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Technical Memorandum

To:	Dale Ortman, P.E.	**Date:**	May 3, 2010
cc:	Tom Furgason, SWCA Cori Hoag, SRK File, SRK	**From:**	Vladimir Ugorets, PhD, SRK Stephen Day, P.Geo. SRK
Subject:	Technical Review of (Tetra Tech, 2010) *Geochemical Pit Lake Predictive Model, Rosemont Copper Project*	**Project #:**	183101

This memorandum provides a technical review of the report, *Geochemical Pit Lake Predictive Model, Rosemont Copper Project* (Tetra Tech, 2010). This review was undertaken, and the Technical Memorandum prepared, at the request of SWCA and the Coronado National Forest, in accordance with a Statement of Work and Request for Cost Estimated from Mr. Dale Ortman dated February 17, 2010. This memorandum was prepared by Vladimir Ugorets and Stephen Day of SRK Consulting, Inc. (SRK).

Additional supporting documents from Tetra Tech on geochemical characterization (Tetra Tech, 2007a, and Tetra Tech, 2007b) and the *Mine Plan of Operations* (WestLand Resources, 2007) also were reviewed as background for preparing this memorandum. The report, *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure* (M&A, 2009), prepared for Rosemont Copper, was reviewed by SRK in February 2010 (SRK, 2010).

Tetra Tech used the results from the Montgomery & Associates M&A) (2009) groundwater model, which is being revised. The M&A revisions may affect the conclusions from the Tetra Tech pit lake predictive model and, therefore, SRK may modify their conclusions in this memorandum when the revised model results are made available.

The comments in the present review are grouped into three topics: (1) pit lake water balance, (2) dynamic system model (DSM) integration, and, (3) geochemical modeling. In general, the comments are requests for information and recommendations that will clarify the use of output from the groundwater model to predict pit-lake hydrogeochemistry, set up the DSM, and more accurately represent pit wall chemistry. Without the requested information and model outputs, SRK cannot adequately judge the model as suitable and defensible.

1 Pit Lake Water Balance

Components of the post-mining pit lake water balance include groundwater inflow and outflow, direct precipitation, pit wall runoff, and evaporation—as described below.

General Comments

SRK found three different sets of simulated lake stage and components of the water balance (groundwater inflow, precipitation, evaporation, and runoff) during our review process, as follows:

1. Source 1—Figure 46 of Montgomery and Associates (M&A) (2009): All components of the pit lake water balance simulated by the groundwater model during 100 years of pit lake infilling are shown in **gallons per minute** (gpm). See Figure 1 below.

2. Source 2—Illustration 5.04 of Tetra Tech (2010): All components of the pit lake water balance for the 200-year period of simulation of pit lake infilling are shown in **acres-feet/year**. See Figure 2 below.

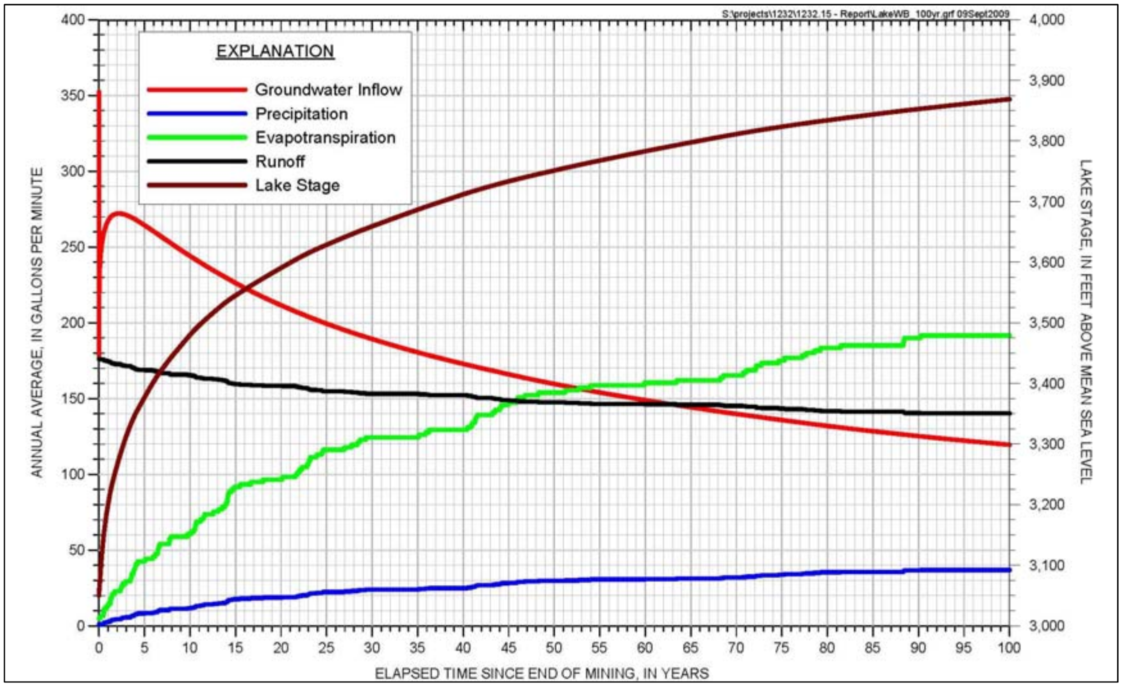

Figure 1. Figure 46 from M&A, 2009, in gallons per minute

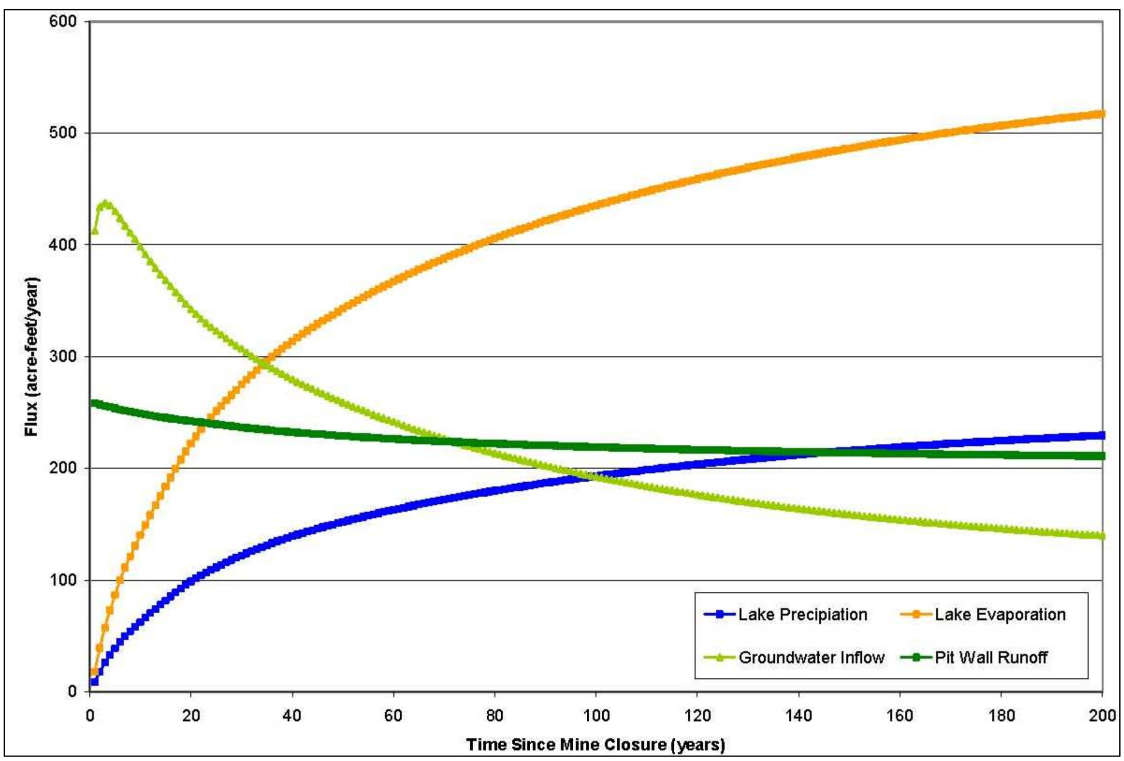

Figure 2. Figure 5.04 from Tetra Tech, 2010, in acre-feet/year

3. Source 3—Electronic Excel DSM input file, *Appendix D - DSM Input.xls* (Tetra Tech, 2010): All components of the pit lake water balance for the 100-year period of simulation of pit lake infilling are listed in **cubic feet per day**. These data were plotted by SRK in units of gpm and acre-feet/year for comparison with the M&A (2009) and Tetra Tech (2010) graphs. See Figure 3, below.

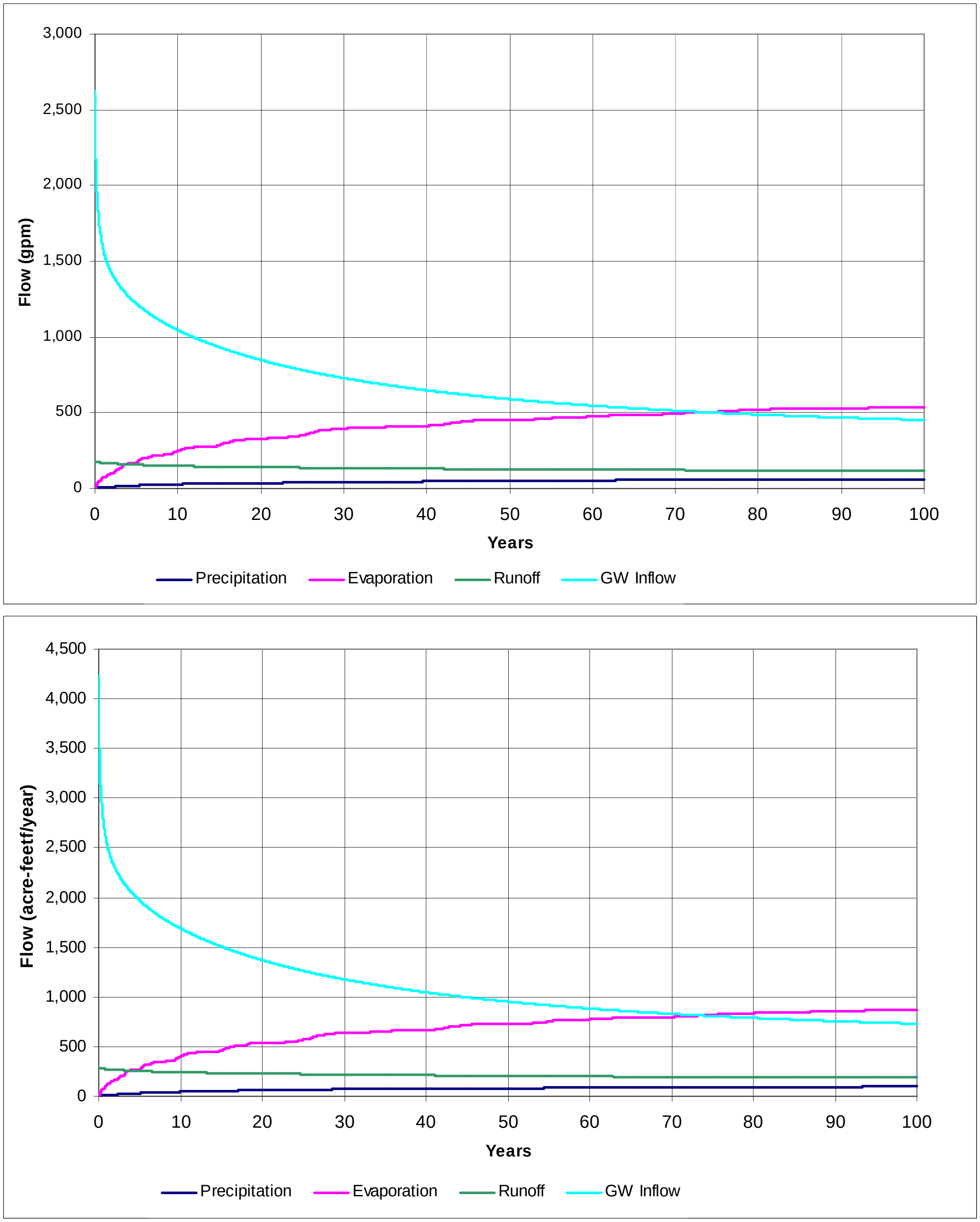

Figure 3. Tetra Tech (2010) data plotted in gpm (upper) and acre-feet/year (lower) (SRK, this review)

SRK found significant differences in the components of the pit lake water balance in these graphs, which were used as input data for the hydrogeochemical analysis. To better illustrate these differences SRK changed all data to the same unit and summarized them at Year 100 (for example) of pit lake infilling. See Table 1, below.

Table 1. Year 100 of pit lake infilling, data from three sources, in gallons per minute

Component of Balance	M&A (2009)(1) (Source 1)	Tetra Tech (2010)(2) (Source 2)	Tetra Tech (2010)(3) (Source 3)
Precipitation to Pit Lake (gpm)	37	121	60
Evaporation from Pit Lake (gpm)	182	273	540
Runoff to Pit Walls (gpm)	150	142	117
Groundwater Inflow (gpm)	120	120	452
Net of Inflow (gpm)	125	110	89
Pit Lake Stage (ft msl)	3,869	3,869	4,142 (?)

Notes: 1 – Estimated from the graph (M&A, 2009, Figure 46) by SRK Consulting.
2 – Estimated from the graph (Tetra Tech, 2010, Figure 5.04) and unit conversions by SRK Consulting.
3 – Appendix D (Tetra Tech, 2010) and unit conversions by SRK Consulting.

It should be noted that SRK found a fourth source of data in the Tetra Tech (2010) electronic Excel DSM output file, *Appendix E - DSM Output.xls*. This file shows simulated groundwater inflow to the pit lake in gpm units for a period of 200 years. Data for the first 100 years are consistent with Figure 46 of M&A (2009), but are very different from input data in the Tetra Tech (2010) DSM input file, *Appendix D - DSM Input.xls*.

The following points are unclear to SRK:

a. The nature of these inconsistencies,
b. How results of the predictions of pit lake infilling during the period of 100 years simulated by the groundwater flow model (M&A, 2009) were incorporated into the 200-year predictions, completed by Tetra Tech (2010), and
c. Exactly what data were used in the Tetra Tech simulation (reported in Appendix D or the input data reported in Appendix E)?

The inconsistencies in the components of the pit lake water balance make it impossible to evaluate the correct use of these components in the analysis performed by Tetra Tech.

Groundwater Inflow

Tetra Tech (2010) used groundwater inflow to the pit lake from results of the 3-D numerical modeling completed by M&A (2009). Tetra Tech states on page 19 of their report that, "*The lake stage versus groundwater inflow relationship was taken exactly from the M&A model and was not critically evaluated for consistency with expected or standard pit inflow curves (M&A, 2009). This data is presented in electronic format in Appendix D.*"

Groundwater inflow is a significant component of the pit lake water balance and depends on hydraulic heads adjacent to and below the pit, the lake stage, and the hydraulic properties of the surrounding country rock. The pit lake stage depends on the depth, size, and geometry of the final pit configuration, and on the other components of the pit lake water balance. Finally, groundwater inflows into the pit lake and lake stage depend on pre-mining hydrogeological conditions and the rate and duration of pit dewatering. The water-balance components can be evaluated precisely only by using a numerical groundwater model, by simulating pit-lake stage iteratively for each time step, and by considering and varying all components of the water balance listed above.

Groundwater Outflow

Tetra Tech assumed groundwater outflow from the pit lake equals zero based on M&A (2009) modeling results that predicted the pit lake to be a permanent hydrologic sink. SRK agrees with this assumption.

Direct Precipitation

Average monthly precipitation data of 22.2 inches per year (in/yr) were taken from the Santa Rita Experimental Range 8 miles to the southwest of the project area, due to the limited duration of the data record at the Rosemont site. The data from both stations closely correspond (where data from the Rosemont site are available). SRK considers the amount of a direct precipitation of 22.2 in/year as reasonable for this study.

Pit Wall Runoff

Pit wall runoff was simulated using a fraction of the precipitation that ultimately reaches the pit lake. This fraction was varied from 15 to 35 percent and was applied to the area of exposed pit walls above the pit lake elevation. (A runoff value of 30 percent from precipitation was used by M&A (2009) to simulate groundwater inflow to the pit lake.)

SRK did not find a value for the area of the ultimate pit in the text of the report (information shown in Tetra Tech, 2010, Illustration 5.01, does not look complete), and was not able to verify the volume of pit wall runoff into the pit lake geochemistry model.

Tetra Tech did not incorporate upgradient drainage runoff into the model, assuming that the upgradient areas will be bermed and the existing drainages will be diverted around the pit.

Evaporation

Tetra Tech estimated a pan evaporation rate of 71.52 in/year. The value was derived from data from the Nogales station adjusted to the Rosemont site, based on a linear trend with each station elevation. The monthly average projected pan evaporation data were converted to a lake evaporation rate using a coefficient 0.7. SRK considers a lake evaporation of 50 in/year as very reasonable for this study.

Components of Water Balance Simulated by M&A (2009) Groundwater Flow Model

SRK reviewed the M&A (2009) groundwater flow model (SRK, 2010) and concluded that this model:

a. Has uncertainties in representing known geology and structures,
b. Does not have the proper external and internal boundary conditions,
c. Needs to be calibrated to transient conditions measured during a 30-day pumping test from multiple pumping wells to increase the limited predictive capability, and
d. Needs to be re-developed and re-run with elements of a sensitivity/uncertainty analysis to illustrate the possible range of predicted parameters.

SRK is of the opinion that direct precipitation, pit lake evaporation, and runoff data used in the M&A (2009) groundwater model may have been used incorrectly. The model uses an evaporation rate from the pit lake of about 34 in/year and precipitation to the pit lake of about 6.8 in/year, instead of 50 in/year and 22 in/year, respectively.

SRK disagrees with the Tetra Tech (2010, pages 1, 2, and 31) statement that “about 95 percent of the contribution to the pit lake will be from groundwater.” Figure 46 of M&A (2009) and Illustration 5.04 of Tetra Tech (2010) do not support this statement. If the authors meant the chemical load instead of the pit lake inflow, it is not clear from the text of the report.

2 Dynamic System Model (DSM) Integration

SRK's evaluation of the DSM computer model, which is discussed in this section, is preliminary because the input data to the model are based on outputs from the M&A (2009) groundwater flow model, which is being revised.

The DSM computer model for the proposed Rosemont mine pit lake was developed in GoldSim™ to simulate the hydrologic water balance and the mixing of chemical loads from the different components of the water balance (e.g. groundwater inflow, pit wall runoff, precipitation). The DSM outputs from the predictive simulations were used as inputs to a final simulation model using PHEEQC.

The DSM includes both stochastic (variable) and deterministic (fixed) parameters. The stochastic parameters were used to assess the uncertainty in the predictions due to the data and analytical constraints and the natural variability in the input parameters (such as precipitation, pit wall runoff, and lake evaporation). Groundwater inflow to the pit was assumed to be a deterministic parameter and was incorporated into the model by a simplified relationship between groundwater inflow and lake stage. This relationship was developed on the basis of outputs from the post-mining predictions made by the numerical groundwater flow model (M&A, 2009).

SRK is of the opinion that this approach of using precipitation, evaporation, and pit wall runoff as stochastic parameters and combining them with a deterministic relationship between groundwater inflow and pit lake stage (QGW = f(HPL)) is very approximate because both groundwater inflow and lake stage depend on these stochastic parameters. It is not clear from the Tetra Tech report how groundwater inflow to the pit lake was simulated (from previous time step based on used relationship QGW = f(HPL), or not?) As mentioned above, it is SRK's opinion that the water-balance components can be evaluated precisely only by using a numerical groundwater model, by simulating pit-lake stage iteratively, and by considering and varying all components of the water balance for the same time period.

SRK also has noticed that the groundwater inflow flow data presented in the file *Appendix D - DSM Input.xls* do not match output data in the file *Appendix E - DSM Output.xls*, as described above.

3 Geochemical Modeling

Components of the geochemical model include characterization of the pit walls as the source of loadings to the pit lake, conceptualization of the pit lake ("Conceptual Geochemical Model"), calculation of loadings from the pit walls, and calculation of concentrations in the pit lake.

General Comment

The overall approach used for the modeling is conventional and reasonable. The characterization data that form the basis for the model are suitable for the intended purpose. The model combined geometrical characterization of the pit with geological and geochemical description of the pit walls with other geochemical inputs (groundwater, precipitation) to calculate the chemistry of water in the pit lake. Geochemical modeling was used to calculate final water quality by considering the solubility of secondary minerals and water-solid interactions.

Details of each step in the geochemical method are reviewed below. SRK has identified concerns with the approach that suggest the pit wall source terms should be re-calculated. SRK's overall impression is that re-calculation could result in increases in concentrations but due to the abundance of acid neutralizing minerals in the host rocks it is unlikely that the modeled pH of the pit water will change. The water is expected to be basic.

In the following sections, a pre-amble review is provided, followed by specific bulleted items for follow-up.

Review of Modeling Steps

Characterization of Pit Walls

The geological setting of the project is described as a "wall rock porphyry system" (Tetra Tech, 2010, p. 3). This contradicts Vector Arizona (2006), which describes the deposit as skarn. The mineralization is hosted by sedimentary and volcanic rocks intruded by porphyry stocks. The mineralization is described as disseminated and vein-controlled copper, zinc, molybdenum, and iron sulfides.

- The deposit type needs to be more fully described because the skarn and porphyry mineralization types have important different implications for geochemical performance.
- It was not clear in the description whether classic porphyry hydrothermal alteration (e.g. potassic, argillic, propylitic) is present at Rosemont, which in some porphyry deposits can exert a control on the geochemical characteristics of the pit walls. Vector (2006, p. 2) indicated "most of the porphyry system including the pyrite shell is absent due to structural controls."

About 10 percent of the ore is described as oxide (Tetra Tech, 2010, p. 3), which presumably occurs as a supergene cap on the hypogene mineralization.

- The Tetra Tech (2010) report lacks a mineralogical description of the supergene zone, which could have different geochemical characteristics from the hypogene zone.

The pit walls were characterized using samples collected from drill core samples. Tetra Tech (2010) determined that sufficient samples had been collected to determine statistically the average characteristics of each rock type in the pit walls. The following limitations to the assessment of sample coverage were noted by SRK:

- Samples were dominantly collected from drilling focused on the core of the deposit. Depending on the type, intensity, and distribution of alteration, the assumption that the samples can be used to characterize the pit walls needs to be investigated. Should a "pyrite halo" be present, it is possible the pit walls have a different style of mineralization from the core of the deposit used to characterize the rock types. Conversely, mineralization intensity may decrease near the pit walls.
- Since lead and zinc vein mineralization can be associated with distal propylitic porphyry alteration and skarn mineralization, the statistical characterization of metal distribution in the pit walls should be considered in addition to acid rock drainage (ARD) potential.
- The statistical evaluation should be extended to consider hydrothermal alteration as a variable.
- The characteristics of wall rock oxide materials should be provided.

Geochemical analysis of the pit walls used various methods that included acid-base accounting (ABA), short-term extraction tests, and kinetic tests. ABA was used to characterize the potential for acidic conditions to develop in the pit walls but the effect of site mineralogy on the method was not presented:

- Calibration of the conventional ABA method to site mineralogy needs to be considered. A more detailed description of the relevant mineralogy including acid generating, acid neutralizing, and water soluble minerals should be provided.
- The calculation of acid potential (AP) appears to have been based on sulfide sulfur though description of the method used to calculate this could not be located. It appears that soluble sulfur is an important component of the rock (Tetra Tech, 2007b, Illustration 3.1). The mineralogical form of soluble sulfur is important as it may be acid generating (e.g. jarosite) or non-acid generating (e.g. gypsum) and should be evaluated for its contribution to AP.

- The Sobek Neutralization Potential (NP) method can lead to over-statement of site-available NP if silicate minerals react in the test. To address this concern, the carbonate mineralogy of the site should be described (e.g. presence of iron carbonates), carbonate analytical data should be presented and compared with NP, and the effect of silicates on NP should be investigated by comparing carbonate and NP determinations.
- The possible effect of blasting on the release of mineral components to blast fines in the pit walls should be considered because the mineralization is described as “vein controlled.”
- Based on these considerations, the application of conventional ARD criteria may need to be re-considered for the site.

Conceptual Geochemical Model

The conceptual geochemical model for the pit lake is presented on page 5 of Tetra Tech (2010). The model should be expanded to include the following considerations:

- The assumed configuration of broken rock in the pit walls;
- The processes leading to leaching of potential contaminants from the pit walls considering the roles of oxidation, dissolution, and water rock interactions;
- Mechanisms for attenuation of acidity and metal loadings from pit walls;
- The effect of submergence of pit walls by the rising pit lake;
- Geochemical reactions between pit lake and walls;
- The potential role of limnological processes in pit lake development (e.g. meromixis); and
- In the event that chemically reducing conditions develop in the pit lake, the effect on attenuation and mobilization of potential contaminants (e.g. arsenic).

Pit Walls Source Term

SRK understands the pit wall source term was developed by assigning runoff water chemistry to each rock type component of the walls and then allowing this loading to enter the pit lake in proportion to the exposure of these rock types in the pit walls (Tetra Tech, 2010, Illustration 4.01).

SRK understands from Tetra Tech (2010, page 13) that loading calculations for the pit walls were based on concentrations taken directly from short-term leach tests (STLTs) because the sulfide content of the rock is low and the tests represent short term contact between water and rock. Assuming our understanding is correct, SRK disagrees with this approach and suggests it may significantly under-predict concentrations in the wall runoff. STLTs use a much higher liquid to solid ratio than will occur under field conditions, contact time in the test may not be sufficient to represent the contact of slow moving water in pit walls, and single pass leachate contact does not demonstrate equilibration of the solids with contact water. Further, testing of core samples may not represent the accumulation of secondary minerals that occurs in pit walls between flushing caused by intermittent storm events.

These concerns are illustrated by the sulfate source term. For the majority of rock types, sulfate source terms are well below 20 mg/L (exceptions are the Epitaph and Horquilla Limestones at 254 and 110 mg/L, respectively). These concentrations are well below the theoretical solubility of gypsum (1600 mg/L), which appears to be present to varying degrees in the pit walls. The effect of solution ratio is shown by comparing field and laboratory kinetic tests (Tetra Tech, 2007b, Illustration 3.7). The field kinetic tests commonly produced sulfate concentrations exceeding 200 mg/L compared to concentrations well below 100 mg/L for the parallel laboratory tests. The kinetic tests also produced concentrations above 100 mg/L for the initial flush, which would appear to represent initial contact water.

- To address this concern, the pit wall source terms should be re-calculated using an approach that considers scale-up from laboratory to site conditions. The approach could consider differences in solution ratios for extraction tests, or scale-up of kinetic test results. Both approaches should ensure that secondary mineral dissolution controls are incorporated.

- The revised source terms should include the potential effect of acidification. It is understood that one of the model runs considered acidification of the Bolsa Quartzite (Tetra Tech, 2010, page 26), but the use of humidity cell data may not be appropriate with scaling of the results to site conditions.
- The use of sub-detection limit values should be explained. For example, the detection limits for selenium in the SPLPs is 0.04 mg/L, which is well above the water quality standard. The modeling inputs (Tetra Tech, 2010, Appendix D) show a large number of parameters as “0” mg/L.

The source terms presented are for pit wall runoff. Should that not already be included, additional source terms are needed for:

- Leaching of oxidized walls that occurs as the pit lake water-level rises; and
- Possible reactions of pit lake water with wall rock due to chemically reducing conditions, should these develop.

Pit Lake Water Chemistry

SRK understands the pit lake water chemistry model was based on mass balance, then the final output from the DSM model at Year 200 was evaluated for thermodynamic controls using PHREEQC (Tetra Tech, 2010, page 25). The modeling used a selection of mainly plausible secondary minerals to control water chemistry (Tetra Tech, 2010, Table 6.01). Minerals like barium arsenate, huntite, and magnesite may form theoretically but they rarely form from natural surface waters. Other components may co-precipitate rather than form discrete minerals (e.g. radium sulfate). The modeling also incorporated the effect of adsorption by iron oxides. This latter effect may be limited because most of the walls are predicted to be non-acidic and iron solubility will be limited. Additional clarification is suggested to improve understanding of the model:

- Provide sample calculation of mass balance.
- Update Table 6.02 (Tetra Tech, 2010) to compare mass balance chemistry and chemistry calculated by PHREEQC, to allow the effect of modeling assumptions to be evaluated.
- Provide graphs to illustrate the progress of concentrations as the pit lake fills.
- Provide a culpability analysis to illustrate sources of loading for each parameter in addition to TDS (Tetra Tech, 2010, Illustration 5.05).

For review purposes, it is useful to consider whether the modeled calculations can be reproduced using a simple scoping level calculation. SRK used the various graphical (Illustration 5.03) and tabulated (Table 4.01, 4.02, 4.03) input models in Tetra Tech (2010) and was able to calculate within 5 percent the predicted concentrations of sulfate and chloride in the pit lake at year 200. The calculation confirmed the significance of groundwater in terms of loading contribution. Using the scoping level calculation, it was determined that re-evaluation of source terms to reflect scale-up could lead to pit walls having a greater influence on pit lake chemistry including elements mobile under non-acidic conditions and with limited sorption capacity. For example, sulfate concentrations could be four times those predicted, and based on experience, selenium concentrations will likely be greater than predicted.

- As a further check on the model, the report might consider adding regional comparisons of actual pit lake chemistry, such as that of the ASARCO Mission mine, which has similar pit wall formations and deposit chemistry.

4 Conclusions and Recommendations

The descriptions of the model provided in the reviewed report do not allow SRK to determine the reliability of the predictions of pit lake water chemistry during post-mining conditions.

In our opinion:

a. Existing inconsistencies in the description of components of the water balance should be resolved; components of the water balance should be consistent with parameters used in the groundwater flow model.

b. Groundwater inflow to the pit lake should be re-evaluated. The re-evaluation should be based on the groundwater model presently being updated by M&A using the recommendations described in SRK (2010) and the correct application of precipitation, evaporation, and run-off data for pit lake simulations.

c. Use of the DSM with stochastic parameters of precipitation, runoff, and evaporation combined with deterministic groundwater output from the numerical groundwater model is a very preliminary and inaccurate approach. This is due to the fact that both groundwater inflow and pit lake elevation depend on the meteorological parameters simulated in the groundwater model deterministically. By stochastically varying these parameters (precipitation, runoff, and evaporation), groundwater inflow will be different in time from that simulated in the groundwater model under an assumption of constant values of these parameters.

d. The conceptual geochemical model for the pit lake does not appear to consider additional factors, as described above, that may influence pit water chemistry

e. The current model may understate pit lake concentrations due to the method used to predict the chemistry of pit wall runoff. Revision of the wall source terms is recommended.

5 References

Montgomery & Associates, 2009, Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure, Rosemont project, Pima County, Arizona: Report prepared for Rosemont Copper by Montgomery & Associates, October 28, 2009, 147 p.

SRK, 2009, Technical review of M&A groundwater flow model report prepared Rosemont Copper: Technical Memorandum prepared for SWCA, February 9, 2010, 6 p.

Tetra Tech, 2007a, Baseline geochemical characterization, Rosemont Copper: Report prepared for Augusta Resource Corporation, Tetra Tech Project No. 320614, June 2007, 41 p., 2 appendices.

_____ 2007b, Geochemical characterization, Addendum I, Rosemont Copper: Report prepared for Rosemont Copper Company, Tetra Tech Project No. 320614.100.07, November 2007, 23 p., 2 appendices.

_____ 2010, Geochemical pit lake predictive model, Rosemont Copper Project: Report prepared for Rosemont Copper, Tetra Tech Project No. 114-320777, February 2010, 33 p., 6 appendices.

Vector Arizona, 2006, Preliminary trip report and Phase 1 Sampling and Analysis Plan: Technical Memorandum to Jamie Sturgess and Mike Pawlowski from Kathy Arnold, Vector Document No. 088/06-05-1400-5.3, July 26, 2006, 7 p.

6 Reviewer Qualifications

The Senior Reviewer for Geochemistry, Stephen Day, P. Geo., is a Principal Geochemist with SRK Consulting in Vancouver, Canada (résumé attached). Mr. Day has more than 30 years of experience in geochemistry; in particular, he has more than 10 years of experience in the development of waste management plans to address acid rock drainage and leaching of mine wastes in general, as related to hard rock mining. One area of Mr. Day's expertise relevant to the present review is in the development of prediction methods for mine planning and modeling of leachate chemistry. Mr. Day was directly responsible for reviewing the geochemistry of the pit lake predictive model.

The Senior Reviewer for Hydrogeology, Vladimir Ugorets, Ph.D., is a Principal Hydrogeologist with SRK Consulting in Denver, Colorado (résumé attached). Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection well fields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and in-situ recovery mines. Dr. Ugorets was directly responsible for reviewing the hydrogeology of the pit lake predictive model.

ATTACHMENT A
Resumes of Key Technical Personnel

Stephen J. Day
Principal Geochemist

Profession Professional Geoscientist

Education M.Sc, Geochemistry, University of British Columbia 1988.
B.Sc., Geology, University of British Columbia 1985.

Registrations/ Affiliations Professional Geoscientist (BC) No. 18,467.
Professional Geologist (Northwest Territories and Nunavut) No L1283.
Association of Professional Engineers and Geoscientists of B.C.
Fellow of the Geological Association of Canada.
Fellow, The Association of Applied Geochemists.

Specialisation

Stephen Day is Principal Geochemist at SRK's Vancouver office. He is an experienced specialist in the development of waste management plans to address acid rock drainage and leaching of mine wastes in general. He has particular expertise in the development of prediction methods for mine planning and modeling of leachate chemistry. His project experience includes development of innovative approaches to management of potentially acid generating wastes at new mines, assessment of existing waste disposal facilities at operating and abandoned mines to determine options for reduction or elimination of contaminated drainage, and environmental audits of mines.

Certification

Occupational Safety and Health Administration (OSHA).
Hazardous Wastes Operations and Emergency Response (OSHA 29 CFR 1910) 40-hour course.

Employment Record

1998 – Present **SRK Consulting (Canada) Inc.,** Principal Geochemist

1992 – 1998 **Dames & Moore**, Senior Geochemist/Manager, Geosciences

1989 – 1992 **Norecol Environmental Consultants Ltd.**, Geochemist

1987 – 1989 **British Columbia Geological Survey**, Geochemist

Publications

Fifteen technical papers on metal leaching and acid rock drainage studies, stream sediment sampling, formation of placer deposits, mineral exploration in glacial terrains.

Stephen J. Day
Principal Geochemist

Key Experience: New Mine Approvals and Permitting

PolyMet Mining Corp., Northmet Project, Minnesota (1999-2001, 2004-current)
- Development and implementation of geochemical test program, and water quality predictions for proposed open pit PGM, nickel and copper mine at the facilities of an existing iron mine.

Taseko Mines, Properity Project (2006-current)
- Geochemical assessment of waste rock and tailings for proposed open pit copper-gold mine.

Niblack Mining, Niblack Project (2006)
- Review of geochemical aspects for permitting of underground exploration development.

Teck Cominco, Morelos Project (2006-2008)
- Geochemical assessment of waste rock and tailings for proposed open pit gold mine.

Miramar, Doris North Project (2006-current).
- Geochemical characterization of quarry rock

AES Wapiti Coal Project, Hillsborough Resources (2006)
- Geochemical characterization of waste rock and coal for proposed drag line coal mine.

Horizon Project, Hillsborough Resources (2006)
- Geochemical characterization of waste rock and coal processing products for proposed underground and open pit coal project.

Barrick Gold, Donlin Creek Project (2006-current)
- Geochemical characterization of waste rock and tailings for proposed open pit gold mine.

Westhawk Development Corp., Coal Creek Project (2006).
- Geochemical characterization of waste rock and proposed small coal mine.

Crowflight Minerals, Bucko Mine (2005)
- Geochemical characterization of rock and tailings for proposed underground nickel mine.

Doublestar Resources, Catface Project
- Geochemical characterization of rock and tailings for proposed open pit copper mine.

Novagold Corporation, Galore Creek Project (2004-current)
- Geochemical characterization
- Prediction of water quality impacts and recommendations for waste handling at a proposed open pit copper-gold mine

Pebble Partnership, Pebble Project (2004-Current)
- Geochemical characterization.
- Prediction of water quality impacts and recommendations for waste handling at a proposed open pit copper-gold-molybdenum mine

Stephen J. Day
Principal Geochemist

bcMetals Corporation, Red Chris Project (2003-Current)
- Geochemical characterization
- Prediction of water quality impacts and recommendations for waste handling at a proposed open pit copper-gold mine

Brule Project, Western Canadian Coal (2004-2006)
- Geochemical characterization, water chemistry predictions and input to waste management planning for a coal mine

Dillon Mine, Western Canadian Coal (2004)
- Geochemical characterization, water chemistry predictions and input to waste management planning for small coal mine

Doublestar Resources Limited, Sustut Copper Project (2001-2003)
- Assessment of geochemical issues for proposed copper mine
- General permitting assistance under the BC Environmental Assessment Process

Barrick Gold Corp, Pascua Project, Chile/Argentina (1999-2001)
- Assessment of waste rock and tailings geochemistry and prediction of drainage quality

Alaska Department of Natural Resources, True North Project (2000-2002)
- Review of expansion proposals for the Fort Knox Mine

BHP Billiton Diamonds, Ekati Diamond Mine™, Northwest Territories (2001-Current)
- Characterization of waste rock and prediction of water quality for the Sable, Pigeon and Beartooth Pipes
- Compilation of Waste Rock Management Plans

Crystal Graphite Corporation, Black Crystal Graphite Project, British Columbia (2001-2002)
- Geochemical characterization of waste rock and tailings for a proposed graphite mine

Teck Corp, Pogo Project, Alaska (1996-2004)
- Geochemical characterization
- Prediction of water quality impacts and recommendations for waste handling at a proposed underground gold mine

Indian and Northern Affairs Canada, Northwest Territories (1999-2001)
- Review of geochemical aspects of Diavik Diamond Mines

Coeur d'Alene Mines, San Bartolome Project, Bolivia (2001-2002)
- Geochemical characterization of waste rock and tailings for a proposed silver mine

Manalta Coal, Telkwa Coal Project, B.C. (1991-2000)
- Development of waste management plan to address acid drainage potential

Sutton Resources, Bulyanhulu Project, Tanzania (1997-1998)
- Waste management planning and prediction of impacts for proposed underground gold mine

Teck Corp, Marte Lobo Project, Chile (1997)
- Assessment of potential impacts to groundwater due to waste rock leaching at proposed open pit gold mine

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Pine Valley Coal, Willow Creek Coal Project, B.C. (1996-1997)
- Baseline evaluation of acid generation potential and water quality for proposed coal mine

Teck Corp, Petaquilla Project, Panama (1996-1997)
- Prediction of potential impacts due to leaching of waste rock at proposed open pit copper mine

Cominco, Kudz-Ze-Kaya project, YT (1996)
- Retained to address acid generation issues in waste management plan for proposed zinc-copper-lead mine

Termopacifico, Colombia (1994)
- Assessment of existing waste management for small coal mines as part of proposed thermal power plant

Manhattan Minerals, Moris Mine, Mexico (1993)
- Developed closure plan for proposed heap leach gold mine. Also addressed acid generation issues

TVI, Canatuan Project, Philippines (1993)
- Development of waste management plan for proposed gold mine

El Condor, Kemess South Project, B.C. (1992)
- Evaluated natural weathering of rock and soil in support of waste management plan for proposed copper mine

Brewery Creek (1991)
- Soil and vegetation geochemistry study

Galore Creek Project (1991)
- Conducted initial assessment of acid generation at proposed large porphyry copper mine

Snip Mine (1991)
- Developed cyanide degradation model for tailings pond

Berg Project (1990)
- Investigated acid generation in waste rock and proposed waste handling approach for porphyry copper mine

Taiwan Limestone Project (1990)
- Conducted environmental assessment of proposed limestone quarry

Geddes Resources, Windy Craggy Project, B.C. (1989-1991)
- Investigated acid generation in waste rock, tailings, and underground workings and developed waste management plan for proposed massive sulphide copper mine

Cinola Project (1989-1990)
- Development of waste rock and tailings management plan for proposed epithermal gold mine

Cheni Gold Mines (1989)
- Developed waste rock handling plan for potentially acid generating rock at gold vein mine

Silver Butte Mine (1989)
- Interpreted acid generation data for waste rock and underground development for proposed massive sulphide base metal mine

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Confidential Client
- Due diligence audit for a proposed porphyry copper mine
- Prediction of impacts due to rock and tailings leaching and recommendation of waste management strategies

Key Experience: Operating Mines

Alaska Department of Environmental Conservation and Hecla Greens Creek Mining Company, Greens Creek Mine
- Team leader for environmental audit of an underground silver mine.

Elk Valley Coal Corporation (2007-current)
- Development of a geochemical model for leaching of selenium to the Elk River and Cardinal River from six large open pit coal mines.

Imperial Metals, Mount Polley Mine (2004-Current)
- Geochemical characterization and water quality predictions for mine expansion.
- Water quality predictions for closure of copper heap leach.

Inmet, Troilus Mine (2005)
- Development of an approach for waste rock segregation at open pit copper gold mine.

BHP Billiton, Mina Tintaya (2005-2006)
- Evaluation of selenium sources in waste rock and downstream attenuation and transport.
- Geochemical characterization for closure planning.

TeckCominco, Elkview Coal Mine (2003)
- Detailed assessment of occurrence and release of selenium from mine facilities, and recommendations for management approaches

Teck Cominco Alaska, Red Dog Mine, Alaska (1997-Current)
- Development of innovative methods for characterization of the geochemical behaviour of waste rock
- Ongoing geochemical advice and interpretation

Thompson Creek Mining, Endako Mine (1999-2000)
- Assessment of waste rock geochemistry

Huckleberry Mines Limited (1996-current)
- Ongoing advice to operating open pit copper and molybdenum on waste management and prediction of long term water quality impacts

TeckCominco, Luscar Ltd., Fording Coal, Elk Valley Coal Mines, British Columbia (1999-2002)
- Technical review of university research on the occurrence and release of selenium from waste rock

Hudson Bay Mining and Smelting (1998)
- Environmental audit of more than ten massive sulphide copper and zinc mines, mills and associated smelter

Confidential, Colombia (1997)
- Assessment of existing environmental liabilities and scoping of environmental impact assessment for an operating coal mine as part of due diligence review

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Cominco Trail Operations, B.C. (1993)
- Developed slag pile leachate model for proposed slag disposal site

Gold Mine Yellowknife, NWT (1993)
- Environmental assessment of operating gold mine as part of due diligence

Macrae Mining, New Zealand (1993)
- Presented arguments on acid generation thresholds in tailings. Evaluated reports on arsenic leaching from waste rock and tailings

Equity Silver Mines (1991)
- Developed water quality model for an acid generating open pit to address disposal of water treatment sludge in pit

Tanco Mining company (1991)
- Environmental audit of tantalum mine and mill

Endako Mines (1990)
- Evaluated acid generation potential of waste rock and tailings at molybdenum mine

Key Experience: Mine Closure Planning

Barrick Gold, Nickel Plate Mine (2005)
- Geochemical characterization for closure planning of waste rock, mine workings and tailings from open pit gold mine.

Teck Cominco, Pine Point Mine (2006)
- Evaluation of monitoring requirements for tailings discharge.

Teck Cominco Alaska, Red Dog Mine (2003-Current)
- Water quality predictions for mine closure planning

Deloitte & Touche, Faro Mine (2002-Current)
- Design and implementation of geochemical studies for closure planning

BHP Billiton, Island Copper Mine (2001-2005)
- Geochemical studies for closure planning
- Chemical load modelling

Hudson Bay Mining and Smelting, Flin Flon Operations (2005)
- Input to estimation of closure costs.

Teck Cominco, HB Mine (2005)
- Review of geochemical issues for tailings.

Viceroy Resources, Brewery Creek Mine (2002-2004)
- Evaluation of water quality aspects related to closure.
- Assessment of selenium leaching.

Inmet, Samatosum Mine (2003)
- Environmental audit of former open pit copper-silver mine.

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BHP Billiton, Confidential Internal Reviews (2002)
- Reviewed geochemical aspects of closure plans for two mines

BHP Billiton, Robinson Mine, Nevada (2001-2002)
- Geological and geochemical characterization of waste rock as part of closure planning for a large open pit copper mine
- Operation of a field laboratory for determination of leachable metal concentrations

British Columbia Ministry of Water Land and Air Protection, Britannia Mine, British Columbia (2001-Current)
- Evaluation of the effects of the use of mine workings for storage of contaminated mine water prior to treatment

Highland Valley Copper, Highmont Mine, BC (2000-2001)
- Geochemical assessment of tailings for closure planning

Dupont Canada, Baker Mine, B.C. (1999-Current)
- Evaluation of long term drainage quality for an inactive underground gold and silver mine
- Closure Planning

TeckCominco Ltd., Sa Dena Hes Mine, Yukon Territory (1999-Current)
- Assessment of geochemical characteristics of underground lead-zinc mines, waste rock and tailings, and downstream loading and impact assessment

Environment Canada, Mount Washington Mine, B.C. (1999-2000)
- Assessment of geochemistry as part of closure planning for a inactive open-pit copper mine

Holden Mine, Washington State (1998-Current)
- Support for Feasibility Study for closure of underground mine, waste rock and tailings
- Development of a site geochemical model to support selection of closure measures for a disused underground copper and zinc mine

Westmin Resources, Premier Gold Mine, B.C. (1998-2002)
- Prediction of long term geochemical behaviour of waste rock and tailings at an open pit gold mine

Homestake, Snip Mine, B.C. (1998)
- Prediction of post-closure impacts due to leaching of mine wastes at underground gold mine

Confidential Client (1996)
- Evaluated leaching of mercury from a former mercury mine as part of decommissioning

COMIBOL, Bolivia (1996-1997)
- Assessment of environmental issues for operating and closed mines as part of due diligence review

Weldwood Canada, Various Properties, B.C. (1996)
- Environmental evaluation of large area of former coal mining to assess remediation measures and potential costs

Stronsay, B.C. and Sa Dena Hes, Y.T. projects (1993)
- Initial assessment of potential environment liabilities

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Kinross Gold, QR Gold Mine, B.C (1993, 1998-2000)
- Predictions of post-closure impacts due to long term leaching of waste rock and pit walls at open pit gold mine

Cominco, Sullivan Mine, B.C. (1992-1998)
- Evaluation of metal leaching from oxidized waste rock and tailings as part of closure planning. Geochemical interpretation of regional groundwater chemistry downgradient of tailings facility. Modelling of dry cover materials for acid generating tailings

Cominco, Pinchi Lake Mine (1994-1995)
- Evaluation of mercury distribution and leaching from mine wastes as part of closure planning

Survey of Abandoned Mines (1991)
- Compiled data relating to acid generation potential at more than 1000 abandoned mines in British Columbia. Assessed five coal and metal mine sites

Key Experience: Government Projects

Association of Professional Engineers and Geoscientists of British Columbia (2006-2007)
- Delivered a short course acid rock drainage assessment (five venues

MEND Program (2005-2006)
- Lead author for a report on the effect of low temperatures on geochemical processes.

U.S. Trade and Development Agency, Dominican Republic (2002)
- Delivered part of a short course to federal government personnel on acid rock drainage assessment and remediation

State of Alaska (2001)
- Workshop on mine site geochemical assessment

Canadian International Development Agency, Peru (2000-2001)
- Preparation of guidelines for inspection of mines

MEND Program (2000-2001)
- Managed and co-authored preparation of report titled Acidic Rock Drainage and Technology Gap Analysis

MEND Program (1996-2000)
- Co-author of technology manual on acid rock drainage prediction, control and treatment

MEND Program (1998)
- Reviewed and assisted with selection section of Procedures for Assessing the Subaqueous Stability of Oxidized Waste Rock

MEND Program (1997)
- Co-authored Blending and Layering Waste Rock to Delay, Mitigate or Prevent Acid Generation

MEND Program (1996)
- Co-authored Guide for predicting water geochemistry from waste rock piles

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Japan International Cooperation Agency, Brazil (1995-1996)
- Part of a multi-disciplinary team led by Mitsubishi that evaluated remediation of coal mines in the State of Santa Catarina

Indian and Northern Affairs (1994)
- Prepared a long range research plan for acid rock drainage

Mine Environment Neutral Drainage Program, Cinola Project, B.C. (1994)
- Assessed long term potential for acid generation in waste rock and evaluated limestone addition to prevent acid release from waste rock

QA/QC for Acid Generation Studies (1990)
- Prepared manual for BC Acid Mine Drainage Task Force

Review of Acid Generation Determination Methods (1990)
- Assessed methods and recommended new approaches to testing for Energy, Mines and Resources Canada

Acid Rock Drainage Technical Guide (1989)
- Co-authored state-of-the-art manual covering prediction and monitoring of acid mine drainage

Key Experience: Contaminated Sites and Other Projects

Ministry of Health
- Directed sampling of 240 wells to assess potential pesticide contamination

Fullerton Lumber
- Assessed soil contamination and potential approaches to on-site processing and soil remediation

Fisheries and Oceans Canada
- Assessed soil, sediment and water contamination at a marine repair station. Developed and costed remediation options

Fisheries and Oceans Canada
- Assessed contaminated woodfill on Crown lands. Developed and costed remediation options

Western Steel
- Interpretation of arsenic sludge chemistry.

Grand Metropolitan
- Assessment and management of several hydrocarbon underground storage tanks

Transport Canada
- Senior review of project to assess liabilities associated with underground fuel storage tanks at 28 remote beacon sites

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Profession Principal Hydrogeologist

Education M.S. (Mining Engineering/Hydrogeology) Geology-Prospecting Institute, Moscow Russia
Ph.D. (Hydrogeology) Geology-Prospecting Institute, Moscow Russia

Registrations/ Affiliations Senior Scientist in Hydrogeology, USSR/Russia
National Ground Water Association
MSHA

Specialization Mining Hydrogeology, Groundwater Modeling, and Wellfield Optimization.

Expertise Dr. Ugorets has more than 31 years of professional experience in hydrogeology, developing and implementing groundwater flow and solute-transport models related to mine dewatering, groundwater contamination, and water resource development. Dr. Ugorets' areas of expertise are in design and optimization of extraction-injection wellfields, development of conceptual and numerical groundwater flow and solute-transport models, and dewatering optimization for open-pit, underground and ISR mines.

Employment Record

2007 – Present **SRK Consulting (U.S.), Inc.,** Principal Hydrogeologist
Denver, CO

1996 – 2007 **Hydrologic Consultants Inc. (HCI),** Senior Hydrogeologist
Lakewood, CO

1991 – 1995 **Hydrogeoecological Research and Design Co (HYDEC),** Lead Hydrogeologist
Moscow, Russia

1978 – 1990 **Geology-Prospecting Institute (MGRI),** Senior Scientist in Hydrogeology
Moscow, Russia

Languages Russian, English

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Publications
English

Ugorets V.I. and Howell, R.L. *2008* “3-D Characterization of Groundwater Flow in Hard-Rock Uranium Deposits”, presented at 2nd International Symposium – Uranium: Resources and Production, VIMS, Moscow, p. 120-121.

Ugorets, V.I., Howell, R.L., and Mahoney, J.J. *2006* “Challenges to Hydrogeologic Investigations in the Canadian North”, presented at 59th Canadian Geotechnical Conference and 7th Joint CGS/IAH-CNC Groundwater Specialty Conference (seatoskygeo.ca), October 2006, Vancouver. Sea to Sky Geotechnique, p. 1608-1612

Ugorets, V.I., and MacDonald, A. K. *2003* “Design and Optimization of Mine Dewatering Based on Ground-Water Flow Modeling,” in Computer Applications in the Minerals Industries (Proceedings of Forth International Conference, CAMI, Calgary, Alberta, Canada).

Ugorets, V.I., Rusdinar, Y., Parseryo, G. and Liu, H. *2002* “Identification of Dewatering Targets for Graberg Pit Using Hydrogeochemical Fingerprint Approach,” presented at 2002 Denver Annual Meeting of The Geological Society of America.

Ugorets, V.I., Hanna, T. M., Howell, R. L., Ternes, T. and McCarter, J. *1999* “Use of Frozen Earth Wall to Reduce Effects of Dewatering on Alluvial Aquifer in Vicinity of the Proposed Aquarius Open Pit Mine,” in Sudbury — Mining and the Environment II (Sudbury, Ontario, Canada). D. Goldsack et al., Eds. Sudbury: Laurentian University, Centre in Mining and Mineral Exploration Research.

Ugorets, V. I., Azrag, E. A. and Atkinson, L. C. *1999* “Use of a Finite Element Code to Model Complex Mine Water Problems,” Annual Meeting of American Institute of Hydrology and Fourth USA/CIS Joint Conference on Environmental Hydrology and Hydrogeology (San Francisco), pp. 163-164. San Francisco: American Institute of Hydrology.

Ugorets, V.I., Azrag, E. A., and Atkinson, L. C. *1998* “Use of a Finite Element Code to Model Complex Mine Water Problems,” in Mine Water and Environmental Impacts (Proceedings of the International Mine Water Association Symposia, Johannesburg, South Africa), Vol. 1, pp. 31-41. Johannesburg: International Mine Water Association.

Ugorets, V.I., Borevsky, B.V., and Borevsky, L. V. *1994* “Regulation of the Movement of Different-Density Fluids During Injection of Waste: An Optimization Model with Special Reference to the Injection System in the Krasnodar Region,” in Scientific and Engineering Aspects of Deep Injection Disposal of Hazardous and Industrial Wastes (Proceedings of the International Conference, Berkeley, California), pp.21. Berkeley, California: Lawrence Berkeley Laboratory.

Ugorets, V.I., and Tserkovsky, Y. A. *1992* “Optimization of Extraction-Injection Wells Sitting in Groundwater Management Problems / Flow Through Porous Media: Fundamentals and Reservoir Engineering Applications, (Proceedings of the International Conference, Moscow, September, 1992), pp. 52-55.

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Russian

Ugorets, V.I., and Tserkovsky, Y. A. *1991* "Optimization Models for Ground-Water Withdrawal and Protection from Contamination Problems" (review). Moscow: Geoinformark.

Ugorets, V. I. and Tserkovsky, Y. A., *1991*"Optimization Model of 2nd Donetsk Ground-Water Intake Site as Applied to the Problem of Ground-Water Safe Yield Re-Evaluation with Ecological Restrictions," in Proceedings of 6th Conference of Young Scientists of Moscow Geological Survey Institute, manuscript deposited in VINITI, No. 2520-B91.

Ugorets, V. I., and Tserkovsky, Y. A., *1990* "Optimization of Water Abstraction from Multi-Layered System with Simultaneous Pumping and Injection of Industrial Ground Water," in Proceedings of 5th Conference of Young Scientists of Moscow Geological Survey Institute, manuscript deposited in VINITI, No. 3011-B90.

Ugorets, V. I., and Tserkovsky, Y. A. *1989* "Evaluation of Safe Yield of Malkinskoe Ground-Water Basin by Using of Optimization Model," in Proceedings of 4th Conference of Young Scientists of Moscow Geological Survey Institute, manuscript deposited in VINITI, No. 4919-B89.

Ugorets, V. I., and Gavich, I. K. *1988* "Hydrodynamic Calculations of Ground-Water Intakes," in Hydrogeodynamics, pp. 271-279. Moscow: Nedra.

Ugorets, V. I., Greisukh, L. V., and Filippova et al, G. A. *1988* "Ground-Water Flow Model of Ala-Archinskoe Ground-Water Basin," in Chu Depression and Optimization Model of its Development. Izv. Vys. Ucheb. Zav., Geologiya I Razvedka, No. 9.

Ugorets, V. I. *1988* "3D Ground-Water Flow Model of Multi-Layered System Using Economic Finite-Difference Schemes," in Proceedings of 3rd Conference of Young Scientists of Moscow Geological Survey Institute, manuscript deposited in VINITI, No. 7857-B88.

Ugorets, V. I., and Tserkovsky, Y. A. *1987* "Axisymmetric Ground-Water Flow Model in Multi-Layered System," in Proceedings of 2nd Conference of Young Scientists of Moscow Geological Survey Institute, manuscript deposited in VINITI, No. 3036-B87.

Ugorets, V. I., Gavich, I. K. and Mikhailova, A. V. *1985* "Optimization of Ground-Water Development by Using Automated System of Management: Water Abstraction Under Complex Hydrogeologic Conditions," in Methods of Ground-Water Protection Against Contamination and Depletion. Moscow: Nedra.

Ugorets, V. I. and Lenchenko, N. N. *1985*. "Hydrodynamic Calculation of Ground-Water Intakes with Variable Pumping Rates," Izv. Vys. Ucheb. Zav., Geologiya I Razvedka, No. 11.

Ugorets, V. I., Gavich I. K, and Mikhailova, A. V. *1984*. "Optimization Models in Hydrogeology," in Mathematical Modeling of Hydrogeological Processes. Novosibirsk: Institute of Hydrology.

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Key Experience: Mining Hydrogeology

- **Grasberg Copper/Gold Mine, West Papua (Indonesia)**: Conducted site characterization, design of hydrogeologic testing, and review of Grasberg open pit and EESS underground mine dewatering on semi-annual and annual basis. Developed a series of conceptual hydrogeologic models and groundwater flow models of the Ertsberg Mining District. Modeling has included development of regional and "window" models, the latter for detailed analysis of pore pressures related to slope stability in open pit and dewatering of underground block caves. Predicted inflow and pore pressures in Grasberg open pit as input to slope stability analysis Predicted inflow to underground mines (the existing IOZ and DOZ block cave mines and the proposed Kucing Liar, and Grasberg Deep block caves, and Big Gossan mine) from karstic limestones under very high (but variable) precipitation. Estimated the persistence of mill water supply during periods of El Niño-induced drought. Evaluated major groundwater sources in vicinity of Grasberg pit and EESS underground mine based on water chemistry fingerprints. Conducted ARD study and predicted quantity and quality of groundwater captured by existing developments and proposed ARD capture drifts and missed water in Wanagon basin. Conducted regional hydrogeology study and developed regional groundwater flow model of Ertsberg mining district to predict potential migration of ARD during post-mining conditions as part of Integrated Control and Capture Plan (ICCP). Conducted training in hydrogeologic data analysis and groundwater flow modeling for PTFI personnel. Developed a special numerical algorithm to simulate non-Darcian flow into underground openings from highly transmissive geologic structures.

- **Snap Lake Diamond Project, Northwest Territories (Canada):** Developed a conceptual hydrogeological, numerical groundwater flow, and hydrogeochemical mixing modes. Work has included a) planning and evaluating the results of hydrogeologic drilling, testing, and groundwater sampling from existing underground workings, b) developing a conceptual hydrogeologic model of the kimberlite dyke partially beneath a lake within open talik and partially below a permafrost, c) predicting inflow to the proposed underground mine, d)simulating hydrologic effect of paste backfilling on mine water discharge, and e) predicting the water quality of the mine discharge under lake and lake draining scenarios by using mixing simulations based on TDS vs. depth profile. Participated in numerous Technical Group meetings to provide hydrogeological input in design and instrumentation of mine test panels for geotechnical analysis. All work was completed for pre-production studies of existing mine and business case improvement studies for expanded mine.

- **Gahcho Kué Diamond Project, Northwest Territories (Canada):** Conducted hydrogeological investigation for desktop and pre-feasibility studies including: a) planning and analyzing results from hydrogeologic testing program (packer and airlift recovery tests and from Westbay monitoring wells, b) developing a comprehensive conceptual hydrogeologic model including kimberlite pipes, permafrost, and open/closed taliks, c) developing a series of numerical groundwater flow and solute transport models, d) predicting inflow to multiple open pits, e) estimating impacts to surface-water bodies in the vicinity of the pits, f) predicting the water quality of the mine water discharge, g) estimating leakage around/under man-made dykes for lake drainage scenario, and f) simulating pit lake infilling and post-mining hydrogeologic conditions taking into consideration a density effect. Represented client at numerous meetings with permitting agencies.

- **Fort à la Corne and Star Diamond Projects, Saskatchewan (Canada):** Conducted hydrogeologic investigations for three diamond projects, including: a) planning and analyzing results of hydrogeologic drilling and testing (including 4 pumping tests), b) developing a comprehensive conceptual hydrogeologic model, c) developing numerical axisymmetric and 3D groundwater flow models, d) predicting inflow to the open pits and designing dewatering systems, e) predicting pore pressures in pit walls as input for the slope-stability analysis, and f) estimating potential environmental impacts to water levels and streamflows during mining/dewatering and pit lake infilling. Represented client at meeting with permitting agencies.

- **Victor Diamond Project in Ontario (Canada):** Developed a series of conceptual hydrogeologic and numerical groundwater flow models for desktop, pre-feasibility, feasibility, and pre-production studies. Work has included a) planning and analyzing results of hydrogeologic investigations (drilling and testing, including 3 long-term pumping tests), b) developing a comprehensive conceptual hydrogeologic model of a karstified limestone groundwater system recharged by surface water through overburden, c) predicting inflow to the proposed open pit, d) designing an dewatering system with an optimal pumping rates and schedule of installation, and e) estimating potential environmental impacts to streamflows, ponds, and muskeg during mining/dewatering and pit- lake infilling. Represented client at numerous meetings with regulators and at public hearings, and prepared detailed discussions of potential environmental impacts.

- **Aquarius Gold Project, Ontario (Canada):** Developed conceptual hydrogeologic model of area of the proposed Aquarius open pit mine. Conducted groundwater flow modeling of inflow to proposed open pit and designed an optimal dewatering system by using traditional pumping wells. Predicted potential effects of dewatering on trout-bearing streams and lake levels within a nearby provincial park and designed potential groundwater mitigation measures. Completed groundwater flow modeling of freeze wall system around the proposed pit and developed hydrogeological input for freeze wall design.

- **Skyline Coal Mine, Utah:** Conducted groundwater flow modeling to evaluate various alternative sources and pathways of groundwater inflow to the underground mine and estimated the effect of mine inflow and pumping on surface-water resources. Predicted long-term dewatering requirements for mine expansion, and assessed Probable Hydrologic Consequences to surface resources using numerical groundwater flow model. Represented client at numerous meetings with permitting agencies, water boards, and plaintiff groups.

- **Premier Diamond Project, South Africa:** Developed axisymmetric groundwater model to predict passive inflow to the open pit and pore pressures in pit walls during future mining development.

- **Confidential Mine Dewatering Project, Russia:** Analysis of all available hydrogeological data and developing recommendations regarding dewatering requirements for different alternative mining methods. Developed groundwater flow model to predict a) inflows to open pit and underground mine (under different mining methods) and b) associated environmental impacts to the surface-water bodies and shallow groundwater system.

- **Confidential Coal Project, Virginia:** Developed groundwater flow model to a) predict inflow to underground coal mine and b) evaluate possible hydrogeologic effect of underground mining on water levels within shallow groundwater systems.

- **Confidential Mine Dewatering of Silver and Gold Deposits in Mexico (states of Durango and Nayarit):** Conducted a technical audit of existing hydrogeological data and developed plan for an effective dewatering system of underground mine workings for the first deposit. Conducted hydrogeological investigations to evaluate possible groundwater inflows to proposed underground mine at the Scoping Study level for the second deposit.

- **Uranium Deposits in the Athabasca Basin (Central Canada) – two confidential projects:** Developed a program of field hydrogeological work and performed an analysis for the collected hydrogeological data to make assessment of groundwater inflow to proposed underground mine for the first project. Comprehensive data analysis and predictions of possible inflows were made based on developed

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numerical groundwater model. Peer review of the dewatering requirements for an underground mine was completed for the second project at the Feasibility Study level, based on additional groundwater flow modeling conducted.

- **Uranium ISR Projects in Russia and Kazakhstan – three confidential projects:** Completed a technical audit of possible uranium recovery by ISR mining. Conducted a comprehensive ISR numerical modeling of one of the projects, including simulation of streamlines and reactive mass transport along them, to evaluate maximum uranium recovery from four paleochannels.

- **Hard Rock Uranium Deposits in Russia – five confidential projects:** Implemented a technical audit and hydrogeological study of groundwater inflow to proposed underground mines, quality of mine water discharge, possible impact to the surface-water bodies. Two 3-D numerical groundwater flow models were developed for two projects at the Pre-Feasibility Study level.

- **Uranium deposit in Niger – a confidential project**: Completed an analysis of available hydrogeological data and made an expert opinion on the possibilities of using ISR method to mine the uranium deposit.

- **Coal deposit in Russia – a confidential project:** Completed hydrogeological study of possible water inflow into underground longwall mine workings and impact to a river flow. Predictions and sensitivity analysis were conducted based on developed 3-D numerical groundwater flow model, calibrated to all available hydrogeological data collected for both pre-mining steady state and trial dewatering transient conditions. Recommendations were developed to reduce uncertainties in hydrogeological characterization, to bring project to the required Feasibility Study level.

- **Confidential Mine Dewatering Project in Columbia:** Technical audit of available hydrogeological data, development and implementation of field hydrogeological program, and assessment by groundwater modeling of possible groundwater inflow to expanded open pit operation mined in vicinity of the river.

- **Polimetallic Ore Deposit in Russia (Kola Peninsula):** Analysis of the available hydrogeological data and the previously performed studies to substantiate the possible impact of proposed in-pit dewatering to a shallow groundwater system and surface water bodies as part of the ESIA.

- **Gold Deposit Project in Pakistan:** Analysis of the available hydrogeological data and the previously performed studies to substantiate the possible impact of proposed in-pit dewatering and mine water supply wellfield to a shallow groundwater system as part of the ESIA.

Key Experience: Russia and Former USSR (1978-1995)

Hydrogeological investigation and numerical modeling of groundwater development for potable, thermal, and industrial water supplies and mine dewatering in complex hydrogeologic settings. Developed and implemented numerical algorithms for optimizing groundwater management under hydrogeologic, environmental, and economic constraints.

Specific project experience includes:

- Groundwater flow modeling to estimate inflow and design dewatering system for Vorontsovskoy open pit gold mine in Ural region of Russia.

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- Wellfield optimizing based on the groundwater flow models to quantify safe yield at the Priokskii (Moscow region), Lesnoe (Tataria), Pozhneyal-Sediuskii (Komi), Avatchinskii (Kamchatka), and Minsk (Belarus) water-supply projects.

- Optimizing pumping from the extraction wells at low salinity groundwater system in Mangyshlak Basin (West Kazakhstan) based on numerical 3-D groundwater flow model. Developing an analytical solution of a complex aquifer-well-pump-pipeline system and selecting appropriate pumping equipment to provide optimal withdrawal. Applying basic principles and methods of automated groundwater monitoring systems for water resource management.

- Developing conceptual, analytical, and numerical methods of wellfield optimization to design cost-effective water supply systems in complex hydrogeologic settings for Sredne-Kliazminsky site in Moscow region.

- Determining safe yield and optimal pumping rates of water-supply wells in multi-aquifer systems, within Malkin groundwater basin in North Caucasus area, and plan protection against contamination and depletion.

- Developing integrated numerical modeling system including groundwater flow, mass transport, and heat transport for Slaviansko-Troitsky iodine-bearing groundwater basin in Kuban to maximize safe yield, optimize wellfield of extraction and injection wells, and develop most rational method of water management.

- Using groundwater flow models to optimize locations and pumping rates of wells to minimize operational and environmental costs at Donetsk (Ukraine) and Ala-Artchinsky (Kirgizstan) water-supply projects.

- Designing and conducting laboratory column tests, experimenting with physical models, and evaluating field infiltration ponds to assess feasibility of purifying waste water through sandy deposits for the uranium mine in Western Kazakhstan.

- Developing numerical code (*OPTLIB*) for simulation of groundwater flow and wellfield optimization under multi-disciplinary constraints. This code was used during hydrogeological studies for all projects in Russia and Former USSR listed above.