

## Technical Memorandum

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<b>To:</b>	Tom Furgason, SWCA	<b>Date:</b>	February 9, 2010
<b>cc:</b>	Dale Ortman, P.E. Cori Hoag, SRK File	<b>From:</b>	Vladimir Ugorets, Ph.D. Larry Cope, M.S. Michael Sieber, P.E.
<b>Subject:</b>	Technical Review of M & A (2009c) Groundwater Flow Model Report Prepared for Rosemont Copper	<b>Project #:</b>	183101

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This review has been undertaken and the Technical Memorandum prepared at the request of SWCA and the Coronado National Forest. The memorandum provides comments related to a review of the report, *Groundwater Flow Modeling Conducted for Simulation of Proposed Rosemont Pit Dewatering and Post-Closure*, (M & A, 2009c) prepared by Errol L. Montgomery & Associates, Inc. (M & A) for Rosemont Copper Company. These comments were prepared by Dr. Vladimir Ugorets, Mr. Larry Cope, and Mr. Michael Sieber of SRK Consulting (U.S.), Inc. (SRK). The groundwater modeling report and supporting documents from M & A regarding the 2008 field program (M & A, 2009a and M & A, 2009b) were reviewed as reference materials for preparing this memorandum.

The technical comments are grouped into four topics: (1) analysis and interpretation of field data, (2) model setup, (3) model calibration, and (4) predictive simulations. In general the comments are requests for information that will clarify the use of measured data in the model, additional model calibration, and additional predictive simulations as part of the sensitivity analysis. Without the requested information and model outputs, SRK cannot adequately judge the model as suitable and defensible.

### 1 Analysis and Interpretation of Field Data

This section summarizes our review of the analysis and interpretation of field data. The field methods used in well construction and aquifer testing are considered acceptable and to standard industry practices.

#### **Horizontal Hydraulic Conductivity**

It is understood that most wells partially penetrated the geologic units that were pump tested. It appears that hydraulic conductivity was calculated from the aquifer test data using the saturated thicknesses of the unit being tested. It is unclear how those calculated values were incorporated into the model given that partial penetration effects could be significant at the pumped wells over 30 days of pumping. However, the effect of partial penetration diminishes with distance from a pumping well. Thus, the data that were used in creating the input data set to the model is unclear. A modification of the results tables in 2009b or in Table 4 of the reviewed report would help in assessing how the data were used.

#### **Vertical Hydraulic Conductivity**

The gaped, screened intervals of the pumping test wells and the multiple level standpipe and grouted-in piezometers as observation wells likely provide an opportunity for analysis of vertical hydraulic conductivity

(Kv). No values for Kv were provided, and as such there is no opportunity to verify the Kv assumptions used in the model. It is recommended that values for Kv be estimated, where possible, from the test data.

### **Hydraulic Influence of Faults**

Analysis of the long-term pumping test data does not include an evaluation of the influence of faults on the values of hydraulic conductivity. The influence of faults on horizontal and vertical hydraulic conductivity appears to be implicit in the values applied to the model. Without the influence of the faults estimated from the test data, the representativeness of the modeled values for hydraulic conductivity cannot be verified.

## **2 Model Setup**

The Rosemont model was constructed using the *MODFLOW-SURFACT* code (including the *LAK2* Package for simulation of the pit lake infilling and the graphical modeling interface, *Groundwater Vistas*). All of the programs are industry-accepted codes for groundwater modeling.

### **Grid Discretization**

Grid discretization (203 rows, 168 columns, and 10 layers with a minimal lateral cell size of 200 ft by 200 ft) is generally adequate to simulate the proposed pit dewatering and post-mining conditions. However, the elevation of the layers (especially in the pit area), made flat for the convenience of the pit lake simulation, does not match the geological/hydrogeological units or zones. The bottom of the model is about 2,000 ft below the ultimate floor of the proposed open pit. The extent of the model and the model thickness are very reasonable to estimate both the horizontal and vertical components of groundwater inflow to the pit/pit lake and the possible impact of the mining operation on the groundwater system during mining and post-mining conditions.

### **Geological Representation**

Ten hydrogeological units in the model area (page 12) are represented in the model by only three geological units (Section 8.3):

1. Quaternary and recent alluvium
2. Late Tertiary to Early Quaternary basin-fill deposits, and
3. Bedrock.

Each geological unit was subdivided by different numerical zones where hydraulic conductivity values were assigned using the PEST optimization subroutine (to be discussed below) during steady-state calibration of the model. In the reviewers' opinion, the simulated west-east modeled cross section shown on Figure 37 of the modeling report poorly matches the geological cross section A-A shown on Figure 4.

### **Simulation of Fault Zones**

The groundwater flow model (M & A, 2009c) also does not include structural features that exist in the model domain. Page 18 of the report indicates that a fault zone through the Davidson Canyon area is a significant hydrogeological feature consisting of at least two major faults; the report states that the "potential hydraulic influence of this fault zone is evaluated as part of this investigation." It is not clear why this very important feature was not incorporated into the model. Even in the case of a lack of data, a sensitivity analysis could be applied for this zone.

### ***Hydraulic Parameters Used in Model***

It is not clear how hydraulic conductivity values (K) were assigned in the model. The **Parameter ESTimation** (PEST) code was used for a model calibration to match water levels in individual monitoring points. However, without consideration of geological and structural features and without histograms or tabulations of the distribution of K by rock type and layer, the validity and accuracy of the results cannot be verified. As an example, it is not clear why the bedrock unit in layer 2 on Figure 37 (K=0.1 to 1 m/day, right part of cross section) is more permeable than it is in layers 1 and 3; or why bedrock in layer 3 on Figure 38 (with K=0.0001 - 0.001 m/day, right part of cross section also) is less permeable than it is in layers 2 and 4, above and below, respectively.

The report does not clearly indicate:

1. Modeled distribution of parameters within different hydrogeological zones,
2. The limits of K used for the PEST iterations, nor the criteria for selecting the limits, and
3. Measured values of K from hydrogeological tests conducted in the field (min, max, and average).

Table 4 does not provide information as to which hydrogeological units are screened, nor is it clear how the aquifer thickness was defined, i.e., is it a real aquifer thickness or the partial-penetrated screen interval? Figures 29 through 36 show simulated horizontal hydraulic conductivity values (zones where K values vary within one order of magnitude). Measured values interpreted from the field test data, are not shown on these figures, and it is difficult to judge how reasonable these distributions are of K values.

The following requests of information are to clarify how the geology and measured hydraulic conductivity/transmissivity values correspond with the model parameters:

1. A table or tables that correlate model layers to rock type, and rock type to measured permeability values.
2. Addition of measured permeability values at the appropriate locations on the model layer cross sections of Figures 37 and 38.
3. Histograms of measured permeability values by rock type.

There is no assessment of vertical anisotropy in the report. M & A (2009c) used  $K_h:K_v = 10:1$  for Qal and QTg units and  $K_h:K_v = 1:1$  for bedrock. However, it is not clear how these ratios were confirmed by hydraulic test data.

Vertical hydraulic conductivities used in the model were assumed but not measured.  $K_v$  is a particularly important parameter in models where significant drawdown occurs next to an open pit. It is requested that values of  $K_v$  be calculated from available field test data to verify the adequacy of the assumptions of vertical anisotropy. The manner in which the individual screened zones of some pumping wells were isolated by packers and the completion geometry of a number of wells suggest that such an analysis is possible. A sensitivity analysis would show the relative importance of  $K_v$  (as well as the other input variables) in predictive simulations.

Storage parameters, generally, look reasonable. However, the values used do not cover the possible range of values. It is entirely possible that the simulated drawdown could be larger in extent than the prediction presented in the report.

### ***Boundary Conditions***

General head boundary (GHB) conditions, applied at the lateral model boundaries, are not clearly described. Section 8.1 of the report (M & A, 2009c) indicates that GHB conditions “were derived from estimates of equilibrium groundwater levels and hydraulic conductivity of the aquifer at model boundaries.” However, it is not clear what parameters of the GHBs were used (specified head, distance, and transmissivity) nor how

they were chosen. The choice of layers, where they were applied on Figure 26 (layers 1 and 2 in most areas, layers 2 and 3, 3 and 4 at the northwestern corner of the model), is not described in the text of the report. Description and assessment of the boundary conditions for the other layers are absent (by definition the *MODFLOW* code authors assumed them to be no-flow).

### **Recharge and Evapotranspiration**

M & A (2009c) conducted thorough research for precipitation and evaporation data in the region of the Rosemont project. A conservative estimate of precipitation was used: 405,000 acre feet /year (ac-ft/yr). M & A's use of such units (ac-ft/yr) for precipitation, recharge, and evapotranspiration, however, makes it difficult for the reviewers to compare the model to precipitation, since precipitation typically is reported in inches per year (in/yr). The estimated precipitation of 405,000 ac-ft/yr converts to 16.62 in/yr, using the model area of 457 square miles (292,480 acres). The regional data indicate this is a reasonable estimate of annual precipitation. The applied recharge from precipitation is 7,016 ac-ft/yr, or about 1.73 percent of annual precipitation. This is a reasonable infiltration for southern Arizona.

It is stated in Section 8.4 of the report (last section of the first paragraph) that "A net inflow of 1,670 ac-ft/yr to upper Cienega Creek basin via the GHB boundaries is considered analogous to basin recharge..." This is not obvious and needs more explanation because the assignment of GHB conditions is not clearly described (see above). The inclusion of inflow from the GHB increases the recharge rate to 9,779 ac-ft/yr, 2.41 percent of the annual precipitation, which is considerably higher. The recharge is summarized at the bottom of page 52, Section 8.4, including the contribution from the upper and lower GHB boundaries. However, the steady-state water balance in Section 8.7.2 does not include the contribution to recharge from the upper and lower portions of the Cienega Creek basin via the GHB boundaries.

The applied evapotranspiration is reported as 4,240 ac-ft/yr. This appears to be reasonable, given the vegetation reported in Table 1 and for conditions in southern Arizona. But again, it is not clear whether this value was adjusted during model calibration.

### **Groundwater Interaction with Streams**

Two perennial reaches along Cienega Creek were simulated. Extraction wells were used to simulate the two perennial, gaining reaches of the creek and injection wells were used to simulate the losing reaches at the downstream end of the creek. Simulating the stream reaches with flux-dependent boundaries does not allow for impacts from groundwater withdrawals during pit dewatering or for any potential production wells to affect the surface water flows in Cienega Creek. Cienega Creek should be simulated with either the *MODFLOW* River Package or Stream Routing Package. Both of these packages are head-dependent methods for simulating groundwater/surface water interactions, and will allow for the flow in Cienega Creek to be affected by the groundwater stresses due to the Rosemont project. Using extraction/injection wells with fixed rates to simulate interaction between groundwater and surface water systems during mining and post-mining conditions is a significant model limitation and needs to be corrected by using the appropriate *MODFLOW* package. It also is not clear why Davidson Creek was not incorporated into the model using the *MODFLOW* Stream Routing Package.

### **Springs**

Five springs with sustained base flows, described on page 7 of the report, were not incorporated into the model, and spring discharge rates were not used for model calibration. If they had been incorporated in the model, this would have provided an additional calibration tool and would allow prediction of the long-term effect of the future pit dewatering on the springs.

### 3 Model Calibration

The model was calibrated only to water levels under steady state, pre-mining conditions. Although the quality line on Figure 41 looks reasonable, it is not clear how good the model reproduces the measured values of hydraulic conductivity (transmissivity) in the field and the measured discharges in the five springs having sustained base flow.

No transient calibration was completed. It is not clear why such a calibration was not completed using data from the long-term multi-well pumping test (30-day pumping test from five wells) in the Rosemont project area. In the reviewers' opinion, the predictive capability of this model is significantly limited by (1) the lack of a description of the results of the steady-state calibration (described above) and (2) the absence of a transient calibration of the model.

### 4 Predictive Simulations

Predictive simulations were completed to predict groundwater inflow to the proposed open pit, pit-lake infilling after mining ceases, and possible impacts to groundwater and surface water systems during both mining and post-mining conditions.

#### *Simulation of Open Pit*

The open pit excavation is a major stress to the groundwater system, and requires a detailed description of how it was incorporated into the model. The following data were not found in the M & A (2009c) report:

1. A drawing showing the ultimate pit plan.
2. A graph showing the ultimate pit bottom vs. time (this information also can be added to the existing Table 5).
3. The number of drain cells used for simulation of the pit excavation.
4. The number of pit plans incorporated into the model (32?).
5. The location of simulated drain cells in plan view.

It should be noted that the drain cells shown on the cross section on Figure 42 depict an ultimate pit-bottom elevation of 3,050 ft above mean sea level (amsl) after 22 years of mining. However, it is not clear whether the model cells above the drain cells shown on this figure also are specified as drain cells within the same column of cells. Figure 42 also does not show the simulated water table within the open pit on the cross section. Figure 45 shows a simulated water table in plan view at the end of mining; however, the water table elevation of 3,300 ft amsl is 250 feet above the ultimate pit-bottom elevation. This fact most likely indicates that all cells within the simulated pit were not completely drained and pit inflow was underestimated (either the conductivity of the drain cells was not large enough, or the entire column of cells above the pit bottom elevation were not specified as drain cells).

#### *Results of Predictive Simulations*

M & A's (2009c) model gives one set of solutions without a range of possible predictive values. A comprehensive sensitivity/uncertainty analysis (which has not been done) is required to define the possible ranges of pit inflows, pit-lake stages, and the extent of drawdown.

A steady-state post-mining prediction also is required to understand the permanent impacts of the proposed mining on the groundwater system.

A groundwater budget simulated by the model was presented only for pre-mining conditions. No budgets were presented for end-of-mining and post-mining conditions, so changes in flow from individual components due to mining could not be evaluated.

## 5 Conclusions

The descriptions of the model provided in the reviewed report do not allow SRK to determine the reliability of the predictions of possible impacts to the groundwater system from the proposed open pit excavation.

In the opinion of the SRK reviewers:

1. It is unclear whether the model sufficiently represents known geology and structures.
2. The assignment of parameters is unclear with respect to how representative the assigned values are of the field-determined test values and the geologic units/rock types.
3. Simulation of groundwater interaction with Cienega Creek by extraction/injection wells with fixed rates does not allow for the groundwater impacts from the Rosemont project to affect the flow system in Cienega Creek.
4. Full calibration of the model has not been completed due to the lack of a transient calibration to the long-term, multi-well pumping test. The model has a limited predictive capability due to the absence of a transient calibration.
5. Drain cells, representing the open pit excavation, most likely were not assigned properly and as a result, the model under predicts inflow/drawdown propagation.
6. The model provides one set of solutions without a discussion of a range of possible predictive values. Due to existing uncertainties in hydrogeological parameters and boundary conditions, a sensitivity/uncertainty analysis should be added to the predictive simulation to illustrate a range of possible impacts to the groundwater system from the proposed pit operation.

## 6 References

Montgomery & Associates, 2009a, Results of phase 2 hydrogeologic investigations and monitoring program, Rosemont Project, Pima County, Arizona, Volumes I and II: unpublished report prepared for Rosemont Copper Company by Errol L. Montgomery & Associates, Inc., February 26, 2009, 45 p., 4 appendices.

Montgomery & Associates, 2009b, Analysis of long-term, multi-well aquifer test during the period November 2008 through January 2009, Rosemont Project, Pima County, Arizona: unpublished report prepared for Rosemont Copper Company by Errol L. Montgomery & Associates, Inc., May 21, 2009, 41 p., 2 appendices.

Montgomery & Associates, 2009c, Groundwater flow modeling conducted for simulation of proposed Rosemont pit dewatering and post-closure: unpublished report prepared for Rosemont Copper by Errol L. Montgomery & Associates, Inc., October 28, 2009, 73 p.

## 7 Reviewer Qualifications

Senior Reviewer, 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.

Attachment A  
Resume

# Vladimir I. Ugorets

## Principal Hydrogeologist



<b>Profession</b>	Principal Hydrogeologist
<b>Education</b>	M.S. (Mining Engineering/Hydrogeology) Geology-Prospecting Institute, Moscow Russia Ph.D. (Hydrogeology) Geology-Prospecting Institute, Moscow Russia
<b>Registrations/Affiliations</b>	Senior Scientist in Hydrogeology, USSR/Russia National Ground Water Association MSHA

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**Specialization** Mining Hydrogeology, Groundwater Modeling, and Wellfield Optimization.

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**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.

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### Employment Record

<b>2007 – Present</b>	<b>SRK Consulting (U.S.), Inc.</b> , Principal Hydrogeologist Denver, CO
<b>1996 – 2007</b>	<b>Hydrologic Consultants Inc. (HCI)</b> , Senior Hydrogeologist Lakewood, CO
<b>1991 – 1995</b>	<b>Hydrogeoecological Research and Design Co (HYDEC)</b> , Lead Hydrogeologist Moscow, Russia
<b>1978 – 1990</b>	<b>Geology-Prospecting Institute (MGRI)</b> , Senior Scientist in Hydrogeology Moscow, Russia

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**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 2<sup>nd</sup> 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).
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- 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.
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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 2<sup>nd</sup> 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.
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- 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.

# Vladimir I. Ugorets

## Principal Hydrogeologist

### 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 Ertzberg 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 Ertzberg 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

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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 a 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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## Principal Hydrogeologist

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.

# Vladimir I. Ugorets

## Principal Hydrogeologist

- 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.