MWH

TECHNICAL MEMORANDUM

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TO: Tom Furgason
SWCA Environmental Consultants

DATE: December 4, 2009

REFERENCE: 1005979

CC: Dale Ortman, *Consultant*
Stephen Taylor, *MWH*

FROM: Nathan W. Haws, Toby Leeson, *MWH*

SUBJECT: **Review Comments of Rosemont Numerical Groundwater Model Update and Simulations; Rosemont EIS Support**

This memorandum presents the findings of MWH's review of the development and simulation results of the numerical groundwater flow model for Rosemont Copper Company's (RCC) proposed mine supply pumping. The review focuses on the data, assumptions, methods, and results used to predict groundwater responses to RCC pumping as presented in two documents: (1) Technical Memorandum, *Second Update to ADWR Model in Sahuarita/Green Valley Area* (Errol L. Montgomery & Associates, Inc. [M&A], 2009a) and (2) Report, *Groundwater Flow Modeling Conducted for Simulation of Rosemont Copper's Proposed Mine Supply Pumping, Sahuarita Arizona* (M&A, 2009b). This review was conducted by MWH, under contract to SWCA Environmental Consultants. The format of this technical memorandum is as follows: (1) discussion of major findings of the review, (2) summary and evaluation of conclusions in M&A (2009b), (3) summary of reviewer concerns and their potential impacts, (4) statement of limitations, and (5) references. The requested figure of sections through the maximum predicted drawdown cone and the statement of qualifications are provided as attachments.

(1) Major Review Findings

M&A (2009a, 2009b) reports the development and simulation of a numerical groundwater flow model for the purpose of predicting the impact of RCC pumping on area groundwater levels. With a few exceptions, the data, assumptions, and methods used to develop the numerical model are reasonable and in conformance with standard accepted industry practices. The methodology for model predictions also follows good practice, with the exception that future pumping may be over-allocated (which would result in under-prediction of groundwater elevations) and some future source/sink terms may not be included (which would result in over-prediction in some locations and under-prediction in others). The methods to post-process and interpret the results are also valid; however, prediction uncertainty has not been appropriately addressed. The evaluation of the updates to the historical and predictive models and the model predictions is further discussed below.

Updates to Historical Model

M&A (2009a, 2009b) developed the numerical groundwater flow model from an existing groundwater flow model recently constructed by the Arizona Department of Water Resources (ADWR) (Mason and Bota, 2006). The ADWR model is a regional-scale model, covering the Tucson Active Management Area (TAMA) and portions of the upper Santa Cruz Active Management Area (SCAMA). The ADWR model incorporates data from hydrogeological investigations, historical pumping records, and other information from government and private entities that define the geology and groundwater occurrence in the TAMA/SCAMA area. This model provides an efficient and credible method for placing the

Rosemont numerical model in the proper historical and regional setting. Because the ADWR model has a large regional scale, it, of necessity, coarsens some local features and processes that may be important for prediction of groundwater flow on a more local scale. M&A (2009a, 2009b) refines and updates the model in the vicinity of Green Valley/Sahuarita to more accurately simulate the hydrogeology and groundwater sources and sinks in the study area (see Figures 1 and 2 of M&A, 2009b).

The updates to the layering, aquifer parameters, and historical source/sink terms of the ADWR model and the grid refinement are all necessary and appropriate. These updates are founded on reputable sources and/or good professional judgment and are reasonable for the hydrogeological context. The major concern with the model updates is that no standard iterative recalibration of the aquifer parameters is performed. M&A (2009b) demonstrates that the model updates improve the model fit to measured data compared to the original ADWR model, but it includes no discussion of an effort to find optimal parameter values. For example, the hydraulic conductivity is adjusted in the cells surrounding the RCC property based on published aquifer test data, but a standard iterative calibration to optimize the value of the hydraulic conductivity, or to determine the spatial extent to which the hydraulic conductivity should be modified, is not conducted. Likewise, no formal calibration is conducted for values of the storage coefficient (which was left unchanged from the ADWR model) or the specific yield. (Note that long-term predictions may become less sensitive to storage coefficient and specific yield, thus justifying leaving them unchanged; however, a sensitivity analysis of model predictions is not conducted, and thus the impact of these parameters is unknown.) It is possible that much of the error between measured and simulated groundwater levels, which can be several tens of feet and shows spatial bias in some areas, is partly a reflection of the model parameters being out of calibration. Although formal calibration throughout the entire model domain may not be practical or necessary, a calibration within the study area could improve the fit between simulated and measured groundwater levels and reduce predictive uncertainty.

Another concern with the model updates is that no consideration is given for the Santa Cruz fault, which runs between the RCC wells and many of the other wells in the study area. Mason and Bota (2006) suspect the fault as a source of some of the large residuals (error between measured and simulated groundwater levels) in the ADWR model. M&A (2009b) documents the fault in the text and figures, but does not modify the model to account for the fault. The rationale for not explicitly accounting for the fault is not discussed in M&A (2009a, 2009b).

Updates to Predictive Model

The updates to the predictive period of the ADWR model (2009 – 2031) are well documented, though much less certain than updates to the historical period of the model. M&A (2009a) provides an extensive revision of estimated future groundwater withdrawals in the study area by obtaining assured water supply documents from ADWR. The assured water supply documents give an indication of expected groundwater withdrawal rates for residential and municipal suppliers, though not necessarily a sure definition of future pumping. For most of the assured water supply documents, M&A (2009a) makes the “conservative” assumption (i.e., in the sense of over-predicting drawdown) that pumping will achieve the full build-out demand. A more likely scenario is that some of the planned residential developments will not achieve build-out capacity or will be significantly delayed. (This may be particularly true with the downturn in the residential development market.) Consequently, the future pumping from residential developments in the study area is likely over-allocated. The results of the historical simulation showed a bias to under-estimate groundwater level. An over-allocation of future pumping would add to this bias toward under-prediction of future groundwater levels.

Other potential future groundwater sinks/sources not included in the model that may impact future groundwater levels within the study area are potential mitigation pumping near the Freeport-McMoRan Sierrita Mine and delivery and underground storage of Central Arizona Project (CAP) water to the Sahuarita/Green Valley area. Freeport-McMoRan, Sierrita Operations is currently in the feasibility stage of developing a plan to mitigate a sulfate plume originating from the Sierrita tailing impoundment. The mitigation action will likely involve hydraulic containment that may require in excess of 15,000 acre-feet per year in additional groundwater withdrawal (Hydro Geo Chem, Inc., 2008; see www.fcx.com/sierrita/home.htm). This would lower groundwater levels southwest of the RCC property (west of Green Valley). Also in the planning stages is the delivery and storage of up to 7,000 acre-feet per year of CAP water (United State Bureau of Reclamation, 2008). The CAP water would recharge the aquifer at an underground storage facility. A proposed site for the facility is within the study area near the RCC property. Recharge from this facility could substantially increase groundwater levels near the RCC, and possibly throughout the study area if the CAP water is used in lieu of groundwater. The magnitude and exact timetable for these projects are uncertain, but they are scheduled during the same time as the predictive simulation period (2009 – 2031).

An assumption of the predictive model, which may be incorrect, is that boundary conditions are static. This assumption is refuted by the continual groundwater level declines throughout the study area. The correctness of the assumption is only a minor concern as the boundary heads likely have relatively little influence on the groundwater levels within the study area.

Model Predictions

As documented above, the confidence in the predictions of future groundwater levels in the numerical model is weakened by intrinsic model structural inaccuracies, calibration inaccuracies, and uncertainty and deficiencies in sources/sinks. These inaccuracies and uncertainties are, to some extent, inherent in all numerical models. Inaccuracy and uncertainty do not necessarily invalidate the model. On the contrary, the model simulates a very complex and dynamic hydrogeological system, and, with the few exceptions noted previously, incorporates the level of complexity appropriate for the use of the model. Still, the predictive uncertainty and limitations of the model should be appropriately documented, managed, and quantified. M&A (2009a, 2009b) adequately documents, manages, and quantifies suspected predictive uncertainty due to intrinsic inaccuracies. Seasonal variations and “calibration” errors are translated to predictive uncertainties that ranges from 10 to 100 feet due to seasonal variations and approximately a 25-foot under-prediction bias at RC-2. M&A (2009b) does not adequately document or quantify predictive uncertainties due to parameter uncertainties and due to uncertainties in future groundwater recharge and withdrawal. These predictive uncertainties could be bounded by conducting a sensitivity analysis of model predictions to parameter and future source/sink variations. Sensitivity analyses are often a component of modeling studies.

The prediction uncertainties will be greatest for the prediction of future groundwater levels with and without RCC pumping. Without a sensitivity analysis, bounding the uncertainty is difficult. Therefore, the future groundwater levels reported in M&A (2009b) should be treated more qualitatively than quantitatively, demonstrating trends rather than absolute groundwater elevations. The confidence in the predicted groundwater levels will further decrease away from RCC property as the grid coarsens and aquifer parameters and source/sinks become less defined.

The predictions of groundwater declines (drawdown) due solely to RCC pumping will be affected less by predictive uncertainty because much of the uncertainty is subtracted out during post-processing. Therefore, the drawdown due to RCC pumping can be interpreted more quantitatively. MWH evaluated the estimates of the drawdown levels due to RCC pumping reported in M&A (2009b, Figures 35, 36) using a simple analytical (Dupruit) solution to estimate steady-state drawdown. Although this solution cannot capture the complexity and transience of the model, it does provide a rough check on drawdown predictions. According to this check, the estimates of groundwater level drawdown due to RCC pumping reported in M&A (2009b) are reasonable.

(2) Summary and Evaluation of Conclusions

The major conclusions relative to the predicted impact of RCC pumping on groundwater levels given in M&A (2009b) are presented in the table below along with MWH’s judgment on their reasonableness.

	M&A Conclusion	MWH Comment
		Conclusions of Historical Simulations
1	"…[T]he match to measured groundwater levels [for the 1940 steady-state simulation] is not excellent in the Rosemont area." (p. 28)	Figure 28 shows that some of the largest discrepancies between the measured and simulated groundwater levels in the steady-state model are in the vicinity of the RCC property; however, these discrepancies are of little concern because the steady-state model does reproduce the general trends of the groundwater level contours and because the effects of the initial conditions (year 1940) on the model predictions (years 2012 – 2031) are likely minimal. Also, as stated in M&A (2009b), the 1940 groundwater levels are themselves of unknown quality.
2	"Accounting for seasonal variation …the model reasonably simulates average groundwater level altitude and groundwater level change in the vicinity of Rosemont properties." (p. 29)	Figures 9 – 11 show that groundwater levels in wells near RCC property are generally under-predicted. The bias toward under-prediction typically increases as the historical simulation progresses in time. Under-predictions can range from between about 10 and 70 feet in the later years. M&A (2009b) attributes the under-prediction to the seasonal pumping from agricultural wells not captured in yearly groundwater level measurements. Seasonal pumping likely is responsible for some of the under-prediction, yet the increasing trend toward under-prediction and the consistent under-prediction at RC-2 suggests a general bias toward under-prediction of groundwater levels in the central basin near Sahuarita and near the RCC property beyond that cause by seasonal variation.
3	"Match of observed and simulated groundwater levels at Rosemont wells E-1 and RC-2 is reasonably accurate." (p. 30)	Figure 15 shows a very reasonable match between simulated and the average of measured groundwater levels for E-1. Simulated groundwater levels for RC-2 has a bias toward under-prediction of about 25 feet. (Note that M&A (2009b) adjusts simulated future groundwater levels upward at RC-2 to account for this bias.)
	Conclusions of Predictive Simulations (2012 through 2031)	
4	"The projected groundwater level altitudes are considered representative of annual average levels." (p. 32; also see Figures 27 - 30)	The predictions of future groundwater level altitudes are subject to considerable uncertainty, including the general bias to under-predict historical groundwater levels, uncertainty in model parameters, the assumptions of future groundwater withdrawals and recharge. Most of the assumptions made in M&A (2009a, 2009b) tend toward over-prediction of groundwater level declines (see comments on Updates to Predictive Model under Major Review Findings). Therefore, the model results likely error on the side of low groundwater level altitudes, in general; although, groundwater level altitudes southwest of the RCC property (west of Green Valley) may be over-predicted because of the failure to include Sierrita mitigation pumping. Because of the large uncertainty in the groundwater level altitudes the future groundwater level altitudes reported in M&A (2009b) should be treated more qualitatively than quantitatively, demonstrating trends rather than absolute groundwater elevations. An analysis of the sensitivity of model predictions to sources of uncertainty would aid in bounding the possible range of groundwater level altitudes.

	M&A Conclusion	MWH Comment
5	"…[P]rojected groundwater drawdown within two miles of the Rosemont properties ranges from about 12 feet to about 88 feet at the western Rosemont property [in year 2012]…[and] from about 30 feet to about 187 feet at the western Rosemont property [in year 2031]." (p. 32-33; also see Figures 31,33)	The regional drawdown estimates are less prone to bias in historical predictions than the groundwater level altitudes, but otherwise, are subject to the same uncertainties and tendencies (i.e., to over-predict groundwater declines) as the predicted groundwater level altitudes. Again, an analysis of the sensitivity of model predictions to sources of uncertainty would aid in bounding the possible range of groundwater level drawdown.
6	"…[P]rojected groundwater drawdown [as a result of Rosemont pumping] within two miles of the Rosemont properties ranges from about 5 feet to about 80 feet at the western Rosemont property [in year 2012]…[and] from about 10 feet to about 107 feet at the western Rosemont property [in year 2031]." (p. 33; also see Figures 35,36)	The predictions of groundwater drawdown due solely to RCC pumping are more certain than the other predictions because much of the uncertainty is subtracted out during post-processing. Therefore, the drawdown due to RCC pumping can be interpreted more quantitatively. The estimates of groundwater level drawdown due to RCC pumping reported in M&A (2009b) are reasonable for the sustained pumping rates and the aquifer properties.
7	"Maximum extent of projected groundwater level drawdown due to Rosemont pumping delineated by the 1-foot drawdown contour (Figure 36) is approximately 10 miles north from the western Rosemont property." (p. 33)	This estimate is for the drawdown after 20 years of RCC pumping. At sustained pumping rates of 5,400 acre-feet per year, then 4,700 feet per year, the 1-foot drawdown will be extensive. Based on the aquifer parameters given in the report, this is a reasonable estimate. Figure 36 shows that the 1-foot drawdown contour also extends approximately 5 to 6 miles south of the western RCC property and across most of the east-west portion of the basin after 20 years of pumping.
8	"…[I]t is expected that future shallow groundwater level estimates can be determined by adding approximately 30 feet to model projected groundwater levels in the area of the west Rosemont property, decreasing to 0 feet added in the area of the east Rosemont property." (p. 34)	The adjustment for predicting future shallow groundwater levels in the vicinity of the Rosemont property is reasonable based on historical evidence. How well future groundwater levels will follow the historical data, and therefore, the validity of this approach for future estimates cannot be determined. Nevertheless, without better information, the adjustment is a reasonable approximation.
9	"[Seasonal] variations [in groundwater levels] are expected to decrease as FICO agricultural pumping begins to convert to residential pumping in the next 10 years." (p. 34)	This is a reasonable expectation based on the assumptions of residential development used in M&A (2009a). If the rate of residential development is less than assumed and agricultural pumping remains as strong influence, seasonal variations will continue.
10	"Impacts [due to Rosemont pumping] will be focused in the immediate area around the proposed Rosemont pumping locations. Substantially larger and longer-term pumping as the result of planned residential development in the area will become the dominant groundwater level influence in the larger area." (p. 35)	As shown in Figure 36 and discussed in Section 7.6.3, additional drawdown resulting from RCC pumping will range from approximately 10 to 107 feet within 2 miles of the western RCC pumping. Assuming that "the larger area" is the area outside of this 2-mile radius, then pumping for residential water supply will likely be the dominant influence, even with the uncertainty in the future pumping estimates. The relative dominance of residential pumping may not be as great as shown in Figures 33 – 34, however, because future residential pumping rates are likely over-allocated (see comments on Updates to Predictive Model under Major Review Findings).

(3) Summary of Concerns

The concerns with the numerical groundwater model and simulations described in M&A (2009a, 2009b) are presented in the table below along with MWH's comments on their potential impacts.

	Concern	Comment
1	Aquifer parameters not calibrated to historical model.	The potential impact of this concern is unknown because an analysis of the sensitivity of model prediction to aquifer parameter values is not performed.
2	Santa Cruz fault is not explicitly included in model.	The Santa Cruz fault could have an important impact on the predicted influence of RCC pumping because the fault runs between the RCC property and many of the municipal, mining, and agricultural water suppliers. M&A (2009a, 2009b) may have a good reason for not including the fault, but the rationale is not discussed.
3	Assumption that future pumping will achieve its full build-out demand as described in assured water supply documents will likely over-predict pumping and groundwater level declines.	This assumption likely results in under-prediction of groundwater levels, particularly to the west and north of RCC property. An analysis of the sensitivity of model predictions to this assumption would aid in bounding the uncertainty in model predictions.
4	Potential future mitigation pumping by the Sierrita Mine not included.	Sierrita Mine mitigation pumping could further decrease groundwater levels southwest of the RCC property. North of the RCC property, the impacts will likely be minor.
5	Potential future aquifer recharge from proposed CAP delivery is not included.	Recharge by CAP water could significantly increase future groundwater levels in the vicinity of RCC property.
6	Specified boundary heads are assumed to be static.	Groundwater levels near the model boundaries will likely decrease in the future; however, the potential impact of this concern is minor because boundary heads likely have relatively little influence on the groundwater levels within the study area.
7	No sensitivity analysis performed	The level of confidence in the model predictions cannot be fully evaluated without an analysis of the sensitivity of the model predictions to the assumptions future pumping and specified aquifer parameters.

(4) Limitations

The review of the model development and simulations conducted for the RCC proposed mine supply pumping is based on information provided in M&A (2009a, 2009b). The review is limited to the data, assumptions, methods, results, and conclusions presented in the text, tables, and figures of these two reports. Verification of the accuracy of the data from sources cited in these reports, or the correctness of its representation in M&A (2009a, 2009b), was beyond the scope of the review. In addition, modeling files were not consulted as a part of the review. Therefore, this review does not cover model construction or solution errors beyond what is provided in the M&A (2009a, 2009b). Also beyond the scope of the review is the data, assumptions, methods, and results of the ADWR model and its documentation (Mason and Bota, 2006).

(5) References

Errol L. Montgomery & Associates, Inc. (M&A). 2009a. Report, *Groundwater Flow Modeling Conducted for Simulation of Rosemont Copper's Proposed Mine Supply Pumping, Sahuarita Arizona.* Prepared for Rosemont Copper Company, April 30, 2009.

M&A. 2009b. Technical Memorandum, *Second Update to ADWR Model in Sahuarita/Green Valley Area*; to Dale Mason (Arizona Department of Water Resources) from Marla Odom, Hale Barter, and Jim Davis; April 27, 2009.

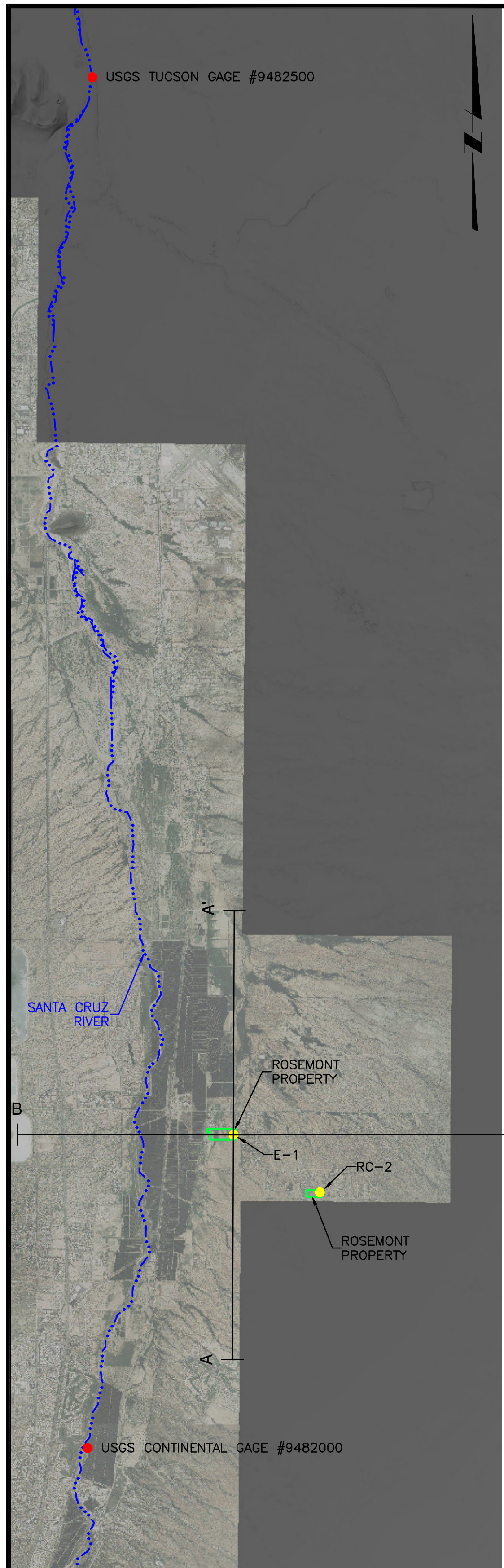
Hydro Geo Chem, Inc. 2008. *Feasibility Study for Sulfate with Respect to Drinking Water Supplies in the Vicinity of the Freeport-Mcmoran Sierrita Inc. Tailing Impoundment, Mitigation Order on Consent Docket No. P-50-06*. Prepared for Freeport-McMoRan, Inc. October 22, 2008. (available at www.fcx.com/sierrita/home.htm)

Mason, D., Bota, L. 2006. *Regional Groundwater Flow Model of the Tucson Active Management Area Tucson, Arizona: Simulation and Application*, Modeling Report No. 13. Arizona Department of Water Resources.

United State Bureau of Reclamation. 2008. *Community Water Co. of Green Valley, Central Arizona Project Water Delivery System Project*. Presentation and public scoping meeting, August 26, 2008. (available at www.usbr.gov/lc/phoenix/reports/capcwc/CWCGVScopingpresentation.pdf)

ATTACHMENT A

CROSS-SECTIONS THROUGH MAXIMUM PREDICTED DRAWDOWN



PLAN

SCALE
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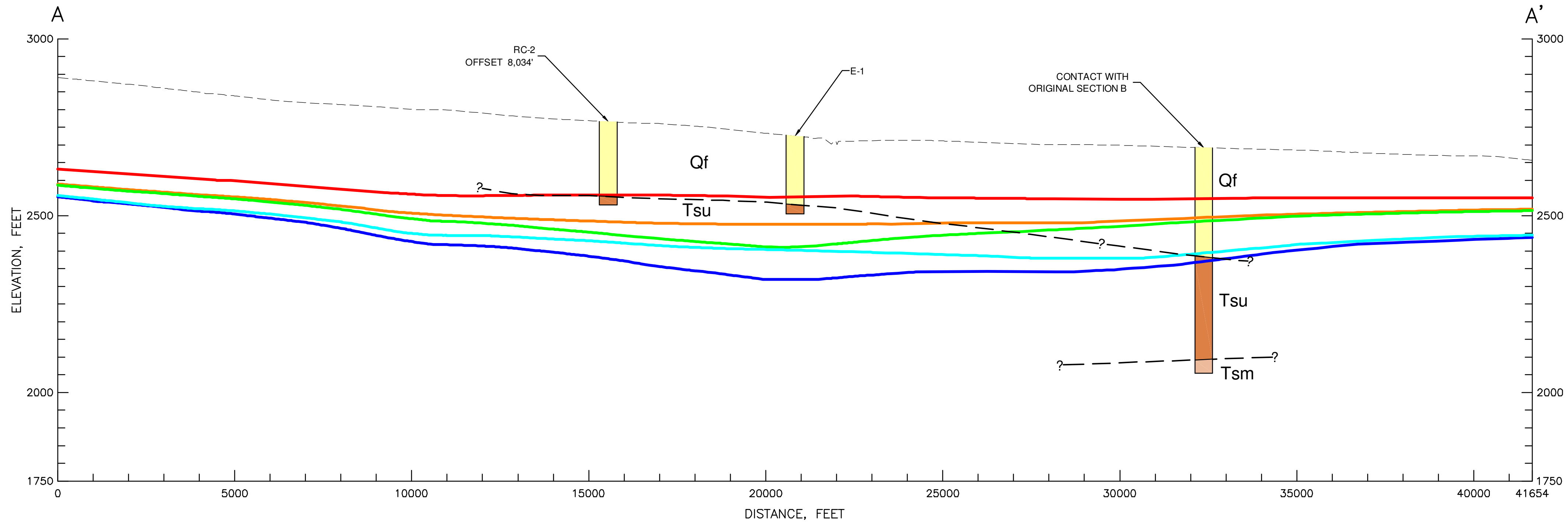
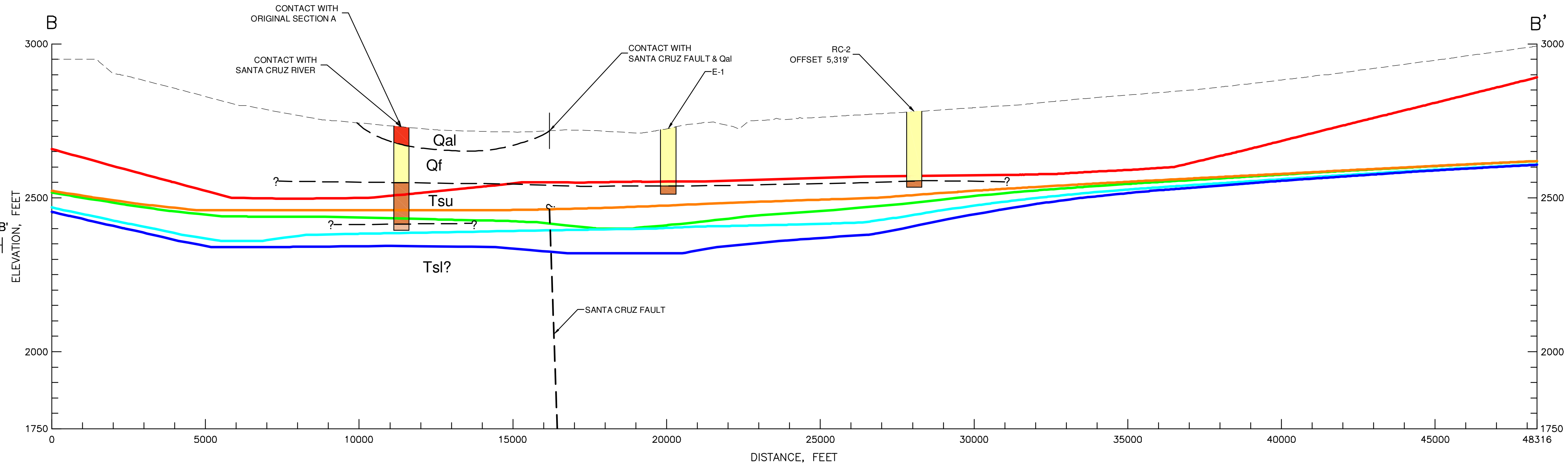


SECTION A-A'

VERTICAL SCALE
200 0 200 FEET
HORIZONTAL SCALE
2000 0 2000 FEET
VERTICAL EXAGGERATION = 10X



SECTION B-B'

VERTICAL SCALE
200 0 200 FEET
HORIZONTAL SCALE
2000 0 2000 FEET
VERTICAL EXAGGERATION = 10X

LEGEND:

- EXISTING GROUND
- WINTER 2004 ~ SPRING 2005 ROSEMONT WATER LEVEL
- 2021 WATER LEVEL WITHOUT ROSEMONT PUMPING
- 2021 WATER LEVEL WITH ROSEMONT PUMPING
- 2031 WATER LEVEL WITHOUT ROSEMONT PUMPING
- 2031 WATER LEVEL WITH ROSEMONT PUMPING

NOTES:

1. THESE CROSS-SECTIONS WERE DEVELOPED USING THE MAPS INCLUDED IN THE REPORT *GROUNDWATER FLOW MODELING CONDUCTED FOR SIMULATION OF ROSEMONT COPPER'S PROPOSED MINE SUPPLY PUMPING, SAHUARITA, ARIZONA* (E. L. MONTGOMERY & ASSOC., 2009).
2. LITHOLOGIC DATA SHOWN ARE INFERRED AND ONLY APPROXIMATE.

DRAFT 10/23/09

ISSUE/REV	DESCRIPTION	TECH	ENG	DATE
B	DRAFT	CHF	RTL	10/23/09
A	DRAFT	CHF	RTL	10/15/09

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DESIGNED BY	T LEESON	10/23/09
DRAWN BY	E MARKS	10/23/09
CHECKED BY	T LEESON	10/23/09
APPROVED BY	T LEESON	10/23/09
PROJECT MANAGER	T LEESON	10/23/09
CLIENT APPROVAL		
CLIENT REFERENCE NO.		

PROJECT LOCATION
PIMA COUNTY, ARIZONA

PROJECT
ROSEMONT EIS TECHNICAL SUPPORT

TITLE
CONCEPTUAL CROSS-SECTIONS

MWH

SHEET 1 of 1
REVISION A
FILE NAME 1005979D002

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ATTACHMENT B

STATEMENT OF QUALIFICATIONS

Statement of Qualifications of Reviewer

The review of M&A (2009a, 2009b) and the preparation of this technical memorandum were conducted by Mr. Nathan W. Haws, Ph.D., P.E. under the direct supervision of Toby Leeson, Supervising Hydrogeologist. Nathan Haws is a professional civil engineer, specializing in subsurface flow and transport. Nathan has more than 10 years of academic and professional experience, including numerical modeling of hydrogeological systems in Arizona. Stephen Taylor is a professional civil engineer with 19 years of experience in hard rock mine applications. Resumes for Nathan Haws and Stephen Taylor are attached.

I attest that the review was prepared under my direct supervision.

Signed,

Toby Leeson, P.G.
Supervising Hydrogeologist
MWH Americas, Inc.

REGISTERED GEOLOGIST
CERTIFICATE NO.
32566
RICHMOND T.
LEESON, JR.
Date Signed 12-4-09
ARIZONA U.S.A.

TOBY LEESON, P.G.
SUPERVISING HYDROGEOLOGIST

EDUCATION:
M.S., Geology, San Diego State University, 1989
B.A., Geology, University of Colorado at Boulder, 1986

REGISTRATIONS:
Professional Geologist: California #RG-5605; Wyoming #PG-2612; Arizona #RG-32566.

PROFESSIONAL ORGANIZATIONS:
National Groundwater Association
International Association of Hydrogeologists

SUMMARY:
Mr. Leeson holds a Master of Science degree in geology and has been working as a professional geologist and hydrogeologist since 1990. He is a professional geologist in the states of Arizona, California and Wyoming. Mr. Leeson has extensive environmental consulting experience serving industrial, federal and mining clients in the western United States and South America. He specializes in environmental sciences, geology, hydrogeology, and groundwater quality. Mr. Leeson has extensive experience in characterizing and modeling geologic and hydrogeologic settings, groundwater resources, environmental impacts, water quality, and contaminated soil and groundwater. Mr. Leeson also has experience in spatial and numerical modeling, including the use of two-dimensional seepage and three-dimensional groundwater flow models. He has executed and managed many field investigations involving subsurface drilling and sampling, monitoring well installation, geologic and hydrogeologic mapping, aquifer parameter testing, soil and soil gas sampling, and groundwater monitoring. He has extensive experience in multi-disciplinary project management and negotiation with regulatory agencies, and is routinely involved with business development activities, including preparation of proposals, statements of qualifications, cost estimation and client relations.

PROFESSIONAL EXPERIENCE:

Mining-Related Projects

Supervising Hydrogeologist, Coronado National Forest, Santa Cruz Valley, Arizona Environmental Impact Statement
Third-party review of baseline data collection, hydrogeologic modeling, water resource assessment, and environmental impact assessment of Augusta Resources proposed Rosemont copper mine. Issues of importance include cumulative impacts of groundwater withdrawal in the Santa Cruz Valley, use of Colorado River water, and local community needs (e.g., agriculture, retirement communities, and residential water).

Project Manager, MINNTAC, Mountain Iron, Minnesota
Environmental Impact Statement
Mr. Leeson was responsible for managing the preparation of an EIS, coordination of technical resources, and quality review of the technical documents for the Minnesota Pollution Control agency in response to a proposal submitted by US Steel's Minntac Mine (iron ore) to discharge water from its tailings basin to the surrounding watersheds. In accordance with State of Minnesota regulations, and as part of the permitting process for the proposed action, the project

team assembled a complete assessment of baseline conditions and potential impacts to relevant environmental resources in the vicinity of the proposed project. Significant resource areas analyzed included surface water hydrology and quality, aquatic life, vegetation, wildlife, wild rice, wetlands, socioeconomics, geotechnical, mining, and mercury.

United Nuclear Corporation, Northeast Church Rock Mine, New Mexico
CERCLA Removal Action, EPA Region 9
MWH has been responsible for managing and executing a Removal Site Evaluation and Removal Action for General Electric (GE) for the Northeast Church Rock (NECR) uranium mine near Gallup, New Mexico since 2003. The mine is an inactive, underground uranium mine and is being closed under CERCLA and the National Contingency Plan. The bulk of the mining lease is located on Navajo surface trust lands. In 2005 EPA Region 9 became the lead regulatory agency of the site in coordination with the Navajo Nation EPA, the State of New Mexico, and the Bureau of Indian Affairs. The EPA issued a draft EE/CA, evaluating removal action alternatives, including the construction and use of a waste disposal cell at the Church Rock Mill Site, about one mile from the mine site. The Mill Site is licensed by the Nuclear Regulatory Commission (NRC) and as such the EE/CA alternative would require an amendment to the existing Mill Site NRC license. NRC regulations require that an EA or EIS be prepared as per NEPA and NRC guidance. MWH is currently preparing an Environmental Report, which is part of the license amendment application and will be used by NRC to prepare the EA or **EIS**.

Project Hydrogeologist, Cyprus Sierrita Corp., Twin Buttes, Green Valley, Arizona
Completed a variety of environmental tasks at an inactive, open pit copper mine in support of closure of multiple facilities, and to bring the property operator into compliance with the Arizona Aquifer Protection Program. Prepared multiple plans for Clean Closure of formerly discharging mine facilities. Prepared a work plan that included a description of the approach, techniques planned, analytical programs and the goal for each facility. Designed and implemented a waste rock characterization program. Analyzed and discussed the results of acid-base accounting tests, humidity cell (simulated weathering) tests and synthetic precipitation leaching procedure tests for metals.

Project Hydrogeologist, Cyprus Sierrita Corporation, Sierrita Mine, Green Valley, Arizona
Assisted Cyprus with ongoing Aquifer Protection Program application efforts for a large open pit copper-molybdenum mine, heap leach and conventional mill. Efforts focused on assessing the completeness of their current Aquifer Protection Program application and supporting documents based on Aquifer Protection Program requirements.

Senior Hydrogeologist, BHP Copper, Pinto Valley Mine, Globe, Arizona
Mr. Leeson developed a summary of site-wide hydrogeologic conditions at an inactive, open-pit copper mine in eastern Arizona. Conducted a pit lake study for the open-pit at the mine to determine the ultimate pit lake level(s) after full-closure of the mine, and the pit lake level at which a hydraulic sink within the open pit would no longer exist. The pit lake study included the development of analytical models for assessing the pit water balances and ground water inflow rates utilizing analytical models. The results of the pit lake study are being used to support the development of closure plans for the mine.

Senior Hydrogeologist, BHP Copper, Copper Cities Mine, Globe, Arizona
Mr. Leeson developed a summary of site-wide hydrogeologic conditions at an inactive, open-pit copper mine in eastern Arizona. Conducted two pit lake studies for the open-pits at the mine. The

objectives of the pit lake studies were to determine the ultimate pit lake levels after full-closure of the mines, and the pit lake levels at which hydraulic sinks within the open pits would no longer exist. The pit lake studies included the development of analytical models for assessing the pit water balances and ground water inflow rates utilizing analytical models. The results of the pit lake studies are being used to support the development of closure plans for the two mine sites.

Project Hydrogeologist, Equatorial Mineral Park Corp., Mineral Park Mine, Kingman, AZ
Completed a variety of hydrogeologic evaluations for Equitorial's Mineral Park open pit, heap leach copper mine. Responsibilities included characterization of groundwater conditions, calculation of potential leakage rates of pregnant leachate solutions (PLS) from lined and unlined collection sumps, feasibility analysis of collecting PLS from the toe of a large leached waste rock dump, and calculation of capture zones for extraction wells at the toe of the dump. Mr. Leeson also evaluated Clean Closure options for an unlined PLS collection pond.

Project Manager, United Nuclear Corporation, St. Anthony and Section 27 Mines, NM
Managed the materials characterization, closeout, reclamation and financial assurance of two inactive uranium mines in the Grants, New Mexico area. The mines are under the jurisdiction of the New Mexico Mining and Minerals Division and are being closed under the New Mexico Mining Act. Particular challenges of the sites include a large open pit with a well developed pit lake that could impact a major drinking water aquifer, and large overburden piles The mines are in a region that has a complex history of other mining impacts and current pressures to further develop the resources.

Senior Hydrogeologist, Phelps Dodge, Little Rock Mine, Silver City, New Mexico
Developed a conceptual closure plan for the inactive Little Rock Mine. The inactive mine area has copper leachate and potential acid rock drainage issues. The site includes copper leach piles, waste rock stockpiles, a mine pit, mine adits, and other disturbance areas. Challenges include a remote area with limited vehicular access.

Senior Hydrogeologist, Client Confidential, Mt. Todd Mine, Northern Territory, Australia
Developed a conceptual closure plan and cost estimate for a mining company considering reopening the Mt. Todd mine. The currently inactive mine area has considerable acid rock drainage issues and is currently being managed by the Northern Territory government. Site includes a tailings facility, heap leach stockpile, waste rock stockpile and a mine pit. Challenges include a tropical climate with heavy seasonal rains. Project was completed in conjunction with MWH's Perth office and also included development of water management options and environmental conditions assessment for the current conditions.

Senior Hydrogeologist, El Paso Corp., Comstock Mill, Silver City, Nevada
Developed a conceptual closure plan for the abandoned Comstock Mill near Silver City, Nevada. Gold mining activities have been conducted in the area since the early 1930s. The Comstock Mill and appurtenant facilities were built in 1978. The site includes a tailings facility and a mill, and is located in a remote area with limited access.

Senior Hydrogeologist, Johnston Mill, USACE RAMS Program, Caliente, Nevada
Developed a conceptual closure plan for the abandoned Johnston Mill near Caliente, Nevada. The site includes an open pit, heap leach pad, solution ponds, open wells and boreholes, and plant buildings and structures.

Geologist, W.R. Grace, Hayden Gulch Coal Mine, Hayden, Colorado
Reclamation management for a bond release. Evaluation of hydrogeology, geologic stability and cause of a landslide at the former surface coal mine high-wall. Management of landslide mitigation activities. Surface water sampling and measurement of flow for evaluation of potential environmental impacts.

Senior Hydrogeologist, Oxbow Mining, LLC, Elk Creek Mine, Somerset, Colorado
Managed and developed a Spill Prevention, Control, and Countermeasure (SPCC) Plan for an underground coal mine as per the Title 40, Code of Federal Regulations, Part 112. The SPCC Plan described measures to prevent oil discharges from occurring, and to prepare the mine personnel to respond in a safe, effective, and timely manner to mitigate the impacts of a spill.

Geologist, W.R. Grace, Hayden and Lay, Colorado
Evaluation of need for reclamation at multiple former exploration drill sites for an exploration bond release.

Senior Hydrogeologist, Rosia Montana Gold Corporation S.A., Romania
Hydrogeologic and geologic support of environmental impact statement and engineering design of tailings facility, surface water ponds and damns, plant site, for a proposed gold mine in Romania. Developed analytical mass balance models for basin wide analysis of contaminants in surface water during critical times of life of mine and closure. Evaluated affects of floods on water quality. Developed conceptual hydrogeologic model and baseline surface water and groundwater conditions. Developed a 2D groundwater contaminant transport model for predicting the fate of cyanide in the proposed tailings basin using SEEP/W and CTRANS/W. Predicted groundwater inflow volumes and evaluated engineering options for the management of groundwater inflow at the proposed plant, which is proposed to be located where overburden and bedrock will have been removed, exposing groundwater.

Hydrogeologist, Newmont Gold, Resurrection Mine, Leadville, Colorado
Surface water quality sampling and measurement of flow and assessment for a Remedial Investigation/Feasibility Study in Colorado's historical mining district.

Geologist, Rhone-Poulenc, Rasmussen Ridge Mine, Soda Springs, Idaho
Evaluation of structural and engineering geologic features in order to assess high-wall stability. Performed bedrock drilling and description of lithologic and structural features.

Hydrogeologist, Peabody Coal, Seneca Coal Mine, Hayden, Colorado
Surface water testing including water quality and flow rate for NPDES permit at multiple locations within coal mine properties.

Project Hydrogeologist, Southern Peru Ltd., Cuajone Mine, Moquegua, Peru
Hydrogeologic and geologic assessment for an environmental impact assessment associated with a proposed copper mine expansion. Executed drilling and well installation programs that included the use of and interpretation of downhole pressure tests (packer tests). Conducted a seep and spring survey.

Environmental/Earth Science Projects

Supervising Hydrogeologist, AREVA, Inc., Idaho Falls, Idaho
Development of groundwater resources assessment in support the licensing of AREVA's proposed uranium enrichment facility in the Snake River Plain of southeastern Idaho After completion of a siting study, MWH was tasked to of support preparation of the Environmental Report (ER), which is the environmental impact analysis document that is submitted by an applicant to the U.S. Nuclear Regulatory Commission (NRC) as part of the license application. The NRC uses the ER as an initial basis to prepare an Environmental Impact Statement under the National Environmental Policy Act. Mr. Leeson was responsible for hydrogeologic site characterization in the fractured basalts, using extensive published research of immediate area, pumping tests, geophysical logging, core logging and installation/sampling of 750 foot deep monitoring wells. He also assisted in the data analysis and preparation of the technical reports for geology and groundwater resources.

Project Hydrogeologist, Department of Defense, Dixie Valley, Nevada
Environmental impact assessment of a proposed geothermal power plant expansion project. Evaluated potential hydrogeologic and geochemical impacts of re-injection of cooler geothermal waters back into the reservoir. Evaluated impacts over an entire groundwater basin to depths of several thousand feet.

Field Geologist, USGS, Regional Geology, Missoula, Montana
Geologic reconnaissance and detailed field mapping of Proterozoic Belt Supergroup rocks, and associated geologic structures, and alluvial deposits using aerial photos in stereo pair, topographic maps and other traditional field methods.

Senior Hydrogeologist, USACE, Moses Lake Wellfield Superfund Site, Washington
Designed, managed and performed Remedial Investigations (CERCLA) of a DNAPL contaminated site consisting of alluvial and bedrock aquifers within an agricultural and urban area largely dependent on groundwater resources. Major responsibilities included design and coordination of field programs under USACE and EPA guidance, hydrogeologic analysis in an alluvial and fractured bedrock system, database management, GIS design and implementation, 3D numeric modeling of the hydrogeology and contaminant transport and spatial analysis of site characteristics. Modeling included the use of TINs, block models, MODFLOW and MT3DMS using Groundwater Modeling System software. Field methods included drilling, well installation, aquifer testing, low-flow groundwater sampling, in-field titration, active soil gas sampling, in-situ XRF analysis, geophysical surveying and field mapping. Responsibilities also included cost estimation, project scoping and technical report preparation.

Project Hydrogeologist, Chevron USA, Richmond, California
Managed and executed multiple subsurface investigations for a large oil refinery. Developed hydrogeologic and geochemical conceptual models. Field methods included soil and bedrock drilling, well installation, cone penetrometer tests, pressure and pump tests, groundwater sampling, free-product measurements and sampling, structural geologic mapping. Responsible for budget and schedule control, project QA/QC, and technical report preparation.

Project Hydrogeologist, Compressor Stations, El Paso Corporation, Roosevelt, Utah
Project management, site characterization and development of corrective action plans for two natural gas compressor stations in the Uintah Basin of eastern Utah. Site soil and groundwater

were contaminated with petroleum hydrocarbons (dissolved-phase and free-product) as associated with natural gas condensate and crude oil. Remedial technologies being employed include: groundwater and free-product extraction, monitored natural attenuation, and enhanced attenuation using oxygen release compounds.

Hydrogeologist, Fairchild Air Force Base, Washington
Monitoring well installation, data analysis and report preparation for a Long-Term Monitoring Program associated with a DNAPL- and LNAPL-contaminated site. Over the past decade, there have been several Site Investigations and Remedial Investigations/Feasibility Studies. The site consists of alluvial and bedrock aquifers within a military and urban area largely dependent on groundwater resources. Responsibilities included interpretation of results of analysis of volatile organic compounds in monitoring and domestic wells and the interpretation of geochemical parameters to assess the applicability of Monitored Natural Attenuation as a remedial approach for addressing trichloroethylene contamination in groundwater. Responsibilities also included the development of a site-wide, web-based database and geographic information system.

Project Geologist, Hewlett Packard, Palo Alto, California
Performed a Remedial Investigation/Feasibility Study of a DNAPL contaminated site consisting of several aquifers. Managed and executed multiple subsurface investigations of the vadose and saturated zones to characterize the site and evaluate remedial options. Developed hydrogeologic and geochemical models. Field methods included drilling, well installation, cone penetrometer tests, pump tests, and groundwater sampling. Responsibilities also included budget and schedule control and technical report preparation.

Project Hydrogeologist, Pacific Gas & Electric Company, Antioch, California
Remedial investigation and remedial engineering for a gas and electric company's former service center contaminated with petroleum hydrocarbons, including gasoline and crude oil. Developed remedial action and site closure alternatives and data collection program for a risk-assessment. Negotiated with regulatory agency. Managed and executed multiple subsurface investigations using a variety of drilling methods, borehole geophysics, detailed soil and groundwater sampling, installation of monitoring wells, vapor monitoring, and aquifer pumping tests. Modeled geology, hydrogeology and aqueous geochemistry. Implemented and coordinated the design, construction, and operation of a groundwater remediation system. Developed and managed a large chemical and hydrologic database and vector GIS. Conducted data collection, processing and QA/QC. Responsibilities also included project and analytical QA/QC.

Staff Geologist, Triangle, Martinez, California
Performed an investigation of the distribution of nickel, zinc, and chromium compounds in near surface soils at a metal plating facility. The investigation included the design and implementation of a statistical grid sampling program in order to evaluate the distribution of contaminants in soils without creating a bias in the sample coverage.

Staff Geologist, Multiple Clients, San Francisco Bay Area, California
Executed numerous subsurface field investigations and groundwater sampling programs using a variety field methods. Conducted geologic and hydrogeologic field mapping. Drilling methods included augers, water, mud and air rotary, cable tool, direct push, limited access drilling rigs and hand augers. Conducted and analyzed aquifer parameter tests including step-drawdown and constant discharge pumping tests, pressure (packer) tests, and rising and falling head slug tests. Conducted groundwater sampling programs under the guidelines of state and federal EPA.

Utilized geophysical methods, including spontaneous potential, gamma ray, resistivity, acoustic televiewer, fluid logging, ground penetrating radar, and magnetometer surveys. Followed stringent field sampling and vapor and groundwater monitoring protocols.

Environmental Scientist, Multiple Clients in San Francisco Bay Area, California
Conducted and managed multiple Phase I Environmental Site Assessments (ESAs) for sites in Northern California following the requirements of the American Standards for Testing and Materials (ASTM). Tasks included site reconnaissance, personnel interviews, review of aerial photographs and historical fire insurance maps, regulatory list searches, agency file reviews, development of physiographic, geologic and hydrogeologic models, and report preparation. Also included limited asbestos and lead-based paint surveys.

Geographic Information Systems/Database Management

Uranium Mine Closures, **New Mexico**
Developed and managed GIS databases in support of environmental investigations, removal action alternatives, and reclamation plans. Used the GIS to manage, visualize and analyze site data, estimate volumes, develop reclamation costs, and technical reporting. Spatial analysis methods included natural neighbor, inverse distance weighting and krigging.

GIS Analyst, Tar Creek Subsidence Study, Picher Oklahoma
The Picher Mining Field in Oklahoma was one of the largest lead and zinc mining fields in the world. MWH, in collaboration with the Tulsa District of the Army Corps of Engineers, has used Geographic Information Systems to develop a risk hazard analysis. High-resolution spatial data were integrated to estimate the maximum potential surface expression of subsidence and the subsidence risk probability. Mr. Leeson was responsible for developing the GIS database and developing the routines for processing and integrating the data (high-resolution aerial photographs, digital elevation models, geologic data, and digitized mine void geometries). The results of the analyses were then used to generate maps of the maximum potential surface expression of subsidence and the subsidence risk probability. These results allow the communities to prevent any further damage to property or risk to human lives as well as better plan for future development.

Database Manager, USACE, Moses Lake Wellfield Superfund Site, Moses Lake, WA
Mr. Leeson developed a data management process and GIS database in support of Remedial Investigations of a DNAPL contaminated site. He utilized cutting-edge hardware/software systems for data collection, data management and modeling, including the USACE's Groundwater Modeling System (GMS), USACE's Environmental Data Management System (EDMS) and Access (relational databases), Trimble GPS tools, ArcView GIS 3.2, Spatial and 3D Analysts and a variety of other spatial data software.

GIS Database Development, Idaho Mining Association, SE Idaho Phosphate Resource Area
Designed, built and managed a desktop and web-based geographic information system and analytical database for water quality modeling and spatial analysis for a regional investigation of selenium contamination of water, soils, vegetation and biological organisms.

Database Manager, ARCO, Superfund Site, Leviathan Mine, California
Designed and managed a GIS-compatible relational database for accessing and managing surface water analytical and flow data, as wells as geotechnical and environmental data. The database was

designed to be used in conducting a Remedial Investigation, Feasibility Study and Risk Assessment of an inactive sulfur mine located on the eastern slope of the Sierra Nevada.

Marin Municipal Water District, Marin County, California
Mapped roads and trails using Trimble GPS equipment for the development of a large Arc/Info GIS system. Incorporated Trimble SatView data for GPS mission planning and optimization of satellite coverage. Preprocessed GPS data for import into Arc/Info.

CONTINUING EDUCATION:

- MWH Manage the Project PM Certification (as per Project Management Institute)
- Knowledge management education
- Geographic Information Systems, 3D Analysis
- Hazardous Chemicals in Soil
- Environmental Law
- OSHA and MSHA Surface Miner Certified
- Emergency first aid and CPR

SPECIALIZED SOFTWARE EXPERTISE:

- AqteSolv (pumping test analysis)
- ArcGIS/ArcView (GIS)
- Global Mapper (spatial data management)
- EnviroInsite (3D data visualization, spatial and statistical analysis)
- Microsoft Access & (relational databases)
- Modflow (3D numerical groundwater flow modeling)
- MT3D and Modpath (3D groundwater and chemical transport modeling)
- Geoslope - SEEP/W & C/TRANS (2D flow and chemical transport modeling)
- Surfer (spatial and statistical analysis)

NATHAN W. HAWS
SENIOR ENGINEER

EDUCATION:

PhD, Environment Engineering, Purdue University, Indiana, USA, 2003
BS/BSc, Civil and Environmental Engineering, Brigham Young University, Utah, USA, 1999
MS/MSc, Civil and Environmental Engineering, Brigham Young University, Utah, USA, 1999

REGISTRATIONS:

Professional Engineer - Civil, Arizona, 48186, 2008
Professional Engineer - Civil, Nevada, 20251, 2009

EXPERIENCE:

Hydrologist, South Yuma County Landfill, Air Quality Screening Evaluation, Yuma, Arizona
Air dispersion screening evaluation using Screen 3 and EPA AP-42 method

Hydrogeologist, Freeport McMoRan, Tailing site characterization, Christmas Mine, Arizona
Collection and characterization of tailing material samples

Project Engineer, Russell Gulch Landfill, Landfill expansion engineering, Globe, Arizona
Type IV expansion design, including alternative cover, liner and slope stability, storm water drainage, and leachate collection

Project Engineer, South Yuma County Landfill, Landfill expansion engineering, Yuma, Arizona
Type IV expansion design, including alternative cover, liner and slope stability, storm water drainage, and leachate collection

Project Scientist, City of Phoenix, Jet-fuel contamination characterization, Phoenix, Arizona
Interpretation of analysis of aged jet fuel contamination to characterize its soil-air-water partitioning properties

Hydrologist, Freeport McMoRan, AZPDES surface water permitting, Arizona
Consultant for permit renewals for Christmas, Bagdad, and Bisbee mines

Inspector, Pima County Solid Waste, Environmental audit of solid waste facilities, Pima County, Arizona
Environmental compliance audit of municipal landfills and refuse transfer stations

Project Engineer, Hexcel Corporation, Remedial design consulting, Kent, Washington
Evaluation of permeable reactive barrier design and economic evaluation of options for remediation of chlorinated solvents

Project Hydrologist and Environmental Engineer, Freeport McMoRan, Flow and Transport in Groundwater, Sierrita Mine
Regional groundwater flow and sulfate transport model construction, calibration, and predictive simulations of mitigation alternatives.

Project Hydrologist and Environmental Engineer, Freeport McMoRan, Flow and Transport in Groundwater, Copper Queen Branch
Regional groundwater flow and sulfate transport model construction, calibration, and predictive simulations of mitigation alternatives

Project Hydrologist and Environmental Engineer, Freeport McMoRan, Flow and Transport in Groundwater, Copper Queen Branch
Regional groundwater flow sulfate transport model construction, calibration, and predictive simulations of mitigation alternatives.

Project Hydrologist and Environmental Engineer, Freeport McMoRan, Flow and Transport in Variably Saturated Water and Air Phases, Sierrita Mine
Prediction of tailing impoundment drain-down.

Project Hydrologist and Environmental Engineer, Russell Gulch Landfill, Flow and Transport in Variably Saturated Water and Air Phases, Various Sites
Alternative landfill cover design and performance evaluation.

Project Hydrologist and Environmental Engineer, South Yuma County Landfill, Flow and Transport in Variably Saturated Water and Air Phases, South Yuma County
Alternative landfill cover design and performance evaluation.

Project Hydrologist and Environmental Engineer, Hexcel Facility, Flow and Transport in variably Saturated Water and Air Phases, Livermore, California
Evaluation of recontamination potential via PCE volatilization from groundwater.

Project Hydrologist and Environmental Engineer, Freeport McMoRan, Surface Water Runoff, Storage, and Routing, Christmas Mine
Long-term water budget of hydrologic loading to tailing impoundments.

PROFESSIONAL DEVELOPMENT:

Model Independent Parameter Estimation (PEST) Workshop

ORGANIZATIONS/MEMBERSHIPS:

Arizona Hydrological Society
American Geophysical Union

PUBLICATIONS AND PRESENTATIONS:

Das, B.S., N.W. Haws, P.S.C. Rao, 2005, *Defining Geometric Similarity in Soils*, Vadose Zone Journal 4:264 270.

Haws, N.W., B. Liu, E.J. Kladivko, P.S.C. Rao, C.W. Boast, D.P. Franzmeier, 2004, *Spatial Variability and Measurement Scale of Infiltration Rate on an Agricultural Landscape*, Soil Science Society of America Journal, 68: 1818 1826.

Haws, N.W., B.S. Das, P.S.C. Rao, 2004, *Dual Domain Solute Transfer and Transport Processes: Evaluation in Batch and Column Experiments,* Journal of Contaminant Hydrology, 75 (3 4)

Haws, N.W., E.J. Bouwer, W.P. Ball, 2006, *The Influence of System Conditions and Modeling Formulation when Simulating Cometabolic Biodegradation in Sorbent-Water Systems*, Advances in Water Resources 29(4): 571-589

Haws, N.W., J. Simunek, P.S.C. Rao, I.C. Poyer, 2005, *Single Porosity and Dual Porosity Modeling of Flow and Transport in Subsurface Drained Fields Using Effective Field Scale Parameters*, Journal of Hydrology 313 (3 4) 257 273

Haws, N.W., P.S.C. Rao, 2004, *The Effect of Vertically Decreasing Macropore Fractions on Simulations of Non Equilibrium Solute Transport*, Vadose Zone Journal, 31: 1300 1308

Haws, N.W., W.P. Ball, E.J. Bouwer, 2006, *Modeling and Interpreting Bioavailability of Organic Contaminant Mixtures in Subsurface Environments*, Journal of Contaminant Hydrology 82(3-4): 255-292

Haws, N. W., W. P. Ball, E. J. Bouwer, 2007, *Effects of Initial Solute Distribution on Contaminant Availability, Desorption Modeling, and Subsurface Remediation*, J. Environ. Qual. 2007 36: 1392-1402.

Haws N. W., M. R. Paraskewich Jr., M. Hilpert, W. P. Ball, 2007, *Effect of fluid velocity on model-estimated rates of radial solute diffusion in a cylindrical macropore column*, Water Resour. Res., 43, W10409, doi:10.1029/2006WR005751.

Perkins, D.B., N.W. Haws, J.W. Jawitz, B.S. Das, P.S.C. Rao, 2007, *Soil Hydraulic Properties as Ecological Indicators in Forested Watersheds Partially Impacted by Mechanized Military Training*, Ecological Indicators, 7: 589-597

Schmidt, J.S., N.W. Haws, R.S. Govindaraju, P.S.C. Rao, 2006, *A Semi-Analytical Model for Transient Flow to a Subsurface Tile Drain*, Journal of Hydrology 317(1-2): 49-62

EMPLOYMENT HISTORY:

Senior Engineer, MWH Americas, Inc., 2009-Present
Project Engineer and Hydrologist, Hydro Geo Chem, Inc. (Tucson and Phoenix, Arizona), 2005-2009
Post-Doctoral Research Fellow, Johns Hopkins University. Dept. of Geography and Environmental Engineering (Baltimore, Maryland), 2004-2005