Peer Review Summary Report

Peer Review of EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

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Henk M. Haitjema, Ph.D.
D. Kirk Nordstrom, Ph.D.
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TABLE OF CONTENTS

I. INTRODUCTION

Versar, Inc. (Versar), an independent EPA contractor, coordinated an external peer review of EPA's Gold King Mine (GKM) Analysis of Fate and Transport in the Animas and San Juan River. The purpose of the three-day peer meeting, held at the EPA's Office of Research and Development (ORD) Laboratory in Athens, Georgia on February 23-26, 2016, was for five expert reviewers to evaluate the scientific integrity of EPA's analysis and characterization of the fate, transport, and potential impacts of acid mine drainage (AMD) release in the Animas and San Juan Rivers. The reviewers met with EPA scientists who presented their analysis and findings to the reviewers. This report summarizes the peer review comments provided during the meeting and presents the reviewers' individual written comments in response to a series of charge questions pertaining to hydrology, geochemistry, fate and transport, and potential impacts from the Gold King Mine release.

I.1 Background on Gold King Mine Analysis of Fate and Transport

On August 5, 2015, EPA was conducting an investigation of the GKM near Silverton, Colorado, to assess the on-going water release of AMD from the mine, and to assess the feasibility of further mine remediation. While excavating near the mine entrance, pressurized water began leaking above the mine tunnel, eventually spilling about three million gallons of water stored behind the collapsed material into Cement Creek, a tributary of the Animas River.

Since that time, personnel from all parts of EPA have been assisting in response efforts. A portion of the response included ORD research to:

- Understand the geochemical drivers that mitigate spill effects within the rivers receiving the AMD;
- Characterize the GKM acid mine drainage spill;
- Characterize transport and fate of AMD in Animas and San Juan Rivers, and;
- Estimate possible future water quality and biological impacts.

A team of ORD scientists with expertise in geochemistry, surface and groundwater hydrology, environmental engineering, water quality modeling, fish biology and bioaccumulation, statistics, and geographical information tools used the following EPA models and GIS tools to analyze the sampling data:

- Water Quality Analysis Simulation Program (WASP) to analyze the transport of metals through rivers;
- Bioaccumulation and Aquatic System Simulator (BASS) to determine the uptake of metals in fish during plume passage;
- Wellhead Analytic Element Mode (WhAEM) to look at groundwater transport and connection of wells to the river;
- EnviroAtlas for data gathering and geospatial analysis.

This project's objectives were to provide analysis of water quality following the release of acid mine drainage in the Animas and San Juan Rivers in a timely manner to 1) generate a comprehensive picture of the plume at the river system level, 2) help inform future monitoring efforts and 3) to predict potential secondary effects that could occur from materials that may remain stored within the system. The project focuses on assessing metals contamination during the plume and in the first month following the event. A quality assurance project plan was developed for the work in this project.

I.2 Peer Review Process

Versar was tasked by EPA with assembling five scientific experts to conduct an external peer review of EPA's Gold King Mine analysis. The peer review process provided a documented, independent, and critical review of the draft analysis, and its purpose was to identify any problems, errors, or necessary improvements to the analysis prior to being published or otherwise released as a final assessment. In assembling these peer reviewers and coordinating the peer review, Versar was charged with evaluating the qualifications of peer review candidates, conducting a thorough conflict of interest (COI) screening process, independently selecting the five peer reviewers, distributing review materials, managing the written peer review period, organizing and hosting the peer review meeting in Athens, Georgia, and developing a final peer review report.

The peer review selection process was initiated by Versar to identify candidate reviewers with expertise in the following areas: (1) geochemistry, (2) fate and transport (water/sediment), (3) water quality analysis simulation (WASP) modeling, (4) groundwater modeling, (5) geospatial analysis (EnviroAtlas modeling), and (6) bioaccumulation. Versar's in-depth and multi-staged evaluation of qualifications was based on each candidate's biosketch, curriculum vitae (CV), and publications. In total, Versar identified and contacted approximately 30 candidate reviewers to determine their interest and availability to participate in this peer review.

In addition to the evaluation of candidates' expertise, Versar conducted a thorough COI screening of the candidate reviewers. Each candidate reviewer was required to complete a series of screening questions to help determine if they were involved with any work and/or organizations that might create a real or perceived COI. Following this screening process, a pool of nine peer reviewers were submitted to EPA. Versar independently selected five reviewers to participate in the peer review and EPA provided consent on the five selected reviewers. In addition, Versar selected Dr. William Stubblefield as Chair of the peer review meeting. Dr. Stubblefield is an internationally recognized expert in the field of aquatic toxicology with a research focus on the effects of metals on ecological receptors, and he has also served on numerous EPA Science Advisory Board (SAB) panels. The list of the five peer reviewers who participated in this meeting is provided below.

Following the selection process, Versar distributed to the reviewers EPA's background material on the Gold King Mine analysis along with 21 charge questions (See Section II). The peer reviewers were charged with evaluating the quality of the science and the analytical approach included in EPA's presentations about the Gold King Mine release. There were no public comments or public involvement on this preliminary analysis of the Gold King Mine release.

Peer Reviewers

Brian S. Caruso, Ph.D., P.E
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Charles R. Fitts, Ph.D.
Fitts Geosolutions, LLC
Scarborough, ME

Henk M. Haitjema Ph.D.
Haitjema Consulting, Inc.
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D. Kirk Nordstrom, Ph.D.
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Boulder, CO

William A. Stubblefield, Ph.D. (chair)
Oregon State University
Corvallis, OR

I.3 Peer Review Meeting

Versar coordinated an external peer review of EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*, and organized and convened a three-day peer review meeting in Athens, Georgia on February 23-25, 2016. The purpose of the peer review was to evaluate the scientific integrity of EPA's analysis of the fate and transport of acid mine drainage from the Gold King Mine release into the Animas and San Juan Rivers. The review was initiated with a pre-meeting kickoff teleconference managed by Versar and included the five peer reviewers. The three day peer review meeting was organized as follows, with Days 1 and 2 having presentations conducted by EPA personnel:

- Day 1 of the meeting (Tuesday, February 23rd) was dedicated to introductions and three presentations conducted by EPA. The topics of these presentations were: overview of the GKM release, geochemistry of the release, and water quality modeling using WASP.

- Day 2 of the meeting (Wednesday, February 24th) was dedicated to three more presentations conducted by EPA. The topics of these presentations were: empirical analysis, bioaccumulation and residue-based effects, and groundwater well modeling.

- Day 3 (Thursday, February 25th) was a closed session in the morning to allow peer reviewers to summarize their written comments and responses to charge questions after seeing the presentations from Days 1 and 2. In the afternoon, the reviewers provided EPA a summarization of the reviewer's initial comments and recommendations.

As part of their initial comments and recommendations, the reviewers commended EPA for an assessment of a challenging, complex scientific issue, working with limited data and a quick timeframe for providing analytical results and general findings. The reviewers also praised EPA for conducting this peer review at an early stage of their analysis so there can be time to fine-tune the modeling, gather additional data, and conduct other necessary research to solidify their conclusions. The reviewers offered numerous recommendations such as improving the quality of the analysis and technical content to refining the clarity of the goals and scope of the entire project. While detailed recommendations are provided in the reviewers' individual written comments provided in Section V, key recommendations and general impressions from the three-day peer review meeting are highlighted below.

- The overall goal of the analysis conducted should be clarified to provide cohesiveness and avoid confusion. The objectives and approaches taken in this analysis are too broad to provide tangible conclusions. For example, one of the stated goals for the EPA program was to characterize the release, transport, and fate of AMD released into the Animas and San Juan Rivers. However, this wide-ranging objective needs to be more concise by narrowing the scope which will enhance conclusions given the complexity of this issue and the limited extant data.

- With respect to one analysis objective for identifying the potential for water quality impacts and implications for future monitoring priorities, there was confusion among the reviewers that the analysis did not constitute a formal risk assessment nor was it designed as such. A key impression from the reviewers is that all of the information presented is similar to a risk assessment and the presentations should include key elements of a risk assessment to more clearly answer questions about potential impacts to human health or ecological resources. Having such a framework would help EPA better communicate impacts and inform stakeholders on long-term monitoring plans.

- Another point of discussion at the meeting involved the data used in EPA's analysis. It is believed that the EPA researchers could only utilize publicly available data, but it was observed by several reviewers that some important historic or background data were missing and that data might be acquired from public sources (e.g. from the U.S. Geological Survey). In addition, the integrity of the data is in part questioned due to the lack of a cohesive and coordinated sampling strategy and quality assurance protocols.

- While listening to the presentations, it became clear to the reviewers that there are limitations as to how far EPA can take the data analyses and conclusions. In several cases, the data uncertainty could have been better addressed with sensitivity analyses and by bracketing solutions showing best and worst case scenarios. With regards to the methods used in the models, several reviewers felt that grouping metals into total metal concentrations severely undermined the soundness of the conclusions. In terms of an exposure assessment, the EPA researchers should focus on select metals that are known to have detrimental human and environmental health impacts instead of lumping all metals into one "total" metals concentration. Evaluation of potential environmental impacts must be done through the comparison of environmental exposure concentrations and exposure concentrations that result in adverse effects. The use of the EPA national recommended water quality criteria for the protection of aquatic life or drinking water criteria as part of an initial screening of risk to select potential contaminants of concern can be used; however, this must be done on a single metal basis. Consideration of metals exposure data on a "total" metals concentration would prohibit this approach.

- Another general impression is that when doing calculations with incomplete data and assumptions, these assumptions and data gaps should be clearly outlined and presented. For example, the WASP model's assumption regarding the pre-release total metal concentrations in Cement Creek caused some confusion among the reviewers. EPA did not have access to any background or historical data upstream of the mine in Cement Creek, therefore the modelers assumed the concentrations after the plume had passed were equivalent to the pre-release concentrations. The reviewers noted that this assumption may have underestimated the total metals load that entered into the Animas River and bracketing the concentrations to show a range of values may be more beneficial.

Following the meeting, peer reviewers were given time to complete their individual written comments, which were submitted to Versar upon completion. These final written comments are contained in Section V of this report and fall into two categories: general impressions and responses to charge questions. Written peer review comments will be considered by EPA to further the projects' objective of providing an analysis of the water quality in the Animas and San Juan Rivers following the release of acid mine drainage from the Gold King Mine.

II. CHARGE TO REVIEWERS

Part 1. Overall Project and Analysis

Question 1. Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?

Question 2. Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.

Question 3. When looking at the full project, are there errors or gaps in the integration process that could have affected the overall analyses and/or the conclusions? Please explain.

Question 4. Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?

Part 2. Fate and Transport

Question 5. Does the research appropriately characterize the metals concentrations and load produced at the Gold King Mine spill?

Question 6. The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?

Question 7. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?

Question 8. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the San Juan River after receiving mine contaminated water from the Animas River?

Part 3. Geochemistry

Question 9. Were the geochemical principles to characterize transport and fate of acid mine drainage appropriately applied and interpreted? Please explain.

Question 10. Were precipitation and mineral saturation analyses of the acid mine drainage appropriately applied for interpreting metals fate in the river system? Please explain.

Question 11. Was the neutralization of acid mine drainage and subsequent fate of dissolved and colloidal/particulate metals appropriately interpreted? Why or why not?

Part 4. Water Quality Analysis Simulation (WASP) Modeling

Question 12. Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.

Question 13. Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.

Question 14. Did the WASP modeling appropriately investigate the remobilization of metals during increased flow? Why or why not?

Part 5. Groundwater Modeling

Question 15. Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?

Question 16. Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.

Question 17. Were the assumptions informing the capture zone and particle tracking analysis appropriate for the intended use? How so?

Question 18. Did the method for calibration of the local scale groundwater flow model performance to the observed drawdown reported in the driller's log serve as an effective method? Please explain.

Part 6. Atlas Modeling

Question 19. Are the sources of the data included in the maps valid, complete, and adequately documented? Are there any points of confusion, gaps, or suggestions for improvement?

Question 20. Do all of the maps and charts communicate the analysis methods and results in such a way as to be readily understood by stakeholders with interest in the impacts of the Gold King Mine spill (e.g., First Nations; NGO's; news media; and State water, recreation, public health, and wildlife managers)? Are there points of confusion, gaps or suggestions for improvement?

Part 7. Bioaccumulation

Question 21. Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?

III. GENERAL IMPRESSIONS

General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	I commend EPA for gathering and analyzing all of this data in an attempt to understand the contaminant plume movement in the Animas and San Juan rivers from the Gold King Mine release. It is always challenging to collect and analyze in a consistent way existing data from a wide range of sources and with different levels of QA/QC. EPA has done a relatively good job in a short time frame at a first cut for this fate and transport analysis. However, the accuracy of information presented is questionable due to a number of reasons and assumptions, the clarity of presentation needs improvement, and the soundness of conclusions is also drawn into question based on these issues. One of the main issues is that the goal of the research appears to be too broad and not specific enough to determine if the information and conclusions are adequate. In some cases the goals and objectives are not entirely clear and appear to be somewhat different in various places in the presentation where they are presented. In general, I believe that EPA should perform this work and prepare the research analysis so that it uses the best science available and presents results as clearly as possible in preparation for a number of issues, including potential lawsuits and Superfund investigations, monitoring plan development, and to inform all stakeholders of what occurred as best as possible. Although many of the conclusions seem generally appropriate based on the analyses performed, the quantification and accuracy of the conclusions are weak due to a great deal of missing information and lack of detailed uncertainty and sensitivity analysis. Several examples of where the analysis and presentation should be improved include: • better definition of goals and objectives to reflect critical information needs • use of EPA national criteria or standards for metals for drinking water and aquatic life as part of an initial screening of risk to select potential contaminants of concern for more detailed analysis and as indicators (instead of primarily evaluating total metals)	

General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	• better use of other existing data and information from previous investigations to evaluate and help confirm background (pre-release) levels for comparison • inclusion of additional data and information for better reactive transport modeling, metals concentration and load calibration, and validation for WASP • better evaluation and presentation of uncertainty and sensitivity analysis of results should identify data gaps in the analysis and for future modeling	
Charles Fitts	It is hard to summarize since there are so many facets of these studies. The soundness of conclusions is discussed under question 4 below. There are many details that need attention, and many of these are just a matter of editing, polishing and fleshing out with more text and detail, which is to be expected in a more final draft. I felt that the overview and empirical analysis sections were generally logical and needed minor work. I have few comments on the geochemical and bioaccumulation portions since I have less background in those areas. The WASP presentation could use a good deal of clarification about the analyses and more caveats about the uncertainties involved and how the results may be used. For example, the deposition/suspension analysis of WASP slides 25-27 seems to be quite uncertain and should be viewed skeptically since the deposition/suspension input parameters do not square with published ranges. In most cases, the WhAEM modeling was sufficient to characterize whether a well likely pulls in some river water, but the modeling approach was not sophisticated enough to predict accurately what fraction of a well's flow came from the river and what the plume breakthrough curve might look like in well concentrations. More sophisticated 3D and localized models could be constructed to improve predictions, but the Key Analysis Question (Groundwater slide 2) may not require such detail for most of the wells.	
Henk Haitjema	The overall goal of the research has been the topic of some mild confusion by me (and the group at large). The agency stressed that the current research does not constitute a formal risk assessment nor was it designed as such. However, the precise purpose of the research has not been articulated very clearly. I must assume that in the end the research presented is to be used as the basis for some form of risk assessment and, if needed, remedial action. As such I have been evaluating the research presented with this ultimate goal in mind.	

General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	Overall the work was well presented although the complexity of some issues and the necessary brevity of the presentations resulted in many interruptions of the presentations with questions or requests for clarifications by the reviewers. While I understand that the EPA researchers could only work with publically available data, it was observed by several reviewers that some important historic (background) data were missing, but might have been acquired from public sources (e.g. the USGS). Most conclusions seemed reasonable, taken into account the limited data and the basic nature of these initial studies. However, in several cases the data uncertainty could have been better alleviated with some sensitivity analyses and by presenting bracketing solutions showing both most favorable and most unfavorable (worst case) scenarios. Finally, I have the impression that communication between different branches of EPA is less than optimal. On several occasions the quality of the studies suffered as a result. For example, the lack of coordination between the various sampling efforts and the lack of information about the sampling and quality assurance protocols cast some doubt on data integrity, hampers data comparisons, and may have resulted in unnecessary data gaps.	
Kirk Nordstrom	The Animas River Team (ART) of the EPA's Office of Research and Development (ORD) involved with research on the fate and transport of potential contaminants from the Gold King Mine (GKM) spill presented, summarized, and interpreted a very large set of diverse data collected by EPA and other technical groups under adverse conditions. Although the data set was large, many necessary parameters were missing and the quality was less than optimal for the objectives of the ART because the accidental release was unexpected and field and lab parameters were collected while the EPA was in an emergency response mode with little time for planning. Hence, the ART was working under a serious handicap and with very tight time constraints. Considering this overall situation, the presentations were impressive. They have made every effort to be thorough in collecting information, careful in most of their decisions on how to proceed with insufficient data, and they have been clear on what information is based on fact, what assumptions were used, what aspects were largely speculative and require follow-up monitoring, and they have reviewed and revised many of their conclusions to keep them as sound as possible. They have been transparent	

General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	about what they have tried to do and completely open to good suggestions. We had, in my opinion, excellent discussions about what can and cannot be done with the available data. That's not to say that there isn't room for improvement. To be sure, some of their assumptions could use revision, some of the methods that were used need modification, and in one instance (bioaccumulation) the effort was highly questionable. Having an independent review to evaluate the work at this point was a wise choice. As long as the recommendations of the reviewers are carefully considered, this mid-point evaluation should prove extremely valuable in helping the ART to achieve its goal. Some of the figures in the presentations were impossible to read either in the hard copy or in the various PowerPoint presentations. These should have been checked and improved. A more logical and consistent sequence to the presentations would have helped also. A more helpful logical and consistent sequence means a clear statement of goals followed by an outline of available data with a tabulation of the logic on how to obtain said goals. Some of this was presented but it was a bit different for each group and the methodology was not always clearly stated. It is difficult to appropriately characterize the metals concentrations and loads when a lot of the important field and lab data were not collected. Immediate field reconnaissance was challenging because of the unexpected accidental and sudden release of mine pool water, the time delay in notifying authorities of the accident, and the time delay in getting personnel and equipment to the field. Of course, under rapid emergency conditions it is difficult to collect enough of the right kind of data. However, it is hard to understand why more field parameters were not measured such as conductivity, pH, and temperature for all samples, why sulfate and Fe(II/III) were not determined when water samples were collected for analyses, and why no samples of GKM effluent were collected during the release. These parameters (pH, conductivity, and Fe(II/III) should always be measured for acid mine water contamination. This is not a criticism of the ART modeling efforts, obviously, but of the lack of guidelines for the field personnel who collected the samples.	

General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	The EPA should have a handbook that recommends what samples and field parameters need to be collected in an emergency mine water spill. Furthermore, the handbook should emphasize the importance of getting water samples of the source water (the Gold King Mine effluent) as soon as possible and throughout the main pulse of mine water release because its chemical composition could, and probably did, change during the release. It is imperative that the chemical composition of the pollutant source be properly characterized because substantial changes in its composition can occur and will affect downstream transport. If the source is not well characterized then it becomes extremely difficult for the team to characterize the changing conditions of the plume as it moves hundreds of kilometers downstream. If the proper parameters had been collected, the ART could have done far better at characterizing the metals and the load, the rate of movement of the plume, the partitioning of metals between dissolved and particulate forms, and the fate of the metals in the plume. What the Team did manage to do with this partial data set is highly commendable, appropriate, and the results were very reasonable. More on this below. Another general impression is that the EPA is not prepared for sudden mine releases like this from an organizational viewpoint. Is there an EPA office in Silverton or Durango? Not as far as I know, but there is a USGS, a USFS, and a BLM office. There is also a BLM in Silverton. Coordinating with these offices could have led to a much better collection of plume samples which would have helped the ART do a much better accounting and modeling of the plume. Does EPA coordinate with local technical staff in Colorado to get the necessary data? Even coordination among EPA Regions and between the Regional Emergency Response Team and the ORD seems to be a problem that would inhibit the rapid flow of essential data and information needed by the ART. To an outsider it appears that the other federal agencies that could help the EPA were not contacted immediately when news of the spill was released. A general rule of thumb is that anybody trying to model the hydrogeochemical dynamics of a field site needs to see the field site. By visiting the sites, the team can get a much better idea of how appropriate their modeling and assumptions are for the goals of the project. I	

General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	was surprised that no one had been allowed to see the area or had ever visited the area. A good field observer has a natural feel for how to model a complex and transient event with limited data. This disconnect between field and modeling effort can lead to inappropriate analyses and conclusions.	
William Stubblefield	The presentations provided in the *Gold King Mine Analysis of Fate and Transport in the Animus and San Juan Rivers* reflected the high degree of effort and quality expended in their preparation. However, the overall objectives of the effort, technical approaches employed, and desired outcomes were not obvious. EPA NERL scientists were clearly at a disadvantage not having been involved in the design of the sampling plan, its implementation, and the assessment of the overall quality of the data. Two analysis objectives were stated in the overview presentation: • Characterize the release, transport and fate of the approximately 3 million gallons of released AMD, with a focus on a suite of metals • Identify the potential for water quality impacts, including municipal wells, and implications for future monitoring priorities. Clearly, a great deal of effort went into addressing the first objective and EPA scientists did a reasonable job of achieving this objective, given the limitations in data and the rapid nature of the response. It is not as clear how the second objective was to be addressed. Prior to the review it was explained that this was not an "ecological risk assessment;" however, to be able to address the second objective it is imperative that environmental exposures for individual metals be adequately described in terms of their magnitude and duration, as a minimum. Given the current state-of-the-science it would also be helpful to have information regarding those physicochemical parameters that can affect the toxicity of individual metals to aquatic organisms (e.g., dissolved organic carbon, pH, and hardness). It was also noted that there was a reasonable set of sediment data analyses (300 samples) but no detailed analysis of this data was presented. It was acknowledged that there is a large amount of data available and that the integration and interpretation of the data represents an onerous task, especially given the rapid analysis time available.	

General Impressions		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	In conclusion, it was somewhat difficult to discern what the objectives of the integrated program were and whether they had been achieved or not. There seemed to be a lack of cohesiveness in the overall program objectives and the approaches taken to achieve these objectives.	

IV. RESPONSE TO CHARGE QUESTIONS

Part 1: Overall Project and Analysis

Question 1 *Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?*		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	Some assumptions about data inclusion, formatting, and use were appropriate, some were not, and some were questionable. There appear to be many questions and issues with regard to the analysis methods and assumptions, many of which affect our evaluation of the assumptions about data inclusion, formatting, and use. Important questions and issues include: • The goals of the fate and transport analysis and modeling are not clear, and in some cases appear to be different in various parts of the presentation materials. • It appears that the WASP TOXI model for toxicants, including metals, was not used. This module incorporates Kd values for partitioning between dissolved and particulate forms, 1^{st} order decay, and diffusion coefficients, for some reactive transport modeling. Also, why was the WASP add-on, Metals Transformation and Assessment (META4), not used for the fate and transport modeling? This module was developed by EPA and can handle reactive transport in complex acid mine drainage-metals systems with precipitation-dissolution reactions incorporating pH and other important parameters. • Important or indicator individual metals should be analyzed and presented in more detail. These should probably include at least Cd, Cu, Pb, and Zn. Summary statistics of data should be calculated at time periods along the length of rivers and compared to EPA drinking water and aquatic life hardness-based criteria to evaluate potential contaminants of concern for fate and transport analysis and initial screening for potential risk.	

Question 1 ***Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	• Why did EPA not use Sondes for continuous monitoring of parameters such as conductivity and pH? • Why was pH and conductivity not measured in many samples? • Why were different sampling and analysis methods and detections limits used by different EPA organizations and for different samples? • Why were other organizations that offered to help with monitoring apparently excluded?	
Charles Fitts	There was some discussion about other possible sources of data from academics and other organizations. If there exist other data particularly at an earlier time near the GKM or Cement Creek, it would be helpful to get that data and include it in the analysis, since it would reduce the uncertainty about the source concentrations and mass.	
Henk Haitjema	In some cases data sources and limitations were not fully explained and required reviewer inquiries. While in most cases an appropriate attempt was made to overcome data scarcity and uncertainty by offering conservative (worst case) scenarios, these were not always well explained.	
Kirk Nordstrom	For the most part, the data that were available were properly included and appropriate. There is the distinct possibility that additional data was collected by university researchers, local stakeholders (such as the Animas Stakeholders Group), mine owners, the US Geological Survey (USGS), The Bureau of Land Management (BLM), and the US Forest Service that has not yet been discovered. For example, I am aware that some data was collected by the USGS which has not been included in the compilation and the presentations. These additional data sources, which included USGS data given to Steve Way of the EPA should be found and included if useful for the modeling.	

Question 1 ***Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	It would have been helpful for me to have the team include chemical analyses of just a few waters samples such as GKM effluent in addition to the samples that defined the tail end of the plume. Then I could do some quick calculations to both confirm what the team had calculated and to see if there are any additional calculations that might need to be considered. The reviewers only saw a graph of a limited number of constituents. Several of the plots were log plots that gave a strange symmetry to the data. I know that in many cases there is such a large range of values that a log plot is necessary but not in all cases. Log plots often make the data look better than it really is. I would suggest that some plots could be divided into 2 or 3 linear plots for better visualization.	
William Stubblefield	The scope and types of available data were adequately described and the limitations of the available data were also discussed. Obviously, there were limitations in the available data and in some cases key parameters that would have been useful for interpreting data were not available (e.g., dissolved organic carbon). The staff doing the analyses had to "make do" with the extant data and they seemed to do an adequate job with what was provided. In some cases, questions were raised regarding the potential availability of data from other non-EPA sources that might exist. EPA is encouraged to seek out and obtain all potential data that would be useful in interpreting the extant data. Potential data sources that should be examined include the USGS and State Department of Environmental Quality and/or Departments of Fish and Wildlife. In addition, it is anticipated that there may be data held by researchers at local Universities and at various Native American organizations.	

Question 2 ***Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	In general the overall integration process of the various analyses at NERL was conducted in a way that provided some meaningful results and conclusions. However, the integration process outside of NERL appears to be a significant barrier to deriving more meaningful results. The lack of consistency in the data between different organizations, data gaps for some important analyses (such as pH and conductivity), and different detection limits and analytes even for the EPA labs, all make the overall integration appear weaker. In addition the apparent lack of integration between ORD NERL, other ORD labs, the regions, and other agencies in terms of response and future monitoring and modeling needs, limits the provision of meaningful results and conclusions. With regard to the presentations, it probably would have been more helpful to present the empirical results before the WASP modeling.	
Charles Fitts	I understand that there has been a pressing timeline for pulling these studies together and that we are looking at first drafts, which I think is the proper stage for having a review that allows time for revision. I expect more effort will go into integration, peer editing, and polishing, which the entire study could benefit from. It would help to expand the overview section so that it explains clearly how each of these parts contribute to achieving the project's goals and describes to what extent each part depends on results from other parts. For example, the same analysis of source mass shows up in both the empirical and WASP sections. Some portions of the work could benefit from additional review and input by additional experts within EPA. Although I am not expert in this area, it seemed that the bioaccumulation study could use such review, as the reviewers indicated that it may need to consider alternate methods that are not based on factors that assume a ratio of river concentration to tissue concentration.	
Henk Haitjema	There were some limited connections between the presentations, particularly between the presentation "Empirical Analysis of Metal Loads & Water Quality Trends Based on	

Reviewer Name	Reviewer Comment	EPA Response
	Question 2 ***Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.***	
	Observed Data" by Dr. Kate Sullivan and Dr. Mike Cyterski and the WASP modeling. However, there was no clear overarching structure in which the various presentations had a clear place. Consequently, the results and conclusions from the individual studies could not easily be related to each other. That said, I recognize that this review was conducted before all studies were fully completed and documented (written up in a report) and as a result the integration could not yet have happened. I believe that the timing of this review, prior to producing a final document, is very beneficial for an optimal impact of the review process. Thus the lack of integration observed is not to be interpreted as a critique on this research effort!	
Kirk Nordstrom	The presentation of the various analyses could have been conducted in a logical sequence. The Empirical Analysis should always go before any modeling efforts based on the observations. Most people would want to see the data first and foremost. It is also better to get a feeling for the data to see what types of modeling approaches are reasonable and which ones aren't. Modeling is usually used to fill in data gaps, to gain more insight into the processes that might explain the data, and to explore possible scenarios to evaluate their consequences. So the data should come first and then the modeling results. Otherwise the sequence with Geochemistry, followed by WASP modeling, Bioaccumulation, and ending with Groundwater seemed appropriate. One aspect that was problematic is that some of the results and the presentations changed several times. That is, we received one copy of PowerPoints by cyberspace before the meeting. At the meeting we received a paper copy of the PowerPoints in a binder where some things had been changed and then when people gave presentations they sometimes had made another update and handed that out to us separately. That tells me that the Team was not quite ready and were still finessing their results. It would have been more appropriate to wait another week or two to make sure there were no important changes before presenting to the reviewers. Last minute modifications are not helpful for a review meeting.	

Question 2 ***Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
William Stubblefield	Is not entirely clear what is meant by the "overall integration process" of the various analyses. For example, some of the reported metals data are presented on the basis of "total metals." This is a fairly nonstandard approach for presenting metals data especially if one of the objectives of the evaluation is to assess potential impacts to exposed aquatic organisms. The array of metals present in the Gold King Mine AMD will have vastly different toxic potencies and will be present in the AMD at greatly different concentrations (ppm to ppb). To conduct an appropriate evaluation of potential effects to exposed organisms, one needs to consider the exposure to the individual metals. It might be better if evaluations were conducted on a few different metals representing a range of toxicities, proportional presence in the AMD, and environmental fate processes. Evaluating metals such as iron, aluminum, copper, and zinc would cover a range of toxicity profiles and presence in the AMD.	

Question 3 ***When looking at the full project, are there errors or gaps in the integration process that could have affected the overall analyses and/or the conclusions? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	Please see comment on question 2 above.	
Charles Fitts	Since the study focused mostly on total metal concentrations, it is possible that it overlooked behaviors of specific species of metals that would be important in subsequent risk assessments and monitoring plans. I also mention this in the fate and transport section, and suggest analyzing the fate and transport of a few metals that are likely to pose risk and may be representative of groups of similar metals. Most of the concentration data we saw in the presentations was from water samples. However, slides 6 and 20 of the overview alluded to over 320 bed sediment samples. Presentation of the sediment data was limited, so if there is more to that story, perhaps more should be presented.	
Henk Haitjema	While the "Overview" presentation offered a "Summary of Findings" (slide 25) that I found relevant and important, there was no overarching presentation that put the various studies together to substantiate these final conclusions. What is needed in addition to the work presented to the reviewers is a document with a clear statement of purpose and explanation of the motivations for the various studies. That same document then must also have a concluding section in which these studies are referenced, and the conclusions integrated into an overall set of conclusions and, where appropriate, recommendations. I did not observe fundamental flaws in the studies that negatively affected the conclusions presented.	
Kirk Nordstrom	The integration process could have been improved by better communication between the Geochemical Analysis and the Empirical Analysis groups. These 2 sections are very closely aligned and have clear overlaps on the source term composition. More discussion was probably needed between these groups to have a better consensus on how to characterize the source term. It seems to me that when writing up the final report these 2 sections might be merged into one. Alternatively, writers should make clear what deserves to be called geochemical analyses and what is empirical. Whenever geochemical modeling is involved it would seem necessary to call it a geochemical analysis, however, mass balances is also considered geochemical modeling. Very often some geochemical reactions need to be	

Question 3 ***When looking at the full project, are there errors or gaps in the integration process that could have affected the overall analyses and/or the conclusions? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	assumed or modeled for the mass balances to make sense. Hence, these two sections should probably be merged.	
William Stubblefield	One of the stated objectives of the effort was "Identify the potential for water quality impacts, including municipal wells, and implications for future monitoring priorities near-term and long-term." It is not clear how this objective was going to be met. Few "exposure" concentrations were provided as a result of the Agencies analysis and little to no indications of how "impacts" were going to be assessed were discussed.	

Question 4 ***Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	The overall conclusions drawn from these analyses generally seem appropriate, but this is somewhat difficult to determine due to the lack of clarity in the goals and objectives of the research. In addition, the conclusions are not entirely scientifically defensible based on the analysis. The primary reasons for this are generally discussed in the overall impressions above and include: • lack of clarity of goals and objectives to reflect critical information needs • lack of use EPA national criteria or standards for metals for drinking water and aquatic life as an initial screening of risk to select potential contaminants of concern for more detailed analysis and as indicators (instead of primarily evaluating total metals) • inadequate use of other existing data and information from previous investigations to evaluate and help confirm background levels for comparison • lack of inclusion of additional data and information for better reactive transport modeling, concentration and load calibration, and validation for WASP • very limited evaluation and presentation of uncertainty and sensitivity analysis of results • lack of identification of data gaps in the analysis and for future modeling	
Charles Fitts	I think the conclusions presented in overview slide 25 are generally sound and on-target. It think that the 4th bullet point about most of the metals being deposited in the Animas streambed could be more specific. The presentation could point out the specific stretches of the Animas River that received the greatest mass of deposition (RK 13-16 and RK 64-96, as discussed in question 7). There is no bullet point about the impact on wells located near the river. I think there should be an additional point made about the potential for impact in wells close enough to the river, but that sampling data showed only well 35m66km with a noticeable plume signal, which was at levels that did not pose any significant risk.	
Henk Haitjema	I believe they were, but as outlined in my response to various questions below, additional work and better documentation are needed.	

Question 4 ***Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Kirk Nordstrom	Not entirely. (1) The geochemical analysis used some flawed assumptions to estimate the GKM effluent composition (see below), (2) alternative approaches to the GKM effluent composition were not considered (see below), (3) sensitivity analyses need to be employed for many of the analyses and modeling with a propagated range of uncertainty; this approach would result in upper and lower bounds for the plume at several locations downstream, and (4) I have a difficulty in seeing any scientifically defensible conclusions coming out of the bioaccumulation study – the lack of fish kills and the caged fish study are much more appropriate to address fish toxicity for such a short transient event than the attempt at modeling that was presented.	
William Stubblefield	A variety of conclusions were provided in a number of the presentations; however, for the purposes of this response, we are assuming that the "summary of key findings" from the overview presentation captures the "overall" conclusions. For the most part these findings were supported by the data provided in the presentations. However, in some cases it is difficult to point specifically to the data that support a given conclusion. This is in part due to the sheer volume of data and the way that the presentations were organized based on the available time for presentation. It is anticipated that a detailed report outlining the analysis that was conducted would provide an opportunity to present an analysis in greater detail. For example, providing metal specific data rather than "total metals data" would provide greater support for the conclusions.	

Part 2: Fate and Transport

Question 5 ***Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	The research makes an attempt to characterize the metals concentrations and loads produced at the Gold King Mine spill. However, it is extremely surprising and unfortunate that EPA collected no samples from the release itself until what appears to be a substantial time period after the release. In addition, no samples were collected at the mouth of Cement Creek (CC) until about 4 hours after the release and after the release/plume had passed. The volume of the release was estimated by the USGS based on the change in the hydrograph at the CC mouth. Four samples were collected at the adit release up to about September 23, 2015. It was not made clear when the first sample at the adit was collected, but appears to be at least many hours to a day after the release. One of these samples collected by EPA was selected to characterize the release and use in subsequent calculations and modeling. It was stated that this was selected because it was the most comprehensive analysis. However, it is not known or made clear why the other samples were not analyzed the same way. The samples are presented on a log graph for most metals, so the variability of the results is not entirely clear. The variability and uncertainty of these adit release results should be analyzed and presented in more detail, and perhaps a mean or median over this time period should be used instead of just one sample. Also, it is not clear if any other samples from inside the adit itself, or from the ongoing drainage, had been collected and analyzed previously, prior to the release. If so, these should be compared to what was observed in the release.	
Charles Fitts	The data were mostly presented as total metals and did an adequate job of portraying the distribution of total metals. The presentation seldom presented data on subgroups of metals or individual metals. It might be instructive to look at empirical data for a few individual metals of interest, selected because of their importance in terms of risk and their characteristic behavior representative of a group of similar metals (e.g. one metal that precipitates at a low pH range and another that precipitates at a higher pH range). Since subsequent studies will be examining risk and monitoring plans that aim to minimize risk,	

Question 5 ***Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	the metals chosen for individual analysis should include ones that are most likely to pose risk.	
Henk Haitjema	As explained below the total metals load leaving Cement Creek were probably underestimated. However, this was recognized in the analyses presented to the reviewers and could not have been avoided in lieu of the lack of more pertinent sampling (sampling of the peak of the plume in Cement Creek).	
Kirk Nordstrom	Characterizing the composition and load of the Gold King Mine spill is problematic. No samples of the mine effluent were taken during the spill event. Samples were taken some days later. When the plume hit the first gage at Cement Creek (at the mouth), samples for chemical analysis were taken well after the peak of the plume had passed. Furthermore, the first 2 samples at the gage were incomplete (no pH, conductivity, or sulfate determinations). In addition, when the plume hit the Cement Creek gage it had picked up additional sediment and dissolved substances that were not part of the original mine pool discharge. Consequently, it makes sense to consider the source water as the plume that was recorded in the Cement Creek gage right before it entered the Animas River. It is still a problem characterizing the water composition at the peak of the Cement Creek discharge because the first sample collected for analysis at the gage was about 5 hours after the spill began and contained only about 20% of the Gold King effluent as well as missing some critical parameters. I think the ART did important calculations to estimate the water composition at the Cement Creek gage peak flow from the GKM release and I shall suggest additional considerations.	

	The Team did a straightforward conservative calculation assuming straight mixing of GKM effluent with upper Cement Creek water with no reaction. This result would normally give a bounding limit to the chemical composition of the plume. But which limit? High or low? If there is a reaction in progress, is that increasing or decreasing metal concentrations? Both are possible. Oxidation and precipitation of iron would tend to remove metals. Dissolution of soluble salts from the eroded waste piles and Cement Creek would increase metals. Erosion of fine clays might provide more surfaces for metal sorption and partitioning from dissolved to the solid phase. From my experience with weathering of mine tailings and waste rock during storm events, there is a brief and sudden increase in dissolved metals during the early rise of the discharge and then a decrease from dilution. In this instance, dilution is with GKM release water and upper Cement Creek flow because it is not a rainstorm event. But there is still likely to be a sudden increase early in the plume movement and then a drop to the concentrations of the GKM effluent for the remaining majority of the plume release followed by decrease to Cement Creek baseline once the GKM plume has passed. This early spike in concentrations would be from the addition of soluble salts and films of concentrated acid mine water contained within the tailings pile downstream and separate from the effluent composition released from the mine. I would anticipate sorption processes to be largely ineffective at this pH (~3) and with higher than normal metal concentrations. The plume is moving too fast for much oxidation and precipitation of iron. Hence, I would argue that the total plume load would be greater than that expected from just the analyses of the GKM effluent in both dissolved and fine particulate matter combined with the estimated discharge. Further, I would argue that the first measured concentrations at the gage on Cement Creek should be close to conservative mixing (20% of GKM and 80% upper Cement Creek water) but that the dissolved concentrations were higher during the first ½ hour of the GKM release. How much higher is very difficult to say so this calculation would be a lower bound that can be compared to another estimate. It can also be compared to a loading calculation that takes a constant composition GKM release as a lower limit after mixing with Cement Creek baseline water. This constant composition chosen by the ART was the August 15 sample because it was the first complete analysis of the mine effluent after the plume had passed. There were 3 other samples that I would say could be used as well from other time periods. Although pH, sulfate concentration, and conductivity data were sometimes missing, it is possible to reconstruct these by optimizing pH and sulfate concentrations using charge balance for pH	

Question 5 ***Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	(using the PHREEQC program) and conductivity balance (using either PHREEQC or WATEQ4F although WATEQ4F would be preferable because it is more reliable for acid mine waters). With regard to estimating the composition of the Gold King effluent water during the spill, the explanation could have been clearer, especially since this composition is critical to the entire interpretation of downstream fate and transport. Unfortunately, the data available is sparse and incomplete which adds to the confusion. As I understand it, there are two key sets of data: (1) direct analyses of the Gold King effluent but collected after most of the spill had occurred with dates of 8-07-15 and 8-11-15 collected by CDPHE and dates of 8-15-15 and 9-21-15 collected by the EPA and (2) Cement Creek samples collected during the tail end of the plume movement (first sample was collected about 5 hours after the spill began). The CDPHE samples are missing critical data such as pH, temperature, conductivity, iron and sulfate concentrations. The Cement Creek samples are Gold King effluent mixed with 80% or more of upper Cement Creek water, possibly mixed with some dissolved soluble salts, eroded sediments, and their pore waters. The GKM effluent composition had to be estimated from these limited pieces of data. The approach taken was to use the Cement Creek USGS gage data to determine the proportion of that water containing GKM effluent. Then unmix the water assuming conservative mixing. Then most of the concentrations were increased by an amount that was estimated by assuming that alunite saturation equilibrium was achieved in the GKM effluent and increasing the aluminum concentration accordingly. Alunite saturation equilibrium was indicated in a paper by Eary (1999) and this is the first time I have heard of making this assumption to estimate a mine water composition. The question is whether this assumption is reasonable and whether there are other, more reasonable approaches. Alunite is a relatively insoluble mineral which is slow to dissolve and precipitate unless the temperature is increased substantially above ambient.	

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Reviewer Name	**Reviewer Comment**	**EPA Response**
	I have read the Eary (1999) paper and the case made for alunite solubility equilibrium at low pH is extremely speculative. I say that because the plots that Eary showed (1) had considerable scatter, (2) were not done the normal way with the log of the activity of the free aluminum ion vs pH – he used dissolved aluminum concentrations vs. pH which doesn't really tell you much and cannot be directly compared to solubility of alunite, and (3) he doesn't show saturation indices for alunite as he does for gypsum, fluorite, and other carbonate and sulfate minerals. Further, he was looking at a pit lake which can be different than underground mine effluent. Not to mention that there are a range of thermodynamic properties for alunite so we really don't know how the solubility might change with solid solution substitution, particle size and crystallinity, and uncertainty in the thermodynamic properties. I am sure that alunite does reach equilibrium solubility in some environments but I would be very hesitant to apply it for this situation. Hence, I would discourage using this type of modeling approach to correct the mine effluent chemistry to the original composition. Instead, I would take the range of composition of the mine effluent water (max and min as bounding conditions) that was sampled later, correcting pH and sulfate concentrations as mentioned above, and compare that to the conservative estimate made from the mixing calculation that the team did from the 1600 hour sample. Then I would consider a 50% to a 100% increase in concentrations during the first ½ hour only of the GKM release to account for washout of the tailings pile for an upper bound of the loading and concentrations. The characterization of the metals concentrations and the loads begins with the field collection of water samples and field parameters, followed by laboratory analyses. The ART did not participate in these activities. There may have been some QA/QC (quality assurance/quality control) tasks done by individuals in the team, but, apparently not as a group effort. Consequently, some unexplained discrepancies occurred in the results presented, such as several elements in which the total (unfiltered, acidified) concentration is substantially less than the dissolved (filtered, acidified) concentration. This discrepancy is	

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	most apparent with As, Sb, Pb, Mo, and V in the Cement Creek samples that were used to estimate the source effluent composition from the mine, which are sometimes discrepant by an order of magnitude or more and that is far greater than the analytical error. One way of avoiding these problems is for the team to engage in conversation with the field collection personnel and with the laboratory and any QA/QC examiners to determine if there were any sampling problems or analytical problems that could explain these anomalies. I have seen similar discrepancies before with metal concentration data from mine-influenced water at Superfund mine sites and the main problem seemed to be the lack of communication between those collecting the samples, those analyzing the samples, and those providing QA/QC. Without knowing field difficulties in collecting samples and whether there were any modifications of normal procedures (waters should be filtered and acidified immediately on collection; unfiltered samples acidified immediately except for anion sample) and without knowing if any serious interferences or possible contamination occurred with the analytical procedures, it becomes impossible to know how best to interpret the data. The higher dissolved concentration could be a contamination problem and the lower total value closer to the truly dissolved value OR the dissolved concentration could be more accurate, and the total concentration could be a result of the sample being collected in a different part of the river or an analytical interference. These are important issues that can affect any attempts at interpreting the results for fate and transport. For this report, everything that can be known about sampling, preservation, and analytical procedures should be spelled out more. There were probably different procedures employed by State, Federal, tribal groups and other parties (for example, were samples sometimes stored for some time before acidification? Was the same acid used among agencies for acidification? Was acidification done with the same strength acid and with the same volume per volume of sample or to the same pH? If samples were filtered, what was the filter pore size? Instead of providing the EPA method numbers for the analytical method, it would be better for the reviewers to simply have the actual instrumental technique employed (ICP-	

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	AES or ICP-MS, etc.) which might be more useful when comparing results from different agencies. Reviewers and stakeholders might want to know the QA/QC for the data. I recommend a table that lists what samples were collected when, by whom, whether filtered on site or not, if filtered what pore size was used, whether acidified on site or later, if later how much later, what and how much acid was used. A separate table can cover QA/QC data (blanks, spiked recoveries, standard reference water samples, alternate methods). These tables can be appendices in the report, but it is essential to include this information because it supports the credibility and usefulness of the data for modeling and interpretation. Also, several metal concentrations that were reported are of questionable value such as cobalt, barium, and beryllium. I know these are easy to determine by ICP-AES and ICP-MS but if there are no obvious toxicological concerns and the concentrations are quite low, then that could be stated explicitly. It could also be stated that certain metals were selected (and others not) for continued description in the plume movement because of their concentrations and their potential toxicity. My understanding is that grab samples were collected rather than width-integrated composite samples. Under the given conditions, it might be that grab samples were the only ones possible at many of the sites, however, some width-integrated samples should have been possible or at least near-central-velocity samples collected. If the team doesn't know what the velocity of river was where the sample was collected, it could easily affect the results. Some information on this aspect should be provided in the final report.	
William Stubblefield	It is difficult to address this question given the "total metals" approach used in the analysis of the data. It would seem logical that there are sufficient individual metals data to permit a "by metal" analysis of exposures. This would be helpful in addressing the questions associated with potential impacts to organisms and would allow for better characterization of the fate and transport of individual metals.	

Question 6 ***The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	There was a reasonable attempt made to estimate metals concentrations at this location (adit and or CC?) using scientifically sound methods based on available data. As stated above, however, there appears to be many questions and issues with regard to the analysis methods and assumptions. At the adit release, estimated concentrations and loads were only based on one sample, whereas the summary statistics, variability, and uncertainty of the four samples collected over the month and half after the release should have been better presented and perhaps used in the analysis. Downstream at the CC mouth, an attempt was made to back calculate the concentrations and loads during the peak flow, and to account for dissolved and particulate metals scoured from CC by the passing flood wave. It is not clear how WASP was used to calculate the Maximum Total Concentration to aid with this. This appears to be done outside of WASP as input to the model as a simple mass balance using the estimated release concentrations, estimated background upstream CC concentrations and flow, and downstream measured flow. This mass balance approach seems to be appropriate. However, the analysis is not clear and background concentrations in CC appear to have been based on post-plume concentrations at the mouth, even though there are many pre-release sample and analysis data available for CC. These previous data could have, and probably should have been used, or at least collected and compared to the background estimates used. The explanation of how the plume concentrations were re-constructed at the CC mouth is not entirely clear. It is not clear whether the PHREEQ modeling was needed, or what value the WASP modeled concentrations are considering; these are estimates based on conservative constituents with no reactive transport.	
Charles Fitts	The calculations that lead to the "estimated peak" concentrations shown in the bar chart of empirical slide 20, the WASP and Empirical concentrations in slide 27, and "Simulated	

Question 6 ***The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	Load" in WASP slide 13 needs to be explained in more detail. This is critical since the extrapolation needed at early times strongly affects the estimated total load in the plume. In the following table, I analyzed total concentrations (Ct) vs. discharge (Q) for the early time observations and the early time simulated concentrations in Silverton.	

Time	Q (cms)	Ct simulated (mg/L)	Ct observed (mg/L)	Ratio Ct simul./Q (mg/L/cms)	Ratio Ct observ./Q (mg/L/cms)	Source
12:45	3.5	37000		10571		WASP slide 13 (W13)
12:45	3.5	29557		8444		Empirical slide 20
16:00	1.1	10500	11485	9545	10441	W13
19:25	0.1	3000	998	30000	9980	W13

It makes sense that higher stream discharge and velocity would correlate to higher suspended sediment load and higher total concentration. Based on observations, it appears that the ratio Ct/Q was about 10,000 at the earliest observations (blue). Lacking other evidence, this ratio may be reasonably applied to earlier times, but there is uncertainty in this extrapolation that should be acknowledged in the report. The simulated ratio Ct/Q was about 10,000 for both the 12:45 and 16:00 Ct estimates (purple), but about 30,000 for the 19:25 Ct estimate (red). It seems reasonable to keep the 10,000 ratio to estimate the early time concentrations, which is close to what was done. I think the bullet item on WASP slide 13 should read "Assume total concentration (Ct) is proportional to flow." Also the 12:45 and early time Ct numbers should be made consistent across the study and consistent with the explanation for how the early concentrations were extrapolated.

Question 6 ***The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	Looking at the graph in WASP slide 13 and the 19:25 row in the above table, the simulated concentrations from about 18:00 onward are systematically higher than observed, and they are noisy, bouncing up and down as though the simulated concentrations could only move in large quantum leaps. This portion of the simulated Ct should be modified to remove the noise and to better match observed Ct, even if the impact on simulation results downstream is minor. Since the source mass is critical to all analyses, this deserves attention. If other concentration data becomes available from other sources for the early hours in Cement Creek or GKM, it should be incorporated in revised source estimates.	
Henk Haitjema	On slide 20 of the "Empirical Analysis" presentation, two approaches are mentioned to arrive at the maximum total concentration (CMAX) in the peak of the plume at 12:45. These are using WASP for CMAX and PHREEQ for maximum dissolved concentration. In fact, as I understand it, WASP was not involved in determining CMAX but a mass balance calculation outside of WASP was used (see discussion under question 14). I cannot comment on the PHREEQ method due to unfamiliarity with this code and the processes it simulates. My overall assessment is that the dissolved concentrations in the peak are probably fairly well estimated, but that the suspended total metals concentration in the peak is almost certainly significantly underestimated. In fact, this is recognized in the current study on slide 20 with the comment on the graph: "Concentrations at 12:45 peak probably much higher." In summary, the current study does offer reasonable estimates of peak concentrations and recognizes the underestimation due to the unknown amounts of suspended materials in the peak of the plume in Cement Creek.	
Kirk Nordstrom	Not entirely. More use should have been made of historical data. This was mostly addressed above.	

Question 6 ***The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	There is a serious problem with some of the analyses (e.g. CC06 and GKM13 collected on 8/15/2015) in that many of the total concentrations of metals were lower than the dissolved concentrations. This can occur from problems with field sampling and samples that were not filtered and acidified on site (which probably did not happen for the earlier collected samples). Hence, a table summarizing the information on how water samples were collected and when filtered and acidified, is crucial to interpreting the results. Also, alkalinities of 5 mg/L are reported for these samples when the pH is too low for there to be any detectable alkalinity. This contradiction needs to be resolved. Further, the acidities are reported but I am not sure they are used or needed anywhere. There are several different methods for acidity so the result is very method dependent. If there is a need to report these, then the method used needs to be documented.	
William Stubblefield	A number of questions were raised regarding the accuracy of the estimated metals concentrations in the original AMD release. EPA staff acknowledged that there was a degree of uncertainty associated with the estimates and this was reflected in the presentations. It was recommended by the reviewers that EPA adopt an approach that characterizes the degree of uncertainty associated with the discharge estimates and incorporate that into the overall presentation. This would result in something of a "sensitivity analysis" that would bound the "best-case" and "worst-case" scenarios.	

Question 7 ***Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	This comment relates to both questions 7 and 8 since they are related. The intent of this question is not clear. Is the intent of this for the post-plume period for all rivers, or just for the post-plume period in CC and during the plume in the Animas and San Juan rivers? Post-plume is important for later or ongoing resuspension or dissolution of metals to the water column during higher flows. Of course during the plume is also important for a number of reasons. Does 'sediment' refer to bed sediment or particulates (or colloids) in the water column? We assume this refers to bed sediment. The methods used for estimating sediment metal concentrations are not clear. Although the methods used for estimating the dissolved and sediment/particulate metals load from CC during the release generally seem appropriate based on the mass balance approach, there appear to be a number of concerning issues. Any previous data from other studies on bed sediments in CC are not presented or used. These could include sediment physical characteristics (particle sizes) and sediment chemistry and metals concentrations. Similarly, any previous background metals concentrations in water are not presented. A significant amount of previous studies by USGS and others in CC and the Animas have been performed with these types of data. It appears that with the exception of sediment data collected by an academic researcher (Dr. Williams?), EPA collected no sediment samples or data during or after the plume to help evaluate sediment metal concentration estimates or calibrate the WASP modeling. It appears that sediment (bed) metals concentrations were not estimated except for those estimated with the WASP model. There are issues with these estimates, as discussed in comments below.	

Question 7 ***Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Charles Fitts	The presentation about measured sediment concentrations was brief: slides 44-48 of the empirical section. There are inherent difficulties in distinguishing plume-event sediment from other sediment, and in concentration variations with sample location. Therefore, it may be difficult to conclude much from sediment concentration data. There did appear to be declining trends in sediment concentrations after the plume passed the lower Animas (lower two graphs of empirical slide 47). There were WASP simulations that indicated where sediments from this event were likely to have deposited (WASP slides 25-27), but as I say elsewhere, these WASP results should be viewed as qualitative, not quantitative. A better approach to estimating where plume sediment was deposited would be to examine time-series of total metal concentrations at gages along the Animas River. Estimate the total mass of metals passing a point in the river by numerically integrating Ct*Q data through time, like appears to be shown in slides 30, 34, 35, and 44 of the empirical presentation. Mass changes from one station to the next one downstream could be due to deposition or mass added or subtracted at tributaries or diversions. From the graph in the lower right of slide 44, it appears that most metals deposited just below Silverton (~RK 13-16) and above Durango (~RK 64-96). This empirical approach to estimating deposition trends has a much stronger basis than the deposition results shown in WASP slides 25-27. This analysis should be expanded and highlighted in the empirical presentation and overview, and the WASP analysis section should compare its results to the empirical analysis estimates of deposition.	

Question 7 ***Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	The relatively flat stretch of the Animas River below the confluence with Cement Creek (~RK 13-16) is an area where a significant fraction of plume suspended sediment probably was deposited. Average plume flow velocity would have dropped dramatically beyond the confluence due to the gentler gradient and wider channel, and the abrupt increase in pH would have promoted precipitation and sorption. This stretch of the Animas has alternating riffles and pools and the larger pools would have been particularly ripe for deposition. The image below shows one >100m pool in the Animas channel in this area. 	

Question 7 ***Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	The WASP modeling was too large-scale and homogenized to capture the local differences in velocity between riffles and pools. WASP slides 25-27 indicated minor deposition in this area, but empirical slide 44 indicates deposition of about 40% of the metals mass from Cement Creek in this stretch. I suspect significant plume mass was deposited in these pools and some will move downstream during subsequent high-discharge events. Note: a typo in empirical slide 38: 2nd line should say "High acidity" or "Low pH". In empirical slide 39, explain what blue dots are in lower right plot. The graphs in empirical slide 48 need axis labels and a better explanation. In empirical slide 50, it would provide helpful perspective to show estimated total metal transport during a typical spring runoff season, in addition to the estimates for the late August storm.	
Henk Haitjema	Generally they were, although other reviewers were often critical of the lumping of metals into a total metals load or concentration.	
Kirk Nordstrom	It must be stated much more clearly that the sediment load is a mix of (1) clays eroded from the tailings pile during GKM release, (2) clays (mostly Fe and Al oxyhydroxides) formed during oxidation and mixing with downstream transport, and (3) clays eroded from Cement Creek during turbulent mixing of the GKM plume. Further, these sediments should be compared to suspended or clay sediments that have been determined earlier in USGS studies to see what the chemical differences are and how much they can be related to the actual GKM release.	

Question 7 ***Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
William Stubblefield	As previously discussed, very little information regarding bed sediment metal concentrations were provided. Currently, the state-of-the-science for evaluating metal concentrations in sediments and the potential impacts on sediment dwelling organisms requires information about the acid volatile sulfide content of the sediment and the simultaneously extracted metal concentrations of other metals present in the sediment. It did not appear that this information was available for the sites downstream of the Gold King Mine.	

Question 8 ***Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the San Juan River after receiving mine contaminated water from the Animas River?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	Please see comment on question 7 above.	
Charles Fitts	I assume the question refers to the San Juan River, not Cement Creek. By the time the plume reached the San Juan River, the muted plume signal was hard to detect and sediment concentrations in the San Juan did not show a discernable plume signal. The data presented on this subject was brief (empirical slide 46). Hopefully the accompanying text, when written, will clearly explain the origin of the data and conclusions drawn from this slide.	
Henk Haitjema	Generally they were, although other reviewers were often critical of the lumping of metals into a total metals load or concentration.	
Kirk Nordstrom	I have not looked at this in detail.	
William Stubblefield	Very little information was provided regarding sediment concentrations in the post-plume period in waters downstream from the GKM and Cement Creek. Information regarding individual metals would be helpful, however it is recognized that it will be difficult to attribute specific metals concentrations to the GKM incident given the ongoing contamination that exists in the area as a result of other operations and abandoned mines.	

Part 3: Geochemistry

Question 9 ***Were the geochemical principles to characterize transport and fate of acid mine drainage appropriately applied and interpreted? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No comment on this question as this topic is outside of my area of expertise.	
Charles Fitts	I am less of an expert in geochemistry, so my comments in this section are limited. I found the discussion of the American tunnel plugging and rising groundwater levels (slide 17) quite interesting from a hydraulics and geotechnical standpoint. I suspect that even if EPA had not done earthwork near the GKM entrance, the plug of loose fill at the GKM entrance may have eventually failed by internal erosion (piping) in a manner similar to what occurred on 5 August 2015. As heads inside the mine rose, the hydraulic gradient across the plug increased. Excavating activities also increased the gradient across the plug, but it is quite possible that even without that activity, the increasing gradient could have eventually triggered a piping failure and a sudden release of water stored behind the plug.	
Henk Haitjema	No comment on this question as this topic is outside of my area of expertise.	
Kirk Nordstrom	Much of the geochemistry followed well-accepted principles but there were some exceptions. I have addressed these in my comments above.	
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Question 10 ***Were precipitation and mineral saturation analyses of the acid mine drainage appropriately applied for interpreting metals fate in the river system? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No comment on this question as this topic is outside of my area of expertise.	
Charles Fitts	No comment on this question as this topic is outside of my area of expertise.	
Henk Haitjema	No comment on this question as this topic is outside of my area of expertise.	
Kirk Nordstrom	For the most part, yes. First, the application of dissolved iron oxidation rates was helpful to point out the enormous increase with pH. However, the fact that microbes can speed up the rate enormously at low pH was not mentioned. This should be mentioned along with the caveat that microbes would not have enough time to develop sufficient colonies in the short time of the release to affect much oxidation. There is often a 1-2 week lag time necessary before microbial colonies are of sufficient concentration to show detectable changes in the ferrous iron concentration. Second, the saturation indices for calcite and dolomite were very pertinent and appropriate. This is especially important in pointing out the neutralizing capacity of the Upper Animas River. It would be really useful for the final report to do a simple mixing with reaction calculations with PHREEQC to simulate the effect of mixing the estimated plume (at or near the peak GKM release) at the mouth of Cement Creek and the Animas River to show the strength of the Animas in neutralizing the plume. The geochemical analysis has made a start down this path but a little more work should be done to complete this effort. I see it as a very important part of the overall characterization. The saturation indices for amorphous gibbsite was an appropriate figure, but it is a little disturbing that the saturation state shows considerable oversaturation for many of the data points. We have not seen quite as much of this amount of oversaturation. Because it is not reasonable to have such supersaturation relative to freshly precipitating Al hydroxides, it should be assumed that some particles were not fully filtered out. As pointed out for the large supersaturation for iron hydroxides, considerable Fe particles get through the filter and indeed, may have been formed during storage of samples if they were not filtered and acidified right away.	

Question 10 ***Were precipitation and mineral saturation analyses of the acid mine drainage appropriately applied for interpreting metals fate in the river system? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Question 11 ***Was the neutralization of acid mine drainage and subsequent fate of dissolved and colloidal/particulate metals appropriately interpreted? Why or why not?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No comment on this question as this topic is outside of my area of expertise.	
Charles Fitts	No comment on this question as this topic is outside of my area of expertise.	
Henk Haitjema	No comment on this question as this topic is outside of my area of expertise.	
Kirk Nordstrom	Yes, a very good start on the neutralization and fate of colloids was done. As mentioned above, a PHREEQC simulation of mixing with reaction to compare with the more qualitative description would wrap this part up nicely. The sorption calculations are considerably speculative, at least in the way they were described. The ART should use Dzombak and Morel's (1990) book on sorption to apply modeling because it is the only place where a self-consistent set of data is available. I am still not sure that scientifically justifiable results can come out of this but at least this would be a starting point. Also, it should be noted that Webster et al. (1998) EST 32, 1361-1368 found that the sorption of acid mine drainage precipitates and schwertmannite were different than ferrihydrite, shifting the sorption edge.	
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Part 4: Water Quality Analysis Simulation (WASP) Modeling

Question 12 ***Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	The methods and results for the WASP modeling were unclear and it appears that a number of common and well-accepted modeling practices were not used, with no clear or acceptable explanation of why. Although I understand that there is a lack of data in some areas and that some time constraints contributed to the approach used, I feel that the problem is important enough that the best modeling approach possible should be used to derive the most accurate and useful results possible. Primary comments and issues are itemized below: • Although the primary goal of the modeling was presented, this goal is very general and vague, which leads to a great deal of generality and uncertainty in the model results. • The segmentation and structure of the model for surface water and sediment segments were briefly discussed, but these should be clearly presented in a map or schematic. • Although the modeled discharge was calibrated to the flow measured at the USGS gages, there was no attempt to include or model major tributary inputs to, or irrigation or other takes from, the main stem of the rivers. These should have been included. It is also not clear whether and why both Geometry equations and Manning's Equation using roughness and slope were used to estimate flow parameters such as velocities. • There appears to have been no attempt to calibrate or validate the modeled concentrations or loads. This is standard practice and there appears to have been adequate data collected during and immediately after the release to at least calibrate the model, so this should have bene done.	

Question 12 ***Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	• It is not clear why the TOXI module of WASP, for some reactive transport of toxicants including metals, was not used. This module includes Kd for partitioning between dissolved and particulate forms, first order decay, and a diffusion coefficient. Why were only total metals modeled, whereas both dissolved and total (or particulate) could have (and probably should have) been simulated. Although WASP cannot model equilibrium precipitation-dissolution reactions based on pH and other parameters like some other models (META4 and OTEQ), it can incorporate Kd values and diffusion coefficients to simulate adsorption and partitioning between the dissolved and solid or particulate phases with suspended sediment in the water column and with bed sediments. It appears that this should have been done. • Also, why was the WASP add-on, Metals Transformation and Assessment (META4), not used for the fate and transport modeling? This module was developed by EPA and can handle reactive transport in complex acid mine drainage-metals systems with precipitation-dissolution reactions incorporating pH and other important parameters. • It is not clear why Scenario 1 was used. Although this scenario could provide a very conservative estimate and upper bound on transport estimates, this scenario may not be conservative if scour of metals in sediment is important, and it is too simplistic and not realistic. • It is not clear what initial and boundary conditions were used for metals and sediment (Total Suspended Solids) concentrations and loads. For concentrations it appears that post-plume metals concentrations were used, whereas previous pre-release data are available and perhaps should have been used. • Although sediment/particulate settling and resuspension was included in Scenario 2, it is not clear why there was no attempt to use any existing information on surface (bed) sediment metals concentrations for model input or calibration. Some of these	

Question 12 ***Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	data may have been available from previous studies to use as model input, and from data collection afterwards for calibration. • In addition, there was no evaluation of sediment particle sizes from any previous data for modeling of settling and resuspension based on velocity and shear stress. It is not clear why the larger shear stresses in Scenarios 2b-2 and 2b-3 were selected and what kind of particle sizes these may relate to. • For Scenario 3 for Long-term Effects, it is not clear why Nov 2010 – Dec 2011 was selected, what the magnitudes of the high flows modeled were, and how representative they are of high flows in these rivers. Using the model to estimate plume movement is good, but using Scenario 1 (due to reasons stated above) and qualitatively matching modeled to observed concentrations visually are very questionable. Why were no standard objective functions (such as Nash Sutcliffe or correlation coefficients) used? This is standard practice.	
Charles Fitts	Overall, the WASP modeling seemed to show that the program could be made to simulate migration and dispersion of the plume in the river that is fairly consistent with observations of the plume's passage. It appeared to be useful for simulating the approximate dilution and dispersion of contaminants, but I felt less comfortable with the analysis of deposition/resuspension since required erosion/deposition parameters were far outside of published ranges. It was not clear to me how the equations for velocity, depth, width (slide 9) and Manning's equation (slide 12) were applied. Our 25 Feb phone call helped clear this up for me, but that section could use clearer explanations about how Q and V as a function of (t, river distance) were calculated. If the velocity equation on slide 9 was not used, as Chris mentioned in our phone call, that equation should be eliminated. Also, there are corrections as noted in our discussion: the constants "a" and "b" in slide 9 equations are duplicated but should not have been, and the graph on that page needs axis labels.	

Question 12 ***Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	It appears that Q was assumed constant from one gage down to the next gage, where the Q abruptly jumps up or down. It seems to me that it would be better to assume a more gradual transition of Q from one gage to the next, because the abrupt jumps in Q ripple through the calculations to cause abrupt jumps in concentrations. If you know where larger tributaries join, you could improve the assumed distribution of Q between gages using that knowledge. I understand from our phone call that WASP is limited to 50 such discharge changes, which is many more than were used in this simulation. So more, smaller jumps in Q could be incorporated into the model to give smoother, less distracting results. Unless I am mistaken, the comparison shown on slide 11 means little, since the model input was constrained to match Q at gages, and all this slide shows is that the constraint worked as expected for a spring hydrograph record. In slide 12 the discrepancies are not large, but they are systematic – modeled velocities are consistently high. The deviation should be explained, and the need for unusually high Manning coefficients should also be discussed and rationalized. Note these typos in slides 15 and 16: the mass flux between the segments n and n+1 should be "QnCn". Numerical dispersion is noted in slide 15. If it is possible to quantify that and compare it to simulated dispersion, that would be helpful. Slide 23 shows two graphs that appear to show the same data. If there is a need for two graphs, explain what they show and how they differ. If there are time-series observed concentrations, they should be shown on these graphs for comparison.	

Question 12 ***Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	In slide 41, it would help to color code the sample dots to indicate how close the measurement was to the passage of the peak plume (e.g. red for within 1 hour of peak, orange for 1-2 hours before or after peak, and so on). Slide 42 should show lines of relevant criteria other than recreation, such as for aquatic life and drinking.	
Henk Haitjema	For the most part it seems that proper use has been made of available data and, when necessary, data from the literature. However, this was not always fully explained during the presentation. Specifically, the formulas presented on slide 9, used to calculate the average water velocity, stream depth, and stream width for a particular model segment of the stream were not fully documented (and contained some erroneous coefficients). A more complete description of exactly what was measured where and how the regression analysis was applied to arrive at the coefficients "a" through "f" must be provided in the final report. In follow up discussions it appeared that WASP did not use the first formula on slide 9 - the formula for velocity. These velocities were obtained using Manning's equation and calibration using observed velocities at USGS gauges, see slide 12. This is of course confusing. The velocity calculation on slide 9 is best removed. It should also be explained why the calibration on page 12 left all observed velocities below the modeled velocities.	
Kirk Nordstrom	It should probably be mentioned that there are other transport codes for this situation (e.g. OTEQ and PHREEQC) and some justification should be given why the team used WASP instead of something else. Especially in light of the fact that OTEQ has been used on mountain streams containing acid mine drainage for about 20 years and PHREEQC has been used longer than that for geochemical modeling of acid mine drainage chemistry. I was glad to see that the team did not try to combine transport with reaction because there is not sufficient data to constrain such modeling.	

Question 12 ***Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Question 13 ***Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	This comment addresses both question 13 and 14 below, since they are related. It is not entirely clear how the application of assumptions and values in WASP modeling addressed particle transport and deposition of the acid mine drainage constituents. As stated above, although sediment/particulate settling and resuspension was included in Scenario 2, it is not clear why there was no attempt to use any existing information on surface (bed) sediment metals concentrations for model input or calibration. Some of these data may have been available from previous studies to use as model input, and from data collection afterwards for calibration. In addition, there was no evaluation of sediment particle sizes from any previous data for modeling of settling and resuspension based on velocity and shear stress. It is not clear why the larger shear stresses in Scenarios 2b-2 and 2b-3 were selected and what kind of particle sizes these may relate to. It is not clear exactly what the settling results (slides 25-28) of the WASP presentation are showing or how they were computed. There appears to be total metals concentrations in the water column, and a certain fraction of this mass settles out into the sediment, creating total metals concentrations in the surface sediments, a certain faction of which can be re-suspended under high flows. But these are presented in units of mg/L instead of mg/kg, which is typical for metals in sediment. Typically you would have particulate metals in the water column which can settle out. In addition, as stated above there appears to be no initial metals concentrations or mass in the surface sediments as an initial condition, although in some locations there should be some of this type of data from previous studies. It is also not clear if there was any initial suspended sediment loads or concentrations in the water column as part of initial conditions.	
Charles Fitts	The estimation of the GKM release load (WASP slide 13) is discussed in question 6 above. The WASP model simulated only the metals loads in the discharge of Cement Creek where it joins the Animas. It assumed zero metals loads in the Animas above Cement Creek and in the San Juan above the Animas. It would make for more meaningful comparisons with	

Question 13 **Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.**		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	observations (e.g. slide 22) if estimated loads from the San Juan and upper Animas were added to the model. Adding these inputs may also impact the simulations of settling and resuspension. I imagine that reasonable estimates of the upper Animas and San Juan loads could be made from longer-term monitoring data. In slide 2 (and 28), the 3rd item says "…upon entering Cement Creek", but I think that should be "…where Cement Creek enters the Animas River." The last item on these slides should start with "Simulations indicated that high flow periods…" to clarify that this is a simulation result, not a measured result. The simulations of sediment deposition and subsequent re-suspension indicated that a likely stretch of river to receive such deposition was from about 65km to about 95 km (WASP slides 25-27). However, the 2b-2 simulation used erosion/deposition critical shear stress thresholds that were far outside expected ranges, thus the results should be viewed only as qualitative. There should be a discussion explaining possible factors that required such large thresholds, and the degree to which these factors render the results useful or not. One problem with the WASP modeling of erosion/deposition is that it must treat long stretches of river as homogeneous with respect to velocity, which is far different than the actual riffle and pool nature of the Animas River where it occupies an alluvial plain. This point is also discussed in question 7. In think plume sediment settled out in the calmer pools to a greater degree than what the WASP model would predict for homogeneous segments. This may, in part, explain why atypical erosion/deposition parameters were required to make the simulation match observations.	
Henk Haitjema	It offered a first approximation to these processes. I appreciate the use of a simple modeling approach as conducted here in view of the limited data availability and the limited study objectives as described by the EPA team leader and the modeler. In particular, I applaud that only the most fundamental processes have been included, while secondary processes	

Question 13 ***Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	that are more difficult to parameterize have been omitted. In this light I agree with the decision to ignore physical dispersion in this modeling exercise. However, some caution is needed to declare the omission of (physical) dispersion conservatively by declaring that the modeling results provide an "upper bound." It does for the concentrations (assuming that numerical dispersion in the model does not simply replace the physical dispersion in the river or even exceeds it), but it is not conservative in predicting early arrival, for instance. The fact that numerical dispersion has not been quantified relative to physical dispersion is a weakness in this study.	
Kirk Nordstrom	As a more general comment – it would seem to me that putting the metals concentrations (dissolved and total) and loads in the perspective of the range of all data for low flow conditions (or similar flow and time of year as the GKM release) would help put the plume release in better perspective. This is where historical data could help considerably. A max and a min from historical data could show some kind of envelope around or near the plume results. Also, it would be better to show the individual metals, especially Cu, Zn, Pb, and As when comparing the peak concentration with river distance and conservative (no settling) scenarios. It is also not clear why some samples that look like they were sampled nearly the same time had such different concentrations. This graph needs a lot better explanation.	
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Question 14 Did the WASP modeling appropriately investigate the remobilization of metals during increased flow? Why or why not?		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	Please see comment on question 13 above.	
Charles Fitts	Since the mechanisms for erosion/deposition in the model were using critical shear stress thresholds that are well outside normal ranges, these results must be viewed with skepticism. Like I said in the previous comment, this makes quantifying concentrations very uncertain and this analysis should probably be viewed as an example of how downstream concentrations could respond during a high flow period, not a prediction of how they will likely respond. That distinction should be made clear in the text. On slide 27, label that these are scenario 2b-2 results, and correct the title of the lower graph so it says "Movement of Total Metals…" The resuspension scenario needs to be outlined clearly. What is the assumed event? Is it a hydrograph from a typical spring runoff period, a shorter duration storm event, or something else?	
Henk Haitjema	I am not sufficiently familiar with the WASP model to adequately evaluate this point. However, I do have an observation on the reconstruction of the total metals concentration in the release flow from the mine as presented on page 13. This calculation was done outside of WASP. In principle, the mass balance calculation as presented by the three formulas on page 13 is elegant due to its simplicity. What became apparent during the discussion, however, is that the assumption that the total metals concentration in the plume as measured at 4 p.m. at the 14^{th} St. Bridge, which is after the peak of the plume passed, is the same as during the peak flow (peak of the plume) at 12:45 may be problematic. Reviewers pointed out that the higher turbulence in the peak flow more likely than not would have caused much more materials in suspension and thus a (much) higher total metals concentration than what was measured at 4 p.m. I concur with that observation and emphasize that the assumption on slide 13 (concentration at 4 p.m. same as in during peak flow) might significantly underestimate the total metals load that entered the Animas River! Thus the problem with this assumption is that it is *not conservative* as to the study objective, assessing the potential impact of the release.	

Question 14 Did the WASP modeling appropriately investigate the remobilization of metals during increased flow? Why or why not?		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	However, the total metals load in the plume further down gradient in the Animas River has been independently estimated from plume size and concentrations there. Thus, the impact assessment of the release downgradient in the Animas River is not dependent on the estimate of the original total metals load in the plume while it was still in Cement Creek. It is more likely than not that the missing portion of the total metals load in Cement Creek (due to the underestimation discussed above) ended up as sediments in the very first kilometers of the Animas River. This is because the flow velocities were quickly reduced as soon as the plume entered the Animas River thus allowing settlement of the larger particulates that might have made up the higher peak flow concentrations. In summary, while I agree that the peak flow concentrations in the plume in Cement Creek may have been underestimated, I do not believe that this underestimation affected the down gradient impact assessment, except perhaps for the sediment load in the first few kilometers of the Animas River.	
Kirk Nordstrom	No comment on this question as this topic is outside of my area of expertise.	
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Part 5: Groundwater Modeling

Question 15 ***Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No comment on this question as this topic is outside of my area of expertise.	
Charles Fitts	I think the analysis is sufficient to conclude that certain wells farther from the river were not susceptible to drawing river water (wells 575m71km, 650m71km, 1000m70km), and that certain wells close to the river likely do draw in river water (well 35m66km and the 5 NM wells). The analysis of well 75m71km was a closer call, and for that well a more sophisticated analysis could shed better light on the extent to which it draws in river water. The analysis conservatively estimates whether wells have potential for drawing river water. By *conservatively* I mean that the potential for drawing river water and the fraction of water drawn from the river is probably overestimated by the WhAEM models. This is discussed in more detail under question 16.	
Henk Haitjema	In principle it is. While a very basic groundwater code (WhAEM) was used, its limited capabilities are consistent with both the very limited data available and the limited objectives of this study. In other words, a more sophisticated model would require additional assumptions and would, therefore, not have offered more insight. To fully assess the sufficiency of the current analysis it is necessary to consider its objectives. The ultimate question to be answered is (from the presentation): "Could drinking water or irrigation wells drawing from river alluvium become impacted from the chemicals associated with the GKM release?" This question may be broken up into three interrelated questions: a) Which wells, if any, receive some of its water from the river? b) What are the travel times of water from the river to those wells? c) What is the dilution in the well of possible contaminants received from the river?	

Question 15 ***Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	Question (a) can be answered with capture zone analyses for the various wells. Question (b) can be answered by use of forward particle tracking starting at the river and ending in the well. Question (c) can be answered by tracing particles backward in time from the well, using a uniform distribution of particles around the well, and then comparing the number of path lines that reach the river to those that do not. WhAEM is EPA's standard model for well capture zone delineation in the context of wellhead protection and can address all three questions. As such it is a logical choice for this analysis. However, it is necessary to consider both the limitations of WhAEM and the limitations in field data, and document how these might impact the outcome of the analysis with the above research questions in mind. I will discuss these limitations in arbitrary order below. **Dupuit-Forchheimer flow** WhAEM falls in the class of codes that solves "two-dimensional flow in the horizontal plane," at least that is how these types of models are routinely referred to. Regretfully, this is misleading terminology! WhAEM is a *Dupuit-Forhheimer model*, which is a model in which resistance to vertical flow is being ignored, thus not vertical flow itself. While the underlying partial differential equation in WhAEM involves only the horizontal coordinates (x and y), flow into the vertical direction can and is being approximated using conservation of mass considerations. Consequently, path lines in WhAEM are being traced in three dimensions. For a Dupuit-Forchheimer model to offer a good approximation to the actual three-dimensional flow regime, its application must be limited to groundwater flow systems in which the horizontal distances traveled by groundwater are much larger than the vertical distances traveled. In practice, this translates into groundwater flow systems in which the distances *L* between boundary conditions (e.g. distance of the well from the river) is larger	

Question 15 ***Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	than five times the aquifer thickness. This is for isotropic aquifers. In case the aquifer is anisotropic, with a lower vertical hydraulic conductivity than the horizontal conductivity, the following criterion may be used (Haitjema 2006): $$L \geq 5H\sqrt{k_h/k_v}$$ Where *H* is the aquifer thickness, k_v is the vertical hydraulic conductivity, and k_h is the horizontal conductivity. Dr. Fitts suggested using a k_h *to* k_v ration of 10 for the Animas alluvium, which seems reasonable to me. The condition in the displayed formula above is not meant for wells that are relatively close to the Animas River, and unfortunately these are the wells of most interest (most likely to receive river water). What is the consequence of violating the Dupuit-Forchheimer criterion for wells near the river? In reality the well – river interaction is influenced by possible (bottom) resistance to flow between the river and the aquifer as well as resistance to vertical flow inside the aquifer. Neither is included in the model presented, although bottom resistance could have been applied. By not including any of these resistances, the flow potential for drawing water from the river that flows into the well is *overestimated*. In other words, the model as constructed *is conservative* with respect to the objectives of this study. To keep the analysis conservative in nature I recommend <u>not</u> adding bottom resistance to the line-sinks representing Animas River. <u>Still to be done</u>: While the analysis as conducted and presented is sound regarding this issue it must be fully documented, including calculations for representative wells to show whether they satisfy the Dupuit-Forchheimer criterion or not. This is currently missing from the analysis! A sketch of the expected three-dimensional flow patterns and those modeled in WhAEM, as suggested by Dr. Fitts, would be useful for full disclosure of this issue. Remember, that the path lines in WhAEM are also 3D, but approximate and thus somewhat different from the "real" 3D path lines in cases where Dupuit-Forchheimer does not apply.	

Question 15 ***Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	What the sketch would not show is the fact that vertical resistance to flow is ignored in the Dupuit-Forchheimer model, which must be made clear in the figure caption. **Single homogeneous aquifer with horizontal base** WhAEM represents the alluvium near the Animas River as a single homogenous aquifer, which means that it lumps the various depositional layers in the alluvium into a single homogenous layer. Furthermore, it assumes a horizontal aquifer base below which no flow is considered. The question is how these simplifications affect the modeling results. Specifically, what effect does this simplification have on the potential well – river interaction? This was not discussed in the presentation, but I will address this below. The actual aquifer base is unknown, but at or below the depth of the wells in the alluvium. In the absence of data it has been assumed in the current analysis that the aquifer base occurs at the bottom of the well under consideration. I agree with this choice! This will generally lead to an underestimation of the aquifer thickness, but does not affect the flow regime as much since the transmissivity in the model does not depend on this assumption because it has been based on a pump test. Assuming for a moment that the transmissivity is accurate (or reasonable) an underestimation of the aquifer thickness will result in an overestimation of the hydraulic conductivity, since the product of the two is the (known) transmissivity. So while the discharge rates in the aquifer, including the flow component from the river if present, are not affected (question a), the *specific discharges* and associated average groundwater flow *velocities* are. An underestimation of the aquifer thickness will result in an underestimation of the groundwater travel times (question b). This is *conservative* in view of the model objective since actual early arrival of contaminants may be later than predicted by the model. The actual aquifer heterogeneity offers the potential for preferential pathways from the river to the well. The WhAEM model assumes a homogeneous aquifer that lacks	

Question 15 ***Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	preferential flow. Consequently, the assumption of homogeneity is **not** conservative in view of the model objectives. Preferential pathways would shorten the travel times from the river to the well (question b). While a multi-layer model may be able to capture this effect to some degree, data on aquifer stratification near the wells or between the wells and the river are absent. Still to be done: The above discussion must be integrated into the description of the modeling analysis to fully disclose the impact of the simplifications and assumptions. It should be pointed out that predicted early arrival times in the wells of chemicals released from the river may not preclude that some (small) portion of the chemicals arrive even earlier due to preferential flow. This is true in spite of the fact that the actual aquifer thickness may be larger than assumed and thus result in slower groundwater velocities, hence later early arrival than predicted by the model. Preferential flow may well outweigh the effect of the aquifer thickness on the groundwater velocities. **Steady state flow** WhAEM models steady state flow, ignoring water that may go into storage or is released from storage due to temporal changes in the water table (unconfined flow) or head (confined flow). For the purpose of capture zone delineation (in the context of wellhead protection), a steady state model is considered adequate. In fact, producing capture zones that change over time seems impractical for the purpose of defining wellhead protection areas. However, replacing the actual transient flow system by a steady state one raises the question what the steady state model actually represents. Haitjema (1995, 2006), using a study by Townley (1995), presents a dimensionless response time τ: $$\tau = \frac{SL^2}{4TP}$$	

Question 15 ***Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?***		
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	where *S* [-] is the aquifer storage coefficient, *L* [m] the distance between head specified boundaries, *T* [m^2/day] the aquifer transmissivity (product of aquifer thickness and hydraulic conductivity), and *P* [days] the period of a periodic forcing function. This formula differs slightly from the one presented on slide 12 due to a different definition of the distance *L*. When considering seasonal variations in flow in the alluvial aquifer, the definition of *L* on slide 12 is more convenient where it is the distance between the river and the valley boundary (rock outcrop). Haitjema (2006) offers the following rules of thumb: $\tau < 0.1$ treat transient flow in the aquifer as successive steady state. $0.1 \leq \tau \leq 1$ transient flow cannot be meaningfully represented by a steady state model. $\tau > 1$ represent transient flow by a steady state model using average boundary conditions. These guidelines are approximate in that values just below 0.1 or just above 1 are to be considered transitional from the aquifer responding relatively fast or slow to transient forcing, respectively. The analysis offered on slide 12 is incomplete and partially incorrect! First of all, successive steady state simulations requires τ to be smaller than **0.1**, not 1 as stated on the slide. Incidentally, I missed this issue during the presentation. Secondly, the parameters used in the equation on slide 12 must be reassessed. Specifically, the storage coefficient *S* is too small for an unconfined aquifer as present in the alluvium surrounding the Animas River. Instead of *S*-values between 0.003 and 0.006 as shown on slide 12, I expect the *S*-value to be more in the order of 0.1. This will increase the dimensionless response time τ by almost two orders of magnitude! Note: The reason for the measured low *S*-value is unclear, although Dr. Fitts suggested that it may be an artifact of an imperfect pump test and I concur.	

Question 15 ***Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?***		
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	Secondly, while the periodicity of *P*=365 days is appropriate to assess the response of the flow system to seasonal variations in recharge (in this case inflow into the aquifer near the rock outcrop) and seasonal variations in river stages, it is not suitable to assess the response of the flow system to short term variations in pumping and short term variations in river stage (e.g. storm surges). For that purpose a periodicity *P*=1 day would be a better choice. This reduction in the value of *P* would further increase the value of τ indicating that the aquifer responds rather slowly to storm events and pumping variations. The current analysis does not distinguish between these long term (seasonal) and short term effects (storm events and pumping variations). Therefore, the current analysis mistakenly suggests that successive steady state is always a good approximation of this transient flow system, while in fact it most likely is not. <u>Still to be done</u>: The analysis on slide 12 has to be redone with appropriately chosen parameters and for different combinations of parameters that apply to different (well) locations *and* include bracketing values for those parameters that are not fully known from field data. None are, of course! It is likely that most of these new calculations of τ will result in values larger than 1 or at least larger than 0.1. I recommend that for values larger than 1 average pumping conditions and average river stages are used in delineating well capture zones. In addition, I suggest repeating the analysis for the actual river stage during the passing by of the plume. I suggest that for values of τ smaller than 1, but larger than 0.1, both average pumping rates and actual pumping rates are used (pumping rates when the wells were turned on). Finally, I suggest producing capture zones for bracketing values of uncertain parameters. The resulting suite of capture zones would account for (1) representing transient flow as steady state and (2) for data uncertainty.	

	Groundwater levels and calibration In almost all cases a groundwater flow model is being calibrated using observed potentiometric heads (confined flow) or water table elevations (unconfined flow). Ideally, base flows in streams are also included as calibration targets. Calibration leads to the determination of most likely hydrogeological parameters such as hydraulic conductivities, aquifer recharge due to precipitation, and perhaps stream bottom resistances. In the current study area (or areas) almost no water level data were shown to be available. I wonder, however, if the many domestic wells in the alluvial aquifer may be on record with the state (well logs). If so, many of them might have static water levels that can be used as calibration targets. Similarly, the high capacity wells (irrigation wells and public water supply wells) may have logs that include static water levels as indeed are shown on slide 11. In the absence of domestic well static water levels, the static water levels in high capacity wells could be used as calibration targets by excluding them one-by-one from the model. This would mean conducting several calibration runs each with one of the high capacity wells replaced by a "test point" (calibration target). Currently, hydraulic gradients toward the Animas River are generated in the model by defining head specified boundaries away from the river. The water released by these head-specified boundaries presumably comes from the surrounding mountains. A common approach in modeling flow in alluvial valleys is to apply so-called "mountain range recharge" along the valley boundaries at the bottom of the surrounding mountains. In WhAEM this would be done using discharge-specified line-sinks along the base of the mountains or boundary of the alluvium. This, of course, is only possible if there are reasonable estimates available for the mountain range recharge rate. However, the measured baseflow increase along the Animas River could offer some insight into this mountain range recharge rate. This baseflow increase has already been considered in the current study as shown on slide 8. Still to be done: The final report on the WhAEM model study should address the uncertainty in groundwater flow rates toward the Animas River and the lack of calibration targets. Possible data sources, as mentioned above, should be discussed and used if data is indeed available. The data uncertainty should be resolved through sensitivity testing. Different possible groundwater flow rates toward the river should be tested in the model	

Question 15 ***Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?***		
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	and their effect on the capture zones (question a), early arrival times of chemicals in the wells (question b), and dilution of chemicals in the well (question c) be shown and discussed. Note: The hydraulic gradient toward the river in combination with the aquifer transmissivity defines the groundwater flow rate toward the river. This groundwater flow rate is what really matters for the shape and orientation of the capture zones, addressing questions (a) and (c). The groundwater flow rates toward the river may be bounded by considering base flow increases along the Animas River as already done on slide 8. The actual hydraulic conductivity as well as the aquifer porosity, however, affect the groundwater flow velocities and thus travel times (question b). A sensitivity analysis on hydraulic conductivity and porosity are thus also in order. <u>References</u> Haitjema, H.M. (1995) *Analytic Element Modeling of Groundwater Flow*. Academic Press, San Diego. Haitjema, H.M. (2006) The Role of Hand Calculations in Ground Water Flow Modeling. *Groundwater*, Vol. 44, No. 6, pages 786 – 791. Townley, L.R. (1995) The Response of Aquifers to Periodic Forcing. *Advances in Water Resources* 18: 125 - 146	
Kirk Nordstrom	No comment on this question as this topic is outside of my area of expertise.	
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Question 16 ***Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No comment on this question as this topic is outside of my area of expertise.	
Charles Fitts	As stated above, the potential for communication between well and river is probably overstated in the WhAEM model results. The main reason is that the models are two-dimensional, not three dimensional. The models neglect the resistance to vertical flow and only account for resistance to horizontal flow. The models treat the river boundary condition as a fully-penetrating vertical curtain of specified head extending from the surface to the bottom of the aquifer. In reality, the river bed is a nearly horizontal constant head boundary atop the aquifer, and the well screen elevations are unknown but probably in the lower portion of the aquifer. For wells closer to the river, vertical resistance is a significant part of the total resistance to flow between the river bank and the well screen. Vertical resistance is even greater in stratified sediments where the vertical hydraulic conductivity (Kv) is much smaller than the horizontal hydraulic conductivity (Kh). For example, consider well 35m66km which is 35 meters from the river (horizontal) with a well screen that is about 25 meters below river. If Kh/Kv = 10 (ratios of 5 to 50 are common), the vertical distance in an equivalent isotropic medium would be about 80 m vertical distance (scale the vertical axis by the square root of Kh/Kv to make an equivalent isotropic medium). In this case, the vertical resistance between river and well screen would likely be greater than the horizontal resistance. Neglecting the vertical resistance in the WhAEM models overestimated the communication between well and river, and underestimated the travel time for flow from river to well. The models presented are very large scale and may be omitting some important features closer to the wells. The alluvial plain has irrigation ditches, old braids, and other surface water features that likely connect to the underlying aquifer. Just NE of well 75m71km there is an old swampy braid that still contains water and had visible discharge into the Animas River (see close-up of Google Map image). Also, there is a braid (Coon Creek) about 1200 ft E of well 35m66km.	

<table>
<tr><th colspan="3">Question 16
Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.</th></tr>
<tr><th>Reviewer Name</th><th>Reviewer Comment</th><th>EPA Response</th></tr>
<tr><td></td><td>The inclusion of vast areas of rock in the far-field of this model seems unnecessary and although the model calibration process took care of critical inputs near the well fields, the largely unknown inputs for the rock and far-field may draw distracting scrutiny. I did not hear of a sound basis for these inputs:
• horizontal K of the rock = 1/100th the horizontal K of alluvium
• calling the rock unconfined with a horizontal base so its saturated thickness grows from around 30 meters near the alluvial aquifer to over several hundred meters to the NW (slide 15)
• The no-flow boundary around the whole modeled area
• The specified head boundaries to the N and W near the model limits
• Zero overland flow from the steep rock areas added to the margins of the alluvium

These poorly-grounded inputs could be avoided by using local scale models of just the alluvial aquifer, one model for each cluster of wells. The outermost boundary conditions could be established as specified-head boundaries where heads of surface waters or wells are known up-gradient in the alluvium, and by no-flow boundaries along estimated flow lines.

Slide 4 shows numerous other wells in the alluvial plain. The domestic well discharges are not likely to be large enough to have much effect, especially since most of their discharge returns to the subsurface in leaching fields. Irrigation wells, on the other hand, could have significant discharges, and some of these are close to municipal wells.

Slides 8 and 9 discuss groundwater inflows into the Animas River. The slides and the notes that were distributed did not explain how this information was incorporated into the model. Were the modeled groundwater discharges to the Animas calibrated to values from these analyses? This should be explained in the text.</td><td></td></tr>
</table>

Question 16 ***Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	I'm not sure the analysis of slide 12 is relevant – that applies to cyclic recharge, and recharge was not included in these models. I have no objection to omitting recharge, since at the scale of these well-river distances in late summer, lateral aquifer flows probably far outweigh recharge flows. I also think that a steady-state analysis is warranted given the limited data, roughly continuous use of municipal wells, and the close proximity of key wells to the river. The 2D models presented are capable of only crudely estimating the fraction of flow that is river water and the timing of river water arrival at the wells. If there is a great need to quantify simulated concentration vs. time at a well, a more accurate approach would be to construct a more localized 3D model that includes all the closer hydrologic boundaries in the alluvial plain. A 3D flow model with enough vertical discretization to capture the resistance between the river bed and the well screen could be created with MODFLOW, AnAqSim, or any number of other 3D groundwater flow codes. This could be done at one or a few of the wells to quantify the impacts of the 2D assumption.	
Henk Haitjema	In general they were, but additional analyses and discussions are needed as indicated in my answer to question 15.	
Kirk Nordstrom	No comment on this question as this topic is outside of my area of expertise.	
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Question 17 ***Were the assumptions informing the capture zone and particle tracking analysis appropriate for the intended use? How so?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No comment on this question as this topic is outside of my area of expertise.	
Charles Fitts	As noted under question 16 above, these 2D simulations probably overestimate the fraction of well discharge coming from the river, and probably underestimate the travel time a conservative tracer takes from river to well. The assumed porosity of 0.20 is probably low for these sediments. Such values are common in poorly sorted (widely graded) unconsolidated materials like glacial till, but for alluvial sands and gravels 0.25 < n < 0.35 is a more common range. The impact of using a higher porosity in the simulations would be slower velocities and increased travel times between river and well. The graphs in slides 25 and 26 would be much more striking with an arithmetic, not logarithmic Y-axis. The presentation did not show models of the RK 171 or RK 179 wells in NM, so it is not possible to comment on those analyses and their conclusions. I assume the final report will provide details on those.	
Henk Haitjema	In general they were, but additional analyses and discussions are needed as indicated in my answer to questions 15. Specifically, I have suggested more sensitivity analyses be conducted, along the lines as to what has been shown on slide 16 and 18. The analysis as presented suggests that the aquifer responds quickly to transient forcing, allowing for successive steady state solutions or instantaneous steady state solutions. I found that analysis to be in error!! In fact, the aquifer probably responds rather slowly and a steady state model is more suitable for representing average conditions. In areas (near wells) where the aquifer may respond neither fast nor slowly, bounding solutions may be offered assuming both a fast and slow responses to transient forcing. The issue is discussed in more detail as part of my answer to question 15.	
Kirk Nordstrom	No comment on this question as this topic is outside of my area of expertise.	

Question 17 ***Were the assumptions informing the capture zone and particle tracking analysis appropriate for the intended use? How so?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Question 18 ***Did the method for calibration of the local scale groundwater flow model performance to the observed drawdown reported in the driller's log serve as an effective method? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No comment on this question as this topic is outside of my area of expertise.	
Charles Fitts	The key factors in estimating the fraction of well discharge from the river are aquifer transmissivity (T), ambient hydraulic gradients, well discharge (Q), and well location relative to the river. The models based input T and Q values on yield test data and river/well locations on maps, which are reasonable approaches. The estimation of ambient gradients was probably the greatest source of uncertainty. Using the USGS well near well near RK 70 was helpful for constraining modeled gradients in that area. However, there are other data that could help constrain the modeled gradients elsewhere. The available aerial images and maps should be examined to determine the location and elevations of other surface waters in the vicinity of the simulated municipal wells. The modeled background gradients should be consistent with observed features, and some surface waters may need to be included as boundary conditions. For example, modeled heads should not be well above ground surface or above surface water elevations, and surface water elevations should not be far above simulated heads. This would be easier to do with smaller, local-scale models. There is uncertainty in many model input parameters (e.g. T distribution, saturated thickness of the aquifer, well screen elevations, vertical conductivities), so a more thorough approach would be to run a suite of simulations (realizations) that investigate the range of possible input variations. However, if the aim of the modeling is to only determine which municipal wells have a chance of pumping a significant amount of river water, the WhAEM simulations with just a single realization probably suffice to draw the broad conclusions shown in the first two "Model Results" columns in the table on slide 28, except in the case of well 75m-71km, which was a close call and could use a more sophisticated analysis to draw conclusions.	
Henk Haitjema	There was a lack of calibration targets (only one USGS monitoring well), but that well has been used in this study to arrive at calibrated values of hydraulic conductivity in the alluvium, see slide 15. In my answer to question 15 I described additional *potential* calibration targets that should be explored.	

Question 18 ***Did the method for calibration of the local scale groundwater flow model performance to the observed drawdown reported in the driller's log serve as an effective method? Please explain.***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Kirk Nordstrom	No comment on this question as this topic is outside of my area of expertise.	
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Part 6: Atlas Modeling

Question 19 ***Are the sources of the data included in the maps valid, complete, and adequately documented? Are there any points of confusion, gaps, or suggestions for improvement?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	It seems as though the purpose of the Atlas modeling, and Atlas itself, were only briefly described in one slide. The purpose of the modeling and data sources were not entirely clear. For example, how do the data sources used in Atlas differ from those in any other publicly available national geospatial databases, such as USGS databases including their 'National Map'? Or do they use some of the same data sources? This all needs more explanation.	
Charles Fitts	I understand that in this section we are to comment on the animations that were presented. I can't comment on whether data sources were valid or complete, since only limited information was included on the animation slides. I think the slides were reasonably labeled and clear about what they were presenting. I found both animations to be quite helpful to visualize the plume's migration and dispersion, and to visualize the spatial variability of concentration data and the response of the system to localized precipitation events. I'm sure these animations would be even more useful to a lay person than a scientist with more background.	
Henk Haitjema	I do not have personal knowledge about the data sources, hence cannot address this question.	
Kirk Nordstrom	No comment on this question as this topic is outside of my area of expertise.	
William Stubblefield	It is assumed that the sources of the data that are included in the Atlas modeling maps are the same as those described in the overview presentation and listed on page 64 of the Empirical Analyses presentation. No additional explanation for the data contained in the specific maps was provided therefore it is difficult to address the validity, completeness, and adequacy of the documentation.	

Question 20 ***Do all of the maps and charts communicate the analysis methods and results in such a way as to be readily understood by stakeholders with interest in the impacts of the Gold King Mine spill (e.g., First Nations; NGO's; news media; and State water, recreation, public health, and wildlife managers)? Are there points of confusion, gaps or suggestions for improvement?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No. The maps and charts for the Atlas modeling need more explanation as to their purpose and what the results are attempting to show and what they are actually showing. The usefulness of these maps is not yet clear.	
Charles Fitts	As noted throughout my comments, there is a need for editing, clarifying, and polishing. We were reviewing early draft figures and tables without the benefit of much additional text. The final report will have much more text to qualify and explain the tables and figures, which will be a big help.	
Henk Haitjema	I trust that the ATLAS maps referenced here are the animations of total metals and arsenic migration along the Cement Creek, Animas River, and San Juan River. I felt that these animations were an effective way of communicating the plume migration through the system and thus quite informative for the stakeholders. Other ATLAS maps that have been used in the various presentations were also quite helpful in communicating the spatial and temporal relationships under discussion. Overall, I find ATLAS an impressive communication tool.	
Kirk Nordstrom	No comment on this question as this topic is outside of my area of expertise.	
William Stubblefield	No comment on this question as this topic is outside of my area of expertise.	

Part 7: Bioaccumulation

Question 21 ***Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
Brian Caruso	No comment on this question as this topic is outside of my area of expertise.	
Charles Fitts	I am not an expert in this area, but from what I understood of the discussion, it seems that the partitioning coefficient approach that was used in this section may not be appropriate for metals that have highly regulated concentrations within organisms.	
Henk Haitjema	I defer comments to Dr. Stubblefield who has the relevant expertise in this area. I do not have any expertise in this area.	
Kirk Nordstrom	I was considerably puzzled by the presentation on the BASS code for several reasons. I found the model that the code is based on to be interesting and theoretically appropriate, but it seemed to me to require so much empirical information that it could be decades before it might be useful. This was confirmed by some of the discussion because there clearly is some debate in the scientific literature as to the practical application of the model. It does seem useful for certain groups of organic contaminants for which it was originally designed but not for metals toxicity. More importantly, I failed to see how this model, with parameters that would come from longer term experiments than the lifetime of the GKM plume, had any relevance. The GKM was a rapid transient event and only similarly transient experiment data with fish would be similar in application. Hence, the caged fish study and the lack of observable fish kills would seem to be the only relevant information to gage toxicity.	

Question 21 ***Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
William Stubblefield	As stated on the EPA web site, the BASS model was developed to "predict the population and bioaccumulation dynamics of age-structured fish assemblages exposed to hydrophobic organic pollutants and class B and borderline metals that complex with sulfhydryl groups (e.g., cadmium, copper, lead, mercury, nickel, silver, and zinc)." In the scope of the GKM effort, the BASS model was used to: 1) predict tissue metals concentrations in trout resulting from estimated dissolved metal concentrations in the Animas and San Juan Rivers and 2) using the estimated tissue concentrations predicted from BASS, make an assessment of "short-term impacts" to trout populations by comparing these values to residue-based tissue concentrations reported in the review by Jarvinen and Ankley (1999). However, this approach seems to be somewhat lacking for a number of reasons. First, the BASS model was developed to predict tissue concentrations using a BCF/BAF approach. This assumes that the concentration of a chemical in the tissues of exposed organisms is a function of waterborne (or waterborne and food) concentrations and that the uptake of the material into tissues is a function of exposure concentration. Steady state concentrations are reached when the rate of uptake is equivalent to the rate of elimination. Most, if not all, of the materials that the model has been used with in the past are neutral, lipophilic organic compounds (e.g., DDT, PCB) or organometallic compounds (e.g., methyl-mercury) that follow these kinetics (i.e., concentration dependent kinetics). Metals, on the other hand, do not follow this model. Many metals are "essential" for life processes (e.g., Co, Cu, Zn) and their concentrations in the body are homeostatically controlled to maintain "constant" concentrations necessary for life processes. BCF values are calculated as the quotient of the internal tissue concentrations divided by the exposure concentration. Thus, with a metal when external concentrations are low, the body actively "concentrates" metals to maintain necessary internal concentrations resulting in extremely high BCFs; in situations when metals exposure concentrations are elevated but tissue concentrations are maintained at homeostatic levels, BCFs are low. A recent review by DeForest et al (2007)	

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Reviewer Name	**Reviewer Comment**	**EPA Response**
	states that "Results indicate that field BAFs, like laboratory BCFs, tend to be significantly ($p \leq 0.05$) inversely related to exposure concentration" and "Data presented indicate that for metals and metalloids, unlike organic substances, no one BAF or TTF can be used to express bioaccumulation and/or trophic transfer without consideration of the exposure concentration." McGeer et al (2003) conclude from their review on the topic of BCFs that: • "The accumulation of Zn, Cd, Cu, Pb, Ni, and Ag in aquatic biota were, in general, remarkably consistent, particularly for Zn, where total body/tissue concentration varied little over a wide range of exposure concentrations, exposure conditions, and species. However, mean BCF values for the six metals were characterized by high variability, and there was an inverse relationship between BCF and exposure concentration. Therefore, using the weight of evidence available, it is virtually impossible to derive a meaningful BCF value that one could say is representative of the BCF for each of the metals. Even when BCFs are limited to the exposure range where chronic toxicity might be expected (based on water-quality guidelines), it is not possible to derive a precise and accurate BCF value To correctly assess potential hazards, it would be necessary to distinguish between essential nutritional accumulations, that which is sequestering and stored, and accumulation that causes adverse effects. Because BCFs are based on the whole-body concentration, the BCF model does not distinguish between these different forms of bioaccumulation and therefore it would seem unlikely that the criterion would be correlated to adverse effects such as chronic toxicity." The second major concern with the approach employed stems from the estimation of adverse effects based on tissue concentrations (i.e., based on comparison of tissue residue levels to those reported by Jarvinen and Ankley (1999)). This approached is built upon the Critical Body Residue (CBR) concept. CBR is the concentration of chemical	

Question 21 ***Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	bioaccumulation in an aquatic organism that corresponds to a defined measure of toxicity (e.g., mortality, reproductive impairment). Rainbow, in his 2002 article, *"Trace Metal Concentrations in Aquatic Invertebrates: Why and So What?"* concludes: "Toxicity is related to a threshold concentration of metabolically available metal and not to total accumulated metal concentration." Finally, Adams et al. 2010, concluded that "Available information suggests that it is not possible to develop universally applicable whole-body CBRs for metals (except for Se, methylmercury or other organo metals[sic]). Aquatic organisms differentially handle accumulated metals with respect to storage, detoxification, and excretion. As a result, measuring total metals in an organism provides limited information on the metal concentration associated with the biologically active pool. However, the benefits of monitoring for contaminant trend and exposure assessment are acknowledged." Finally, based on the presentations made it seems clear that the waterborne exposures following the Gold King Mine incident were reasonably short-term in nature (hours not days) and were characterized by an initial spike in concentration that dissipated rapidly returning to pre-spill conditions. Kinetics of such an exposure would suggest that steady-state whole body tissue concentrations would not have been achieved given the duration of the exposure and its variable nature. Initial impacts to organisms would likely have been acute in nature due to the initial pulse exposure. Whole body tissue concentrations would not reflect possible effects to organisms. If the analysis objective of the bioaccumulation and residue-based effects evaluation was to "assess the expected implications of the Gold King Mine release on Animus River biota" it would seem that a more traditional and straightforward approach to evaluating the potential impacts could be achieved by comparing estimated exposure concentrations for individual metals to appropriate state standards or US EPA Ambient Water Quality Criteria.	

Question 21 ***Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?***		
Reviewer Name	**Reviewer Comment**	**EPA Response**
	<u>References:</u> Adams WJ, Blust R, Borgmann U, Brix KV, DeForest DK, Green AS, Meyer JS, McGeer JC, Paquin P, Rainbow PS, Wood CM. 2010. Utility of Tissue Residues for Predicting Effects of Metals on Aquatic Organisms. Integrated Environmental Assessment and Management. 7:75–98. DeForest DK, Brix KV, Adams WJ. 2007. Assessing metal bioaccumulation in aquatic environments: The inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration. Aquatic Toxicology 84:236–246. Jarvinen AW, Ankley GT. 1999. Linkage of effects to tissue residues: Development of a comprehensive database for aquatic organisms exposed to inorganic and organic chemicals.: Society of Environmental Toxicology and Chemistry Pensacola, FL McGeer JC, Brix KV, Skeaff JM, Deforest DK, Brigham SI, Adams WJ, Green A. 2003. Inverse Relationship Between Bioconcentration Factor and Exposure Concentration for Metals: Implications for Hazard Assessment of Metals in the Aquatic Environment. Environmental Toxicology and Chemistry, 22:1017–1037 Rainbow PS. 2002. Trace metal concentrations in aquatic invertebrates: why and so what? Environmental Pollution 120:497–507	

V. INDIVIDUAL PEER REVIEWER COMMENTS

Review By:
Brian S. Caruso, Ph.D., P.E.

Peer Review Comments on EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

Brian S. Caruso, Ph.D., P.E.
U.S. Geological Survey
February 29, 2016

I. GENERAL IMPRESSIONS

I commend EPA for gathering and analyzing all of this data in an attempt to understand the contaminant plume movement in the Animas and San Juan rivers from the Gold King Mine release. It is always challenging to collect and analyze in a consistent way existing data from a wide range of sources and with different levels of QA/QC. EPA has done a relatively good job in a short time frame at a first cut for this fate and transport analysis. However, the accuracy of information presented is questionable due to a number of reasons and assumptions, the clarity of presentation needs improvement, and the soundness of conclusions is also drawn into question based on these issues. One of the main issues is that the goal of the research appears to be too broad and not specific enough to determine if the information and conclusions are adequate. In some cases the goals and objectives are not entirely clear and appear to be somewhat different in various places in the presentation where they are presented.

In general, I believe that EPA should perform this work and prepare the research analysis so that it uses the best science available and presents results as clearly as possible in preparation for a number of issues, including potential lawsuits and Superfund investigations, monitoring plan development, and to inform all stakeholders of what occurred as best as possible. Although many of the conclusions seem generally appropriate based on the analyses performed, the quantification and accuracy of the conclusions are weak due to a great deal of missing information and lack of detailed uncertainty and sensitivity analysis.

Several examples of where the analysis and presentation should be improved include:

- better definition of goals and objectives to reflect critical information needs
- use of EPA national criteria or standards for metals for drinking water and aquatic life as part of an initial screening of risk to select potential contaminants of concern for more detailed analysis and as indicators (instead of primarily evaluating total metals)
- better use of other existing data and information from previous investigations to evaluate and help confirm background (pre-release) levels for comparison
- inclusion of additional data and information for better reactive transport modeling, metals concentration and load calibration, and validation for WASP
- better evaluation and presentation of uncertainty and sensitivity analysis of results should identify data gaps in the analysis and for future modeling

II. RESPONSE TO CHARGE QUESTIONS

Part 1: Overall project and analysis

1. Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?

Some assumptions about data inclusion, formatting, and use were appropriate, some were not, and some were questionable. There appear to be many questions and issues with regard to the analysis methods and assumptions, many of which affect our evaluation of the assumptions about data inclusion, formatting, and use. Important questions and issues include:

- The goals of the fate and transport analysis and modeling are not clear, and in some cases appear to be different in various parts of the presentation materials.
- It appears that the WASP TOXI model for toxicants, including metals, was not used. This module incorporates Kd values for partitioning between dissolved and particulate forms, 1^{st} order decay, and diffusion coefficients, for some reactive transport modeling. Also, why was the WASP add-on, Metals Transformation and Assessment (META4), not used for the fate and transport modeling? This module was developed by EPA and can handle reactive transport in complex acid mine drainage-metals systems with precipitation-dissolution reactions incorporating pH and other important parameters.
- Important or indicator individual metals should be analyzed and presented in more detail. These should probably include at least Cd, Cu, Pb, and Zn. Summary statistics of data should be calculated at time periods along the length of rivers and compared to EPA drinking water and aquatic life hardness-based criteria to evaluate potential contaminants of concern for fate and transport analysis and initial screening for potential risk.
- Why did EPA not use Sondes for continuous monitoring of parameters such as conductivity and pH?
- Why was pH and conductivity not measured in many samples?
- Why were different sampling and analysis methods and detections limits used by different EPA organizations and for different samples?
- Why were other organizations that offered to help with monitoring apparently excluded?

2. Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.

In general the overall integration process of the various analyses at NERL was conducted in a way that provided some meaningful results and conclusions. However, the integration process outside of NERL appears to be a significant barrier to deriving more meaningful results. The lack of consistency in the data between different organizations, data gaps for some important analyses (such as pH and conductivity), and different detection limits and analytes even for the EPA labs, all make the overall integration appear weaker. In addition the apparent lack of integration between ORD NERL, other ORD labs, the regions, and other agencies in terms of response and future monitoring and modeling needs, limits the provision of meaningful results and conclusions. With regard to the presentations, it probably would have been more helpful to present the empirical results before the WASP modeling.

3. Looking at the full project, are there errors or gaps in the integration process that could have affected the overall analyses and/or the conclusions? Please explain.

Please see comment on question 2 above.

4. Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?

The overall conclusions drawn from these analyses generally seem appropriate, but this is somewhat difficult to determine due to the lack of clarity in the goals and objectives of the research. In addition, the conclusions are not entirely scientifically defensible based on the analysis. The primary reasons for this are generally discussed in the overall impressions above and include:

- lack of clarity of goals and objectives to reflect critical information needs
- lack of use EPA national criteria or standards for metals for drinking water and aquatic life as an initial screening of risk to select potential contaminants of concern for more detailed analysis and as indicators (instead of primarily evaluating total metals)
- inadequate use of other existing data and information from previous investigations to evaluate and help confirm background levels for comparison
- lack of inclusion of additional data and information for better reactive transport modeling, concentration and load calibration, and validation for WASP
- very limited evaluation and presentation of uncertainty and sensitivity analysis of results
- lack of identification of data gaps in the analysis and for future modeling

<u>Part 2: Fate and transport</u>

5. Does the research appropriately characterize the metals concentrations and load produced at the Gold King Mine spill?

The research makes an attempt to characterize the metals concentrations and loads produced at the Gold King Mine spill. However, it is extremely surprising and unfortunate that EPA collected no samples from the release itself until what appears to be a substantial time period after the release. In addition, no samples were collected at the mouth of Cement Creek (CC) until about 4 hours after the release and after the release/plume had passed. The volume of the release was estimated by the USGS based on the change in the hydrograph at the CC mouth. Four samples were collected at the adit release up to about September 23, 2015. It was not made clear when the first sample at the adit was collected, but appears to be at least many hours to a day after the release. One of these samples collected by EPA was selected to characterize the release and use in subsequent calculations and modeling. It was stated that this was selected because it was the most comprehensive analysis. However, it is not known or made clear why the other samples were not analyzed the same way. The samples are presented on a log graph for most metals, so the variability of the results is not entirely clear. The variability and uncertainty of these adit release results should be analyzed and presented in more detail, and perhaps a mean or median over this time period should be used instead of just one sample. Also, it is not clear if any other samples from inside the adit itself, or from the ongoing drainage, had been collected and analyzed previously, prior to the release. If so, these should be compared to what was observed in the release.

6. The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?

There was a reasonable attempt made to estimate metals concentrations at this location (adit and or CC?) using scientifically sound methods based on available data. As stated above, however, there appears to be many questions and issues with regard to the analysis methods and assumptions.

At the adit release, estimated concentrations and loads were only based on one sample, whereas the summary statistics, variability, and uncertainty of the four samples collected over the month and half after the release should have been better presented and perhaps used in the analysis. Downstream at the CC mouth, an attempt was made to back calculate the concentrations and loads during the peak flow, and to account for dissolved and particulate metals scoured from CC by the passing flood wave. It is not clear how WASP was used to calculate the Maximum Total Concentration to aid with this. This appears to be done outside of WASP as input to the model as a simple mass balance using the estimated release concentrations, estimated background upstream CC concentrations and flow, and downstream measured flow. This mass balance approach seems to be appropriate. However, the analysis is not clear and background concentrations in CC appear to have been based on post-plume concentrations at the mouth, even though there are many pre-release sample and analysis data available for CC. These previous data could have, and probably should have been used, or at least collected and compared to the background estimates used.
The explanation of how the plume concentrations were re-constructed at the CC mouth is not entirely clear. It is not clear whether the PHREEQ modeling was needed, or what value the WASP modeled concentrations are considering; these are estimates based on conservative constituents with no reactive transport.

7. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?

This comment relates to both questions 7 and 8 since they are related. The intent of this question is not clear. Is the intent of this for the post-plume period for all rivers, or just for the post-plume period in CC and during the plume in the Animas and San Juan rivers? Post-plume is important for later or ongoing resuspension or dissolution of metals to the water column during higher flows. Of course during the plume is also important for a number of reasons. Does 'sediment' refer to bed sediment or particulates (or colloids) in the water column? We assume this refers to bed sediment.

The methods used for estimating sediment metal concentrations are not clear. Although the methods used for estimating the dissolved and sediment/particulate metals load from CC during the release generally seem appropriate based on the mass balance approach, there appear to be a number of concerning issues. Any previous data from other studies on bed sediments in CC are not presented or used. These could include sediment physical characteristics (particle sizes) and sediment chemistry and metals concentrations. Similarly, any previous background metals concentrations in water are not presented. A significant amount of previous studies by USGS and others in CC and the Animas have been performed with these types of data. It appears that with the exception of sediment data collected by an academic researcher (Dr. Williams?), EPA collected no sediment samples or data during or after the plume to help evaluate sediment metal concentration estimates or calibrate the WASP modeling.

It appears that sediment (bed) metals concentrations were not estimated except for those estimated with the WASP model. There are issues with these estimates, as discussed in comments below.

8. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the San Juan River after receiving mine contaminated water from the Animas River?

Please see comment on question 7 above.

<u>Part 3: Geochemistry</u>

9. Were the geochemical principles to characterize transport and fate of acid mine drainage appropriately applied and interpreted? Please explain.

No comment on this question as this topic is outside of my area of expertise.

10. Were precipitation and mineral saturation analyses of the acid mine drainage appropriately applied for interpreting metals fate in the river system? Please explain.

No comment on this question as this topic is outside of my area of expertise.

11. Was the neutralization of acid mine drainage and subsequent fate of dissolved and colloidal/particulate metals appropriately interpreted? Why or why not?

No comment on this question as this topic is outside of my area of expertise.

Part 4: Water Quality Analysis Simulation (WASP) modeling

12. Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.

The methods and results for the WASP modeling were unclear and it appears that a number of common and well-accepted modeling practices were not used, with no clear or acceptable explanation of why. Although I understand that there is a lack of data in some areas and that some time constraints contributed to the approach used, I feel that the problem is important enough that the best modeling approach possible should be used to derive the most accurate and useful results possible.

Primary comments and issues are itemized below:

- Although the primary goal of the modeling was presented, this goal is very general and vague, which leads to a great deal of generality and uncertainty in the model results.
- The segmentation and structure of the model for surface water and sediment segments were briefly discussed, but these should be clearly presented in a map or schematic.
- Although the modeled discharge was calibrated to the flow measured at the USGS gages, there was no attempt to include or model major tributary inputs to, or irrigation or other takes from, the main stem of the rivers. These should have been included. It is also not clear whether and why both Geometry equations and Manning's Equation using roughness and slope were used to estimate flow parameters such as velocities.
- There appears to have been no attempt to calibrate or validate the modeled concentrations or loads. This is standard practice and there appears to have been adequate data collected during and immediately after the release to at least calibrate the model, so this should have bene done.
- It is not clear why the TOXI module of WASP, for some reactive transport of toxicants including metals, was not used. This module includes Kd for partitioning between dissolved and particulate forms, first order decay, and a diffusion coefficient. Why were only total metals modeled, whereas both dissolved and total (or particulate) could have (and probably should have) been simulated. Although WASP cannot model equilibrium precipitation-dissolution reactions based on pH and other parameters like some other models (META4 and OTEQ), it can incorporate Kd values and diffusion coefficients to simulate adsorption and partitioning between the dissolved and solid or particulate phases with suspended sediment in the water column and with bed sediments. It appears that this should have been done.
- Also, why was the WASP add-on, Metals Transformation and Assessment (META4), not used for the fate and transport modeling? This module was developed by EPA and can handle reactive transport in complex acid mine drainage-metals systems with precipitation-dissolution reactions incorporating pH and other important parameters.
- It is not clear why Scenario 1 was used. Although this scenario could provide a very conservative estimate and upper bound on transport estimates, this scenario may not be conservative if scour of metals in sediment is important, and it is too simplistic and not realistic.

- It is not clear what initial and boundary conditions were used for metals and sediment (Total Suspended Solids) concentrations and loads. For concentrations it appears that post-plume metals concentrations were used, whereas previous pre-release data are available and perhaps should have been used.
- Although sediment/particulate settling and resuspension was included in Scenario 2, it is not clear why there was no attempt to use any existing information on surface (bed) sediment metals concentrations for model input or calibration. Some of these data may have been available from previous studies to use as model input, and from data collection afterwards for calibration.
- In addition, there was no evaluation of sediment particle sizes from any previous data for modeling of settling and resuspension based on velocity and shear stress. It is not clear why the larger shear stresses in Scenarios 2b-2 and 2b-3 were selected and what kind of particle sizes these may relate to.
- For Scenario 3 for Long-term Effects, it is not clear why Nov 2010 – Dec 2011 was selected, what the magnitudes of the high flows modeled were, and how representative they are of high flows in these rivers.

Using the model to estimate plume movement is good, but using Scenario 1 (due to reasons stated above) and qualitatively matching modeled to observed concentrations visually are very questionable. Why were no standard objective functions (such as Nash Sutcliffe or correlation coefficients) used? This is standard practice.

13. Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.

This comment addresses both question 13 and 14 below, since they are related. It is not entirely clear how the application of assumptions and values in WASP modeling addressed particle transport and deposition of the acid mine drainage constituents. As stated above, although sediment/particulate settling and resuspension was included in Scenario 2, it is not clear why there was no attempt to use any existing information on surface (bed) sediment metals concentrations for model input or calibration. Some of these data may have been available from previous studies to use as model input, and from data collection afterwards for calibration. In addition, there was no evaluation of sediment particle sizes from any previous data for modeling of settling and resuspension based on velocity and shear stress. It is not clear why the larger shear stresses in Scenarios 2b-2 and 2b-3 were selected and what kind of particle sizes these may relate to.

It is not clear exactly what the settling results (slides 25-28) of the WASP presentation are showing or how they were computed. There appears to be total metals concentrations in the water column, and a certain fraction of this mass settles out into the sediment, creating total metals concentrations in the surface sediments, a certain faction of which can be re-suspended under high flows. But these are presented in units of mg/L instead of mg/kg, which is typical for metals in sediment. Typically you would have particulate metals in the water column which can settle out. In addition, as stated above there appears to be no initial metals concentrations or mass in the surface sediments as an initial condition, although in some locations there should be some of this type of data from previous studies. It is also not clear if there was any initial suspended sediment loads or concentrations in the water column as part of initial conditions.

14. Did the WASP modeling appropriately investigate the remobilization of metals during increased flow? Why or why not?

Please see comment on question 13 above.

Part 5: Groundwater modeling

15. Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?

No comment on this question as this topic is outside of my area of expertise.

16. Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.

No comment on this question as this topic is outside of my area of expertise.

17. Were the assumptions informing the capture zone and particle tracking analysis appropriate for the intended use? How so?

No comment on this question as this topic is outside of my area of expertise.

18. Did the method for calibration of the local scale groundwater flow model performance to the observed drawdown reported in the driller's log serve as an effective method? Please explain.

No comment on this question as this topic is outside of my area of expertise.

Part 6: Atlas modeling

19. Are the sources of the data included in the maps valid, complete, and adequately documented? Are there any points of confusion, gaps, or suggestions for improvement?

It seems as though the purpose of the Atlas modeling, and Atlas itself, were only briefly described in one slide. The purpose of the modeling and data sources were not entirely clear. For example, how do the data sources used in Atlas differ from those in any other publicly available national geospatial databases, such as USGS databases including their 'National Map'? Or do they use some of the same data sources? This all needs more explanation.

20. Do all of the maps and charts communicate the analysis methods and results in such a way as to be readily understood by stakeholders with interest in the impacts of the Gold King Mine spill (e.g., First Nations; NGO's; news media; and State water, recreation, public health, and wildlife managers)? Are there points of confusion, gaps or suggestions for improvement?

No. The maps and charts for the Atlas modeling need more explanation as to their purpose and what the results are attempting to show and what they are actually showing. The usefulness of these maps is not yet clear.

Part 7: Bioaccumulation

21. Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?

No comment on this question as this topic is outside of my area of expertise.

Review by:
Charles R. Fitts, Ph.D.

Peer Review Comments of
EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

Charles R. Fitts, Ph.D.
Fitts Geosolutions, LLC
February 29, 2016

I. GENERAL IMPRESSIONS

It is hard to summarize since there are so many facets of these studies. The soundness of conclusions is discussed under question 4 below. There are many details that need attention, and many of these are just a matter of editing, polishing and fleshing out with more text and detail, which is to be expected in a more final draft. I felt that the overview and empirical analysis sections were generally logical and needed minor work. I have few comments on the geochemical and bioaccumulation portions since I have less background in those areas. The WASP presentation could use a good deal of clarification about the analyses and more caveats about the uncertainties involved and how the results may be used. For example, the deposition/suspension analysis of WASP slides 25-27 seems to be quite uncertain and should be viewed skeptically since the deposition/suspension input parameters do not square with published ranges. In most cases, the WhAEM modeling was sufficient to characterize whether a well likely pulls in some river water, but the modeling approach was not sophisticated enough to predict accurately what fraction of a well's flow came from the river and what the plume breakthrough curve might look like in well concentrations. More sophisticated 3D and localized models could be constructed to improve predictions, but the Key Analysis Question (Groundwater slide 2) may not require such detail for most of the wells.

II. RESPONSE TO CHARGE QUESTIONS

Part 1: Overall project and analysis

1. Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?

There was some discussion about other possible sources of data from academics and other organizations. If there exist other data particularly at an earlier time near the GKM or Cement Creek, it would be helpful to get that data and include it in the analysis, since it would reduce the uncertainty about the source concentrations and mass.

2. Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.

I understand that there has been a pressing timeline for pulling these studies together and that we are looking at first drafts, which I think is the proper stage for having a review that allows time for revision. I expect more effort will go into integration, peer editing, and polishing, which the entire study could benefit from.

It would help to expand the overview section so that it explains clearly how each of these parts contribute to achieving the project's goals and describes to what extent each part depends on results from other parts. For example, the same analysis of source mass shows up in both the empirical and WASP sections.

Some portions of the work could benefit from additional review and input by additional experts within EPA. Although I am not expert in this area, it seemed that the bioaccumulation study could use such review, as the reviewers indicated that it may need to consider alternate methods that are not based on factors that assume a ratio of river concentration to tissue concentration.

3. Looking at the full project, are there errors or gaps in the integration process that could have affected the overall analyses and/or the conclusions? Please explain.

Since the study focused mostly on total metal concentrations, it is possible that it overlooked behaviors of specific species of metals that would be important in subsequent risk assessments and monitoring plans. I also mention this in the fate and transport section, and suggest analyzing the fate and transport of a few metals that are likely to pose risk and may be representative of groups of similar metals.

Most of the concentration data we saw in the presentations was from water samples. However, slides 6 and 20 of the overview alluded to over 320 bed sediment samples. Presentation of the sediment data was limited, so if there is more to that story, perhaps more should be presented.

4. Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?

I think the conclusions presented in overview slide 25 are generally sound and on-target. It think that the 4th bullet point about most of the metals being deposited in the Animas streambed could be more specific. The presentation could point out the specific stretches of the Animas River that received the greatest mass of deposition (RK 13-16 and RK 64-96, as discussed in question 7). There is no bullet point about the impact on wells located near the river. I think there should be an additional point made about the potential for impact in wells close enough to the river, but that sampling data showed only well 35m66km with a noticeable plume signal, which was at levels that did not pose any significant risk.

<u>Part 2: Fate and transport</u>

5. Does the research appropriately characterize the metals concentrations and load produced at the Gold King Mine spill?

The data were mostly presented as total metals and did an adequate job of portraying the distribution of total metals. The presentation seldom presented data on subgroups of metals or individual metals. It might be instructive to look at empirical data for a few individual metals of interest, selected because of their importance in terms of risk and their characteristic behavior representative of a group of similar metals (e.g. one metal that precipitates at a low pH range and another that precipitates at a higher pH range). Since subsequent studies will be examining risk and monitoring plans that aim to minimize risk, the metals chosen for individual analysis should include ones that are most likely to pose risk.

6. The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?

The calculations that lead to the "estimated peak" concentrations shown in the bar chart of empirical slide 20, the WASP and Empirical concentrations in slide 27, and "Simulated Load" in WASP slide 13 needs to be explained in more detail. This is critical since the extrapolation needed at early times strongly affects the estimated total load in the plume. In the following table, I analyzed total concentrations (Ct) vs. discharge (Q) for the early time observations and the early time simulated concentrations in Silverton.

Time	Q (cms)	Ct simulated (mg/L)	Ct observed (mg/L)	Ratio Ct simul./Q (mg/L/cms)	Ratio Ct observ./Q (mg/L/cms)	Source
12:45	3.5	37000		10571		WASP slide 13 (W13)
12:45	3.5	29557		8444		Empirical slide 20
16:00	1.1	10500	11485	9545	10441	W13
19:25	0.1	3000	998	30000	9980	W13

It makes sense that higher stream discharge and velocity would correlate to higher suspended sediment load and higher total concentration. Based on observations, it appears that the ratio Ct/Q was about 10,000 at the earliest observations (blue). Lacking other evidence, this ratio may be reasonably applied to earlier times, but there is uncertainty in this extrapolation that should be acknowledged in the report. The simulated ratio Ct/Q was about 10,000 for both the 12:45 and 16:00 Ct estimates (purple), but about 30,000 for the 19:25 Ct estimate (red). It seems reasonable to keep the 10,000 ratio to estimate the early time concentrations, which is close to what was done. I think the bullet item on WASP slide 13 should read "Assume total concentration (Ct) is proportional to flow." Also the 12:45 and early time Ct numbers should be made consistent across the study and consistent with the explanation for how the early concentrations were extrapolated.

Looking at the graph in WASP slide 13 and the 19:25 row in the above table, the simulated concentrations from about 18:00 onward are systematically higher than observed, and they are noisy, bouncing up and down as though the simulated concentrations could only move in large quantum leaps. This portion of the simulated Ct should be modified to remove the noise and to better match observed Ct, even if the impact on simulation results downstream is minor.

Since the source mass is critical to all analyses, this deserves attention. If other concentration data becomes available from other sources for the early hours in Cement Creek or GKM, it should be incorporated in revised source estimates.

7. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?

The presentation about measured sediment concentrations was brief: slides 44-48 of the empirical section. There are inherent difficulties in distinguishing plume-event sediment from other sediment, and in concentration variations with sample location. Therefore, it may be difficult to conclude much from sediment concentration data. There did appear to be declining trends in sediment concentrations after the plume passed the lower Animas (lower two graphs of empirical slide 47). There were WASP simulations that indicated where sediments from this event were likely to have deposited (WASP slides 25-27), but as I say elsewhere, these WASP results should be viewed as qualitative, not quantitative.

A better approach to estimating where plume sediment was deposited would be to examine time-series of total metal concentrations at gages along the Animas River. Estimate the total mass of metals passing a point in the river by numerically integrating Ct*Q data through time, like appears to be shown in slides 30, 34, 35, and 44 of the empirical presentation. Mass changes from one station to the next one downstream could be due to deposition or mass added or subtracted at tributaries or diversions. From the graph in the lower right of slide 44, it appears that most metals deposited just below Silverton (~RK 13-16) and above Durango (~RK 64-96). This empirical approach to estimating deposition trends has a much stronger basis than the deposition results shown in WASP slides 25-27. This analysis should be expanded and highlighted in the empirical presentation and overview, and the WASP analysis section should compare its results to the empirical analysis estimates of deposition.

The relatively flat stretch of the Animas River below the confluence with Cement Creek (~RK 13-16) is an area where a significant fraction of plume suspended sediment probably was deposited. Average plume flow velocity would have dropped dramatically beyond the confluence due to the gentler gradient and wider channel, and the abrupt increase in pH would have promoted precipitation and sorption. This stretch of the Animas has alternating riffles and pools

and the larger pools would have been particularly ripe for deposition. The image below shows one >100m pool in the Animas channel in this area.

The WASP modeling was too large-scale and homogenized to capture the local differences in velocity between riffles and pools. WASP slides 25-27 indicated minor deposition in this area, but empirical slide 44 indicates deposition of about 40% of the metals mass from Cement Creek in this stretch. I suspect significant plume mass was deposited in these pools and some will move downstream during subsequent high-discharge events.

Note: a typo in empirical slide 38: 2^{nd} line should say "High acidity" or "Low pH".

In empirical slide 39, explain what blue dots are in lower right plot.

The graphs in empirical slide 48 need axis labels and a better explanation.

In empirical slide 50, it would provide helpful perspective to show estimated total metal transport during a typical spring runoff season, in addition to the estimates for the late August storm.

8. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the San Juan River after receiving mine contaminated water from the Animas River?

I assume the question refers to the San Juan River, not Cement Creek. By the time the plume reached the San Juan River, the muted plume signal was hard to detect and sediment concentrations in the San Juan did not show a discernable plume signal. The data presented on this subject was brief (empirical slide 46). Hopefully the accompanying text, when written, will clearly explain the origin of the data and conclusions drawn from this slide.

Part 3: Geochemistry

9. Were the geochemical principles to characterize transport and fate of acid mine drainage appropriately applied and interpreted? Please explain.

I am less of an expert in geochemistry, so my comments in this section are limited. I found the discussion of the American tunnel plugging and rising groundwater levels (slide 17) quite interesting from a hydraulics and geotechnical standpoint. I suspect that even if EPA had not done earthwork near the GKM entrance, the plug of loose fill at the GKM entrance may have eventually failed by internal erosion (piping) in a manner similar to what occurred on 5 August 2015. As heads inside the mine rose, the hydraulic gradient across the plug increased. Excavating activities also increased the gradient across the plug, but it is quite possible that even without that activity, the increasing gradient could have eventually triggered a piping failure and a sudden release of water stored behind the plug.

10. Were precipitation and mineral saturation analyses of the acid mine drainage appropriately applied for interpreting metals fate in the river system? Please explain.

No comment on this question as this topic is outside of my area of expertise.

11. Was the neutralization of acid mine drainage and subsequent fate of dissolved and colloidal/particulate metals appropriately interpreted? Why or why not?

No comment on this question as this topic is outside of my area of expertise.

<u>Part 4: Water Quality Analysis Simulation (WASP) modeling</u>

12. Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.

Overall, the WASP modeling seemed to show that the program could be made to simulate migration and dispersion of the plume in the river that is fairly consistent with observations of the plume's passage. It appeared to be useful for simulating the approximate dilution and dispersion of contaminants, but I felt less comfortable with the analysis of deposition/resuspension since required erosion/deposition parameters were far outside of published ranges.

It was not clear to me how the equations for velocity, depth, width (slide 9) and Manning's equation (slide 12) were applied. Our 25 Feb phone call helped clear this up for me, but that section could use clearer explanations about how Q and V as a function of (t, river distance) were calculated. If the velocity equation on slide 9 was not used, as Chris mentioned in our phone call, that equation should be eliminated. Also, there are corrections as noted in our discussion: the constants "a" and "b" in slide 9 equations are duplicated but should not have been, and the graph on that page needs axis labels.

It appears that Q was assumed constant from one gage down to the next gage, where the Q abruptly jumps up or down. It seems to me that it would be better to assume a more gradual transition of Q from one gage to the next, because the abrupt jumps in Q ripple through the calculations to cause abrupt jumps in concentrations. If you know where larger tributaries join, you could improve the assumed distribution of Q between gages using that knowledge. I understand from our phone call that WASP is limited to 50 such discharge changes, which is many more than were used in this simulation. So more, smaller jumps in Q could be incorporated into the model to give smoother, less distracting results.

Unless I am mistaken, the comparison shown on slide 11 means little, since the model input was constrained to match Q at gages, and all this slide shows is that the constraint worked as expected for a spring hydrograph record.

In slide 12 the discrepancies are not large, but they are systematic – modeled velocities are consistently high. The deviation should be explained, and the need for unusually high Manning coefficients should also be discussed and rationalized.

Note these typos in slides 15 and 16: the mass flux between the segments n and n+1 should be "QnCn".

Numerical dispersion is noted in slide 15. If it is possible to quantify that and compare it to simulated dispersion, that would be helpful.

Slide 23 shows two graphs that appear to show the same data. If there is a need for two graphs, explain what they show and how they differ. If there are time-series observed concentrations, they should be shown on these graphs for comparison.

In slide 41, it would help to color code the sample dots to indicate how close the measurement was to the passage of the peak plume (e.g. red for within 1 hour of peak, orange for 1-2 hours before or after peak, and so on).

Slide 42 should show lines of relevant criteria other than recreation, such as for aquatic life and drinking.

13. Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.

The estimation of the GKM release load (WASP slide 13) is discussed in question 6 above.

The WASP model simulated only the metals loads in the discharge of Cement Creek where it joins the Animas. It assumed zero metals loads in the Animas above Cement Creek and in the San Juan above the Animas. It would make for more meaningful comparisons with observations (e.g. slide 22) if estimated loads from the San Juan and upper Animas were added to the model. Adding these inputs may also impact the simulations of settling and resuspension. I imagine that reasonable estimates of the upper Animas and San Juan loads could be made from longer-term monitoring data.

In slide 2 (and 28), the 3rd item says "…upon entering Cement Creek", but I think that should be "…where Cement Creek enters the Animas River." The last item on these slides should start with "Simulations indicated that high flow periods…" to clarify that this is a simulation result, not a measured result.

The simulations of sediment deposition and subsequent re-suspension indicated that a likely stretch of river to receive such deposition was from about 65km to about 95 km (WASP slides 25-27). However, the 2b-2 simulation used erosion/deposition critical shear stress thresholds that were far outside expected ranges, thus the results should be viewed only as qualitative. There should be a discussion explaining possible factors that required such large thresholds, and the degree to which these factors render the results useful or not.

One problem with the WASP modeling of erosion/deposition is that it must treat long stretches of river as homogeneous with respect to velocity, which is far different than the actual riffle and pool nature of the Animas River where it occupies an alluvial plain. This point is also discussed in question 7. In think plume sediment settled out in the calmer pools to a greater degree than what the WASP model would predict for homogeneous segments. This may, in part, explain why atypical erosion/deposition parameters were required to make the simulation match observations.

14. Did the WASP modeling appropriately investigate the remobilization of metals during increased flow? Why or why not?

Since the mechanisms for erosion/deposition in the model were using critical shear stress thresholds that are well outside normal ranges, these results must be viewed with skepticism. Like I said in the previous comment, this makes quantifying concentrations very uncertain and this analysis should probably be viewed as an example of how downstream concentrations could respond during a high flow period, not a prediction of how they will likely respond. That distinction should be made clear in the text.

On slide 27, label that these are scenario 2b-2 results, and correct the title of the lower graph so it says "Movement of Total Metals…" The resuspension scenario needs to be outlined clearly. What is the assumed event? Is it a hydrograph from a typical spring runoff period, a shorter duration storm event, or something else?

Part 5: Groundwater modeling

15. Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?

I think the analysis is sufficient to conclude that certain wells farther from the river were not susceptible to drawing river water (wells 575m71km, 650m71km, 1000m70km), and that certain wells close to the river likely do draw in river water (well 35m66km and the 5 NM wells). The analysis of well 75m71km was a closer call, and for that well a more sophisticated analysis could shed better light on the extent to which it draws in river water. The analysis conservatively estimates whether wells have potential for drawing river water. By *conservatively* I mean that the potential for drawing river water and the fraction of water drawn from the river is probably overestimated by the WhAEM models. This is discussed in more detail under question 16.

16. Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.

As stated above, the potential for communication between well and river is probably overstated in the WhAEM model results. The main reason is that the models are two-dimensional, not three dimensional. The models neglect the resistance to vertical flow and only account for resistance to horizontal flow. The models treat the river boundary condition as a fully-penetrating vertical curtain of specified head extending from the surface to the bottom of the aquifer. In reality, the river bed is a nearly horizontal constant head boundary atop the aquifer, and the well screen elevations are unknown but probably in the lower portion of the aquifer. For wells closer to the river, vertical resistance is a significant part of the total resistance to flow between the river bank and the well screen. Vertical resistance is even greater in stratified sediments where the vertical hydraulic conductivity (Kv) is much smaller than the horizontal hydraulic conductivity (Kh). For example, consider well 35m66km which is 35 meters from the river (horizontal) with a well screen that is about 25 meters below river. If Kh/Kv = 10 (ratios of 5 to 50 are common), the vertical distance in an equivalent isotropic medium would be about 80 m vertical distance (scale the vertical axis by the square root of Kh/Kv to make an equivalent isotropic medium). In this case, the vertical resistance between river and well screen would likely be greater than the horizontal resistance. Neglecting the vertical resistance in the WhAEM models overestimated the communication between well and river, and underestimated the travel time for flow from river to well.

The models presented are very large scale and may be omitting some important features closer to the wells. The alluvial plain has irrigation ditches, old braids, and other surface water features that likely connect to the underlying aquifer. Just NE of well 75m71km there is an old swampy braid that still contains water and had visible discharge into the Animas River (see close-up of Google Map image). Also, there is a braid (Coon Creek) about 1200 ft E of well 35m66km.

The inclusion of vast areas of rock in the far-field of this model seems unnecessary and although the model calibration process took care of critical inputs near the well fields, the largely unknown inputs for the rock and far-field may draw distracting scrutiny. I did not hear of a sound basis for these inputs:

- horizontal K of the rock = $1/100^{th}$ the horizontal K of alluvium
- calling the rock unconfined with a horizontal base so its saturated thickness grows from around 30 meters near the alluvial aquifer to over several hundred meters to the NW (slide 15)
- The no-flow boundary around the whole modeled area
- The specified head boundaries to the N and W near the model limits
- Zero overland flow from the steep rock areas added to the margins of the alluvium

These poorly-grounded inputs could be avoided by using local scale models of just the alluvial aquifer, one model for each cluster of wells. The outermost boundary conditions could be established as specified-head boundaries where heads of surface waters or wells are known up-gradient in the alluvium, and by no-flow boundaries along estimated flow lines.

Slide 4 shows numerous other wells in the alluvial plain. The domestic well discharges are not likely to be large enough to have much effect, especially since most of their discharge returns to the subsurface in leaching fields. Irrigation wells, on the other hand, could have significant discharges, and some of these are close to municipal wells.

Slides 8 and 9 discuss groundwater inflows into the Animas River. The slides and the notes that were distributed did not explain how this information was incorporated into the model. Were the modeled groundwater discharges to the Animas calibrated to values from these analyses? This should be explained in the text.

I'm not sure the analysis of slide 12 is relevant – that applies to cyclic recharge, and recharge was not included in these models. I have no objection to omitting recharge, since at the scale of these well-river distances in late summer, lateral aquifer flows probably far outweigh recharge flows. I also think that a steady-state analysis is warranted given the limited data, roughly continuous use of municipal wells, and the close proximity of key wells to the river.

The 2D models presented are capable of only crudely estimating the fraction of flow that is river water and the timing of river water arrival at the wells. If there is a great need to quantify simulated concentration vs. time at a well, a more accurate approach would be to construct a more localized 3D model that includes all the closer hydrologic boundaries in the alluvial plain. A 3D flow model with enough vertical discretization to capture the resistance between the river bed and the well screen could be created with MODFLOW, AnAqSim, or any number of other 3D groundwater flow codes. This could be done at one or a few of the wells to quantify the impacts of the 2D assumption.

17. Were the assumptions informing the capture zone and particle tracking analysis appropriate for the intended use? How so?

As noted under question 16 above, these 2D simulations probably overestimate the fraction of well discharge coming from the river, and probably underestimate the travel time a conservative tracer takes from river to well.

The assumed porosity of 0.20 is probably low for these sediments. Such values are common in poorly sorted (widely graded) unconsolidated materials like glacial till, but for alluvial sands and gravels $0.25 < n < 0.35$ is a more common range. The impact of using a higher porosity in the simulations would be slower velocities and increased travel times between river and well.

The graphs in slides 25 and 26 would be much more striking with an arithmetic, not logarithmic Y-axis.

The presentation did not show models of the RK 171 or RK 179 wells in NM, so it is not possible to comment on those analyses and their conclusions. I assume the final report will provide details on those.

18. Did the method for calibration of the local scale groundwater flow model performance to the observed drawdown reported in the driller's log serve as an effective method? Please explain.

The key factors in estimating the fraction of well discharge from the river are aquifer transmissivity (T), ambient hydraulic gradients, well discharge (Q), and well location relative to the river. The models based input T and Q values on yield test data and river/well locations on maps, which are reasonable approaches. The estimation of ambient gradients was probably the greatest source of uncertainty. Using the USGS well near well near RK 70 was helpful for constraining modeled gradients in that area. However, there are other data that could help constrain the modeled gradients elsewhere. The available aerial images and maps should be examined to determine the location and elevations of other surface waters in the vicinity of the simulated municipal wells. The modeled background gradients should be consistent with observed features, and some surface waters may need to be included as boundary conditions. For example, modeled heads should not be well above ground surface or above surface water elevations, and surface water elevations should not be far above simulated heads. This would be easier to do with smaller, local-scale models.

There is uncertainty in many model input parameters (e.g. T distribution, saturated thickness of the aquifer, well screen elevations, vertical conductivities), so a more thorough approach would be to run a suite of simulations (realizations) that investigate the range of possible input variations. However, if the aim of the modeling is to only determine which municipal wells have a chance of pumping a significant amount of river water, the WhAEM simulations with just a single realization probably suffice to draw the broad conclusions shown in the first two "Model Results" columns in the table on slide 28, except in the case of well 75m-71km, which was a close call and could use a more sophisticated analysis to draw conclusions.

Part 6: Atlas modeling

19. Are the sources of the data included in the maps valid, complete, and adequately documented? Are there any points of confusion, gaps, or suggestions for improvement?

I understand that in this section we are to comment on the animations that were presented. I can't comment on whether data sources were valid or complete, since only limited information was included on the animation slides. I think the slides were reasonably labeled and clear about what they were presenting. I found both animations to be quite helpful to visualize the plume's migration and dispersion, and to visualize the spatial variability of concentration data and the response of the system to localized precipitation events. I'm sure these animations would be even more useful to a lay person than a scientist with more background.

20. Do all of the maps and charts communicate the analysis methods and results in such a way as to be readily understood by stakeholders with interest in the impacts of the Gold King Mine spill (e.g., First Nations; NGO's; news media; and State water, recreation, public health, and wildlife managers)? Are there points of confusion, gaps or suggestions for improvement?

As noted throughout my comments, there is a need for editing, clarifying, and polishing. We were reviewing early draft figures and tables without the benefit of much additional text. The final report will have much more text to qualify and explain the tables and figures, which will be a big help.

Part 7: Bioaccumulation

21. Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?

I am not an expert in this area, but from what I understood of the discussion, it seems that the partitioning coefficient approach that was used in this section may not be appropriate for metals that have highly regulated concentrations within organisms.

Review by:
Henk M. Haitjema, Ph.D.

Peer Review Comments on
EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

Henk M. Haitjema, Ph.D.
Haitjema Consulting, Inc.
February 28, 2016

I. GENERAL IMPRESSIONS

The overall goal of the research has been the topic of some mild confusion by me (and the group at large). The agency stressed that the current research does not constitute a formal risk assessment nor was it designed as such. However, the precise purpose of the research has not been articulated very clearly. I must assume that in the end the research presented is to be used as the basis for some form of risk assessment and, if needed, remedial action. As such I have been evaluating the research presented with this ultimate goal in mind.

Overall the work was well presented although the complexity of some issues and the necessary brevity of the presentations resulted in many interruptions of the presentations with questions or requests for clarifications by the reviewers. While I understand that the EPA researchers could only work with publically available data, it was observed by several reviewers that some important historic (background) data were missing, but might have been acquired from public sources (e.g. the USGS).

Most conclusions seemed reasonable, taken into account the limited data and the basic nature of these initial studies. However, in several cases the data uncertainty could have been better alleviated with some sensitivity analyses and by presenting bracketing solutions showing both most favorable and most unfavorable (worst case) scenarios.

Finally, I have the impression that communication between different branches of EPA is less than optimal. On several occasions the quality of the studies suffered as a result. For example, the lack of coordination between the various sampling efforts and the lack of information about the sampling and quality assurance protocols cast some doubt on data integrity, hampers data comparisons, and may have resulted in unnecessary data gaps.

II. RESPONSE TO CHARGE QUESTIONS

<u>Part 1: Overall project and analysis</u>

1. Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?

In some cases data sources and limitations were not fully explained and required reviewer inquiries. While in most cases an appropriate attempt was made to overcome data scarcity and uncertainty by offering conservative (worst case) scenarios, these were not always well explained.

2. Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.

There were some limited connections between the presentations, particularly between the presentation "Empirical Analysis of Metal Loads & Water Quality Trends Based on Observed Data" by Dr. Kate Sullivan and Dr. Mike Cyterski and the WASP modeling. However, there was no clear overarching structure in which the various presentations had a clear place. Consequently, the results and conclusions from the individual studies could not easily be related to each other. That said, I recognize that this review was conducted before all studies were fully completed and documented (written up in a report) and as a result the integration could not yet have happened. I believe that the timing of this review, prior to producing a final document, is very beneficial for an optimal impact of the review process. Thus the lack of integration observed is not to be interpreted as a critique on this research effort!

3. Looking at the full project, are there errors or gaps in the integration process that could have affected the overall analyses and/or the conclusions? Please explain.

While the "Overview" presentation offered a "Summary of Findings" (slide 25) that I found relevant and important, there was no overarching presentation that put the various studies together to substantiate these final conclusions. What is needed in addition to the work presented to the reviewer is a document with a clear statement of purpose and explanation of the motivations for the various studies. That same document then must also have a concluding section in which these studies are referenced, and the conclusions integrated into an overall set of conclusions and, where appropriate, recommendations. I did not observe fundamental flaws in the studies that negatively affected the conclusions presented.

4. Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?

I believe they were, but as outlined in my response to various questions below, additional work and better documentation are needed.

<u>Part 2: Fate and transport</u>

5. Does the research appropriately characterize the metals concentrations and load produced at the Gold King Mine spill?

As explained below the total metals load leaving Cement Creek were probably underestimated. However, this was recognized in the analyses presented to the reviewers and could not have been avoided in lieu of the lack of more pertinent sampling (sampling of the peak of the plume in Cement Creek).

6. The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?

On slide 20 of the "Empirical Analysis" presentation, two approaches are mentioned to arrive at the maximum total concentration (CMAX) in the peak of the plume at 12:45. These are using WASP for CMAX and PHREEQ for maximum dissolved concentration. In fact, as I understand it, WASP was not involved in determining CMAX but a mass balance calculation outside of WASP was used (see discussion under question 14). I cannot comment on the PHREEQ method due to unfamiliarity with this code and the processes it simulates.

My overall assessment is that the dissolved concentrations in the peak are probably fairly well estimated, but that the suspended total metals concentration in the peak is almost certainly significantly underestimated. In fact, this is recognized in the current study on slide 20 with the comment on the graph: "Concentrations at 12:45 peak probably much higher." In summary, the current study does offer reasonable estimates of peak concentrations and recognizes the underestimation due to the unknown amounts of suspended materials in the peak of the plume in Cement Creek.

7. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?

Generally they were, although reviewers were often critical of the lumping of metals into a total metals load or concentration.

8. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the San Juan River after receiving mine contaminated water from the Animas River?

Generally they were, although reviewers were often critical of the lumping of metals into a total metals load or concentration.

Part 3: Geochemistry

9. Were the geochemical principles to characterize transport and fate of acid mine drainage appropriately applied and interpreted? Please explain.

No comment on this question as this topic is outside of my area of expertise.

10. Were precipitation and mineral saturation analyses of the acid mine drainage appropriately applied for interpreting metals fate in the river system? Please explain.

No comment on this question as this topic is outside of my area of expertise.

11. Was the neutralization of acid mine drainage and subsequent fate of dissolved and colloidal/particulate metals appropriately interpreted? Why or why not?

No comment on this question as this topic is outside of my area of expertise.

Part 4: Water Quality Analysis Simulation (WASP) modeling

12. Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.

For the most part it seems that proper use has been made of available data and, when necessary, data from the literature. However, this was not always fully explained during the presentation. Specifically, the formulas presented on slide 9, used to calculate the average water velocity, stream depth, and stream width for a particular model segment of the stream were not fully documented (and contained some erroneous coefficients). A more complete description of exactly what was measured where and how the regression analysis was applied to arrive at the coefficients "a" through "f" must be provided in the final report.

In follow up discussions it appeared that WASP did not use the first formula on slide 9 - the formula for velocity. These velocities were obtained using Manning's equation and calibration using observed velocities at USGS gauges, see slide 12. This is of course confusing. The velocity calculation on slide 9 is best removed. It should also be explained why the calibration on page 12 left all observed velocities below the modeled velocities.

13. Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.

It offered a first approximation to these processes. I appreciate the use of a simple modeling approach as conducted here in view of the limited data availability and the limited study objectives as described by the EPA team leader and the modeler. In particular, I applaud that only the most fundamental processes have been included, while secondary processes that are more difficult to parameterize have been omitted. In this light I agree with the decision to ignore physical dispersion in this modeling exercise. However, some caution is needed to declare the omission of (physical) dispersion conservatively by declaring that the modeling results provide an "upper bound." It does for the concentrations (assuming that numerical dispersion in the model does not simply replace the physical dispersion in the river or even exceeds it), but it is not conservative in predicting early arrival, for instance. The fact that numerical dispersion has not been quantified relative to physical dispersion is a weakness in this study.

14. Did the WASP modeling appropriately investigate the remobilization of metals during increased flow? Why or why not?

I am not sufficiently familiar with the WASP model to adequately evaluate this point. However, I do have an observation on the reconstruction of the total metals concentration in the release flow from the mine as presented on page 13. This calculation was done outside of WASP. In principle, the mass balance calculation as presented by the three formulas on page 13 is elegant due to its simplicity. What became apparent during the discussion, however, is that the assumption that the total metals concentration in the plume as measured at 4 p.m. at the 14th St. Bridge, which is after the peak of the plume passed, is the same as during the peak flow (peak of the plume) at 12:45 may be problematic. Reviewers pointed out that the higher turbulence in the peak flow more likely than not would have caused much more materials in suspension and thus a (much) higher total metals concentration than what was measured at 4 p.m. I concur with that observation and emphasize that the assumption on slide 13 (concentration at 4 p.m. same as in during peak flow) might significantly underestimate the total metals load that entered the Animas River! Thus the problem with this assumption is that it is *not conservative* as to the study objective, assessing the potential impact of the release.

However, the total metals load in the plume further down gradient in the Animas River has been independently estimated from plume size and concentrations there. Thus, the impact assessment of the release downgradient in the Animas River is not dependent on the estimate of the original total metals load in the plume while it was still in Cement Creek. It is more likely than not that the missing portion of the total metals load in Cement Creek (due to the underestimation discussed above) ended up as sediments in the very first kilometers of the Animas River. This is because the flow velocities were quickly reduced as soon as the plume entered the Animas River thus allowing settlement of the larger particulates that might have made up the higher peak flow concentrations.

In summary, while I agree that the peak flow concentrations in the plume in Cement Creek may have been underestimated, I do not believe that this underestimation affected the down gradient impact assessment, except perhaps for the sediment load in the first few kilometers of the Animas River.

Part 5: Groundwater modeling

15. Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?

In principle it is. While a very basic groundwater code (WhAEM) was used, its limited capabilities are consistent with both the very limited data available and the limited objectives of this study. In other words, a more sophisticated model would require additional assumptions and would, therefore, not have offered more insight. To fully assess the sufficiency of the current analysis it is necessary to consider its objectives.

The ultimate question to be answered is (from the presentation): "Could drinking water or irrigation wells drawing from river alluvium become impacted from the chemicals associated with the GKM release?"

This question may be broken up into three interrelated questions:

d) Which wells, if any, receive some of its water from the river?
e) What are the travel times of water from the river to those wells?
f) What is the dilution in the well of possible contaminants received from the river?

Question (a) can be answered with capture zone analyses for the various wells. Question (b) can be answered by use of forward particle tracking starting at the river and ending in the well. Question (c) can be answered by tracing particles backward in time from the well, using a uniform distribution of particles around the well, and then comparing the number of path lines that reach the river to those that do not.

WhAEM is EPA's standard model for well capture zone delineation in the context of wellhead protection and can address all three questions. As such it is a logical choice for this analysis. However, it is necessary to consider both the limitations of WhAEM and the limitations in field data, and document how these might impact the outcome of the analysis with the above research questions in mind. I will discuss these limitations in arbitrary order below.

Dupuit-Forchheimer flow

WhAEM falls in the class of codes that solves "two-dimensional flow in the horizontal plane," at least that is how these types of models are routinely referred to. Regretfully, this is misleading terminology! WhAEM is a *Dupuit-Forhheimer model*, which is a model in which resistance to vertical flow is being ignored, thus not vertical flow itself. While the underlying partial differential equation in WhAEM involves only the horizontal coordinates (x and y), flow into the vertical direction can and is being approximated using conservation of mass considerations. Consequently, path lines in WhAEM are being traced in three dimensions.

For a Dupuit-Forchheimer model to offer a good approximation to the actual three-dimensional flow regime, its application must be limited to groundwater flow systems in which the horizontal distances traveled by groundwater are much larger than the vertical distances traveled. In practice, this translates into groundwater flow systems in which the distances *L* between boundary conditions (e.g. distance of the well from the river) is larger than five times the aquifer thickness. This is for isotropic aquifers. In case the aquifer is anisotropic, with a lower vertical hydraulic conductivity than the horizontal conductivity, the following criterion may be used (Haitjema 2006):

$$L \geq 5H\sqrt{k_h/k_v}$$

Where *H* is the aquifer thickness, k_v is the vertical hydraulic conductivity, and k_h is the horizontal conductivity. Dr. Fitts suggested using a k_h *to* k_v ration of 10 for the Animas alluvium, which seems reasonable to me. The condition in the displayed formula above is not meant for wells that are relatively close to the Animas River, and unfortunately these are the wells of most interest (most likely to receive river water).

What is the consequence of violating the Dupuit-Forchheimer criterion for wells near the river? In reality the well – river interaction is influenced by possible (bottom) resistance to flow between the river and the aquifer as well as resistance to vertical flow inside the aquifer. Neither is included in the model presented, although bottom resistance could have been applied. By not including any of these resistances, the flow potential for drawing water from the river that flows into the well is *overestimated*. In other words, the model as constructed *is conservative* with respect to the objectives of this study. To keep the analysis conservative in nature I recommend <u>not</u> adding bottom resistance to the line-sinks representing Animas River.

<u>Still to be done</u>: While the analysis as conducted and presented is sound regarding this issue it must be fully documented, including calculations for representative wells to show whether they

satisfy the Dupuit-Forchheimer criterion or not. This is currently missing from the analysis! A sketch of the expected three-dimensional flow patterns and those modeled in WhAEM, as suggested by Dr. Fitts, would be useful for full disclosure of this issue. Remember, that the path lines in WhAEM are also 3D, but approximate and thus somewhat different from the "real" 3D path lines in cases where Dupuit-Forchheimer does not apply. What the sketch would not show is the fact that vertical resistance to flow is ignored in the Dupuit-Forchheimer model, which must be made clear in the figure caption.

Single homogeneous aquifer with horizontal base

WhAEM represents the alluvium near the Animas River as a single homogenous aquifer, which means that it lumps the various depositional layers in the alluvium into a single homogenous layer. Furthermore, it assumes a horizontal aquifer base below which no flow is considered. The question is how these simplifications affect the modeling results. Specifically, what effect does this simplification have on the potential well – river interaction? This was not discussed in the presentation, but I will address this below.

The actual aquifer base is unknown, but at or below the depth of the wells in the alluvium. In the absence of data it has been assumed in the current analysis that the aquifer base occurs at the bottom of the well under consideration. I agree with this choice! This will generally lead to an underestimation of the aquifer thickness, but does not affect the flow regime as much since the transmissivity in the model does not depend on this assumption because it has been based on a pump test. Assuming for a moment that the transmissivity is accurate (or reasonable) an underestimation of the aquifer thickness will result in an overestimation of the hydraulic conductivity, since the product of the two is the (known) transmissivity. So while the discharge rates in the aquifer, including the flow component from the river if present, are not affected (question a), the *specific discharges* and associated average groundwater flow *velocities* are. An underestimation of the aquifer thickness will result in an underestimation of the groundwater travel times (question b). This is *conservative* in view of the model objective since actual early arrival of contaminants may be later than predicted by the model.

The actual aquifer heterogeneity offers the potential for preferential pathways from the river to the well. The WhAEM model assumes a homogeneous aquifer that lacks preferential flow. Consequently, the assumption of homogeneity is **not** conservative in view of the model objectives. Preferential pathways would shorten the travel times from the river to the well (question b). While a multi-layer model may be able to capture this effect to some degree, data on aquifer stratification near the wells or between the wells and the river are absent.

<u>Still to be done</u>: The above discussion must be integrated into the description of the modeling analysis to fully disclose the impact of the simplifications and assumptions. It should be pointed out that predicted early arrival times in the wells of chemicals released from the river may not preclude that some (small) portion of the chemicals arrive even earlier due to preferential flow. This is true in spite of the fact that the actual aquifer thickness may be larger than assumed and thus result in slower groundwater velocities, hence later early arrival than predicted by the model. Preferential flow may well outweigh the effect of the aquifer thickness on the groundwater velocities.

Steady state flow

WhAEM models steady state flow, ignoring water that may go into storage or is released from storage due to temporal changes in the water table (unconfined flow) or head (confined flow). For the purpose of capture zone delineation (in the context of wellhead protection), a steady state model is considered adequate. In fact, producing capture zones that change over time seems impractical for the purpose of defining wellhead protection areas. However, replacing the actual transient flow system by a steady state one raises the question what the steady state model actually represents. Haitjema (1995, 2006), using a study by Townley (1995), presents a dimensionless response time τ:

$$\tau = \frac{SL^2}{4TP}$$

where S [-] is the aquifer storage coefficient, L [m] the distance between head specified boundaries, T [m^2/day] the aquifer transmissivity (product of aquifer thickness and hydraulic conductivity), and P [days] the period of a periodic forcing function. This formula differs slightly from the one presented on slide 12 due to a different definition of the distance L. When considering seasonal variations in flow in the alluvial aquifer, the definition of L on slide 12 is more convenient where it is the distance between the river and the valley boundary (rock outcrop). Haitjema (2006) offers the following rules of thumb:

$\tau < 0.1$ treat transient flow in the aquifer as successive steady state.
$0.1 \leq \tau \leq 1$ transient flow cannot be meaningfully represented by a steady state model.
$\tau > 1$ represent transient flow by a steady state model using average boundary conditions.

These guidelines are approximate in that values just below 0.1 or just above 1 are to be considered transitional from the aquifer responding relatively fast or slow to transient forcing, respectively.

The analysis offered on slide 12 is incomplete and partially incorrect! First of all, successive steady state simulations requires τ to be smaller than **0.1**, not 1 as stated on the slide. Incidentally, I missed this issue during the presentation. Secondly, the parameters used in the equation on slide 12 must be reassessed. Specifically, the storage coefficient S is too small for an unconfined aquifer as present in the alluvium surrounding the Animas River. Instead of S-values between 0.003 and 0.006 as shown on slide 12, I expect the S-value to be more in the order of 0.1. This will increase the dimensionless response time τ by almost two orders of magnitude!

Note: The reason for the measured low S-value is unclear, although Dr. Fitts suggested that it may be an artifact of an imperfect pump test and I concur.

Secondly, while the periodicity of P=365 days is appropriate to assess the response of the flow system to seasonal variations in recharge (in this case inflow into the aquifer near the rock outcrop) and seasonal variations in river stages, it is not suitable to assess the response of the flow system to short term variations in pumping and short term variations in river stage (e.g. storm surges). For that purpose a periodicity P=1 day would be a better choice. This reduction in the value of P would further increase the value of τ indicating that the aquifer responds rather slowly to storm events and pumping variations.

The current analysis does not distinguish between these long term (seasonal) and short term effects (storm events and pumping variations). Therefore, the current analysis mistakenly suggests that successive steady state is always a good approximation of this transient flow system, while in fact it most likely is not.

Still to be done: The analysis on slide 12 has to be redone with appropriately chosen parameters and for different combinations of parameters that apply to different (well) locations *and* include bracketing values for those parameters that are not fully known from field data. None are, of course! It is likely that most of these new calculations of τ will result in values larger than 1 or at least larger than 0.1. I recommend that for values larger than 1 average pumping conditions and average river stages are used in delineating well capture zones. In addition, I suggest repeating the analysis for the actual river stage during the passing by of the plume. I suggest that for values of τ smaller than 1, but larger than 0.1, both average pumping rates and actual pumping rates are used (pumping rates when the wells were turned on). Finally, I suggest producing capture zones for bracketing values of uncertain parameters. The resulting suite of capture zones would account for (1) representing transient flow as steady state and (2) for data uncertainty.

Groundwater levels and calibration

In almost all cases a groundwater flow model is being calibrated using observed potentiometric heads (confined flow) or water table elevations (unconfined flow). Ideally, base flows in streams are also included as calibration targets. Calibration leads to the determination of most likely hydrogeological parameters such as hydraulic conductivities, aquifer recharge due to precipitation, and perhaps stream bottom resistances. In the current study area (or areas) almost no water level data were shown to be available.

I wonder, however, if the many domestic wells in the alluvial aquifer may be on record with the state (well logs). If so, many of them might have static water levels that can be used as calibration targets. Similarly, the high capacity wells (irrigation wells and public water supply wells) may have logs that include static water levels as indeed are shown on slide 11. In the absence of domestic well static water levels, the static water levels in high capacity wells could be used as calibration targets by excluding them one-by-one from the model. This would mean conducting several calibration runs each with one of the high capacity wells replaced by a "test point" (calibration target).

Currently, hydraulic gradients toward the Animas River are generated in the model by defining head specified boundaries away from the river. The water released by these head-specified boundaries presumably comes from the surrounding mountains. A common approach in modeling flow in alluvial valleys is to apply so-called "mountain range recharge" along the valley boundaries at the bottom of the surrounding mountains. In WhAEM this would be done using discharge-specified line-sinks along the base of the mountains or boundary of the alluvium. This, of course, is only possible if there are reasonable estimates available for the mountain range recharge rate. However, the measured baseflow increase along the Animas River could offer some insight into this mountain range recharge rate. This baseflow increase has already been considered in the current study as shown on slide 8.

Still to be done: The final report on the WhAEM model study should address the uncertainty in groundwater flow rates toward the Animas River and the lack of calibration targets. Possible data sources, as mentioned above, should be discussed and used if data is indeed available. The data uncertainty should be resolved through sensitivity testing. Different possible groundwater flow rates toward the river should be tested in the model and their effect on the capture zones (question a), early arrival times of chemicals in the wells (question b), and dilution of chemicals in the well (question c) be shown and discussed. Note: The hydraulic gradient toward the river in combination with the aquifer transmissivity defines the groundwater flow rate toward the river. This groundwater flow rate is what really matters for the shape and orientation of the capture zones, addressing questions (a) and (c). The groundwater flow rates toward the river may be bounded by considering base flow increases along the Animas River as already done on slide 8. The actual hydraulic conductivity as well as the aquifer porosity, however, affect the groundwater flow velocities and thus travel times (question b). A sensitivity analysis on hydraulic conductivity and porosity are thus also in order.

References
Haitjema, H.M. (1995) *Analytic Element Modeling of Groundwater Flo*w. Academic Press, San Diego.

Haitjema, H.M. (2006) The Role of Hand Calculations in Ground Water Flow Modeling. *Groundwater*, Vol. 44, No. 6, pages 786 – 791.

Townley, L.R. (1995) The Response of Aquifers to Periodic Forcing. *Advances in Water Resources* 18: 125 - 146

16. Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.

In general they were, but additional analyses and discussions are needed as indicated in my answer to question 15.

17. Were the assumptions informing the capture zone and particle tracking analysis appropriate for the intended use? How so?

In general they were, but additional analyses and discussions are needed as indicated in my answer to questions 15. Specifically, I have suggested more sensitivity analyses be conducted, along the lines as to what has been shown on slide 16 and 18. The analysis as presented suggests that the aquifer responds quickly to transient forcing, allowing for successive steady state solutions or instantaneous steady state solutions. I found that analysis to be in error!! In fact, the aquifer probably responds rather slowly and a steady state model is more suitable for representing average conditions. In areas (near wells) where the aquifer may respond neither fast nor slowly, bounding solutions may be offered assuming both a fast and slow responses to transient forcing. The issue is discussed in more detail as part of my answer to question 15.

18. Did the method for calibration of the local scale groundwater flow model performance to the observed drawdown reported in the driller's log serve as an effective method? Please explain.

There was a lack of calibration targets (only one USGS monitoring well), but that well has been used in this study to arrive at calibrated values of hydraulic conductivity in the alluvium, see slide 15. In my answer to question 15 I described additional *potential* calibration targets that should be explored.

Part 6: Atlas modeling

19. Are the sources of the data included in the maps valid, complete, and adequately documented? Are there any points of confusion, gaps, or suggestions for improvement?

I do not have personal knowledge about the data sources, hence cannot address this question.

20. Do all of the maps and charts communicate the analysis methods and results in such a way as to be readily understood by stakeholders with interest in the impacts of the Gold King Mine spill (e.g., First Nations; NGO's; news media; and State water, recreation, public health, and wildlife managers)? Are there points of confusion, gaps or suggestions for improvement?

I trust that the ATLAS maps referenced here are the animations of total metals and arsenic migration along the Cement Creek, Animas River, and San Juan River. I felt that these animations were an effective way of communicating the plume migration through the system and thus quite informative for the stakeholders. Other ATLAS maps that have been used in the various presentations were also quite helpful in communicating the spatial and temporal relationships under discussion. Overall, I find ATLAS an impressive communication tool.

Part 7: Bioaccumulation

21. Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?

I defer comments to Dr. Stubblefield who has the relevant expertise in this area. I do not have any expertise in this area.

Review by:
D. Kirk Nordstrom, Ph.D.

Peer Review Comments on
EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

D. Kirk Nordstrom, Ph.D.
US Geological survey
February 29, 2016

I. GENERAL IMPRESSIONS

The Animas River Team (ART) of the EPA's Office of Research and Development (ORD) involved with research on the fate and transport of potential contaminants from the Gold King Mine (GKM) spill presented, summarized, and interpreted a very large set of diverse data collected by EPA and other technical groups under adverse conditions. Although the data set was large, many necessary parameters were missing and the quality was less than optimal for the objectives of the ART because the accidental release was unexpected and field and lab parameters were collected while the EPA was in an emergency response mode with little time for planning. Hence, the ART was working under a serious handicap and with very tight time constraints. Considering this overall situation, the presentations were impressive. They have made every effort to be thorough in collecting information, careful in most of their decisions on how to proceed with insufficient data, and they have been clear on what information is based on fact, what assumptions were used, what aspects were largely speculative and require follow-up monitoring, and they have reviewed and revised many of their conclusions to keep them as sound as possible. They have been transparent about what they have tried to do and completely open to good suggestions. We had, in my opinion, excellent discussions about what can and cannot be done with the available data.

That's not to say that there isn't room for improvement. To be sure, some of their assumptions could use revision, some of the methods that were used need modification, and in one instance (bioaccumulation) the effort was highly questionable. Having an independent review to evaluate the work at this point was a wise choice. As long as the recommendations of the reviewers are carefully considered, this mid-point evaluation should prove extremely valuable in helping the ART to achieve its goal.

Some of the figures in the presentations were impossible to read either in the hard copy or in the various PowerPoint presentations. These should have been checked and improved.

A more logical and consistent sequence to the presentations would have helped also. A more helpful logical and consistent sequence means a clear statement of goals followed by an outline of available data with a tabulation of the logic on how to obtain said goals. Some of this was presented but it was a bit different for each group and the methodology was not always clearly stated.

It is difficult to appropriately characterize the metals concentrations and loads when a lot of the important field and lab data were not collected. Immediate field reconnaissance was challenging because of the unexpected accidental and sudden release of mine pool water, the time delay in notifying authorities of the accident, and the time delay in getting personnel and equipment to the field. Of course, under rapid emergency conditions it is difficult to collect enough of the right kind of data. However, it is hard to understand why more field parameters were not measured such as conductivity, pH, and temperature for all samples, why sulfate and Fe(II/III) were not determined when water samples were collected for analyses, and why no samples of GKM effluent were collected during the release. These parameters (pH, conductivity, and Fe(II/III) should always be measured for acid mine water contamination. This is not a criticism of the ART modeling efforts, obviously, but of the lack of guidelines for the field personnel who collected the samples.

The EPA should have a handbook that recommends what samples and field parameters need to be collected in an emergency mine water spill. Furthermore, the handbook should emphasize the importance of getting water samples of the source water (the Gold King Mine effluent) as soon as possible and throughout the main pulse of mine water release because its chemical composition could, and probably did, change during the release. It is imperative that the chemical composition of the pollutant source be properly characterized because substantial changes in its composition can occur and will affect downstream transport. If the source is not well characterized then it becomes extremely difficult for the team to characterize the changing conditions of the plume as it moves hundreds of kilometers downstream. If the proper parameters had been collected, the ART could have done far better at characterizing the metals and the load, the rate of movement of the plume, the partitioning of metals between dissolved and particulate forms, and the fate of the metals in the plume. What the Team did manage to do with this partial data set is highly commendable, appropriate, and the results were very reasonable. More on this below.

Another general impression is that the EPA is not prepared for sudden mine releases like this from an organizational viewpoint. Is there an EPA office in Silverton or Durango? Not as far as I know, but there is a USGS, a USFS, and a BLM office. There is also a BLM in Silverton. Coordinating with these offices could have led to a much better collection of plume samples which would have helped the ART do a much better accounting and modeling of the plume. Does EPA coordinate with local technical staff in Colorado to get the necessary data? Even coordination among EPA Regions and between the Regional Emergency Response Team and the ORD seems to be a problem that would inhibit the rapid flow of essential data and information needed by the ART. To an outsider it appears that the other federal agencies that could help the EPA were not contacted immediately when news of the spill was released.

A general rule of thumb is that anybody trying to model the hydrogeochemical dynamics of a field site needs to see the field site. By visiting the sites, the team can get a much better idea of how appropriate their modeling and assumptions are for the goals of the project. I was surprised that no one had been allowed to see the area or had ever visited the area. A good field observer has a natural feel for how to model a complex and transient event with limited data. This disconnect between field and modeling effort can lead to inappropriate analyses and conclusions.

II. RESPONSE TO CHARGE QUESTIONS

Part 1: Overall project and analysis

1. Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?

For the most part, the data that were available were properly included and appropriate. There is the distinct possibility that additional data was collected by university researchers, local stakeholders (such as the Animas Stakeholders Group), mine owners, the US Geological Survey (USGS), The Bureau of Land Management (BLM), and the US Forest Service that has not yet been discovered. For example, I am aware that some data was collected by the USGS which has not been included in the compilation and the presentations. These additional data sources, which included USGS data given to Steve Way of the EPA should be found and included if useful for the modeling.

It would have been helpful for me to have the team include chemical analyses of just a few waters samples such as GKM effluent in addition to the samples that defined the tail end of the plume. Then I could do some quick calculations to both confirm what the team had calculated and to see if there are any additional calculations that might need to be considered. The reviewers only saw a graph of a limited number of constituents.

Several of the plots were log plots that gave a strange symmetry to the data. I know that in many cases there is such a large range of values that a log plot is necessary but not in all cases. Log plots often make the data look better than it really is. I would suggest that some plots could be divided into 2 or 3 linear plots for better visualization.

2. Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.

The presentation of the various analyses could have been conducted in a logical sequence. The Empirical Analysis should always go before any modeling efforts based on the observations. Most people would want to see the data first and foremost. It is also better to get a feeling for the data to see what types of modeling approaches are reasonable and which ones aren't. Modeling is usually used to fill in data gaps, to gain more insight into the processes that might explain the data, and to explore possible scenarios to evaluate their consequences. So the data should come first and then the modeling results. Otherwise the sequence with Geochemistry, followed by WASP modeling, Bioaccumulation, and ending with Groundwater seemed appropriate.

One aspect that was problematic is that some of the results and the presentations changed several times. That is, we received one copy of PowerPoints by cyberspace before the meeting. At the meeting we received a paper copy of the PowerPoints in a binder where some things had been changed and then when people gave presentations they sometimes had made another update and handed that out to us separately. That tells me that the Team was not quite ready and were still finessing their results. It would have been more appropriate to wait another week or two to make sure there were no important changes before presenting to the reviewers. Last minute modifications are not helpful for a review meeting.

3. Looking at the full project, are there errors or gaps in the integration process that could have affected the overall analyses and/or the conclusions? Please explain.

The integration process could have been improved by better communication between the Geochemical Analysis and the Empirical Analysis groups. These 2 sections are very closely aligned and have clear overlaps on the source term composition. More discussion was probably needed between these groups to have a better consensus on how to characterize the source term. It seems to me that when writing up the final report these 2 sections might be merged into one. Alternatively, writers should make clear what deserves to be called geochemical analyses and what is empirical. Whenever geochemical modeling is involved it would seem necessary to call it a geochemical analysis, however, mass balances is also considered geochemical modeling. Very often some geochemical reactions need to be assumed or modeled for the mass balances to make sense. Hence, these two sections should probably be merged.

4. Were the overall conclusions that were drawn from these analyses appropriate scientifically defensible based on the analysis? Why or why not?

Not entirely. (1) The geochemical analysis used some flawed assumptions to estimate the GKM effluent composition (see below), (2) alternative approaches to the GKM effluent composition were not considered (see below), (3) sensitivity analyses need to be employed for many of the analyses and modeling with a propagated range of uncertainty; this approach would result in upper and lower bounds for the plume at several locations downstream, and (4) I have a difficulty in seeing any scientifically defensible conclusions coming out of the bioaccumulation study – the lack of fish kills and the caged fish study are much more appropriate to address fish toxicity for such a short transient event than the attempt at modeling that was presented.

Part 2: Fate and transport

5. Does the research appropriately characterize the metals concentrations and load produced at the Gold King Mine spill?

Characterizing the composition and load of the Gold King Mine spill is problematic. No samples of the mine effluent were taken during the spill event. Samples were taken some days later. When the plume hit the first gage at Cement Creek (at the mouth), samples for chemical analysis were taken well after the peak of the plume had passed. Furthermore, the first 2 samples at the gage were incomplete (no pH, conductivity, or sulfate determinations). In addition, when the plume hit the Cement Creek gage it had picked up additional sediment and dissolved substances that were not part of the original mine pool discharge. Consequently, it makes sense to consider the source water as the plume that was recorded in the Cement Creek gage right before it entered the Animas River. It is still a problem characterizing the water composition at the peak of the Cement Creek discharge because the first sample collected for analysis at the gage was about 5 hours after the spill began and contained only about 20% of the Gold King effluent as well as missing some critical parameters. I think the ART did important calculations to estimate the water composition at the Cement Creek gage peak flow from the GKM release and I shall suggest additional considerations.

The Team did a straightforward conservative calculation assuming straight mixing of GKM effluent with upper Cement Creek water with no reaction. This result would normally give a bounding limit to the chemical composition of the plume. But which limit? High or low? If there is a reaction in progress, is that increasing or decreasing metal concentrations? Both are possible. Oxidation and precipitation of iron would tend to remove metals. Dissolution of soluble salts from the eroded waste piles and Cement Creek would increase metals. Erosion of fine clays might provide more surfaces for metal sorption and partitioning from dissolved to the solid phase. From my experience with weathering of mine tailings and waste rock during storm events, there is a brief and sudden increase in dissolved metals during the early rise of the discharge and then a decrease from dilution. In this instance, dilution is with GKM release water and upper Cement Creek flow because it is not a rainstorm event. But there is still likely to be a sudden increase early in the plume movement and then a drop to the concentrations of the GKM effluent for the remaining majority of the plume release followed by decrease to Cement Creek baseline once the GKM plume has passed. This early spike in concentrations would be from the addition of soluble salts and films of concentrated acid mine water contained within the tailings pile downstream and separate from the effluent composition released from the mine. I would anticipate sorption processes to be largely ineffective at this pH (~3) and with higher than normal metal concentrations. The plume is moving too fast for much oxidation and precipitation of iron. Hence, I would argue that the total plume load would be greater than that expected from just the analyses of the GKM effluent in both dissolved and fine particulate matter combined with the estimated discharge. Further, I would argue that the first measured concentrations at the gage on Cement Creek should be close to conservative mixing (20% of GKM and 80% upper Cement Creek water) but that the dissolved concentrations were higher during the first ½ hour of the GKM release. How much higher is very difficult to say so this calculation would be a lower bound that can be compared to another estimate. It can also be compared to a loading calculation that takes a constant composition GKM release as a lower limit after mixing with Cement Creek baseline water. This constant composition chosen by the ART was the August 15 sample because it was the first complete analysis of the mine effluent after the plume had passed. There were 3 other samples that I would say could be used as well from other time periods. Although pH, sulfate concentration, and conductivity data were sometimes missing, it is possible to reconstruct these by optimizing pH and sulfate concentrations using charge balance for pH (using the PHREEQC program) and conductivity balance (using either PHREEQC or WATEQ4F although WATEQ4F would be preferable because it is more reliable for acid mine waters).

With regard to estimating the composition of the Gold King effluent water during the spill, the explanation could have been clearer, especially since this composition is critical to the entire interpretation of downstream fate and transport. Unfortunately, the data available is sparse and incomplete which adds to the confusion. As I understand it, there are two key sets of data: (1) direct analyses of the Gold King effluent but collected after most of the spill had occurred with dates of 8-07-15 and 8-11-15 collected by CDPHE and dates of 8-15-15 and 9-21-15 collected by the EPA and (2) Cement Creek samples collected during the tail end of the plume movement (first sample was collected about 5 hours after the spill began). The CDPHE samples are missing critical data such as pH, temperature, conductivity, iron and sulfate concentrations. The Cement

Creek samples are Gold King effluent mixed with 80% or more of upper Cement Creek water, possibly mixed with some dissolved soluble salts, eroded sediments, and their pore waters. The GKM effluent composition had to be estimated from these limited pieces of data. The approach taken was to use the Cement Creek USGS gage data to determine the proportion of that water containing GKM effluent. Then unmix the water assuming conservative mixing. Then most of the concentrations were increased by an amount that was estimated by assuming that alunite saturation equilibrium was achieved in the GKM effluent and increasing the aluminum concentration accordingly. Alunite saturation equilibrium was indicated in a paper by Eary (1999) and this is the first time I have heard of making this assumption to estimate a mine water composition. The question is whether this assumption is reasonable and whether there are other, more reasonable approaches. Alunite is a relatively insoluble mineral which is slow to dissolve and precipitate unless the temperature is increased substantially above ambient.

I have read the Eary (1999) paper and the case made for alunite solubility equilibrium at low pH is extremely speculative. I say that because the plots that Eary showed (1) had considerable scatter, (2) were not done the normal way with the log of the activity of the free aluminum ion vs pH – he used dissolved aluminum concentrations vs. pH which doesn't really tell you much and cannot be directly compared to solubility of alunite, and (3) he doesn't show saturation indices for alunite as he does for gypsum, fluorite, and other carbonate and sulfate minerals. Further, he was looking at a pit lake which can be different than underground mine effluent. Not to mention that there are a range of thermodynamic properties for alunite so we really don't know how the solubility might change with solid solution substitution, particle size and crystallinity, and uncertainty in the thermodynamic properties. I am sure that alunite does reach equilibrium solubility in some environments but I would be very hesitant to apply it for this situation. Hence, I would discourage using this type of modeling approach to correct the mine effluent chemistry to the original composition. Instead, I would take the range of composition of the mine effluent water (max and min as bounding conditions) that was sampled later, correcting pH and sulfate concentrations as mentioned above, and compare that to the conservative estimate made from the mixing calculation that the team did from the 1600 hour sample. Then I would consider a 50% to a 100% increase in concentrations during the first ½ hour only of the GKM release to account for washout of the tailings pile for an upper bound of the loading and concentrations.

The characterization of the metals concentrations and the loads begins with the field collection of water samples and field parameters, followed by laboratory analyses. The ART did not participate in these activities. There may have been some QA/QC (quality assurance/quality control) tasks done by individuals in the team, but, apparently not as a group effort. Consequently, some unexplained discrepancies occurred in the results presented, such as several elements in which the total (unfiltered, acidified) concentration is substantially less than the dissolved (filtered, acidified) concentration. This discrepancy is most apparent with As, Sb, Pb, Mo, and V in the Cement Creek samples that were used to estimate the source effluent composition from the mine, which are sometimes discrepant by an order of magnitude or more and that is far greater than the analytical error. One way of avoiding these problems is for the team to engage in conversation with the field collection personnel and with the laboratory and any QA/QC examiners to determine if there were any sampling problems or analytical problems that could explain these anomalies. I have seen similar discrepancies before with metal concentration data from mine-influenced water at Superfund mine sites and the main problem seemed to be the lack of communication between those collecting the samples, those analyzing the samples, and those providing QA/QC. Without knowing field difficulties in collecting samples and whether there were any modifications of normal procedures (waters should be filtered and acidified immediately on collection; unfiltered samples acidified immediately except for anion sample) and without knowing if any serious interferences or possible contamination occurred with the analytical procedures, it becomes impossible to know how best to interpret the data. The higher dissolved concentration could be a contamination problem and the lower total value closer to the truly dissolved value OR the dissolved concentration could be more accurate, and the total concentration could be a result of the sample being collected in a different part of the river or an analytical interference. These are important issues that can affect any attempts at interpreting the results for fate and transport.

For this report, everything that can be known about sampling, preservation, and analytical procedures should be spelled out more. There were probably different procedures employed by State, Federal, tribal groups and other parties (for example, were samples sometimes stored for some time before acidification? Was the same acid used among agencies for acidification? Was acidification done with the same strength acid and with the same volume per volume of sample or to the same pH? If samples were filtered, what was the filter pore size? Instead of providing the EPA method numbers for the analytical method, it would be better for the reviewers to simply have the actual instrumental technique employed (ICP-AES or ICP-MS, etc.) which might be more useful when comparing results from different agencies. Reviewers and stakeholders might want to know the QA/QC for the data. I recommend a table that lists what samples were collected when, by whom, whether filtered on site or not, if filtered what pore size was used, whether acidified on site or later, if later how much later, what and how much acid was used. A separate table can cover QA/QC data (blanks, spiked recoveries, standard reference water samples, alternate methods). These tables can be appendices in the report, but it is essential to include this information because it supports the credibility and usefulness of the data for modeling and interpretation.

Also, several metal concentrations that were reported are of questionable value such as cobalt, barium, and beryllium. I know these are easy to determine by ICP-AES and ICP-MS but if there are no obvious toxicological concerns and the concentrations are quite low, then that could be stated explicitly. It could also be stated that certain metals were selected (and others not) for continued description in the plume movement because of their concentrations and their potential toxicity.

My understanding is that grab samples were collected rather than width-integrated composite samples. Under the given conditions, it might be that grab samples were the only ones possible at many of the sites, however, some width-integrated samples should have been possible or at least near-central-velocity samples collected. If the team doesn't know what the velocity of river was where the sample was collected, it could easily affect the results. Some information on this aspect should be provided in the final report.

6. The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?

Not entirely. More use should have been made of historical data. This was mostly addressed above.

There is a serious problem with some of the analyses (e.g. CC06 and GKM13 collected on 8/15/2015) in that many of the total concentrations of metals were lower than the dissolved concentrations. This can occur from problems with field sampling and samples that were not filtered and acidified on site (which probably did not happen for the earlier collected samples). Hence, a table summarizing the information on how water samples were collected and when filtered and acidified, is crucial to interpreting the results. Also, alkalinities of 5 mg/L are reported for these samples when the pH is too low for there to be any detectable alkalinity. This contradiction needs to be resolved. Further, the acidities are reported but I am not sure they are used or needed anywhere. There are several different methods for acidity so the result is very method dependent. If there is a need to report these, then the method used needs to be documented.

7. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?

It must be stated much more clearly that the sediment load is a mix of (1) clays eroded from the tailings pile during GKM release, (2) clays (mostly Fe and Al oxyhydroxides) formed during oxidation and mixing with downstream transport, and (3) clays eroded from Cement Creek during turbulent mixing of the GKM plume. Further, these sediments should be compared to suspended or clay sediments that have been determined earlier in USGS studies to see what the chemical differences are and how much they can be related to the actual GKM release.

8. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the San Juan River after receiving mine contaminated water from the Animas River?

I have not looked at this in detail.

<u>Part 3: Geochemistry</u>

9. Were the geochemical principles to characterize transport and fate of acid mine drainage appropriately applied and interpreted? Please explain.

Much of the geochemistry followed well-accepted principles but there were some exceptions. I have addressed these in my comments above.

10. Were precipitation and mineral saturation analyses of the acid mine drainage appropriately applied for interpreting metals fate in the river system? Please explain.

For the most part, yes. First, the application of dissolved iron oxidation rates was helpful to point out the enormous increase with pH. However, the fact that microbes can speed up the rate enormously at low pH was not mentioned. This should be mentioned along with the caveat that microbes would not have enough time to develop sufficient colonies in the short time of the release to affect much oxidation. There is often a 1-2 week lag time necessary before microbial colonies are of sufficient concentration to show detectable changes in the ferrous iron concentration.

Second, the saturation indices for calcite and dolomite were very pertinent and appropriate. This is especially important in pointing out the neutralizing capacity of the Upper Animas River. It would be really useful for the final report to do a simple mixing with reaction calculations with PHREEQC to simulate the effect of mixing the estimated plume (at or near the peak GKM release) at the mouth of Cement Creek and the Animas River to show the strength of the Animas in neutralizing the plume. The geochemical analysis has made a start down this path but a little more work should be done to complete this effort. I see it as a very important part of the overall characterization.

The saturation indices for amorphous gibbsite was an appropriate figure, but it is a little disturbing that the saturation state shows considerable oversaturation for many of the data points. We have not seen quite as much of this amount of oversaturation. Because it is not reasonable to have such supersaturation relative to freshly precipitating Al hydroxides, it should be assumed that some particles were not fully filtered out. As pointed out for the large supersaturation for iron hydroxides, considerable Fe particles get through the filter and indeed, may have been formed during storage of samples if they were not filtered and acidified right away.

11. Was the neutralization of acid mine drainage and subsequent fate of dissolved and colloidal/particulate metals appropriately interpreted? Why or why not?

Yes, a very good start on the neutralization and fate of colloids was done. As mentioned above, a PHREEQC simulation of mixing with reaction to compare with the more qualitative description would wrap this part up nicely.

The sorption calculations are considerably speculative, at least in the way they were described. The ART should use Dzombak and Morel's (1990) book on sorption to apply modeling because it is the only place where a self-consistent set of data is available. I am still not sure that scientifically justifiable results can come out of this but at least this would be a starting point. Also, it should be noted that Webster et al. (1998) EST 32, 1361-1368 found that the sorption of acid mine drainage precipitates and schwertmannite were different than ferrihydrite, shifting the sorption edge.

Part 4: Water Quality Analysis Simulation (WASP) modeling

12. Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.

It should probably be mentioned that there are other transport codes for this situation (e.g. OTEQ and PHREEQC) and some justification should be given why the team used WASP instead of something else. Especially in light of the fact that OTEQ has been used on mountain streams containing acid mine drainage for about 20 years and PHREEQC has been used longer than that for geochemical modeling of acid mine drainage chemistry.

I was glad to see that the team did not try to combine transport with reaction because there is not sufficient data to constrain such modeling.

13. Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.

As a more general comment – it would seem to me that putting the metals concentrations (dissolved and total) and loads in the perspective of the range of all data for low flow conditions (or similar flow and time of year as the GKM release) would help put the plume release in better perspective. This is where historical data could help considerably. A max and a min from historical data could show some kind of envelope around or near the plume results.

Also, it would be better to show the individual metals, especially Cu, Zn, Pb, and As when comparing the peak concentration with river distance and conservative (no settling) scenarios. It is also not clear why some samples that look like they were sampled nearly the same time had such different concentrations. This graph needs a lot better explanation.

14. Did the WASP modeling appropriately investigate the remobilization of metals during increased flow? Why or why not?

No comment on this question as this topic is outside of my area of expertise.

Part 5: Groundwater modeling

15. Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?

No comment on this question as this topic is outside of my area of expertise.

16. Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.

No comment on this question as this topic is outside of my area of expertise.

17. Were the assumptions informing the capture zone and particle tracking analysis appropriate for the intended use? How so?

No comment on this question as this topic is outside of my area of expertise.

18. Did the method for calibration of the local scale groundwater flow model performance to the observed drawdown reported in the driller's log serve as an effective method? Please explain.

No comment on this question as this topic is outside of my area of expertise.

Part 6: Atlas modeling

19. Are the sources of the data included in the maps valid, complete, and adequately documented? Are there any points of confusion, gaps, or suggestions for improvement?

No comment on this question as this topic is outside of my area of expertise.

20. Do all of the maps and charts communicate the analysis methods and results in such a way as to be readily understood by stakeholders with interest in the impacts of the Gold King Mine spill (e.g., First Nations; NGO's; news media; and State water, recreation, public health, and wildlife managers)? Are there points of confusion, gaps or suggestions for improvement?

No comment on this question as this topic is outside of my area of expertise.

Part 7: Bioaccumulation

21. Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?

I was considerably puzzled by the presentation on the BASS code for several reasons. I found the model that the code is based on to be interesting and theoretically appropriate, but it seemed to me to require so much empirical information that it could be decades before it might be useful. This was confirmed by some of the reviewer discussion because there clearly is some debate in the scientific literature as to the practical application of the model. It does seem useful for certain groups of organic contaminants for which it was originally designed but not for metals toxicity. More importantly, I failed to see how this model, with parameters that would come from longer term experiments than the lifetime of the GKM plume, had any relevance. The GKM was a rapid transient event and only similarly transient experiment data with fish would be similar in application. Hence, the caged fish study and the lack of observable fish kills would seem to be the only relevant information to gage toxicity.

Review by:
William A. Stubblefield, Ph.D.

Peer Review Comments on
EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

William A. Stubblefield, Ph.D.
Oregon State University
February 29, 2016

I. GENERAL IMPRESSIONS

The presentations provided in the *Gold King Mine Analysis of Fate and Transport in the Animus and San Juan Rivers* reflected the high degree of effort and quality expended in their preparation. However, the overall objectives of the effort, technical approaches employed, and desired outcomes were not obvious. EPA NERL scientists were clearly at a disadvantage not having been involved in the design of the sampling plan, its implementation, and the assessment of the overall quality of the data. Two analysis objectives were stated in the overview presentation:

- Characterize the release, transport and fate of the approximately 3 million gallons of released AMD, with a focus on a suite of metals
- Identify the potential for water quality impacts, including municipal wells, and implications for future monitoring priorities.

Clearly, a great deal of effort went into addressing the first objective and EPA scientists did a reasonable job of achieving this objective, given the limitations in data and the rapid nature of the response. It is not as clear how the second objective was to be addressed. Prior to the review it was explained that this was not an "ecological risk assessment;" however, to be able to address the second objective it is imperative that environmental exposures for individual metals be adequately described in terms of their magnitude and duration, as a minimum. Given the current state-of-the-science it would also be helpful to have information regarding those physicochemical parameters that can affect the toxicity of individual metals to aquatic organisms (e.g., dissolved organic carbon, pH, and hardness). It was also noted that there was a reasonable set of sediment data analyses (300 samples) but no detailed analysis of this data was presented. It was acknowledged that there is a large amount of data available and that the integration and interpretation of the data represents an onerous task, especially given the rapid analysis time available.

In conclusion, it was somewhat difficult to discern what the objectives of the integrated program were and whether they had been achieved or not. There seemed to be a lack of cohesiveness in the overall program objectives and the approaches taken to achieve these objectives.

II. RESPONSE TO CHARGE QUESTIONS

<u>Part 1: Overall project and analysis</u>

1. Given the data that were available to the researchers at the time, were assumptions about data inclusion, formatting, and use appropriate? How so?

The scope and types of available data were adequately described and the limitations of the available data were also discussed. Obviously, there were limitations in the available data and in some cases key parameters that would have been useful for interpreting data were not available (e.g., dissolved organic carbon). The staff doing the analyses had to "make do" with the extant data and they seemed to do an adequate job with what was provided.

In some cases, questions were raised regarding the potential availability of data from other non-EPA sources that might exist. EPA is encouraged to seek out and obtain all potential data that would be useful in interpreting the extant data. Potential data sources that should be examined include the USGS and State Department of Environmental Quality and/or Departments of Fish and Wildlife. In addition, it is anticipated that there may be data held by researchers at local Universities and at various Native American organizations.

2. Was the overall integration process of the various analyses conducted in a way that provided meaningful results and conclusions? Please explain.

Is not entirely clear what is meant by the "overall integration process" of the various analyses. For example, some of the reported metals data are presented on the basis of "total metals." This is a fairly nonstandard approach for presenting metals data especially if one of the objectives of the evaluation is to assess potential impacts to exposed aquatic organisms. The array of metals present in the Gold King Mine AMD will have vastly different toxic potencies and will be present in the AMD at greatly different concentrations (ppm to ppb). To conduct an appropriate evaluation of potential effects to exposed organisms, one needs to consider the exposure to the individual metals. It might be better if evaluations were conducted on a few different metals representing a range of toxicities, proportional presence in the AMD, and environmental fate processes. Evaluating metals such as iron, aluminum, copper, and zinc would cover a range of toxicity profiles and presence in the AMD.

3. Looking at the full project, are there errors or gaps in the integration process that could have affected the overall analyses and/or the conclusions? Please explain.

One of the stated objectives of the effort was "Identify the potential for water quality impacts, including municipal wells, and implications for future monitoring priorities near-term and long-term." It is not clear how this objective was going to be met. Few "exposure" concentrations were provided as a result of the Agencies analysis and little to no indications of how "impacts" were going to be assessed were discussed.

4. Were the overall conclusions that were drawn from these analyses appropriate and scientifically defensible based on the analysis? Why or why not?

A variety of conclusions were provided in a number of the presentations; however, for the purposes of this response, we are assuming that the "summary of key findings" from the overview presentation captures the "overall" conclusions. For the most part these findings were supported by the data provided in the presentations. However, in some cases it is difficult to point specifically to the data that support a given conclusion. This is in part due to the sheer volume of data and the way that the presentations were organized based on the available time for presentation. It is anticipated that a detailed report outlining the analysis that was conducted would provide an opportunity to present an analysis in greater detail. For example, providing metal specific data rather than "total metals data" would provide greater support for the conclusions.

Part 2: Fate and transport

5. Does the research appropriately characterize the metals concentrations and load produced at the Gold King Mine spill?

It is difficult to address this question given the "total metals" approach used in the analysis of the data. It would seem logical that there are sufficient individual metals data to permit a "by metal" analysis of exposures. This would be helpful in addressing the questions associated with potential impacts to organisms and would allow for better characterization of the fate and transport of individual metals.

6. The concentration of metals near the release site in the receiving waters had to be estimated from samples collected after the much of the plume had passed. Were the estimates of metals concentration at this location appropriately calculated through scientifically sound methods using available data?

A number of questions were raised regarding the accuracy of the estimated metals concentrations in the original AMD release. EPA staff acknowledged that there was a degree of uncertainty associated with the estimates and this was reflected in the presentations. It was recommended by the reviewers that EPA adopt an approach that characterizes the degree of uncertainty associated with the discharge estimates and incorporate that into the overall presentation. This would result in something of a "sensitivity analysis" that would bound the "best-case" and "worst-case" scenarios.

7. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the Animas River?

As previously discussed, very little information regarding bed sediment metal concentrations were provided. Currently, the state-of-the-science for evaluating metal concentrations in sediments and the potential impacts on sediment dwelling organisms requires information about the acid volatile sulfide content of the sediment and the simultaneously extracted metal concentrations of other metals present in the sediment. It did not appear that this information was available for the sites downstream of the Gold King Mine.

8. Were the data analyzed and visualized properly in regards to sediment metal concentrations in the post-plume period in Cement Creek and the San Juan River after receiving mine contaminated water from the Animas River?

Very little information was provided regarding sediment concentrations in the post-plume period in waters downstream from the GKM and Cement Creek. Information regarding individual metals would be helpful, however it is recognized that it will be difficult to attribute specific metals concentrations to the GKM incident given the ongoing contamination that exists in the area as a result of other operations and abandoned mines.

Part 3: Geochemistry

9. Were the geochemical principles to characterize transport and fate of acid mine drainage appropriately applied and interpreted? Please explain.

No comment on this question as this topic is outside of my area of expertise.

10. Were precipitation and mineral saturation analyses of the acid mine drainage appropriately applied for interpreting metals fate in the river system? Please explain.

No comment on this question as this topic is outside of my area of expertise.

11. Was the neutralization of acid mine drainage and subsequent fate of dissolved and colloidal/particulate metals appropriately interpreted? Why or why not?

No comment on this question as this topic is outside of my area of expertise.

Part 4: Water Quality Analysis Simulation (WASP) modeling

12. Did the WASP modeling appropriately apply modeling parameters to estimate the movement of plume water? Please explain.

No comment on this question as this topic is outside of my area of expertise.

13. Did the application of assumptions and values in WASP modeling appropriately address particle transport and deposition of the acid mine drainage constituents? Please explain.

No comment on this question as this topic is outside of my area of expertise.

14. Did the WASP modeling appropriately investigate the remobilization of metals during increased flow? Why or why not?

No comment on this question as this topic is outside of my area of expertise.

Part 5: Groundwater modeling

15. Is the analysis as presented sufficient to evaluate the potential for impact of the acid mine release from the GKM on pumping wells located in the floodplain aquifers downstream of the spill?

No comment on this question as this topic is outside of my area of expertise.

16. Were the assumptions informing the choice and construction of the groundwater flow model appropriate for the intended use? Please explain.

No comment on this question as this topic is outside of my area of expertise.

17. Were the assumptions informing the capture zone and particle tracking analysis appropriate for the intended use? How so?

No comment on this question as this topic is outside of my area of expertise.

18. Did the method for calibration of the local scale groundwater flow model performance to the observed drawdown reported in the driller's log serve as an effective method? Please explain.

No comment on this question as this topic is outside of my area of expertise.

Part 6: Atlas modeling

19. Are the sources of the data included in the maps valid, complete, and adequately documented? Are there any points of confusion, gaps, or suggestions for improvement?

It is assumed that the sources of the data that are included in the Atlas modeling maps are the same as those described in the overview presentation and listed on page 64 of the Empirical Analyses presentation. No additional explanation for the data contained in the specific maps was provided therefore it is difficult to address the validity, completeness, and adequacy of the documentation.

20. Do all of the maps and charts communicate the analysis methods and results in such a way as to be readily understood by stakeholders with interest in the impacts of the Gold King Mine spill (e.g., First Nations; NGO's; news media; and State water, recreation, public health, and wildlife managers)? Are there points of confusion, gaps or suggestions for improvement?

No comment on this question as this topic is outside of my area of expertise.

Part 7: Bioaccumulation

21. Given the limitations of the BASS model, how appropriate is the simulation of bioaccumulation of As, Cd, Cu, Pb, and Zn in the Animas River trout fishery? What are the strengths and weaknesses of using this approach?

As stated on the EPA web site, the BASS model was developed to "predict the population and bioaccumulation dynamics of age-structured fish assemblages exposed to hydrophobic organic pollutants and class B and borderline metals that complex with sulfhydryl groups (e.g., cadmium, copper, lead, mercury, nickel, silver, and zinc)." In the scope of the GKM effort, the BASS model was used to: 1) predict tissue metals concentrations in trout resulting from estimated dissolved metal concentrations in the Animas and San Juan Rivers and 2) using the estimated tissue concentrations predicted from BASS, make an assessment of "short-term impacts" to trout populations by comparing these values to residue-based tissue concentrations reported in the review by Jarvinen and Ankley (1999). However, this approach seems to be somewhat lacking for a number of reasons.

First, the BASS model was developed to predict tissue concentrations using a BCF/BAF approach. This assumes that the concentration of a chemical in the tissues of exposed organisms is a function of waterborne (or waterborne and food) concentrations and that the uptake of the material into tissues is a function of exposure concentration. Steady state concentrations are reached when the rate of uptake is equivalent to the rate of elimination. Most, if not all, of the materials that the model has been used with in the past are neutral, lipophilic organic compounds (e.g., DDT, PCB) or organometallic compounds (e.g., methyl-mercury) that follow these kinetics (i.e., concentration dependent kinetics). Metals, on the other hand, do not follow this model. Many metals are "essential" for life processes (e.g., Co, Cu, Zn) and their concentrations in the body are homeostatically controlled to maintain "constant" concentrations necessary for life processes. BCF values are calculated as the quotient of the internal tissue concentrations divided by the exposure concentration. Thus, with a metal when external concentrations are low, the body actively "concentrates" metals to maintain necessary internal concentrations resulting in extremely high BCFs; in situations when metals exposure concentrations are elevated but tissue concentrations are maintained at homeostatic levels, BCFs are low. A recent review by DeForest et al (2007) states that "Results indicate that field BAFs, like laboratory BCFs, tend to be significantly ($p \leq 0.05$) inversely related to exposure concentration" and "Data presented indicate that for metals and metalloids, unlike organic substances, no one BAF or TTF can be used to express bioaccumulation and/or trophic transfer without consideration of the exposure concentration." McGeer et al (2003) conclude from their review on the topic of BCFs that:

- "The accumulation of Zn, Cd, Cu, Pb, Ni, and Ag in aquatic biota were, in general, remarkably consistent, particularly for Zn, where total body/tissue concentration varied little over a wide range of exposure concentrations, exposure conditions, and species. However, mean BCF values for the six metals were characterized by high variability, and there was an inverse relationship between BCF and exposure concentration. Therefore, using the weight of evidence available, it is virtually impossible to derive a meaningful BCF value that one could say is representative of the BCF for each of the metals. Even when BCFs are limited to the exposure range where chronic toxicity might be expected (based on water-quality guidelines), it is not possible to derive a precise and accurate BCF value

  To correctly assess potential hazards, it would be necessary to distinguish between essential nutritional accumulations, that which is sequestering and stored, and accumulation that causes adverse effects. Because BCFs are based on the whole-body concentration, the BCF model does not distinguish between these different forms of bioaccumulation and therefore it would seem unlikely that the criterion would be correlated to adverse effects such as chronic toxicity."

The second major concern with the approach employed stems from the estimation of adverse effects based on tissue concentrations (i.e., based on comparison of tissue residue levels to those reported by Jarvinen and Ankley (1999)). This approached is built upon the Critical Body Residue (CBR) concept. CBR is the concentration of chemical bioaccumulation in an aquatic organism that corresponds to a defined measure of toxicity (e.g., mortality, reproductive impairment). Rainbow, in his 2002 article, *"Trace Metal Concentrations in Aquatic Invertebrates: Why and So What?"* concludes: "Toxicity is related to a threshold concentration of metabolically available metal and not to total accumulated metal concentration." Finally, Adams et al. 2010, concluded that "Available information suggests that it is not possible to develop universally applicable whole-body CBRs for metals (except for Se, methylmercury or other organo metals[sic]). Aquatic organisms differentially handle accumulated metals with respect to storage, detoxification, and excretion. As a result, measuring total metals in an organism provides limited information on the metal concentration associated with the biologically active pool. However, the benefits of monitoring for contaminant trend and exposure assessment are acknowledged."

Finally, based on the presentations made it seems clear that the waterborne exposures following the Gold King Mine incident were reasonably short-term in nature (hours not days) and were characterized by an initial spike in concentration that dissipated rapidly returning to pre-spill conditions. Kinetics of such an exposure would suggest that steady-state whole body tissue concentrations would not have been achieved given the duration of the exposure and its variable nature. Initial impacts to organisms would likely have been acute in nature due to the initial pulse exposure. Whole body tissue concentrations would not reflect possible effects to organisms.

If the analysis objective of the bioaccumulation and residue-based effects evaluation was to "assess the expected implications of the Gold King Mine release on Animus River biota" it would seem that a more traditional and straightforward approach to evaluating the potential impacts could be achieved by comparing estimated exposure concentrations for individual metals to appropriate state standards or US EPA Ambient Water Quality Criteria.

References:

Adams WJ, Blust R, Borgmann U, Brix KV, DeForest DK, Green AS, Meyer JS, McGeer JC, Paquin P, Rainbow PS, Wood CM. 2010. Utility of Tissue Residues for Predicting Effects of Metals on Aquatic Organisms. Integrated Environmental Assessment and Management. 7:75–98.

DeForest DK, Brix KV, Adams WJ. 2007. Assessing metal bioaccumulation in aquatic environments: The inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration. Aquatic Toxicology 84:236–246.

Jarvinen AW, Ankley GT. 1999. Linkage of effects to tissue residues: Development of a comprehensive database for aquatic organisms exposed to inorganic and organic chemicals.: Society of Environmental Toxicology and Chemistry Pensacola, FL

McGeer JC, Brix KV, Skeaff JM, Deforest DK, Brigham SI, Adams WJ, Green A. 2003. Inverse Relationship Between Bioconcentration Factor and Exposure Concentration for Metals: Implications for Hazard Assessment of Metals in the Aquatic Environment. Environmental Toxicology and Chemistry, 22:1017–1037

Rainbow PS. 2002. Trace metal concentrations in aquatic invertebrates: why and so what? Environmental Pollution 120:497–507

Appendix A
List of Peer Reviewers

Peer Review of EPA's
Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers

EIA Conference Room, EPA Laboratory
960 College Station Rd
Athens, GA 30605

February 23-25, 2016

LIST OF PEER REVIEWERS

Brian S. Caruso, Ph.D., PE.
U.S. Geological Survey
Colorado Water Science Center
Denver, CO

Charles R. Fitts, Ph.D.
Fitts Geosolutions, LLC
Scarborough, ME

Henk M. Haitjema, Ph.D.
Haitjema Consulting, Inc.
Bloomington, IN

D. Kirk Nordstrom, Ph.D.
U.S. Geological Survey
Boulder, CO

William A. Stubblefield, Ph.D. (chair)
Oregon State University
Albany, OR

Appendix B
Meeting Agenda

Peer Review of EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

EIA Conference Room, EPA Laboratory
960 College Station Rd
Athens, GA 30605

February 23-25, 2016

Day 1

8:00 AM	**Welcome, Goals of Meeting, and Introductions** David Bottimore, Versar, Inc.
8:15 AM	**Conflict of Interest Disclosure** David Bottimore, Versar, Inc.
8:20 AM	**Welcome by EPA and Overview of Background Documents** Dr. Jennifer Orme-Zavaleta (by video) & Dr. Jay Garland (by video)
8:30 AM	**Chair's Introduction and Review of Charge** Dr. William "Bill" Stubblefield, *Chair*
8:45 AM	**Presentation & Discussion: Analysis of Fate and Transport in the Animas and San Juan Rivers: Overview** Dr. Kate Sullivan
10:00 AM	*Break**
10:15 AM	**Presentation & Discussion: Analysis of Fate and Transport in the Animas and San Juan Rivers: Geochemistry of the release** Dr. John Washington
12:00 PM	*Lunch**
1:00 PM	**Presentation & Discussion: Analysis of Fate and Transport in the Animas and San Juan Rivers: Water Quality Modeling Using WASP** Dr. Chris Knightes (by video), Anne Neal
4:00 PM	*Break**
4:15 PM	**Wrap up for the Day** Dr. Kate Sullivan
4:30 PM	**Reviewer Executive Session**
5:00 PM	**Adjourn**

**Time for breaks and lunch are approximate and at the Chair's discretion.*

Peer Review of EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

EIA Conference Room, EPA Laboratory
960 College Station Rd
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February 23-25, 2016

Day 2

8:00 AM **Recap of Day 1 and Agenda for Day 2**
David Bottimore & Dr. Kate Sullivan

8:15 AM **Presentation & Discussion: Analysis of Fate and Transport in the Animas and San Juan Rivers: Empirical Analysis**
Dr. Kate Sullivan, Dr. Mike Cyterski, Anne Neale

10:45 AM *Break**

11:00 AM **Presentation & Discussion: Analysis of Fate and Transport in the Animas and San Juan Rivers: Bioaccumulation and Residue-Based Effects**
Dr. Craig Barber

12:15 PM *Lunch Break**

1:30 PM **Presentation & Discussion: Analysis of Fate and Transport in the Animas and San Juan Rivers: Ground Water Wells**
Dr. Stephen Kraemer

3:15 PM *Break**

3:30 PM **Reviewer Executive Session**

5:00 PM **Adjourn**

**Time for breaks and lunch are approximate and at the Chair's discretion.*

Peer Review of EPA's
Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers

EIA Conference Room, EPA Laboratory
960 College Station Rd
Athens, GA 30605

February 23-25, 2016

Day 3

8:00 AM **Reviewer Writing Session**

11:45 AM *Lunch**

1:00 PM **Reviewer Debrief & Summarizations**
Dr. Jennifer Orme-Zavaleta (by video) & Dr. Jay Garland (by video)

2:30 PM **Wrap Up**
David Bottimore, Versar, Inc.
Dr. William "Bill" Stubblefield, *Chair*

3:00 PM **Adjourn**

3:15 PM **Shuttle from Hotel to Airport**

**Time for breaks and lunch are approximate and at the Chair's discretion.*

Appendix C
List of EPA Attendees

LIST OF EPA ATTENDEES

Peer Review of EPA's *Gold King Mine Analysis of Fate and Transport in the Animas and San Juan Rivers*

February 23-25, 2016

Dr. Craig Barber – Systems Exposure Division/Integrated Environmental Modeling Branch

Dr. Mike Cyterski – Computational Exposure Division/Watershed Exposure Branch

Dr. Jay Garland – Director, NERL Systems Exposure Division

Dr. Andy Gillespie – Associate Director for Ecology, National Exposure Research Laboratory

Dr. John Johnston – Chief, Watershed Exposure Branch, Computational Exposure Division

Dr. Chris Knightes – Computational Exposure Division/Watershed Exposure Branch

Dr. Stephen Kraemer – Systems Exposure Division/Integrated Environmental Modeling Branch

Dr. Jennifer Orme-Zavaleta – Director, ORD National Exposure Research Laboratory

Anne Neale – Systems Exposure Division/Ecological & Human Community Analysis Branch

Dr. Kate Sullivan – Chief, Systems Exposure Division/Integrated Environmental Modeling Branch

Dr. John Washington – Exposure Methods & Measurement Division/Environmental Chemistry Branch

Appendix D
Curricula Vitae

BRIAN S. CARUSO, Ph.D., P.E.

Supervisory Hydrologist/Chief of Hydrologic Studies
Acting Associate Director
U.S. Geological Survey
Colorado Water Science Center
Denver, CO. 80225
303-236-6879
Email: bcaruso@usgs.gov

PROFESSIONAL SUMMARY/HIGHLIGHTS:

- Over 25 years of experience in water resources and environmental science, research, planning and management including government, academia, and consulting. I have been responsible for managing over 30 multidisciplinary professional staff and $10 million annually in projects.
- Currently Chief of Hydrologic Studies/Supervisory Hydrologist with the U.S. Geological Survey Colorado Water Science Center in Lakewood, Colorado. Acting Associate Director for Hydrologic Studies for the Center.
- Previously Chief of the Wetlands and Watersheds Unit/Supervisory Environmental Scientist, and Technical Liaison/Environmental Scientist with the US Environmental Protection Agency Region 8 and Office of Research and Development in Denver, Colorado from 2004-2009.
- From 1996-2000, Director of Technical Services for water resources science, engineering, and management with the Otago Regional Council in Dunedin, New Zealand.
- Ph.D. in Hydrology and Water Resources/Environmental Engineering from Colorado State University.
- 15 years of scientific consulting experience throughout the western US and internationally.
- Associate Editor for Riparian Ecology and Management for the Journal of the American Water Resources Association, with over 40 peer-reviewed publications in international journals and over 50 technical consulting reports.
- Expertise in surface and groundwater hydrology/water quality; hydrologic, hydraulic and contaminant fate and transport modeling; water quality monitoring; aquatic ecology; wetlands and riparian ecology; impact assessment; risk analysis; nonpoint source pollution; deterministic and statistical modeling; analysis of land use and climate change impacts; mining and contaminated sites investigation and remediation; and ecosystem restoration.

CURRENT POSITION:

November 2015 - present: Acting Associate Director - U.S. Geological Survey, Colorado Water Science Center, Denver, CO. Responsible for all aspects of water resources science management for surface water and groundwater hydrologic studies projects throughout Colorado, the western U.S., and nationally. This includes strategic planning, research projects coordination, external collaboration, and internal capacity building. Work includes collaborating with a wide range of USGS and external organizations, including the National Research Program, national Offices of Surface Water and Groundwater, other Federal, state, and local agencies, numerous universities, and water managers/users. Much of this work involves research on water availability needs in a changing climate, including Rocky Mountain snowmelt monitoring and modeling, watershed modeling for the National Water Census and Water Smart, and developing tools for water availability analysis and technology development. Perform and coordinate research, and review and approve all technical work products including research proposal, reports, and journal articles.

June 2015 - present: Supervisory Hydrologist/Chief of Hydrologic Studies - U.S. Geological Survey, Colorado Water Science Center, Denver, CO. Manage a wide range of water resources studies, water quality assessments, and monitoring/research programs throughout Colorado and the western U.S. These include studies involving regional water quality, water supply and climate variability, contaminant fate and transport, energy development and impacts, sediment and geomorphology, wetlands, aquatic ecology and biology, basin-wide assessments, stormwater monitoring, and natural hazards. Supervise 17 multidisciplinary staff including surface water hydrologists, research hydrologists, water quality specialists, soil scientists, GIS specialists, and aquatic ecologists/fishery biologists. Responsible for strategic and annual planning, budgeting, operations, reporting, and a $4 million annually in projects. Collaborate with a wide range of USGS, federal, state, local and tribal government and stakeholder organizations, and interact with many other scientists, natural resource managers, and government officials.

PAST POSITIONS:

June 2009 - May 2015: Associate Professor – University of Canterbury, Department of Civil and Natural Resources Engineering, Christchurch, New Zealand. Taught and coordinated courses in Hydrology, Water Resources, and Ecological Engineering. Performed and supervised student research as part of the Hydrological and Ecological Engineering Research Group. Director of 3rd Professional Year Studies (senior honors students). Member of the Joint Working Group for the Waterways Center for Freshwater Management. Performed and supervised research on hydrology, water quality, pollutant fate and transport, hydroecology, modeling, and restoration of surface/groundwater and aquatic ecosystems.

Jan 2007 - June 2009: Supervisory Environmental Scientist/Chief of the Wetlands and Watersheds Unit, EPA Region 8, Ecosystems Protection and Remediation Program, Denver, CO. Managed wetlands and watersheds studies, monitoring, protection, and restoration programs throughout the Rocky Mountains and Plains region in six western states and 26 tribal nations in EPA Region 8. Managed 10 professional scientists, as well as consultants and grantees, working on regional and site-specific research and monitoring, regulatory protection, and restoration of streams, wetlands, water quality, and watersheds impacted by agriculture, urban development, industry, and climate change. This included analysis of impacts to surface waters; protection and mitigation/restoration program development; managing tribal water quality programs; administering contracts and grants with other organizations to help build capacity; and community outreach and education. Responsible for analyzing and implementing natural resource protection regulations including the Clean Water Act, NEPA, and Endangered Species Act. Also responsible for strategic and annual planning, budgeting, operations, reporting, and a $5 million annual budget. Collaborated with a wide range of EPA, federal, state and local government and stakeholder organizations, and interacted with numerous scientists, policy analysts, and government officials.

May 2004 - Jan 2007: Environmental Scientist/Technical Liaison, EPA Office of Research and Development (ORD), Office of Science Policy, Denver, CO. Technical Liaison for ORD and Region 8 providing expert services and advice on environmental and hydrologic science, investigation, and restoration at Superfund sites, mined watersheds, and other sites in the western US. Work included hydrologic and water quality studies, contaminant fate and transport modeling, and aquatic resources restoration at high-profile sites throughout the arid and semiarid western US. Also collaborated with and advised a wide range of other government agencies, including USGS, on key environmental and aquatic science issues and research projects. Led and contributed to the planning and implementation of several mined watershed restoration and metals fate and transport modeling conferences and workshops. Served on the science committee of the Hazardous Substances Research Center at Colorado State University and numerous other government committees.

Sep 2000 - May 2004: Project Manager – CDM Federal Programs Corp, Denver, CO. Project Manager for a wide range of environmental and water resources projects in the western US, including senior advisor to EPA on ecosystems investigation and restoration projects. Work included hydrologic and water quality studies and modeling; watershed, river, and wetlands restoration; environmental impact assessment; contaminated sites investigation and remediation, and permitting for hydroelectric power re-licensing. Also responsible for technical review of work products for EPA, US Forest Service, US Army Corps of Engineers, Bureau of Reclamation, and local government agencies.

Oct 1997 - Aug 2000: Director of Technical Services - Otago Regional Council, Dunedin, New Zealand. Directed the environmental/resource science, water resources/river engineering, land resources management, and biodiversity programs for the council. The Regional Council is responsible for all natural resources management in this ecologically diverse region from the Southern Alps to the Pacific Ocean. Responsibilities included research and monitoring of surface and groundwater hydrology and quality, aquatic ecology, wetlands, soils, point source discharges, and contaminated sites throughout the region. Also responsible for river and wetland restoration, flood management, watershed management/nonpoint source pollution control, invasive species/biodiversity management, and stakeholder collaboration as part of these programs. Included leading and mentoring staff, budget planning and tracking, program effectiveness evaluation and reporting, and working extensively with other scientists and policy analysts.

June 1996 – Jan 1998: Assistant Professor – School of Earth Sciences, Victoria University of Wellington, New Zealand. Taught undergraduate and graduate courses in environmental science, physical environmental processes, environmental impact assessment, and hydrology and water resources. Supervised graduate students and conducted research on environmental impacts of mining and agriculture, particularly contaminant transport and water quality impacts. Research projects included evaluation of nutrient sources and transport in steep, agricultural hill country and assessment of environmental and socioeconomic costs and benefits of gold mining in New Zealand.

Dec 1989 – June 1996: Manager of Water Resources - S.M. Stoller Corp, Boulder, CO. Served as Project Manager for wide range of environmental and water resources studies/engineering projects in the western US.

Projects included site-wide surface water and sediment monitoring and ecological risk assessment at high-profile contaminated sites, and numerous other environmental and water resources projects in the Rocky Mountains involving hydrologic and water quality studies and ecosystem restoration. Responsible for senior technical review of all work products, mentoring of staff, and business development.

June 1993 - Dec 1995: Research Associate/Coprincipal Investigator - Colorado State University, Ft Collins, CO/EPA Region 8, Denver, CO. Conducted applied research on the development of a watershed-based methodology for assessment of nonpoint source pollution from abandoned metal mines as part of PhD dissertation for EPA. The study site was the Animas River Basin in the San Juan Mountains, Colorado.

June 1985 – Dec 1989: Senior Hydrologist – Morrison-Knudsen Corporation, Denver CO. Performed surface and groundwater investigations, hydrologic and water quality monitoring and modeling, risk assessment, and restoration planning and design for the Rocky Mountain Arsenal Superfund site and other contaminated sites in the western US.

June 1984 – June 1985: Research Assistant - University of Colorado, Dept of Civil Engineeering, Boulder, CO. Conducted hydrologic and water quality studies and modeling of the City of Boulder municipal alpine watershed, Colorado, as part of MS research.

EDUCATION:

Ph.D. 1995 Hydrology and Water Resources/Environmental Engineering, Colorado State University, Ft. Collins, CO.
M.S. 1987 Water Resources and Environmental Engineering, University of Colorado, Boulder, CO.
B.S. 1982 Environmental and Forest Biology, State University of New York College of Environmental Science and Forestry, Syracuse, N.Y.

AWARDS:

US EPA Office of Research and Development Superior Accomplishment Award 2006
US EPA Office of Research and Development Superior Accomplishment Award 2005
US EPA Office of Research and Development Superior Accomplishment Award 2004
National Academy of Engineering one of 100 Outstanding Young Engineers 2001
IBM/Colorado State University Environmental Engineering Graduate Fellowship
University of Colorado Research Assistantship
State University of New York Regents Scholarship

REPRESENTATIVE PROJECTS:

USGS Colorado Water Science Center Projects. Colorado and Nationwide. Direct research and other scientific projects and supervise multidisciplinary scientists working on a wide range of USGS and other collaborative water science projects. Representative projects include:

- ***National Water Census and WaterSMART. USGS and Bureau of Reclamation.*** This project involves improving the tools and information available to effectively evaluate water-resource availability as part of one of the USGS six core science directions for the 2007–17decade. It includes developing better techniques for estimating streamflow at ungaged sites across the U.S., application of the USGS Precipitation-Runoff Modeling System, and improved modeling of evapotranspiration and sublimation. The project also helps to inform a broader initiative by DOI, WaterSMART (Sustain and Manage America's Resources for Tomorrow), which provides multiagency funding to pursue a sustainable water supply for the Nation.
- ***Water, Energy, and Biogeochemical Budgets (WEBB). USGS.*** This project aims to understand fundamental hydrologic processes controlling water, energy, biogeochemical, and sediment fluxes over a range of temporal and spatial scales, and the interactions of these processes, including the effect of atmospheric and climatic variables.
- ***Hydrologic Benchmark Network (HBN), Western Site Coordination. USGS and National Park Service.*** HBN involves long-term water-quality monitoring at 11 stations in the western U.S. The network consists of 37 watersheds across the U.S. that provide long-term measurements of stream and river flow, water quality, aquatic biology, and soil chemistry in areas that are minimally affected by human activities.
- ***Atmospheric Deposition and Ecosystem Effects/Rocky Mountain Snowpack Chemistry. USDA Forest Service, National Park Service, Colorado Department of Public Health and Environment, and Teton Conservation District.*** This project involves monitoring snowpack chemistry in National Parks and National Forests across the Rocky Mountain Region, as well as in other areas of the western U.S. and Alaska, to provide a better

understanding of annual concentrations and depositional amounts of selected nutrients and other constituents in snow resulting from atmospheric deposition.

- ***Long-Term Lakes Monitoring, Colorado. USDA Forest Service.*** This includes conducting long-term monitoring of lake chemistry in selected wilderness areas in Colorado to detect changes that may occur in response to atmospheric deposition of pollutants and climate change.
- ***Hydrologic and Flood Studies, Colorado. Colorado Department of Transportation.*** Directing a number of studies and staff monitoring, modeling, and evaluating hydrologic processes and risks associated with road transportation infrastructure throughout Colorado.

EPA Region 8 Aquatic Resources Monitoring and Research. Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming. Managed all of the aquatic resources science and research in the region associated with physical impacts to wetlands, rivers and streams, and lakes from development activities, habitat loss, and climate change. This included regional mapping and condition assessment of wetlands and other aquatic resources, evaluation of wetland and stream ecosystem functions and services within watersheds, water quality impacts and standards development, and evaluation of the biophysical and chemical connectivity of wetlands, headwaters, perennial, intermittent and ephemeral streams with navigable waters. Much of my work on wetland and stream connectivity has fo cused on the Upper Colorado River Basin.

EPA Region 8 Aquatic Resources Restoration. Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming. Program manager for mitigation and restoration of wetlands, streams and rivers, and lakes impacted by development activities and pollution across the region. Worked closely with the US Army Corps of Engineers, States, Indian tribes, nonprofit organizations, and other Federal agencies on restoration policy, science, design and implementation, monitoring, and evaluation of effectiveness. Led strategic planning and development of annual work plans, budgets, and reports for this work.

Lake Clearwater Wetlands and Ahuriri River Hydrology, Water Quality and Restoration, New Zealand. Department of Conservation. Principal Investigator evaluating the hydrology and water quality of wetlands, streams and rivers, and lakes in the high country of the South Island and developing and implementing restoration strategies. This includes evaluating and modeling flow interactions with vegetation, including invasive species, impacts of nonpoint source pollution (sediment, nitrogen and phosphorus) from agricultural activities, and habitat degradation and loss. Evaluating the effectiveness of current restoration efforts and planning and designing new measures including wetlands restoration and passive/constructed wetlands treatment systems.

Environmental Flows and Water Allocation Planning for the Orari River, New Zealand. Environment Canterbury. Evaluated existing information and previous reports on environmental flows and water allocation in the Orari River Catchment. Developed a comprehensive summary report on past investigations, the hydrology of the catchment including floods and low flows, surface water-groundwater interactions, water quality, sediment transport, aquatic ecology, and water takes for irrigation and other uses. Made recommendations for additional monitoring, studies, and modelling.

Regional Evaluation of Mining-Related Metals Contamination, Risks, and Innovative Remediation Technologies in Ukraine and Georgia. EPA, Office of Research and Development, Office of International Affairs, US State Department, Science and Technology Center of Ukraine. Directed an international collaborative research project in the two Former Soviet Union countries of Ukraine and Georgia to (1) characterize the regional extent and significance of mining-related acid mine drainage and metals contamination in groundwater and surface water in two large priority mining-districts and the associated human health risks, and (2) determine what innovative characterization and remediation technologies are used, available, or being developed that could address these problems. The project included field sampling and analysis of metals and related contaminants in groundwater, surface water, soils and wastes, and evaluation of ecological and human health risks. The effectiveness of the use of a permeable reactive barrier, combined with sulfate reducing bacteria, was also investigated, including bench-scale laboratory studies and a field-scale pilot/demonstration of the technology to determine feasibility and cost effectiveness.

Project River Recovery 10-Year Review, Upper Waitaki Basin, New Zealand. Department of Conservation. Conducted an independent 10-year review and critical evaluation of the effectiveness of the Department of Conservation’s braided, gravel-bed river and wetland restoration program in the high country of Canterbury. This included evaluating achievement of project goals and objectives, effectiveness of restoration projects, recovery of natural channel and riparian/floodplain habitat and native species, changes in sediment transport regime and channel geomorphology, and water quality improvements. Provided comprehensive report to the Department and published two scientific papers in international peer-reviewed journals on this work.

Alamosa River Watershed Assessment and Restoration Planning, Colorado. Alamosa Riverkeeper. As part of an Environmental Justice grant from US EPA Region 8, assisted this watershed group with development of a comprehensive watershed assessment and restoration plan to identify, evaluate, and prioritize major issues and restoration approaches/projects within the watershed and river. This included impacts from the Summitville Mine, metals, and acidity; agriculture including nutrients, sediment, grazing, and bank erosion; irrigation withdrawals and dewatering of the river; point source discharges; and channelization and flood control activities. It also included working cooperatively with other organizations including the Colorado Water Conservation Board, US Forest Service, and the Colorado Department of Justice.

Upper Truckee River and Wetland Restoration, Lake Tahoe, California. California Tahoe Conservancy. Assisted with development of a restoration plan and design for the Upper Truckee River, the primary inflow to Lake Tahoe, and Truckee Wetland/Marsh, the largest wetland in the Lake Tahoe Basin. This included restoring the natural geomorphologic functioning of the river and wetland, providing additional open water in the wetland, protecting and enhancing native vegetation and endangered species, managing flood flows, improving water quality in the river, wetland, and lake, and providing recreational opportunities. Evaluated water quality processes and functions in the watershed and aquatic systems, including pollutant sources, transport, and impacts, particularly interactions between the wetland, lake, river, and groundwater. Recommended methods to improve water quality through restoration activities.

Restoration and Enhancement of Rivers and Aquatic Ecosystems, Otago, New Zealand. Otago Regional Council. Directed the restoration of riparian/floodplain areas and wetlands, water quality, aquatic ecology, geomorphology, and hydrologic and hydraulic function of a range of aquatic ecosystems throughout the region, including rivers severely modified by channelisation, flood control works, and floodplain encroachment. Also included enhancement of aesthetics and recreational opportunities. Involved comprehensive hydrologic/hydraulic modelling; water quality, ecologic and geomorphologic investigations; conceptual and final design, extensive public/community consultation, and construction management. Implementation included planting native vegetation, providing access to water and recreational opportunities, and channel and bank reconstruction for flood and low flows and aquatic habitat including using boulder weirs, pools, runs, riffles, and erosion control structures.

Evaluation of Climate Change, Drought and Low River Flows, Otago, New Zealand. Otago Regional Council. Managed monitoring and reporting on climate trends, variability and impacts on water and land resources across the region. Included estimating river low flows using statistical and deterministic models, assessing water quality and aquatic ecology impacts and recovery from low flows and drought, and evaluating the effectiveness of methods to protect instream uses.

Assessment of Diffuse Phosphorus Pollution in the Lake Hayes Catchment, Otago, New Zealand. Otago Regional Council. Managed the monitoring and assessment of surface water and groundwater hydrology, water quality, and aquatic ecology of a high country/mountain agricultural and tussock grassland catchment. Involved data collection; analysis of contaminant spatial and temporal variability; evaluation of aerial photography and satellite imagery; detailed assessment of catchment topography, vegetation, geology, soils, erosion, and land use based on field data and GIS; targeting critical phosphorus source areas; and implementing BMPs such as stream bank erosion control and riparian management.

Hydrologic Study of Upper San Joaquin River Basin for Big Creek Hydroelectric Power Project Relicensing/Environmental Impact Statement (EIS), Sierra Nevada, California. Southern California Edison. Team leader for the comprehensive evaluation of the hydrology and water management in the Upper San Joaquin Basin, a high altitude watershed in the Sierra Nevada Mountains between Yosemite and Sequoia National Parks, as part of an EIS for relicensing of the Big Creek hydroelectric power project. Reviewed all existing hydrologic data, developed a database and GIS maps, filled data gaps, recommended additional monitoring strategies, and analyzed and summarized data using a range of statistical methods. Evaluated extreme events including floods and low flows. Modeled the natural, unimpaired hydrology of the watershed using regional analysis techniques. Evaluated the environmental impacts of operations on the hydrology of the watershed, including use of the Indicators of Hydrologic Alteration (IHA) methodology to quantify impacts. Provided information for and coordinated with assessment of impacts to geomorphology, aquatic biology, wetlands and floodplains, and recreation. Developed a comprehensive hydrologic report and the hydrology section of the EIS.

Water Quality Study for Salmon Creek Rehabilitation and Water Supply EIS, Washington. Colville Confederated Tribes and Bonneville Power Administration. Team leader for the evaluation of water quality impacts from Salmon Creek rehabilitation alternatives, including supplying water from the Okanogan River for irrigation and instream uses, and development of the water quality section of an EIS. The water supply alternatives would allow natural flows to meet minimum instream flows for fish in Salmon Creek during critical periods. The preferred alternative included constructing a pumping station and pipeline for water diversion from the Okanogan River and delivery to an irrigation canal, reduction of flows in the Okanogan River, and increases in flows in Salmon Creek. Alternatives also include upgrade of an existing water pumping station, purchase of water rights, and replacement of a feeder canal from Salmon Creek to a reservoir. Potential impacts evaluated included bank and bed erosion, sedimentation, temperature increases, reduction of dissolved oxygen, and stormwater quality effects. Lead the development of the water quality section of the EIS.

Water Quality Study and Modeling of Rogue River for Prospect Hydroelectric Power Project Relicensing/ EIS, Oregon. Pacificorp. Directed and helped perform the water quality component of an EIS for relicensing of this hydrolelctric project on the Rogue River. This included comprehensive stream temperature and dissolved oxygen modeling using QUAL2E to evaluate impacts to water quality and aquatic biota in the Rogue River from alternative operational schemes. Modeled several reaches and tributaries upstream and downstream of dams and canals, including some dynamic, diurnal modeling. Provided technical direction for model calibration, validation, and statistical analysis of temperature and dissolved oxygen relationships and diurnal variability. Developed a comprehensive water quality report and the water quality component of the EIS.

Walker River Watershed Nonpoint Source Pollution Assessment and Management, Nevada/California. Walker River Irrigation District. Project Manager assessing and managing NPS pollution and related issues in the watershed causing impairment of the Walker River, Bridgeport Reservoir, and Walker Lake. Pollution includes sediment, nutrients including nitrogen and phosphorus, bacteria, metals, elevated water temperatures, and low dissolved oxygen. Sources include agriculture, mining, urban development, and groundwater. Evaluated hydrologic and water quality monitoring data, surface water/groundwater interactions, and NPS sources; developed plans for additional monitoring to fill data gaps, assisted with TMDL development; and provided technical support for development of a hydrologic/irrigation operations model. Developed BMP strategies working in cooperation with other agencies, universities/research organizations, and community groups. Participated in a mediation group composed of over 30 agencies and private organizations, and served on the Hydrology Technical Team providing recommendations to the group.

Bridge Creek Restoration Design, Washington. Colville Confederated Tribes. Provided senior technical review and evaluation of a design for restoration of Bridge Creek, Washington. This included evaluation of design of bank and bed erosion control, re-contouring, meander, reconnection of the channel with the floodplain, riparian planting, boulder weirs and grade control, and other fish habitat features. It also involved evaluation of hydrologic and hydraulic analyses and the adequacy of structure and channel dimensions. Ensured that the final design with drawings and specifications was adequate for construction bidding.

Dungeness River Watershed Comprehensive Irrigation District Management Plan and Habitat Conservation Plan, Washington. Dungeness River Agricultural Water Users Association. Involved with the integration of water quality issues with the development of a Comprehensive Irrigation District Management Plan (CIDMP) and Habitat Conservation Plan (HCP) for the Dungeness River Watershed on the Olympic Peninsula. The CIDMP and HCP were being developed to address ESA issues for eight listed species. This was a pilot project funded by the Washington Department of Agriculture to mitigate the impacts of agriculture, irrigation, grazing and other activities on aquatic ecosystems. Evaluated point and NPS pollution sources, transport, and impacts on water quality and aquatic life including bacteria, sediment, nutrients, and pesticides. Recommended methods to integrate water quality and BMPs into irrigation and habitat conservation planning and management.

San Clemente Reservoir Water Quality and Biological Assessment, California. California and American Water Company. Conducted a water quality assessment as part of a biological assessment evaluating the existing surface and subsurface water quality of this water supply reservoir, the Carmel River and San Clemente Creek, and associated sediments. The project included a comprehensive evaluation of the likely effects of water drawdown for dam failure risk reduction on water quality including nutrients, sediment, and metals, and threatened fish species including steelhead. Evaluated water quality sampling and sediment boring results; surface and subsurface water and sediment interactions; and impacts of drawdown operations, extended low water levels, high-flow/flood events, and refilling of the reservoir. Prepared a monitoring plan and recommended operating procedures to mitigate impacts and options for dam removal.

Feasibility Study and Conceptual Design of Marsh Habitat Restoration, Washington. ATOFINA. Evaluated alternatives and developed a conceptual plan/design for restoration of marsh dendritic habitat in the Hybelos Waterway, Tacoma, Washington. This included detailed evaluation of the bathymetry of the waterway; preparation of a conceptual plan/design for habitat restoration including rock berms, provision of fill and substrate, tidal inlets and channels, and tidal, marsh, and upland habitat; evaluation of habitat benefits; and estimation of construction costs.

Water Quality Monitoring and Assessment, Technical Assistance for Classification of Montana Lakes. Montana Department of Environmental Quality. Assisted with the development of a classification system for lakes throughout Montana and lake water quality standards. Determined and evaluated physical characteristics of lakes based on bathymetric maps using GIS and AutoCad software. This information is being used to develop lake water quality indices and criteria for nutrients and other parameters.

Boulder Creek Irrigation Diversion Design for Walden Ponds Wildlife Area Water Supply. Boulder County Parks and Open Space Department, Colorado. Managed the design of an irrigation diversion structure on Boulder Creek to supply water to the Walden Ponds Wildlife Area, which has suffered drought and declining water levels over the past few years. This included evaluation of irrigation and diversion requirements and alternatives, preparation of a conceptual/preliminary design and final design, and development of a comprehensive design report. Evaluated a range of Boulder Creek flows and levels, County water rights and irrigation ditch flow requirements, diversion alternatives, environmental impacts of alternatives, and associated mitigation measures to minimize impacts to the creek. Factors influencing the most appropriate design included channel slope, water velocities and levels, sediment regime, environmental impacts, and cost. Alternatives evaluated include a conventional concrete weir diversion spanning Boulder Creek, and a more natural cross-vein boulder weir with diversion structure, which was selected as the recommended alternative. The design provided a stable structure that is not adversely impacted by flow, sediment movement, or geomorphic changes in the creek channel. The project included preparation of conceptual, preliminary, and final designs with plans and specifications and bid/construction documents. It also involved preparation of a comprehensive design report that included the final design plans and specifications, evaluation of requirements and alternatives, assumptions, design methods, rationale for the selected design, and cost estimates for capital construction, operational maintenance, and field construction management/supervision.

Upper Tenmile Creek Watershed Modeling, Assessment and Restoration, Montana. U.S. Environmental Protection Agency, Region 8. Developed a comprehensive, steady-state water quality model for evaluation of metals fate and transport to support watershed and stream restoration using the US EPA model WASP5. Directed model development, calibration, and validation and used the model to evaluate sediment and contaminant loadings; low-flow requirements for aquatic life; impacts of storm and snowmelt flows; in-stream processes including water/sediment/metals interactions; data and model uncertainties; and restoration alternatives and design. Assisted with the development and application of the Revised Universal Soil Loss Equation for modeling sediment and contaminant source inputs to the creek during high flows events. Developed a comprehensive modeling report and directed the preparation of the sediment section of an assessment report.

Questa Mine Assessment and Restoration, New Mexico. U.S. Environmental Protection Agency, Region 6. Provided senior technical review of a work plan for assessment and restoration activities and scoping for the Molycorp Questa Molybdenum Mine, including project planning and expert technical assistance, organizing and analyzing existing data, document technical review, identifying data gaps, and providing assessment and restoration recommendations. Provided ongoing technical support and oversight, including participating on the Technical Review Committee, for assessment and restoration of the mine. Reviewed and evaluated a wide range of studies and reports on hyrogeochemical background (pre-mining) conditions; surface and groundwater hydrologic and chemical loading analyses and modeling; erosion and stability of tailings and waste rock piles; engineering alternatives analyses; and closure plans. Provided comments and recommendations for revision of these documents. Also provided technical assistance with ecological and human health risk assessments, and recommendations for incorporation of operational and future closure activities into restoration planning.

Basin Creek Watershed Assessment, Montana. U.S. Environmental Protection Agency, Region 8. Provided senior technical review of a preliminary assessment report based on all existing data for the watershed. This included evaluation of data collection, analysis, and risk assessment methods and results for surface water, groundwater, sediment, soils, air, and biological data, including data collected by EPA, USGS, and the State of Montana. Made recommendations for comprehensive statistical analysis of surface water and sediment data.

South Platte River Restoration, Colorado. U.S. Army Corps of Engineers, Omaha District. Project Manager providing technical assistance for the restoration and enhancement of a highly modified reach of the South Platte River in downtown Denver in cooperation with the City and County of Denver, Urban Drainage and Flood Control District, and the Greenway Foundation. Work involved preparation of a comprehensive site investigation work plan; evaluation of previous investigations; sampling and analysis of river bank soils and bed sediments for chemical and physical characteristics; and preparation of a comprehensive investigation report. Also included technical assistance for a restoration feasibility study including evaluating existing ecological habitat, alternative restoration measures, potential future habitat, and costs and benefits for each alternative including effects of dam removal on aquatic biota and habitat.

Butte Hill/Silver Bow Creek Modeling, Assessment and Restoration, Montana. U.S. Environmental Protection Agency, Region 8. Reviewed and evaluated a stochastic stormwater quality model for runoff from Butte Hill and impacts to Silver Bow Creek. Recommended improvements and helped to revise the model to incorporate additional hydrologic and water quality monitoring data, surface water/groundwater interactions, impacts from background/upstream sub-basins, and BMPs. Provided ongoing evaluation and technical support to ensure the model was used appropriately to assess impacts to Silver Bow Creek and evaluate restoration alternatives.

Anaconda Smelter and Warm Springs Creek Assessment and Restoration, Montana. U.S. Environmental Protection Agency, Region 8. Developed design criteria for addressing floodplain/fluvial tailings and sediments in Warm Springs Creek for restoration of water quality, aquatic habitat and fluvial geomorphology of the creek. Evaluated all hydrologic and water/sediment quality data for the site and sediment-water interactions. Criteria were based on metals concentrations in water and tailings/sediment, channel bed and bank erosion, metals partitioning, storm water and groundwater inputs, State and Federal water quality criteria, and channel realignment/restoration design objectives. Also assisted with development of site-wide surface water monitoring and management plans.

Inactive and Abandoned Mines Assessment and Reclamation, Montana and Idaho. U.S. Forest Service. Provided senior technical review of a work plan for assessment and reclamation of five abandoned mine and tailings sites in Montana and Idaho. Provided senior technical review of the assessment and reclamation planning report for the Spring Creek Tailings Area in Deer-Lodge National Forest, Montana. This included detailed review of the assessment of existing data and information; data collected as part of the engineering evaluation/cost analysis; data analysis and risk assessment for surface water, groundwater, stream sediments, tailings, soils, air, and biota; evaluation and cost analyses of reclamation alternatives including land use controls, tailings removal, regrading, capping, revegetation, landfill disposal, and stream restoration.

Midvale Slag Site and Jordan River Modeling, Assessment and Restoration, Utah. U.S. Environmental Protection Agency, Region 8. Investigated and evaluated alternatives for restoration of the Jordan River, the primary river in the Salt Lake Valley that flows through the Midvale site, including mine slag and tailings. Evaluated the river's hydrology, hydraulics, and floodplain characteristics; contaminant and sediment sources and transport; river water and sediment quality; aquatic biota and habitat; human health and ecological risks; and requirements for target fish species. Developed restoration objectives and evaluated alternatives including contaminant source controls, meanders, erosion control, weirs/dams for pools, substrate modifications, riparian planting, addition of boulders and other cover, public access, and aesthetic improvements. Evaluated the costs and benefits of alternatives and developed restoration conceptual plans/designs. Also evaluated the impacts of contaminated groundwater on the river and alternatives for groundwater containment and in-situ and wetlands treatment to protect the river. This included modeling groundwater flow and contaminant transport, surface water/groundwater interactions, and several restoration alternatives using USGS MODFLOW and Groundwater Vistas.

Cache Creek Flood Modeling, California. U.S. Army Corps of Engineers, Sacramento District. Performed hydraulic modeling of floods on Cache Creek, a major tributary of the Sacramento River near Sacramento, using COE HEC-RAS to evaluate flood risk and mitigation/management options as part of a feasibility study. Refined the model incorporating detailed analysis of bridges and levees, and modeled several flood mitigation alternative scenarios including new and relocated levees, channel modifications, bed and bank armouring, and removal and/or replacement of bridges.

Gilt Edge Mine Assessment and Restoration, South Dakota. U.S. Environmental Protection Agency, Region 8. Prepared a Sampling and Analysis Plan, including a Field Sampling Plan and Quality Assurance Project Plan, and assisted with field work for site-wide surface water and sediment sampling and streamflow measurements. Developed a comprehensive water and chemical mass balance model that incorporates both deterministic and stochastic components. Used the model to evaluate annual, monthly, and storm/snowmelt runoff; inputs to the water treatment plant; risk of treatment plant bypass; changes in pond/pit storage; and the time required to dewater ponds/pits as part of the evaluation of restoration alternatives and development of an Interim Water Treatment Feasibility Study. Provided ongoing technical direction for statistical analysis of surface water and sediment monitoring data.

California Gulch Modeling and Restoration, Colorado. U.S. Environmental Protection Agency, Region 8. Provided senior technical review of a restoration plan for several smelter, mill, slag and contaminated soil sites. Developed preliminary hydrologic and hydraulic models using COE HEC-1 and HEC-RAS for design of surface water run-on diversion channels, contaminated runoff collection channels, sedimentation ponds, and restoration of Lincoln and South Evans gulches.

Flathead Lake TMDLs and Restoration Planning, Montana. Flathead Basin Commission, State of Montana Department of Environmental Quality. Task leader for data analysis and modeling to assist with TMDL development, watershed restoration planning, and implementation of restoration efforts. Assisted with evaluation of contaminant loadings and restoration planning/implementation around the lake including evaluating near-shore sources of sediment, nitrogen, and phosphorus; stormwater runoff; forestry, agricultural, municipal/urban, and industrial loadings; surface water/groundwater interactions and groundwater inputs; and septic system loadings and costs and benefits of alternative wastewater systems.

Santa Margarita River Watershed Water Quality Modeling, California. U.S. Bureau of Reclamation, Lower Colorado District. Worked with a range of stakeholders to plan, develop, and implement a watershed water quality model using the Watershed Assessment Risk Management Framework (WARMF). Evaluated existing and proposed future water quality monitoring requirements and programs throughout the watershed, defining modeling objectives, evaluating existing watershed models, assessing watershed/land use characteristics and relationships to water quality, and defining modeling tasks and budgets. This included modeling nitrogen, phosphorus, sediment, and dissolved oxygen; developing and implementing TMDLs; assessing the assimilative capacity of the river, point and nonpoint source pollution, stormrwater runoff, ecological habitat/ water quality relationships, surface water/groundwater interactions, monitoring requirements, and municipal/urban, agricultural, forestry, and recreational, and hydrological/habitat modification impacts; and developing a comprehensive report.

Southwest Florida Regional Water Quality Study, Florida. U.S. Army Corps of Engineers, Jacksonville District. Assisted with planning a comprehensive regional water quality study as part of the Southwest Florida Feasibility Study and Comprehensive Everglades Restoration Program. The study involves developing a baseline water quality data set for the southwest Florida region and identifying opportunities for water quality improvement and restoration of southwest Florida and Everglades ecosystems. It includes evaluating existing data and information on ambient water quality (surface water, groundwater, sediments, atmospheric deposition, and biota) and developing a consistent database; assessing baseline water quality; identifying water quality problems, beneficial uses, and impairment of uses; evaluating TMDLs and water quality/ ecosystem restoration alternatives; identification of data gaps; and preparation of a comprehensive report.

Regional Water Resources Monitoring and Assessment. Otago Regional Council, New Zealand. Directed the comprehensive regional monitoring and assessment of climate, surface water and groundwater hydrology and use, water quality, and aquatic ecology. Included extensive data collection and management (including use of telemetry systems) using fixed stations and special studies, statistical data analysis, application of GIS, prioritization/targeting of impaired watersheds and water bodies, and preparation of comprehensive watershed and regional reports.

Restoration and Enhancement of Rivers and Aquatic Ecosystems. Otago Regional Council, New Zealand. Included restoration of riparian/floodplain areas and wetlands, water quality, aquatic ecology, geomorphology, and hydrologic and hydraulic function of a range of aquatic ecosystems throughout the region, including rivers severely modified by channelization, flood control works, and floodplain encroachment. Also included enhancement of aesthetics and recreational opportunities. Involved comprehensive hydrologic/hydraulic modeling using HYCEMOS, Topmodel, MIKE 11 and HEC-RAS; water quality, ecologic and geomorphologic investigations; conceptual and final design, extensive public/community consultation, and construction management. Implementation included planting native vegetation, providing access to water and recreational opportunities, and channel and bank reconstruction for flood and low flows and aquatic habitat including using boulder weirs, pools, runs, riffles, and erosion control structures.

Catchment Nonpoint Source Water Quality/Contaminant Transport Modeling. Otago Regional Council, New Zealand. Applied AGNPS, CREAMS and QUAL2E in several catchments to identify diffuse sediment, phosphorus and nitrogen source areas, transport pathways, transformation, impacts on receiving waters, and total maximum daily loads to support beneficial uses and target BMPs in the catchments.

Floodplains and Flood Hazard Evaluation. Otago Regional Council, New Zealand. Involved assessment of natural hazards associated with river systems including flood risk, floodplain inundation, erosion and sedimentation. Included review of existing, historical flooding and damage information; evaluation of river bed levels and temporal changes; detailed hydrologic and hydraulic modeling using HYCEMOS, Topmodel, MIKE 11 and HEC-RAS; feasibility studies for flood hazard mitigation; development of comprehensive reports; and community consultation.

River Engineering/Management. Otago Regional Council, New Zealand. Included operation of flood warning systems, operation and maintenance of several flood control and drainage schemes, and river engineering for flood management. Involved design, construction, operation, repair and maintenance of flood banks, dams and other flood control structures, open-channel drains, pumping stations, and culverts; channel and bank erosion control; removal of sediment/gravel build-up; and channel shaping.

Sustainable Land Resources and Catchment Management. Otago Regional Council, New Zealand. Included regional monitoring of soils, vegetation and land use emphasising application of 'indicators'; use of watershed approaches for assessment of land use/ water quality relationships and nonpoint source pollution; targeting problem areas and implementing BMPs; extension including public/community education, outreach, technology/information transfer, and technical assistance; and development and application of environmental farm plans/quality management systems.

Groundwater Investigations. Otago Regional Council, New Zealand. Performed regional and aquifer/site-specific groundwater investigations and monitoring involving hydrologic, hydraulic, and geochemical studies. Included field sampling, water level measurements, aquifer tests, and use of geophysical techniques. Involved laboratory coordination, statistical data analysis and mapping, modeling using numerical models including USGS MODFLOW and analytical models, and preparation of comprehensive reports

Contaminated Sites Management. Otago Regional Council, New Zealand. Involved the investigation and management/remediation of contaminated sites throughout the Otago region. This included site identification, prioritization, sampling and analysis, environmental and human health risk assessment, feasibility studies, remedial design, construction and operation, and ongoing monitoring of groundwater surface water, sediments, soils and biota. Work included landfills, gas works and timber treatment sites.

Regional Resource Planning. Otago Regional Council, New Zealand. Provided senior technical input to and advice for development of regional plans for water, land, air, the coast, and waste management. Included reviewing and evaluating draft plans and providing expert scientific and technical opinions, documentation and reports to support plan objectives, policies, rules, regulations, and other non-regulatory methods to achieve environmental goals.

Water Discharge Permit Monitoring. Otago Regional Council, New Zealand. Directed monitoring of point source discharges to water from industries, municipalities, landfills, and other sources for compliance auditing of discharge permits. The program included sampling, laboratory coordination, database development/management, data analysis, and preparation of compliance reports.

Evaluation of Impacts of Landslides on Contaminant Sources and Transport in Steep Pastoral Hill Country, New Zealand. Conducted a study involving comprehensive field instrumentation and measurement of flow and contaminant transport in streams, surface runoff, vadose zone water and groundwater, and data analysis including evaluation of spatial and temporal variability of nitrogen and phosphorus at the hillslope and catchment scale. Wrote a proposal and received $15,000 grant from Victoria University of Wellington.

Comparative Analysis and Technology/Information Transfer of New Zealand and US Agricultural Nonpoint Source Pollution Management Approaches. Performed comprehensive evaluation of legislation, organizations, and approaches for economic incentives, outreach and education, monitoring, modeling, and BMPs for agricultural nonpoint source pollution control in both countries. Wrote a proposal and received $5,000 grant from the New Zealand Ministry of Research Science and Technology. Developed a comprehensive report with methods and results.

Surface/Storm Water and Nonpoint Source Pollution Monitoring. Denver International Airport, Colorado. Managed the planning, design, and implementation of a hydrologic and water quality monitoring program for background and downstream conditions at DIA. This included developing a comprehensive monitoring plan and conceptual design of flow measurement weirs and automated stream-gaging and sampling stations, final design and construction management of the stations, and monitoring baseflows and storm water flows. The program also involved analytical laboratory coordination, data management, data analysis, and evaluation and recommendation of BMPs for nonpoint source pollution control.

Investigation of a Radioactive Tailings Site. City of Boulder, Colorado. Managed the preparation of a work plan, surface radiological surveys, and sampling and analysis of soils, groundwater, surface water, and sediment for radionuclides and metals. Evaluated potentially applicable water quality standards and radionuclide standards for soils, as well as the potential impacts of the site on Boulder Creek. Performed a risk evaluation, monitored radionuclides during construction of a water main through the area, and evaluated and recommended engineering alternatives to excavate and dispose of contaminated soils and minimize potential human health risks. Prepared a comprehensive report with all methods, results, and recommendations.

Evaluation of U.S. Army Corps of Engineers/Federal Emergency Management Agency (FEMA) Flood Study. City of Carlsbad, New Mexico. Reviewed and performed a detailed analysis of the flood study and 100-year floodplain delineation performed by COE/FEMA, performed hydrologic and hydraulic modeling of several basins using HEC-1 and HEC-2, provided detailed comments on the COE/FEMA report, and prepared a comment report and maps for submittal to the agencies.

REFEREED ARTICLES:

Shrestha, B, Cochrane, T.A., **Caruso, B.S**., Arias, M.E. and Piman, T. Submitted. Uncertainty in flow and sediment predictions due to future climate scenarios and hydrological sediment modeling for the 3S Basin, Lower Mekong River Basin. *Journal of Hydrology*.

Caruso, B.S., King, R. Newton, S. and Zammit, C. Submitted. Simulation of climate change effects on hydropower operations in headwater lakes, New Zealand. *River Research and Applications*.

Caruso, B.S., Newton, S., King, R. and Zammit, C. Submitted. Modeling climate change impacts on hydropower lake inflows in a mountain basin. *Hydrological Processes*.

Caruso, B.S., Cochrane, T., Paine, M., McCready, S., Nicholson, N. Submitted. Spatial and temporal water quality patterns in a coastal intermittently closed and open lake impacted by agricultural nonpoint source nutrient pollution. *Estuaries and Coasts*.

Ingersoll, G.P., Miller, D.C., Morris, K.H., McMurray, J.A., Port, G., and **Caruso, B.S.** In Press. Changing regional emissions of airborne pollutants reflected in the chemistry of snowpacks and wetfall in the Rocky Mountain Region, USA, 1993-2012. *Water, Air and Soil Pollution*.

Caruso, B.S., Booker, D. and M. Scarsbrook. In Press. Chapter 2 - Changes in regional hydrology, water quality and ecology in the last 10 years. In: Advances in New Zealand freshwater science. Eds: Pearson, C., Davie, T., Jellyman, P., and Harding, J. New Zealand Hydrological Society, Wellington.

McMillan, H., **Caruso, B.S.** and M.S. Srinivasan. In Press. Chapter 7 - Lateral hydrological processes. In: Advances in New Zealand freshwater science. Eds: Pearson, C., Davie, T., Jellyman, P., and Harding, J. New Zealand Hydrological Society, Wellington.

Caruso, B.S. In Press. The imbalance of science and policy for aquatic resources jurisdiction in the semi-arid western U.S. Chapter in AGU Book on the Imbalance of Nature.

Caruso, B.S. 2015. A hydrologic connectivity index for jurisdictional analysis of headwater streams in a montane watershed. *Environmental Monitoring and Assessment.* DOI: 10.1007/s10661-015-4862-2.

Javernick, L., Hicks, D. M., Measures, R., **Caruso, B.S.** and J. Brasington. 2015. Numerical modelling of braided rivers with Structure-from-Motion derived terrain models. *River Research and Applications*. DOI:10.1002/rra.2918.

Uster, B. O'Sullivan, A.D., Young Ko, S., Evans, A., Pope, J., Trumm, D. and **B.S. Caruso.** 2014. The use of mussel shells in upward-flow sulfate-reducing bioreactors treating acid mine drainage. *Mine Water and the Environment*. Online first. DOI: 10.1007/s10230-014-0289-1.

Caruso, B.S. 2014. GIS-based classification of streams in a mountain watershed for jurisdictional evaluation. *Journal of the American Water Resources Association.* 1-21. DOI: 10.1111/jawr.12189.

Javernick, L., Brasington, J. and **B.S. Caruso**. 2014. Modelling the topography of shallow braided rivers using Structure-from-Motion photogrammetry. *Geomorphology* 213:166-182. DOI: 10.1016/j.geomorph.2014.01.006.

Wadworth-Watts H.D., **Caruso B.S.**, O'Sullivan A.D. and R. Clucas. 2013. A hydrological and nutrient load balance for the Lake Clearwater catchment, Canterbury, New Zealand. *Journal of Hydrology New Zealand* 52(2):61-82.

Caruso, B.S., O'Sullivan, A.D., Faulkner, S., Sherratt, M. and R. Clucas. 2013. Agricultural diffuse nutrient pollution transport in a high country wetland complex. *Water, Air, and Soil Pollution* 224:1695. DOI: 10.1007/s11270-013-1695-x.

Caruso, B.S., Edmondson, L. and C. Pithie. 2013. Braided river flow and invasive vegetation dynamics in the New Zealand Southern Alps. *Environmental Management* 52:1-18. DOI: 10.1007/s00267-013-0070-4.

Caruso, B.S., Pithie, C. and L. Edmondson. 2013. Invasive riparian vegetation response to flow regimes and flood pulses in a braided river. *Journal of Environmental Management* 125:156-168. DOI: 10.1016/j.jenvman.2013.03.054.

Caruso, B.S., Ross, A., Shuker, C. and T. Davies. 2013. Flood hydraulics and impacts on invasive vegetation in a braided river floodplain, New Zealand. *Environment and Natural Resources Research* 3(1):92-110. DOI: 10.5539/enrr.v3n1p92.

Caruso, B.S., Rademaker M., Balme, A. and T.A. Cochrane. 2013. Flood modelling in a high country mountain catchment, New Zealand: comparing statistical and deterministic model estimates for ecological flows. *Hydrological Sciences Journal* 58(2):1-14. DOI:10.1080/02626667.2012.752577.

Caruso, B.S. 2013. Hydrologic modification from hydroelectric power operations in a mountain basin. *River Research and Applications* 29(4):420-440. DOI: 10.1002/RRA.1609.

Arias, M.E., Cochrane, T.A., Piman, T., Kummu, M., **Caruso, B.S.** and T.J. Killeen. 2012. Landscape assessment of flooding and habitats of the Tonle Sap Lake Floodplain, Cambodia: historical interaction and future scenarios. *Journal of Environmental Management* 112:53-66.

Caruso, B.S., Mirtskhulava, M., Wireman, M., Schroeder, W., Kornilovich, B. and S. Griffin. 2012. Effects of manganese mining on water quality in the Caucasus Mountains, Republic of Georgia. *Mine Water and the Environment* 31:16–28. DOI: 10.1007/s10230-011-0163-3.

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Caruso, B.S. and J. Haynes. 2011. Biophysical-regulatory classification and profiling of streams across management units and ecoregions. *Journal of the American Water Resources Association* 47(2):386-407.

Caruso, B.S. and J. Haynes. 2010. Connectivity and jurisdictional issues for aquatic resources in the Rocky Mountains and Great Plains. *Wetlands* 30:865-877.

Butler, B.A, **Caruso. B.S.** and J.F. Ranville. 2009. Reactive transport modeling of remedial scenarios to predict cadmium, copper, and zinc in North Fork Clear Creek, Colorado. *Remediation Journal* 19(4):101-119. DOI 10.1002/rem.20221.

Caruso, B.S. and M. Bishop. 2009. Seasonal and spatial variation of metal loads from natural flows in the Upper Tenmile Creek Watershed, Montana. *Mine Water and the Environment* 28:166–181. DOI 10.1007/s10230-009-0073-9.

Caruso, B.S. and H.E. Dawson. 2009. Impacts of groundwater metal loads from bedrock fractures on water quality of a mountain stream. *Environmental Monitoring and Assessment* 153:405-425. DOI 10.1007/s10661-008-0367-6.

Caruso, B.S., Cox, T.J., Runkel, R.L., Velleux, M.L., Bencala, K.E., Nordstrom, D.K., Julien, P.Y., Butler, B.A., Alpers, C.N., Marion, A. and K.S. Smith. 2008. Metals fate and transport modeling in streams and watersheds: state-of-the-science and USEPA workshop review. *Hydrological Processes* 22:4011-4021.

Caruso, B.S. and T.J. Cox. 2008. Modeling effects of natural flow restoration on metals fate and transport in a mountain stream impacted by mine waste. *Journal of the American Water Resources Association* 44(3):535-551.

Caruso, B.S. and P.W. Downs. 2007. Rehabilitation and flood management planning in a steep, boulder-bedded stream. *Environmental Management* 40:256–271.

Caruso, B.S. 2006. Effectiveness of braided, gravel-bed river restoration in the Upper Waitaki Basin, New Zealand. *River Research and Applications* 22:905-922.

Caruso, B.S. 2006. Project River Recovery: Restoration of braided gravel-bed river habitat in New Zealand's high country. *Environmental Management* 37(6):840-861.

Caruso, B.S. 2005. Simulation of metals total maximum daily loads and remediation in a mining-impacted stream. *Journal of Environmental Engineering* 131(5):777-789.

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Caruso, B.S. and K. Wangerud. 2002. Deterministic and stochastic water balance modeling of the Gilt Edge Mine Superfund Site, South Dakota. *Society for Mining, Metallurgy, and Exploration Transactions 2002*, 312:104-112.

Caruso, B.S. 2002. Temporal and spatial patterns of extreme low flows and effects on stream ecosystems in Otago, New Zealand. *Journal of Hydrology* 257(1-4):115-133.

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Caruso, B.S. 2000. Effects of landslides on contaminant sources and transport in steep pastoral hill country. *Journal of Hydrology New Zealand* 39(2):127-154.

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Caruso, B.S. and J.C. Loftis. 1999. Screening assessment of dissolved zinc from inactive mines in a mountain watershed. *Environmental Monitoring and Assessment* 56:147-176.

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Caruso, B.S. and R.C. Ward. 1998. Assessment of nonpoint source pollution from inactive mines using a watershed-based approach. *Environmental Management* 22(2):225-243.

McConchie, J.A. and **B.S. Caruso**. 1997. Hutt River. In: Jayawardena, A.W., Takeuchi, K., and Machbub, B. (Eds.) *Catalogue of Rivers for Southeast Asia and the Pacific - Volume II*. UNESCO - International Hydrology Programme, Jakarta. pp. 224-250.

Caruso, B.S. 1996. Development of a watershed-based methodology for analysis of nonpoint source pollution from abandoned metal mines for targeting restoration. In: McDonnell, J.J., Stribling, J.B., Neville, L.R. and Leopold, D.J. (Eds.) *Proceedings of Watershed Restoration Management Symposium,* American Water Resources Association, Syracuse, NY, July 14-17, 1996. pp. 481-490.

CONFERENCE PRESENTATIONS AND ABSTRACTS:

Caruso, B.S., Mirtskhulava, M., Wireman, M., Schroeder, W., Kornilovich, B., Griffin, S. 2015. Manganese mining impacts on water quality in the Caucasus Mountains, Republic of Georgia. 10th International Conference on Acid Rock Drainage, Santiago Chile. 14-21 April.

Khadka, D., Caruso, B.S. and C. Zammit. 2014. Modelling climate change effects on spatial variability in subcatchment flows in a mountain basin, New Zealand. Abstract presented at 2014 Fall Meeting, AGU, San Francisco, California. 15-19 December.

Caruso, B.S. 2014. Analysis of headwaters hydrologic connectivity for jurisdictional evaluation in a Rocky Mountain watershed. *2014 Joint Aquatic Sciences Meeting. Portland, Oregon. 18-23 May.*

Javernick, L.A., **Caruso, B.S.**, Hicks, M., Brasington, J., Davies, T. and R. Measures. 2014. Modeling flood-induced processes causing Russell lupin mortality in the braided Ahuriri River, New Zealand. *River Restoration Northwest Stream Restoration Symposium. Stevenson, Washington. 4-6 February.*

Caruso, B.S. 2013. The imbalance between nature and management: jurisdictional evaluation of headwaters in a mountain watershed (Invited). *Abstract H53K-05 presented at 2013 Fall Meeting, AGU, San Francisco, California. 9-13 December.*

Javernick, L.A., **Caruso, B.S.**, Measures, R., Hicks, M. and J. Brasington. 2013. Fluvial terrain models produced with Structure-from-Motion and optical bathymetric mapping: Fit for the purpose of numerical modelling. *Abstract EP41E-08 presented at 2013 Fall Meeting, AGU, San Francisco, California. 9-13 December.*

Khadka, D., **Caruso, B.S.** and C. Zammit. 2013. Climate change impacts on future streamflows in the Hakataramea River Catchment. *Proceedings of the New Zealand Hydrological Society Annual Conference, Palmerston North, New Zealand. 19-22 November.*

Khadka, D., **Caruso, B.S.** and C. Zammit. 2013. Climate change impacts on future streamflows in the Hakataramea catchment. *Post Graduate Student Conference Day, Waterways Centre for Freshwater Management, Christchurch, New Zealand. 12 November.*

Caruso, B.S. 2012. Hydrological connectivity and science and policy integration issues for aquatic resource jurisdictional determinations in a semi-arid region of the western U.S. *Abstract GC42B-05 presented at 2012 Fall Meeting, AGU, San Francisco, California. 3-7 December.*

Javernick, L.A., Brasington, J., **Caruso, B.S.**, Hicks, M. and T.R. Davies. 2012. Creating high quality DEMs of large scale fluvial environments using Structure-from-Motion. *Abstract H31E-1168 presented at 2012 Fall Meeting, AGU, San Francisco, California. 3-7 December.*

Javernick, L., Brasington, J., **Caruso, B.**, Davies, T.R.H. and D.M. Hicks. 2012. Creating high quality DEMs of large scale fluvial environments using Stucture-from-Motion. *Proceedings of the New Zealand Hydrological Society Annual Conference, Nelson, New Zealand. 27-30 November.*

Wadworth-Watts, H., **Caruso, B.S.** and A.D. O'Sullivan. 2012. Sources of nutrient loading in the Lake Clearwater Catchment, Canterbury. *Proceedings of the New Zealand Hydrological Society Annual Conference, Nelson, New Zealand. 27-30 November.*

Javernick, L., Brasington, J., **Caruso, B.S.**, Davies, T.R.H., and D.M. Hicks. 2012. Creating high quality DEMs of large scale fluvial environments using Stucture-from-Motion. *Post Graduate Student Conference Day, Waterways Centre for Freshwater Management, Christchurch, New Zealand. 22 November.*

Wadworth-Watts, H.D., **Caruso, B.S.** and A.D. O'Sullivan. 2011. Hydrological and nutrient transport balances for an inter-montane catchment, Canterbury, New Zealand. *Proceedings of the 50th New Zealand Hydrological Society Conference, Wellington, New Zealand, 5 -9 December 2011.*

Caruso, B.S. 2011. Science and policy integration issues for stream and wetland jurdisdictional determinations in the semi-arid western U.S. *Proceedings of the American Water Resources Association 2011 Annual Water Resources Conference. Albuquerque, New Mexico, 7 - 10 November 2011.*

Arias, M.E., Cochrane, T.A., **Caruso, B.S.**, Killeen, T., and M. Kummu. 2011. A landscape approach to assess impacts of hydrological changes to vegetation communities of the Tonle Sap Floodplain. *34th International Association for Hydro-Environment Engineering World Congress - Balance and Uncertainty, 33rd National*

Hydrology and Water Resources Symposium, and 10th National Conference on Hydraulics in Water Engineering. Brisbane, Australia. 26 June - 1 July, 2010.

Caruso, B.S., O'Sullivan, A.D., Faulkner, S., Sherratt, M. and R. Clucas. 2010. Diffuse agricultural impacts to a high country wetland resource. *New Zealand Hydrological Society 2010 Annual Conference, Dunedin, New Zealand, 6-10 December 2010. In Proceedings of the New Zealand Hydrological Society 2010 Annual Conference.*

Caruso, B.S. and Haynes J. 2010. Aquatic resources connectivity and jurisdictional determinations during June 2007-2008 in EPA Region 8. *American Society of Limnology and Oceanography/North American Benthological Society Joint 2010 Summer Meeting, Santa Fe, New Mexico, 6-11 June 2010.*

Caruso, B.S. 2010. Indicators of hydrologic alteration for hydroelectric power development in the Upper San Joaquin Basin, California, USA. Auckland, New Zealand: *17th Congress of the Asia and Pacific Division of the International Association of Hydraulic Engineering and Research incorporating the 7th International Urban and Watershed Management Conference, 21-24 Feb 2010. In Proceedings of the 17th Congress of the Asia and Pacific Division of the International Association of Hydraulic Engineering and Research incorporating the 7th International Urban and Watershed Management Conference.*

Caruso, B.S. and J. Haynes. 2009. Connectivity and jurisdictional issues for aquatic resources in the Rocky Mountains and Great Plains, USA. Whangarei, New Zealand: *New Zealand Hydrological and Freshwater Sciences Societies Joint Conference. 23-27 November 2009. In Proceedings of the New Zealand Hydrological and Freshwater Sciences Societies Joint Conference.*

Caruso, B.S. 2009. Keynote Speaker: An international perspective: water allocation in the US and comparison to New Zealand. Wellington, New Zealand: *Meeting the Challenges of Water Allocation: Learning from Each Other, New Zealand Hydrological Society Workshop, 5-6 Oct 2009. In Proceedings Meeting the Challenges of Water Allocation: Learning from Each Other, New Zealand Hydrological Society Workshop.*

Caruso, B.S. 2009. Connectivity and jurisdictional issues for aquatic resources in the Rocky Mountains and Great Plains, USA. *2009 New Zealand Hydrological Society/New Zealand Freshwater Sciences Society Joint Conference - Waters for the Future: Balancing its Values, Whangarei, New Zealand.*

Kornilovych, B., Wireman, M., **Caruso, B.S.**, Koshik, Y, Pavlenko, V. and V. Tobilko. 2008. The use of a permeable reactive barrier for contaminated groundwater in Ukraine. In *Proceedings of the 3rd Central and Eastern European Conference on Health and the Environment in Cluj-Napoca, Romania.*

Kornilovych, B., Pavlenko, V., Koshik, Y., **Caruso, B.S.** and M. Wireman. 2008. The use of a chemical permeable reactive barrier for solving the ecological problems of mine enterprises. *IV International Scientific and Practical Conference: "Ecological Safety: Problems and What to Do?", Russia*, pp. 236-240.

Caruso, B.S. and H.E. Dawson. 2008. Impacts of groundwater metal loads from bedrock fractures on water quality of a mountain stream. *2008 US EPA/National Groundwater Association Remediation of Abandoned Mine Lands Conference*. Denver, CO.

Cox, T.J. and B.S. Caruso. 2008. Modeling metals pollution in surface waters. *2008 US EPA/National Groundwater Association Remediation of Abandoned Mine Lands Conference*. Denver, CO.

Caruso, B.S., Cox, T., and M. Bishop. 2006. Modeling effects of natural flow restoration on metals fate and transport in Upper Tenmile Creek, Montana. *EPA Hard Rock 2006 Conference*, Tucson, AZ.

Caruso, B.S. and M. Sanders. 2004. Evaluation of the effectiveness of Project River Recovery in the Upper Waitaki Basin. *New Zealand Hydrological Society 2004 Conference*, Queenstown, New Zealand.

Caruso, B.S. 2003. Modeling metals TMDLs in a mining-impacted watershed. *Water Environment Federation, TMDL 2003 Proceedings,* Chicago, IL.

Caruso, B.S. 2002. Modeling metals transport and sediment/water interactions in a mining impacted mountain stream. *9th International Symposium on the Interactions Between Sediments and Water*. Banff, Canada. May 5-10.

Caruso, B.S. and P.W. Downs. 2002. Planning and design of urban river restoration in a steep, coastal New Zealand catchment. *Water Environment Federation,.Watershed 2002 Conference Proceedings,* Orlando, FL.

Caruso, B.S., Wangerud, K. and K. Olds. 2002. Deterministic and stochastic water balance modeling of the Gilt Edge Mine Superfund Site, South Dakota. *Society for Mining, Metallurgy, and Exploration 2002 Annual Meeting*, Phoenix, AZ.

Downs, P.W. and **B.S. Caruso**. 2000. The Three Streamscapes Project: fluvial geomorphology context for rehabilitation opportunities in the Water of Leith, Dunedin, New Zealand. In: *Proceedings of Gravel Bed Rivers 2000 Conference*, University of Canterbury, Christchurch, New Zealand.

Caruso, B.S. 1998. Estimation of low flows in Otago: practice and problems. In: *Abstracts of New Zealand Hydrological Society Annual Meeting*. 24-27 November, 1998. University of Otago, Dunedin, New Zealand.

Caruso, B.S. and J.C. Loftis, 1996. Screening-level assessment of nonpoint source pollution from inactive hardrock mines in the Cement Creek Basin, Colorado. In: *Proceedings of Tailings and Mine Waste '96 Conference, Colorado State University,* Ft. Collins, CO.

Caruso, B.S. 1996. Targeting criteria and assessment information goals for diffuse pollution in mined watersheds. In: *Proceedings of Watershed '96 Conference, Water Environment Federation.* pp. 932-935, Albuquerque, NM.

Caruso, B.S. 1996. Attributes and uncertainty of catchment water quality data. In: *Hydrology '96 "From Inputs to Outputs". New Zealand Hydrological Society Symposium*, Wellington, New Zealand.

Caruso, B.S. 1992. Design of an event-based surface-water monitoring program at Rocky Flats Plant, Colorado. In: *Proceedings of Spectrum '92: Nuclear and Hazardous Waste Management Conference*, Denver, CO.

Caruso, B.S. 1992. Development of a sitewide surface-water and sediment monitoring program at Rocky Flats Plant, In: *Proceedings of Colorado Water Engineering and Management Conference*, Denver, CO.

Caruso, B.S. 1992. Characterization of surface-water quality at Rocky Flats Plant. In: *Proceedings of Colorado Hazardous Waste Management Society 1992 Annual Conference,* Denver, CO.

REFEREED REPORTS AND REPORT CHAPTERS:

Over 50 scientific and technical refereed reports and report chapters, including consultant and government reports.

INVITED LECTURES:

Caruso, B.S. 2009. Surface water hydrology and metals transport at hard rock mine sites. *US EPA, National Center for Disease Control and Public Health, Science and Technology Center of Ukraine Workshop, Environmental Characterization (Ground Water and Surface Water) and Risk Assessment at Hard Rock Mine Sites, Tbilisi, Georgia.*

Caruso, B.S. 2009. An international perspective: Water allocation in the US and comparison to New Zealand. Invited Keynote presentation. *New Zealand Hydrological Society Workshop - Meeting the Challenges of Water Allocation: Learning From Each Other, Wellington, New Zealand.*

Caruso, B.S. 2005. Modeling metals fate and transport in the Upper Tenmile Creek Watershed, Montana. *US EPA Council on Regulatory Environmental Modeling, Region 8 Metals Fate and Transport Modeling for Contaminated Sites and Mercury TMDLs Seminar, Denver, CO.*

Caruso, B.S. 2004. Contrasts between water management in New Zealand and the United States. Invited Plenary presentation, *New Zealand Hydrological Society 2004 Conference, Queenstown, New Zealand.*

Caruso, B.S. 2001. Planning and design of urban river restoration in a steep, coastal New Zealand catchment. *Hydrology and Water Resources Seminar, Department of Civil Engineering, Colorado State University, Ft. Collins, CO.*

Caruso, B.S. 1999. Environmental indicators: Issues and use for resource management in Otago. Invited paper in: Holt, A., Dickenson, K., and Kearsley, G.W. (Eds.) *Proceedings of the Environmental Indicators Symposium,* University of Otago, Dunedin. pp. 65-73.

Ph.D. DISSERTATION AND M.S. THESIS:

Caruso, B.S. 1995. A Watershed-Based Methodology for Assessment of Nonpoint Source Pollution from Inactive Mines. Ph.D. Dissertation, Department of Civil Engineering, Colorado State University, Ft. Collins, CO.

Caruso, B.S. 1987. Hydrologic Water Quality Modeling of an Alpine Watershed. M.S. Thesis, Institute of Arctic and Alpine Research/Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, CO.

RESEARCH SUPPORT:

Engineered Lake Levels Feasibility Study - Environment Canterbury, Ngai Tahu, and Ministry for the Environment, March 2013 – May 2015 ($205,000), PI: B. Caruso.

Hydrological Assessment and Feasibility Study for Stewart Island Hydropower Renewable Energy Resource, Venture Southland and Southland Regional Council. Jan 2013 – May 2015 ($30,000), PI: B. Caruso.

Modelling Flood Effects on Braided River Floodplain Riparian Vegetation. Department of Conservation PhD Research Grant, January 2012 – May 2015 ($13,000), PI: B. Caruso.

Modelling the Hydrology of Mountain Catchments and Effects of Climate Change on Water Resources using TOPNET, Summer Scholarship, University of Canterbury, November 2009 – January 2011 ($5,000), PI: B. Caruso.

Evaluation of the Effectiveness of New Zealand Water Resources and Aquatic Ecosystem Restoration Programmes, Summer Scholarship, University of Canterbury, November 2009 – January 2010 ($5,000), PI: B. Caruso.

An International Perspective: Water Allocation in the US and Comparison to New Zealand, Small Advice Grant for Freshwater - Foundation for Research Science and Technology, Tasman District Council, and New Zealand Hydrological Society, October 2009 ($5,000), PI: B. Caruso.

Evaluation and Revision of the Metals Exposure and Transport Assessment (META4) Model, US EPA Office of Research and Development, April – December 2009 ($25,000), PI: B. Caruso, co-PIs: B. Butler, US EPA and R. Runkel, US Geological Survey

Regional Evaluation of Mining-Related Metals Contamination, Risks, and Innovative Remediation Technologies in Ukraine and Georgia, US State Department, Former Soviet Union Biochemical Weapons Redirect Program, January 2007 - December 2009 ($325,000), PI: B. Caruso, co-PI: M. Wireman, US EPA.

Modeling Metals Fate and Transport in Streams and Watersheds Workshop, US EPA Office of Research and Development, September 2006 - March 2007 ($22,000), PI: B. Caruso.
Classification of Montana Lakes for Development of Nutrient Criteria, State of Montana Department of Environmental Quality, January – September, 2003 ($10,000), PI: B. Caruso.
Watershed Water Quality Research and Assessment for the Alamosa River Watershed, US EPA Region 8 and Alamosa Riverkeeper Environmental Justice Grant, January - December 2003 ($20,000), PI: A Hirsch, RMR Consultants, co-PI: B. Caruso.
Critical Review of Project River Recovery – New Zealand's Braided River Restoration Program, New Zealand Department of Conservation, December 2002 – December, 2003 ($10,000), PI: B. Caruso.
Comparative Analysis of New Zealand and US Approaches for Agricultural Nonpoint Source Pollution Management, New Zealand Ministry of Research, Science and Technology, January - December 1997 ($5,000), PI: B. Caruso.
Evaluation of Impacts of Landslides on Contaminant Sources and Transport in a Steep, Pastoral Catchment, Victoria University of Wellington, School of Earth Resources, September, 1996 – December, 1997 ($15,000), PI: B. Caruso.
A Watershed-Based Methodology for Assessment of Nonpoint Source Pollution from Inactive Mines, US EPA Region 8 Rocky Mountain Headwater Mining Waste Initiative, Colorado Center for Environmental Management (US Dept. of Energy and Western Governor's Association grant), May 1993 - April, 1995 ($45,000), PI: B. Caruso, co-PI: J. Loftis, Colorado State University.
In addition, secured over $2.5 million in scientific and technical environmental consulting contracts over the last 15 years.

COURSES TAUGHT:
ENNR 422 - Water Resources and Irrigation Engineering
ENNR 405 – Ecological and Bioresources Engineering
ENNR 322 - Ecological Engineering
ENNR 320 – Integrated Catchment Analysis
ENVI 114 - Environment and Resources: the Foundations
ENVI 214 - Environment and Resources: New Zealand Perspectives
GEOG 223 - Physical Environmental Processes: Field Methods
GEOG 323 - Advanced Physical Environmental Processes
PHYG 404 - Hydrology and Water Resources

STUDENT RESEARCH SUPERVISION:

Completed PhD Theses:
Luke Javernick, 2014. Relationship Between Flood Events and Vegetation Mortality in the Braided Ahuriri River, New Zealand. Department of Civil and Natural Resources Engineering, University of Canterbury.
Mauricio Arias (Co-Supervisor), 2013. Impacts of Hydrological Changes to Vegetation Production of the Tonle Sap Floodplain, Cambodia. Department of Civil and Natural Resources Engineering, University of Canterbury.

Completed MS/ME Theses:
Henry Wadworth-Watts, 2013. A Hydrological and Nutrient Transport Budget for an Inter-Montane Catchment. Department of Civil and Natural Resources Engineering, University of Canterbury.
Eugene Beran, 2011-2013. Flood Modelling in a High Country Mountain Catchment. Department of Civil and Natural Resources Engineering, University of Canterbury.
Esther Jensen, 1998. Impacts of Landslips on Contaminant Sources in Steep Pastoral Hill Country – Lake Tutira, North Island, New Zealand. M.S. Thesis, School of Earth Resources, Victoria University of Wellington. Thesis Committee: Michael Crozier and Jack McConchie.
Alfred Ayah, 1998. Environmental and Socio-economic Costs and Benefits of Gold Mining in New Zealand. M.A. Thesis, Environmental Studies Program, Victoria University of Wellington. Thesis Committee: Paul Mosley and Roger Lawrence.
Mark Herrmann, 1997. Environmental Impact Assessment Strategies: An International Comparison. M.A. Thesis, Environmental Studies Program, Victoria University of Wellington. Thesis Committee: Paul Mosley and Roger Lawrence.

Current PhD Candidates:
Denjam Khadka, 2011-2015. Modelling Climate Change Effects on Water Resources in a Mountain Basin.
Tuyen Dinh, 2015-2018. Impacts of climate change and deforestation on the ecology and hydrology of mountainous areas.

Benjamin Uster (Co-Supervisor), 2012-2015. Quantifying Rate-Limiting Processes in Sustainable Engineered Bioreactors for Treating Mining-Influenced Waters.

Bikesh Shrestha (Co-Supervisor), 2014-2017. Integrated Sediment Management for Catchments with Hydropower Dams: Opportunity, Costs, and Uncertainty.

Senior Student Research Project Reports:

Ellen Worthington and Geoff Lyman, 2014. Modelling Climate Change Impacts on Braided River Floodplain Ecology and Restoration.

Ben Nicholson and Jordan Cathcart, 2014. Modelling Effects of Agricultural Land Use on Water Quality in High Country Tussock Grassland Catchments.

Simon Newton and Regan King, 2014. Modelling Climate Change Impacts on Hydropower Generation in the Upper Waitaki Basin.

Anthony Jordan, 2014. Analysis and Modelling of the Effects of Climate Patterns on River Flows.

Ben Nicholson, 2013-2014 Summer Scholarship. Evaluation of Water Quality and Tributary Nutrient Loads for Restoration of Te Waihora/Lake Ellesmere.

Daniel McMullan and Ben Young, 2013. Analysis and Modelling of Snowmelt in Mountain Catchments using TopNet.

Michael Paine and Stuart McCready, 2013. Monitoring and Analysis of Water Quality in Relation to the Water Level of Te Waihora/Lake Ellesmere.

Skye Patterson-Kane and Jess Newlands, 2013. Analysis and Modelling of Braided River Flow Regimes and Floodplain Effects.

Subodh Dhakal, 2011. Modelling the Hydrology of Mountain Catchments and Effects of Climate Change on Water Resources using TopNet.

Alicia Fleck and Andrea Talia'uli, 2011. Analysis of Surface Water Flows in a High Country Stream-Wetland-Lake Complex.

Laura Edmondson and Callum Pithie, 2011. Analysis of Braided River Flood Characteristics and Floodplain Effects.

Claire Murray, 2010-2011 Summer Scholarship. Aquatic Restoration in New Zealand, Overview and Evaluation.

Alex Ross and Claire Shuker, 2010. Impacts of River Flows on Exotic Vegetation in the Ahuriri River.

Mhairi Rademaker and Andrew Balme, 2010. Understanding the Hydrology of the Ahuriri River, Upper Waikati Basin, New Zealand.

Summer Faulkner and Michaela Sherratt, 2010. Lake Clearwater Wetlands Diffuse Pollution Study.

PhD Thesis Oral Examiner:

Aidi Alias, 2015. Integrating WDM mechanisms for reducing and managing domestic water usage. PhD. Thesis, Department of Civil and Environmental Engineering, University of Auckland.

Muhammad Hashmi, 2011. Watershed scale climate change projections for use in hydrologic studies: Exploring new dimensions. Ph.D. Thesis, Department of Civil and Environmental Engineering, University of Auckland.

Masters Thesis Examiner:

Eric Kilaka, 2015. The effects of windbreaks on the effectiveness of sprinkler irrigation systems. M.E. Thesis, Department of Civil and Natural Resources Engineering, University of Canterbury.

Elisabeth Liddle, 2014. Assessing the state of the water quality, the challenges to provision, and the associated water development considerations in Ndola, Zambia. M.Sc. Thesis, Department of Geography, University of Otago.

Cheng Shi, 2014. Hydrological and chemical characteristics of Mathews Lagoon and Bogy Pond, Wairarapa - Essential information for the decision making process of wetland restoration. M.Sc. Thesis, Department of Biology, Victoria University of Wellington.

Simon Pollack, 2011. Assessing groundwater/surface water connectivity and the effect on groundwater quality in Alexandra, Central Otago. M.Sc. Thesis, Department of Geography, University of Otago.

Joseph Wheeler, 2010. Hydrodynamic modeling and quantification of available habitat in constructed wildlife reserves. M.E. Thesis, Department of Civil and Natural Resources Engineering, University of Canterbury.

PhD Oral Examination Organizer:

Colin Whittaker, 2014. Ph.D. Thesis, Department of Civil and Natural Resources Engineering, University of Canterbury.

Vinod Sadashiva, 2011. Ph.D. Thesis, Department of Civil and Natural Resources Engineering, University of Canterbury.

Craig McCauley, 2011. Ph.D. Thesis, Department of Civil and Natural Resources Engineering, University of Canterbury.

PROFESSIONAL ACTIVITIES:

Member

American Geophysical Union, 2004 to present
American Water Resources Association, 1995 to present
International Association of Hydrological Sciences, 1996 to present
New Zealand Hydrological Society, 1996 to present
Organizing Committee, 2007 Annual Conference

Associate Editor for Riparian Ecology and Management, *Journal of the American Water Resources Association*

Journal Reviewer: *Journal of Environmental Engineering, Environmental Management, Journal of Environmental Management, Environmental Monitoring and Assessment, Hydrological Sciences Journal, Journal of Hydrology, Journal of Hydrology (New Zealand), Wetlands, Ecohydrology*

Book reviews: *Journal of the American Water Resources Association*

Proposal Reviews

US EPA Regional Applied Research Effort (RARE) grants 2004, 2006, 2007
US EPA Science to Achieve Results (STAR) Small Business Innovative Research (SBIR) grants 2006
US State Department US-Egypt Joint Science and Technology Program grants 2005
US EPA Region 8 Environmental Education grants 2005
US EPA Region 8 Regional Priority grants 2005
US EPA Mine Waste Technology Program grants 2004, 2005
US EPA Community Action for a Renewed Environment (CARE) grants 2004

Organizer

US EPA, National Center for Disease Control and Public Health, Science and Technology Center of Ukraine, Environmental Characterization (Ground Water and Surface Water) and Risk Assessment at Hard Rock Mine Sites Workshop, Tbilisi, Georgia, 2009
New Zealand Hydrological Society Annual Meeting, Taupo, New Zealand, 2007
US EPA Office of Research and Development Metals Fate and Transport Modeling Workshop, Denver, CO, 2007
US EPA Abandoned Mine Lands Innovative Treatment Technologies Workshop, Coeur d'Alene, ID, 2007
US EPA Council on Regulatory Environmental Modeling, Integrated Modeling for Integrated Environmental Decision-Making Workshop, Research Triangle Park, NC, 2007
US EPA Office of Research and Development Hard Rock 2006 Conference, Tucson, AZ, 2006
US EPA Abandoned Mine Lands Innovative Treatment Technologies Workshop, Denver, CO, 2005
US EPA Council on Regulatory Environmental Modeling, Region 8 Metals Fate and Transport Modeling for Contaminated Sites and Mercury TMDLs Seminar, Denver, CO, 2005

Moderator

US EPA Office of Research and Development Metals Fate and Transport Modeling Workshop, Denver, CO, 2007
US EPA Office of Research and Development Hard Rock 2006 Conference, Tucson, AZ, 2006
US EPA Abandoned Mine Lands Innovative Treatment Technologies Workshop, Denver, CO, 2005

REFEREES FOR BRIAN S. CARUSO

Available upon request.

CHARLIE FITTS
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79 Winnocks Neck Road
Scarborough, Maine 04074
cfitts@fittsgeosolution.com
(207) 510-7650

EDUCATION

Ph.D. Civil Engineering, University of Minnesota, Minneapolis, MN, 1990

M.S. Civil Engineering, University of Minnesota, Minneapolis, MN, 1985

M.S. Geological Sciences, Cornell University, Ithaca, NY, 1979

B.A. Geology/Biology, Colby College, Waterville, ME, 1976

EMPLOYMENT AND EXPERIENCE

1991-present: Owner, Fitts Geosolutions, LLC (selected examples)

Advised numerous consultants, helping them use AnAqSim groundwater flow modeling software to simulate remediation scenarios, coastal interface flow, mine dewatering, recharge basins, and regional aquifer modeling.

Advised a consulting company about modeling dissolved salt solute transport from a collapsed salt mine into an overlying aquifer in western New York State.

Performed a forensic analysis of pumping tests with a new well in a municipal well field in central Maine, to learn why the new well sand filter failed.

Analyzed aquifer properties and estimated the potential yield of wells near springs in central Maine using 3-D MODFLOW simulations.

Analyzed pumping tests and capture zones for seven different remediation projects for an Indiana environmental consulting firm.

Analyzed two 48-hour pumping tests and created a 3D MODFLOW model to simulate the impacts of proposed groundwater pumping on the sustainability of surface water flows in a sand and gravel aquifer in Fryeburg, ME.

Analyzed the rate of diffusion of radioactivity out of the concrete containment structure at the decommissioned Maine Yankee nuclear power plant in Wiscasset, Maine, to help with decision about whether to remove the structure. Developed both analytic and finite-difference mathematical models of the diffusion. Helped design educational displays about groundwater for Poland Spring Bottling Co.

Analyzed construction dewatering at a site with a braced excavation and sheet-pile cutoff wall. Used MODFLOW to model 3-D transient flow to sumps inside the cutoff wall. Estimated pump discharges and times to achieve drawdown in stages.

Gave a two-hour short course on non-equilibrium solute transport processes and modeling to geologists and engineers at a Massachusetts groundwater consulting company.

Analyzed the patterns of drawdown near a well field in an anisotropic aquifer, for a consultant in Maryland.

Retained as an expert on groundwater contamination in a class-action law suit regarding MTBE contamination in Maine. Researched the transport and toxicity properties of MTBE relative to other compounds in gasoline and other common organic chemicals.

One of a panel of experts hired by the city of Indianapolis to review mathematical modeling of groundwater flow in the vicinity of three municipal well fields.

Developed mathematical models of seepage beneath a proposed dam in Switzerland for an electric utility.

Provided technical counsel related to a lawsuit involving the timing of gasoline releases and contaminant migration in Waterboro, ME.

Performed review of geotechnical and geohydrological aspects of a proposed special waste landfill expansion in Norridgewock, Maine.

Analyzed construction dewatering at a site with a braced excavation and sheet-pile cutoff wall. Used MODFLOW to model 3-D transient flow to sumps inside the cutoff wall. Estimated pump discharges and times to achieve drawdown in stages.

Testified as an expert witness in New York DEC hearings regarding a proposed large gravel mining operation in western New York. Testimony was about groundwater flow modeling of potential impacts.

1991-2014: University of Southern Maine, Gorham, ME, Professor of Geoscience (1991-2014), Associate Dean of the College of Science, Technology, and Health (2013-2014), Professor Emeritus (2015-)

Acting Director of Environmental Science and Policy Program 2001-2003, Chair of Geosciences Department, 2007-2011.

Courses taught at USM: *Physical Geology, Oceanography, Floods Glaciers and Changing Climate, Atmospheric Science, Water Resources, Groundwater Flow and Quality, Groundwater*

Modeling, and *Topics in Groundwater Contamination*. Positive student evaluations of teaching: typically 1 to 1.5 on a scale of 1 to 5, 1 being best.

Principal Investigator or Co-PI on research grants: a) develop environmental geophysics capability at USM, b) evaluate groundwater flow in a sand and gravel aquifer near a local water supply well field, c) evaluate the same aquifer geometry with seismic refraction surveys, d) mapping and modeling a glaciofluvial aquifer in Wells, ME. Advised and mentored students on these grants.

Reviewed and continue to review 2-6 journal articles per year for several journals including *Water Resources Research, Ground Water, Advances in Water Resources, Journal of Hydraulic Engineering, and Journal of Hydrology*.

Guest lectured on various groundwater topics at Colorado State U., U. Wyoming, U. Colorado, Colorado State U., U. Maine, U. New Hampshire, Colby College, Tufts U.

1987-1991: GeoTrans, Inc., Harvard, MA. Principal Engineer, groundwater consulting (selected examples)

Responsible for computer operations in the Massachusetts regional office. Responsible for computer hardware and software used for groundwater modeling. Trained others in the use of computers, software, and models.

Provided technical consultation regarding the characterization and remediation of a contaminated industrial site. Recommended and helped design deep bedrock monitoring wells, a ten-day pilot test of the groundwater extraction/treatment system, and laboratory experiments to assess the sorption of chlorinated organic contaminants. Mediated discussions between the present and former landowners regarding the remedy, which included groundwater extraction and treatment, soil excavation, and ex-situ soil venting.

Investigated dissolved TCE and PCE contamination in the vicinity of water supply wells. Used soil gas surveys and micro-well installations in the sand and gravel aquifer to map the distribution of contaminated groundwater and help define the source of contamination.

Helped design and oversee the construction of a passive trench to skim petroleum LNAPL off the water table in an unconfined aquifer.

Evaluated solvent contamination problems and potential remedies at two industrial sites in New Jersey. Defined, as well as possible, the probable sources and timing of contaminant releases to help settle a litigated dispute between the owner and its insurance companies.

Evaluated hydrogeologic conditions at proposed landfill sites for private clients in Maine, Minnesota, and New Jersey. Using analytic and numerical models, analyzed the three-dimensional groundwater flow patterns for pre- and post-construction conditions. Estimated drawdowns and discharges associated with proposed underdrain systems, assessed the contaminant migration patterns for hypothetical failures. Recommended monitoring systems and contingency plans to minimize the potential adverse impacts on groundwater.

Estimated off-site contaminant discharges via groundwater at seven hazardous waste sites in Niagara Falls, for a study of contaminant discharges to the Niagara River.

Set up and monitored a 48 hour pumping test at a landfill site in Minnesota. Used pressure transducers and data loggers to collect data at eight wells. Estimated formation hydraulic conductivity and storativity from the test.

Taught a workshop on the use of the USGS modular three-dimensional groundwater flow model (MODFLOW) to engineers and geologists at a large consulting firm.

Provided technical counsel and expert testimony regarding contaminant migration via groundwater to the Delaware River. Gave testimony in a deposition and in the trial.

1986-1987: CDM, Boston, MA. Water Resources Engineer, groundwater consulting (selected examples)

Evaluated groundwater flow and contaminant transport patterns for the US EPA at two Superfund hazardous waste sites in New Jersey. Used a three-dimensional finite element program for flow simulation and a random-walk particle tracking program for simulation of contaminant transport. Evaluated alternatives for site cleanup, and the effectiveness of an existing slurry-wall barrier.

1979-1983, 1985-1986: GEI Consultants, Winchester, MA., Geologist/Engineer, geotechnical consulting (selected examples)

Investigated groundwater contamination in the vicinity of paper mill waste dewatering lagoons. Field program consisted of borings, well installations, hydraulic testing, surface and groundwater sampling. Did 2-D modeling of groundwater flow and contaminant transport patterns.

Design of a 1500 foot embankment dam in Maine. Soil and rock conditions were mapped in the foundation and borrow areas. Strength and permeability tests were performed on borrow materials. Seepage and stability analyzes were performed, a design was recommended, and the dam was constructed.

Evaluated the liquefaction potential of a sand being considered for construction of large offshore oil drilling caissons in the Arctic Ocean. Performed dynamic triaxial strength tests to determine the liquefaction behavior as a function of density.

Simulated groundwater flow beneath a dam in Colorado. The simulated heads were used in stability analyses of the dam.

Field experience includes installation and monitoring of: soil borings, groundwater monitoring wells, dedicated groundwater sampling systems, borehole permeability tests, large-scale pumping tests, gas monitoring wells, pneumatic and electronic piezometers, borehole inclinometers, settlement plates and tiltmeters.

Performed geotechnical lab tests including permeability tests in triaxial cells, triaxial compression tests, cyclic triaxial compression tests, resonant column dynamic triaxial torsion tests, consolidation tests, direct shear tests, compaction tests, and index tests.

COMMERCIAL SOFTWARE

Fitts, C.R., *AnAqSim (Analytic Aquifer Simulator)*. This software is based on the techniques outlined in the 2010 *Water Resources Research* journal article. It simulates groundwater flow analytically and allows multiple layers, anisotropy, heterogeneity, and transient flow. 106 page User Guide. First released in 2011, with 1-3 releases per year since then. See http://www.fittsgeosolutions.com.

Fitts, C.R., *AnAqSimEDU (Analytic Aquifer Simulator, free educational version)*. Like *AnAqSim*, but with limited capabilities. Supplement to *Groundwater Science*, *2nd ed*ition. First released in 2012.

Fitts, C.R., *TWODAN*, Two-dimensional analytic groundwater flow model, Windows program and 41 page manual. Over 500 licenses distributed to a wide range of domestic and foreign universities, consulting firms, and public agencies. First released in 1993.

Fitts, C. R., *SOLUTRANS*, a computer program for modeling groundwater contaminant transport using analytic solutions. About 50 licenses have been distributed to universities, consulting firms, and public agencies. First released in 1999.

BOOKS

Fitts, C.R., 2012, *Groundwater Science 2nd ed.*, 672 p., Academic Press (Elsevier), Amsterdam.

Over 6000 print copies sold (both editions), adopted by geology and civil engineering departments at 50+ universities including Colorado State U., Penn State U., Arizona State U., U. Colorado, U. Massachusetts , U. New Mexico, U. Wyoming, U. Wisconsin, Rutgers U., U. Maine, SUNY Buffalo, N. Carolina State U., Harvard U., Texas A&M, U. Alberta (Canada), Manchester U. (U.K.), Delft University of Technology (Netherlands), U. Utrecht (Netherlands), and U. Copenhagen (Denmark).

Fitts, C.R., 2012, *Groundwater Science, 2nd ed. Solutions Manual*, 76 p., Academic Press (Elsevier Science), Amsterdam.

Fitts, C.R., 2002, *Groundwater Science*, 450 p., Academic Press (Elsevier), San Diego.

JOURNAL ARTICLES

Hocking, M, C. Beverly, C. Fitts, and B. Kelly, in review 2016, Quantifying Leaky Wells using the Analytic Element Method, submitted to *Groundwater*.

Fitts, C.R., J. Godwin, K. Feiner, C. McLane, and S. Mullendore, 2015, Analytic Element Modeling of Steady Interface Flow in Multilayer Aquifers Using AnAqSim, *Groundwater*, 53 (3), 432–439, doi: 10.1111/gwat.12225

Fitts, C.R., 2010, Modeling Aquifer Systems with Analytic Elements and Subdomains, *Water Resources Research*, 46, W07521, doi:10.1029/2009WR008331.

Fitts, C.R., 2006, Exact Solution for Two-Dimensional Flow to a Well in an Anisotropic Domain, *Ground Water*, 44(1), 99-101.

Fitts, C.R., Analytic Modeling of Impermeable and Resistant Barriers, *Ground Water*, 35(2), 312-317, 1997.

Fitts, C.R., Uncertainty in Deterministic Groundwater Transport Models due to the Assumption of Macrodispersive Mixing: Evidence from the Cape Cod and Borden Tracer Tests, *Journal of Contaminant Hydrology*, 23, 69-84, 1996.

Fitts, C.R. and Strack, O.D.L., Analytic Solutions for Unconfined Groundwater Flow Over a Stepped Base, *Journal of Hydrology*, 177, 65-76, 1996.

Fitts, C.R., Well Discharge Optimization Using Analytic Elements, *Ground Water*, 32(4), 547-550, 1994.

Fitts, C.R., Modeling Three-Dimensional Flow about Ellipsoidal Inhomogeneities, with Application to Flow to a Gravel-Packed Well and Flow Through Lens-Shaped Inhomogeneities, *Water Resources Research*, 27(5), 815-824, 1991.

Fitts, C.R., Simple Analytic Functions for Modeling Three-Dimensional Flow in Layered Aquifers, *Water Resources Research*, 25(5), 943-948, 1989.

CONFERENCE PRESENTATIONS (since 2004)

Fitts, C. R., 2013, Response of groundwater/surface water systems to pumping and other stresses, Maine Water Conference, Augusta, ME.

Fitts, C. R, 2011, Analytic Element Modeling with Subdomains and Finite-Difference Time Steps, International Ground Water Modeling Center MODFLOW and More, Golden, CO.

Fitts, C. R., 2010, Engineered Perched Aquifers for Low-Cost Small Water Supplies, National Ground Water Association Ground Water Summit, Denver, CO.

Fitts, C.R., 2007, Analyzing the Sustainability of Groundwater Pumping in the Fryeburg Sand and Gravel Aquifer, Maine Water Conference, Augusta, ME.

Fitts, C.R., 2006, Modeling Groundwater Flow in Layered, Anisotropic, and Heterogeneous Aquifer Systems using Discrete Analytic Domains, Geological Society of America Annual Meeting, Philadelphia, PA.

Fitts, C.R., 2006, Discrete Analytic Domains: A New Technique for Groundwater Flow Modeling in Layered, Anisotropic, and Heterogeneous Aquifer Systems, MODFLOW and More 2006, International Ground Water Modeling Center, Golden, CO.

Fitts, C.R., 2006, Discrete Analytic Domains: A New Method to Model Complex Aquifer Systems with Layers, Anisotropy, and Heterogeneity, 5th International Conference on the Analytic Element Method, Kansas State University, Manhattan, KS.

Fitts, C.R., 2004, Discrete Analytic Domains: A New Technique for Groundwater Flow Modeling in Layered, Anisotropic, and Heterogeneous Aquifer Systems, American Geophysical Union Fall Meeting, San Francisco, CA.

Fitts, C.R., 2004, Discrete Analytic Domains: a New AEM Formulation for Modeling Anisotropy and Heterogeneity, USEPA/NGWA Fractured Rock Conference, Portland, ME.

PROFESSIONAL AFFILIATIONS

Registered Professional Engineer, Maine #5513

Member, National Ground Water Association

Curriculum Vitae **updated: 2-2-2016**

Haitjema, Hendrik Marten

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Bloomington, IN
USA
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www.haitjema.com

EDUCATION

Ph.D. - Civil Engineering, 1982, University of Minnesota. Thesis Title: 'Modeling Three-dimensional Flow in Confined Aquifers using Distributed Singularities.'
Master's Degree - (Ingenieurs, includes Bachelor Degree) in Civil Engineering (specialty: Sanitary Engineering), 1976, Delft University of Technology, The Netherlands.

ACADEMIC APPOINTMENTS

- August 2012 – present - Professor Emeritus, , School of Public and Environmental Affairs, Indiana University.
- 1997-August 2012 **-**Professor, School of Public and Environmental Affairs, Indiana University. Duties: Teaching in the field of Groundwater Flow, Geotechnical Engineering and Applied Mathematics. Research in the field of Groundwater Flow.
- 1997-present - Professor (part time), Department of Geology, Indiana University Purdue University, Indianapolis.
- 1997-present - Professor (part time), Department of Geology, Indiana University.
- 1984-1997 - Associate Professor, School of Public and Environmental Affairs, Indiana University. Duties: Teaching in the field of Groundwater Flow, Geotechnical Engineering and Applied Mathematics. Research in the field of Groundwater Flow.
- 1989-1997 - Associate Professor (part time), Department of Geology, Indiana University Purdue University, Indianapolis.
- 1988-1997 - Associate Professor (part time), Department of Geology, Indiana University.
- 1982-1984 - Assistant Professor, Department of Civil and Mineral Engineering, University of Minnesota. Duties: Teaching in the field of Soil Mechanics, research in the field of Groundwater Flow.
- 1978-1982 - Instructor, Department of Civil and Mineral Engineering, University of Minnesota. Duties: Teaching in the field of Soil Mechanics, research in the field of Groundwater Flow

OTHER APPOINTMENTS AND PROFESSIONAL CONSULTANTSHIPS

- **1978 (3 months) -** *Hydrologist at HARO B.V.* (Geotechnical and Hydrological Consulting Firm, The Netherlands). Duties: Stationed in Kenya to perform the final hydrological studies for three drinking water projects. The study included field surveys. (Leave of absence from both the University of Minnesota and the Delft University of Technology).
- **1977-1978 -** *Junior Engineer at the University of Minnesota.* Duties: During a 4-month leave of absence from the Delft University of Technology I was employed by the U of M to participate in a research project at the Department of Civil and Mineral Engineering: the modeling of groundwater flow near the Tennessee-Tombigbee Waterway under contract with the U.S. Army Corps of Engineers.
- **1976-1978 -** *Scientific Officer at the Delft University of Technology.* Duties: Research in soil mechanics and groundwater flow. Advising graduate students. Participation in the design of advanced triaxial test

equipment and designing of computer programs for modeling fresh/salt water interface flow. Member of national committees: 'Artificial Recharge of Groundwater' and 'In Situ Testing of Bearing Capacity of Foundation Piles.'

- **1976 (2 months) -** *Project Engineer at IWACO* (International Water Engineer Consultants). Duties: Design and use of computer models to study the environmental impact of pumping salt water from underneath the dunes near The Hague (The Netherlands).
- **1974-1976 -** *Research Engineer at the 'Provincial Drinking Water Company of Northern Holland.'* Duties: 1) Study drinking water injection in a saline aquifer in Northern Holland (Master's thesis research). 2) Hele Shaw model study at the Geotechnical Laboratory of the Delft University of Technology.

LICENSURE AND CERTIFICATION

Certified Hydrologist (groundwater) by the American Institute of Hydrology (AIH).

PROFESSIONAL SOCIETIES

Koninklijk Instituut van Ingenieurs (KIVI)
Netherlands Society for Soil Mechanics and Foundation Engineering
American Geophysical Union (AGU)
Indiana Water Resources Association (IWRA)
National Ground Water Association (NGWA)

HONORS

Editor-in-Chief of the journal *Groundwater*
Bechert Award of the Indiana Water Resources Association (2013)
Funded *Braun/Braun Intertec Visiting Professorship* at the Civil Engineering Department of the University of Minnesota (January – May 2005)
SPEA Graduate Teaching Award (2005)
SPEA Graduate Teaching Award (1998)
Teaching Excellence Recognition Award (TERA) (1998)
SPEA Undergraduate Teaching Award (1992)
SPEA Graduate Teaching Award (1992)
William G. Wilber – John S. Zogorski Leadership Award for exemplary service as President of IWRA 1990
Delft University of Technology Award of 350 guilders for special performance during the preparation of the Master's Thesis, 1976.

TEACHING ASSIGNMENTS

Indiana University School of Public and Environmental Affairs (1985-present)

Groundwater Flow Modeling (undergraduate)
Introduction to Groundwater Hydrology (undergraduate)
Mathematics for Environmental Sciences (graduate)
Mathematics for Environmental Sciences (undergraduate)
Environment and People (undergraduate)
Introduction to Environmental Sciences (undergraduate)
Soil Mechanics and Science (graduate)
Groundwater Flow Modeling (graduate)
Elements of Fluid Mechanics (undergraduate)
Environmental Policy (undergraduate)
Environmental Policy Analysis (graduate)

University of Minnesota Department of Civil and Mineral Engineering (1980-1984)

Elements of Soil Mechanics (undergraduate)
Soil Mechanics Laboratory (undergraduate)

SERVICES

University Service, Indiana University

SPEA Services

1. Ph.D. in Environmental Sciences program director 2009 - present
2. MSES program director 2008 - present
3. MSES program director 2004
4. ESAP faculty chair (1997 - 2004)
5. Ph.D. Program Director (1993 - 1997)
6. Resident Director SPEA - EUR/LUR Student Exchange Program for 16 students in
7. Rotterdam during Spring 1988.

SPEA Committees

1. Member search committee for Management Science position
2. Chair MSES Curriculum Advisory Committee (2006-present)
3. P&T – Personnel Committee (2006-present)
4. Chair MSES Curriculum Revision Committee (2005-2006)
5. P&T Committee (1997-1998)
6. Promotion & Tenure Policies (1997-1999)
7. Promotion & Tenure Policies Subcommitee on Teaching (1997-1999)
8. ESAP Screening Committee for Delft Exchange Program (chair) (1997-present)
9. Ph.D. Admissions Committee (1988- present) (chair: 1993- 1997)
10. Graduate Admissions Committee (1997- 1998).
11. Search Committee Candidate in Env. Planning & Management (IUPUI) (1997)
12. Undergraduate Policy Committee (1989 - 1993) (Chair since 1990) and (1997))
13. Chair of the SPEA Computing Committee (1995 - 1996)
14. Graduate Policy Committee (1993 - 1996)
15. Computer Committee (1993 - 1998)
16. Prof. Grad. Progr. & Fin. Aid Committee (1991 - 1993)
17. Search committee Env. Scientist/Engineer (1990- 1992)
18. Equipment Committee (1989- 1991, 1993- 1995)
19. International Programs Committee (1988 - 1994)
20. Teaching/experiential learning/professional development committee (1986 - 1990)
21. Computing and Quantitative Analysis Committee (1985 - 1989) (Chair Bloomington
    i. Committee, since 1987)
22. Ad Hoc Undergraduate Microcomputer Use Committee (1984 - 1986)
23. Strategic Planning Task Force (1985 - 1986)
24. Search Committee for Waste Management Engineer (1984 - 1985)

Geological Sciences Committees

1. Member of the search committee for the Boyce Professorship (2000-present)
2. Search Committee for Geological Engineer, 1984.
3. Committee on program development for the proposed B.S. in Environmental and Geological Engineering, 1984.

IU. Committees

1. Member of the IUB Tenure Advisory Committee (2008)
2. Chair of the IUB Tenure Advisory Committee (2007)
3. Member of the IUB Tenure Advisory Committee (2006)
4. Member of the IU Teaching and Research Preserve committee (2001)
5. Member of GIS Task Force (IUPUI) (2000-2002).
6. Member of the Promotion Advisory Committee IUB (1998-2002)

7 Member of the BSES SPEA/COAS committee (1996)
8 Academic Computing Policy Committee (ACPC) (1990 - present) (Chair of the Standards and Technology subcommittee).
9 Staff Merit Award Committee (Chair Subc.) (1991)
10 Research Computing Planning Committee (RCPC) appointed by Dean of Academic Computing 1986-1987.

Student Service, Indiana University

1 Ph.D. advisor: Daniel Abrams (2008-present), Maksym Gusyev (2004-present), Victor A. Kelson (1993-1998), Kenneth Luther (1993-1997), Jack Wittman (1990- 2000), Sherry Mitchell-Broker (1987 - 1993), Abdel M. Ebraheem (1987- 1989), Steve Kraemer (1985- 1990).
2 Member Ph.D. committee: Hye Yun Park (2006-2007), Deborah Opokauh (Geology 2003-present), Nora Czar (2002-present), Won-Tea Chung (2001-present), Sally Letsinger (Geological Sc.) (1996 - 2000), Sujoy Ghose (Geological Sc.) (1993-1997), Jerry Johnston (SPEA)(1996-200-), Charles Crawford (1986 - 1996), Glen Bear (Geological Sc.) (1992-1997), Mark Krieger (Chemistry) (1989- 1994), Robert Shannon (1990- 1995).
3 Advisor for the Water Resources Concentration (1985 - present).
4 Advisor for Masters thesis research Mary Willett (1990), Admir Ceric (1999-2000).
5 Advisor for BSES thesis research Tamara Ratcliff (2000-2002), Sharon Fahler (2006-present).
6 Freshman advisor.

University Service, University of Minnesota

1 Design and installation of a new undergraduate soil mechanics laboratory (1980).
2 Design and installation of soil mechanics laboratory in new CE building (1979 - 1984). Undergraduate student advisor (1984).
3 Co-advisor of several masters students.

Public Service

1 Expert witness services to the U.S. Justice Department regarding U.S. vs Rapanos (wetland litigation) (2006-present).
2 *Expert professional services (incl. affidavit) related to the permit application for CCW disposal in an abandoned coal mine in Indiana (related to earlier testimony regarding this case in 1995 and 1996, see below) (March 28, 2005).
3 *Expert witness services (incl. affidavit) opposing Senate Bill 392, which provides an exception for Washington County on IDEM rule 329 IAC 10-16-8 prohibiting the location of landfills in karst terrain. On behalf of Lawrence Vanore of Sommer Barnard Ackerson in Indianapolis, IN during 2003.
4 Expert professional services to the U.S. Justice Department regarding the case “False Cape Enterprises, Inc. East Virginia” contact Mr. Robert Foster (2001 – 2002).
5 Expert professional services to the U.S. Justice Department regarding the case US v. False Cape Enterprises, Inc. contact Mr. Robert Foster (2001 – 2002).
6 Expert professional services to the U.S. Justice Department regarding the case “Sea Base Development, Inc. East Virginia (Bosher Site)” contact Mr. Robert Foster (2001 – 2002).
7 Expert professional services to the U.S. Justice Department regarding the case US v. Transamerica Services contact Mr. Robert Foster (July, 2001 – 2002).
8 Member of the Bloomington PCB Task Force, July 2000 – 2005.
9 Expert testimony for the US government regarding the case US vs Rapanos (with Dan Willard) (July, 1998 - 2000).
10 Expert professional services for Kendall law office (Indianapolis) regarding land-applied paper mill sludge from Kiefert Paper Mill in Brownstown, IN (June 2005).
11 *Expert professional services to Lewis and Associates Law Office (Orland, IN) regarding the sediment pollution of the Fawn River near Orland, IN (1998 – present).
12 Presentation for public hearing for IDEM regarding the proposed Hickory Hill Landfill, Lowel, IN, February 18, 1998.
13 Moderator for SPEA State House Colloquium “Source Water Assessment Planning in Indiana”,

Indianapolis, February 24, 1998.

14 Capture zone delineations for three communities in Indiana, for IDEM with students in E554 (May 1998).
15 Expert testimony for the City of New Haven at a hearing of the Indiana Hazardous Waste Site Approval Authority in opposition of an expansion of the Adams Center Facility near Fort Wayne. Hearing date: March 20, 1996.
16 Expert testimony for Hoosier Environmental Council at a hearing of the Natural Resources Study Committee in opposition of the proposed disposal of coal combustion waste in the Little Sandy #10 mine in Daviess County. Hearing date: August 30, 1996.
17 Expert testimony for Hoosier Environmental Council at a hearing of the Natural Resources Commission in opposition of the proposed disposal of coal combustion waste in the Little Sandy #10 mine in Daviess County. Hearing date: July 27, 1995.
18 Environmental Impact of the Gumwood Road Well Field near Mishawaka, Indiana, study performed for IDEM (1992)
19 Groundwater evaluations for the County Line Landfill, Indiana (1990).
20 Groundwater flow modeling for Cohen, Milstein, Hausfeld & Toll and Robert D. Gary, Jori Bloom Naegele & Thomas R. Theads regarding the Uniontown Landfill site (1990).
21 Invited participant of the workshop organized by the St. Joseph River Basin Commission, Nov. 30, 1990.
22 Invited participant of the workshop "Indiana Water: Issues for the '90s and Beyond" (September 25 - 26, 1990) organized by the Indiana Water Resources Research Center, Purdue University.
23 Study of subsidence due to depressurization of old mines, for Mr. J. Jarrett (1990 - present).
24 Groundwater evaluations regarding Shelbyville, Indiana (for IDEM) (1989 - present).
25 Presentation at I.U. Mini University: "Groundwater Contamination: How It Affects Everybody," (June 20, 1989).
26 Groundwater flow study for citizens in Clay Township regarding the projected Gumwood Road Well Field of the City of Mishawaka, (1989).
27 Member of the Indiana Groundwater Task Force, an inter-agency task force which oversees the implementation of Indiana's Groundwater Strategy, (1988-1989).
28 Groundwater study near the Tippecanoe Landfill (Indiana) for IDEM (1988-1989).
29 Review of groundwater study for TRW in Lafayette, IN. Review performed for IDEM (July 1987).
30 Review of groundwater study for the Shelbyville municipal well field. Review performed for IDEM (August 1987).
31 Groundwater contamination study for the Fountain School Corporation, Veedersburg, Fountain County, Indiana (1986).
32 Groundwater study/testimony for the 'Citizens against Landfills, Inc.,' Plymouth, Indiana (1985-1991).
33 Wrote a side bar on groundwater modeling in the leading article of Indiana Business Magazine (Jan. 1986) (on invitation).
34 Member of a national Dutch committee on testing pile foundations (1977).
35 Member of a national Dutch committee on artificial recharge during dewatering activities (1977).

PROFESSIONAL ACTIVITIES

1. Convener Analytic Element Workshop, October 31 – November 1, 2008, Bloomington, IN
2. Technical Committee MODFLOW and More 2008: Ground Water and Public Policy, May 19-21, 2008 Golden, CO.
3. Technical Committee 5th International Conference on the Analytic Element method in Manhattan, KA, May 14-17, 2006.
4. Technical committee 4th International Conference on the Analytic Element Method in Saint-Etienne, France, 1-5 April, 2003.
5. Review panel for Fulbright Senior Specialists program (2001-2002).
6. Invited Workshop for the National Rural Water Association in Spokane, WA on June 12, 2001.
7. Convener (with de Lange) of a special session on Analytic Elements at the XIV International Conference on Computational Methods in Water Resources, Delft, The Netherlands, June 23-28, 2002.
8. Invited panel member for the Groundwater Fluxes Across Interfaces section of a workshop sponsored by the National Research Council, Door County, Wisconsin, May 12-14, 2002.
9. Convener (with Jankovic) of a special session on analytic elements for the AGU spring meeting in Washington, DC, May 28-31, 2002.

10. Convener (with Hunt) of a special session on analytic elements on the GSA meeting in Denver, CO, October 27 – 30, 2002.
11. Review panel member for South Florida Water management District on Minimum Aquifer levels for the Lower West Coast aquifers, September 27-28, 2000.
12. Panel member and moderator at the "Third International Conference on Analytic Element Modeling of Groundwater Flow", Brainerd, MN, April 16 – 19, 2000.
13. Invited for the workshop "Modeling and Management of Emerging Environmental Issues. Expert Workshop 2000. Sponsored by E.I. du Pont de Nemours and Company. Held at Penn State Great Valley Campus on July 25-27, 2000.
14. Invited short course on groundwater flow modeling for the Ohio EPA, Columbus, OH, March 27-28, 2000.
15. Invited panel member on Research Needs at the International Riverbank Infiltration Conference in Louisville, KY November 3-6, 1999.
16. Invited presentation for geologists of Brunei Shell Petroleum in Seria, Brunei January 27, 1999.
17. Member of the Technical Committee of the Third International Conference on the Analytic Element Method (April 2000, Minnesota).
18. Invited short course on the use of the analytic element model GFLOW for source water assessment, for the Wisconsin DNR and USGS, Madison Wisconsin, December 8-10, 1999 (with Vic Kelson).
19. Instructor of short course "Groundwater Modeling with the Analytic Element Method", July 6 – 10, 1998, for the South Florida Water Management District (SFWMD), West Palm Beach, Florida.
20. Instructor of short course "Analytic Element Modeling of Groundwater Water Flow" (with V.A. Kelson), for the USEPA at Kerr Lab, Ada, OK, February 24 – 26, 1997.
21. Moderator at the international conference "Analytic Based Modeling of Groundwater Flow" April 7 - 10, 1997, Nunspeet, The Netherlands.
22. Moderator at the international conference "Water: A trigger for conflict/A reason for cooperation" March 7-10, 1996 at Indiana University, Bloomington.
23. Instructor of short course "Analytic Element Modeling of Groundwater Flow" (with Victor Kelson), organized by E3 (Environmental Education Enterprises, Inc.), April 19-21, 1995, San Francisco, Febr. 7- 9, 1996, Orlando, June 19 - 21, 1996, Scottsdale.
24. Member of the technical committee for the international conference "Analytic Based Modeling of Groundwater Flow", scheduled for 1997 in the Netherlands.
25. Chairman of the organizing committee and host of the international conference "Analytic Element Modeling of Groundwater Flow", Indianapolis, April 19-21, 1994.
26. Member of the organizing committee of the "First Indiana Water Forum", Fall 1993.
27. Member of the organizing committee of the Midwest Groundwater Conference in Indianapolis, November 1991.
28. Member of organizing committee of American Water Resources Association (AWRA) Conference on Water Quality, Toledo, Ohio, April 1991.
29. President of the Indiana Water Resources Association (IWRA), the Indiana chapter of the American Water Resources Association (AWRA) (1990).
30. Organized and hosted the 11th Annual Water Resources Symposium "Conjunctive Surface Water and Groundwater Studies," sponsored by IWRA at Nashville, Indiana, June, 1990.
31. Member of the technical committee of the NWWA/IGWMC international conference "Solving Groundwater Problems with Models" in Indianapolis, February 1989.
32. Reviewer of the Journal of Irrigation and Drainage Engineering of ASCE (1989-Present).
33. Editor of " Hydrological Science and Technology," a refereed journal of the American Institute of Hydrology (1988-Present).
34. Reviewer for Journal of Hydrology (1988-Present).
35. Reviewer for Water Resources Research (1986-Present).
36. Reviewer for National Science Foundation (1986-Present).
37. Groundwater impact study for a projected Oil Shale pilot plant in Southern Indiana, P.I. Dan Willard, funded by Cliffs Engineering, Inc. (1986).
38. Modeling thermal energy injection in unconfined aquifers for Battelle Memorial Institute, funded by the Department of Energy (1986).
39. Invited participation in a workshop on the hydrology of crystalline rocks, at the University of Arizona in Tucson (1979).
40. Participation in a study for the Department of the Environment (England), 'Numerical Modeling of Water

in Rock Masses,' which was conducted by Dr. P.A. Cundall (1982).

41. Participation in groundwater flow study performed by Dr. O.D.L. Strack for the Battelle Pacific Northwest Laboratory. Subject: Flow in Fissured Porous Media (1981 - 1982).
42. Preliminary feasibility study about the injection and recovery of hot water near the projected St. Paul Energy Park. Study was funded by the Minnesota Geological Survey (1981).

Consulting

1 Development of a coupled GFLOW – MODFLOW model for enhanced surface water groundwater interactions on a large regional scale. This project is funded by the USGS Milwaukee Wisconsin office (2005-present).
2 Maintenance of WhAEM for the USEPA (2006)
3 Expert professional services in the case LeClerq v. Lockformer Co for the law offices of Goldberg Kohn representing Met-Coil Systems Corporation. (September, 2004 – October, 2004).
4 Expert professional services in the case LeClerq v. Lockformer Co for the law offices of Greenberg, Traurig, LLP representing Mestek, Inc. (October, 2004 – January 2005).
5 Development of WhAEM version 3 funded by the USEPA. WhAEM is a public domain groundwater flow modeling program, published by the USEPA, for its wellhead protection program. (2002-2003).
6 Enhancement of the AEM solver GFLOW1 for coupling with the USGS MMS software. This project is funded by the USGS in Madison Wisconsin. (2002-2003).
7 Expert witness support for Spence, Moriatity & Shockey regarding the Homestake mining pollution case in New Mexico (2003-2004).
8 *Consulting services to Mifflin and Associates, including testimony at a hearing for the State Engineer of the state of Nevada (2000 - 2003).
9 Expert professional services to Young Riley Dudley & DeBrota (Indianapolis) regarding the case William Gordon vs. Guide Corporation and General Motors Corporation (2001).
10 Expert professional services for Sommer & Barnard (Indianapolis) regarding the proposed Lake County landfill in Lake County, Indiana (2001).
11 Expert witness services for Bayliff, Harrigan, Cord & Maugan regarding TCE contamination due to Conrail in Elkhart County, IN (1999-2001).
12 Expert professional services (affidavit) for Steward and Erwin (Indianapolis) regarding the case Ramsey Development Corporation vs. Tuchman Cleaners Inc. et al. (1999).
13 Expert witness services to Cohen, Millstein, Hausfeld &Toll regarding the case Yslava vs. Hughes Aircraft (1997).
14 Groundwater hydrology assessment for the S.R.O.D. related to the Hickory Hills Landfill in northwestern Indiana (1997-1998).
15 Expert witness services to Barron & Budd regarding the Pfohl Brothers Landfill case (1998).
16 Expert witness services to Allen, Lippes & Shon regarding the Four County Landfill case in Indiana (1997)
17 Wellhead protection study for the city of Columbus, Indiana, with SIECO, Inc., (1995- 1997).
18 Technical support to August Mack Environmental, Inc., Indianapolis (1993-present).
19 Expert professional services for Vandenberg regarding Cotter Uranium Mill (1998).
20 Groundwater flow modeling study related to the Cotter Uranium Mill contaminant releases in Cannon City, CO. For Kevin Hannon and Ass. Denver, CO. (1993-1995).
21 Groundwater flow study related to TCE releases at Johnson Controls, Inc. for the law firm of Yoder, Ainsly, Ulmer and Buckingham, Goshen, Indiana (1993).
22 Groundwater flow modeling related to TCE releases from Organic Chemical in Columbia and Cassatt, SC. For Allen, Lippes & Shon, Buffalo, New York (1993-1995).
23 Groundwater review regarding contaminant releases by Boeing. For McLaren/Hart Env. Eng. Corp., Lester, PA. (1993).
24 Groundwater modeling of the dilution of radionuclides in domestic wells near a nuclear waste repository, with Golder Geosyst. Assoc., Inc., Sweden, (1991).
25 Groundwater modeling for Sieco, Inc. regarding wellhead protection of the Columbus (Indiana) Cities Utilities' well field (1990 - 1997).
26 *Groundwater flow study regarding groundwater contamination at the Texas Eastern Terminal near Seymour, Indiana. For Pardieck, Gill & Vargo, P.C. Seymour, Indiana. (1990-2004).
27 Groundwater study for Delta Environmental Consultants, Inc. regarding a gasoline spill in Fort Collins, CO (1989- 1990).

28 Groundwater flow instruction to staff of Hoosier Environmental Services, Inc. (1990).
29 Groundwater flow study with Hoosier Environmental Services, Inc. for Allison Gear Division in Indianapolis, (1989).
30 Groundwater study near the Four County Landfill (Indiana) for the law firm Allen, Lippes, and Shonn (1988-1989).
31 Groundwater contamination study for the law firm, 'Szaferman, Lakind, Blumstein, Walter and Blader' in New Jersey; aquifer contamination in Warren Township, N.J. (1987-1989).
32 Groundwater contamination study for the law firm, 'Allen, Lippes and Shonn'; contaminant migration in Battle Creek, Michigan (1986-1989).
33 Groundwater contamination study for Philadelphia law firm 'Cohen, Shapiro, Polisher, Shiekmann and Cohen'; contaminant migration in Bradley Gardens, Bridgewater, NJ. (1986-1989). Groundwater modeling advise to ATEC Associates, Inc., Indianapolis (1985-1988).
34 Modeling of contaminant migration from a road salt pile toward production wells. Funded by Heileman Brewery at La Crosse, Wisconsin and carried out as a consultant for Layne Western Co., Inc. (1984).
35 Dewatering study for a tunnel near Zwolle (The Netherlands). Study was funded by HARO, B.V. (1983).
36 Participation in a study performed by Strack of the possibly contamination of the Chippewa Spring Water, for Kraus and Anderson, Inc. (1979).

GRANTS, FELLOWSHIPS AND AWARDS

1. “Modeling Support for Ground Water Resources on the Sheyenne Grasslands in North Dakota”, funded by the US Forest Service, $30,000 (2008-2011)
2. “Developing a guidance document for application of source water capture zones”, funded by the Indiana Department of Environmental Management (IDEM) (1999 - 2000). Project Manager: Mary Hoover.
3. “Investigation of Hydrologic Modeling Needs for the Multimedia Integrated Modeling System”, subcontract with Georgia Institute of Technology, PI. Christa Peter-Lidard, for USEPA, 1999-2001.
4. "Modeling Three-Dimensional Flow in Regional Unconfined Aquifers", funded by EPA, $250,000 (1994-1997).
5. "Groundwater Modeling Studies for the Office of Environmental Response of the Indiana Department of Environmental Management (IDEM)" (with Dr. Backhus) $22,000 (1995-1997).
6. "Wellhead protection modeling in Marion County", as part of the Center for Urban Policy and the Environment, SPEA at IUPUI, $80,000 (1994-1995).
7. "Hoosier Heartland Groundwater Study", for Hoosier Heartland Resource Conservation and Development Council, $25,000 (1994).
8. Groundwater contamination research for Crane Naval Weapons Center. Project manager (six P.I.s) $600,000 (Groundwater lab: $140,000) (1993-1994).
9. "Groundwater Modeling Studies for the Office of Environmental Response of the Indiana Department of Environmental Management (IDEM)" $19,000 (1993-1994).
10. "Groundwater flow modeling in the Walnut Creek Watershed (Iowa)" funded by the Soil's Tilth Laboratory, Ames, Iowa, $50,000 (1994-1996).
11. "Groundwater flow modeling in the Walnut Creek Watershed (Iowa)" as part of the MASTER project funded by USEPA, USGS, and USDA. $20,000.- (1992-1993).
12. "Statewide groundwater modeling" as part of the Center for Urban Policy and the Environment, SPEA at IUPUI, $60,000 (1992-1994).
13. "Groundwater modeling studies" for the Office of Environmental Response of the Indiana Department of Environmental Management (IDEM) $18,500 (1992-1993).
14. "Supra-Regional Modeling of Groundwater Response to Climate Change" funded by the National Institute for Global Environmental Change (NIGEC), U.S. Department of Energy (DOE), $68,000 (1992).
15. "Demonstration of the Analytic Element Method for Wellhead Protection", funded by Kerr Laboratories (EPA) $70,000 (1991-1993).
16. "Supra-Regional Modeling of Groundwater Response to Climatic Change" funded by the National Institute for Global Environmental Change (NIGEC), U.S. Department of Energy (DOE), $117,000 (1991).
17. "Supra-Regional Modeling of Groundwater Response to Climatic Change" funded by the National Institute for Global Environmental Change (NIGEC), U.S. Department of Energy (DOE), $103,747 (1990).
18. "Groundwater Modeling Studies" for the Office of Environmental Response of the Indiana Department of Environmental Management (IDEM) $14,100 (1991-1992).

19. "Groundwater Modeling Studies" for the Office of Environmental Response of the Indiana Department of Environmental Management (IDEM) $14,100 (1990-1991).
20. Groundwater modeling studies for the Office of Environmental Response of the Indiana Department of Environmental Management (IDEM), $12,500 (1988-1989).
21. SPEA 1988 Summer Faculty Fellowship for a groundwater flow study regarding multiple fluid flow $4 500 1988.
22. Groundwater modeling subcontract for "Proposed Deep Well Injection Study for the Great Lakes Region" with Indiana Geological Survey, $6,200 Jan. 1987 - Jul. 1987.
23. "Development of computer simulations of geotechnical laboratory and field tests" Small Grants Program, University of Minnesota, with Dr. A. Drescher, $1,900 1984.
24. "An Initial Study of Thermal Energy Storage in Unconfined Aquifers," Pacific Northwest Battelle Laboratory, $35,000 Nov. 1982 - Jan. 1984.

PUBLICATIONS

Books and book chapters

1 *Analytic Element Modeling of Groundwater Flow,* H.M. Haitjema, Academic Press, Inc., San Diego, 400 pages, 1995.

2 Chapter 8.2 "*Groundwater Flow Modeling*" H.M. Haitjema. In "Standard Handbook of Environmental Health, Science, & Technology (ed. Jay Lehr) McGraw-Hill, New York, 2000.

Articles (refereed)

1. "Field test of a hybrid Finite-Difference and analytic Element Regional Model," D.B. Abrams, H.M. Haitjema, D.T. Feinstein, and R.J. Hunt, Vol. 54, No. 1, *Groundwater*, pp. 66-73, January-February 2016
2. Darcy Velocity is not a Velocity" Henk M. Haitjema and Mary P. Anderson, Groundwater, Vol. 54, No. 1, pp. 1, January-February 2016.
3. "Simulation of Water-table aquifers using specific saturated thickness," Rodney Sheets, Mary Hill, Henk Haitjema, Alden Provost, and John Masterson, *Groundwater*, Vol. 53, No. 1, pp. 151 – 157, January-February 2015.
4. "The Cost of Modeling" Henk M. Haitjema, *Groundwater*, Vol. 53 No. 2, pp. 179, March-April 2015.
5. "Reading Groundwater in the 21st Century" Thad Plumley and Henk Haitjema, *Groundwater*, Vol. 53 No. 4, pp.507, July-August 2015.
6. "Impact Factor or Impact" Henk M. Haitjema, *Groundwater*, Vol. 53, No. 6, pp. 825, November-December, 2015.
7. "Drowning in Papers" Henk M. Haitjema, *Groundwater*, Vol. 52, No. 4, pp 487, July-August 2014.
8. "Groundwater Grows" Henk M. Haitjema, *Groundwater* Vol.52, No. 3, pp.325, May-June 2014.
9. "On modeling weak sinks in MODPATH," Daniel Abrams, Henk Haitjema, and Leon Kauffman, *Groundwater*, Vol. 51, No. 4, pp. 597 – 602, July-August 2013.
10. "Use of Nested Flow Models and Interpolation Techniques for Science-Based Management of the Sheyenne National Grassland, North Dakota, USA" M.A. Gusyev, H.M. Haitjema, C.P. Carlton, and M.A. Gonzalez, *Groundwater*, Vol. 51, no. 3, pp 414 – 420, May – June 2013.
11. "Approximate Solutions for Radial Travel Time and Capture Zone in Unconfined Aquifers, " Yangxiao Zhou and Henk Haitjema, *Groundwater*, Vol. 50, No. 5, September-October, 2012.
12. "A low-dimensional hillslope-based catchment model for layered groundwater flow," S. Broda, M. Larocque, C. Paniconi and H. Haitjema, *Hydrological Processes,* vol. 26, issue 18, pp. 2814-2826, 30 August 2012.
13. "Modeling flow in wetlands and underlying aquifers," Maksym Gusyev and Henk Haitjema, *Journal of Hydrology*, 408, pp. 91-99, 2011.
14. "An exact solution for a line-sink in the presence of leakage or transient flow," Maksym Gusyev and Henk Haitjema, *Advances in Water Resources,* vol. 34, issue 4, pp. 519-525, April 2011.
15. "Truncating cross-sectional groundwater models under wetlands" Henk Haitjema, Maksym Gusyev, and Mark Wilsnack, *Journal of Hydrological Engineering*, Vol. 15, No. 7, pp: 537 – 543, July 1, 2010.

16. “A hybrid finite difference and analytic element groundwater model” Henk Haitjema, Daniel Feinstein, Randy Hunt, and Maksym Gusyev, *Groundwater*, 48, no. 4: 538 – 548, 2010
17. “Modeling Flow into Horizontal Wells in a Dupuit-Forchheimer Model” Henk Haitjema, Sergey Kuzin, Vic Kelson, and Daniel Abrams, *Ground Water*, Vol. 48, No. 6, pages 878 – 883, 2010
18. “The role of hand calculations in groundwater flow modeling” 2006, Henk Haitjema, GROUND WATER, Vol 44, No. 6, pages 786-791, November – December.
19. “Foreword: Ground Water Flow Modeling with the Analytic Element Method” 2006, Hendrik M. Haitjema, Randall J. Hunt, Igor Jankovic, and Wim J. de Lange, *GROUND WATER* 44, no. 1: 1-2.
20. “A Fast Direct Solution Method Nonlinear Equations in an Analytic Element Model” 2006, Henk Haitjema, *GROUND WATER* 44, no. 1: 102-105
21. “Are Water Tables a Subdued Replica of the Topography?” 2005, Henk M. Haitjema and Sherry Mitchell-Bruker, *GROUND WATER* 43, no. 6: 781-786.
22. “On using simple time-of-travel capture zone delineation methods”, Admir Ceric and Henk Haitjema, *GROUND WATER*, Vol.43, No.3, May-June, 2005
23. “Simulating ground water-lake interactions: approaches, analyses, and insights”, Hunt, Randy, Henk Haitjema, James Krohelski and Daniel Feinstein, *GROUND WATER*, Vol. 41, No. 2, March – April, pages 227-237, 2003.
24. “Improving a regional model using reduced complexity and parameter estimation”, Vic Kelson, Randy Hunt and Henk Haitjema, *GROUND WATER*, volume 40 number 2, March-April, pages 132-143, 2002
25. “Selecting MODFLOW cell sizes for accurate flow fields”, H. M. Haitjema, V. A. Kelson and W. de Lange, Vol 39, No. 6, *GROUND WATER*, Nov.-Dec., pages 931-938, 2001.
26. “Approximate analytic solutions to 3D unconfined groundwater flow within regional 2D models”, K.H. Luther and H.M. Haitjema, *J. of Hydrology*, 229, pp 101-117, 2000.
27. An Analytic Element Solution to Unconfined Flow near Partially Penetrating Wells, K.H. Luther and H.M. Haitjema, *J. of Hydrology*, 226, pp 197-203, 1999.
28. Numerical Experiments on the Residence Time Distributions of Heterogeneous Groundwatersheds , K.H. Luther and H.M. Haitjema, *J. of Hydrology,* Volume 207, nos. 1-2, pp 1 – 17, 1998.
29. Recycling Input Data During Analytic Element Modeling in Marion County, Indiana,, J.F. Wittman, H.M. Haitjema and L. Studebaker, *Water Resources Bulletin,* V33:1, pp 47-54, 1996.
30. Using the Stream Function for Flow Governed by Poisson's Equation, H.M. Haitjema and V.A. Kelson, *J. of Hydrology,* 187, pp 367-386, 1996.
31. Modeling Steady State Conjunctive Groundwater and Surface Water Flow with Analytic Elements, S. Mitchell-Bruker and H.M. Haitjema, *Water Resource. Res.,* Vol. 32, No. 9, pp 2725 - 2732, September 1996.
32. On the Residence Time Distribution in Idealized Groundwatersheds, H.M. Haitjema, *J. of Hydrology,* 172, pp 127-146, 1995.
33. GAEP: A Geographic Preprocessor for Groundwater Flow Modeling, V.A. Kelson and H.M. Haitjema, *Hydrological Science and Technology,* Vol. 8, pp 74-84, 1993.
34. Modeling Regional Groundwater Flow in Fulton County Indiana, H.M. Haitjema, *Ground Water,* Vol. 30, No.5, pp. 660-666, 1992.
35. Groundwater Hydraulics Considerations Regarding Landfills, H.M. Haitjema, *Water Resources Bulletin,* Vol. 27, No.5, pp. 791-796, 1991.
36. An Analytic Element Model for Transient Axi-Symmetric Interface Flow, H.M. Haitjema, *J. of Hydrology,* 129, pp. 215-245, 1991.
37. Modeling the Effect of Density Flow on Waste Spreading During and After Deep Well Injection, M.R. Willett, H.M. Haitjema, and J.A. Rupp, *Hydrological Science and Technology,* Vol. 6, No.1-4, 1990.
38. A new Analytic Function for Modeling Partially Penetrating Wells, H.M. Haitjema and S.R. Kraemer, *Water Resources Res.,* Vol. 24, No. 5, pp. 683-690, May 1988.
39. Evaluating Solid Angles Using Contour Integrals, H.M. Haitjema, *Appl. Math. Model.,* Vol. 11, Feb. 1987.
40. Comparing a Three-Dimensional and a Dupuit-Forchheimer Solution to a Circular Recharge Area in a Confined Aquifer, H.M. Haitjema, *J. of Hydrology,* Vol. 91, pp. 83-101, 1987.
41. Modeling three-dimensional flow in confined aquifers by superposition of both two- and three-dimensional analytic functions, H.M. Haitjema, *Water Resources Research,* Vol. 21, No. 10, Oct. 1985.
42. Modeling double aquifer flow using a comprehensive potential and distributed singularities, II: Solution for inhomogeneous permeabilities, O.D.L. Strack and H.M. Haitjema, *Water Resources Research,* Vol. 17, No. 5, Oct. 1981.

43. Modeling double aquifer flow using a comprehensive potential and distributed singularities, I: Solution for homogeneous permeability, O.D.L. Strack and H.M. Haitjema, *Water Resources Research,* Vol. 17, No. 5 Oct. 1981.
44. The use of vortex rings for modeling saltwater upconing, H.M. Haitjema, *L.G.M. Mededelingen,* Part XXI No. 2, June 1980. (Tribute to Prof. G. De Josselin De Jong) (invited).
45. Numerical application of vortices to multiple fluid flow in porous media, H.M. Haitjema, *Delft Progress Report,* 2, 1977.
46. Linear residence time distribution definitely optimal for damping of pulse type, stochastical and periodical quality fluctuations, in response to ir. K. Maas' criticism on my paper "Optimum residence time distribution of a recharge and recovery system for damping of quality fluctuations." *H20* (10), No. 14 (Dutch) (invited), 1977.
47. Optimum residence time distribution of a recharge and recovery system for damping of quality fluctuations, H.M. Haitjema, *H20* (10), No. 6 (Dutch), 1977.

Conference Proceedings

1. "Assessing transport on non-point source pollutants to surface waters and wells: Nitrates in the Kirkwood-Cohansey Aquifer System" by Daniel Abrams and Henk Haitjema, AGU conference December 13, 2010 in San Francisco.
2. "Groundwater transport of nitrates to streams: A lumped parameter model" Daniel Abrams and Henk Haitjema, presented at the Indiana Water Resource Association (IWRA) meeting on May 27, 2010 at Purdue University, West Lafayette.
3. "A new formulation for conjunctive flow in wetlands and underlying aquifer" M. Gusyev and H. M. Haitjema, in proceedings of and oral presentation at 5th International Conference on the Analytic Element Method, Kansas State University, Manhattan, KA, May 14 – 17, 2006.
4. "The Role of Hand-Calculations in Groundwater Flow Modeling," Henk Haitjema, in proceedings of MODFLOW and More 2003, September 16-19, 2003.
5. "Some Cell-Size Selection Criteria for MODFLOW", Henk Haitjema, Vic Kelson, Wim de Lange, proceedings of MODFLOW 2001 and other modeling odysseys, IGWMC, Golden, Colorado, September 11- 14, 2001.
6. The Development and Maintenance of the Groundwater Resource in the USA, H.M. Haitjema, "International Conference on Finding Solutions for Water Management Problems," Seoul, Korea, September 13, 1996.
7. Hierarchical Approach to Modeling Surface-Groundwater Interactions: The Walnut Creek (Iowa) Watershed in Regional Perspective, H.M. Haitjema, S. Mitchell-Broker, and S.R. Kraemer, Conference: "Agriculture Research to Protect Water Quality," SWCS, Minneapolis, MN, February 21-24, 1993.
8. Very large scale regional aquifer modeling including local detail, H.M. Haitjema, Abdel-Azim M. Ebraheem and S. Mitchell-Broker, poster and paper at International Conference: "Solving Groundwater Problems with Models," Indianapolis, Indiana, February 7-9, 1989.
9. A modeling approach to regional fracture flow systems, S.R. Kraemer and H.M. Haitjema, International Conference: "Solving Groundwater Problems with Models," Indianapolis, Indiana, February 7-9, 1989.
10. An analytic element approach to modeling multiple fluid flow, H.M. Haitjema, International Conference: "Solving Groundwater Problems with Models," Indianapolis, Indiana, February 7-9, 1989.
11. Regional modeling of fractured rock aquifers, S.R. Kraemer and H.M. Haitjema, International Conference on "Groundwater contamination: use of models in decision-making," Amsterdam, The Netherlands, October 26-29, 1987.
12. Developments and applications of three-dimensional analytic element models for transport modeling. H.M. Haitjema, International Conference on "Groundwater contamination: use of models in decision-making," Amsterdam, The Netherlands, October 26-29, 1987.
13. "Modeling three-dimensional flow near a partially penetrating well in a stratified aquifer," H.M. Haitjema, proceedings of "Solving Groundwater Problems with Models," Denver Feb. 10-12, pages 532-540, 1987.
14. "A practical approach to regional three-dimensional flow modeling," H.M. Haitjema, National Water Well Association (NWWA) conference 'Practical applications of groundwater models, in Columbus, Ohio August 19-20, 1985.
15. "Artificial recharge during dewatering activities," H.M. Haitjema, submitted and presented on invitation for the American Institute of Hydrology (AIH) at the workshop: 'A national survey: Selected problems and

solutions in applied Hydrology and Hydrogeology,' in Minneapolis, Minnesota May 16-17, 1985.

16. "Development of a predictive tool for unconfined aquifer TES," H.M. Haitjema, Proceedings DOE Physical and Chemical Energy Storage Contractor's Review Meeting, Arlington, Virginia.
17. "Inter-active modeling of the aquifers near the Tennessee-Tombigbee Waterway," O.D.L. Strack, H.M. Haitjema and J.J. Melnyk, Proceedings IFAC, Cleveland, Ohio 1980.
18. "Dynamic storage of fresh water in a saline aquifer", H.M. Haitjema, Proceedings SWIM, England 1977.

Selected Technical Reports

1 “Replacing upper MODFLOW layers by a GFLOW model” report to the USGS in Wisconsin, 2005 – present.
2 “Time of Travel Capture Zone Delineation for Wellhead Protection”, H.M. Haitjema for Indiana Department of Environmental Management (IDEM), December, 2000.
3 “Assessing the Suitability of MODFLOW for Modeling Advective Transport”, Henk Haitjema and Vic Kelson, for RIZA (National Institute for Integrated Water Management), The Netherlands, (84 pages), November 15, 1998.
4 A Regional Analytic Element Model to Investigate the Extent of Drawdowns on the Groundwater Flow Regime due to the Dewatering of the Proposed Crandon Mine”, H.M. Haitjema and V.A. Kelson, reprot to Wisconsin Department of Natural Resources (WDNR), (42) January, 1998.
5 Modeling Three-Dimensional Groundwater Flow on a Regional Scale Using the Analytic Element Method, H.M. Haitjema, V. Kelson, and K. Luther, final report for the USEPA, contract CR 823637-01-1, 1997.
6 IU-SPEA 1995-1996 Groundwater Technical Support Activities for the Indiana Department of Environmental Management, H.M. Haitjema, K. Luther, J. Wittman, final report to IDEM, 1997.
7 "Capture Zone Delineation for the Municipal Well Fields Columbus, Indiana", H.M. Haitjema, Vic Kelson, Jack Wittman, for Sieco, Inc., Columbus IN, October 21, 1996 (55 pages).
8 "Delineation of Wellhead Protection Areas in Marion County," J.F. Wittman and H.M. Haitjema, publication # 95-E14 Center for Urban Policy and the Environment, SPEA at IUPUI, June 1995 (pp. 49).
9 "Report of Groundwater Flow and Contaminant Migration Modeling at the Ammunition Burning Ground, Crane NSWC, Indiana, H.M. Haitjema and V.A. Kelson, submitted to the U.S. Army Corps of Engineers, December 19, 1994.
10 "W*h*AEM User's Guide", H.M. Haitjema and O.D.L. Strack, prepared for USEPA under contract with Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, October 1994.
11 "Wellhead protection study of the Fall Creek pumping station", for Indiana Water Company (IWC), 1993.
12 "Well Head Protection of the Southern Well Fields near Columbus, Indiana", H.M. Haitjema and J.F. Wittman, prepared for Sieco Inc. under contract with the Columbus City Utilities, May 21, 1992.
13 "Environmental Impact of the Gumwood Road Well Field near Mishawaka, Indiana", H.M. Haitjema, prepared for IDEM, May 11, 1992.
14 "Preliminary Findings Regarding the Effect of Pumping the Old Works Underneath the Minnehaha Mine on Subsidence", H.M. Haitjema, prepared for Jack Jarrett, September 11, 1989.
15 "Computer modeling of the effects of density differences on waste spreading in the Mt. Simon sandstone in Northwest Indiana," H.M. Haitjema and Mary Willet, prepared for the Indiana Geological Survey for Underground Injection Practices Council. Study is part of the Deep Well Injection study for the Great Lakes Region. Report is part of a comprehensive report submitted by the Indiana Geological Survey, 1987.
16 "Preliminary ATES Simulations for the Student Recreation Building of the University of Alabama", H.M. Haitjema, prepared for Pacific Northwest Laboratory under contract B-P1228A-N (1986)
17 "An Initial Study on Thermal Energy Storage in Unconfined Aquifers", H.M. Haitjema and O.D.L. Strack, final report to Battelle Northwest Laboratory, PNL-5815, April 1, pages 107 (1986).
18 "Recommendations and Comments regarding the pressure relief system and the environmental modeling of the divide-cut section of the Tennessee Tombigbee Waterway." Report to U.S. Army Corps of Engineers, Nashville district, O.D.L. Strack and H.M. Haitjema (1982).
19 "Report on the feasibility of injection and recovery of hot water near the projected St. Paul Energy Park: recharge and recovery wells in the upper glacial drift," H.M. Haitjema (1981).

20 "Final report of computer inter-active modeling of the dewatering for the Tennessee- Tombigbee Waterway", O.D.L. Strack, H.M. Haitjema, and G. Heizman, Report to the U.S. Army Corps of Engineers, Nashville District (1978).
21 "Preliminary predictions of final drawdowns near the Tennessee-Tombigbee Waterway," O .D.L. Strack and H.M. Haitjema, Report to the U.S. Army Corps of Engineers, Nashville District (1977) .
22 "Hele Shaw model test" (in Dutch), H.M. Haitjema, IWACO report (1976).
23 "Sensitivity analysis for discontinuities in a resistance layer" (in Dutch), H.M. Haitjema, IWACO report (1976).

Monographs

1 "Accounting for resistance to 3D flow near horizontal wells or galleries in a Dupuit-Forchheimer model," September 24, 2002.
2 "Dealing with resistance to flow into surface waters," September 29, 2002.
3 "Fresh and salt water interface flow in GFLOW 2000," October 24, 2002.
4 "Modeling lake-groundwater interactions in GFLOW 2000," March 4, 2002.
5 "Solution strategies in GFLOW1," October 20, 2002.
6 "Theory of modeling inhomogeneity domains in GFLOW1," January 24, 2001.
7 Calculated Fixed Radius Issues, H.M. Haitjema for the Microbial Contamination Workshop of the USEPA, Irvine, CA, July 11, 1996.
8 Applied Mathematics for Environmental Sciences, H.M. Haitjema, class notes, (1985, revised 1992, revised 1998).
9 Elements of Fluid Mechanics, H.M. Haitjema, class notes, (1986)
10 The use of line doublets to model discontinuous material properties in two-dimensional linear elasticity, H.M. Haitjema, University of Minnesota (1981).
11 Introduction of inhomogeneous fluid and aquifer properties in non-steady three-dimensional groundwater flow by application of vortex distributions, H.M. Haitjema, Technical University of Delft (1978).
12 Calculation examples for artificial recharge to limit the effect of a dewatering system (in Dutch), Technical University of Delft (1977).

Other

1. "Source Water Protection in the USA: Ensuring Clean Drinking Water" Henk Haitjema and Maksym Gusyev, edited by Roy Shin and published by the Seoul Development Institute, Korea, July 2006.
2. On line manual and help system for the computer program WhAEM for Windows95/NT produced under contract with Dynamac Corporation for the USEPA, 1997
3. "Demonstration of the Analytic Element Method for Wellhead Protection", H. M. Haitjema, O. D. L. Strack, and S. R. Kraemer, EPA Project Summary, EPA/600/SR94/210, produced by USEPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, March 1995.
4. "Computers Helping Protect Groundwater Environment", H.M. Haitjema, editorial in the Indiana Manufacturer, the Ohio Manufacturer, and the Kentucky Manufacturer, December 1994.
5. 'Wanted: Soil detectives,' side bar in article on groundwater pollution in Indiana, published in the January 1986 issue of INDIANA BUSINESS Magazine.

Invited Presentations

1. "Model Complexity: A Cost Benefit Issue" at the Annual meeting of the Geological Society of America (GSA) in Minneapolis, MN October 2011 and at Flinders University, Adelaide Australia, December 2012.
2. "Holland Waterland" at the Dutch Week on March 23, 2010 at the IUB campus. Dutch Week is organized by the Dutch program of the Germanic Department at UIB with sponsorship from West European Studies.
3. "Replacing upper MODFLOW layers with an Analytic Element Model: An alternative to grid refinement" MODFLOW and more 2008, May 18 – 21, 2008, Golden, CO.
4. "A coupled Analytic Element – Finite Difference Approach to Groundwater Flow Modeling" (with Feinstein and Hunt) at the 5th international conference on the analytic element method in Manhattan, KA, May 14 – 18, 2006.
5. "Analytic Element Screening Models" at the Braun Intertec headquarters in Minneapolis, Minnesota,

April 21, 2005.

6. "Analytic Element Screening Models" at the Civil Engineering Department of the University of Minnesota, February 27, 2005.
7. "Groundwater Modeling: Decision making models for watershed management" at the joint Indiana University - Magdenburg University workshop on "Hochwasserschutz durch nachhaltige Einzugsgebietsbewirtschaftung – Strategien und Beispiele" in Magdenburg, Germany June 29, 2004.
8. "A fast direct solution method for non-linear equations in an analytic element model" at the 4th international conference on the analytic element method in Saint Etienne, France, November 20-21, 2003.
9. "Analytic element modeling of groundwater flow," invited by the Illinois Groundwater Association at their annual meeting in Urbana, November 13, 2002.
10. Presentation at the Valpariso University on April 3, 2001.
11. Presentation at the University of Buffalo on October 4, 2001.
12. Presentation at the University of Western Australia in Perth on October 24, 2001.
13. Presentation at Flinders University in Adelaide on October 30, 2001.
14. Guest lecture in advanced groundwater flow modeling course at the Geology Department of the University of Wisconsin, Madison, March 23, 2001.
15. "Water War in the Desert", H. M. Haitjema, Department of Mathematics and Computer Science, Valparaiso University, April 3, 2001.
16. Training session (1 afternoon) on groundwater flow modeling for the National Rural Water Association In-Service Training in Spokane, Washington, June 12, 2001.
17. "Estimating the non-point source groundwater contribution to surface water pollution: A lumped parameter approach", H. M. Haitjema, Monitoring and Modeling Nonpoint Source Pollution in Agricultural Landscapes, Indianapolis, August 28, 2001.
18. "The Role of the analytic element method in groundwater flow modeling", H. M. Haitjema, University of New York at Buffalo, October 4, 2001.
19. "The Role of the analytic element method in groundwater flow modeling", H. M. Haitjema, University of Western Australia, Perth, October 24, 2001.
20. "The Role of the analytic element method in groundwater flow modeling", H. M. Haitjema, Flinders University, Adelaide, October 30, 2001
21. "Analytic Solutions to Three-Dimensional Flow: The Past and the Future", H.M. Haitjema, Fall Meeting AGU, San Francisco, December 14 –19, 2000.
22. "It's over…. Some Closing Remarks", Third International Conference on Analytic Element Modeling of Groundwater Flow", Brainerd, MN, April 16 – 19, 2000.
23. "Step-Wise Groundwater Flow Modeling: Keep it Simple", H.M. Haitjema, Spring Meeting AGU, Boston, May 26 – 29, 1998.
24. "The Meaning of Capture Zone Delineation", H.M. Haitjema, at the annual meeting of the American Rural Water Association in Indianapolis, October, 1997.
25. "All Models are not Created Equal", H.M. Haitjema, key note address at the international conference "Analytic Based Modeling of Groundwater Flow", Nunspeet, The Netherlands, April 7-10, 1997.
26. "Groundwater Residence Time Distributions in Watersheds", H.M. Haitjema, International Conference on Advances in Groundwater Hydrology--A Decade of Progress--, Tampa, FL, November 16-20, 1997.
27. "Application of the analytic element method to the Four County Landfill", H.M. Haitjema, Civil Engineering Department, Purdue University (Prof. J. Delleur), January 26, 1995.
28. "Introduction and Development of the Analytic Element Method of Groundwater Flow Modeling", H.M. Haitjema, Northeast Region meeting of U.S. Geological Survey Ground-Water Specialists, Indianapolis, May 17-20, 1994.
29. "Why Model Three-Dimensional Flow if You Can Go Dupuit-Forchheimer?," H.M. Haitjema, International Conference on Analytic Element Modeling of Groundwater Flow, Indianapolis, April 19-21, 1994.
30. "Capture Zone Delineation Modeling with EPA's New Wellhead Protection Program WhAEM", H.M. Haitjema (presenter) and O.D.L. Strack, Short course at the International Ground Water Modeling Center, Colorado School of Mines, Golden, Colorado, November 17-19, 1993.
31. "Conjunctive Surface Water and Groundwater Modeling with the Analytic Element Method," H.M. Haitjema (presenter) and S. Mitchell-Broker, presented at the Silver Anniversary Meeting of the International Society for Mathematical Geology, Prague, Czech Republic, October 11 15, 1993.
32. "Use of the Analytic Element Method for Regionalization of Local Groundwater Studies", H.M. Haitjema

(presenter) and S. Mitchell-Bruker, at USDA Soil Tilth Laboratory, Aimes, Iowa, September 10-11, 1992.

33. "Demonstration of the Analytic Element Method for Well Head Protection", H.M. Haitjema, EPA contractors conference, Dallas, Texas, June 24-25, 1992.
34. Invited presentation at the Geology Department of IUPUI, Indianapolis, October 1, 1992.
35. "Uses of Models in Hydrogeology," national conference on Hazardous Materials Management organized by Indianapolis Center for Advanced Research, Inc., Indianapolis, July 25, 1989.
36. Panel member on Groundwater Issues at the 35th Annual Indiana Farmers Union State Convention, January 26-27, 1989.
37. Invited presentation at the Technical University of Delft, The Netherlands, March 4, 1988.
38. Invited presentation at TNO Delft, The Netherlands, February 15, 1988.
39. Invited presentation at the College of Engineering of the University of Cincinnati, December 3, 1987.
40. Invited presentation at the Council of State Government's Groundwater Seminar in Indianapolis on November 19, 1986.
41. Computer modeling of two ATES systems in Tuscaloosa, Alabama. Invited presentation on Experts Meeting organized by Pacific Northwest Laboratories for DOE in St. Paul October 16-17, 1986.
42. Invited presentation at the conference 'Indiana Groundwater: Regulations, Risk Assessment and Remedies,' at Indianapolis (Oct. 1985).
43. Invited presentation on groundwater flow modeling at the International Groundwater Modeling Center, Holcomb Research Institute, Indianapolis (Feb. 1985).
44. Invited presentation for a national Dutch committee on artificial recharge of aquifers (1975).

Selected Presentations

1. “Truncating cross-sectional groundwater flow models under wetlands” (with Wilsnack) at the international conference MODFLOW and More 2006 in Golden, CO, May 21-25, 2006.
2. “The Role of hand calculations in groundwater flow modeling” at the international conference MODFLOW and More 2003, September 16-19, 2003.
3. “Modeling Lake-Aquifer interactions with analytic elements” Haitjema H.M. and R.J. Hunt, presented at Annual Geological Society of America (GSA) meeting in Denver, CO, October 27 – 30, 2002
4. Presentation at the National Nonpoint Source Monitoring Workshop in Indianapolis on August 28.
5. Paper accepted at MODFLOW 2001 conference in Golden, CO, but attendance prevented by September 11 events.
6. “Only a mater of resolution”, H.M. Haitjema, “Third International Conference on Analytic Element Modeling of Groundwater Flow”, Brainerd, MN, April 16 – 19, 2000.
7. “Capture zone delineation: Are simple methods adequate?”, H.M. Haitjema, Indiana Water Resources Association, Spring meeting, Mitchell Indiana, June 14-16, 2000.
8. Stepwise capture zone delineation: From circle to cell”, H.M. Haitjema, Midwest Groundwater Flow Conference, Columbus, OH, October 17-19,2000.
9. “An Analytic Element Screening Model of Regional Flow Surrounding a Proposed Mine near Crandon, Wisconsin”, H.M. Haitjema and V.A. Kelson, at the AWRA conference “Water Resources Management: Changes as We Approach the 21 Century”, March 5 – 6, 1998, Green Lake, WI
10. “Comprehensive Well Field Modeling for Marion County, Indiana”, J. Wittman, H.M. Haitjema, G. Lindsey, at the international conference “Analytic Based Modeling of Groundwater Flow”, Nunspeet, The Netherlands, April 7-10, 1997.
11. “An Analytic Element Solution to Unconfined Groundwater Flow near Partially Penetrating Wells”, K.H.Luther and H.M. Haitjema, at the international conference “Analytic Based Modeling of Groundwater Flow”, Nunspeet, The Netherlands, April 7-10, 1997.
12. “A Massively-Parallel Analytic Element Code”, V.A. Kelson and H.M. Haitjema at the international conference “Analytic Based Modeling of Groundwater Flow”, Nunspeet, The Netherlands, April 7-10, 1997.
13. "An Analytic Element Solutions to Unconfined Flow near a Partially Penetrating Well," K.H. Luther and H.M. Haitjema poster at 1996 AGE Spring Meeting, Baltimore, Maryland, May 20-24, 1996.
14. "Analytic Element Screening Technique for Numerical Groundwater Models", V.A. Kelson and H.M. Haitjema, poster at the Midwest Groundwater Conference, Columbia, Missouri, October 16-18, 1995.
15. "Capture Zone Modeling Using the WhAEM (Wellhead Analytic Element Model), S.R. Kraemer

(presenter), H.M. Haitjema and O.D.L. Strack, International Conference on Analytic Element Modeling of Groundwater Flow, Indianapolis, April 19-21, 1994.

16. "Effects of Climate Change on Groundwater in Dual Aquifer Settings", H.M. Haitjema (presenter) and J.F. Wittman, NIGEC conference at Oak Ridge, March 1994.
17. "Effective Continuum Representations of Discrete Fracture Networks for Regional Scale GroundWater Modeling", S.R. Kraemer (presenter) and H.M. Haitjema, AGE Chapman conference, Burlington, Vermont, September 12, 1994.
18. "Wellhead Protection Zone Delineation Using Analytic Element Models", Victor Kelson (presenter) and H.M. Haitjema, Midwest Ground Water Conference, Champaign Illinois, October 6-8, 1993.
19. "The Effects of Climate Change on Recharge to Regional Bedrock Aquifers in Glacial Settings," Jack Wittman (presenter) and H.M. Haitjema, Midwest Groundwater Conference, Bismark, South Dakota, October 4-6, 1992.
20. "Modeling Groundwater and Surface Water Interactions with Analytic Elements", S. Mitchell-Broker (presenter) and H.M. Haitjema, AGE Fall Meeting, San Francisco, December 9-13, 1991.
21. "Including Three-Dimensional Flow in a Regional Analytic Element Model", H.M. Haitjema, at the National Water Well Association (NWWA) sponsored international Groundwater Conference in Moscow, July 1-5, 1989.

CURRICULUM VITAE

2016-03-01

DARRELL KIRK NORDSTROM

BORN: San Francisco, California, November 14, 1946

TITLE: Senior Research Hydrologist (Geochemistry)/ Project Chief
U.S. Geological Survey
3215 Marine Street
Boulder, CO 80303
(303)541-3037; FAX (303)541-3084; email: dkn@usgs.gov

EDUCATION: B.A. (Chemistry) Southern Illinois University, 1969
M.S. (Geology) University of Colorado, 1971 Independent Research, "Electrochemical Geothermometry of Coexisting Sulfides"
Ph.D. (Geochemistry) Stanford University, 1977; Dissertation, "Hydrogeochemical and Microbiological Factors Affecting the Heavy Metal Chemistry of an Acid Mine Drainage System"

RESEARCH INTERESTS:
Chemical Modeling of Natural Waters
Geochemistry of Acid Mine Drainage
Geothermal Chemistry
Microbiological Processes Affecting Inorganic Water Chemistry
Arsenic Geochemistry
Groundwater Geochemistry in Crystalline Bedrock
Analytical Methods for Major, Minor, Trace and Redox Species in Natural Waters
Evaluation of Thermodynamic Data for Geochemical Modeling
Geochemistry of Radioactive Waste Disposal

EMPLOYMENT:

1991-present: Hydrogeochemist and Project Chief, Geochemical modeling of acid waters, U.S. Geological Survey, Boulder, Colorado

1993-2004: Adjunct Professor, Geological Sciences Department, University of Colorado, Boulder, Colorado

1980-91: Hydrogeochemist and Project Chief, Trace element partitioning in natural waters, U.S. Geological Survey, Menlo Park, California

1976-80: Assistant Professor, environmental geochemistry, Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia

1974-76: Research Chemist, trace element investigations in natural waters, U.S. Geological Survey, Menlo Park, California

1973-74: Research Assistant, mercury project, Stanford University, Stanford, California

1972-73: Medical Research Assistant, ion-selective micro-electrode measurements across cell membranes, University of Colorado, Medical Center, Denver, Colorado

1971-72: Medical Lab Technician, General Rose Memorial Hospital, Denver, Colorado

1971-73: Research Assistant, high pressure-high temperature reactions of fluorine-bearing silicate assemblages, University of Colorado, Boulder, Colorado

1969-71: Teaching Assistant in freshman geology and in mineralogy, University of Colorado, Boulder, Colorado

1967-69: Research Assistant, crystallographic studies of hydrated minerals, Southern Illinois University, Carbondale, Illinois

1966-67: Research Assistant, synthesis of triazo- and tetraazo-pentalenes, Southern Illinois University, Carbondale, Illinois

1964-66: Research Assistant, surface property investigations on monomolecular films, Southern Illinois University, Carbondale, Illinois

SUMMER EMPLOYMENT:

1970: Geologist, geochemical mapping and lab studies of hydrothermal alteration, Anaconda Company, Salt Lake City, Utah

1968 & 1969: Assistant Caretaker, Camp Fire Council, Nevada City, California

1967: Research Assistant, organic geochemistry of Illinois shales, Illinois State Geological Survey, Champaign-Urbana, Illinois

PROFESSIONAL SOCIETIES:

American Association for the Advancement of Science
Geochemical Society
Geological Society of America (Hydrogeology Division)
Mineralogical Society of America
International Association of Geochemists and Cosmochemists
International Mine Water Association

HONORS AND AWARDS:

Sigma Xi Grant in Aid of Research, 1970
Grant from the Anaconda Company, 1970
National Science Foundation Fellowship, 1970-71
Stanford Scholarship, 1975-76
American Men and Women of Science, 33rd edition
Who's Who in the West, 21st edition
Birdsall-Dreiss Distinguished Lectureship Award, Geological Society of America, 1996
Fellow, Mineralogical Society of America, 2000
Fellow, Geological Society of America, 2001
Meritorious Service Award, US Department of the Interior, 2002
Cooperative Conservation Award, US Department of the Interior, 2008
International Ingerson Lecture Award, International Association Geochemists & Cosmochemists, 2009
Friend of Water-Rock Interaction Award, 2010
Adrian Smith Lecture Award, University of Waterloo, 2011
USGS Water Research Lecture Award, 2012
Adjunct Professor, Department of Chemistry, Murdoch University, Perth, Australia 2014-2017

BOARD MEMBER

Member, Board of Radioactive Waste Management, National Academy of Sciences, 1990-96
Member, Science Advisory Board, Thermal Biology Institute, Montana State University, 2000-2009

TEACHING EXPERIENCE:

Southern Illinois University (1969)	Teaching Assistant, X-Ray Crystallography
University of Colorado (1969-70) University of Colorado (1971-72)	Lab Instructor, Freshman Geology Lab Lab Instructor, Mineralogy Lab Lectures on Irreversible Thermodynamics
Stanford University (1974-76)	Applied Aqueous Thermodynamics, Thermodynamics, Electrolytes and Geochemistry
University of Virginia (1977-80)	Environmental Thermodynamics, Chemistry of Natural Waters, Aqueous Geochemistry, Theoretical Geochemistry, Microbial Biogeochemistry
US Geological Survey (1985-2000)	Geochemistry of Ground Water Systems 2-week Training Course
Clarion University Coal Institute (November 8, 1989)	1-day seminar on Geochemistry of Acid Mine Waters
Society of Economic Geologists (1993)	Short course on Environmental Geochemistry of Mineral Deposits
ASSMR (1993) (American Society for Surface Mining Reclamation)	Short course on Implications of Aqueous Geochemistry in Mine Reclamation, Spokane, WA
CIEMAT/ENRESA, Madrid (1994) (Spanish Nuclear Waste Agency)	Short course on Aqueous Geochemistry and Geochemical Modeling (with Blair Jones)
University of Colorado (1995)	Semester course on Environmental Geochemistry
CIEMAT/ENRESA, Madrid (1996)	Short course on Isotope Hydrogeochemistry (with Niel Plummer)
ATSDR (Atlanta, GA, 1997) (Agency for Toxic Substances and Disease Registry)	Short course on Geochemical Modeling (with Jim Ball)
Porto University (2008)	Short Course on Arsenic Geochemistry, April 28-May 3
State of California Water Board (2009)	Short Course on Characterizing, Predicting, and Modeling Water Quality at Mine Sites, May 18-21
Wuhan University, Hubei, China (2009)	Advances in Hydrogeochemistry, March 23-26
University of Concepcion, Chile (2010)	Short Course on Mining and Sustainability, October 11-15
Society for Economic Geologists (2010)	Environmental Geochemistry for Modern Mining, October 29-30, Denver, CO (Annual Meeting of Geological Society of America)
EPA Webinar Workshop (2013)	Predicting and modeling water chemistry associated with hardrock mine sites, February 13
National University of Salta, Argentina (2015)	Short Course on the Geochemistry of Acid Mine Drainage
Murdoch University, Australia (2015)	1-day Master Class on Introduction to Geochemical Modeling
China University of Geosciences Wuhan China (2015)	half-day seminar on Introduction to PHREEQC

CONSULTING EXPERIENCE:

California State Water Quality Control Board (1977)
U.S. Geological Survey, Reston, Virginia (1977-80)
Virginia State Water Control Board (1976-1980)
U.S. Department of Energy, Argonne National Laboratory (1979)
Swedish Nuclear Fuel and Waste Management Company (SKB, 1980-1990); six months advisory work in Stockholm (1983)
US Environmental Protection Agency (1983-present) several mine site characterizations, remediations, litigations, short courses
US National Park Service (1994- present) advising Park Rangers at Yellowstone National Park, Wyoming, and at Serpentine Hot Springs Reserve, Alaska
Finnish Nuclear Waste Commission (1983-1990)
Atomic Energy of Canada, Ltd. (1987)

Pocos de Caldas Natural Analog (Nuclear Waste) Project, Brazil (1987-1990)
Cigar Lake Natural Analogue Project and Atomic Energy of Canada, Ltd. (1990-1992)
Spanish Nuclear Waste Management Agency (ENRESA) (1991-2000)
U.S. Department of Justice (1995-2001; 2009-present) on Superfund Mine Sites
U.S. Department of Energy, Rocky Flats Superfund site (2000-2004)
Spanish Geological Survey (2000-2008)
Portuguese Geological Survey (2008-2010)
Keystone Center (2008- present), member of Science Advisory Committee on Pebble Mine
French Geological Survey (2010-present)
Norwegian Geological Survey (2010)

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stability field for schuetteitte ($Hg_3O_2SO_4$) and corderoite ($Hg_3S_2C1_2$) at 298 K, *In* Jenne, E. A., ed., Chemical Modeling in Aqueous Systems, Am. Chem. Soc. Symp. Series 93, 339-352.

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176. Nordstrom, D.K. (2007) Geochemical meddling, microbing, Marsing, and mitigating mine drainage, Goldschmidt Conference, Cologne, Germany, August 19-24 (keynote).

177. Planer-Friedrich, Britta, …. (2007) Goldschmidt Conference, Cologne, Germany, August 19-24.

178. Nordstrom, D.K., McCleskey, R.B., and Ball, J.W. (2007) Oxidation reactions of iron, arsenic, sulfur, and antimony in Yellowstone's geothermal waters: interfacing with microbiology and the complexities of thioarsenic species, International Symposium on Environmental Biogeochemistry, ISEB-18, Taupo, New Zealand.

179. Alpers, C.N., Nordstrom, D.K., Verosub, K.L., and Helm-Clark, Catherine (2007) Paleomagnetic determination of pre-mining metal-flux rates at the Iron Mountain superfund Site, Northern California, Eos Trans. AGU 88 (23) Jt. Assem. Suppl. Abstract GP41B-04.

180. Nordstrom, D.K. (2007) Geochemical modeling, predictions, and the remediation of mine sites, Geological Society of America Annual Meeting, Oct. 28-31, Denver, CO (keynote).

181. McCleskey, R.B., Nordstrom, D.K., and Ball, J.W. (2007) Source and fate of metals in the Gibbon River, Yellowstone National Park, USA, Geological Society of America Annual Meeting, Oct. 28-31, Denver, CO.

182. Nordstrom, D.K., Susong, D.D., McCleskey, R.B., Ball, J.W., and Runkel, R.L. (2008) Chemical anatomy of the Firehole River: Results from the September 2007 synoptic sampling, Geothermal Biology and Geochemistry, NSF Research Coordination Network and MSU Thermal Biology Institute, Jan. 10-13, 2008

183. McCleskey, R.B., Nordstrom, D.K., Susong, D.D., and Ball, J.W. (2008) Source and fate of thermal and non-thermal solutes in the Gibbon River, Yellowstone National Park, USA, Geothermal Biology and Geochemistry, NSF Research Coordination Network and MSU Thermal Biology Institute, Jan. 10-13, 2008

184. Nordstrom, D.K. (2008) Research and remediation issues for hard-rock metal mines, Workshop on metal mines and their remediation, May 13-15, 2008.

185. Garcia-Domínguez, E., Bruno, M., Nordstrom, D.K., and Young, L.Y. (2008) Arsenic oxidizing chemoautrophic microorganisms from geothermal water and sediments, Am. Soc. Microbiol. Ann. Mtg., June 1-5, 2008, Boston, MA.

186. Asta, M.P., Nordstrom, D.K., McCleskey, R.B., and Cama, J. (2008) Arsenic and iron oxidation in presence of bacteria of the Iberian Pyritic Belt (SW Spain) and its environmental implications, Second International Congress on Arsenic in the Environment: Arsenic from Nature to Humans, May 21-23, Valencia, Spain (won best student poster).

187. Nordstrom, D.K., Planer-Friedrich, B., and Wallschläger, D. (2008) Complexities of arsenic speciation in sulfidic geothermal waters, Second International Congress on Arsenic in the Environment: Arsenic from Nature to Humans, May 21-23, Valencia, Spain (keynote).

188. Thomas H. Osborne, Heather E. Jamieson, Karen A. Hudson-Edwards, D. Kirk Nordstrom, Joanne M. Santini (2008) Bacterial arsenite oxidation in cold environments, Society for General Microbiology, Dublin, Ireland.

189. Alpers, C.N., Majzlan, J., Koch, C.B., Bishop, J.L., Coleman, M.L., Dyar, M.D., McCleskey, R.B., Myneni, S.C.B., Nordstrom, D.K., and Sobron, P. (2008) Chemistry and spectroscopy of iron-sulfate minerals from Iron Mountain, California, U.S.A., Goldschmidt Conference, Vancouver, B.C.

190. Nordstrom, D.K. (2008) Science, engineering and the remediation of metal mine sites, Workshop on remediation of metal mines in the Iberian Pyrite Belt, Seville, Spain, Nov. 17-19, 2008 (keynote).

191. Nordstrom, D.K., Susong, D.D., McCleskey, R.B., Ball, J.W., and Runkel, R.L. (2008) Chemical anatomy of the Firehole River, Geol. Soc. Am. Ann Mtg., Oct. 5-9, 2008, Houston, TX.

192. Asta, M.P., Nordstrom, D.K., McCleskey, R.B. (2008) Simultaneous oxidation rates of iron and arsenic in acid mine drainage (Rio Tinto, Spain) and of arsenic and antimony in neutral mine drainage (Giant Mine, Canada), Geol. Soc. Am. Ann Mtg., Oct. 5-9, 2008, Houston, TX.

193. Sherman, L.S., Blum, J.D., Nordstrom, D.K., McCleskey, R.B., Barkay. T., and Vetriani, C. (2008) Mass-Independent Fractionation of Mercury in Hydrothermal Systems, Am. Geophys. Union,

Dec. 15-19, San Francisco, CA.

194. Mitchell, K.R. et al. (2008) Geochemical controls on microbial community composition from varied hot spring environments, Am. Geophys. Union, Dec. 15-19, San Francisco, CA Abstract B53D-07.

195. Nordstrom, D.K. (2009) Pitfalls and limitations of mineral equilibrium assumptions for geochemical modeling of water-rock interactions at mine sites, International Conference on Acid rock Drainage (ICARD), Skellefteå, June 22-25, Sweden.

196. Nordstrom, D.K. (2009) Hydrogeochemical processes governing the origin, transport, and fate of major and trace elements from mine wastes and mineralized rock, 24th Int. Appl. Geochem. Symp., June 1-4, Fredericton, New Brunswick, Canada (keynote).

197. Nordstrom, D.K. (2009) Modeling, validation, and environmental and applied geochemistry: Issues in philosophy and communication, International Ingerson Lecture Award, 24th Int. Appl. Geochem. Symp., June 1-4, Fredericton, New Brunswick, Canada.

198. Nordstrom, D.K. (2009) Hydrogeochemical processes governing the origin, transport, and fate of major and trace elements from mine wastes and mineralized rock, Geol. Soc. Am. Ann. Mtg., Oct. 18-21, Portland, OR.

199. Nordstrom, D.K. and Zheng, Y. (2009) Natural arsenic enrichment: Effects of the diagenetic-tectonic-hydrothermal cycle, Geol. Soc. Am. Ann. Mtg., Oct. 18-21, Portland, OR.

200. Fawcett, S.E., Jamieson, H.E., and Nordstrom, D.K. (2009) Geochemical controls on arsenic and antimony mobility in sediment and pore-water in a mine-impacted lacustrine environment, Geol. Soc. Am. Ann. Mtg., Oct. 18-21, Portland, OR.

201. Nordstrom, D.K. (2009) Water quality and climate change: an example with acid rock drainage, Geol. Soc. Am. Ann. Mtg., Oct. 18-21, Portland, OR.

202. Nicholson, A. and Nordstrom, D. (2010) Aluminum buffering and mineral equilibria in acid-sulfate systems, SME Ann. Mtg., Feb. 28-Mar. 3, Phoenix, AZ.

203. Nordstrom, D. K. (2010) Water quality and climate change: Examples with acid-rock drainage, USGS Global Change Conference, March 9-11.

204. Nordstrom, D.K. (2010) Geothermal arsenic, 3rd International Arsenic Congress, Tainan, Taiwan, May 17-21.

205. Nordstrom, D.K. (2010) Evaluating aqueous geochemical models and codes, USGS Modeling Conference, June 7-11.

206. Nordstrom, D.K., McCleskey, R.B., Susong, D.D., and Ball, J.W. (2010) Arsenic not attenuated during downstream transport in Gibbon and Firehole Rivers, Yellowstone National Park, Goldschmidt Geochemistry Conference, Knoxville, TN, June 14-17.

207. Nordstrom, D.K., R. Blaine McCleskey, and James W. Ball (2010) Challenges in the analysis and interpretation of acidic waters, International Mine Water Association, Cape Breton University, Nova Scotia, Canada, September 6-9.

208. Verplanck, P.L., Mueller, S.H., Goldfarb, R.J., Nordstrom, D.K., and Youcha, E.K. (2010) Hydrogeochemistry of arsenic in circumneutral groundwater, Ester Dome, Fairbanks mining district, Alaska, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 31-Nov. 3.

209. Nordstrom, D.K. (2010) Strengths and limitations on the use and misuse of aqueous geochemical models, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 31-Nov. 3.

210. Nordstrom, D.K. (2010) Various origins of circumneutral mine drainage and problems with classification, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 31-Nov. 3.

211. McCleskey, R.B., Nordstrom, D.K., and Ryan, J.N., (2010) Electrical conductivity: Theory and applications for natural waters, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 31-Nov. 3.

212. Nordstrom, D.K. (2011) Acid mine drainage and responsible mining, Goldschmidt 2011, International Geochemistry Conference, Prague, Czech Republic, August 14-19, 2011.

213. Campbell, K., Nordstrom, D.K., and Hay, M. (2011) Kinetic modeling of microbial Fe(II) oxidation, Fe(III) hydrolysis, and mineral precipitation in acid waters, Goldschmidt 2011, International Geochemistry Conference, Prague, Czech Republic, August 14-19, 2011.

214. Nordstrom, D.K. (2011) Natural pyrite weathering rate in a small catchment compared with mined catchments, Geol. Soc. Amer. Ann. Mtg., Minneapolis, MN, Oct. 9-12.

215. Nordstrom, D.K. (2012) Natural pyrite weathering rate in a small catchment compared with mined catchments and lab rates, Goldschmidt 2012, International Geochemistry Conference, Montreal, Quebec, June 25-29, 2012.

216. Nordstrom D.K. and McCleskey, R.B. (2012) As, Sb, Mo, V, W, and Se oxyanions in Yellowstone's thermal waters, Goldschmidt 2012, International Geochemistry Conference, Montreal, Quebec, June 25-29, 2012.

217. Nordstrom, D.K. (2012) Improving the reliability of water analyses: Beyond QA/QC, 9th International Symposium on Environmental Geochemistry, Aveiro, Portugal, July 15-21, p. 168.

218. Nordstrom, D.K. and McCleskey, R.B. (2012) Comparison of oxyanion geochemistry (As, Sb, Mo, V, W, Se) in Yellowstone's thermal waters and downstream fluvial transport, Geol. Soc. Amer. Ann. Mtg., Charlotte, NC, Nov. 4-7.

219. Christian, K., Nordstrom, D.K., McCleskey, R.B., and Campbell, K.M. (2012) An analysis of methods for measuring aqueous iron redox species, Geol. Soc. Amer. Ann. Mtg., Charlotte, NC, Nov. 4-7.

220. Sydow, L.A., Bennett, P.C. and Nordstrom, D.K. (2012) Cinder Pool's sulfur chemistry: Implications for the origin of life in hydrothermal environments, American Geophysical Union Annual Meeting, San Francisco, CA, Dec. 3-7.

221. Williams, A., Phan, A.T., Sumner, D.Y., Alpers, C.N., Campbell, K.M., and Nordstrom, D.K. (2013) Filamentous biosignature preservation in the iron mountain massive sulfide deposit: implications for biosignature detection on mars, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 27-30.

222. Alpers, C.N., Nordstrom, D.K., Campbell, K.M., Spitzley, J., Bunte, D., and Sickles, J. (2013) Four decades of research on environmental geochemistry and mineralogy in support of remediation at

the iron mountain mine superfund site, California, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 27-30.

223. Campbell, K.M., Alpers, C.N., Nordstrom, D.K., Blum, A.E., Williams, A.J. (2013) Biogeochemical processes involved in formation of schwertmannite-rich scale in a pipeline carrying acid mine drainage at iron mountain mine, California, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 27-30.

224. Jamieson, H.E., Bromstad, M., Nordstrom, D.K., Plumlee, G.S., Mormon, S.A. (2013) The legacy of arsenic trioxide at the Giant mine, Yellowknife, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 27-30.

225. Nordstrom, D.K. (2013) Serendipity and a tao of geochemistry, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 27-30.

226. Williams, A.J., Phan, A.T., Sumner, D.Y., Alpers, C.N., Campbell, K.M., Nordstrom, D.K. (2013) Filamentous biosignature preservation in the Iron Mountain massive sulfide deposit: Implications for biosignature detection on Mars, Geol. Soc. Amer. Ann. Mtg., Denver, CO, Oct. 27-30.

227. Nordstrom, D.K. (2013) Improving internal consistency of standard state thermodynamic data for sulfate ion, portlandite, barite, celestine, and associated ions, Procedia Earth and Planetary Sciences 7, 624-627 (WRI-14, Avignon, France).

228. Königsberger, E., Majzlan, J., Nordstrom, D.K. (2014) Solubility and thermodynamic data for metal arsenates, IUPAC Solubility Data meeting, Karlsruhe, Germany, July.

229. Nordstrom, D.K., Majzlan, J., Königsberger, E., Campbell, K.M. (2014) Critical evaluation of thermodynamic data for selected arsenic minerals and aqueous species with applications to natural waters, Geol. Soc. Amer. Ann. Mtg., Vancouver, B.C., Canada, Oct. 19-22.

230. Nordstrom, D.K., Smith, K., Campbell, K.M. (2014) Extraction of useful resources from mining-influenced water (MIW), EPA National Conference on Mining-Influenced Water, Albuquerque, NM, Aug. 11-14.

231. Nordstrom, D.K., Alpers, C.A. (2014) Formation of iron-sulfate minerals by oxidation of pyrite and aqueous ferrous iron and evaporation of acid mine water, GAC-MAC Ann. Mtg., Fredericton, N.B., Canada, May 21-23.

232. Nordstrom, D.K. (2015) Antimony and arsenic: how far does the comparison go? Antimony 2015, Antimony in the Environment, Leipzig, Germany, Oct. 6-9 (keynote).

233. Maest, A.S., Nordstrom, D.K. (2015) A chromatogram of geochemical reactions: Interpreting humidity cell tests, Geol. Soc. Amer. Ann. Mtg., Baltimore, MD, Nov. 1-4.

234. Nordstrom, D.K., Geesey, G., Barkay, T., King, S., McCleskey, R.B., Krabbenhoft, D.P., Roth, D.A. (2015) Geothermal mercury and microbiology in western North America, Geol. Soc. Amer. Ann. Mtg., Baltimore, MD, Nov. 1-4.

235. Campbell-Hay, K.M., Alpers, C.N., Nordstrom, D.K. (2016) Challenges and potential benefits of managing acidic mining influenced water, ACS Symp., San Diego, CA,

PRESENTATIONS (excluding abstracts) at SCIENTIFIC MEETINGS and INVITED LECTURES

1966 – "The surface hydrolysis of some phosphate esters," Illinois Institute of Technology. Chicago, IL. 17th Ann. Undergrad. Am. Chem. Soc. Symposium.

1975 – "Acid mine waters in Shasta County, California," Water Quality Conference of Pacific Coast Schools, California Institute of Technology, Pasadena, CA.

1977 – "The great California acid trip: The weathering of massive sulfide deposits in Shasta County, California," Geological Society of Washington, Washington, D.C.

1982 – "Water chemistry data from the Stripa Test Site, "Stripa Project Meeting Vienna, AUSTRIA.

1983 – "Stripa groundwaters," Water Chemistry Workshop on Problems Related to Radioactive Waste Disposal, Turku-Abo, FINLAND.

1983 – "Geochemical characterization of the Stripa groundwaters," Stripa Project Meeting, Stockholm, SWEDEN.

1984 – "Geochemical investigations on the Stripa groundwaters," Stripa Project Meeting, Munich, WEST GERMANY.

1984 – "Hydrogeochemical investigations on the Stripa groundwaters," Stripa Project Meeting, Stockholm, SWEDEN.

1984 – "Aluminum transformations in acidic natural waters," Acid rain workshop, Uppsala, SWEDEN.

1985 – "Phase 1 and 2 geochemical investigations on the Stripa ground waters," Stripa Project Mtg., Meiringen, SWITZERLAND.

1986 – "Water chemistry data from Phase 2, Stripa Project," Stripa Project Meeting, Paris, FRANCE.

1986 – "Hydrogeochemical interpretation of Hastholmen data," IVO and Finnish Geol. Survey Mtg., Helsinki, FINLAND.

1986 – "Phase 2 Hydrogeochemical results," Stripa TSG Mtg., Stockholm, SWEDEN.

1987 – "Presentation and discussion on the hydrogeochemical characterization of the Stripa groundwaters," Stripa TSG Mtg., Helsinki, FINLAND.

1987 – "Results from hydrogeochemical studies on the Stripa Project," AECL Water Chemistry Workshop, Pinawa, Manitoba, CANADA.

1989 – "Chemical modeling of groundwater at Pocos de Caldas," Pocos Meeting, Saanen-Gstaad, SWITZERLAND.

1989 – "Hydrochemistry of groundwaters at Pocos de Caldas," Pocos Meeting (Jan.), Saanen-Gstad, SWITZERLAND.

1990 – "Review of chemical modeling of acid mine drainage in the U.S.," RATAP meeting, Wigamog, Ontario, CANADA.

1990 – "Results from Geochemical modeling of groundwaters at Pocos," Pocos meeting (Mar.), Saanen-Gstaad, SWITZERLAND.

1990 – "Hydrogeochemistry of two natural analogues sites at Pocos de Caldas, Brazil," Final Pocos de Caldas Workshop, Pitlochry, SWITZERLAND.

1991 – "Record-breaking acid mine drainage and environmental restoration at Iron Mountain, Shasta Co., California," Bay Area Mineralogists, Los Altos Hills, CA.

1994 – "Forward and inverse geochemical modeling with applications to acid mine drainage" and "Negative pH, ultra acidic mine waters and the challenge of environmental restoration at Iron Mountain Mine, California," Retention and mobilization of heavy metals in waste deposits and soils, Heavy Metals Workshop, Kronlund, SWEDEN.

1998 – "Geochemical modeling, thermodynamic databases, and the impact on water quality issues," National Institute of Standards and Technology, Gaithersburg, MD.

1998 – "Geochemistry of the arsenic-pyrite connection and biogeochemical processes leading to arsenic mobility in natural waters," International Conference on Arsenic Pollution of Ground Water in Bangladesh, Dhaka, Bangladesh, Feb. 8-12.

1998 – "Negative pH, ultra-acidic mine waters, and the challenge of environmental restoration at the Iron Mountain Mine superfund site, California," Fort Lewis College, Durango, CO (NSF-sponsored summer course on Environmental Science and Philosophy).

1998 – "Model validation and the philosophy of science," Fort Lewis College, Durango, CO (NSF-sponsored summer course on Environmental Science and Philosophy).

1998 – "Arsenic mass poisoning in the Bengal Delta," California State Water Resources Board, Sacramento, CA.

1999 – "Why not to plug a mine," Holden Mine site meeting, Holden, WA, sponsored by USFS.

1999 – "Why not to plug a mine: Negative pH and extremely acid mine waters at the Iron Mountain Mine Superfund site, California," EPA monthly seminar series, Denver, CO.

1999 – "Negative pH, ultra-acidic mine waters, and the challenge of environmental restoration at the Iron Mountain Mine superfund site, California," Fort Lewis College, Durango, CO (NSF-sponsored summer course on Environmental Science and Philosophy).

1999 – "Model validation and the philosophy of science," Fort Lewis College, Durango, CO (NSF-sponsored summer course on Environmental Science and Philosophy).

2000 – "Arsenic mass poisoning in the Bengal Delta," 6th International Symposium on Metal Ions in Biology and Medicine, San Juan, Puerto Rico, May 7-10.

2001 – "Arsenic geochemistry: An overview of an underhanded element," EPA Workshop on Managing Arsenic Risks to the Environment: Characterization of waste, chemistry, and treatment and disposal," May 1-3, Denver, CO.

2001 – "From research to remediation: The hydrogeochemistry of acid mine waters." International Symposium on Bioremediation Technology, Leipzig, Germany, Mar. 21-23.

2002 – “Inorganic contaminants: Common, persistent and toxic,” International Conference GeoProc2002, Bremen, Germany, Mar. 4-7.

2002 – “Geochemical modeling and the reliability of thermodynamic databases,” National Institute of Standards and Technology, Boulder, CO, November.

2005 – “Pre-mining ground-water quality at Molycorp’s Questa molybdenum mine: The final stretch,” USGS, Denver Federal Center, Denver, Colorado.

2005 –“Pre-mining ground-water quality at Molycorp’s Questa molybdenum mine: Preliminary conclusions,” URS, Denver Tech Center, Denver, Colorado.

2007 – “Problems with geochemical modeling of Fe and Al in acidified surface and ground waters,” USEPA Metals fate and transport modeling workshop, Feb. 13-14, Denver, CO.

2007 – “Accomplishments and future needs,” Ten-year anniversary of the BLM and USDA FS Abandoned Mine Lands Programs, Silverton, CO, September 26-27, 2007.

2008 – “Science, Engineering, and Remediation of Metal Mining Sites,” Workshop on the Remediation of Polymetallic Mine Sites, University of Seville, Seville, Spain, November 17-21.

2009 – “Groundwater geochemistry, hydrogeology, and coupled processes,” DUSEL Workshop, Lead, SD, Oct. 1-3.

2010 – “Modeling, “validation,” and applied and environmental geochemistry – Issues in philosophy and communication,” Norwegian Geological Survey, Trondheim, Norway, Sept. 28.

2010 – “Arsenic in the environment – Overview of sources, sinks, and worldwide occurrences,” University of Freiberg, Freiberg, Germany, Oct. 1.

2010 – “Modeling, “validation,” and applied and environmental geochemistry – Issues in philosophy and communication,” French Geological Survey (BRGM, Orleans, France), October 4.

2010 – “Arsenic in the environment – Overview of sources, sinks, and worldwide occurrences,” French Geological Survey (BRGM, Orleans, France), October 6.

SEMINARS AT UNIVERSITIES AND THE USGS

1973 – "Irreversible thermodynamics," A series of seminars for "Advanced Topics in Theoretical Petrology," University of Colorado, Boulder, CO.

1977 – "Geochemistry of acid mine drainage from massive sulfide deposits," Virginia Polytechnic Institute and State University, Blacksburg, VA.

1978 – "The weathering of massive sulfide deposits in Shasta County, California," Pennsylvania State University, University Park, PA.

1979 – "A review of electrolyte models," U.S. Geol. Survey, Reston, VA.

1981 – "The great California acid trip - and other mine drainage stories," University of Waterloo, Waterloo, CANADA.

1981 – "The effect of sulfate on aluminum concentrations in natural waters," Stanford University, Stanford, CA.

1981 – "Pyrite oxidation and the formation of acid mine waters," WRD research seminar, U.S.G.S.

1981 – "Geochemistry of acid mine waters from massive sulfide deposits," Lawrence Livermore Laboratory, Livermore, CA.

1982 – "Sorption vs. solubility in the aluminum sulfate system: An exercise in semantics," University of Waterloo, Waterloo, CANADA.

1982 – "Acid mine drainage from massive sulfide deposits and the process of pyrite oxidation," Nevada District Office, WRD, U.S.G.S., Carson City, NV.

1982 – "Geochemical evidence for residual metamorphic/magmatic fluids: a source of salinity in deep granitic groundwaters," University of Colorado, Boulder, CO.

1983 – "The computation of chemical equilibrium in natural waters: problems, pitfalls and promises," Royal Institute of Technology, Stockholm, SWEDEN.

1983 – "The effect of sulfate on the aqueous geochemistry of aluminum," Royal Institute of Technology, Stockholm, SWEDEN.

1983 – "Pyrite oxidation and the formation of acid mine waters," Stockholm University, Stockholm, SWEDEN.

1983 – "Chemical modeling and radioactive waste disposal," Riso National Laboratories, DENMARK.

1983 – "Evolution of saline groundwaters in Sweden," Chalmers Institute of Technology and Goteborg University, SWEDEN.

1984 - "The Swedish Radioactive Waste Disposal Program," WRD Seminar, Menlo Park, CA.

1984 – "The geochemistry of the deep granitic groundwaters at the Stripa Test Site," WRD Seminar, Menlo Park, CA.

1984 – "Evidence for fluid inclusion-derived salinity in the deep granitic groundwaters of the Stripa Test Site," IGP Seminar, Menlo Park, CA.

1984 – "On the interpretation of saline groundwaters in crystalline rocks," Finnish Radioactive Waste Commission, Helsinki, FINLAND.

1984 – "Hydrogeochemical investigations at Stripa," Lawrence Livermore Laboratory, Livermore, CA.

1985 – "Chemical modeling of natural waters: problems, pitfalls and promises," Syracuse University, Syracuse, NY.

1985 – "Geochemical investigations at the Stripa Test Site," University of Virginia, Charlottesville, VA.

1985 – "The formation of acid mine waters and related geoalchemy," Indiana University, Bloomington, IN.

1988 – "Environmental chemistry of acid mine drainage: Precious metal mining wastes. What the future holds," Phoebe Apperson Hearst Distinguished Lecturer, University of California, Berkeley, CA.

1988 – "The International Stripa Project: New lessons in granite-water interactions for radioactive waste management, "University of California at Davis, Davis, CA.

1989 – "Geochemical Thermodynamics and Phase Equilibria," Royal Institute of Technology, Stockholm, Sweden.

1989 – "Formation and properties of alunite and jarosite," Australian - U.S. Conference on acid saline lakes and groundwaters, Honolulu, HW.

1989 – "Deep granite-groundwater interactions at the Stripa research site, Sweden," Bern University, Bern, SWITZERLAND.

1989 – "Progress in interpreting geochemical processes in acid mine waters," Lehigh University, PA.

1989 – "Geochemistry of Acid Mine Waters," one-day invited seminar at Clarion University, Coal Institute, PA.

1989 – "Hydrogeochemistry of deep granitic groundwaters: Lessons from the Stripa experience," Stanford University, Stanford, CA.

1990 – "The continuing saga of aluminum geochemistry in natural waters," Stanford University, Stanford, CA.

1990 – "Interpretive Groundwater Geochemistry," 1 week invited seminar at University of Bern, SWITZERLAND.

1990 – "Geochemical Processes in Acid Mine Waters," Invited talk at the Illinois State Water Survey, Champaign-Urbana, Illinois.

1990 – "Chemical modeling of acid mine waters in the western U.S.," Toxic Waste Proceedings, U.S.G.S., Monterey, CA.

1990 – "Extremely acid mine waters from Iron Mountain, California," University of Waterloo, Waterloo, Ontario, Canada.

1990 – "Record-breaking acid mine waters from Iron Mountain Mine, California,: Environment Canada, Saskatoon, Canada.

1990 – "Acid mine waters in the Western U.S. and clean-up strategies," Canadian Institute of Mining and Metallurgy, Saskatchewan Branch, Saskatoon, Canada

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1991 – "Record-breaking acid mine drainage and environmental restoration at Iron Mountain, California", WRD Seminar, Menlo Park, CA.

1991 – "Extremely acid mine waters and unusual efflorescent sulfate minerals at Iron Mountain, California," Bay Area Mineralogists, Los Altos, CA.

1991 – "Another one for Guiness: Record-breaking acid mine waters from Iron Mountain, California, A superfund site undergoing rehabilitation," Stanford University, Stanford, CA.

1991 – "Evaluating thermodynamic data (but not for fun or profit);" "Hydrogeochemical modeling in the Pocos de Caldas Natural Analogue Study;" "A new dimension in mine waste contamination: The geochemistry of ultra-acid mine waters;" Three invited lectures at the University of Texas, Austin, TX.

1992 – "Applications of geochemical modeling to the interpretation and management of acid mine waters" invited lecture at University of Nevada, Reno, NV.

1992 – "Geochemistry and environmental restoration of extremely acidic mine waters at Iron Mountain, California," University of Colorado, Boulder, CO.

1992 – "The Iron Mountain Mine Superfund Anomaly: Ultra-acid mine water, negative pH, and the challenge of environmental restoration," WRD Seminar, Reston, VA.

1992 – "Geochemical modeling and the application of thermodynamic data to the interpretation of natural water chemistry," National Institute of Standards and Technology, Gaithersburg, MD.

1992 – "Extremely acidic mine waters and the application of geochemical models," GD Seminar, U.S.G.S., Denver Federal Center, CO.

1992 – "The International Stripa Project: New Hypotheses of Granite-Water Interactions and Lessons for High-Level Radioactive Waste Research," U.S.G.S., WRD, California District Office, Sacramento, CA.

1992 – "The Iron Mountain Mine Superfund Anomaly: Ultra-acidic mine water, negative pH and the challenge of environmental restoration," Distinguished Lecture Series, University of Wyoming, Laramie, WY.

1993 – "Ultra-acid mine waters, negative pH, and the environmental restoration of Iron Mountain Mine, California," Federal Building, Helena, MT.

1993 – "Fundamentals of aqueous geochemistry and trace metal mobility," Soc. Econ. Geol. Short Course on Environmental Geochemistry of Mineral Deposits, Denver, CO.

1993 – "Geochemistry of acid mine drainage," Soc. Econ. Geol. Short Course in Environmental Geochemistry of Mineral Deposits, (with Charles Alpers) Denver, CO.

1993 – "Implications of aqueous geochemistry in mine reclamation," Am. Soc. Surface Mining Reclamation, Spokane, WA.

1993 – "Geochemical modeling of ground waters in radioactive waste research and the current controversy on model validation," Colorado School of Mines, Golden, CO.

1993 – "Negative pH, ultra-acid mine waters and the Iron Mountain Mine Superfund anomaly," SUNY, Stony Brook, NY.

1993 – "USGS investigations related to abandoned mine lands," U.S. Department of the Interior, Washington, D.C.

1994 – "Groundwater Geochemistry," one-week short course presented at CIEMAT, Madrid, Spain, with Blair Jones.

1994 – "Model validation is not valid; some comments on the current controversy," WRD Seminar, Boulder, CO.

1994 – "Environmental Geochemistry of Sulfide Mine-Wastes," Short course presentation at Geol. Assoc. Canada - Min. Assoc. Canada Ann. Mtg.

1994 – "Negative pH, ultracidic mine waters, and the challenge of environmental restoration of the Iron Mountain Superfund Site," EPA Training Workshop, Denver, CO.

1994 – "Model validation and other chimeras: some personal thoughts on the philosophy of science," WRD Seminar, Reston, VA.

1994 – "Development of mobile chemical laboratories for water analyses: the Spanish experience and an NRP prototype," WRD Seminar, Reston, VA.

1994 – "The occurrence of thiosulfate in Yellowstone geothermal waters: some preliminary data," WRD Seminar, Reston, VA.

1995 – "Geochemical Modeling and Thermodynamic Data Evaluation - an interactive sport," EPA, Athens, GA.

1996 – Birdsall-Dreiss Distinguished Lectureship Series (44 institutions), 2 lectures: (1) "Negative pH, ultra-acidic mine waters, and the challenge of environmental restoration at Iron Mountain, California," and (2) "Model validation and other chimeras: some personal thoughts on the philosophy of science."

1996 – "Isotope Hydrogeochemistry," 4-day short course at CIEMAT, Madrid, Spain, with Niel Plummer.

1996 – "Model validation and other chimeras," University of Iceland, Reykjavik, Iceland.

1996 – "Arsenic oxidation, speciation, and attenuation in springs and acid mine waters: examples from waters in the Western U.S." USGS Arsenic Workshop, Sutter Creek, CA.

1997 – "Mining and Water Quality," Boulder Kiwanis Club, Colorado.

1997 – "Negative pH, ultra-acidic mine waters and the challenge of environmental restoration at Iron Mountain Superfund Site," ATSDR, Atlanta, GA.

1997 – "Model validation and other chimeras: some personal reflections on the philosophy of science," ATSDR, Atlanta, GA.

1997 – "Negative pH, ultra-acidic mine waters and the challenge of environmental restoration at Iron Mountain Superfund Site," CDC National Environmental Health Labs,

1997 – "Rare earth element geochemistry during acidic weathering," USGS California District Office, Sacramento, CA.

1997 – “Negative pH, ultra-acidic mine waters and the challenge of environmental restoration at Iron Mountain Superfund Site,” California Institute of Technology, Pasadena, CA.

1997 – “Model validation and other chimeras: some personal reflections on the philosophy of science,” Royal Insitute of Technology, Stockholm, Sweden.

1997 – “Negative pH, ultra-acidic mine waters, and the challenge of environmental restoration at the Iron Mountain Mine Superfund Site ,” Royal Insitute of Technology, Stockholm, Sweden.

1997 – “Sulfur redox chemistry in the geothermal waters of Yellowstone National Park and the origin of thiosulfate,” University of Montana, Missoula, MT.

1997 – “Negative pH, ultra-acidic mine waters and the challenge of environmental restoration at Iron Mountain Superfund Site,” University of Montana, Missoula, MT.

1997 – “Negative pH, ultra-acidic mine waters and the challenge of environmental restoration at Iron Mountain Superfund Site,” USGS, Montana District Office, Helena, MT.

1997 – “Geochemical measurements and modeling for mine site characterization,” US Forest Service meeting, Reno, NV.

1997 – “Sulfur redox chemistry in Yellowstone National Park: Occurrence and origin of thiosulfate and natural oxidation of elemental sulfur,” University of Wyoming, Laramie, WY.

1998 – "Science and regulatory practice: the search for certainty," Science for Watershed Decisions on Abandoned Mine Lands: Review of Preliminary Results, USGS AML Workshop, Denver, CO.

1998 – "Geochemical modeling, thermodynamic databases, and their impact on water-quality issues," NIST, Gaithersburg, MD.

1998 – “Negative pH, ultra-acidic mine waters, and the challenge of environmental restoration at the Iron Mountain Mine superfund site, California,” University of California, Berkeley, CA.

1998 – "Arsenic mass poisoning in Bengal (West Bengal, India and Bangladesh): A report on the International Conference in Dhaka," USGS Headquarters, Reston, VA.

1998 – “Arsenic mass poisoning in Bengal (West Bengal, India and Bangladesh): A hydrogeological catastrophe of enormous proportions,” University of Colorado, Geology Department, Boulder, CO.

1998 - "Arsenic mass poisoning in Bangladesh," USGS Boulder Research Center, Boulder, CO.

1998 – “Negative pH, ultra-acidic mine waters, and the challenge of environmental restoration at the Iron Mountain Mine superfund site, California,” Fort Lewis College, Durango, CO (NSF-sponsored summer course on Environmental Science and Philosophy).

1998 – “Model validation and the philosophy of science,” Fort Lewis College, Durango, CO (NSF-sponsored summer course on Environmental Science and Philosophy).

1998 – “Rare earth element geochemistry in acid waters,” USGS California District Office, Sacramento, CA.

1998 – “Arsenic mass poisoning in the Bengal Delta,” California State Water Resources Board, Sacramento, CA.

1999 – “Exploring the redox chemistry of sulfur in Yellowstone National Park,” University of Wisconsin, Madison, WI.

1999 – “Arsenic mass poisoning in the Bengal Delta: A calamity affecting millions,” University of Wisconsin, Madison, WI.

1999 – “From research to remediation: Application of reactive-transport modeling to the acid mine drainage at Summitville, Colorado,” University of Wisconsin, Madison, WI.

1999 – “Negative pH, ultra-acidic mine waters, and the challenge of environmental restoration at the Iron Mountain Mine superfund site, California,” Fort Lewis College, Durango, CO (NSF-sponsored summer course on Environmental Science and Philosophy).

1999 – “Model validation and the philosophy of science,” Fort Lewis College, Durango, CO (NSF-sponsored summer course on Environmental Science and Philosophy).

1999 – “Why not to plug a mine,” Holden Mine site meeting, Holden, WA.

1999 – “Negative pH efflorescent mineralogy and the challenge of environmental restoration at the Iron Mountain Superfund Site,” Toulouse University, Toulouse, France.

1999 – “Advances in thermodynamic properties needed for geochemical modeling,” Toulouse University, Toulouse, France.

2000 – “Negative pH, acid efflorescences, and why not to plug a mine,” Montana State University, Bozeman, MT.

2000 – “Sulfur redox chemistry in Yellowstone National Park,” Montana State University, Bozeman, MT.

2000 – “Advances in the hydrogeochemistry and microbiology of acid mine waters,” Royal Institute of Technology, Stockholm, Sweden.

2000 – “Negative pH and geochemistry of acid mine waters,” University of Colorado, Boulder, CO.

2000 – “The Aznalcollar mine waste impoundment release in south-central Spain”, University of Colorado, Boulder, CO.

2000 – “Arsenic and sulfur redox chemistry in the thermal waters of Yellowstone National Park: Biotic or abiotic reactions?” University of Colorado, Boulder, CO.

2001 – “Arsenic, sulfur, and iron redox chemistry in thermal waters at Yellowstone National Park: Biotic or abiotic processes?” Montana State University, May.

2001 – “Arsenic, sulfur, and iron redox chemistry in thermal waters at Yellowstone National Park: Biotic or abiotic processes?” USGS seminar, Western Regional Headquarters, Menlo Park, CA, August 6.

2002 – “Arsenic, iron, and sulfur oxidation reactions at Nymph Creek, Yellowstone National Park: Biotic or Abiotic?,” Regensburg University, Germany, Mar. 1.

2002 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at Iron Mountain, California,” Far Eastern Geological Institute, Russian Academy of Sciences, Vladivostok, Russia, August 16.

2002 – “Arsenic, sulfur, and iron redox chemistry in thermal waters at Yellowstone National Park: Biotic or abiotic processes?” Sheffield University, Sheffield, UK, Sept. 6.

2002 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at Iron Mountain, California,” Geochemical Speciation meeting, Mineralogical Society, Salford University, Manchester, UK, Sept. 9-10.

2002 – “Arsenic, sulfur, and iron redox chemistry in thermal waters at Yellowstone National Park: Biotic or abiotic processes?” British Geological Survey, Wallingford, UK., Sept. 12.

2002 – “Arsenic, sulfur, and iron redox chemistry in thermal waters at Yellowstone National Park: Biotic or abiotic processes?” University of Leeds, Leeds, UK., Sept. 14.

2002 – “Arsenic, sulfur, and iron redox chemistry in thermal waters at Yellowstone National Park: Biotic or abiotic processes?” USGS, Reston, Virginia.

2004 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at the Iron Mountain Superfund site, California – or why not to plug a mine” Geoscience Applications and Developments/ Treatment technologies for mining impacted water, Workshop at the Geological Institute of the Technical University of the Mining Academy at Freiberg, Freiberg Technical University, Freiberg, Germany, June 18

2004 – “Sampling and analysis of natural and contaminated waters” Freiberg Technical University, Freiberg, Germany, Oct.

2004 – “What are background water-quality concentrations at mining sites and who cares?” Freiberg Technical University, Freiberg, Germany, Oct.

2004 – "Deciphering arsenic geochemistry and redox processes in thermal waters of Yellowstone National Park, USA," Department of Environmental Science and Engineering Gwangju Institute of Science and Technology (GIST), Gwangju, South Korea, Dec. 7

2005 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at the Iron Mountain Superfund mine site, California;” “Deciphering arsenic geochemistry and redox processes in thermal waters of Yellowstone National Park, USA;” “What was background ground-water quality at an active mine site before mining,” Department of Geological Sciences, University of Zaragoza, Zaragoza, Spain, April 5

2005 – “A river on the edge – Water quality of the Red River and the USGS background study” Decision-makers field conference 2005 Taos Region, New Mexico, May 18

2006 – “Biotic and abiotic redox reactions in the thermal waters of Yellowstone National Park,” CSM NSF course, Jan. 11.

2006 – “Worldwide occurrences of arsenic in ground water” Jadavpur University, School of Environmental Sciences, Kolkata, India, January 30.

2006 – “Geochemistry and high arsenic concentrations in ground waters of Fairbanks, Alaska” Jadavpur

University, School of Environmental Sciences, Kolkata, India, January 30.

2006 – “Conclusions of the USGS Questa background study,” Questa Public mtg, NM

2007 – “How seasonal and climatic change affect water quality from mining activities,” University of Wyoming, Laramie, WY

2007 – “Inferring background ground-water quality at mine sites” British Geological Survey, Wallingford, UK

2007 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at Iron Mountain, California,” Korea University, Seoul, S. Korea

2007 – “Oxidation reactions of Fe, S, As, and Sb in thermal waters of Yellowstone National Park,” Korea University, Seoul, S. Korea

2008 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at Iron Mountain, California,” Department of Geosciences, Tulsa University, April 9.

2008 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at Iron Mountain, California,” Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal, May 6.

2008 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at Iron Mountain, California,” University de Aveiro, Aveiro, Portugal, May 9.

2008 – “Research and remediation issues for hard-rock metal mines: Negative pH, why mine plugging can be hazardous, and “natural background,” IST University, Lisbon, Portugal, May 13.

2008 – “Arsenic speciation in sulfidic geothermal waters of Yellowstone National Park,” Lisbon University, Lisbon, Portugal, May 14.

2008 – “Research and remediation issues for hard-rock metal mines,” Portuguese Geological Survey (INETI), May 19.

2008 – “Science, Engineering, and Remediation of Metal Mining Sites,” Porto University, Porto, Portugal, November 28.

2008 – “New studies on the chemistry of thermal waters of Yellowstone National Park,” Porto University, Porto, Portugal, December 3.

2008 – “Science, Engineering, and Remediation of Metal Mining Sites,” Aveiro University, Aveiro, Portugal, December 4.

2009 – “Arsenic in the environment – Sources, sinks, and worldwide occurrences,” Department of Environmental Toxicology, University of California, Davis, February 6.

2009 – “Distinguishing abiotic from biotic oxidation reactions of iron, sulfur, arsenic, and antimony,” Department of Biology, Toho University of Medicine, Tokyo, Japan, March 19.

2009 – “Arsenic in the environment – Sources, sinks, and worldwide occurrences,” China University of Geosciences, Wuhan, China, March 23-26.

2009 – "Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at Iron Mountain, California," China University of Geosciences, Wuhan, China, March 23-26.

2009 – "Surprise – Granitic groundwater chemistry influenced by fluid inclusions," China University of Geosciences, Wuhan, China, March 23-26.

2009 – "Oxidation reactions of Fe, S, As, and Sb in Yellowstone's geothermal waters," China University of Geosciences, Wuhan, China, March 23-26.

2009 – "Acid rock drainage and climate change," China University of Geosciences, Wuhan, China, March 23-26.

2009 – "Model validation and issues in the philosophy of science," China University of Geosciences, Wuhan, China, March 23-26.

2009 – " 'Background' 'baseline' and 'pre-mining' water-quality considerations at metal mining sites: Lessons from the Questa Project," China University of Geosciences, Wuhan, China, March 23-26.

2009 – "Global water-quality issues," China University of Geosciences, Wuhan, China, March 23-26.

2009 – "Arsenic in the environment – Sources, sinks, and worldwide occurrences," Chinese Geological Survey, Beijing, April 8.

2009 – "Geochemistry of acid mine drainage," Chinese Geological Survey, Beijing, April 8.

2009 – "Geochemistry of acid mine drainage," Chinese Academy of Sciences, Beijing, April 9.

2009 – "Geologic processes that concentrate arsenic in the environment," Bureau of Economic Geology, University of Texas, Austin, April 22; Phil Bennett's class also, April 23.

2009 – "Arsenic in the environment – Sources, mobility, and worldwide occurrences," USGS Science and Human Health, May 26, Denver, CO.

2009 – "Arsenic in the environment – Sources, sinks, and worldwide occurrences," Umeå University, Department of Chemistry, Umeå, Sweden, July 3.

2009 – "Arsenic in the environment – Sources, sinks, and worldwide occurrences," Royal Institute of Technology, Department of Land and Water resources Engineering, Stockholm, Sweden, July 6.

2009 – "So what does happen to contaminants from Yellowstone's thermal waters? Results from synoptic sampling of the Gibbon and Firehole Rivers" USGS, Reston, VA, Nov. 17.

2009 – "Yellowstone's contaminated waters – transport of As, F, Hg, H_2S from thermal waters to the rivers and the air," Syracuse University, Syracuse, NY, Nov. 19.

2010 – "Arsenic in the environment: Overview of sources, sinks, and worldwide occurrences," National Taiwan University, Taipei, Taiwan, May 14.

2010 – "Arsenic in the environment: Overview of sources, sinks, and worldwide occurrences," University of Oregon, Eugene, OR, Nov. 19.

2010 – "Arsenic in the environment: Overview of sources, sinks, and worldwide occurrences," Oregon

State University, Corvallis, OR, Nov. 19.

2011 – “Yellowstone’s contaminated waters – Chemistry and transport of As, H_2S, Hg, and F,” Adrian Smith Distinguished Lecturer, Department of Earth and Environmental Sciences, University of Waterloo, Canada, March 25.

2011 – “Yellowstone’s contaminated waters – Chemistry and transport of As, H_2S, Hg, and F,” Department of Geology, University of Wyoming, November 7, 2011.

2011 – “Facts, fiction, and fracking” Scientific Seminar Shale Gas, Envirhônalp and l’Institute des Sciences de la Terre, University of Grenoble, Grenoble, France, November 25, 2011.

2011 – “Facts, fiction, and fracking” Shale gas committee, Valvignères, France, November 25, 2011.

2012 – “Arsenic in the geosphere meets the anthroposphere” USGS, Reston, VA, Feb.15, 2012.

2012 – “Yellowstone’s contaminated waters: Source, fate, and transport of hydrothermal solutes in our largest National Park,” Department of Geology, Southern Illinois University, Carbondale, IL, March 22, 2012.

2012 – “Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at the Iron Mountain Superfund site, California,” Department of Chemistry and Biochemistry, Southern Illinois University, Carbondale, IL, March 23, 2012.

2012 – “Hydrogeochemical processes governing the origin, transport and fate of major and trace elements from mine wastes and mineralized rock to surface waters,” USGS Water Science Center, Tacoma, WA, May 17.

2012 – “Hydrogeochemical processes governing the origin, transport and fate of major and trace elements from mine wastes and mineralized rock to surface waters,” USGS Water Science Center, Albuquerque, NM, May 21.

2012 – “Hydrogeochemical processes governing the origin, transport and fate of major and trace elements from mine wastes and mineralized rock to surface waters,” USGS Water Science Center, Pembroke, NH, Nov. 1.

2012 – “Hydrogeochemical processes governing the origin, transport and fate of major and trace elements from mine wastes and mineralized rock to surface waters,” USGS Water Science Center, Louisville, KY, Nov. 9.

2012 – “Hydrogeochemical processes governing the origin, transport and fate of major and trace elements from mine wastes and mineralized rock to surface waters,” USGS Water Science Center, Lansing, MI, Nov. 13.

2012 – “Hydrogeochemical processes governing the origin, transport and fate of major and trace elements from mine wastes and mineralized rock to surface waters,” USGS Water Science Center, Carson City, NV, Dec. 4.

2012 – “Hydrogeochemical processes governing the origin, transport and fate of major and trace elements from mine wastes and mineralized rock to surface waters,” USGS Water Science Center, Henderson, NV, Dec. 6.

2012 – "Geothermal water chemistry, arsenic, and Yellowstone," China University of Geosciences Wuhan, Wuhan, China, Nov. 25.

2012 – "Hydrogeochemical processes of trace elements in mined or mineralized areas," China University of Geosciences Wuhan, Wuhan, China, Nov. 26.

2012 – "Fluoride geochemistry in water-rock interactions," China University of Geosciences Wuhan, Wuhan, China, Nov. 27.

2013 – "Arsenic in the geosphere meets the anthroposphere," USGS Boulder facilities, Boulder, CO, Nov. 6.

2014 – "Predicting and modeling: with examples of acid mine drainage from metal mines," China University of Geosciences Wuhan, Wuhan, PRC, Mar. 14

2014 – "Mercury geochemistry of thermal waters in Yellowstone National Park," China University of Geosciences Wuhan, Wuhan, PRC, Mar. 15

2014 – "Thermodynamic data evaluation for geochemical modeling," China University of Geosciences Wuhan, Wuhan, PRC, Mar. 16

2014 – "Arsenic in the geosphere meets the anthroposphere," Nanjing University, Nanjing, PRC, Mar. 19

2014 – "Arsenic in the geosphere meets the anthroposphere," China University of Geosciences Beijing, Beijing, PRC, Mar. 21

2014 – "Predicting and modeling: with examples of acid mine drainage from metal mines," China University of Geosciences Beijing, Beijing, PRC, Mar. 21

2015 – "Negative pH, efflorescent mineralogy, and the challenge of environmental restoration at the Iron Mountain superfund site, California," Murdoch University, WA, Australia, Feb. 23

2015 – "The contaminated waters of Yellowstone National Park; highlights from 20 years of studies," Murdoch University, WA, Australia, Feb. 24

2015 – "Some non-scientific aspects of scientific research," China University of Geosciences Wuhan, Wuhan, PRC,

2015 – "Arsenic geochemistry," Salta University, Salta, Argentina

2015 – "Negative pH, efflorescent mineralogy, and the challenges of environmental restoration at the Iron Mountain Superfund Mine Site, California" Salta University, Salta, Argentina

2015 – "To plug or not to plug: Unintended consequences of mine plugging" University of Colorado, Boulder,

Advisor (or external examiner) for graduate students

Robert Kleinmann, Ph.D. (1979), Princeton University
William Barnard, M.S. (1977-80), University of Virginia.
Thomas Dagenhart, Jr., M.S. (1976-80), University of Virginia.

John Walton, M.S. (1977-80), University of Virginia.
Steve Goodwin, M.S. (1977-79), University of Virginia.
William Keene, Jr. (1972-78), University of Virginia
Carl Moses, M.S. (1977-80), University of Virginia.
Andy Davis, M.S. (1977-80), University of Virginia.
Doug Burns, M.S. (1978-81), University of Virginia.
Rona Donahoe, Ph.D. (1981-84), Stanford University.
Mark Wheeler, M.S. (1980-84), University of California, Davis.
Susan Stipp, Ph.D. (1984-90), Stanford University.
Victoria Carlson-Foscz, M.S. (1990-91), Dartmouth College.
Rachel Wing, M.S. (1984-87), Stanford University.
Marcella Hutchinson, M.S. (1992-96), University of Colorado.
Thanh To, Ph.D. (1996), University of Colorado.
James Ball, Ph.D. (1991-96), University of Arizona.
Tom Al, Ph.D. (1996), University of Waterloo, Ontario, Canada (external reviewer).
Yong Xu, Ph.D. (1997), State University of New York, Stony Brook (external reader).
Maria José Gimeno, Ph.D. (1993-98), University of Zaragoza, Spain.
Bo Stromberg, Ph.D. (1997), Royal Institute of Technology, Stockholm, Sweden (opponent).
Andy Horn, M.S.. (1995-1997), University of Colorado.
Richard McLaughlin, Ph.D. (1998), University of Waterloo, Ontario, Canada (external reviewer).
Jeffrey Bails, M.S. (1997-98), University of Colorado.
Jeanette Jerz, Ph.D. (1998- 2002), Virginia Polytechnic Institute, Blacksburg, VA.
Lisa Cavé, M.S., Ph.D. (1999-2002), University of Cape Town, Republic of South Africa
Britta Planer-Friederich, Ph. D. (2002-2004), Freiberg Technical University, Freiberg, Germany
Juliana Becker, M.S. (2003-2004), Freiberg Technical University, Freiberg, Germany
Patricia Acero, Ph.D. (2003-06), CSIC, University of Barcelona, Spain
Chris Hubbard, Ph.D. (2005-07), University of Reading, UK (external examiner)
Blaine McCleskey, Ph.D. (2002-10), University of Colorado
Maria Pilar Asta Andres, Ph.D. (2007-2009), CSIC, Barcelona Technical University, Barcelona, Spain
Nuno Durães, Ph.D. (2008-2011), Porto University, Porto, Portugal
Nathaniel Wilson, PhD. (2008), University of Auckland, Auckland, New Zealand (external examiner)
Adele Manda Jones, Ph.D. (2009), University of New South Wales, Australia (external examiner)
Timothy Maloney, M.S. (2010-11), University of Wyoming
Tessa Jones, Ph.D. (2010-12), South Dakota School of Mines and Technology
Mandy Hoyer, M.S. (2002-2004), Freiberg Technical University, Freiberg, Germany
Joanna E.H. Barrell, M.S. (2012-2013), Colorado School of Mines
Hanna Kaasaleinen, Ph.D (2012), University of Iceland (external examiner)
Xiangyu Zhu, Ph.D. (2014-2016), Nanjing University, People's Republic of China

Post-Doctoral and Research Associates

Charles Alpers (Ph.D., University of California-Berkeley, 1988-90)
Niklaus Waber (Ph.D., University of Bern, Switzerland, 1990-91)
Jenny Webster (Ph.D., University of Western Australia, 1992)
Philip L. Verplanck (Ph.D., University of Colorado, 1997-2000)
Maria Elvira Hernandez Garcia (Ph.D., Complutense University, Madrid, Spain, 2001-2002)
Maria do Rosario Mela de Costa Pereira (Ph.D., UTAD, Portugal, 2006)
Yamin Deng, (Ph.D., China University of Geosciences, Wuhan, China, 2009-2010)
Maria José Gimeno (Ph.D., Zaragoza University, Spain, 2010)
Qinghai Guo (Ph.D., China University of Geosciences Wuhan, 2013)
Li-Nan Huang (Ph.D., Sun Yat-Sen University, 2013-2017)

OTHER CONFERENCES ATTENDED:

1971 – Gordon Research Conference, Inorganic Geochemistry: Metamorphic fluids and mixed volatiles, Holderness, NH.

1975 – Gordon Research Conference, Inorganic Geochemistry: Thermodynamics in igneous petrology, Holderness, NH.

1976 – Sixth Symposium on Coal Mine Drainage Research, Louisville, KY.

1987 – Mineralogical Society of America Short Course on Thermodynamic Modeling, Wickenburg, AZ.

1990 – Mineralogical Society of America Short Course on Mineral-Water Interface Geochemistry, Tanglewood, TX.

1992 – Fifth CEC Natural Analogue Working Group and Alligator Rivers Final Workshop, Toledo, Spain.

2011 – Antimony in the Environment, Jena, Germany

2012 – Summary of Environmental Baseline Documents, Proposed Pebble Mine, Anchorage, AK

2012 – EPA Hardrock Mining Conference, Apr. 3-5, Denver, CO.

COMMITTEE ASSIGNMENTS:

1979 – Co-chairman (with George R. Helz) for Geochemistry Program of the SE Sectional Meeting of GSA.

1979 – Thermodynamic Workshop: the Binary System NaCl-H2O, U.S.G.S., Reston, VA.

1979 – External Examining Committee Member for the Ph.D. Dissertation Defense of R. Kleinmann, Department of Geological Sciences, Princeton University, "The biogeochemistry of acid mine drainage and a method to control acid formation."

1980 – Peer Review Committee Member for Water Chemistry, WRD, U.S.G.S.

1980 – Meeting of the Hydrogeochemical Advisory Group for the OECD/NEA SKBF/KBS Stripa Project, Phase I, Vienna, AUSTRIA

1982 – Sediment Chemistry Workshop, U.S.G.S., Reston, VA.

1982 – Chairman of the Hydrogeochemical Advisory Group (HAG) for the OECD/NEA: SKBF/KBS Stripa Project, Meeting in Vienna, AUSTRIA.

1983 – Chairman of HAG Meeting in Stockholm, SWEDEN.

1983 – Watershed Study Meeting, WRD, U.S.G.S., Atlanta, GA.

1983-91 – Member of Technical Advisory Committee to the EPA on the Iron Mountain Main Superfund Site.

1984 – Chairman of HAG Meeting in Munich, WEST GERMANY.

1984 – Stripa Project Technical Subgroup Meeting, Stockholm, SWEDEN.

1985 – Stripa Project Technical Subgroup Meeting, Zurich, SWITZERLAND.

1985 – Peer Review Committee Member for Water Chemistry, WRD, U.S.G.S.

1986 – Chairman of the HAG Meeting, Stripa Project, Paris, FRANCE.

1986 – Stripa Project; Technical Subgroup Meeting, Stockholm, SWEDEN.

1986 – Technical Reviewer for GSA abstracts, Annual Meeting.

1986 – Co-chairman for Aqueous Geochemistry Session of GSA Annual Meeting.

1986 – Phase II Stripa Project Subgroup Meeting, Bath, ENGLAND.

1987 – Stripa Project Technical Subgroup Meeting, Helsinki, FINLAND.

1988 – Peer Review Committee Member for Groundwater Chemistry, WRD, U.S.G.S.

1989 – Pocos de Caldas Project Subgroup Coordinator.

1989 – Associate Member of Mine Environment Neutral Drainage (MEND).

1990-96 – National Academy of Sciences, Board of Radioactive Waste Management.

1995 – Library Issues Team, USGS.

1995 – NSF/EPA Environmental Biogeochemistry Review Panel.

1998-99 – Clarke Medal Committee, Geochemical Society

2000 – Arsenic Steering Committee and Co-chair for USGS Arsenic Workshop

2000 – NSF Review Committee for Low-Temperature/Environmental Geochemistry

2000 – International Technical Review Committee for Swedish MiMi Program (Mining and the Environment Research Foundation)

2002-06 – Scientific Advisory Board Member for the Thermal Biology Institute, Montana State University, Bozeman, MT

2005 – Reviewer for NAS/NRC report on the Coeur d'Alene Mining Superfund Megasite book

EDITORIAL RESPONSIBILITIES

Associate Editor for *Journal of Contaminant Hydrology*, 1986-7.

Co-editor for "Sulfate Minerals – Crystallography, Geochemistry, and Environmental Significance," with John Jambor and Charles Alpers, Mineralogical Society of America and Geochemical Society, 2000.

Editor for "Groundwater Geochemistry: A practical guide to modeling of natural and contaminated systems" by B.J. Merkel and B. Planer-Friedrich, 2005, Springer, Berlin and second edition, 2008.

Managing Editor for Geochemistry for *Earth-Science Reviews* (2006-2009)

Co-editor for "Arsenic: Environmental Geochemistry, Mineralogy, and Microbiology," with Rob Bowell, Charles Alpers, and Heather Jamieson, Mineralogical Association of America and Geochemical Society, 2014.

WILLIAM A. STUBBLEFIELD, Ph.D. &

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EDUCATION
Ph.D. (Aquatic Toxicology) University of Wyoming, 1987.
M.S. (Toxicology/Toxicodynamics) University of Kentucky, 1979.
B.S. (Biological Sciences/Chemistry) Eastern Kentucky University, 1977.

SCIENTIFIC SOCIETY AFFILIATIONS
Society of Environmental Toxicology and Chemistry
Society of Toxicology
Pacific Northwest Regional Chapter of the Society of Environmental Toxicology and Chemistry

PROFESSIONAL HISTORY

2009-present	Oregon State University Department of Environmental and Molecular Toxicology; Professor/Senior Research
2002-2009	Parametrix, Inc.
2002-2009	Oregon State University Department of Environmental and Molecular Toxicology, Courtesy Faculty
1998-2002	Colorado State University Department of Environmental Health, Affiliate Faculty
1990-2002	Colorado State University Department of Fisheries and Wildlife Biology, Affiliate Faculty
1987-2002	ENSR Consulting and Engineering
1985-1987	Mobay Corporation; Health, Environment, and Safety Division
1983-1985	University of Wyoming, Fish Physiology and Toxicology Laboratory
1979-1983	Exxon Corporation, Research and Environmental Health Division

PUBLICATIONS

Stubblefield WA. 1979. *Quantitative administration of insecticide vapors to rats*. M.S. thesis. University of Kentucky, Lexington, KY.

Stubblefield WA, AW Maki. 1985. Environmental hazard assessment of refinery effluents. In: Bergman HL, Kimerle RA, Maki AW, eds, *Environmental Hazard Assessment of Effluents*. Pergamon Press, Elmsford, NY.

Johnson HE, DW Behrens, KL Dickson, WP Gulledge, JL Hamelink, GF Lee, TG Miller, WH Peltier, WA Stubblefield. 1985. Discussion Synopsis: Hazard Assessment Case Histories. In Bergman HL, Kimerle RA, Maki AW, eds, *Environmental Hazard Assessment of Effluents*. Pergamon Press, Elmsford, NY.

McKee RH, WA Stubblefield, SC Lewis, RA Scala, GS Simon, LR DePass. 1986. Evaluation of the dermal carcinogenic potential of tar sands bitumen-derived liquids. *Fund. Appl. Toxicol*. 7(2):228-235.

Stubblefield WA. 1987. *Acclimation-induced changes in the toxicity of xenobiotics in rainbow trout*. Ph.D. dissertation. University of Wyoming, Laramie, WY.

Stubblefield WA, RH McKee, RW Kapp, JP Hinz. 1989. An evaluation of the acute toxic properties of tar sands-derived oils. *Fund. Appl. Toxicol*. 9(1):59-65.

Steadman BL, WA Stubblefield, TW LaPoint, HL Bergman. 1991. Decreased survival of rainbow trout exposed to No. 2 fuel oil caused by sublethal pre-exposure. *Environ. Toxicol. Chem*. 10(3):355-363.

Stubblefield WA, PA Toll. 1993. Effects of incubation temperature and warm-water misting on hatching success in artificially incubated mallard duck eggs. *Environ. Toxicol. Chem.* (12)10: 695-700.

Stubblefield WA, GA Hancock, WH Ford, HH Prince, RK Ringer. 1995. Evaluation of the toxic properties of naturally weathered *Exxon Valdez* crude oil to surrogate wildlife species. In Wells PG, Butler J, Hughes JS, eds, *Exxon Valdez: Environmental Impact and Recovery Assessment*, ASTM STP 1219, American Society for Testing and Materials, Philadelphia, Pennsylvania. Pp. 665-692.

Boehm PD, DS Page, ES Gilfillian, WA Stubblefield, EJ Harner. 1995. Shoreline ecology program for Prince William Sound following the *Exxon Valdez* oil spill: Part 2 - Chemistry and toxicology. In Wells PG, Butler J, Hughes JS, eds, *Exxon Valdez: Environmental Impact and Recovery Assessment*, ASTM STP 1219, American Society for Testing and Materials, Philadelphia, Pennsylvania. Pp. 347-397.

Neff JM, WA Stubblefield. 1995. Chemical and toxicological evaluation of water quality following the *Exxon Valdez* oil spill. In Wells PG, Butler J, Hughes JS, eds, *Exxon Valdez: Environmental Impact and Recovery Assessment*, ASTM STP 1219, American Society for Testing and Materials, Philadelphia, Pennsylvania. Pp. 141-177.

Stubblefield WA, GA Hancock, WH Ford, RK Ringer. 1995. Acute and subchronic toxicity of naturally weathered *Exxon Valdez* crude oil to mallards and ferrets. *Environ. Toxicol. Chem.* 14:1941-1950.

Stubblefield WA, GA Hancock, WH Ford, RK Ringer. 1995. Effects of naturally weathered *Exxon Valdez* crude oil on mallard reproduction. *Environ. Toxicol. Chem*. 14:1951-1960.

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Stubblefield WA, EJ Van Genderen, TR Brock. 2007. Cobalt: Application of an International Approach for Developing Environmental Criteria/Guidelines/Standards for Metals. Society of Environmental Toxicology and Chemistry Annual Meeting. Milwaukee, WI. November 2007.

Redman A, J McGrath, W Stubblefield, A Maki, D DiToro. 2007. Quantifying the concentration of crude oil microdroplets in oil-water preparations. Society of Environmental Toxicology and Chemistry Annual Meeting. Milwaukee, WI. November 2007.

Stubblefield WA, EJ Van Genderen, CE Schlekat. 2007. Effects of Nickel to marine organisms: Compilation of available data and derivation of a marine PNEC. Society of Environmental Toxicology and Chemistry Annual Meeting. Milwaukee, WI. November 2007.

Stubblefield WA, G Merrington, D McGough. 2009. Manganese: Application of an International Approach for Developing Environmental Criteria/Guidelines/ Standards for the Protection of Aquatic Organisms. Society of Environmental Toxicology and Chemistry Annual Meeting. New Orleans, LA. November 2009.

Heijerick D, L Regoli, W Stubblefield, Sandra Carey. 2011. Bioaccumulation of molybdenum in the aquatic environment: literature and laboratory/field-generated data. Society of Environmental Toxicology and Chemistry Annual Meeting. Milano, Italy. May 2011.

Oorts K, P Van Sprang, W Stubblefield, E Smolders. 2011. Effects assessment of cobalt in the terrestrial environment. Society of Environmental Toxicology and Chemistry Annual Meeting. Milano, Italy. May 2011.

Langdon C, S Pargee, W. Stubblefield. 2012. Acute effects of fresh and weathered MC252 crude oil and dispersants on mollusc and echinoderm larvae. Society of Environmental Toxicology and Chemistry Annual Meeting. Long Beach, CA. November 2012.

Stubblefield WA, AS Cardwell, WJ Adams, RW Gensemer, E Nordheim, RC Santore. 2012. The toxicity of aluminum to 8 different aquatic species, at a pH of 6. Society of Environmental Toxicology and Chemistry Annual Meeting. Long Beach, CA. November 2012.

Cardwell A, W Stubblefield, W Adams, R Gensemer, E Nordheim, R. Santore. 2012. Evaluation of Aluminum Chronic Toxicity to Fathead Minnow and Zebrafish Using a Flow-Through pH-Control Toxicity Test System. Society of Environmental Toxicology and Chemistry Annual Meeting. Long Beach, CA. November 2012.

Pargee S, C Langdon, W Stubblefield, E Stefansson, S Blunt, S Gage. 2013. Development of a chronic toxicity test methodology to determine effects of fresh and weathered MC252 oil and dispersant on Eastern oyster larvae. Society of Environmental Toxicology and Chemistry Annual Meeting. Nashville, TN. November 2013.

Nordtug T, B Henrik Hansen, K Hammer, I Overjordet, I Andreassen, P Wold, A Olsen, D Altin, W Stubblefield, A Edgington. 2013. Experimental system for exposure of pelagic fish eggs to crude oil dispersions (potential for oil dispersions to cause cardiac toxicity). Society of Environmental Toxicology and Chemistry Annual Meeting. Nashville, TN. November 2013.

Gondek J, R Gensemer, W Stubblefield, A Cardwell, R Santore, A Ryan, W Adams, E Nordheim. 2013. A comparative analysis of aquatic HC05 values for aluminum using Biotic Ligand Model- vs. hardness-normalized toxicity data. Society of Environmental Toxicology and Chemistry Annual Meeting. Nashville, TN. November 2013.

Santore R, A Ryan, F Kroglund, Hans-Christian Teien, P Rodriquez, W Stubblefield, A Cardwell, W Adams, E Nordheim. 2013. Predicting aluminium toxicity as a mixture of effects from dissolved and precipitated metal. Society of Environmental Toxicology and Chemistry Annual Meeting. Nashville, TN. November 2013.

Finch BE, Edgington AJ, Stubblefield WA. 2014. Photo-enhanced Toxicity of Fluoranthene to Gulf of Mexico Marine Organisms at Early Life Stages and Two Ultraviolet Intensities. Pacific Northwest SETAC 23rd Annual Meeting: Tacoma, WA (platform)

Finch BE, Stubblefield WA. 2014. Gulf Killifish (Fundulus grandis) Aquaculture and Utility as a Toxicological Model. Society of Environmental Toxicology and Chemistry North America Annual Meeting: Vancouver, B.C. November 2014.

Finch BE, Stubblefield WA. 2015. Photo-enhanced Toxicity of Fresh and Weathered Macondo Crude Oils to Gulf of Mexico Marine Organisms. Pacific Northwest SETAC Annual Meeting: Portland, OR.

Finch BE, Stubblefield WA. 2015. Photo-enhanced toxicity of Fresh and Weathered Crude Oil to Gulf of Mexico Fish and Shrimp. Gulf of Mexico Research Initiative: Houston, TX.

Finch BE, Stubblefield WA. 2015. Gulf of Mexico Marine Organism's Susceptibility to Photo-enhanced Toxicity of Fluoranthene at Different Life Stages and Ultraviolet Light Intensities. Gulf of Mexico Research Initiative: Houston, TX.

Finch BE, Stubblefield WA. 2015. Gulf of Mexico Marine Organism's Susceptibility to Photo-enhanced Toxicity of Fluoranthene at Different Life Stages and Ultraviolet Light Intensities. EMT Research Day: Corvallis, OR.

S Marzooghi, BE Finch, WA Stubblefield, O Dmytrenko, SL Neal, DM DiToro. 2015. Modeling Phototoxicity of Petroleum during Oil Spill. Society of Environmental Toxicology and Chemistry Annual Meeting. Salt Lake City, UT. November 2015.

de Jourdan B, A Cardwell, A Fernandez, WA Stubblefield. 2015. Along came a SPDR: A novel approach to creating truly dissolved solutions for use in flow-through toxicity testing. Society of Environmental Toxicology and Chemistry Annual Meeting. Salt Lake City, UT. November 2015.

Finch BE, S Marzooghi, DM DiToro, WA Stubblefield. 2015. Photo-enhanced Toxicity of Fresh and Weathered Macondo Crude Oils to Marine Organisms Exposed to Natural and Artificial Sunlight. Society of Environmental Toxicology and Chemistry Annual Meeting. Salt Lake City, UT. November 2015.

Santore R, A Ryan, D DeForest, WA Stubblefield, A Cardwell, W Adams. 2015. Predicting aluminum toxicity as a mixture of effects from dissolved and precipitated metal. Society of Environmental Toxicology and Chemistry Annual Meeting. Salt Lake City, UT. November 2015.

Finch BE, WA Stubblefield. 2015. Interactive Effects of Mixtures of Phototoxic PAHs. Society of Environmental Toxicology and Chemistry Annual Meeting. Salt Lake City, UT. November 2015.

PROFESSIONAL ACTIVITIES

Scientific Society Service

Society of Environmental Toxicology and Chemistry (SETAC) !
- Past-President (2005) !
- President (2004) !
- Vice-President (2003) !
- Board of Directors (1995-1998; 2002-2005) !
- Program Co-Chairman 1994, 2002, and 2010 annual meetings !
- Chairman Awards Committee (2009-2010) !
- Chairman Publications Advisory Council (1995-2003; 2010-2011) !
- Member of *Environmental Toxicology and Chemistry* Editorial Board (1994-1997) !
- Chairman Professional Opportunities Committee (1992-1995) !
- Committee member Publications Committee (1989-1992) and the Nominations Committee (1985-1987) !
- Assistant Editor of the Society of Environmental Toxicology and Chemistry Newsletter !
- Associate Editor Society of Environmental Toxicology and Chemistry Special Publications. !

Invited Conferences and Program Reviews

Surface Water Quality Standards Review Committee for the Arizona Department of Environmental Quality (1989-1990).

U.S. Environmental Protection Agency Workshop on Mesocosms. !Duluth, Minnesota, September 14-17, 1987.

U.S. Environmental Protection Agency Complex Effluent Program Review. September 1990.

U.S. Environmental Protection Agency, ECOTOX Database Review, Duluth, Minnesota. August 1994.

U.S. Environmental Protection Agency, Science to Achieve Results (STAR) Fellowship Review, Wasington D.C. 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008.

U.S. Environmental Protection Agency, Peer-reviewer for National Sediment Inventory, Washington DC, 1996, 1999.

U.S. Environmental Protection Agency, Science Advisory Board, Multimedia, Multipathway, and Multireceptor Risk Assessment (3MRA) Model System Panel, Washington DC, 2003.

U.S. Environmental Protection Agency, Science Advisory Board, Framework for Inorganic Metals Risk Assessment Review Panel, Washington DC, 2005.

U.S. Environmental Protection Agency, Review of Lead Air Quality Criteria Document. Raleigh, North Carolina. 2006, 2010-13.

U.S. Environmental Protection Agency, Peer review of EPA's Waste Minimization Prioritization Tool (WMPT), April 2007.

U.S. Environmental Protection Agency Workshop on the use of *H. ateca* in toxicity testing. Chicago, Illinois, March 2010.

U.S. Environmental Protection Agency, Science Advisory Board - Ecological Processes and Effects Committee (EPEC). October 2011-September 2017.

U.S. Environmental Protection Agency, Peer review of "An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska." August 2012.

SETAC Pellston Conference on Environmental Hazard Assessment of Effluents. Cody, Wyoming. August 1982.

SETAC Pellston Conference on Avian Toxicity Testing Methods. Pensacola, Florida, December 1994.

SETAC Pellston Conference on Sediment Risk Assessment, Pacific Grove, California, April 1995.

SETAC Pellston Conference on Reassessment of Metals Criteria for Aquatic Life Protection, Pensacola, Florida, February 1996.

SETAC Pellston Conference on Reevaluation of the State of the Science for Water Quality Criteria Development; Gregson, Montana, June 1998.

SETAC Pellston Conference on Predicting Ecological Impacts from Laboratory Toxicity Tests; Cornwall, Quebec, Canada, May 1999.

SETAC Pellston Conference on The Role of Dietary Exposures in the Evaluation of Risk of Metals to Aquatic Organisms; Florsinent, British Columbia, Canada, August 2002.

SETAC Pellston Conference on Persistent, Bioaccumulative, and Toxic Materials (PBT); Pensacola, FL, May 2003

Metals Environmental Risk Assessment Guidance (MERAG) Science Consolidation Workshop (Workshop chair); London, UK, May 2005.
SETAC Technical Workshop on Environmental Quality Standards; Faringdon, Oxfordshire, UK, August 2006.
SETAC Technical Workshop on "Improving the Usability of Ecotoxicology in Regulatory Decision-Making." Shepherdstown, WV, September 2015.

Academic Courses or Professional Continuing Education
University of Wisconsin, Madison - Department of Engineering Professional Development Program. *Understanding Aquatic Toxicity Testing*, October 1992, Anchorage, Alaska.
Colorado State University - Department of Fisheries and Wildlife, *Environmental Toxicology*, Spring 1990.
Colorado State University - Department of Environmental Health, *Environmental Risk Assessment*, Spring 1996/1998/2000/2002.
Oregon State University - Department of Molecular and Environmental Toxicology, *Ecological Risk Assessment*, Winter 2003/2004/2005/2006/2007/2008.
Oregon State University - Department of Molecular and Environmental Toxicology, *Aquatic Toxicology*, Spring 2005/2006/2007/2008/2010/2011/2012/2013/2014/2015/2016.
Oregon State University - Department of Molecular and Environmental Toxicology, *Seminar Series: The Adverse Outcome Pathway: Bridging gaps between mechanisms and modes of action in ecological risk assessment,* Winter 2014