Investigation of Predictions for Acidic Drainage at the Vangorda Plateau, Faro Mine Complex (Faro, YT)

MEND Report 1.70.1

This work was done on behalf of MEND and sponsored by:
The Mining Association of Canada (MAC) and MEND

May 2008

Investigation of Predictions for Acidic Drainage at the Vangorda Plateau, Faro Mine Complex (Faro, YT)

MEND: 1.70.1

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May 2008

EXECUTIVE SUMMARY

The Vangorda and Grum open pit mines operated from 1990 to 1998. This report compares pre-approval acidic mine drainage modeling predictions, actual monitoring data and post-development modeling predictions. The results of the comparison provide insight into the effectiveness of prediction methodologies and guidance for general application of these methodologies.

The Vangorda and Grum mines provided additional ore feed for the mill at the adjacent Faro Mine, developed in the late 1960s. Two pits and three waste rock dumps comprise the major components at the Vangorda and Grum mine site. One waste rock dump contains overburden and is not considered a source of significant contaminant loading. All of the components fall within the Vangorda Creek watershed, a creek unaffected by the Faro Mine.

Based on experience at the Faro Mine and other sulphide base metal mines, regulators and the project developer (Curragh Resources Incorporated) recognized the potential for acidic mine drainage at the Vangorda and Grum mines. As a result, documentation to support project approval included predictions of acidic mine drainage. Monitoring programs during mine operation and after closure tracked water quality throughout the site. In 2003, the Canadian and Yukon governments assumed responsibility for mine reclamation at this site. As part of closure planning, they commissioned updated modeling for acidic mine drainage. This series of modeling and monitoring throughout various phases of the mine lifecycle provides an opportunity to evaluate the effectiveness of acidic mine drainage prediction methodologies.

Pre-development and post-operational modeling followed similar approaches for waste rock sources. Both models assessed receiving water quality by utilizing water and contaminant load balances that incorporated contaminant loads from key sources including pits, sulphide cells and waste rock dumps. The modeling approaches both relied on empirical data for predicting the long-term geochemical performance of source materials, using this information to predict seepage and runoff concentrations for both expected and worst-case conditions. The pre-development modeling utilized empirical data from the adjacent Faro mine, while the post-operational predictions utilized empirical data from the Vangorda and Grum mines. Both exercises considered the results of humidity cell tests, using the results 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. The empirical approach for predicting waste rock contaminant loads appears to substantially underestimate loading in conditions where the empirical data are not reflective of well-developed acidic mine drainage conditions.

For pits, the pre-development and post-operational predictions relied on substantially different approaches and data sources. The pre-development predictions were based on water quality data from the Faro mine combined with theoretical predictions of inflow rates. The post-operational predictions relied on empirical data to develop water balances for the pits and understand seepage water quality. For sulphide materials, the pre-development predictions substantially underestimated the loading from pit walls.

The comparison of pre-development modeling, monitoring results and post-operational modeling for acidic mine drainage at the Vangorda and Grum mines leads to some conclusions that can help guide future mine planning.

- Modeling results are most sensitive to the predictions of contaminant concentrations from key load sources, though flow rates through waste rock materials are also important.
- Reliance on seepage data from existing facilities as an empirical input for modeling should be done with caution because these data could underestimate the future concentrations and loading.
- 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 uses empirical data, the laboratory based modeling approach may warrant further consideration especially when the empirical data are from sites where acidic mine drainage may not be fully developed, or where the loading may not have reached sampling locations.
- Changes in mine plans and failure to effectively implement key mitigation measures can lead to significant increases in contaminant loading above those predicted in modeling exercises. 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 and updated based on monitoring data.

Résumé

Les mines à ciel ouvert Vangorda et Grum ont été exploitées de 1990 à 1998. Ce rapport compare les prévisions de la modélisation du drainage minier acide préalable à l'approbation, les données du suivi actuelles et les prévisions de la modélisation post-développement. Les résultats de la comparaison donnent une idée de l'efficacité des méthodes de prévision et orientent l'application générale de ces méthodes.

Les mines Vangorda et Grum ont fourni du minerai supplémentaire à l'usine de concentration située à la mine Faro, adjacente à Vangorda et à Grum. La mine Faro a débuté ses activités à la fin des années 1960. Deux mines à ciel ouvert et trois haldes de stériles sont les principales composantes du site des exploitations minières Vangorda et Grum. Une halde de stériles renferme les morts-terrains. Cette halde n'est pas une grande source de contaminants. Toutes les composantes sont situées dans le bassin hydrologique du ruisseau Vangorda et la mine Faro n'a aucun impact sur ce ruisseau.

En se fondant sur l'expérience acquise à la mine Faro et aux autres mines de métaux communs sulfurés, les organismes de réglementation et l'exploitant du projet (Curragh Resources Incorporated) ont reconnu qu'il pourrait éventuellement y avoir du drainage minier acide aux mines Vangorda et Grum. Par conséquent, la documentation déposée en vue de l'approbation du projet comprenait des prévisions du drainage minier acide. Des programmes de suivi exécutés durant l'exploitation de la mine et après la fermeture de celle-ci ont permis de déterminer la qualité de l'eau sur l'ensemble du site. En 2003, les gouvernements du Canada et du Yukon ont assumé la responsabilité de la restauration de ce site. Dans la planification de la fermeture, ils ont commandé une modélisation actualisée du drainage minier acide. Cette série de modélisations et d'activités de suivi aux diverses étapes du cycle de vie de la mine permet d'évaluer l'efficacité des méthodes de prévision du drainage minier acide.

La modélisation pré-développement et post-opérationnelle a suivi des approches similaires pour les sources de stériles. Les deux modèles ont évalué la qualité de l'eau réceptrice en utilisant les charges en eau et en contaminant qui contenaient des contaminants des sources clés, notamment les mines à ciel ouvert, les cellules de sulfure et les haldes de stériles. Les méthodes de modélisation ont misé sur les données empiriques pour prédire le comportement géochimique à long terme des matières brutes, en utilisant cette information pour prévoir l'infiltration et les concentrations du ruissellement dans le cas des conditions prévues et dans le pire des scénarios. La modélisation pré-développement a utilisé les données empiriques provenant de la mine Faro, alors que les prévisions post-opérationnelles ont utilisé les données empiriques issues des mines Vangorda et Grum. Les deux exercices ont pris en considération les résultats des essais réalisés avec des cellules d'humidité et ont utilisé les résultats à des fins de confirmation. Dans les deux cas, les cellules d'humidité ont donné lieu à la prévision de conditions pires que dans le cas des modèles utilisant les données empiriques, mais la nocivité de ces conditions n'a pas mené à la révision des intrants et des hypothèses de la modélisation. L'approche empirique pour prédire les charges de contaminants dans les stériles semble sous-évaluer grandement l'apport en contaminants lorsque les données empiriques ne reflètent pas un drainage minier acide bien développé.

Pour les mines à ciel ouvert, les prévisions pré-développement et post-opérationnelles étaient fondées sur des approches et des sources de données très différentes. Les prévisions pré-développement étaient basées sur les données sur la qualité de l'eau provenant de la mine Faro ainsi que sur les prévisions théoriques des débits entrants. Les prévisions post-opérationnelles ont misé sur les données empiriques pour produire les bilans hydriques des mines à ciel ouvert et déterminer la qualité des eaux de ruissellement. Pour les matériaux sulfurés, les prévisions pré-développement ont beaucoup sous-évalué la charge provenant des parois des mines à ciel ouvert.

La comparaison de la modélisation pré-développement, des résultats du suivi et de la modélisation post-opérationnelle pour le drainage minier acide aux mines Vangorda et Grum permet de tirer des conclusions qui peuvent contribuer à l'orientation de la planification de mines futures.

- Les résultats de la modélisation sont plus sensibles aux prévisions des concentrations de contaminants issues des sources clés de la charge, même si les débits à travers les stériles sont, eux aussi, importants.
- Il faut être prudent si l'on s'en remet aux données des eaux de ruissellement provenant des installations existantes comme intrants empiriques pour la modélisation parce que ces données pourraient sous-évaluer les concentrations et la charge futures.
- Les résultats des essais en laboratoire (c.-à-d. les cellules d'humidité) doivent être étudiés attentivement. Lorsqu'une modélisation utilisant les essais en laboratoire indique des conditions plus défavorables que celles qui sont prévues par une modélisation utilisant les données empiriques, un examen plus poussé de la modélisation basée sur les essais en laboratoire peut s'avérer nécessaire, particulièrement lorsque les données empiriques proviennent de sites où le drainage minier acide n'a pas atteint son plein développement, ou encore, où la charge n'a pas atteint les points d'échantillonnage.
- Les modifications apportées aux plans de la mine et l'absence de mise en oeuvre efficace de mesures clés d'atténuation des effets peuvent mener à des hausses de la charge de contaminants si importantes qu'elles sont supérieures à celles qui ont été prévues dans les exercices de modélisation. Il faut absolument prendre des mesures pour régler les questions liées à la qualité de l'eau dans l'avenir et mettre en place des mécanismes pour assurer leur mise en œuvre complète. À mesure que le développement de la mine progresse et que la conception de la mine évolue, les prévisions de la qualité de l'eau doivent être vérifiées et mises à jour d'après les données du suivi.

ACKNOWLEDGEMENTS

Funding for this report was provided by the Mine Environment Neutral Drainage program (MEND).

The Faro Mine Closure Planning Office provided access to post-development modeling information.

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Wade Stogran (Aur Resources Inc),
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Stephen Day (SRK Consulting) and
Charlene Hogan (MEND Secretariat, NRCan)

All photos were provided by Bill Slater Environmental Consulting.

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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 Environment Neutral Drainage (MEND) 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. A recent report from the US looked at Environmental Impact statements and compared the predicted water quality to operational water quality.[1] They found uneven availability of data and quality of predictions across a range of mines, and noted that mines with acidic drainage require special attention for appropriate mitigation approaches.[2] Given the history of predictions and long term availability of data, the Faro mine is a good Canadian example to review and to reduce long term costs in the remediation process.

Predictions have been utilized for many years, so 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 variances that occurred between the development phase to the operation and post-operation phases.

The objectives of this report are:

1) To review predictions and outcomes for mine acidic drainage at the 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 open pits and waste rock

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[1] Kuipers et al. 2006.

[2] Kuipers et al. 2006.

dumps 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. An overview of the site and the adjacent Faro mine is provided in Figure 1.[3] 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. However, as discussed in section 4 of this report, there were differences in the geology that influenced the water quality outcomes.

The Vangorda deposit was mined between 1990-93 by Curragh Resources. It closed during 1993-4, during which time Indian and Northern Affairs Canada, INAC took over care and maintenance. At this time, the open pit was allowed to start filling with water, water treatment with lime 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 in 1992.

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 because it is till overburden material. The general site layout is shown on Figure 2 produced by SRK Consulting in 2005. Some components are also shown on Photo 1.

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[3] Minnow, 2007

Photo 1: Vangorda/Grum Mine Site, September 2005[4]

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.

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 the deepest point. 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.

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 Grum 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.

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[4] Bill Slater

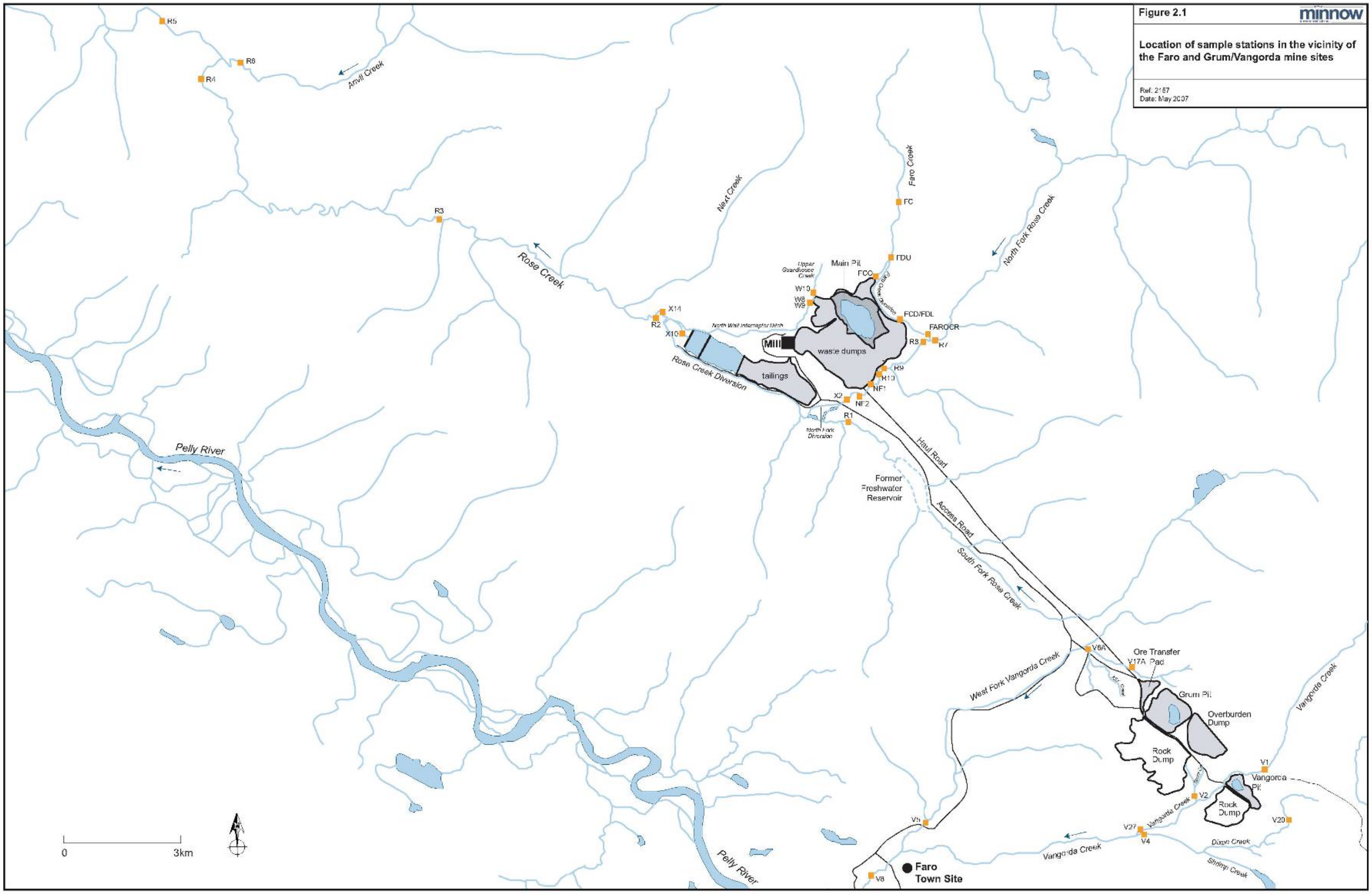

Figure 1: Site Overview. Minnow, 2007.

1990 estimates of waste rock quantities for Grum and Vangorda waste are provided in Table 1. Section 4.2 of this report elaborates on the geochemistry of the waste rock and loads from the various mine workings.

Table 1: Pre-Development Waste Rock Quantity Estimates[5]

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

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 after all mining was completed for the Grum and Vangorda Waste Rock Dumps (Table 2).

Table 2: As-Built Waste Rock Quantities

Rock Type	Grum Pit (x 10^6 tonnes)[6]			Vangorda Pit (x 10^6 tonnes)[7]		
	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 investigating the waste rock quantities to support renewed closure planning initiatives with the site receiver Deloitte and Touche. The 2002 GLL “as-built” quantities are substantially higher than SRK’s estimates of waste rock quantities at Vangorda (19.8 x 10^6 tonnes x 9.6 x 10^6 tonnes) and Grum (174.1 x 10^6 vs. 28 x 10^6 tonnes)[8]. For the Grum waste rock, there is significant discrepancy between the SRK estimates of waste rock quantities and the original mine plan which is reflected in the 2002 GLL “as-built” quantities. The Grum pit was never developed to its original design, only phase one was completed. Therefore the as-built waste rock quantities are much lower than the pre-development estimates. The original mine plan proposed excavation of approximately 75 x 10^6 tonnes in phase one of the Grum Pit. The SRK estimates for Grum only consider sulphide and phyllite waste. Since only phase one was completed, it appears that the SRK estimate of approximately 28 x 10^6 tonnes are likely the most accurate reflection of the size of the Grum Main Waste Rock Dump, though this is difficult to confirm.

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

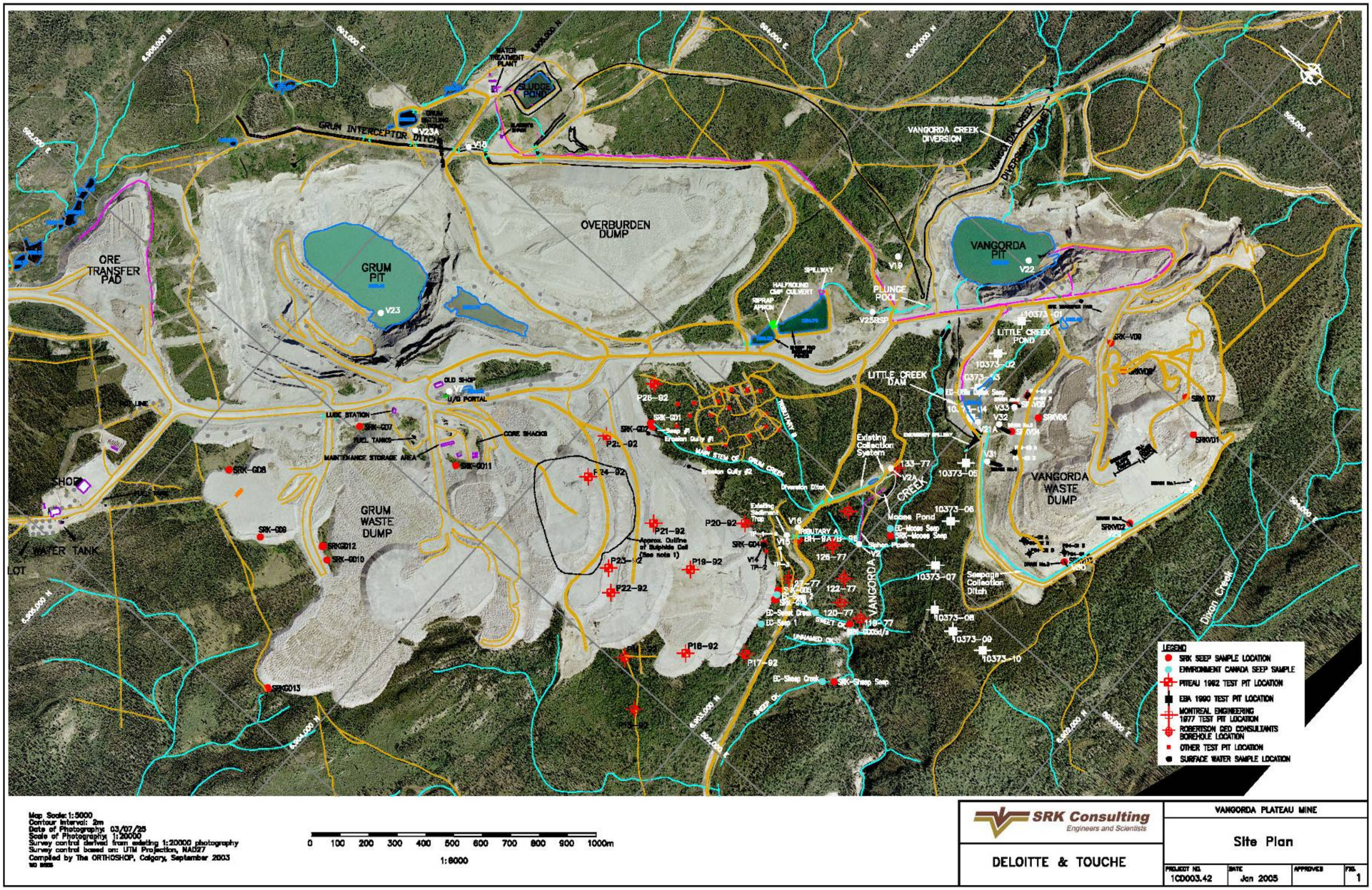

Figure 2: Vangorda/Grum Mine Site – SRK, 2005

3.0 STUDY METHODS

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 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.

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 as a sentinel species for the site's water quality. There are other species that might be relevant and important to study, however there is little water quality data available other than zinc for the pre-development sampling.

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 to evaluate the relationship between acidic drainage and the 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 Dump and Vangorda Waste Rock Dump.

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 (storage areas for high sulphide content materials to be separated from other waste rock) 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 1989 project proposal did recognize three different phases of water quality impacts associated with the proposed flooding of the Vangorda Pit. The model was only used to predict long-term steady-state conditions.[9,10]

Prediction of overall loading to 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. Loads from the natural sources were added to the model outputs 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 confluence of Vangorda Creek with Pelly River (at the ”mouth”) and where the original creek was diverted around the mine development at the mine site (at the “diversion”). INAC began operating an automatic recording station in lower Vangorda Creek in 1977. The facility operated only during ice-free periods from May to September.

Due to a limited data set, estimates of monthly streamflow relied on records from nearby long-term gauging stations. The stations ‘Pelly River Below Vangorda’ (22,100 km^2 catchment area, 15 years of record) and ‘Ross River’ (7,250 km^2 catchment area, 27 years of record) formed the basis

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[9] CRI, 1989, Chapter 5

[10] CRI, 1990-1, Chapter 7

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.

Table 3: Pre-Development Estimates – Mean Monthly Discharge (x1000 m^3)[11]

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. 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). With the exception of V10, which has not been active since the start of mine development, locations of relevant monitoring stations are shown on Figure 1.

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.

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[11] Source: CRI, 1989, s. 3.2.1.2

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 upstream reference station V1, and also downstream at stations V8 and V10.[12] Total and extractable zinc concentrations were relatively low on average at reference station V1 (average 0.014 mg/L zinc, maximum 0.1 mg/L zinc), station V8 (average 0.017 mg/L zinc, maximum 0.052 mg/L zinc) and station V10 (average 0.019 mg/L zinc, maximum 0.04 mg/L zinc). [13] A full data set of metals was not analysed in this time-frame, which makes comparison difficult.

The pre-development analysis calculated mean annual contaminant concentrations using a combination of extractable metals analyses and total metals analyses on water samples. 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. However, this pre-development estimate was determined during times of exploration that were affecting water quality in the area, there is no true baseline estimate. 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.[14]

4.2 Loads from Mine Related Sources

4.2.1 Flow Rates - Pits

Prediction of water quality loads from the site required estimates of flow rates into the open pits. The seepage and runoff into pits were two components the model considered when evaluating the loadings from the 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. During operation of the Grum Pit, 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

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[12] CRI, 1989, Tables A-16, A-25, A-26
[13] CRI, 1989, Tables A-16, A-25, A-26
[14] CRI, 1990-1, p. 2-2

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.[15] Modelling using flow nets indicated water seeps would enter the open pit along the NE slopes and partial dewatering of slopes would result. Post-abandonment seepage rate predictions were lower because they assumed that the open pit would be filled with water.

Runoff into the Vangorda and Grum 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 which were being designed to keep surface water flows out of the pit during operation. 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)[16]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
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	117.42
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	63.37
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	32.15
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	225.01
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	320.53
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	362.00
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	39.52
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	15.83
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	79.15
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	134.50
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	232.38
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	356.49
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	722.66
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	380.25

Source: SRK Jul 89, App A

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[15] CRI, 1989, Table A-46

[16] CRI, 1989, Appendix 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, which is described in Appendix B of the Initial Environmental Evaluation.[17] 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 movement 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 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 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).[18] 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.

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[17] CRI, 1989, Appendix B

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

Table 5: Runoff and Infiltration Estimates for Waste Rock Dumps (x 1000 m^3)[19]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
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	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	42.91
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	46.56
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	89.47
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	39.38
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	42.71
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	82.09
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	12.02
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	13.04
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	25.06
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	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	10.76
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	235.89
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	246.65
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	11.39
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	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	11.39
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	3.45
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	269.95
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	273.40

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%).[20] The 1989 IEE plan predicted the sulphide waste was to have no ore value and indicated that it would be sent to waste rock-dumps and remain in pit walls.[21] The altered phyllite had sulphide stringers and was considered to contain only minor sulphides. This material was expected to only rarely classify as ore. Even though they contained some sulphides, the 1989

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[19] CRI, 1989, Appendix A

[20] CRI, 1989, P. 2-7

[21] CRI, 1989, P.2-9

IEE plan stated that these materials could not be readily or reliably differentiated from unaltered phyllites and therefore would be excluded from the sulphide waste storage area.[22]

The characterization of the Vangorda Pit wall 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, is present from weathering),
- phyllites in the south west, and
- sulphides in a narrow area in the south east.[23]

At that time, it was estimated that the pit wall was composed of the following rock types, 30% sulphides, 60% phyllites and 10% carbonaceous phyllites.[24]

Photo 2: Vangorda Pit, September 2005[25]

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[22] CRI, 1989, P. 2-9

[23] RGC, 1996, Volume 2, p. 5-10

[24] RGC, 1996, Volume 2, p. 5-13

[25] Bill Slater.

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[26]

	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 requiring finer grinding, 8x higher gold content

The 1989 IEE described of the Units of sulphide rock types for acid potential based on sulphide content (variability by rock type in a range of 2-60% sulphide).[27] Different rock types were estimated to have a lower acid potential and a range of 2-60% pyrite.[28] This sulphide waste was to be deposited in the Vangorda waste dump during production.[29] The 1989 IEE plan proposed that the one type of altered phyllite with sulphide stringers, and minor sulphides would be deposited in the phyllite cell.[30]

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. This trend was similar for the carbonates, the type and amount change character over short ranges.[31] The rock types and associated mineralogy for the content of the Vangorda deposit are listed in Table 7.

Table 7: Mineralogy Content of Vangorda Deposit

Rock Type	***Minerals***
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 - $(Mg,Fe,Al)_6(Si,Al)_4O_{10}(OH)_8$ Muscovite - $KAl_2(AlSi_3O_{10})(OH)_2$, Kaolinite - $Al_2Si_2O_5(OH)_4$ Quartz - SiO_2
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), lithium (Li)
Feldspar	silicates of aluminum that may contain potassium, sodium, calcium or barium

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[26] CRI, 1989, P. 2-5
[27] CRI, 1989, P. 2-7
[28] CRI, 1989, P. 2-8
[29] CRI, 1989, P.2-9
[30] CRI, 1989, P. 2-9
[31] CRI, 1989, P. 2-62

4.2.5 Geochemical Predictions – Modeling Approach

The pre-development modeling for contaminant concentrations did not attempt to analyze the acidic drainage predictions. 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 for modeling. The project documentation in the IEE 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 the seepage, the modeling assumed that these concentrations would vary throughout 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 varied throughout 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 seepage data.

Photo 3: Grum Dump, June 2005[32]

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[32] Bill Slater

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 Vangorda 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 of 10.27 mg/L Zn, but more flow was expected from north wall.[33]

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

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 IEE (and addendums) 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

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[33] CRI, 1989, Table A-46

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 sampling point X23. At the time, concentrations at sampling point 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 of zinc for phyllite was lower than the AMMC for sampling point X23.

At the time of the analysis in 1990, 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 8.

Table 8: Annual Distribution of Zinc Concentrations (mg/L)[34]

	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

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[34] CRI, 1989, Appendix A

Some additional AMMC were considered in a sensitivity analysis for the model and carried out for abandonment conditions only.[35] Two additional cases were considered, however only zinc data was consistently available for the model. 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 sampling point X23 – with concentrations similar to the long-term zinc concentrations in an inoculated humidity cell (100 mg/L).
- The AMMC for the phyllite cell was 12 mg/L, estimated based on the long-term zinc concentrations in an inoculated humidity cell. This was lower than the base case AMMC but was still used 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 the treatment plant effluent had a zinc concentration equal to the effluent limit of 0.5 mg/L.

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. 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 the Vangorda Pit, the Vangorda Waste Rock, the Grum Pit and the Grum Sulphide Cell. For abandonment, the model estimated concentrations with and without till covers on the Vangorda Waste Rock Dump and the Grum Sulphide Cell.[36]

Subsequent modeling considered eight additional abandonment scenarios.[37] These scenarios focused on alternatives for abandonment of the Vangorda Waste Rock Dump. Where these scenarios considered treatment, the model assumed that 90% of water (and load) would be collected and treated from all mine-related sources.

A second addendum presented further additional modeling for abandonment conditions May 1990.[38] 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 the water (and load) would be collected and treated from relevant sources that could include the Vangorda Waste Rock Dump, the Grum Sulphide Cell and the Vangorda Pit walls.

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[35] CRI, 1990-1, Chapter 7
[36] CRI, 1989, Chapter 5
[37] CRI, 1990-1, Chapter 7
[38] CRI, 1990-2, Chapter 4

Of the many scenarios modeled, not all 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 sulphide/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 was found to be very similar. Pre-development load predictions for the operational and abandonment scenarios are provided in Table 9.

Table 9: Pre-Development Zinc Loading Predictions before Water Treatment (kg)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Operations[39]												
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[40]												
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

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[39] CRI, 1989, Appendix A

[40] CRI, 1990-1, Chapter 6

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. For example, none of the models had considered travel time delays or attenuation making it difficult to compare directly between predictions and monitoring results.

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.[41] SRK completed additional modeling in 2004 through 2007 to support closure planning initiatives.[42] 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 than GLL's 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. SRK's predictions consider a variety of closure options because the analysis was carried out for closure planning purposes. 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 from 1996 is described in section 4.2.3.[43] 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)[44] data set for 1990-95 show Station V22 (Vangorda pit water) had high zinc (mean 26.73 mg/L Zn, max 396 mg/L Zn in April 1992), high sulphate (mean 481.5 mg/L, max 3,020 mg/L in April 1992), and flow rate 691.2 m^3/day.[45]

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[41] GLL, 2002, Appendix A

[42] SRK, 2004-3

[43] RGC, 1996, Volume 2, p. 5-13

[44] RGC, 1996

[45] RGC, 1996, *Appendix E*

From these monitoring results, an average load of 6.74 tonnes Zn/year is estimated (almost 10x 1989 estimates) and 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).

Water levels have fluctuated in the Vangorda Pit since operations ceased in 1998. It 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, and water depths had reached over 40 m by 2003.

Photo 4: Grum Pit, September 2005[46]

Closure planning investigations in 2005 included estimates of current and predicted loadings for both Vangorda and Grum Pits.[47] The estimates relied on the water quality data described in Table 10. 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 taken in 2003 and 2004

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[46] Bill Slater

[47] SRK, 2006

included 18 samples from Grum Pit and 16 samples from Vangorda Pit. In 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 used for pre-development modeling (10 mg/L).

Table 10: Rock Types for Estimation of Wall Rock Seep[48]

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. These water balance estimates are presented in Table 11.

Table 11: Grum and Vangorda Water Balance

	Grum	***Vangorda***
Mean annual runoff	270 mm	362 mm
Mean annual precipitation	450 mm	380 mm
Lake evaporation estimates	352 mm	493 mm

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. Table 12 shows net inflow estimates for Grum and Vangorda pits.

Table 12: Grum and Vangorda Pit Net Inflows (x 1000m^3)[49]

	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

The loading estimates for conditions in 2004 probably represent the best estimates for comparison with pre-development operational predictions. For the Vangorda Pit, the results of this comparison need to take into consideration that the pit walls have remained exposed for much longer than the original development plan anticipated. For the Grum Pit, the results should recognize that the original predictions anticipated a much larger pit. The 2005 estimates included predictions for

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[48] SRK, 2006
[49] SRK, 2006

loading from flooded Vangorda and Grum Pits. These conditions are similar to those used for abandonment conditions in pre-development estimates and represent a reasonable comparison. The 2005 predictions only include total annual loads from 2004 which are presented in Table 13.

Table 13: 2005 Zinc Load Predictions – Grum and Vangorda Pits

Pit	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.[50]

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 Dump. These monitoring results most likely represent conditions similar to those considered for the pre-development operational modeling because the modeling considered exposed dump surfaces as that currently exist on the site. It should be noted however, that the pre-development 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 seep 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.[51] 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.

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[50] SRK, 2007-2

[51] SRK, 2007-1

5.3 Monitoring Results – Vangorda Waste Rock

Seepage monitoring has been carried out at the Vangorda Waste Rock Dump throughout the operational and care-and-maintenance phases. The construction of the till berm in 1994 included installation of six toe drains to allow free flow of water through the berm. When flowing, these drains have served as sampling locations for seepage from the Vangorda Dump. The results of the 2005 sampling are described in the 2005 Annual Environmental Report, Water Licence QZ03-059.[52] Additional data are provided in GLL 2002. Summary information is described in Table 14. Because there are few flow records and no record of zero flow sampling events, loads cannot be estimated based on these sampling events.

Table 14: Water Quality – Vangorda Waste Rock Drains

Drain	Flow Consistency	Seep Site # Samples	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 pumped to the Little Creek Pond prior to 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 pumped 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 results in Little Creek Pond indicated zinc concentrations averaging 596 mg/L for two samples. This represented a sharp increase from previous sampling results 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 the Vangorda Waste Rock Dump were not part of the GLL 2002 contaminant load balance because the load was assumed to report to the water treatment plant.

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 to be a significant source of loading (with NP/AP of 0, net NP average -525 kg $CaCO_3$/Tonne, and paste pH 3.7).[53] These fines also have high levels of stored soluble metal loads (extraction test

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[52] GLL, 2006

[53] ICAP, 1996, Volume 2, p. 5-2

results for Sb, As, Cd, Cr, Co, Cu, Fe, Pb, Mn, Ni, Zn completed). Pyritic quartzite from the pit wall was deposited at the north side of the Vangorda waste dump because of potential for future milling.[54]

Photo 5: Vangorda Waste Rock Dump, June 2005[55]

The 1996 ICAP description of the Vangorda pit altered phyllites differs from the 1989-90 IEE previously presented. 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.[56]

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 a paste pH 5.5).[57] 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.[58]

Grum waste rock samples showed higher sulphur content and lower sulphate than Faro samples.[59] The acid generating minerals were high in the waste rock content (1 sample had 53% pyrite, 1%

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[54] RGC, 1996, Volume 2, p. 5-3
[55] Bill Slater
[56] RGC, 1996, Volume 2, p. 5-4
[57] RGC, 1996, Volume 2, p. 5-20
[58] RGC, 1996*, Appendix H*, January 1997, Section 4.4.2
[59] RGC, 1996*, Appendix H*, January 1997, Section 4.5.2

arsenopyrite, 1% pyrrhotite, 0.5 chalcopyrite, 28% quartzite, 4% sericite, 12% carbonate, a second sample had 80% pyrite).[60]

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 15) were developed by utilizing regional data with confirmation using the local data for Vangorda Creek.

Comparison of values between Table 15 and Table 3 show relatively good agreement between pre-development and post-operational predictions for receiving water flows.

Table 15: Post-Operational Estimates – Mean Monthly Discharge (m^3/s)[61]

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 a 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.[62] 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

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[60] RGC, 1996*, Appendix H*, January 1997, Section 4.5.2

[61] SRK, 2004-3

[62] SRK, 2004-1

estimated some runoff. For uncovered waste rock, both modeling exercises considered all of the water to be contaminated.

SoilCover was used in post-operational modeling 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.[63]

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. This included review of historic geochemical testing (acid-base accounting, metal analysis, and short-term 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. Laboratory programs included acid-base accounting, extraction testing and humidity cells.[64]

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.

A range of predictions was used for estimating loading from waste rock dumps. Three conditions were considered for seepage water quality based on application of: (1) average seepage water quality to current understanding of dump geochemical composition, (2) maximum observed seepage concentrations to current understanding of dump geochemical composition, and (3) 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 the 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 phases. 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 used 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 16.

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[63] SRK, 2004-3

[64] SRK, 2004-2

Table 16: Post-Operational Estimates of Contaminant Concentrations and Loading for Waste Rock[65]

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 a 45% infiltration.

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

To confirm the predictions 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 predictions based on empirical data. For Grum, there is substantial variation between theoretical predictions and those based on empirical data.[66]

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[65] SRK, 2004-3

[66] SRK, 2004-3

6.0 SUMMARY AND ANALYSIS

Tables 17, 18 and 19 summarize the predictions, approaches and key assumptions for pre-development and post-operational zinc loading estimates. Table 17 addresses receiving water loading and Tables 18 and 19 address loading from pits and waste rock respectively.

The pre-development and post-operational methodologies and assumptions for estimating receiving water conditions and background zinc loading had some minor differences (Table 17). As expected, the sources of data for understanding these conditions were different, especially for background zinc concentrations for which pre-development estimates relied on data throughout Vangorda Creek, while post-operational estimates relied on data from upstream of the mine site. The changes in methodology, assumptions and data sources result in differences in the estimates of background flow and zinc concentration predictions for the two modeling exercises. However, the resulting differences in predicted zinc load are minor in comparison to the loads expected from mine-related sources.

Table 17: Receiving Water Zinc Load Predictions

	Pre-Development (1989-1990) Estimates	**Post-Operations(2003-2007) Estimates**
Model Inputs – Flow	Mean monthly discharge	Mean monthly discharge
Mean Annual Runoff Estimate – Vangorda Creek at Town of Faro (90.5 km^2)	244 mm	238 mm
Mean Annual Runoff Estimate – Vangorda Creek d/s of mine site (31.41 km^2)	244 mm	323 mm
Sources of Flow Data	1. Pelly River below Vangorda 2. Ross River 3. Vangorda Creek (June-Sep 1985)	Regional Data
Methodology re: flow estimates.	Regional analysis with correlation during common periods of record. Same yield used for all Vangorda Creek sub-watersheds.	Regional analysis with correlation during common periods of record. Yields for sub-watersheds varied according to size and elevation.
Zinc Load Estimates	30 kg/month in Vangorda Creek at the Town of Faro 11 kg/month in Vangorda Creek d/s of the mine site.	0.0137 mg/L (approx. 25 kg/mth in Vangorda Creek at the Town of Faro and 12 kg/mth d/s of the mine site.)
Model Inputs/Assumptions – Zinc	Mean monthly background zinc load. Model assumed constant monthly background load throughout the year.	Annual average background zinc concentration. Model assumed constant concentration throughout the year.
Sources of Zinc Data	Pre-development monitoring in Vangorda Creek u/s and d/s of the mine site – combination of extractable and total metals analyses.	Monitoring data from Vangorda Creek u/s of the mine site – during operations.

For estimating zinc loads from pits, the pre-development and post-operational methodologies relied on substantially different methodologies and data sources (Table 18). The pre-development estimates relied on theoretical predictions of seepage flow rates and water quality data from the Faro Pit. The post-operational estimates were able to rely on empirical data to develop water balances for the pits and understand seepage water quality.

The post-operational water balances probably provide a better estimate of flow rates into the pits and they suggest that the pre-development estimates may have over-predicted the flow rates. It should be recognized however, that the pre-development estimates did not consider evaporation for the operational conditions.

The seepage monitoring data used for the post-development predictions illustrate that the pre-development predictions substantially underestimated the seepage zinc concentrations for Vangorda Pit. The pre-development estimates for Grum Pit appear to have over-estimated concentrations during operations and underestimated them during abandonment. The underestimates for Grum Pit at abandonment would likely have been more severe if the pit had been developed to its planned size. The differences in seepage water quality predictions resulted in large differences between the pre-development and post-operational predictions for zinc loads from pits, especially Vangorda Pit.

The pre-development and post-operational methodologies for estimating zinc loads from waste rock were similar in many ways (Table 19). While the methodologies utilized different models for estimating flow distributions (infiltration, runoff, evaporation), both of the models relied on similar types of input data. The post-operational model provides a more up-to-date methodology for estimating flow patterns in the waste rock, but still relies heavily on the input information, including estimates of soil permeabilities.

The estimates of infiltration through waste rock covers are similar for both pre-development and post-operational modeling, varying by about 10% of mean annual precipitation. While this difference is small, it can account for a substantial variation in load predictions because the predicted zinc concentrations are so high.

The methodologies for predicting zinc concentrations from waste rock were similar. Both relied on empirical data to support the predictions. However, the data sources were quite different – with pre-development predictions relying on Faro data while post-operational predictions rely on data from Vangorda and Grum. Also, the additional 15 years of experience at Faro has provided some guidance about the potential zinc concentrations and the maturity of the water quality degradation at the time of the pre-development estimates. The post-operational modeling and the ongoing monitoring suggest that the pre-development predictions of zinc loading were severely underestimated for the Vangorda waste rock, primarily due to underestimates of the seepage water quality. Initial post-operational estimates for Grum waste rock suggested that the pre-development estimates were more accurate. However, recent monitoring data indicate that both approaches may have underestimated potential loading from Grum waste rock.

Table 18: Zinc Load Predictions from Pits

	Vangorda Pit			**Grum Pit**		
	Pre-development	**Monitoring**	**Post-operations**	**Pre-development**	**Monitoring**	**Post-operations**
Model Inputs – Flow (x1000 m^3/yr)	Seepage - 321 Runoff - 117	Total during operations - 227	Net Inflow 224	Seepage – 380 Runoff – 723	n/a	Net Inflow 260
Methodology re: Seepage	Well formulae Three pit wall areas considered		Pit water balances using data on pit water levels and estimates of mean annual runoff, precipitation and evaporation.	Well formulae		Pit water balances using data on pit water levels and estimates of mean annual runoff, precipitation and evaporation.
Seepage annual distribution	Rainfall data and Faro seepage flow data			Rainfall data and Faro seepage flow data		
Methodology re: Runoff	Same unit runoff as for overall Vangorda C. watershed			Same unit runoff as for overall Vangorda Creek watershed		
Runoff annual distribution	Same as for Vangorda Creek distribution			Same as for Vangorda Creek distribution		
Model Inputs – Zinc	Annual mean monthly zinc concentrations based on seepage and pit water monitoring at Faro.	Mean during operations – 28.9 mg/L 1998-2004 average – 66mg/L	Seepage concentrations based on seepage monitoring in Vangorda Pit and areas of wall rock exposure	Annual mean monthly zinc concentrations based on seepage and pit water monitoring at Faro.	Mean during operations – 0.66 mg/L 1998-2004 average – 7 mg/L	Seepage concentrations based on seepage monitoring in Grum Pit and areas of wall rock exposure
Seasonal distribution of zinc concentrations	Based on Faro data		Not addressed	Based on Faro data		Not addressed
Seepage Zinc Inputs	During operations: all areas – 10 mg/L After abandonment: Areas 1 and 2 – 10 mg/L, Area 3 – 2 mg/L		Concentrations vary between 46 (carbonaceous and non-calcareous phyllite) and 780 mg/L (pyretic phyllite)	During operations – 10 mg/L After abandonment – 0.04 mg/L		Concentrations vary between 0.014 (till) and 28 (sulphides) mg/L.
Runoff Zinc Inputs	During operations – 40 mg/L After Abandonment – 0.3 mg/L			During operations – 40 mg/L After Abandonment – 0.02 mg/L		
Predicted Pit Zinc Loads (kg/yr)	Operations – 7991 Abandonment - 792		At 2004 water level – 18000 Flooded - 13000	Operations – 12800 Abandonment - 27		At 2004 water level – 350 Flooded – 80

Table 19: Zinc Load Predictions from Waste Rock Dumps

	Vangorda Waste Rock Dump			**Grum Waste Rock Dump**		
	Pre-development	**Monitoring**	**Post-operations**	**Pre-development**	**Monitoring**	**Post-operations**
Waste Rock Flows (x1000 m^3/yr)	Operations, seepage – 90 Abandonment, seepage – 25 Abandonment, runoff - 82		Based on plan areas of waste rock dumps	Operations, seepage – 247 Abandonment, seepage – 270 Abandonment, runoff - 11		Based on plan areas of waste rock dumps
Model Utilized - Flow	HELP (VII)		SoilCover	HELP (VII)		SoilCover
Assumptions/Results – current/operational conditions (% MAP)	Uncovered waste rock – no runoff 37% infiltration		Uncovered, Seepage + Runoff, 45%	Uncovered waste rock – no runoff 37% infiltration		Uncovered, Seepage + Runoff, 45%
Assumptions/Results – Closure conditions (% MAP)	Covered 10% infiltration 35% runoff		Covered, 5% infiltration.	Sulphide cell covered 10% infiltration and 35% runoff for covered area		Varying covers, 5% infiltration on sulphide cell, 20% infiltration on remainder
Runoff annual distribution	Same as for Vangorda Creek distribution		SoilCover Model	Same as for Vangorda Creek distribution		SoilCover Model
Infiltration annual distribution	Based on seepage flows at Faro		SoilCover Model	Based on seepage flows at Faro		SoilCover Model
Model Inputs – Zinc	Contaminant concentrations from waste rock types 28.6 mg/L	Avg. concentrations to 2002: 279 to 2118 mg/L 2005 concentrations: 118 to 10350 mg/L	Contaminant concentrations from waste rock types	Contaminant concentrations from waste rock types Sulphide: 28.6 mg/L Other waste rock: 0.26 mg/L	2002-2006: <MDL to 110 mg/L	Contaminant concentrations from waste rock types
Zinc Loading Predictions (kg/yr)	Operations: 1920 Abandonment: 460		Operations (Future 1): 92251 Abandonment (Future 2): 24174	Operations: 365 Abandonment: 168	1997-2000: 177	Operations (Future 1): 377 (2004), 1367 (2005) Abandonment (Future 2): 227
Data Sources re: Zinc Concentrations	Seepage data from Faro waste rock		Seepage data from Vangorda and Grum waste rock	Seepage data from Faro waste rock		Seepage data from Vangorda and Grum waste rock
Seasonal distribution of zinc concentrations	Based on Faro data		Not addressed	Based on Faro data		Not addressed

The above summary describes 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.

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 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 20 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 realistic of expected conditions. In retrospect, contaminant concentrations at Faro have continued 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 long term or 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 20: 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
Separate cells for sulphide & phyllite waste	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 INAC 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 Vangorda pit	unknown	- phyllite compacts to a greater extent than at Faro site, insufficient and improperly sampled groundwater data available	IEE 1989 :ICAP 1996

Water Quality Model:	***Occurrence***	***Comments***	***Source (Predicted:Update)***
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 18 mg/L), Shrimp Creek V10 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 meteorological & hydrologic data	IEE 1989
Stream flow estimates for Vangorda Creek (7.7 L/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 & does not 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 e.g. Aluminum possibly from Kaolinite, underestimates neutral leaching of metals	IEE Addendum 1990 : ICAP 1997, EIS 2007
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 of these parameters could result in lower empirical concentrations than those which may develop in the long-term. It should be stressed that the geology needs to be very similar between the ore bodies for the seepage data to be of much use.

3. The results of laboratory testing (i.e. humidity cells) should be considered carefully. When modeling that utilizes laboratory testing results indicates conditions more adverse than those predicted by modeling that uses empirical data, the laboratory based modeling approach 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 (hydraulic conductivity), can be quite sensitive to assumptions about flow rates through these systems (i.e. covered waste rock dumps). Better methods for estimating these infiltration flows would likely help to improve predictions through covers and waste rock dumps. 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, as well as changing flow paths that can change flushing characteristics.

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 for the Vangorda site. 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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