Investigation of Predictions for Acidic Drainage at Vangorda Mine (Faro, Yukon Territory)

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CCSG Associates

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Investigation of Predictions for Acidic Drainage at Vangorda Mine (Faro, Yukon Territory)

1.0 Introduction

For several decades, governments and mining companies have recognized mine acidic drainage as a considerable maintenance, management, environmental and financial challenge at many mines in Canada, both during mine operation and closure processes. This recognition led to the development of methodologies for predicting the magnitude of acidic drainage expected from proposed mining projects. Beginning in the 1980s, such predictions became a familiar component of mine development proposals. The Mine Effluent Neutral Drainage program has provided a focus for developing and refining the predictions.

Accurate prediction is crucial to appropriate planning and mine design, and increases efficiency while minimizing the expense of development. Future environmental consequences can be ameliorated by more accurate predictions of effects which will lead to a better understanding of management needs and up-front planning.

Because predictions have been utilized for many years, some projects that included pre-development predictions have now reached post-development and closure phases. Monitoring data and, in some cases, post-development predictions are now available for comparison with the initial predictions. These projects offer an opportunity to evaluate the accuracy of initial predictions and identify reasons for variation between predictions and outcomes.

This report investigates predictions of mine acidic drainage made during project development and evaluates the variances that occurred during operation and post-operation phases.

The objectives of this report are:

1) To review predictions and outcomes for mine acidic drainage at Vangorda mine.
2) To compare the models and data used in prediction and evaluate the effectiveness of the process.
3) To assess assumptions and trends in data analysis to improve predictive capability for mine acidic drainage.
4) To identify possible reasons for variances between predictions and outcomes.

This report reviews pre-approval modeling predictions for mine acidic drainage and compares this with monitoring data and post-development modeling predictions. The pits and waste rock at the Vangorda/Grum component of the Faro Mine are reviewed as the primary components of the case study.

2.0 Site Description

2.1 Development History

The Vangorda/Grum mine site is a lead/zinc open pit mine located near Faro, Yukon Territory. The project developed an Initial Environmental Evaluation during 1988-1990. Curragh Resources, the project developer, recognized that acidic drainage would be a significant concern for this mine and incorporated predictions within its environmental assessment and permitting documentation. Curragh Resources proposed several measures to minimize and address the effects of acidic drainage. Experience at the adjacent Faro Mine, opened in the late 1960s, provided some guidance about conditions that could be expected.

The Vangorda deposit was mined in 1990-93. It closed during 1993-4, during which time DIAND took over care and maintenance. At this time, the pit was allowed to start filling, water treatment was stopped, the Vangorda collector ditch was constructed (to collect seepage from the Vangorda Waste Rock), the waste rock was re-sloped and a partial till cover was added on the re-sloped area.

Anvil Range Mining Corporation began mining in 1994. Mining of the Vangorda Mine continued until early 1998. Anvil Range also mined the Grum deposit, beginning in 1994 and continuing until mine closure in 1998. Initial stripping of the Grum deposit began under Curragh Resources.

Anvil Range Mining Corporation has been in bankruptcy protection since 1998. Closure planning for the site is now underway under the Joint Type II Mines Office (Yukon Government and Indian and Northern Affairs Canada). The interim receiver, Deloitte and Touche Inc., is responsible for care-and-maintenance.

2.2 Site Components

The Vangorda/Grum Mine includes five principle sources of potential contamination including two pits and three waste rock dumps. One of these, the Grum Overburden Dump, is not expected to be a significant contaminant source. The general site layout is shown on Figure 1, repeated from the 2006 Water Licence Annual Environmental Report.[1] Some components are also shown on Photo 1.

The Vangorda Pit is approximately 1.15 km long, 350 m wide and 150 m deep at the deepest point. It covers an area of approximately 17 ha. The 1989 project description estimated approximately 6.0 x 10^6 tonnes of ore in the Vangorda Pit.

[1] GLL, 2007

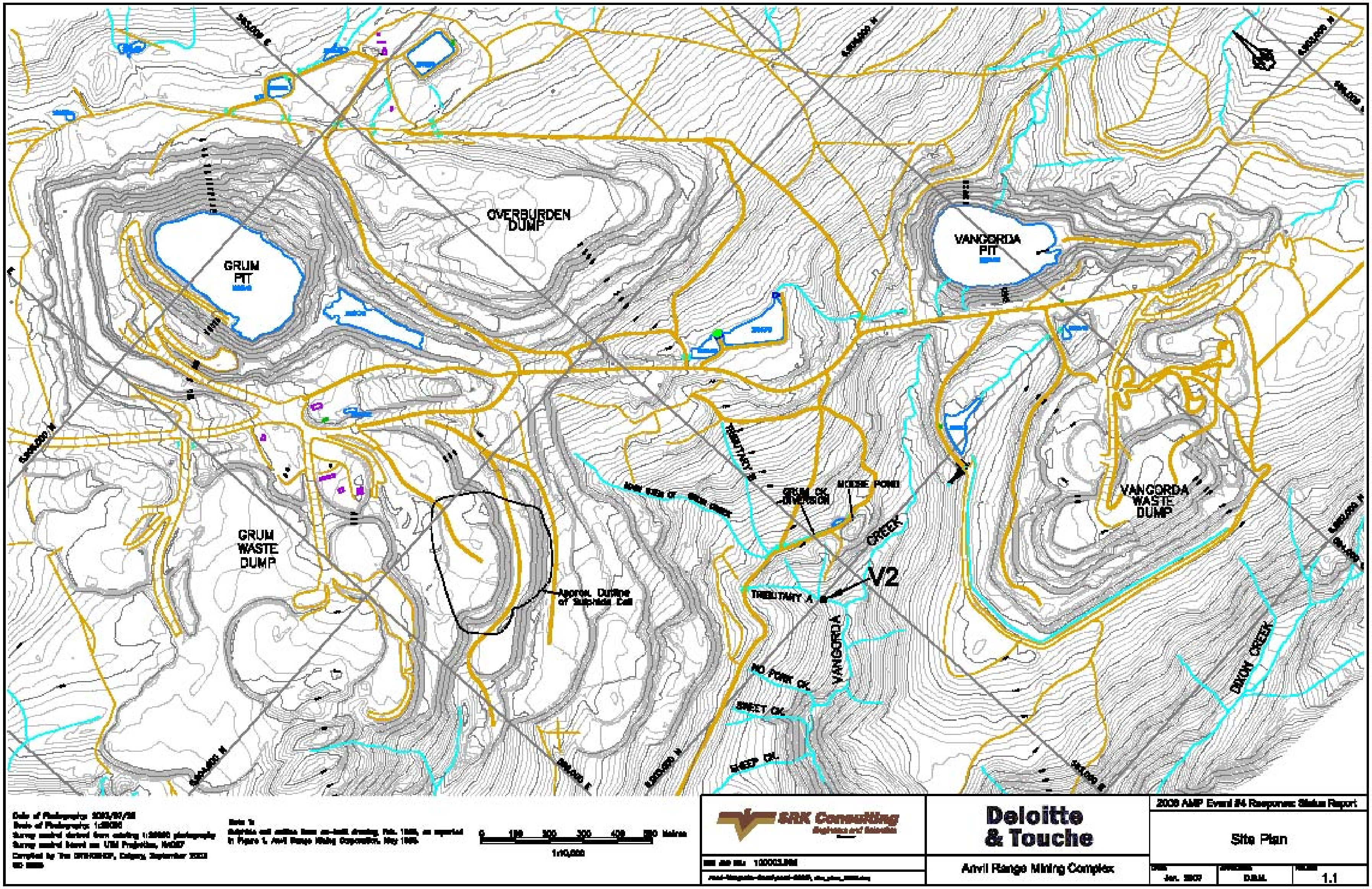

Figure 1: Vangorda/Grum Mine Site Plan – GLL, 2007

The Grum Pit covers an area of approximately 800 m long and 700 m wide with an area of approximately 28 ha. It is approximately 180 m deep at its deepest. The 1989 project description estimated approximately 24.0 x 10^6 tonnes of ore in the Grum Pit. Mining did not recover all of this ore. Primarily only the first phase of mining described in 1989 was completed.

Photo 1: Vangorda/Grum Mine Site – September 2005

Waste rock from the pits was placed in three main waste rock dumps. The Vangorda Waste Rock Dump is located southwest of the Vangorda Pit within the drainage of Vangorda Creek. The main Grum Waste Dump is located south of the Grum Pit and drains primarily to Grum Creek and Vangorda Creek. One lobe of the dump, sometimes referred to as the Southwest Dump drains to AEX Creek, a tributary of West Vangorda Creek which is in turn a tributary of Vangorda Creek. The Grum Overburden Dump is located southeast of the Grum Pit and contains overburden material from the surface of the Grum Pit.

1990 estimates of waste rock quantities for Grum and Vangorda waste are provided in Table 1.

Table 1: Pre-Development Waste Rock Quantity Estimates[2]

Rock Type	Grum Pit		Vangorda Pit	
	Volume (m^3)	Mass (t)	Volume (m^3)	Mass (t)
Till Overburden	13.3×10^6	27.9×10^6	3.1×10^6	6.5×10^6
Sulphide Waste Rock	2.2×10^6	6.3×10^6	1.2×10^6	3.4×10^6
Phyllite Waste Rock	52.5×10^6	151.5×10^6	2.1×10^6	6.2×10^6

Notes: 1. All quantities in bank cubic metres.
2. Mine planning assumed a bulking factor of 1.3.

Gartner Lee Ltd. (GLL, 2002) and Robertson Geoconsultants (RGC, 1996) provide "as-built" quantities of waste rock for Grum and Vangorda waste rock dumps (Table 2).

Table 2: As-Built Waste Rock Quantities

Rock Type	Grum Pit (x 10^6 tonnes)[3]			Vangorda Pit (x 10^6 tonnes)[4]		
	Main and Southwest	Over-burden	Total	Main Dump	Other Dumps	Total
Till Overburden		24.0	24.0			
Sulphide Waste Rock	3.8		3.8	3.0	0.8	3.8
Phyllite Waste Rock	146.3		146.3	16.0		16.0

In 2002, SRK began investigations of waste rock to support renewed closure planning initiatives. As part of its investigations, SRK estimated waste rock quantities. The 2002 as-built quantities are substantially higher than SRK's estimates of waste rock quantities at Vangorda (9.6×10^6 vs. 19.8×10^6 tonnes) and Grum (28×10^6 vs. 174.1×10^6 tonnes)[5]. For the Grum Waste Rock, there is significant discrepancy between the 2003 estimates of waste rock quantities and the original mine plan which is reflected in the 2002 "as-built" quantities. The original mine plan proposed excavation of approximately 75×10^6 tonnes in phase one of the Grum Pit. The 2003 estimates for Grum appear to only consider sulphide and phyllite waste. Since only phase one was completed, it appears that the 2003 estimate of approximately 28×10^6 tonnes likely most accurately reflects the size of the Grum Main Waste Rock Dump, though this is difficult to confirm.

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[2] Sources: Volumes – CRI, 1990-1 ss. 3 and 4. Densities derived from CRI 1989 ss. 2.4.3 and 2.4.4.
[3] GLL, 2002, s. 3.3.2
[4] RGC, 1996, p. 5-18
[5] CRI, 2004-1, p.7

3.0 Study Methods

Pre-development through to current post-operations monitoring data are available. Pre-mining predictions estimated contamination associated with acidic drainage for operations and abandonment phases of the project. Post-operations modeling has been compiled to predict acidic drainage conditions in the future.

This study compares the pre-development predictions, operational and post-operational monitoring data, and post-operational predictions. The study considers predictions for background flows, background water quality, source flows and source water quality because all are key components in estimating overall contaminant loading and concentrations in the environment. The predictions at different time frames and longer term source and downstream water quality have been compared for evaluating effectiveness in prediction.

Pre-development predictions focused on analysis of zinc as an indicator of water quality. Zinc has been the primary contaminant of concern at the site, though other contaminants also warrant consideration. This study also focuses on comparisons of predictions related to zinc.

There is a range of monitoring data available for surface and ground water, sediment, invertebrate and fish biology, pit and waste rock source data. The quality of sampling and analysis protocol vary widely. This study focuses on water quality data because it provides the most direct relationship to acidic drainage from mine contaminant sources.

4.0 Prediction Methodology and Results – Pre-Development

The following section describes pre-development monitoring data as well as water quality models and predictions of contaminant loading for the Vangorda/Grum Mine. Four main sources of loading were addressed in the modeling: Grum Pit, Vangorda Pit, Grum Waste Rock (Main Dump) and Vangorda Waste Rock.

Pre-development predictions of water quality impacts from the Vangorda and Grum Mine developments relied on a water and load balance model. The model predicted contaminant loading from key sources that included pits, sulphide cells and waste rock dumps. While the impact assessment considered construction, operation and abandonment phases, the assessment of metal contaminants using the model was limited to the operation and abandonment phases. For the abandonment phase, the project proposal recognized three different phases of water quality impacts associated with the proposed filling of the Vangorda Pit. The model was only used to predict long-term steady-state conditions.[6,7]

[6] CRI, 1989, Chapter 5

Prediction of overall loading in the receiving environment required estimates of loading from each mine component. Developing the specific source loading estimates relied on inputs for predicted pit wall seepage rates, pit wall seepage contaminant concentrations, waste rock infiltration rates and waste rock seepage contaminant concentrations. The model predicted loading on a monthly basis, requiring additional inputs describing the seasonal variation in flow rates and contaminant concentrations. Methodologies and approaches for predicting flow rates, contaminant concentrations and seasonal patterns are detailed below.

Prediction of potential effects on the aquatic environment required consideration of both mine loading and natural sources of contaminants. The model did not directly incorporate flows, concentrations and loads from natural sources, but they were considered additively for interpreting overall environmental loading and concentrations.

4.1 Loads from Natural Sources

4.1.1 Streamflow

Pre-development estimates of receiving water contaminant concentrations and loads considered two locations on Vangorda Creek: the mouth and the mine site ("at the diversion"). DIAND began operating an automatic recording station in lower Vangorda Creek in 1977. The facility operated only during ice-free periods.

Because of the limited data, estimates of monthly streamflow relied on records from nearby long-term gauging stations. Pelly River Below Vangorda (22,100 km^2, 15 years of record) and Ross River (7,250 km^2, 27 years of record) stations formed the basis for the analysis. Flow rates on Rose Creek from a single year of record (1968) were also considered. The mean monthly discharges and yields during common periods of record in 1985 (June – September) were used to develop a correlation between Pelly River, Ross River and Vangorda Creek. These correlations were then applied to the historical mean monthly discharges and yields for each watershed to develop estimates of flow rates for Vangorda Creek. Estimates for Vangorda Creek at the mine site were proportional to the area within the overall Vangorda Creek watershed – no further adjustment of area/yield relationships was applied. Pre-development estimates of mean monthly discharge for the two Vangorda Creek stations are presented in Table 3.

Pre-development consideration of extreme flow events considered peak flows (for design of physical structures) but did not consider extreme low flow events for evaluating worst case contaminant concentration conditions.

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[7] CRI, 1990-1, Chapter 7

Table 3: Pre-Development Estimates – Mean Monthly Discharge (x1000 m^3)[8]

Month	Vangorda Creek at Faro 90.8 km^2	Vangorda Creek at Diversion 17.7 km^2
January	241	54
February	220	49
March	241	54
April	233	52
May	4634	911
June	5884	1140
July	3161	616
August	2678	509
September	2125	415
October	1446	295
November	700	130
December	482	107
Annual	22045	4330

4.1.2 Background Water Quality and Natural Loads

Curragh Resources began water quality monitoring in Vangorda Creek in 1987, though some earlier monitoring had been completed by other companies and agencies prior to this. For the evaluation of water quality impacts, Curragh relied on mean annual zinc concentrations in lower Vangorda Creek (V8 – Vangorda Creek Below Faro) and Vangorda Creek below the mine site (V10 – Vangorda Creek 100 m below Shrimp Creek Confluence).

Water quality data for V8 included 22 samples collected between June 1987 and March 1989. For V10 there were 14 samples collected between October 1987 and March 1989. Most samples were collected during open water periods though there are some data from winter.

Water quality in Vangorda Creek periodically showed concentrations elevated above CCME Guidelines for the Protection of Freshwater Aquatic Life levels for copper, iron, lead, zinc and total suspended solids at the reference station V1, and also downstream at stations V8 and V10.[9] Zinc concentrations were relatively low on average at reference station V1 (average 0.014mg/L zinc, maximum 0.1mg/L zinc), station V8 (average 0.017mg/L zinc, maximum 0.052mg/L zinc) and station V10 (average 0.019mg/L zinc, maximum 0.04mg/L zinc).[10] A full data set of metals was not analysed in this time-frame, which makes analysis difficult.

[8] Source: CRI, 1989, s. 3.2.1.2
[9] CRI, 1989, Tables A-16, A-25, A-26
[10] CRI, 1989, Tables A-16, A-25, A-26

The pre-development analysis calculated mean annual contaminant concentrations using a combination of extractable metals analyses and total metals analyses. These mean values were calculated directly from sample concentrations, with no consideration of weighting for flow rates. The annual average concentrations of contaminants were combined with estimates of annual average flow rates to develop estimates of annual average contaminant loads. For predicting total contaminant concentrations in receiving water, these loads were assumed to be evenly distributed throughout the year.

At V8 for example, the average zinc concentration was 0.16 mg/l with a monthly average flow (based on total annual average flow) of 1.864×10^6 m^3 resulting in a monthly zinc load estimate of 30 kg from natural sources. Using the same methodology, the monthly zinc load estimate at V10 was 11 kg. These loads were considered additively with source loads to estimate total loading and concentrations at receiving water locations.[11]

4.2 Loads from Mine Related Sources

4.2.1 <u>Flow Rates - Pits</u>

Prediction of water quality loads required estimates of flow rates into pits. The model considered loading from pits due to two components: seepage into pits and runoff into pits.

Estimates for pit seepage rates relied on theoretical analyses using simple well formulae. Seepage flow distribution was based on rainfall data and seepage flow records from Faro.

The results were compared with data from the Faro Pit. For Grum Pit during operation, the estimate assumed that 75% of total seepage was intercepted by wells above the pit walls. During the abandonment phase, the estimates assumed that the wells would no longer be in operation. As a result, post-abandonment seepage estimates for Grum Pit are higher than operational estimates even though the estimates assume that the post-abandonment pit will be full of water.

For the Vangorda Pit, seepage was estimated for three different pit wall areas to allow differentiation in both flow rates and contaminant concentrations. The estimates assumed that pumping of pit walls would not be necessary. The 1989 Initial Environmental Evaluation (IEE) predicted that the north wall of the Vangorda pit would have the greatest flows and consequent zinc load.[12] Flow nets indicated water seeps would enter pit at NE slopes and partial dewatering of slopes would result. Post-abandonment seepage rate predictions were lower because they assumed that the pit would be filled with water.

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[11] CRI, 1990-1, p. 2-2
[12] CRI, 1989, Table A-46

Runoff into pits was calculated using the mean monthly unit runoff rates that were applied to the overall Vangorda Creek watershed. This unit runoff was applied to areas below proposed diversion structures. Seasonal distribution was based on the Vangorda Creek unit discharge distribution.

Pre-development runoff and seepage estimates for Vangorda and Grum pits are summarized in Table 4.

Table 4: Seepage and Runoff Flow Into Pits (x 1000 m^3)[13]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vangorda Pit Operations												
Runoff	1.45	1.31	1.45	1.41	24.70	30.93	16.71	13.80	11.25	7.99	3.51	2.91
Seepage A 1	1.90	1.72	2.38	4.15	15.24	11.06	8.57	8.09	5.99	3.33	0.46	0.48
Seepage A 2	0.95	0.95	1.19	2.14	7.62	5.71	4.29	4.05	3.10	1.67	0.24	0.24
Seepage A 3	6.67	6.67	8.33	15.00	53.33	40.00	30.00	28.33	21.67	11.67	1.67	1.67
Total Seepage	9.52	9.34	11.9	21.29	76.19	56.77	42.86	40.47	30.76	16.67	2.37	2.39
Vangorda Pit Abandonment												
Runoff	4.48	4.04	4.48	4.34	76.15	95.36	51.50	42.55	34.68	24.64	10.83	8.95
Seepage A 1	1.16	1.04	1.16	2.15	9.64	6.76	5.37	5.07	3.82	2.29	0.52	0.54
Seepage A 2	0.46	0.42	0.46	0.88	3.86	2.70	2.15	2.03	1.53	0.92	0.21	0.21
Seepage A 3	2.31	2.09	2.31	4.41	19.28	13.51	10.75	10.14	7.65	4.59	1.04	1.07
Total Seepage	3.93	3.55	3.93	7.44	32.78	22.97	18.27	17.24	13	7.8	1.77	1.82
Grum Pit Operations												
Runoff	2.88	2.60	2.88	2.78	48.88	61.21	33.06	27.31	22.26	15.81	6.96	5.75
Seepage	10.71	9.68	13.39	23.33	85.71	62.21	48.21	45.53	33.70	18.75	2.59	2.68
Grum Pit Abandonment												
Runoff	8.94	8.05	8.94	9.64	151.8	190.1	102.7	84.81	69.12	49.12	21.59	17.85
Seepage	10.71	9.68	13.39	25.92	88.39	64.80	50.89	48.21	36.29	21.43	5.18	5.36

Source: SRK Jul 89, App A

4.2.2 Flow Rates - Waste Rock

Pre-development estimates of seepage and runoff flow rates from waste rock were developed using the HELP (VII) computer model. As with the pits, estimates were developed for operation and abandonment phases.

The HELP model uses climatologic, soil and design data to produce daily estimates of water ovement across, into, through and out of landfills. In the model, the runoff estimate is estimated by using the Soil Conservation Service Runoff Curve Number method, while percolation and vertical water routing are estimated using Darcy's Law for saturated flow with modifications for unsaturated

[13] CRI, 1989, Appendix A

conditions. Additional analytical methods are used to estimate lateral drainage and evapo-transpiration.

Estimates for the operational phase assumed that no covers were in place on waste rock dumps and, as a result, there would be no runoff. For these conditions, the results of the HELP model estimated that evaporation and infiltration represented 63% and 37% respectively of the total annual precipitation.

For abandonment, the modeling assumed that the Vangorda Dump and the Grum Sulphide Cell would be covered with three metre thick till covers consisting of 2 m of moderately compacted (90% Modified Proctor) till underlain by 1 m of normally compacted till (93% Modified Proctor).[14] The remaining areas of the Grum Dump were to remain uncovered. For covered areas, the modeling considered five layers for the abandonment estimates: moderately compacted upper till layer, barrier till layer, waste rock, lateral drainage layer representing toe drains, and the underlying till layer. Inputs assumed hydraulic conductivities for the cover till layers were 1.4×10^{-6} cm/s and 1.0×10^{-6} cm/s for the upper and lower layers respectively. The in-situ till was assumed to have a conductivity of 1.0×10^{-8} cm/s. With these assumptions, the HELP model predicted that infiltration, evaporation and runoff for covered areas would be 10%, 55% and 35% respectively of the total annual precipitation. These assumptions were applied to both the Vangorda Dump and the Grum Sulphide Cell, though there was no till underlying the Grum Sulphide Cell and the design did not incorporate plans for toe drains.

Runoff distribution for waste dumps was based on the Vangorda Creek unit discharge distribution. This same distribution formed the basis for estimating seasonal distribution of infiltration, but these values were adjusted after considering recorded seepage flows from waste dumps at Faro.

The modeling assumed that steady state infiltration would be equal to long-term flows from the base of the dumps – calculated as the sum of lateral drainage and percolation. Pre-development estimates of runoff and infiltration from waste rock dumps are summarized in Table 5.

[14] CRI, 1990-1, p. 7-7

Table 5: Runoff and Infiltration Estimates for Waste Rock Dumps (x 1000 m^3)[15]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vangorda Waste Rock – Operations												
Runoff	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Infiltration												
Sulphide	0.68	0.68	0.91	1.12	7.55	10.46	6.31	5.29	4.25	3.42	1.12	1.12
Phyllite	0.74	0.74	0.99	1.22	8.19	11.34	6.84	5.74	4.61	3.71	1.22	1.22
Total	1.42	1.42	1.9	2.34	15.74	21.8	13.15	11.03	8.86	7.13	2.34	2.34
Vangorda Waste Rock – Abandonment												
Runoff												
Sulphide	0.49	0.44	0.49	2.08	6.68	10.37	5.60	4.63	3.77	2.68	1.18	0.97
Phyllite	0.53	0.48	0.53	2.25	7.24	11.25	6.07	5.02	4.09	2.91	1.28	1.06
Total	1.02	0.92	1.02	4.33	13.92	21.62	11.67	9.65	7.86	5.59	2.46	2.03
Infiltration												
Sulphide	0.27	0.27	0.29	0.71	2.16	2.57	1.54	1.35	1.14	0.93	0.50	0.29
Phyllite	0.29	0.29	0.32	0.77	2.34	2.79	1.67	1.46	1.24	1.01	0.54	0.32
Total	0.56	0.56	0.61	1.48	4.5	5.36	3.21	2.81	2.38	1.94	1.04	0.61
Grum Waste Rock – Operations												
Runoff	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Infiltration												
Sulphide	0.17	0.17	0.23	0.28	1.89	2.62	1.58	1.33	1.07	0.86	0.28	0.28
Other	3.76	3.76	5.02	6.16	41.50	57.46	34.66	29.07	23.37	18.81	6.16	6.16
Total	3.93	3.93	5.25	6.44	43.39	60.08	36.24	30.4	24.44	19.67	6.44	6.44
Grum Waste Rock – Abandonment												
Runoff												
Sulphide	0.14	0.13	0.14	0.60	1.93	3.00	1.62	1.34	1.09	0.78	0.34	0.28
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.14	0.13	0.14	0.60	1.93	3.00	1.62	1.34	1.09	0.78	0.34	0.28
Infiltration												
Sulphide	0.08	0.08	0.08	0.20	0.62	0.74	0.44	0.39	0.33	0.27	0.14	0.08
Other	4.26	4.26	5.68	6.97	46.96	65.02	39.22	32.90	26.45	21.29	6.97	6.97
Total	4.34	4.34	5.76	7.17	47.58	65.76	39.66	33.29	26.78	21.56	7.11	7.05

4.2.3 Source Geochemical Characterization - Pits

The 1989 IEE describes the sulphide rock types as containing a range of both sulphide (2-60%) and pyrite (2-60%).[16] The sulphide waste was predicted to have no ore value and the 1989 IEE plan indicated that it would be sent to waste rock-dumps and remain in pit walls.[17] The altered phyllite had sulphide stringers and was consider to contain only minor sulphides. This material was expected to only rarely classify as ore. Even though they contained some sulphides, the 1989 IEE plan stated that these materials could not be readily or reliably differentiated from unaltered phyllites and therefore would be excluded from sulphide waste unit.[18]

[15] CRI, 1989, Appendix A
[16] CRI, 1989, P. 2-7
[17] CRI, 1989, P.2-9
[18] CRI, 1989, P. 2-9

The Vangorda Pit wall characterization in 1996 shows:

- altered phyllites in the upper north east,
- carbonaceous phyllite with moderate to weak acid generation in the north west (iron, but not zinc, is present from weathering),
- phyllites in the south west, and
- sulphides in the south east narrow slot.[19]

At this time, it was estimated that the pit wall was 30% sulphides, 60% phyllites and 10% carbonaceous phyllites.[20]

Photo 2: Vangorda Pit, September 2005

[19] RGC, 1996, Volume 2, p. 5-10
[20] RGC, 1996, Volume 2, p. 5-13

4.2.4 Source Geochemical Characterization – Waste Rock

Pre-development characterization of waste rock at Vangorda/Grum partially relied on comparison with waste rock at the Faro Mine. A comparison of Faro and Vangorda mineralogy is provided in Table 6.

Table 6: Mineralogy of Faro and Vangorda Deposits[21]

	Faro	Vangorda
Deposit form	thick horizon, less phyllitic waste, substantial barren sulphide waste banding	several distinct, highly contorted horizons separated by barren phyllite waste
Grain size	Coarse grain, low gold content	Fine grain size, complex mineral intergrowth req. finer grinding, 8x higher gold

The 1989 IEE described of the Units of suphide rock types for acid potential based on sulphide content (Units 4E>4G> 4H> 4A in a range of 2-60% sulphide).[22] The Units 4B,C,D were estimated to have a lower acid potential and a range of 2-60% pyrite.[23] This sulphide waste was to be deposited in the Vangorda waste dump during production.[24] The 1989 IEE plan proposed that the Unit 4L altered phyllite with sulphide stringers, and minor sulphides of Unit 4E would be deposited in the phyllite cell.[25]

Overall, the pre-development proposal concluded that heterogeneous waste rock at Vangorda, both in distribution of sulphide type and amount, changes character significantly over short lengths of drill core. Similarly, the carbonates type and amount change character over short ranges.[26]

The content of the Vangorda mineralogy was described as follows:

Sulphides:
Pyrite - FeS_2
Pyrrohtite - FeS

Carbonates:
Calcite - $CaCO_3$
Dolomite - $CaMg(CO_3)_2$
Ankerite - $Ca(Fe,Mg,Mn)(CO_3)_2$

Altered Phyllite:
Chlorite - $(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$

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[21] CRI, 1989, P. 2-5
[22] CRI, 1989, P. 2-7
[23] CRI, 1989, P. 2-8
[24] CRI, 1989, P.2-9
[25] CRI, 1989, P. 2-9
[26] CRI, 1989, P. 2-62

Muscovite - $KAl_2(AlSi_3O_{10})(OH)_2$,
Kaolinite - $Al_2Si_2O_5(OH)_4$
Quartz - SiO_2
Other constituents that may be in micaceous rock -Calcium (Ca), barium (Ba), rubidium (Rb), and cesium (Cs) can substitute for sodium (Na) and potassium (K); manganese (Mn), chromium (Cr), and titanium (Ti) for magnesium (Mg), iron (Fe), and lithium (Li).
Feldspar - silicates of aluminum that may contain potassium, sodium, calcium or barium.

Photo 3: Grum Dump, June 2005

4.2.5 Geochemical Predictions – Modeling Approach

The pre-development modeling for contaminant concentrations did not attempt to analyze the ARD chemical reactions. Instead, it relied on ongoing monitoring results from the Faro Mine site and results of some humidity cell tests. No specific details are provided about the relationships between the empirical data and the estimates used in modeling. The project documentation included detailed results for the humidity cell tests, but no details of the seepage data from the Faro Mine Site.

In addition to estimating the average contaminant concentrations in seepage, the modeling assumed that these concentrations would vary through the year. This observation arose from the preliminary seepage data at the Faro Mine Site. The distribution of monthly concentrations in the model relied on calculation of monthly proportions of the overall annual load. Proportioning on the basis of load was necessary as both flow and concentrations were varied through the year. The methodology relied on calculating an Annual Mean Monthly Concentration (AMMC) defined as the total annual metal loading divided by the total annual discharge. The proportion selected for each month was based on distributions derived from preliminary Faro seep data.

The selected profile applied a contaminant concentration peak in April for both pit walls and waste rock, reflecting flushing of accumulated soluble metal salts by snow melt. For pit walls, these peak concentrations were assumed to decline gradually through the summer and fall. For waste rock, the April peak concentrations were assumed to decline rapidly to a relatively constant summer level – reflecting higher summer flows after the spring flush, providing dilution for the salts produced each summer.

4.2.6 Geochemical Predictions – Pits

Pre-development estimates of contaminant concentrations for pit wall seepage relied on Faro Pit seepage data. "Preliminary" results from seepage monitoring indicated that the Annual Mean Monthly Concentration (AMMC) of zinc, for example, was approximately 10 mg/L. For modeling purposes, this mean concentration was assigned to all seepages emanating from pit walls during operation. For Vangorda Pit, three separate seepage zones were identified. Seepage from north wall was identified as the largest source load of zinc in the pit, followed by the north east wall, and the south west wall. Each was predicted to have similar concentrations 10.27 mg/L Zn, but with more flow from north wall.[27]

After abandonment, the Grum Pit was assumed to be flooded to a level above all sulphide exposures. Therefore, the modeling for the abandonment phase assumed an AMMC for zinc of 0.04 mg/L for the Grum Pit.

At the Vangorda Pit, some sulphide materials were to remain exposed above the expected flood level. As a result, the seepage from Areas 1 and 2 was predicted to maintain a zinc AMMC of 10 mg/L while submersion of Area 3 was predicted to reduce the zinc AMMC to 2 mg/L.

Predicted zinc concentrations in runoff entering both Vangorda and Grum pits during operations were assumed to be 40 mg/L, based on water quality in the bottom of the Faro Pit. At abandonment, the model assumed that runoff contaminant concentrations would be much lower due to less exposure to

[27] CRI, 1989, Table A-46

sulphide rock. Predicted runoff zinc concentrations for Vangorda and Grum Pits were 0.3 mg/L and 0.02 mg/L respectively.

4.2.7 Geochemical Predictions – Waste Rock

Pre-development estimates of contaminant concentrations in waste rock seepage were based on a combination of Faro Mine seepage monitoring data and humidity cell test results. No specific details are provided about the relationships between the empirical data and the estimates used in modeling. The project documentation included detailed results for the humidity cell tests, but no details of the seepage data from the Faro Mine Site.

Seepage from the main Grum waste rock dumps was assigned an AMMC of 0.26 mg/L for zinc. Data from Faro indicated that similar unsegregated dumps had zinc seepage concentrations between 0.01 mg/L and 1.6 mg/L. Seepage from the Grum and Vangorda sulphide dumps was assigned an AMMC of 28.6 mg/L for zinc, based on results of sulphide waste humidity cell tests which had zinc concentration peaks over 70 mg/L. The 28.6 mg/L concentration was assumed to be conservative because it was substantially higher than zinc concentrations from the Faro Main Dump at X23. At the time, concentrations at X23 had an AMMC of 21.2 mg/L for zinc. Seepage from the Vangorda phyllite dump was assigned an AMMC of 15.7 mg/L for zinc. This concentration was selected because the phyllite was considered to have lower ARD potential than the sulphide waste. The selected value was lower than the AMMC for X23.

At the time of the analysis, some waste rock seepage at the Faro Mine had zinc concentrations in the order of 300 mg/L. These concentrations were not considered relevant to planning for Vangorda/Grum because the flow from these seeps was very low and the loading contribution minimal.

Modeling for waste rock assumed that the above AMMC concentrations would occur during both operation and abandonment phases. Annual distributions of zinc concentrations for pit runoff, pit seepage and waste rock drainage are shown in Table 7.

Some additional AMMC were considered in a sensitivity analysis for the model.[28] This was carried out for abandonment conditions only. Two additional cases were considered. A worst case scenario developed for the sensitivity analysis included the following assumptions:

- Average pit wall seepage from the NE and SW walls of the Faro Pit were arbitrarily doubled to represent pit wall AMMCs for the Vangorda Pit at abandonment (24.2 mg/L).
- The AMMC for sulphide cells was assigned a value 5 times higher than the average value at X23 – with concentrations similar to the long-term zinc concentrations in an inoculated humidity cell (100 mg/L).

[28] CRI, 1990-1, Chapter 7

- The AMMC for the phyllite cell utilized an estimate from the long-term zinc concentrations in an inoculated humidity cell – 12 mg/L. This was lower than the base case AMMC but was still utilized in the "worst case" scenario because it was considered to represent the latest results.
- The unsegregated area of the Grum Dump was assigned an AMMC of 3.0 mg/L (10 x the base case). No explanation is provided.

Some of the scenarios considered in modeling included collection and treatment of contaminated water. The modeling conservatively assumed that treatment plant effluent had a zinc concentration equal to the effluent limit of 0.5 mg/L.

Table 7: Annual Distribution of Zinc Concentrations (mg/L)[29]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vangorda Pit – Operations												
Runoff	19.0	19.0	37.0	74.0	56.0	37.0	37.0	37.0	37.0	37.0	19.0	19.0
Seepage	3.5	3.5	5.0	12.5	12.5	11.5	11.5	9.5	9.5	6.5	5.0	2.0
Grum Pit – Operations												
Runoff	19.0	19.0	37.0	74.0	56.0	37.0	37.0	37.0	37.0	37.0	19.0	19.0
Seepage	3.0	3.0	5.0	12.0	12.0	11.0	9.0	10.0	10.0	7.0	5.0	2.0
Vangorda Pit – Abandonment												
Runoff	0.1	0.1	0.2	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.1	0.1
Seepage A1 & A2	3.5	3.5	5.0	12.5	12.5	11.5	11.5	9.5	9.5	6.5	5.0	2.0
Seepage A3	0.5	0.5	0.7	2.0	2.0	1.8	1.8	1.5	1.4	1.0	0.75	0.2
Grum Pit – Abandonment												
Runoff	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Seepage	0.02	0.03	0.02	0.05	0.06	0.05	0.02	0.03	0.06	0.02	0.02	0.02
Waste Rock – Runoff												
Operation & Aband. w/o cover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aband. w Cover	0.01	0.01	0.01	0.05	0.03	0.04	0.02	0.02	0.02	0.01	0.01	0.01
Waste Rock – Seepage												
Grum Sulphide	8.0	12.0	25.0	50.0	40.0	30.0	25.0	25.0	25.0	25.0	12.0	8.0
Grum Other	0.1	0.1	0.1	0.5	0.3	0.4	0.2	0.2	0.2	0.1	0.1	0.1
Vangorda Sulphide	8.0	12.0	25.0	50.0	40.0	30.0	25.0	25.0	25.0	25.0	12.0	8.0
Vangorda Phyllite	3.0	8.0	12.0	36.0	23.0	14.0	14.0	14.0	12.0	14.0	8.0	3.0

4.2.8 Predicted Source Loads

For project planning and assessment purposes the initial modeling evaluated two scenarios for operations and two scenarios for abandonment.

[29] CRI, 1989, Appendix A

For operations, the model estimated mine-related receiving water loading with and without treatment of effluent from dumps and pits. In the treatment scenario, the model assumed that 100% of water (and load) would be collected and treated from Vangorda Pit, Vangorda Waste Rock, Grum Pit and Grum Sulphide Cell. For abandonment, the model estimated concentrations with and without till covers on the Vangorda Waste Rock and the Grum Sulphide Cell.[30]

Subsequent modeling considered several (8) additional abandonment scenarios.[31] These scenarios focused on alternatives for abandonment of the Vangorda Waste Rock. Where these scenarios considered treatment, the model assumed that 90% of water (and load) would be collected and treated from all mine-related sources.

The results of further additional modeling for abandonment conditions were presented in May 1990.[32] The focus of this modeling was to evaluate the potential effectiveness of till covers over the upper, exposed portion of the Vangorda Pit. For these scenarios, the modeling assumed that 80% of water (and load) would be collected and treated from relevant sources that could include Vangorda Dump, Grum Sulphide Cell and Vangorda Pit walls.

Of the many scenarios modeled, only some are relevant for consideration in this study. First, the operational scenarios will provide loadings relevant for comparison with monitoring results from the site. Second, abandonment scenario 1.4 from SRK February 1990 provides the most relevant information for comparison with updated abandonment estimates. This scenario included construction of the dump generally in its current location, segregation of sulpide/phyllite waste, construction of till berms around each waste type to form separate cells, and placement of a three metre thick till cover. While this scenario is not identical to that modeled for current closure planning purposes, it is very similar. Pre-development load predictions for these scenarios are provided in Table 8.

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[30] CRI, 1989, Chapter 5
[31] CRI, 1990-1, Chapter 7
[32] CRI, 1990-2, Chapter 4

Table 8: Pre-Development Loading Predictions Before Water Treatment (kg)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Operations[33]												
Grum Dump	0	0	1	3	12	23	7	6	5	2	1	1
Grum Sulphide	1	2	6	14	76	79	40	33	27	21	3	2
Grum Dump Total												365
Vangorda Sulphide	5	8	23	56	302	314	158	132	106	86	13	9
Vangorda Phyllite	2	6	12	44	188	159	96	80	55	52	10	4
Vangorda Dump Total												1920
Vangorda Pit	61	58	113	370	2335	1797	1111	895	708	404	79	60
Grum Pit	87	78	173	486	3766	2949	1657	1466	1161	716	145	115
Abandonment – Alternative 1.4[34]												
Grum Dump	0.43	0.43	0.57	3.48	14.09	26.00	7.84	6.58	5.29	2.13	0.70	0.70
Grum Sulphide	0.62	0.94	2.10	10.23	25.01	22.43	11.13	9.78	8.27	6.76	1.73	0.67
Grum Dump Total												168
Vangorda Sulphide	1.29	1.94	4.34	21.14	51.69	46.36	23.01	20.21	17.10	13.97	3.58	1.40
Vangorda Phyllite	1.09	2.88	4.65	33.92	66.28	48.45	28.74	25.23	18.32	17.42	5.32	1.17
Vangorda Dump Total												460
Vangorda Pit	7.27	6.57	10.61	48.45	237.75	161.68	121.30	91.19	68.48	30.40	5.49	2.62
Grum Pit	0.34	0.41	0.40	1.43	7.58	6.09	2.56	2.72	3.22	1.17	0.42	0.38

5.0 Monitoring Results and Post-Operation Predictions

The following section describes operation and post-operation monitoring data as well as post-operation water quality models and predictions of contaminant loading for the Vangorda/Grum Mine.

Water quality monitoring programs at Vangorda/Grum have been ongoing throughout the operations, temporary closure and post-operation phases. The scope of these monitoring programs has varied as the needs for data have changed. The results from these monitoring programs provide some information for comparison with original predictions of water quality and loading. In many cases, the data require interpretation through additional modeling exercises to illustrate the comparisons.

[33] CRI, 1989, Appendix A
[34] CRI, 1990-1, Chapter 6

Post-operation contaminant load modeling has been carried out on at least two occasions. GLL completed an initial model in 2002 to support a water licence application for a care-and-maintenance licence.[35] SRK completed additional modeling in 2004 through 2007 to support closure planning initiatives.[36] Like the initial modeling exercises, the post-operational studies relied on water and contaminant load mass balances. GLL's modeling relied on empirical surface water data for estimating load sources. The model only considered sources that were contributing directly to surface water, not those that were subject to treatment. SRK's modeling is significantly more detailed and attempts to predict loading from all sources based on various site data.

Results of monitoring as well as methodology and results for post-operational modeling exercises are described in the following sections. Because it was carried out for closure planning purposes, SRK's predictions consider a variety of closure options. Only those that are most comparable to pre-development closure options are considered in this comparison study.

5.1 Monitoring Results and Post-Operation Predictions – Pits

The Vangorda Pit wall characterization in 1996 showed altered phyllites in the upper north east, carbonaceous phyllite with moderate to weak acid generation in the north west (iron but not zinc from weathering),phyllites in the south west and sulphides in the south east narrow slot.[37] It was estimated that the pit wall was 30% sulphides, 60% phyllites and 10% carbonaceous phyllites.[38]

Water quality in the Vangorda Pit during operation had a mean zinc concentration of 28.9 mg/L and a peak concentration of 396 mg/L. The average zinc concentration had increased to 66 mg/L by 1998-2004. These concentrations significantly exceed the IEE worst case scenario predictions (pit seep predicted 18.25 mg/L zinc).

The Integrated Comprehensive Abandonment Plan (ICAP)[39] data set for 1990-95 show Station V22 (Vangorda pit water) had high zinc (mean 26.73mg/L Zn, max 396 mg/L Zn in April 1992), high sulphate (mean 481.5 mg/L, max 3,020mg/L in April 1992), and flow rate 691.2 m3/day.[40] From these monitoring reports, it can be estimated that an average load of 6.74 tonnes Zn/year (almost 10x 1989 estimates), 120 tonnes sulphate/year will enter the Vangorda pit. These monitored levels significantly exceed the worst case scenario concentrations predicted in the 1989 IEE (pit seep predicted 18.25 mg/L zinc) and approach the worst predicted load (8 tonnes/ yr zinc).

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[35] GLL, 2002, Appendix A
[36] SRK, 2004-3
[37] RGC, 1996, Volume 2, p. 5-10
[38] RGC, 1996, Volume 2, p. 5-13
[39] RGC, 1996
[40] RGC, 1996, *Appendix E*

Photo 4: Grum Pit, September 2005

Since operations ceased in 1998, water levels have fluctuated and the Vangorda Pit contained over 40 m of water in late 2003 and late 2004. For part of this post-operation period, the pit has been used for disposal of water treatment sludge. Both changes in water levels and storage of sludge could affect loading from the Vangorda Pit.

Water quality in the Grum Pit during operation had a mean zinc concentration of 0.66 mg/L and a peak concentration of 4.49 mg/L. Contaminant loading cannot be estimated from operational data because flow information is inadequate. At the end of operations in 1998, the Grum Pit began to fill with water. Zinc concentrations increased during this time. The average zinc concentration between 1998 and 2004 was approximately 7 mg/L. Water depths were over 40 m by 2003.

Closure planning investigations in 2005 included estimates of current and predicted loadings for both Vangorda and Grum Pits.[41] The estimates relied on water quality described in Table 9. For the purposes of this estimate, no attempt was made to identify seasonal variation in seepage water quality from pit walls. The water quality estimates are the average of runoff water quality from seep samples collected within each rock unit. The sample set included 18 samples from Grum Pit and 16 samples from Vangorda Pit, taken in 2003 and 2004. In

[41] SRK, 2006

some cases, seepage data from waste rock was used to supplement information collected from pit seep samples. The post-operation modeling utilizes zinc concentrations that are substantially higher than those utilized for pre-development modeling (10 mg/L).

Table 9: Water Types For Estimation of Wall Rock Loadings to Vangorda and Grum Pit Lakes[42]

Pit	Rock Type	Exposure Above Final Spill Elev. (m^2)	Zn Concentration (mg/L)
Grum	Calcareous, carbonaceous, and non-calcareous phyllite	228,000	0.02
	Massive and disseminated sulphides	11,000	28
	Till	197,000	0.014
Vangorda	Carbonaceous phyllite and non-calcareous phyllite	29,000	46
	Undifferentiated massive and disseminated sulphides	71,000	450
	Bleached pyretic phyllite	2,000	780
	Till	48,000	0.0050

Updated estimates for pit water balances were developed utilizing estimates of mean annual runoff, precipitation and evaporation for each of the pits. The mean annual runoff was estimated as 270 mm and 362 mm for Grum and Vangorda Pits respectively. Mean annual precipitation estimates were 450 mm and 380 mm. Lake evaporation estimates were 352 mm and 493 mm. Table 10 shows net inflow estimates for Grum and Vangorda Pits.

Table 10: Grum and Vangorda Pit Net Inflows (x 1000m^3)[43]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vangorda Pit	5	5	3	-3	42	80	27	9	17	19	11	9
Grum Pit	8	6	2	-10	58	51	24	15	51	29	15	11

Calculation of overall loading to pits relied on the contaminant concentrations, net inflows and relative areas of rock types exposed at any given water level. Sources below the water level in pits and from secondary mineral salts exposed on pit walls were assumed to be negligible.

The loading estimates for current conditions (2004) probably represent the best estimates for comparison with pre-development operational predictions. For Vangorda Pit, the results of this comparison need to recognize that the pit walls

[42] SRK, 2006
[43] SRK, 2006

have remained exposed for much longer than the original development plan anticipated. For Grum Pit, the results should recognize that the original predictions anticipated a much larger pit. The 2005 estimates included predictions for loading from flooded Vangorda and Grum Pits. These conditions are similar to those utilized for abandonment conditions in pre-development estimates and represent a reasonable comparison. The 2005 predictions only include total annual loads which are presented in Table 11.

Table 11: 2005 Zinc Load Predictions – Grum and Vangorda Pits

Pit	Current (2004) Load (kg/yr)	Closure Flood Elevation (m asl)	Post Flooding Load (kg/yr)
Vangorda	18000	1130	13000
Grum	350	1230	80

The post-operation prediction for Vangorda Pit is 50% higher than the pre-development prediction, showing relatively good agreement. These values are also similar to the loads calculated in the ICAP. The post-operation predictions for Grum Pit are substantially lower than the pre-development predictions which estimated a load of 12,800 kg/yr.

Monitoring of pit conditions continued through 2005 and 2006. Mass balance estimates using the data collected during these two additional years indicated that loading in both Vangorda and Grum Pits may be higher than predicted in 2005.[44]

5.2 Monitoring Results – Grum Waste Rock

Seepage monitoring at three sites adjacent to the Grum Dump has been part of water licence monitoring throughout the operational and care-and-maintenance periods.

In 2002 GLL completed the "Preliminary Water Balance and Contaminant Load Study" in support of a water licence application. In this study, GLL utilized site monitoring data and calculated loads for comparison with measured loads in receiving water. The study included a prediction of loading from the Grum Waste Rock Dump, based on water quality in Grum Creek upstream of Vangorda Creek. Using this information, GLL estimated the zinc load from Grum Waste Rock Dump as approximately 177 kg/yr between November 1997 and October 2000.

Since 2002, samples have been collected two times per year at 18 seep sites around the Grum Waste Rock. These monitoring results likely represent conditions similar to those considered for the pre-development operational modeling because the modeling considered exposed dump surfaces as currently exist on the site. It should be recognized however, that the pre-development

[44] SRK, 2007-2

predictions anticipated that the Grum Dump would contain over 150 million tonnes of waste rock. Current estimates suggest that the dump contains less than 30 million tonnes.

For some sites, there are trends in water quality which indicate that the influence of mine waste is increasing with time. Zinc concentrations in seeps between 2002 and 2006 vary from below detection limit (0.005 mg/L) to 110 mg/L.[45] Flows are variable and loading estimates have not been developed based on these data. The sum of average loads for all seeps is approximately 10.8 kg/day or 3957 kg/year.

5.3 Monitoring Results – Vangorda Waste Rock

Seepage monitoring has been carried out at the Vangorda Waste Rock throughout the operational and care-and-maintenance phases. The construction of the till berm in 1994 included installation of six toe drains to pass water through the berm. When flowing, these drains have served as sampling locations for seepage from the Vangorda Dump. The results of 2005 sampling is described in the 2005 Annual Environmental Report, Water Licence QZ03-059.[46] Additional data are provided in GLL 2002. Summary information is described in Table 12. Because there are few flow records and no record of zero flow sampling events, loads cannot be estimated.

Table 12: Water Quality – Vangorda Waste Rock Drains

Drain	Flow Consistency	2005 Zinc Conc. (mg/L)	Avg. Zinc Conc. to 2002
No. 1	No Flow Ever Recorded		
No. 2	Intermittent	118 (1 Sample)	
No. 3	Consistent Flow	398 (2 Samples)	279
No. 4	Intermittent	1660 (2 Samples)	
No. 5	Consistent Flow	10350 (2 Samples)	2118
No. 6	Consistent to 2001, Intermittent since then.	8880 (2 Samples)	1030

Little Creek Pond serves as a collection point for seepage from the Vangorda Dump. During operations, water from the Vangorda Pit was transferred to the Little Creek Pond prior for transfer to the treatment plant. As a result, the operational data for Little Creek Pond do not provide guidance about loading or concentrations from the dump. Since operation ceased, water from the pit has been transferred directly to the water treatment plant, with water from Little Creek Pond pumped to Vangorda Pit for storage. The post operational water quality is more relevant to waste rock dump conditions, though the pond also captures local runoff. 2005 sampling in Little Creek Pond returned zinc concentrations averaging 596 mg/L for two samples. This represented a sharp increase from

[45] SRK, 2007-1
[46] GLL, 2006

previous sampling where zinc concentrations had been less than 100 mg/L. GLL 2002 reports a 1997-2000 average zinc concentration of 7.7 mg/L.

Loading estimates for Vangorda Waste Rock were not part of the GLL 2002 contaminant load balance because the load was assumed to report to the water treatment plant.

Photo 5: Vangorda Waste Rock, June 2005

5.4 Post-Operation Waste Rock Characterization

Post-operation information suggests that the Vangorda Waste Rock Dump may contain some materials that were not originally intended to be placed in the dump. The top 6-10 metres of the Vangorda deposit was moderately oxidized and contained cyanide soluble copper which interfered with the lead and zinc flotation. As a result, this material was placed in the sulphide cell of the waste rock dump and later screened to remove the less oxidized coarse fraction that was processed as ore. The oxidized fine material remains in the waste rock dump and is considered a significant source of loading (with NP/AP of 0, net NP average -525 kg $CaCO_3$/Tonne, and paste pH 3.7).[47] These fines also have high levels of stored soluble metal loads (extraction test results for Sb, As, Cd, Cr, Co, Cu, Fe, Pb, Mn, Ni, Zn). Pyritic quartzite from the pit wall was deposited at the north side of the Vangorda waste dump because of potential for future milling.[48]

[47] ICAP, 1996, Volume 2, p. 5-2
[48] RGC, 1996, Volume 2, p. 5-3

The 1996 ICAP description of the Vangorda pit altered phyllites differs from the 1989-90 IEE. The ICAP states that all of the Vangorda phyllites are altered and many contain at least minor pyrite or pyrrhotite with relatively little calcite. It states that for this reason, all phyllites from Vangorda were considered acid generating and placed in the south west portion of the bermed rock dump. The Vangorda phyllites may also have more leachable nickel and cobalt than the Faro deposit.[49]

The ICAP states that the Vangorda sulphide waste rock is potentially acid generating (with NP/AP of 0.1, net NP average -738 kg $CaCO_3$/Tonne, and paste pH 6.8), as is the phyllite (with NP/AP of 0 and net NP average -700 kg $CaCO_3$/Tonne, and paste pH 5.5).[50] Testing on samples of calcareaous phyllite showed a strong acid consuming capacity, with NP values in excess of 150 kg $CaCO_3$/tonne and NP/AP ratios of 10:1 or greater.[51]

Grum waste rock samples showed higher sulphur content and lower sulphate than Faro samples.[52] The acid generating minerals were high in the waste rock content (1 sample had 53% pyrite, 1% arsenopyrite, 1% pyrrhotite, 0.5 chalcopyrite, 28% quartzite, 4% sericite, 12% carbonate, another had 80% pyrite).[53]

5.5 Post-Operation Predictions – Waste Rock

5.5.1 Waste Rock – Flow Predictions

Like the pre-development modeling, the post-operational modeling was supported by estimates of mean monthly discharge. Similar to the pre-development flows, the estimates (Table 13) were developed by utilizing regional data with confirmation using the local data for Vangorda Creek.

Comparison of values between Table 13 and Table 3 show relatively good agreement between pre-development and post-operational predictions for receiving water flows.

[49] RGC, 1996, Volume 2, p. 5-4
[50] RGC, 1996, Volume 2, p. 5-20
[51] RGC, 1996, *Appendix H*, January 1997, Section 4.4.2
[52] RGC, 1996, *Appendix H*, January 1997, Section 4.5.2
[53] RGC, 1996, *Appendix H*, January 1997, Section 4.5.2

Table 13: Post-Operational Estimates – Mean Monthly Discharge (m^3/s)[54]

Month	Vangorda Creek at Faro – V8 (x1000 m^3) 90.5 km^2	Vangorda Creek d/s of Mine - V27 (x1000 m^3) 31.41 km^2
January	407	220
February	309	173
March	324	185
April	567	301
May	4337	2006
June	4448	2048
July	3119	1445
August	2191	1020
September	2933	1358
October	1549	727
November	741	367
December	575	299
Annual	**21501**	**10149**

Post operational modeling required estimates of background water quality. The background water quality estimates were based on mean values from monitoring data for sampling station V1, located on Vangorda Creek upstream of the mine. The initial version of post-operational modeling did not consider seasonal variations in background water quality and utilized an annual average of 0.0137 mg/L. This would result in an annual average load of approximately 300 kg at V8. This compares well with the pre-development prediction of approximately 360 kg.

Post-operational loading estimates for waste rock are based on plan area for dumps. Estimates for the existing dump conditions assumed, based on site investigations, that dump drainage (seepage and surface runoff) would be 45% of mean annual precipitation.[55] This estimate was based on modeling completed using the SoilCover model that predicts the exchange of moisture between the atmosphere and a soil surface. This 45% estimate compares relatively well with the pre-development estimate of approximately 37% though the pre-development estimates assumed there would be no runoff from uncovered dump surfaces while the post-operational estimates estimated some runoff. For uncovered waste rock, both modeling exercises considered all of the water to be contaminated.

Post-operational modeling utilized SoilCover to estimate flow rates through a variety of cover materials and thicknesses. The modeling predicted infiltration ranging from 0% to 7%. For initial modeling of proposed closure covers, the load balance model assumed infiltration of 5% through till covers of 1.5 m in thickness and 20% through till covers of 0.5 m in thickness.[56]

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[54] SRK, 2004-3
[55] SRK, 2004-1
[56] SRK, 2004-3

5.5.2 Waste Rock – Geochemical Predictions

In order to understand and predict seepage chemistry for waste rock, post-operational modeling evaluated historic information and collected additional data. The program included review of historic geochemical testing (acid-base accounting, metal analysis, short-term leachability and long-term leachability) and historic seepage monitoring results. The program also included additional mapping of waste rock using surface surveys, test pits, trenches and drilling. Additional monitoring programs were established including gas and thermal monitoring in waste dumps and extensive seepage monitoring. Additional lab programs included acid-base accounting, extraction testing and humidity cells.[57]

For modeling purposes, estimates of seepage water quality were primarily based on correlation between seepage quality data and contributing rock types. Humidity cells, oxygen levels and thermal monitoring were used to confirm estimates using empirical seepage data. Seepage types were divided into three broad categories based on pH and zinc concentrations. For Grum, seeps were further divided on the basis of sulphate concentrations.

The modeling utilized a range of predictions for estimating loading from waste rock dumps. Three conditions were considered: (1) seepage water quality assigned based on application of average seepage water quality to current understanding of dump geochemical composition, (2) seepage water quality assigned based on application of maximum observed seepage concentrations to current understanding of dump geochemical composition, and (3) seepage water quality assigned based on application of maximum observed seepage water quality to rock types assigned on the basis of net neutralizing potential and zinc content of waste rock. These conditions have been referred to as Current Average, Current Maximum and Worst Case Future as well as Future 1, Future 2 and Future 3.

The Future 1 case probably offers reasonable comparison to pre-development load predictions for operations because it represents the average prediction of load that is currently being produced by waste rock, though monitoring confirms that this load is not currently reporting to receiving environments. This discrepancy is likely due to attenuation and travel times, neither of which were considered in the pre-development or post-operational monitoring exercises. The Future 2 case probably offers the best comparison to pre-development predictions for the abandonment because it is the case that is currently being utilized for closure planning purposes. Post-operational modeling does not include predictions of seasonal variability in seepage water quality. Estimates of water quality and loads for Future 1 and Future 2 are presented in Table 14.

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[57] SRK, 2004-2

Table 14: Post-Operational Estimates of Contaminant Concentrations and Loading for Waste Rock[58]

Dump	Future 1		Future 2		
	Zinc Conc. (mg/L)	Zinc Load (kg/yr)	Zinc Conc. (mg/L)	Zinc Load (kg/yr)	
		Uncovered		Uncovered	Covered
Grum Sulphide	3.0	108	5.1	185	21
Grum Main	3.0	267	5.1	457	203
Grum Southwest	0.005	1	0.009	4	2
Grum Overburden	0.005	1	0.009	3	1
Total Grum		**377**		**649**	**227**
Vangorda Sulphide	2948	46385	6990	109967	12219
Vangorda Main	737	41264	1728	96719	10747
Vangorda Overburden	21	165	46	358	40
Baritic Fines	2948	4437	6990	10519	1169
Total Vangorda		**92251**		**217563**	**24174**

Notes: Future 1 loads consider uncovered conditions with 45% infiltration, for comparison with pre-development operational conditions.
Future 2 loads consider: (a) for uncovered conditions, 45% infiltration, and (b) for covered conditions, 5% infiltration for Grum Sulphide, and all Vangorda Waste Rock; 20% infiltration for other areas.
Model assumes that load is directly proportional to flows – i.e. concentrations do not change.

Seepage monitoring since 2004 has indicated that seepage quality is changing, especially at the Grum Dump. As a result, some seepage types have been reassigned and 2005 estimates predicted Grum Dump loads of 1367 kg/yr for Future 1, assuming 45% infiltration.

The post-operations estimates of waste rock loading are substantially different from the pre-development estimates.

To confirm the estimates based on empirical seepage data, post-operational modeling also included estimates of waste rock loading based on the results of kinetic testing. The kinetic test results were scaled to field conditions by utilizing internal dump temperature and pore gas data. This approach predicted Grum Dump and Vangorda Dump loadings of approximately 134,000 kg/yr and 213,000 kg/yr respectively. Vangorda theoretical predictions agree well with Future 2

[58] SRK, 2004-3

predictions based on empirical data. For Grum, these is substantial variation between theoretical predictions and those based on empirical data.[59]

6.0 Analysis

This analysis compares the results of pre-development predictions, monitoring and post-operation predictions. While there are some differences between the pre-development and post-operational estimates of background contributions to overall loading, these differences are relatively minor. They also are minor contributors to the overall predicted loading. There are differences in the estimates of loading from pit walls, though these are not consistent for both pits. The flow rate components of pit wall loading are in relatively good agreement, but the concentration components are variable. The largest differences in load estimates relate to predicted loadings from waste rock, where the pre-development estimates are substantially lower than the post-operations estimates, especially for Vangorda Dump. Monitoring results for Grum Dump appear to be worsening, leading to increases in predicted loads.

From the above comparison, it appears that the estimates of contaminant concentrations have the greatest variability from pre-development to post-operational modeling. The prediction methodologies for both modeling exercises were fundamentally quite similar. Both exercises relied on use of empirical data as the primary method of prediction. Both exercises also considered the results of humidity cell tests, but they used these results mostly for confirmation purposes. In both cases, the humidity cells predicted worse conditions than the empirical based models, but the adversity of these conditions did not lead to revision of modeling inputs and assumptions.

Estimates of flow rates from waste rock dumps also create variation between the two modeling exercises. Because infiltration through covered surfaces is assumed to be quite small, and because the post-operational model assumes constant concentrations with variable flow, small changes in infiltration rates could lead to substantial changes in loading. Modeling results for both models appear to be quite sensitive to waste rock infiltration rates, especially for covered conditions.

Because the prediction methods for waste rock loads are similar, it appears that the substantial differences in contaminant loading estimates for waste rock probably arises from two main changes in model inputs: (1) changes in mine plan, and (2) changes in input data. The implications of both are discussed below.

The original mine plan for Vangorda/Grum included segregation and storage of waste rock and implementation of mitigation measures to reduce acid rock

[59] SRK, 2004-3

drainage. While some of these measures were completed, many of the plans changed and implementation of mitigation did not occur, or was delayed. These divergences from the mine plans that originally formed the basis for the water quality predictions have likely affected the monitoring results and the input assumptions utilized in post-operational modeling. Table 15 provides a summary of key mine design, water quality model, and geophysical assessment assumptions and criteria that were used in water quality predictions.

As stated above, both modeling exercises relied on empirical data to estimate water quality from mine components. The data available to support the predictions were substantially different however: pre-development model inputs relied on data from the Faro Mine while post-operational model inputs relied on a much larger data set from Vangorda and Grum mines.

High seepage contaminant concentrations from Faro were not fully considered in pre-development monitoring because they were not considered to be a realistic estimation of expected conditions. In retrospect, contaminant concentrations at Faro have considered to change and increase since that modeling. The data set for post-development modeling relies, in part, on results from the Vangorda Waste Rock seepage monitoring, where contaminant levels deteriorated very quickly. As a result, the post-development predictions for Vangorda indicate a much larger load than originally predicted. The post-development predictions for Grum rely on a smaller data set with less evidence of water quality deterioration. However, the conditions at Grum are continuing to change and it appears that the data may not reflect mature conditions. Predictions based on these data could have similar issues to the pre-development predictions which relied on earlier Faro Mine data.

Both modeling exercises included consideration of humidity cell data to validate the estimates based on empirical data. For the cases where the empirical data sets are not reflective of well-developed ARD (pre-development modeling and Grum Waste Rock post-operational modeling), the humidity cell analyses predict higher contaminant loads. The monitoring results and post-operational modeling indicate that the results of humidity cell studies may have been worthy of greater consideration in the pre-development modeling.

For both modeling exercises, the estimates for pit wall contaminant concentrations fall generally within the same order of magnitude. In the post-operational estimates however, the pit loads are completely overshadowed by dump loads. For the Vangorda Pit, the estimates compare quite well for the two modeling exercises. For the Grum Pit, the post-operational modeling predicts much lower loads than those predicted pre-development. In this case, the pre-development predictions did not rely on empirical data related to specific rock types, while the post-operational predictions did. Monitoring and modeling over the past several years indicates that the original post-operational modeling may underestimate the loads for Grum Pit. This suggests that, like the waste rock estimates, modeling results may be affected by the lack of mature ARD data for Grum.

While the current evidence suggests that waste rock loads are much more significant than pit wall loads, the initial work on modeling provided a strong focus on pit wall loads and identified them as a much more significant source. The monitoring data support the conclusion that waste rock will be a larger long-term source.

Table 15: Summary of key mine design, water quality model, and geophysical assessment assumptions and criteria used in pre-development water quality predictions.

Criteria	*Occurrence*	*Comments*	*Source (Predicted:Update)*
Mine Design:			
Maximum pit depth 100m	yes	-not known how much water inflow is from the deep or shallow groundwater, or from leaks in the Vangorda Creek diversion	IEE 1989
Sulphide & phyllite waste cells separate	partial	-two cells built: inadequate separation of waste types, heterogenous waste rock (both sulphides and phyllite), surface mapping shows widespread sulphides -additional materials put in waste dump were potentially acid generating, i.e. baritic fines	IEE 1989 : ICAP 1996-7
Till berm for waste cells	partial	-rock berm will have greater permeability than till	IEE 1989
3 metre till cover for waste cells	partial	-currently covered, 2 metre depth of till on area that was re-sloped by DIAND in 1994, cover integrity varied	IEE 1989: ICAP 1996
Water treatment on Vangorda plateau	yes	-range of effluent water quality discharged from treatment plant (chart source data for station V25)	IEE 1989 : ICAP 1997, EIA 2007
Pit flooding reduces acid generation from pit seeps	no	-pit water pumped & treated, keep level low to manage treatment	IEE 1989: YTWB 2006
Stream diversion efficacy	no	-increases water to pit and water treatment required -diversion originally planned to be removed immediately after mining, to allow pit filling.	IEE 1989 : YTWB 2004
Post abandonment mitigative measures need to be implemented in mine design and development	partial	- waste cells designed and developed - post-development measures not completed yet – delayed beyond original planned dates	IEE 1989
Phyllite bedrock provides confining layer for high pore water pressure conditions at	unknown	- phyllite compacts to a greater extent than at Faro site, insufficient and	IEE 1989 :ICAP 1996

Criteria	Occurrence	Comments	Source (Predicted:Update)
Vangorda pit		improperly sampled groundwater data available	
Water Quality Model:			
Baseline data accurate	no	-reference station data higher in mid 1990s during pre-mining at Vangorda was affected by Faro mine development (TSS high at 18mg/L), Shrimp Creek better baseline, also possibly inaccurate lab results	IEE 1989 : ICAP 1996, EIA 2007
Faro experience relevant to Vangorda water quality predictions	partial	-different mineralogy & deposit form	IEE 1989
10 week humidity test accurate water quality & acid generation rate prediction	partial	-water quality modelling considered humidity cell testing, but did not address high concentrations.	IEE 1989
Gravity-based parameters of HELP II landfill modelling sufficient to predict waste rock impact on water quality	no	- waste rock only partially covered, HELP does not estimate runoff, pore water, compaction or capillary influence	IEE 1989
Parameters in water quality prediction model detailed	no	- limited meterologic & hydrologic data	IEE 1989
Stream flow estimates for Vangorda Creek (7.7L/sec/km^2) based on correlation with Pelly River	unknown	- actual stream flow for Vangorda Creek	IEE 1989
Greater seepage flow from north east Vangorda pit wall estimated to be greater pit water quality influence than south east			IEE 1989
Till cover will influence modelled zinc load	yes	- model shows lower zinc from waste rock cells	IEE 1989
Data comparability for water quality assessment and model change over time	no	- different stations sampled at different times, some analysis leaves out outlying data & doesn't include spike variability in data, limited data set for early data	IEE 1989, Addendum 1990, ICAP 1996, EIS 2007
Primary source of metals indicated in water quality prediction from acid generation of sulphides	partial	- leaching of metals from altered phyllite also important eg. Aluminum possibly from Kaolinite, underestimates neutral leaching of metals	IEE Addendum 1990 : ICAP 1997, EIS 2007

Criteria	*Occurrence*	*Comments*	*Source (Predicted:Update)*
Zinc is primary indicator of water quality	no	- variable surface water quality, other key indicators are sulphate, hardness, conductivity, manganese, magnesium, calcium, strontium, sodium, uranium and ammonia	IEE Addendum 1990 : EIS 2007
Zinc load estimate 792 kg Zn/yr to Vangorda pit (0.792 tonnes Zn/yr)	no	- 1997 estimate based on monitoring data 10 x 1989 at 6.74 tonnes Zn/year entering the pit	IEE 1989 : ICAP 1997
Geophysical Assessment:			
Visual assessment that pyrrhotite content is lower than Faro	no	- underplays reactivity of pyrite which has been analysed to be up to 80% in some Vangorda Plateau samples, and presence of marcosite	IEE 1989 : ICAP 1996-7
Slumping below phyllite cell is not due to permafrost and poses no concern for adequate waste containment	unknown	-stability has not become an additional concern below phyllite cell	IEE 1989
Altered phyllite is estimated non-acid generating and can be effectively separated from sulphide waste rock	no	- altered phyllite has sulphide stringers, the deposit form changes between heterogeneous rock types in small ranges making separation difficult	IEE 1989 : ICAP 1997

7.0 Conclusions

This report has compared pre-development water quality predictions with monitoring results and post-operational water quality predictions for the Vangorda/Grum Mine. The comparison was completed in order to identify key areas of modeling approaches that have the greatest affect on their accuracy and ability to predict future conditions.

The Vangorda/Grum Mine offered an excellent opportunity for completing a comparison of results of various modeling and monitoring programs. The mine was developed at a time when ARD issues were of significant concern and the original mine planning considered the potential for ARD. This required modeling for water quality impacts of ARD. Subsequent regulatory and investigative monitoring continued to track the development of ARD. At the conclusion of mining, the operator sought bankruptcy protection and the responsibility for closure planning fell to the Canadian federal government. Additional post-closure modeling of future water quality was carried out to support the renewed closure planning activities. The similarity of the fundamental modeling approaches utilized for both modeling exercises adds further value to the comparison.

The results of the comparison point to some key conclusions that should be considered in future modeling exercises. These are described below.

1. Predictions of contaminant concentrations from mine sources contribute the greatest degree of variability to modeling outputs and are critical to effective estimation of overall loads.

2. Reliance on seepage data from existing facilities as an empirical input for modeling should be done with caution. Unless the empirical data come from sites that have been in place for long periods of time, the empirical data could underestimate the future concentrations and loadings: travel times, wetting of dumps, attenuation, delays in onset of ARD, and complex chemistry with changing characteristics and driving forces over time all could result in lower empirical concentrations than those which may develop in the long-term.

3. The results of laboratory testing (i.e. humidity cells) should be considered carefully. When modeling that utilizes laboratory testing indicates conditions more adverse than those predicted by modeling that utilizes empirical data, the laboratory based modeling may warrant further consideration especially when the empirical data are from data sets with short time spans. The comparison for Vangorda/Grum suggests that seepage concentrations reflected by laboratory analyses may materialize, even if they are not currently present on the site.

4. Future water quality predictions, especially for systems with low infiltration rates, can be quite sensitive to assumptions about flow rates through these systems (i.e. covered waste rock dumps). Better methods for estimating these flows would likely help to improve predictions. In addition, the relationship between flow rates and concentration may need to be considered because waste rock dumps are complex chemistry systems that change over time.

5. Changes in mine plans and failure to effectively implement key mitigation measures are likely partially responsible for increased concentrations and differences for post-operational modeling estimates. The mine plan for primary design features is important for setting appropriate assumptions and criteria in water quality prediction models. Changes in the mine plan need to be tracked and their possible effects on water quality should be considered at each stage. Measures that are intended to help address future water quality issues are critical and mechanisms need to be in place to make sure they are completed. As mine development progresses and mine design evolves, water quality predictions need to be verified with monitoring data and updated.

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