
CT2B	Silty Sand	11.9
CT2Bs	Silty Sand	23.1
CT3A	Sand w/ Gravel	7.5
CT3B	Sand w/ Gravel	7.5
CT1	Silty Sand	12.3
CT4	Silty Sand w/ Gravel	11.5

s – surface sample (1cm); [1]September 26, 2007

4 WATER BALANCE DERIVATION

4.1 Cold Regions Hydrological Model Overview

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

4.2 Model Data Assembly

4.2.1 Meteorological Data

The two Vangorda cover meteorological stations were not operated during the study period; hence hourly data from the nearby VanGrum meteorological stations were used for the water balance analyses. Because of the close proximity of the stations, the VanGrum data was determined to be the most appropriate dataset for the project. A few short periods of missing VanGrum precipitation and relative humidity data were filled in using the Faro Airport meteorological station. Table 3 provides a summary of model input parameters.

Table 3: Selected VanGrum Meteorological Parameters - 2007/08

2007/2008 VANGRUM	Temp (^{0}C)	RH (%)	WindV (m/s)	Solar Rad (W/m^2)	Rain/Snow* (mm)
Sept. 1-30	3.6	76.6	2.4	88	68.3
Oct. 1-31	-3.3	85.1	2.4	44	35.4
Nov. 1-30	-8.7	81.1	2.7	18	8.2
Dec. 1-31	-14.9	82.2	2.4	6	19.3
Jan. 1-31	-16.8	76.6	2.6	12	20.1
Feb. 1-29	-15.4	73.8	2.6	39	17.3
Mar. 1-31	-8.2	65.0	2.9	109	18.9
Apr. 1-30	-2.6	61.3	2.7	180	25.6
May 1-31	5.4	58.4	2.7	213	47.6
June 1-30	8.8	59.7	2.4	225	87.8

*Period Total

The model was run from February 1 to June 30, 2008 to capture the snowmelt period (98 and 97 mm of snow water equivalent, which were simulated to accumulate between September 1, 2007 and February 1, 2008 on the horizontal and sloping covers, respectively, were added as inputs to the model). Snow surveys were carried out by Water Resources staff on April 8, 2008 (Table 4). The Faro area snowpack for this period was 133 percent of normal as indicated by the nearby Rose Creek snow course station. Four of the six covers, one horizontal and three sloped, were largely bare of snow at the time of the survey. This indicated that the snowmelt process was significantly more advanced on the Vangorda waste rock dump, as compared to the Faro and Grum dumps where the snowpack had not yet begun to melt, with the exception of south facing slopes. Snow conditions on the two Vangorda covers with remaining snow showed evidence of some melting, as indicated by the density values of 46 and 67 percent for CT2B and CT3A, respectively, as compared to the nearby VanGrum meteorological station location which had a pre-melt value of 24 percent. Ridges around the perimeter of these two covers (as compared to the others with less pronounced ridges (see photographs 1, 2 and 3)) were likely responsible for the snow cover variation between trial covers. The winter snowpack was likely greater within the ridged covers as a result of trapping of blowing snow and snowmelt process delayed by minimizing exposure to solar radiation. The meteorological data used in the analyses is presented in Appendix B.

Table 4: Vangorda Covers and VanGrum Meteorological Station Snow Survey Data - April 8, 2008

	CT2B Snow Depth (cm)	Weight Snow (cm^3 water)	CT3A Snow Depth (cm)	Weight Snow (cm^3 water)	VanGrum Snow Depth (cm)	Weight Snow (cm^3 water)
	72	26	45	16	51	19
	35		17		58	
	23		0		69	
	20		0		61	
	26		3		50	7
	33	9	17	7	54	
	27		19		54	
	30		14		45	9
	23		28	7	53	
	33	7	42		51	
	24		53	19	50	14
	25		25		50	
	20		22		60	
	17		0		62	15
	30	10	0		65	
	35	12	6		56	
	29		23	10	49	15
	29		40	16		
	60	21	10			
			12			
Mean	31.1	14.2	18.8	12.5	55.2	13.2
Density (%)		45.5		66.5		23.9
SWE (mm)		141.7		125.0		131.7

4.2.2 Physical Data

The test covers were treated as three single HRUs, horizontal till, sloped till and sloped glacio-fluvial. For soil moisture accounting purposes, the soil is handled in two layers, with the top layer representing the recharge layer. Evaporation can only occur from this recharge layer, while evapotranspiration can occur from the lower root zone layer. Since evapotranspiration is not a consideration in the test cover analyses, all soil moisture accounting occurs in the top layer (<0.5 m) of the multiple layer covers.

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

Table 5: HRU Physical Parameters

	CT2A2B	*CT1-4*	*CT3A3B*
Material	Till	Till	Glacio-fluvial
HRU Area (km^2)	0.0007	0.0007	0.0007
Latitude (deg)	62.25	62.25	62.25
Elevation (m)	1180	1160	1160
Aspect (deg)	0	199	199
Slope Angle (deg)	0	38	38
Roughness Ht (m)	0.01	0.05	0.05
Soil Class	10	7	6
Fall Soil Saturation (%)	50	85	75
Albedo	0.20	0.20	0.20

5 SIMULATION OUTPUT

The water balance simulations for the 2008 study period was carried out at 1 hour intervals using meteorological data and physical parameters as specified. The annual water balance for the three test covers is summarized in Table 6, 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 R_r is rainfall runoff (mm). Recharge represents the net change in soil and groundwater storage, and is the main component of subsurface storage.

Table 6: Vangorda Trial Cover Snowmelt Water Balance Summary (February 1 - June 30, 2008)

	Area (km^2)	**Melt (mm)**	**Rain (mm)**	**Evap (mm)**	**Inf-Snow (mm)**	**Inf-Rain (mm)**	**RO-Snow (mm)**	**RO-Rain (mm)**	**Recharge (mm)**
CT2A2B	0.0007	172	132	94	3	64	163	64	-17
CT1-4	0.0007	169	135	104	7	104	159	27	14
CT3A3B	0.0007	169	135	104	11	106	155	25	20

Though infiltration during snowmelt and rainfall events is the primary mechanism for recharge, it is not used directly in the water balance calculation but is listed in Table 6 for accounting purposes. Infiltrated water is available for evaporation and a portion of this component may later become a loss. The model simulated insignificant amounts of blowing snow and sublimation. Comparison of the Vangorda dump and VanGrum meteorological station data indicate that wind velocities are typically higher at Vangorda, and should produce greater amounts of sublimation and drifting snow (as is suggested by Photographs 1 and 2). Recharge for the study period was simulated to be -17, 14 and 20 mm, for the horizontal till, sloped till and sloped glacio-fluvial covers respectively. The horizontal cover is simulated to have a negative recharge primarily because due to the significant simulated runoff, which in reality does not leave the HRU, but is accumulated in depressions resulting in ponding. Because of the relatively impervious nature of the compacted surface, most water will likely evaporate, while a smaller portion will infiltrate over time. The model does not have an open water evaporation routine and is not able to account for the ponded water, hence the negative water balance which in reality will either evaporate or infiltrate. The greater recharge for the sloped surfaces appears to be directly related to grain size which is larger on the sloped covers due to the erosion of the fine material from the surface enhancing infiltration.

6 DISCUSSION AND CONCLUSIONS

A comparison of the 2005/06 Vangorda cover water balance summary (Table 7) was made to assess the consistency of the modeling results. Because the 2008 study period included only the snowmelt component of the annual water balance, the 2005/06 snowmelt period only is directly comparable.

Table 7: Vangorda Test Cover Water Balance Summary - 2005/06

	Area (km^2)	Melt (mm)	Rain (mm)	Evap (mm)	Inf-Snow (mm)	Inf-Rain (mm)	Run-Snow (mm)	Run-Rain (mm)	Recharge (mm)
CT2A2B	0.0007	104	220	152	33	141	0.0	55	117
CT1-4	0.0007	104	222	99	17	156	3.8	45	178
CT3A3B	0.0007	104	222	99	17	174	3.0	28	196

The 2008 snowmelt was 160 % of the 2006 melt as a result of the heavy seasonal snowpack. During 2008 93 % of snowmelt was simulated to be runoff from the sloped surfaces as compared to 3 % in 2006. This is likely a result of an early and rapid melt on a surface that was saturated, due to a late fall rainfall, prior to freeze-up. Fall precipitation during 2007 was 165 % of 2005 at the VanGrum meteorological station and air temperatures during September and October were lower. Snowmelt infiltration is fairly minor in both years, though greater during the low snowmelt year. Simulated snowmelt infiltration represented 19 and 16 % of snowmelt for the horizontal and sloped covers respectively during 2006, and, 2 and 5 % during 2008. As with runoff the relatively low simulated infiltration during 2008 is likely a result of saturated fall conditions reducing the infiltration opportunity time.

Simulated evaporation during 2005/06 was 47 and 30 % of combined snowmelt and rainfall for the horizontal and sloped covers respectively, while, during the partial 2008 season, these values were 31 and 34 %. The difference here can be attributed to the greater amount of rainfall, relative to the total water input in 2006. The rainfall provides water to the surface in a repeated manner during the active evaporation season, whereas the melt generally provides a one-time input which is more prone to runoff as was the case in 2008.

Recharge during the partial 2008 season was significantly less than 2005/06, but this parameter is not readily comparable because of variable time period.

Water balance analyses were carried out for horizontal till, sloped till and sloped glacio-fluvial test material covers of the Vangorda waste rock dump. The analyses were carried out for the February 1 to June 30, 2008 period to capture the spring snowmelt event. The 2007/08 snowpack for the area was relatively high, as represented by the Rose Creek snow course station, which had an April 1 snow water equivalent which was 133 percent of normal. The following relationship was used to calculate the annual water balance for the test covers:

$$R_e = S + R – E – R_s - R_r$$

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 R_r is rainfall runoff (mm). Each of the components of the water balance was simulated using CRHM.

Simulated rainfall and snowmelt for the study period are similar for the three test covers.

Simulated evaporation is slightly greater for the sloped covers as compared to the horizontal covers due to greater energy on the southwest facing slope and greater amounts of available water.

Simulated infiltration and runoff appear to be related to material grain size as would be expected, with infiltration amounts directly related to, and runoff rates inversely related to material size, except for runoff from the horizontal covers. Infiltration to the sloped till and glacio-fluvial covers, is greater relative to the horizontal covers, because of the more permeable nature of the material. The glacio-fluvial material is coarser and more permeable than the till. Placed on the sloped surfaces, both materials have undergone some erosional modifications with the surface fines eroded from the sloped cover, and rills and gullies established, increasing permeability over that of the horizontal covers.

Rainfall infiltration is simulated to be generally greater than snowmelt infiltration, because of the greater volume of rain, and likely a greater ability of the rainwater to infiltrate material which is less frozen during this period.

The significantly large runoff values for the horizontal covers are anomalous, due to limitations of the model. Except for some nominal runoff from the edges, very little runoff would be expected to occur from the horizontal covers. The significantly large runoff values listed in Table 6 represent water that is available for runoff, but because the covers are relatively flat and horizontal, snowmelt and rainfall water would drain to, and pond in surface depressions. At this point in time, CRHM is not configured to deal directly with ponded water. This would require the flat HRU be further subdivided into "ponded water" and "exposed" soil surfaces, and, it would also require a routine for the determination of the relative size or distribution of this ponded water. Technically, the "runoff" component on the flat surfaces becomes "surface storage", which would eventually be distributed between evaporation and infiltration. The relative importance of these two components of "ponded water" will depend on the size and distribution of the surface depression features. Because of the relatively impervious nature of the horizontal surface, most water will likely evaporate, while a smaller portion will infiltrate over time. At this point in the analysis, the "runoff" component from the flat surfaces is accounted for in the recharge calculation.

Recharge for the study period was simulated to be -17, 14 and 20 mm, for the horizontal till, sloped till and sloped glacio-fluvial covers respectively. The horizontal cover is simulated to have a negative recharge primarily due to the significant simulated runoff, which in reality does not leave the HRU, but is accumulated in depressions resulting in ponding. The model does not have an open water evaporation routine and is not able to account for the ponded water resulting in the negative water balance. In reality the ponded water will either evaporate or infiltrate likely resulting in a positive water balance. The greater recharge for the sloped surfaces appears to be directly related to grain size which is larger on the sloped covers due to the erosion of the fine material from the surface enhancing infiltration.

The simulated results provide an assessment of recharge to the Vangorda waste rock dump trial covers for the February 1 to June 30, 2008 study period which largely represents the snowmelt period. In terms of cover performance the simulated results indicate that snowmelt infiltration is significantly less than snowmelt runoff. As with most natural surfaces this is largely governed by the cover characteristics and by the antecedent moisture conditions. It is likely that infiltration on sloped covers may be greater than on the horizontal covers.

At this time, it is not possible to validate the simulated results, since corresponding trial cover data are yet unavailable.

8 REFERENCES

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FIGURES

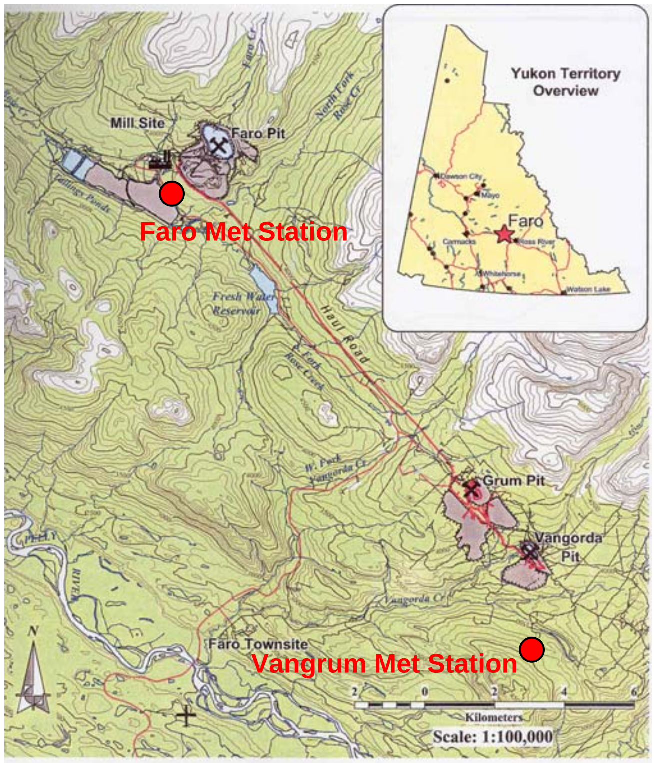


Figure 1: Location Plan (from Gartner Lee Ltd., 2002)

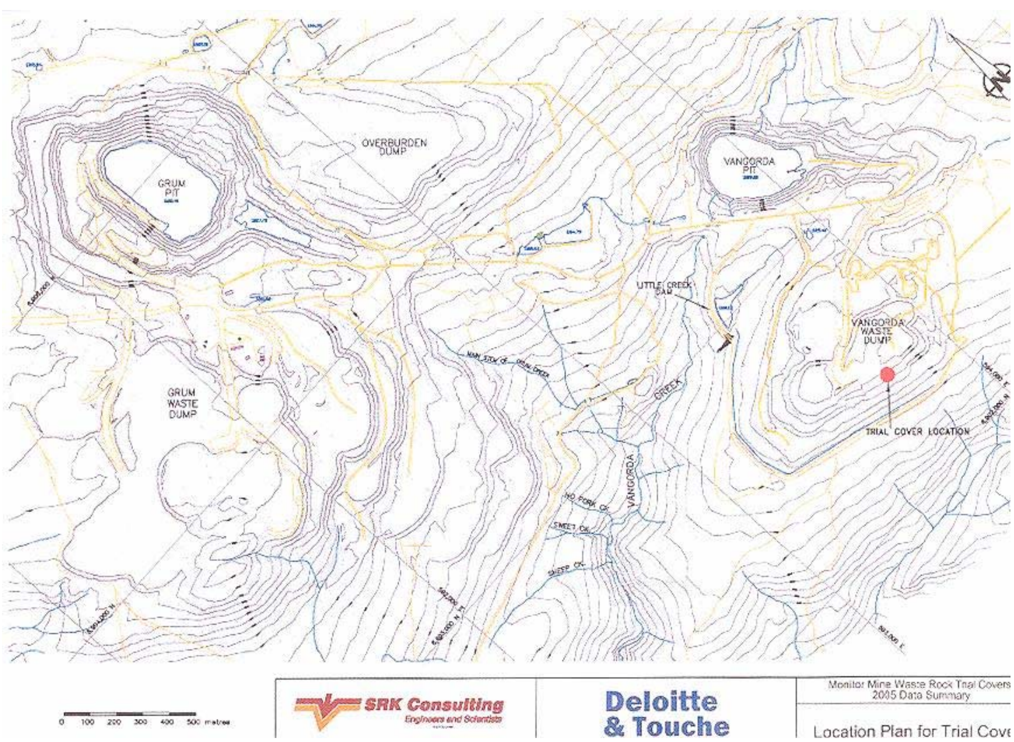
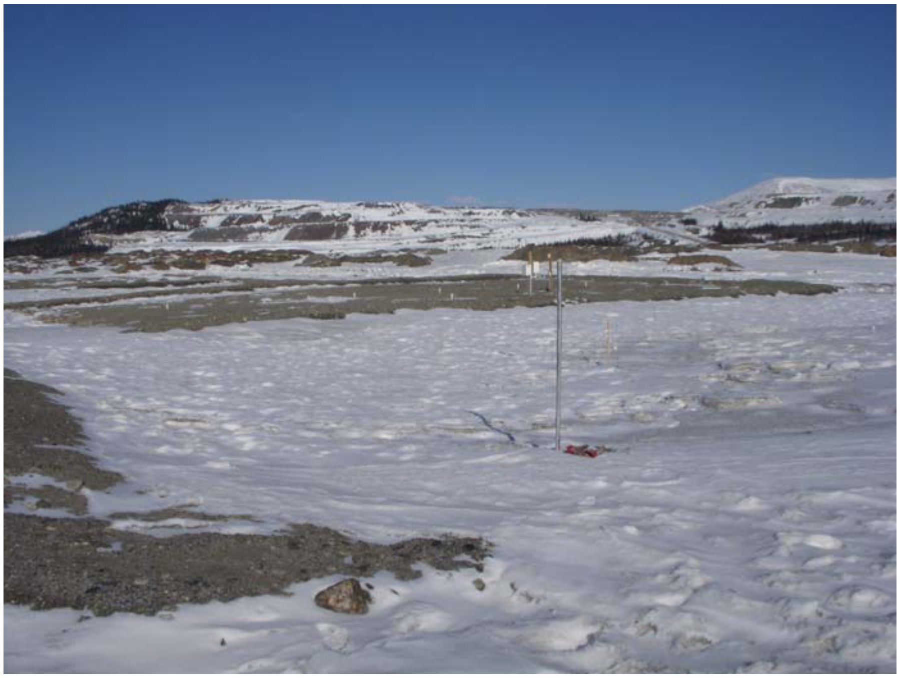


Figure 2: Vangorda Test Covers Location (from SRK, 2006)

Figure 3: Vangorda Test Cover Locations (from SRK, 2006)

PHOTOGRAPHS



Photograph 1: Cover CT2B (with snow) with CT2A in Background

Photo 2: Trial Cover CT3A

Photo 3: Vangorda Trial Cover CT3B

APPENDIX A

WORKPLAN

INVESTIGATION OF ANVIL RANGE MINING CORPORATION (FARO) WASTE DUMP WATER BALANCES – 2007/08

Task 1: Maintain Faro and Vangrum meteorological stations
- 1.1 Service, inspect and repair if required Faro and VanGrum meteorological stations
- 1.2 Upgrade precipitation instrumentation[1]

Task 2: Refine water balance for Vangorda trial covers[2]
- 2.1 Carry out pre-freeze up soil moisture surveys
- 2.2 Carry out winter and spring snow surveys
- 2.3 Refine Vangorda trial cover water balance estimates based on Vangorda meteorological data and CHRM model
- 2.4 Consider adapting infiltration module for coarse material (waste rock)

Task 3: Final Report
- 3.1: Write draft final report
- 3.2: Make modifications to final report based on review comments

1 Capital cost $10,000 per station
2 Modelling the 2008 snowmelt event would require the project to extend through the fiscal year to December 2008

APPENDIX C

CRHM INPUT METEOROLOGICAL DATA

Electronic Copy Available Upon Request