STS CONSULTANTS, INC.

FATE AND TRANSPORT MODELING OF ARSENIC IN A WETLAND SYSTEM

RFP ONLY!

PREPARED FOR:

STS CONSULTANTS LTD.

PREPARED BY:

GEOTRANS, INC.
4888 PEARL EAST CIRCLE
SUITE 300-E
BOULDER, COLORADO 80301
(303) 440-4556

5/23/96

1 INTRODUCTION

The Company

GeoTrans was established in 1979 by Dr. James Mercer and Dr. Charles Faust as a state-of-the-art groundwater flow and solute transport modeling consulting firm. GeoTrans has six offices across the U.S. with over 130 personnel, consisting of geologists, hydrogeologists, geochemists, environmental and geotechnical engineers, toxicologists, biologists and computer scientists. GeoTrans is a wholly-owned subsidiary of Tetra Tech, Inc., a 2000-person environmental consulting company with over 70 offices throughout the United States, Europe and Asia.

Typically, in the numerical modeling field, there are the researchers who develop model codes for simulating groundwater flow and contaminant transport, and there are users who apply the model codes to real problems. GeoTrans is unique in that we are both a developer and user of model codes. We have over 50 numerical model codes in our software library for use on real-world problems. Over the past 17 years, GeoTrans has developed more than 15 flow and transport model codes, which are currently being used by private industry, universities and government agencies.

GeoTrans has continued to advance the modeling frontier in both the development and application of model codes. We are industry leaders for simulating complex transport of multi-phase contaminants, for coupling geochemical models to groundwater contaminant transport codes, for coupling Geographical Information System (GIS) to groundwater model codes and for the innovative applications of existing model codes to fractured aquifer systems . GeoTrans developed one of the first three-dimensional non-aqueous phase liquid (NAPL) codes (SWANFLOW) for simulating the transport of immiscible liquids, such as hydrocarbons.

The Staff

GeoTrans proposes to staff this project with professionals whose expertise and experience includes geology, hydrogeology and geochemistry. We are proposing a focused, highly capable team as **key personnel**.

Our key personnel proposed are James Erickson, P.G., as Project Manager; Chen Zhu, Ph.D. for geochemistry support; Karen Maley for project support, and Jennifer Franz for modeling support. Bio-sketches for this team are featured below.

PROJECT MANAGER AND MODELER: James Erickson, P.G.

Mr. Erickson is proposed as the project manager and will guide the model development and predictive scenarios. He is a Principal Hydrogeologist with 18-years experience and has extensive experience with the development of numerical models for simulating groundwater flow and contaminant transport. Mr. Erickson recently completed the development of a three-dimensional regional flow model, with contaminant particle tracking, for simulating the transport and remediation of groundwater contaminated with VOCs at a superfund site in California. He has developed models to evaluate the transport and remediation of metals, radio nuclides and organic contaminant at mine sites, hazardous waste landfills, radioactive waste landfills and superfund sites. He has extensive experience with finite difference, finite element, analytical element and parameter estimation models for simulating groundwater flow, density-dependent flow and contaminant transport under saturated and unsaturated conditions. Mr. Erickson co-authored an Electric Power Research Institute (EPRI) guidance document for electric utilities entitled "Techniques to Develop Data for Hydrogeochemical Models (1989)." He wrote and developed a surface-water/groundwater interface module for the MODFLOW model to evaluate the impacts of groundwater pumpage on surface-water lake stages in Palm Beach County, Florida. Mr. Erickson was formerly with the U.S. Geological Survey, where his responsibilities included the characterization of the high-level nuclear waste repository on the Nevada Test Site, and research into numerical modeling methods for analyzing multiple-well tracer tests.

GEOCHEMISTRY: Chen Zhu Ph.D.

Dr. Chen Zhu will provide geochemical oversight for the modeling effort. He is a Senior Geochemist, with over 7-years' experience in the geochemical behavior of metals. Dr. Zhu's technical experience includes analyzing water-quality data; characterizing the dominant water-rock interactions at sites; performing geochemical speciation and solubility modeling using geochemical codes to determine controls in water chemistry and groundwater chemistry evolution along flow paths; evaluation of aquifer acidity and neutralization potential; modeling of contaminant mobility and retardation using surface complexation models. Dr. Zhu is currently working on a research project for the Ada Oklahoma Laboratory, which involves the coupling of a contaminant transport model to a geochemical model for simulating acid plume and metals transport.

Dr. Zhu has authored and presented numerous technical papers as well as journal articles concerned with geochemistry. He has been published in the *American Mineralogist*, *Geology*, *American Geophysical Union Transactions*, and has presented papers at the Society of Petroleum Engineers and Geologic Society of America.

GEOCHEMISTRY/MODELING SUPPORT: Karen Maley

Karen Maley will provide both geochemical support and model data set compilation. She has expertise in both hydrogeology and geochemistry. Ms. Maley is trained in the use of analytical and geochemical models that simulate contaminant fate and transport in multimedia systems, particularly groundwater systems. Ms. Maley's academic and professional background in geochemistry includes both characterization and modeling work with inorganics. She conducted geochemical data analysis and equilibrium modeling of metals and radio nuclides in groundwater at an eastern Wyoming uranium mill tailings site. Additionally, she performed a geochemical study of acid mine drainage at the Rawley Twelve Mine and Mill, an inactive copper-lead-silver mine and southern Colorado CERCLA site.

*MODELING SUPPORT: **Jennifer Franz***

Ms. Franz will perform modeling support, including model input data set development and post-processing of model results. She is a staff hydrogeologist with over 2-years experience. Ms. Franz is experienced in environmental field data collection, aquifer test analysis, analytical modeling, and GIS database development. Her responsibilities have included performing field investigations for Bear Creek uranium mill in Wyoming involving core-sample collection and analysis, geological and mineralogical characterization of tailings and water-level observations. Ms. Franz was the primary field geologist for El Paso County, Colorado's underground storage tank site characterization and remediation. She supervised ecological sampling and well installations and performed groundwater sampling and aquifer testing. Ms. Franz is currently developing an 100-megabyte GIS database for a large superfund site in California.

Complete professional resumes for this team are included in the **Appendices.** To demonstrate the expertise, depth, and variety of personnel GeoTrans can offer, we have included a section of resumes for Support Personnel who are available on an as-needed basis. This section follows the team resumes as part of the Appendices. An organizational chart is included to graphically illustrate the configuration of our team (figure 1).

Organization Chart

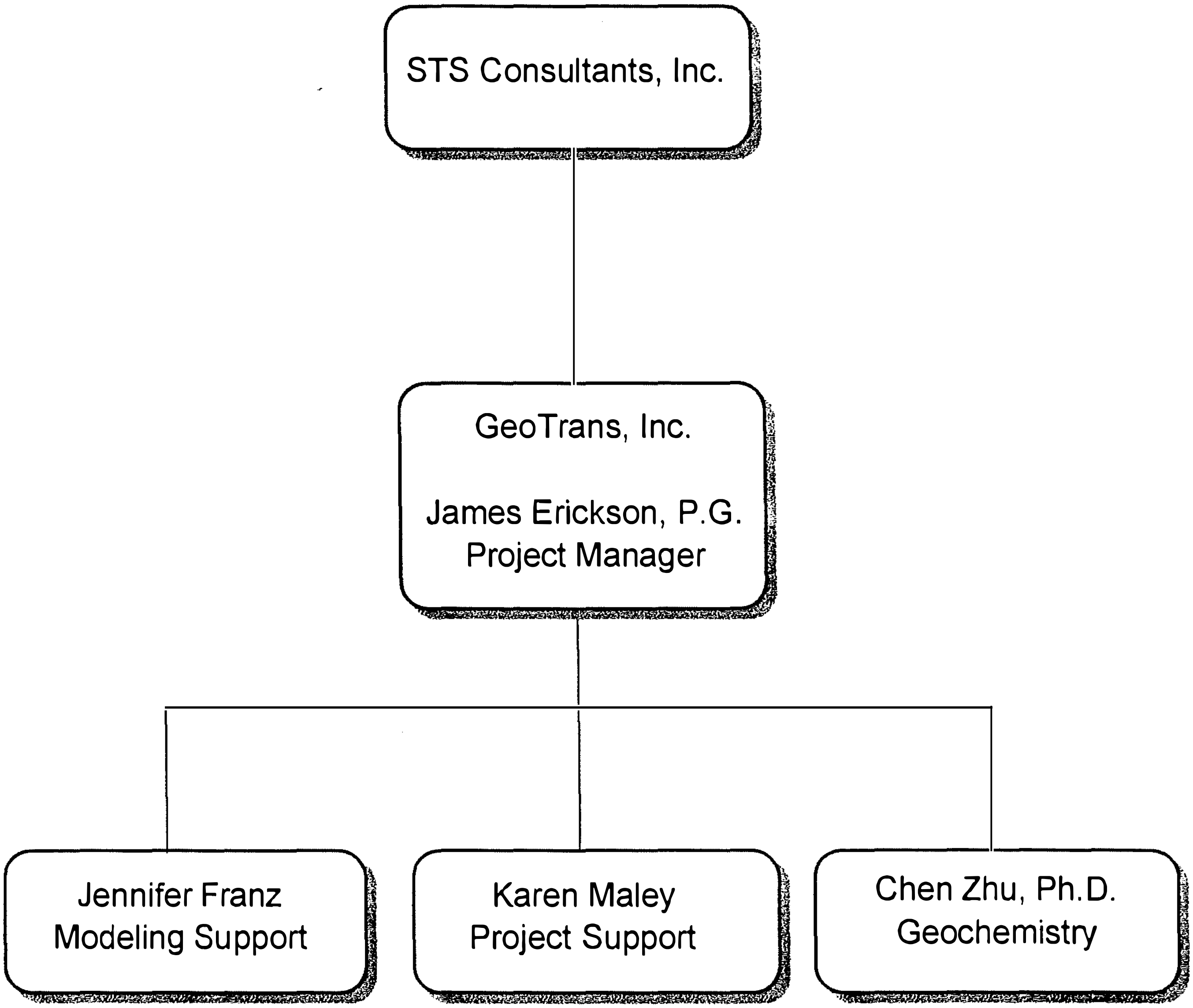

Figure 1

2 CORPORATE EXPERIENCE

2.1 GROUNDWATER FLOW & TRANSPORT MODELING

GeoTrans develops and applies a variety of models which simulate groundwater flow and the movement of contaminants in an environmental system. Model results provide technically supportable answers to common questions regarding past and future conditions at hazardous waste sites. Using such tools to evaluate the migration and fate of contaminants in and between air, soil, and water is an extremely cost-effective method of understanding potential environmental liabilities.

GeoTrans has a library of computer codes, many of which were developed in-house. Typical modeling applications include:

- Simulation of hypothetical scenarios to evaluate potential environmental impacts;
- Remedy evaluation at hazardous waste sites;
- Critical review of regulatory agency models;
- Risk assessment; and
- Water resource development.

GeoTrans has developed more than 50 three-dimensional groundwater flow and solute transport models to simulate complex hydrogeologic and geochemical systems. Three-dimensional modeling require substantially more design and calibration expertise than standard two-dimensional applications. GeoTrans' has developed cost effective pre- and post-processing software to expedite the development and calibration of these models.

GeoTrans uses simulation techniques to evaluate the performance and cleanup effectiveness of alternative corrective actions at hazardous waste sites. This allows cost-effective testing of remedial alternatives prior to the expense of field implementation. Our analysis of cleanup effectiveness has often been used to provide industry and regulators with realistic expectations regarding the performance of remedial activities. A representative listing of GeoTrans' modeling experience is illustrated in the table below (SELECTED GROUNDWATER MODEL APPLICATIONS).

SELECTED GROUNDWATER MODEL APPLICATIONS

Site	Flow	Transport	Code	Remedy
Bear Creek Uranium, WY	✓	✓	BIO1D, TwoDan, MINTEQA2	U,E,C
Sheffield, IL	✓	✓	FTWORK, RESSQ	U,E,W,I,C
SRS-F & H Area, SC	✓	✓	FTWORK, MOD3D	U,E,I,C
Love Canal, NY	✓		FLAMINCO, USGS2D	U,E,D,C
Black Mesa Mines, AZ	✓		MODFLOWP	E,U
San Gabriel Superfund, CA	✓	✓	MODFLOW, MODPATH	E,U
Prices Landfill, NJ	✓		USGS2D	E
Hyde Park Landfill, NY	✓	✓	SWANFLOW	U,I,E
Flying Cloud Landfill, MN	✓	✓	MODFLOW, MODPATH	W
Crandon Mines, WI	✓	✓	MODELGIS	U
Nevada Test Site	✓	✓	MODFLOW, MC.TRANS	U
Boeing Western Processing	✓	✓	MODFLOWP, MT3D, MC.TRANS	E,W,I,C,U

E - Extraction (Pumping) Well I - Injection Well C - Cap
W - Barrier Walls D - Drain, Sumps U - Uncontrolled

GeoTrans has access to over 100 commercial flow and transport models that are routinely used within our industry. Additionally, GeoTrans has developed several numerical models to facilitate our technical processes as well as numerous interface applications in a variety of programming languages to allow for front-end use, pre-processing, post-processing, and data exchange. Some of the software more commonly used by GeoTrans' scientists and engineers are listed below (GROUNDWATER COMPUTER CODES).

GROUNDWATER COMPUTER CODES

Code	Description	Developed
FTWORK	Three-Dimensional Flow & Transport	In-House for DOE
SWIFT	Three-Dimensional Flow & Transport	USGS/NRC
MODFLOW	Three-Dimensional Flow	USGS
BIO1D	One-Dimensional Biodegradation & Sorption Kinetics Transport	In-House
FLAMINCO	Three-Dimensional Flow & Transport Saturated-Unsaturated Porous Media	In-House
SWANFLOW	Three-Dimensional Flow; Saturated-Unsaturated Water and NAPLs	In-House for EPA
MODPATH	Particle Tracking	USGS
STLINE	Particle Tracking	In-House
HELP	Leachate Generation	EPA
ModelGIS™	A GIS Interface to MODFLOW	In-House for SFWMD
MODMAN	Optimization Module for MODFLOW	In-House for EPA
SiteGIS™	Environmental Data Management System	In-House
MC.TRANS	One-dimensional transport with matrix diffusion and Monte Carlo uncertainty analysis	In-House for DOE

GeoTrans has extensive experience with both the development and application of a variety of GIS platforms in the DOS and UNIX environments. Geographic Information Systems (GIS) allows integration of environmental, physiographic, demographic and land-use data into a comprehensive system that compiles information in a graphical format. The integration of data in this format allows for greater quality assurance and flexibility in data interpretation.

3 TECHNICAL APPROACH

3.1 Project Understanding

An arsenic spill resulting from a train car derailment occurred approximately 40 years ago at the site. No documentation exists as to the type of arsenic spilled; however, based on soil and water samples, it appears to be a sodium arsenite. Two discrete areas of distressed vegetation were mapped at the site. These areas coincide with the maximum observed arsenic concentration in the soils and water.

Soil samples collected at the site indicate that the highest concentrations are adjacent to the railroad tracks, with a maximum concentration of 10,700 mg/kg. Arsenic concentrations in the soil rapidly decrease to the north and south, and the soils contamination plume is elongated to the east towards the river. Background soil arsenic concentrations appear to be around 2 to 4 mg/kg. No soil samples were collected on the southern and southeastern side of the railroad tracks. Arsenic concentrations decrease with depth and are restricted to the upper 8 feet of peat/sediments at the site.

Pore-water and surface-water samples were collected at a number of locations at the site. Water samples are restricted to the immediate vicinity of the stressed vegetation; background samples were collected adjacent to the railroad tracks, on the east side of the river, and north of the plume. The maximum arsenic concentration in water samples is in areas of maximum soil concentrations. The highest concentration measured in water samples is 920 mg/l. Arsenic concentrations range from 0.064 to 0.69 mg/l south of the railroad tracks and from ND to 0.0066 mg/l upgradient (north) of the plume.

Limited hydrologic data were provided with the Request for Proposal (RFP) for determining groundwater flow directions; however, based on the land-surface topography and the locations of surface-water bodies in the area, a conceptual model for groundwater flow can be developed. The deeply incised river valley is a natural groundwater sink for this area, where groundwater discharges from the surrounding highlands to the river valley. Groundwater in the alluvial deposits of river valley either continues as subsurface flow or discharges to the river.

The marsh area that contains the arsenic plume was formed by the deposition of alluvial sediments. The marsh area is on the inside of a broad river meander (approximately 0.5 miles across), with the river to the east, west and north of the marsh. Groundwater in the alluvial deposits is most likely moving from the northwest to the southeast, following the approximate orientation of the valley in this area; however, water-level fluctuations within the peat/sediment deposits in the marsh (from land surface to about 8 feet below land surface) are probably caused by changes in river stage. It is anticipated that the permeability of the upper peat deposits is high and readily transmits changes in river stage back into the marsh. The average groundwater flow direction is from the marsh into the river, but during high river stage, the flow close to the river is probably reversed. The reversal in flow direction as a result of increased river stage is well documented and is commonly referred to as bank storage. - flood plain

Another source of water to the marsh is groundwater discharge from the highlands to the west and from the alluvium beneath the peat/sediment deposits. The potential volume of groundwater discharge to the marsh may be high given the potentially high permeability of the alluvial deposits and the upward hydraulic gradient in the vicinity of the river and Lake Michigan.

Sorption of arsenic to the peat deposits appears to be a significant geochemical process, which slows the groundwater transport rate of arsenic to the river. Concentrations in the peat/sediment samples are about a factor of 10 to 450 times higher than the concentrations in adjacent water samples. The significant difference in arsenic concentrations between the peat/sediments and water samples is an indication that sorption reactions needs to be included in the model transport simulations.

The high arsenic concentration adjacent to the railroad track may be due to pore waters flowing beneath and through the backfill used for the construction of the railroad track. Local and regional groundwater flow directions are not well defined in this area, but are expected to be in a southerly to southeasterly direction paralleling the river. In addition, seasonal fluctuations in river stage will impact the shallow groundwater fluctuations resulting in temporary changes in groundwater flow directions in the vicinity of the arsenic plume.

The base material used in the construction of the railroad track may be impacting shallow groundwater flow directions within the marsh. Based on the east-west orientation of the arsenic plume, it appears that the railroad track backfill material is diverting shallow groundwater flow from a predominantly southeasterly flow direction to an easterly flow direction.

3.2 Fate and Transport Modeling Approach

TASK 1 - INITIAL DATA REVIEW

Prior to developing a fate and transport model, GeoTrans will review all historical reports and data for the site in order to develop conceptual models for the shallow hydrogeologic and geochemical systems. In addition to site specific reports, GeoTrans will work with STS Consultants to obtain any reports and data developed by the State, U. S. Geological Survey or universities on the regional groundwater system for this area. Data that are important for developing a numerical flow and transport model of this area include:

- Potentiometric surface maps;
- Aquifer permeabilities and thicknesses;
- Estimates of groundwater flow velocities and directions;
- Temporal groundwater and river stage fluctuations;
- Vertical components of groundwater flow for marsh;
- Total arsenic plume mass in water and sediments;
- Background arsenic concentrations;
- Estimates of the distribution coefficient for arsenic (K_d);
- Estimates of the retardation coefficient for arsenic (R);

If existing data prove to be inadequate to support model development, TASK 1 will provide a basis for developing a focused data collection effort and literature review to address data deficiencies.

TASK 2 - MODEL DEVELOPMENT

Model Selection

Real-world groundwater flow and contaminant transport problems are three-dimensional and require data in three-dimensions in order to accurately characterize the hydrogeologic and geochemical systems. However, the costs and time required to collect data in three dimensions are not always justified based on the complexity of the groundwater flow system and the need to accurately characterize it. If the objective of the transport model is to approximate arsenic concentrations as a function of time at the river, than a three dimensional model is not required. This can be accomplished with a one- or two-dimensional model. If temporal changes in the arsenic concentrations as a function of groundwater and river-stage fluctuations are required, than a three-dimensional model, with three-dimensional characterization data may be needed to accurately simulate the transient transport of arsenic..

A one-dimensional transport model is sufficient to establish the approximate arrival time of the arsenic plume at the river, the approximate shape of the concentration breakthrough curve as a function of time, and the approximate time required for all of the arsenic to be naturally flushed from the marsh. The data that currently exist for the site do not justify the time and monies required to development a three-dimensional flow and transport model. Groundwater fluxes and flow directions are not well defined at the site. The accuracy of the model predictions for a three-dimensional model will not be significantly improved over that of a one-dimensional model, because three-dimensional, transient data do not exist for calibrating the more complex model.

GeoTrans proposes the use of a one-dimensional transport code entitled "BIO1D". The BIO1D code was developed by GeoTrans for simulating the transport of organic, inorganic, metals and radioactive contaminants. The BIO1D code is capable of simulating the biodegradation of organic contaminants, and the radioactive decay of radio nuclides. BIO1D is a proprietary, but publicly available code that has been bench marked and verified against analytical and other numerical models. It is widely used by government agencies, universities, and private industry.

The main advantages to the use of the BIO1D code are that it can simulate the one-dimensional transport of arsenic from the marsh to the river and accurately account for the adsorption/desorption of arsenic as a function of time. Most contaminants are transported at a rate that is less than the groundwater velocity. The ratio of the groundwater velocity to the contaminant velocity is termed the retardation coefficient (R), which generally has a value of 1 or greater. The distribution coefficient (K_d) is typically used to calculate the retardation coefficient of solutes in a groundwater system. GeoTrans will perform a literature search to obtain representative estimates of the K_d for arsenic in an organic (marsh) environment. We will also use existing concentration data for the site to estimate the in-situ K_d for the marsh/arsenic system. Given that arsenic may be transported from the marsh to the river over a period of hundreds of years, retardation can significantly impact the time-variant flux of arsenic to the river and the maximum predicted breakthrough concentration.

The main disadvantage to the use of a one-dimensional flow and transport model is that the three-dimensional complexity of the groundwater flow system cannot be accurately modeled with a one-dimensional code. Simplifying assumptions need to be made in order to compress the three-dimensional flow and transport system into one dimension. Depending on the complexity of the groundwater flow system, these assumptions may have significant impacts on the predicted concentrations. In addition, the groundwater velocity is held constant along a flow path and is not allowed to change. The assumption that the groundwater velocity is constant along the flow path may not be valid in complex groundwater flow systems, with time-variant changes in groundwater flow directions and magnitude.

If the flow direction from the marsh to the river reverses during periods of high river stage, the transport rate of arsenic to the river may be overestimated by a model that only allows flow to occur in one direction (ie towards the river). If background concentration groundwater is discharging into the marsh from beneath and mixing with the arsenic plume waters, then the model may over predict the average arsenic concentrations at the river for a unit cross section of aquifer. Therefore, by simplifying a complex three-dimensional flow and transport system into one dimension, mechanisms that potentially may reduce the transport time and magnitude of the arsenic concentrations at the river are not adequately represented in the model.

Sensitivity Analysis

One of the primary concerns of the State regulatory agencies concerning the transport modeling effort will be the assumptions used to develop the conceptual model and to estimate flow and transport parameter values in the model. The more site-specific data available to quantify the hydrogeologic and geochemical systems the better we will be able to develop defensible conceptual and numerical models. A limited number of sensitivity analyses will be performed to evaluate the sensitivity of the model to changes in the estimated model parameter values, such as groundwater velocity and the retardation coefficient. The sensitivity analysis will provide a tool for estimating the potential error in the model predicted arsenic concentrations at the river as a result of the estimated range in parameter values.

Additional Data Requirements:

The accuracy of the numerical model is only as good as the data used to develop the conceptual model and to quantify the groundwater flow system. At present the shallow groundwater flow directions and velocities are not well defined at the site. Additional piezometers would help to better quantify shallow groundwater flow directions and hydraulic gradients. Without these data, it may be difficult to quantify the groundwater direction and velocity used in the transport model analysis.

In addition to the hydraulic gradient, an estimate of the hydraulic conductivity for the shallow peat deposits is needed to better quantify the groundwater velocity. The sensitivity of the model to the velocity used for the transport simulations will significantly impact the transport times and predicted concentrations at the river.

Groundwater concentration data for locations between the stressed vegetation and the river will help to better quantify the arsenic retardation and provide downgradient data with which to calibrate the model. The information provided to GeoTrans indicates that no data were collected east of the stressed vegetation.

Installation of nested piezometers into the alluvial deposits beneath the marsh are needed to measure vertical hydraulic-head differences and to estimate the potential vertical groundwater flux component. Even though one-dimensional model cannot explicitly account for the effects of this vertical groundwater flux component, these data can be used to estimate the potential dilution of the arsenic concentrations at the river. Without these data, it will be difficult to present a strong technical argument to the State justifying concentrations reduction as a result of groundwater dilution.

TASK 3 - PREDICTIVE SCENARIOS

GeoTrans will work with STS Consultants to develop a limited number of "what if" predictive scenarios for the transport model. These predictive scenarios may include an evaluation of:

1) Seasonal changes in the local groundwater velocity as a result of river stage and groundwater fluctuations;
2) Effects of reducing the hydraulic gradient in the vicinity of the arsenic plume;
3) Reductions in the total mass of arsenic available for transport; and
4) Changes in the long-term groundwater flow directions.

It may be advisable to work directly with the State in developing predictive scenarios, such that their concerns can be addressed during the initial model development and predictive simulations. GeoTrans has found that it is best to have the regulatory agencies in agreement with the technical approach during the early phases of the project. We recommend that the modeling approach and predictive scenarios be presented to State personnel for their review before starting model development. For costing purposes, GeoTrans has assumed that approximately 1.5 to 2 weeks will be required to perform and analyze the results of the predictive simulations.

TASK 4 - REPORTING

At the conclusion of the modeling effort, GeoTrans will prepare a letter report detailing the findings of our BIO1D fate and transport modeling for arsenic. Included in the report will be discussions of model development, input parameters and estimation techniques, modeling assumptions, calibration, sensitivities and predictive simulations results. Particular attention will be focused on natural attenuation mechanisms and their predicted effects on future arsenic concentrations at the river. Modeling results will be summarized both in tabular form and in color illustrations.

One draft letter report will be provided to STS Consultants for comment and review at the completion of Task 3. Three copies of the final report will be provided at the completion of the project.

TASK 5 - REGULATORY SUPPORT

GeoTrans will provide regulatory support relating to the findings and implications of this modeling effort. Our experts in contaminant hydrology are experienced in communicating technical information to regulators on behalf of our clients. In this arsenic study, it will be particularly important to convey an understanding of the natural processes that control arsenic concentrations as a function of time.

GeoTrans' reputation for being at the cutting edge of numerical model development and application will be instrumental in establishing technical credibility for the modeling results. If requested, we can provide the services of nationally recognized experts from within the company to help present and defend the results of the modeling effort to State and Federal regulators. Resumes of a few of these experts are included with our proposal package. We have provided information on hourly rates, but cannot estimate the amount of time that this task will require. GeoTrans will provide STS with a budget estimate for this task after a more defined scope has been developed.

4 SCHEDULE

GeoTrans will begin Task 1 immediately following notification to proceed. The initial data review is expected to be brief, requiring only about a few days to review the available material and extract estimates for model input parameters. Model development will then begin, directly following by predictive scenario modeling. These two tasks will require an estimated three to five weeks to complete. A final letter report incorporating STS feedback will be delivered approximately one week after comments are received. Our cost estimate provides for one day of travel for the project manager to present the results to STS and/or to regulators when the need arises. Our proposed project schedule is illustrated below (Figure 2):

Proposed Project Schedule

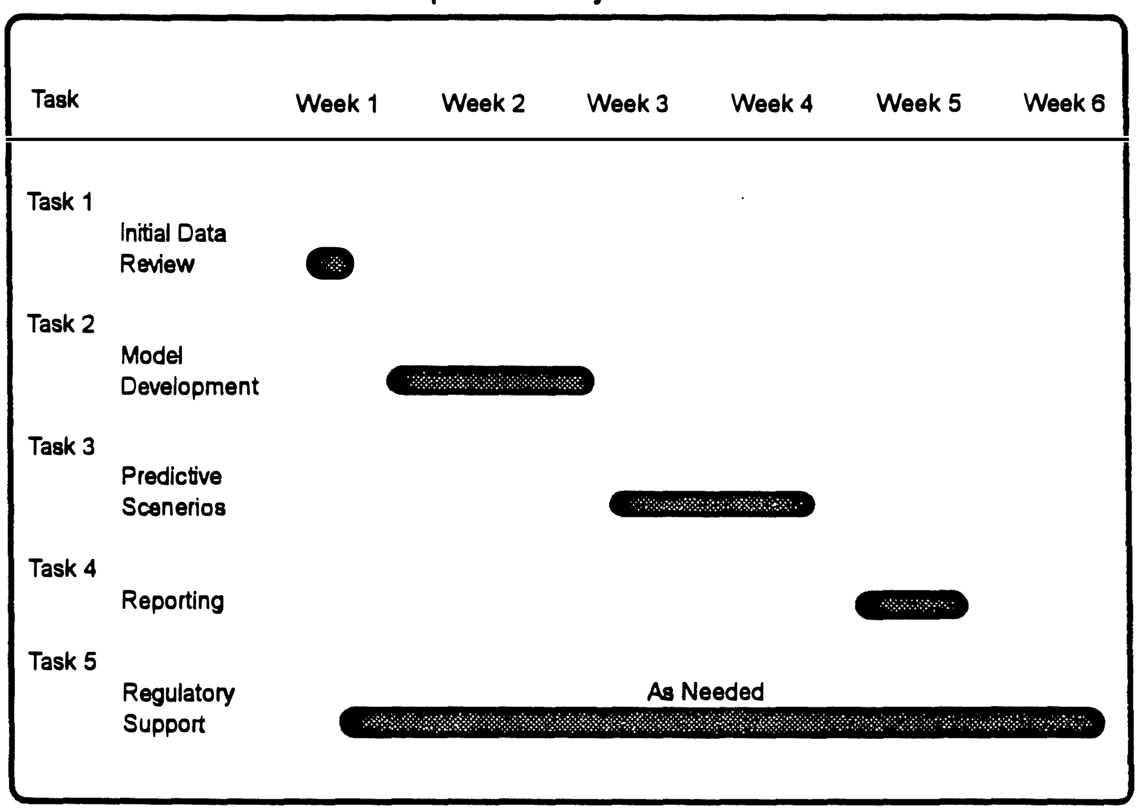

Figure 2

Project Team
Professional Resumes

JAMES R. ERICKSON

Principal Hydrogeologist
GeoTrans, Inc.

Professional Expertise:

Numerical modeling
Groundwater flow and solute transport modeling
Fracture hydrology
Radioactive waste disposal
Mining hydrogeology
Allocation support PRP Committees
Water resource investigations

Education:

M.S., Hydrogeology, Colorado State University, 1985
B.S., Geology, University of Wisconsin, 1976

Professional Experience:

March 1986 - Present
Principal Hydrogeologist, GeoTrans, Inc., Boulder, Colorado.
Mr. Erickson is a Senior Project Manager and Office Manager for the GeoTrans' Boulder office. He has provided principal investigator oversight on a number of GeoTrans' projects involving the integration of field data collection programs with numerical model development for litigation support. Projects have ranged in size up to $1.4 million and have included groundwater flow, contaminant transport and fate analyses as part of hazardous/nuclear waste, water resources and mining related investigations.

May 1981 - March 1986
Hydrogeologist, U.S. Geological Survey, Water Resources Division, Nuclear Hydrology Program, Lakewood, Colorado.
Co-project Leader and Investigator for the characterization of a potential high-level nuclear waste repository for the NNWSI program.

December 1977 - August 1980
Hydrogeologist, U.S. Geological Survey, Water Resources Division, Champaign, Illinois.
Assistant Project Leader for the hydrogeologic characterization of a low-level radioactive-waste disposal site near Sheffield, Illinois from 1977 to 1980.

November 1976 - December 1977
Hydrogeologist, U.S. Geological Survey, Water Resources Division, Madison, Wisconsin.

Relevant Project Experience:

Project manager of a Superfund PRP allocation analysis for the San Gabriel Valley Baldwin Park Operable Unit (OU) Steering Committee; the San Gabriel Valley groundwater basin in California is contaminated with VOCs from industrial manufacturing, storage, disposal, and solvent recycling operations in the valley over the past 55 years. The allocation analysis includes: (1) the development of a three-dimensional flow (MODFLOW) and particle tracking (MODPATH) models of the San Gabriel Valley groundwater basin; (2) the development and implementation of a technically defensible allocation approach that allows for a reduction in individual PRP allocation based on site investigations; (3) the development of databases for management and analysis of PRP data; and (4) the development of software programs to calculate PRP allocations.

Project manager for the development of an Alternative Concentration Limits (ACL) permit application for a uranium tailings impoundment in Wyoming. The permit application required the use of an Analytical Element Model (TWODAN) for analyzing the response of the shallow groundwater aquifer to shutting off the recovery well system currently capturing contaminated groundwater down gradient of the impoundment, and the use of a geochemical transport code (BIO1 D) for predicting the long-term concentrations of trace metal contaminants at POC and POE locations downgradient of the impoundment.

Project manager of a nation-wide, six-year research study for the collection, analysis and development of hydrogeologic and geochemical data sets for the validation of coupled groundwater flow and geochemical numerical models. The research program consisted of: (1) the evaluation of over 300 potential candidate sites for the selection of up to seven sites for detailed hydrogeologic and geochemical data collection; (2) the development of a guidance manual for data requirements and usage in numerical models; (3) the development of innovative field techniques to characterize both saturated and unsaturated groundwater flow and geochemical processes at utility sites; and (4) the hydrogeologic characterization and analysis of electric utility ash and FGD disposal ponds at three sites in the southeastern, midwestern and southwestern areas of the United States.

Development of a three-dimensional, groundwater flow (MODFLOW), particle tracking (STLINE) and solute transport model (SEFTRAN) for a hazardous waste landfill site in Louisiana to assess the impacts of contaminant transport on a shallow water supply aquifer. Numerical models were successfully used to predict the long-term effectiveness of the existing recovery well system and the locations of additional recovery wells to prevent off-site migration of organic contaminants.

Project Manager for density-dependent flow analyses and geochemical characterization at a mine tailings facility in Utah, in support of a permit to expand the tailings impoundment. The density-dependent flow analysis required the use of both a two-dimensional flow model (SWIFT) and analytical techniques to evaluate the effects of high TDS fluids on the local groundwater flow and solute transport system.

Project manager for characterizing the extent of hydrocarbon contamination resulting from leaking underground storage tanks and for developing potential remedial alternatives.

Development of a three-dimensional groundwater flow model (MODFLOW) to assess the impacts of municipal wellfield pumpage on the shallow aquifer and lakes in Palm Beach County, Florida. The analysis of groundwater pumpage on surface-water lakes required the development of a coupled groundwater flow/lake-stage module for the MODFLOW code. This module was successfully used to simulate historical groundwater/surface water elevations in the region and to predict the long-term impacts of groundwater withdrawals on lake stages.

Analysis of infiltration and leachate generation, evaluating alternative cover designs for a large tailings pile impoundment at a precious metals mine in Colorado. The evaluation of alternative cover designs required the use of an unsaturated/saturated flow model (EFLOW) for simulating seasonal variations in recharge to the tailings impoundment from rainfall and snow melt events in a high-mountain alpine environment.

Development and implementation of a site characterization program to evaluate NAPL, pesticides and metal contamination at an abandoned landfill in Los Angeles.

Development of a field program to analyze the effectiveness of a recovery well system at a hazardous waste landfill site in Louisiana.

Development of an analytical open-pit inflow model to predict inflow volumes according to pit advancement and configurations for a coal mine in Arizona.

Provided technical review of a mine permit application for a large open-pit coal mine in Arizona.

Performed a hydrogeologic and geochemical evaluation of a uranium tailing impoundment in Wyoming. Provided technical support for developing alternatives for dewatering the tailings impoundment and limiting the transport of low pH fluids and metals from the facility.

Regional aquifer characterization and evaluation for a surface coal mining project in Arizona.

Development of a numerical parameter-estimation technique for the analysis of single-well tracer tests at a potential high-level nuclear waste disposal site at Yucca Mountain on the Nevada Test Site. The numerical technique required the use of the U.S. Geological Survey MOC code coupled to a parameter estimation module for the analysis of tracer test data.

Supervising the drilling, sample collection, well construction, and hydrologic testing of deep wells (3,000-4,000 feet) as part of the characterization of the Yucca Mountain site for high-level nuclear waste disposal.

Analysis of hydrogeologic tests in fractured rock at the Yucca Mountain site.

Designed and implemented an in-situ single and multiple well tracer tests to assess travel times and retardation mechanisms at the Yucca Mountain site.

Quantified the complex glacial stratigraphy for a low-level radioactive-waste disposal site near Sheffield, Illinois; assisted in the development of both the conceptual and two-dimensional groundwater flow models; designed and supervised the drilling, sampling, well construction, and hydraulic testing of a 40 well monitoring system; supervised the construction of a 290-foot tunnel under four waste disposal trenches to characterize unsaturated groundwater flow and radionuclide transport.

Constructed water-level and contamination potential maps for counties in southeastern Wisconsin.

Installed, tested, and analyzed monitor well systems for hydrologic investigations.

Professional Affiliations:

American Geophysical Union
Professional Geologist, Wyoming, #1765

Publications and Presentations:

1. Holcombe, L.J., J.R. Erickson, J.J. Fruchter, C.M. Thompson, and A. Weinberg, 1994. Model validation data set for utility by-product management sites -- Volume I: Site characterization data, Electric Power Research Institute, Palo Alto, California, in publication.

2. Holcombe, L.J., J.R. Erickson, J.J. Fruchter, C.M. Thompson, and A. Weinberg, 1994. Model validation data set for utility by-product management sites -- Volume II: Post disposal plume data, Electric Power Research Institute, Palo Alto, California, in publication.

3. Holcombe, L.J., J.R. Erickson, J.J. Fruchter, C.M. Thompson, and A. Weinberg, 1992. Comanagement of coal combustion by-products and low volume wastes -- A midwestern site, Electric Power Research Institute, Palo Alto, California, TR-100955.

4. Fruchter, J.J., J.M. Thomas, R.K. Waddell, and J.R. Erickson, 1992. Strategies for field calibration and validation of groundwater models, Electric Power Research Institute, Palo Alto, California, TR-101063.

5. Holcombe, L.J., J.R. Erickson, J.J. Fruchter, C.M. Thompson, and J.A. Rehage, 1991. Comanagement of coal combustion by-products and low-volume wastes: a southwestern site, prepared by Radian Corporation, GeoTrans, Inc., and Battelle Pacific Norwest Laboratories, Electric Power Research Institute, Palo Alto, California, EN-7545.

6. Erickson, J.R., 1990. A field investigation of groundwater quality at a waste co-management pond, presented at Edison Electric Institute Groundwater Task Force Symposium on Technology and Policy Development, July 18-19, Washington, D.C.

7. Erickson, J.R., 1990. Site characterization methods for groundwater monitoring and modeling, presented at Electric Power Research Institute Seminar on Waste Disposal and Groundwater Quality Assessment Methods, August 7-8, Atlanta, Georgia.

8. Murarka, I.P., and J.R. Erickson, 1990. Case studies and results for actual waste management/ co-management sites, presented at Electric Power Research Institute Seminar on Waste Disposal and Groundwater Quality Assessment Methods, August 7-8, Atlanta, Georgia.

9. Electric Power Research Institute, 1989. Techniques to develop data for hydrogeochemical models, prepared by Radian Corporation, GeoTrans, Inc., and Battelle Pacific Northwest Laboratories, Electric Power Research Institute, Palo Alto, California, EN-6637.

10. Star, I. , J.R. Erickson, and R.K. Waddell, 1989. Groundwater monitoring manual; prepared for and copyrighted by the Edison Electric Institute, Washington, DC.

11. Dacey, C.A., J.R. Erickson, and R.K. Waddell, 1988. A coupled three-dimensional groundwater flow and lake-stage model of northern Palm Beach County, Florida, American Water Resources Association Symposium on Coastal Water Resources, Wilmington, North Carolina.

12. Erickson, J.R., C.A. Dacey, and R.K. Waddell, 1987. A coupled three-dimensional groundwater flow and lake-stage model of northern Palm Beach County, Florida, AGU, San Francisco, California.

13. Erickson, J.R., and R.K. Waddell, 1985. Identification and Characterization of Hydrologic Properties of Fractured Tuff Using Hydraulic and Tracer Tests--Test Well USW H-4, Yucca Mountain, Nye County, Nevada, U.S. Geological Survey Water-Resources Investigations Report 85-4066, 30 p.

14. Erickson, J.R., D.L. Galloway, and K. Karasake, 1985. Interpretations of Falling-Head Injection Test Data for Fractured Volcanic Tuffs, Yucca Mountain, Nevada Test Site, GSA, Orlando, Florida.

15. Erickson, J.R., and R.K. Waddell, 1985. Parameter-Estimation Techniques for the Analysis of Single-Well Tracer Tests, AGU, Baltimore, Maryland.

16. Galloway, D.L., and J.R. Erickson, 1985. Tracer Test for Evaluating Nonpumping Intraborehole Flow in Fractured Media, ANS, San Francisco, California.

17. Waddell, R.K., and J.R. Erickson, 1984. Transport Experiments in Fractured Tuffs at Yucca Mountain, Nevada Test Site, AGU, Cincinnati, Ohio.

18. Foster, J.B., J.R. Erickson, and R.W. Healy, 1983. Hydrogeology of a Low-Level Radioactive-Waste Disposal Site Near Sheffield, Illinois, U.S. Geological Survey Water-Resources Investigations Report 83-4125, 83 p.

19. Erickson, J.R., 1980. Hydrogeology of a Low-Level Radioactive Waste Disposal Site Near Sheffield, Illinois, North-Central Section GSA, Bloomington, Indiana.

20. Foster, J.B., and J.R. Erickson, 1979. Preliminary Report on the Hydrogeology of a Low-Level Radioactive-Waste Disposal Site Near Sheffield, Illinois, U.S. Geological Survey Open File Report 79-1545, 87 p.

21. Sherrill, M.G., and J.R. Erickson, 1979. Water-Table Map of Walworth County, Wisconsin, U.S. Geological Survey Water-Resources Investigations Report 79-42.

22. Sherrill, M.G., J.J. Schiler, and J.R. Erickson, 1979. Water-Table Map of Milwaukee County, Wisconsin, U.S. Geological Survey Water-Resources Investigations Report 79-40.

CHEN ZHU, Ph.D.

Senior Geochemist
GeoTrans, Inc.

Professional Expertise:

Groundwater and solid waste geochemistry
Contaminant transport analysis and modeling
Geochemical/chemical modeling and simulation of remediation processes
Analytical instruments and procedures
Geographic Information System (GIS)

Education:

Ph.D., Aqueous Geochemistry, The Johns Hopkins University, 1992
M.Sc., Geochemistry, The University of Toronto, 1987
B.S., Geology (with honors), Chengdu Institute of Technology, 1982

Professional Experience:

1994 - Present
Senior Geochemist, GeoTrans, Inc., Boulder, Colorado.

Relevant Project Experience:

Senior Geochemist for a project at the Western Processing Superfund site in Kent, Washington. Performed geochemical modeling using PHREEQE to help designing a field pilot study to reduce heavy metal contaminations. Assisted in evaluation of batch and column sorption experimental data.

Geochemistry Task Technical Leader for the Department of Energy (DOE) Nevada Test Site (NTS) Environmental Restoration program's investigations. Constructed a large water quality database and performed data quality evaluation; analyzed and modeled regional groundwater chemistry to understand the genesis of groundwater, groundwater-aquifer reactions along the flow paths, groundwater flow directions and crossflow between aquifers; performed statistical analysis of partitioning coefficients (Kd); evaluated C-14 dating of groundwater ages and calculated groundwater velocity; analyzed H, O, Sr, U, Cl isotope data; ranked potential risks of radionuclides based on health risks, concentrations, and mobility; and implemented Quality Assurance/Quality Control (QA/QC) program for the geochemistry work.

Senior Geochemist for a uranium mill's Alternative Concentration Limits (ACL) permit application project. Responsible for geochemical evaluation of the potential of contaminant migration. Analyzed water quality data; characterized the dominant water-rock interactions at the site; carried out geochemical speciation-solubility modeling using MINTEQA2 to determine controls in water chemistry and groundwater chemistry evolution along the flow paths; evaluated aquifer acidity and neutralization potential; modeled contaminant mobility and retardation using surface complexation model in MINTEQA2; calculated acid plume total acidity and projected its potential migration down the gradient; performed one-dimensional transport model using BIO1D.

Senior Geochemist, developed a conceptual model and computer code for coprecipitation, which is used by national laboratories and environmental and oil companies to study radionuclide migration at waste disposal sites, naturally occurring radioactive materials problems, and waste reduction and waste containment processes. Consulted for Du Pont and Chevron on co-precipitating Pb from waste streams and predicting compositions of oil-field radioactive wastes.

Ph.D. degree dissertation research at the Johns Hopkins University. Projects include hydrogeological modeling of fluid flow and thermal history in mid-continent sedimentary basins as related to the formation of Mississippi Valley-type Pb-Zn ore deposits. Developed a computer code which couples fluid flow equation with silica precipitation kinetics. Evaluated thermochemical and physical parameters for modeling heavy metal complexes, radionuclides speciation, and metal-organic complexes in soil and groundwater, and published results in prestigious journals.

Professional Affiliations:

Member, American Geophysical Union
Member, American Chemical Society
Member, Geochemical Society
Peer Reviewer, National Science Foundation, and Journals *Geochemica et Cosmochimica Acta, American Mineralogist, Journal of Volcanology and Geothermal Research*

Awards and Honors:

Post-doctoral Fellowship, 1991-1992, MIT/Woods Hole Oceanographic Institution
Gilman Fellowship, 1987-1990, The Johns Hopkins University
H.V. Ellsworth Award in Mineralogy, 1985-1987, The University of Toronto

Publications:

1. Zhu, C., Yeh, (George) Gour-Tsyh, and Richard K. Waddell, 1994. A new approach to model trace metal contaminant transport. Submitted to the American Institute of Hydrology Annual Meeting, May, 1995, Denver, Colorado.

2. Zhu, C., H. Xu, E. Ilton, D. Veblen, and D. Henry, M.K. Tivey, and G. Thompson, 1994. TEM-AEM observations of high-Cl amphibole and biotite and possible petrologic implications. *American Mineralogist* 79:909-920.

3. Zhu, C., M. Rafal, S. Sanders, and N. Scrivner, 1994. Modeling oil field mixed scales (coprecipitation) and formation damage. *Proceedings of International Symposium on Formation Damage Control, Society of Petroleum Engineer*, Paper #27372, p.321, February 14-16, 1994, Lafayette, Louisiana.

4. Zhu, C., 1993. New pH sensor for hydrothermal fluids. *Geology*, 21: 983-986.

5. Zhu, C., S. Sanders, M. Rafal, and N. Scrivner, 1993. Modeling coprecipitation reactions as the control of trace elements mobility in groundwater. *Geology Society of America Abstr. with Programs*, 25(6): A-376.

6. Zhu, C., S. Sanders, and M. Rafal, 1993. Simulation of coprecipitation processes: A case study of the coprecipitation of Ra-BaSO4. *OLI Technical Report*, 25p.

7. Zhu, C., H. Xu, E. Ilton, D. Veblen, and D. Henry, 1993. A TEM study of high-Cl amphiboles and biotite: Possible petrological interpretations. *Geological Society of America Abstr. with Programs*, 25(6): A371, invited.

8. Xu, H., E. Ilton, C. Zhu, D. Veblen, 1993. TEM study of high-Cl amphiboles and other biopyriboles. *American Geophysical Union Transactions*, 74(16): M12A-3.

9. Zhu, C. and D.A. Sverjensky, 1992. F-Cl-OH partitioning between apatite and biotite. *Geochimica et Cosmochimica Acta*, 56: 3435-3467.

10. Zhu, C., 1992. Predicting fluoride and chloride concentrations of fluids. *Geological Society of American Abstr. with Programs*, 24(7): A206.

11. Zhu, C. and D.A. Sverjensky, 1991. Partitioning of F-Cl-OH between minerals and hydrothermal fluids. *Geochimica et Cosmochimica Acta*, 55: 1837-1858.

12. Zhu, C., 1991. Biotite (Mg, Fe, Al^{VI})(F, Cl, OH) reciprocal mixing properties: Evidence from F-Cl-OH partitioning between apatite and biotite (abstr.). *Geological Society of America Abstr. with Programs*, 23(5): A95.

13. Zhu, C. and D.A. Sverjensky, 1991. A set of consistent thermodynamic properties for fluorapatite, hydroxyapatite, and chlorapatite (abstr.). *American Geophysical Union Transactions*, 72(17): 145.

14. Zhu, C., and D.A. Sverjensky, 1990. Partitioning of F, Cl, and OH between minerals and hydrothermal fluids (abstr.). *Geological Society of America Abstr. with Programs*, 22(7): A157.

15. Sverjensky, D.A., P. A. Molling, and C. Zhu, 1990. Chemical mass transfer calculations for magmatic hydrothermal systems (abstr.). *Program and Abstracts*. V.M. Goldschmidt Conference, Baltimore, 1990.

16. Zhu, C., 1989. X-ray diffraction and scanning electron microscopy studies of clay minerals at Buick Mine, SE Missouri. *Bulletin of Chengdu Institute of Technology*, 12: 36-48.

KAREN MALEY

Project Geologist/Hydrogeologist
GeoTrans, Inc.

Professional Expertise:

Hydrogeologic field investigations and data analysis
Groundwater and vadose zone sampling and monitoring
Aquatic geochemistry and geochemical modeling
Contaminant fate and transport modeling
Geostatistical modeling

Education:

M.S., Environmental Science and Engineering, Colorado School of Mines, 1994
B.S., Geology, Colorado State University, 1987
Graduate coursework: Geological Sciences, University of California, Santa Barbara, 1988

Professional Experience:

1994 - Present
Project Geologist/Hydrogeologist, GeoTrans, Inc., Boulder, Colorado.
Specializes in groundwater sampling, aquifer testing and borehole packer testing.

September 1993 - May 1994
Teaching Assistant, Environmental Science and Engineering Division, Colorado School of Mines, Golden, Colorado.

1989 - 1992
Geologist, Ebasco Environmental, Denver, Colorado.
Prepared detailed technical reports including the Remedial Investigation Summary Report for the Rocky Mountain Arsenal, the *Waste Stream and Residue Identification and Characterization Report* for the Rocky Flats Plant, and the *Phase III RFI/RI Report for Rocky Flats Plant Operable Unit 1*. Integrated diverse data sets to provide comprehensive assessments of contamination. Prepared formal responses to regulatory agencies. Compiled and presented data in maps, tables, and cross-sections.

January 1989 - April 1989
Field Assistant, Geological Sciences Department, University of California, Santa Barbara, California.

June 1987 - December 1988
Teaching and Research Assistantships, Geological Sciences Department, University of California, Santa Barbara, California.

Relevant Project Experience:

Provided technical support to the State of Colorado Attorney General's Office and Department of Public Health and Environment in their negotiations with the Army and other parties to settle on remedies for contaminated sites at the Rocky Mountain Arsenal. Researched methods used by the Army in its Feasibility Study to calculate volumes of soil with contaminant levels exceeding certain risk-based standards. Attempted to independently duplicate the Army's method and results by using identical logic and software. Provided the State with a thorough description and critique of the Army's volume calculation method including a limited analysis of model sensitivity. Setup fully functional models to calculate exceedence areas, volumes, and geometries for three controversial sites at the Rocky Mountain Arsenal: Former Basin F, Basin A, and South Plants Central Processing Area. Assessed volume estimate uncertainties on a site-by-site basis for the top ten sites at the arsenal.

Rig Geologist involved in hazardous waste site investigations at CERCLA and RCRA sites including the Department of Energy Rocky Flats Plant near Denver; the Department of Energy Portsmouth Plant near Piketon Ohio; the Illinois Department of Nuclear Safety Geff Alternative Site in Wayne County, Illinois; and the Mid-America Industrial Park in Pryor, Oklahoma. Supervised drilling operations, sampled contaminated soils and logged soil samples. Performed well and piezometer installation, well development and groundwater sampling; as well as aquifer testing, borehole packer testing.

Conducted geochemical data analysis and equilibrium modeling of inorganic contaminants in groundwater at an eastern Wyoming uranium mill tailings site. Assessed quality and applicability of geochemical data and evaluated temporal trends in contaminant concentrations. Utilized both the MINTEQA2 and PHREEQE geochemical codes to predict contaminant mobility as a function of pH and groundwater flow direction.

Conducted a detailed geochemical study of acid mine drainage related pollution at the Rawley Twelve Mine and Mill, a southern Colorado CERCLA site. Tasks included the following: (1) on-site assessment of pollution sources and selection of appropriate sampling locations; (2) installation of a rectangular-notch weir for surface water flow measurement; (3) installation of suction lysimeters in the vadose zone of a mill tailings pile for pore water sampling; (4) sampling of solid wastes, contaminated surface water, and contaminated vadose zone pore waters on multiple occasions over a seven-month period; (5) complete laboratory analyses of all samples using atomic absorption spectrophotometry (metals), ion chromatography (major ions), and X-ray diffraction (solids); (6) rigorous assessment of laboratory data quality; (7) MINTEQA2 modeling to predict contaminant speciation and fate; (8) computation of annual pollutant loading rates for multiple sources; and (9) complete write up, presentation, and defense of this work as a Master's Thesis at the Colorado School of Mines.

Assisted in preparing the *Phase III RI/RFI Report for [the DOE] Rocky Flats Plant Operable Unit 1* (the "881 Hillside"). Duties included technical writing, editing, internal consistency and Quality Assurance/Quality Control (QA/QC) reviews, and production of final geologic logs in both hard copy and digital formats.

Served as a rig geologist for Remedial Investigation/Remedial Field Investigation (RI/RFI) investigation at the Department of Energy Rocky Flats Plant Operable Unit 1 (OU) (the "881 Hillside"), and also for the Rocky Flats Plant sitewide geologic characterization. Logged both alluvial and bedrock borings and installed numerous monitoring wells. Conducted aquifer tests (chiefly slug tests and baildown tests) and participated in aquifer test data analysis. Responsible for overseeing day-to-day rig operations and ensuring compliance with detailed standard operating procedures. Maintained up-to-date records of all rig activities, including the generation of potentially RCRA-hazardous wastes. Worked in both "Level C" and "Level B" personal protective equipment (both air-purifying and supplied-air respirators).

Served as a member of a team of technical writers in producing the *Waste Stream and Residue Identification and Characterization Report* for the Rocky Flats Plant. This extensive, multi volume report describes all waste-generating processes that exist at the Rocky Flats Plant and records the frequency and volume of waste generation associated with each process. In addition, each waste is characterized as either hazardous or nonhazardous under RCRA, and the final disposal method for each waste is documented. Due to the nature of some of the waste-generating processes at the Rocky Flats Plant, this job involved exposure to "UCNI"-classified nuclear information and thus required UCNI clearance.

Was a principal technical writer in the production of the *Remedial Investigation Summary Report* for the Rocky Mountain Arsenal. This task involved summarizing and integrating enormous quantities of data collected throughout the Remedial Investigation at the Rocky Mountain Arsenal, which is among the largest and most complex Remedial Investigations undertaken in CERCLA history. Tasks included extensive technical writing and editing, integrating diverse data sets to provide comprehensive assessments of contamination, preparing formal responses to regulatory agency comments, and compiling and presenting data in maps, tables, and cross-sections.

Served as a rig geologist in field investigations at the Illinois Department of Nuclear Safety Geff Alternative site in Wayne County, Illinois; the DOE Portsmouth Plant near Piketon, Ohio; and the Army Corps of Engineers Mid-America Industrial Park in Pryor, Oklahoma. Oversaw both vertical and angle drilling; logged soil samples and rock core; installed, developed, and sampled monitoring wells; and conducted packer tests to assess formation tightness.

Health and Safety Training:

Health and Safety Operations at Hazardous Materials Sites (40-hour training in accordance with 29 CFR 1910.120 [e]), 1989

Health and Safety Operations at Hazardous Materials Sites (8-hour refresher training in accordance with 29 CFR 1910.120 [e][3]), 1994

Radiation Safety for Environmental Restoration, Rocky Flats Plant, 8 hours, 1991

JENNIFER M. FRANZ

Staff Geologist
GeoTrans, Inc.

Professional Expertise:

CADD
Database development
Regulatory compliance

Education:

B.S., (Minor, Water Resources), Geology, State University of New York at Oneonta, 1993

Professional Experience:

June 1994 - Present
Staff Geologist, GeoTrans, Inc., Boulder, Colorado.

January 1994 - June 1994
Design Assistant, Mechanical Design and Drafting, CVC Products, Rochester, New York.

December 1989 - September 1993
Drafting, Lehigh Design Company, Rochester, New York.

December 1990 - February 1991
Mechanical Drafting, Applied Mechanical Technologies, Inc., Rochester, New York.

1988 - 1989
Drafting, Eastman Kodak Company, Rochester, New York.

Relevant Project Experience:

Responsible for geochemical data development for project analysis at the Nevada Test Site. Organized and developed Aquifer Test Database for numerous sites at the Nevada Test Site.

Performed field operations, data collection, and analysis at Bear Creek Uranium Site, Wyoming, including water level observation and core sampling.

Performed mechanical drafting using Intergraph 32C Workstation and 32 Microstation CAD System.

Collected lake bottom profiles, water turbidity data and temperature profiles. Created bathymetric maps for two lake basins. Presented results at the Northeastern Section Meeting of Geological Society of America, March 1991.

Performed a seismic and gravimetric study to determine the extent of an anonymously shallow bedrock ridge located adjacent to a valley wall and to explain this deviation from the classic u-shape associated with glaciated valleys.

Researched federal and state laws with respect to hazardous waste, transport and fate of contaminants, groundwater investigations, groundwater sampling protocol and risk assessments.

Publications:

1. Franz, J.M., 1993. Ice-contact lake environment, Bering Glacier, *Journal of Geologic Education*.

2. Franz, J.M., 1993. Unusual configuration of the Devonian-Pleistocene unconformity in Susquehanna Valley, Oneonta, New York: Evidence for a subglacial meltwater inlet to glacial Lake Otego, Abstract G.S.A.

3. Franz, J.M., 1992. Ice-contact lake environment, Bening Glacier, AK. Abstract G.S.A.

Support Personnel Professional Resumes

RICHARD K. WADDELL, Jr., Ph.D.

Vice President, Boulder Office, and Principal Hydrogeologist GeoTrans, Inc.

Professional Expertise:

RCRA/CERCLA investigations
Numerical modeling of flow and transport processes
Hydrogeologic characterization studies
Reclamation of uranium mill tailings
Geochemical studies of inorganic contaminants
Conceptual design and analysis of remedial actions
Litigation support

Education:

Ph.D., Geology, The Pennsylvania State University, 1977
M.S., Geology, University of Texas at Austin, 1973
B.A., Geology, University of Texas at Austin, 1970

Professional Experience:

March 1985 - Present
Principal Hydrogeologist, Vice President, GeoTrans, Inc., Boulder, Colorado.
Currently serves in the capacity of Principal Investigator and Key Hydrogeologist for the Department of Energy (DOE) Nevada Test Site Environmental Restoration Program's investigations. Specializing in geohydrologic transport analysis, including groundwater flow and solute transport, regulatory support, and groundwater remediation.

June 1982 - 1984
Faculty Affiliate, Department of Earth Resources, Colorado State University, Fort Collins, Colorado.

June 1977 - March 1985
Hydrogeologist, U.S. Geological Survey, Water Resources Division, Nuclear Hydrology Program, Lakewood, Colorado.
Principal investigator for group characterization of the hydrology of the Nevada Test Site region. Investigated the mechanisms of fluid flow and solute transport in fractured volcanic rocks and retardation mechanisms affecting transport of radionuclides in groundwater. Experience included management of field operations, deep-well drilling and testing numerical modeling, and interpretation of geologic, hydrologic, chemical, and geophysical data.

July 1971 - December 1971
Research Assistant, The Pennsylvania State University, University Park, Pennsylvania.
Investigated abatement techniques for acid and iron pollution.

September 1973 - May 1974
Teaching Assistant, The Pennsylvania State University, Department of Geosciences, University Park, Pennsylvania.

January 1972 - June 1972
Research Assistant, Christian, Miller, and Honts, Austin, Texas.
Preparation of Environmental Impact Statement for a proposed HUD Title VII New Town, located on the recharge zone of the Edwards Aquifer.

July 1971 - December 1971
Research Assistant. University of Texas, Austin, Texas.
Stress analysis of the upper crust using hydraulic well-fracturing data.

Relevant Project Experience:

Mr. Waddell has over 17 years experience which includes RCRA/CERCLA investigations; numerical modeling of flow and transport processes; hydrogeologic characterization studies; reclamation of uranium mill tailings; geochemical studies of inorganic contaminants; conceptual design and analysis of remedial actions; and litigation support.

Principal investigator and key hydrogeologist for the DOE Nevada Test Site Environmental Restoration program's investigations. Responsibilities include providing technical leadership of a $65 million investigation of radionuclide transport from underground nuclear tests. This investigation includes drilling of hydrologic test and core holes to depths of 5,500 feet, collection of water samples for characterization of regional flow and contaminant distribution, measurement of spring flow and discharge through evapotranspiration, estimation of recharge, aquifer tests in both fractured and porous rock, development of three-dimensional geologic models using Geographic Information System (GIS) and development of regional and local scale flow and transport models. Drilling activities include design of wells, performance of pumping and straddle packer aquifer tests, evaluation of drilling fluids, geological logging, and design and construction of deep multiple-completion character wells.

Project leader and principal investigator for the site characterization program of NNWSI repository for six years in the Nuclear Hydrology Program of the U.S. Geological Survey. Responsibilities included the technical direction of the in-situ tracer studies including design, implementation, and evaluation of tests to assess retardation factors and travel time estimates. In addition, responsible for technical direction of regional groundwater flow studies and associated sensitivity and uncertainty assessments for a finite-element model of the Nevada Test Site.

Principal investigator for a project at the Western Processing Superfund site in Kent, Washington. Activities involved review of data collected from pump-and-treat operations, geochemical studies of the groundwater as it pertains to the mobility of metals, estimation of the time required to meet remediation targets, and development of recommendations to shorten the remediation period and thus reduce costs.

Principal investigator for a project involving a hydrocarbon spill in the Los Angeles basin. Project entailed development of a three-dimensional model of groundwater flow in the West Coast Basin, the application of particle-tracking techniques to evaluate the rate and direction of contaminant (BTEX) movement, and recommending sites for groundwater extraction wells to remediate the groundwater. The model was used to facilitate negotiations with the Region Water Quality Board.

Litigation and expert witness support at a trial involving the Odessa, Texas Chromium I NPL site. Reviewed RI/FS reports and other studies to determine the source of chromium in soils and groundwater. Provided deposition and trial testimony, and technical support to the trial attorneys.

Project manager providing technical support to municipalities named as Potentially Responsible Parties (PRPs) at the Lowry Landfill, Denver, Colorado. Services included serving on the technical subcommittee of the PRP group, investigations of the quantities of sewage sludge disposed and the associated toxic and carcinogenic risks, sampling of sludge and sewage to determine the concentrations of hazardous substances, and recommendations for negotiations with Environmental Protection Agency (EPA).

Project manager providing technical oversight for RI/FS investigations at a rail yard contaminated by chlorinated solvents and diesel fuel. Activities include negotiation of an RI/FS workplan; development of the groundwater monitoring program; review of workplans for groundwater, soil, sludge, and air characterization activities, and treatability testing; and interpretation of monitoring data.

Peer reviewer to the UMTRAP contractor on the suitability of Cheny Reservoir site near Grand Junction, Colorado for construction of disposal cells for the Grand Junction tailings, and on geochemical attenuation mechanisms at Gunnison, Colorado.

Principal investigator on a dewatering project associated with the construction of a highway interchange near the Los Angeles International Airport. The project involved design and installation of wells for pumping tests, installation and slug testing of monitor wells, collection of water-quality data to determine the extent of BTEX contamination from nearby leaking USTs and computer modeling to predict the amount of water which will discharge into the drains throughout the life of the interchange.

Principal investigator of a groundwater characterization study at the Brown and Bryant pesticide site at Barstow, California. Project involves installation of monitor wells in the perched and regional aquifers, collections of core samples for laboratory characterization of physical properties, aquifer testing, and computer simulation of a pump-and-treat system to prevent off-site migration of contaminants.

Project geochemist for a study of the seepage from Basins F and H at the Savannah River Site, South Carolina. Project entailed review of monitoring data, geochemical-speciation modeling of groundwater chemistry using PHREEQE, and interpretation of chemical processes affecting the transport of metals in the groundwater.

Project manager providing technical oversight support to the Yakima Indian Nation regarding BWIP at the Hanford Reservation. The project entailed review of DOE work plans and reports, field oversight of hydrologic testing programs, and independent interpretation of chemical and permeability information for the deep basalts.

Principal investigator for a review of a surface-water monitoring program at a large coal mine in the western United States, and review of historical streamflow and precipitation data to determine whether sedimentation ponds have any measurable effect on streamflow.

Principal investigator for water-rights studies at two coal mines in Colorado. The studies involved evaluating the quantity of water expected to flow into surface pits and the impact on water rights in the vicinity, modeling of the effects of groundwater pumpage relative to stream depletion, and preparation of augmentation plans.

Project member reviewing hydrologic and geologic studies for the proposed high-level radioactive waste repository at Yucca Mountain, Nevada Test Site.

Principal investigator of a water resources investigation in Arizona. Responsibilities included the development of a regional groundwater model to assess impacts of well field withdrawals, and oversight of staff efforts in supporting mining and reclamation permits and economic evaluation of groundwater resources.

Principal investigator of a water resources investigation involving the development of a three-dimensional groundwater flow model to assess municipal well field impacts on shallow aquifers and lakes, and to evaluate mitigation alternatives.

Principal investigator and project leader for a multi-site investigation of hazardous waste contamination including radionuclides under CERCLA/SARA. Responsibilities include technical and financial direction of the project. This work involves detailed site assessment, data evaluation and interpretation, and performance assessment of remedial clean-up plans. Project management responsibilities also require coordination and supervision of other technical consultants and field support subcontractors.

Principal investigator and project leader of a geochemical and modeling study of contaminants at a uranium mill in Wyoming. Performed geochemical speciation modeling in order to determine controls in water chemistry. Modeled the drainage of the tailings, incorporating unsaturated properties of the materials. Predicted the long-term movement of contaminants, accounting for the declining rate of drainage, retardation due to sorption, and precipitation of gypsum.

Principal investigator for a predictive modeling study at an oil and organic solvent disposal site being remediated under RCRA/HSWA. Techniques were developed for incorporating geologic data for over 250 borings into a three-dimensional flow model of the site. Partitioning of organic solvents between oil and water phases were incorporated into a transport model which accounted for the inventories of contaminants in each of the liquid phases. Remedial alternatives were evaluated. The results were used in successful negotiations with EPA.

Professional Certification:

Registered Geologist, California, No. 4736

Health and Safety Training:

Hazardous Materials Safety Training Course (40-hour training as required by 29 CFR 1910.120 [e] [8])

Hazardous Materials Safety, Supervisor, and Refresher Training, (40-hour training in accordance with 29 CFR 1910.120 [e]2, e[8])

Health and Safety Operations at Hazardous Materials Sites 29 CFR 1910.120 [e] [8] - (8-hour Refresher Training)

Honors and Awards:

Chevron Oil Company Fellowship 1972-73
Outstanding Graduate Student, Houston Geological Society, 1972-73

Publications:

1. Mercer, J.W. and R.K. Waddell, 1993. Contaminant transport in groundwater, Chapter 16, in *Handbook of Hydrology*, D.R. Maidment (editor), McGraw-Hill, Inc., New York.

2. Schmierer, K., and R.K. Waddell, 1990. Determination of ultimate compliance at an NPL Pump and Treat site: Superfund 1990 conference, Washington, D.C., December, 1990.

3. Electric Power Research Institute, 1989. Techniques to develop data for geohydrochemical modeling, prepared by Radian Corporation, GeoTrans, Inc., and Battelle Pacific Northwest Laboratories, EPRI, Palo Alto, CA 94304.

4. Star, I., J.R. Erickson, and R.K. Waddell, 1989. Groundwater monitoring manual; prepared for and copyrighted by the Edison Electric Institute, Washington, D.C.

5. Dacey, C.A., J.R. Erickson, and R.K. Waddell, 1988. A coupled three-dimensional groundwater flow and lake-stage model of northern Palm Beach County, Florida, American Water Resources Association Symposium on Coastal Water Resources, Wilmington, NC.

6. Erickson, J.R., C.A. Dacey, and R.K. Waddell, 1987. A coupled three-dimensional groundwater flow and lake-stage model of northern Palm Beach County, Florida, AGU, San Francsico, CA.

7. Erickson, J.R., and R.K. Waddell, 1985. Identification and characterization of hydrologic properties of fractured tuff using hydraulic and tracer tests--test well SUWH-4, Yucca Mountain, Nye County, Nevada, US Geological Survey Water-Resources Investigations Report 85-4066, 30 p.

8. Erickson, J.R., and R.K. Waddell, 1985. Parameter-estimation techniques for the analysis of single-well tracer tests, AGU Baltimore, MD.

9. Czarnecki, J.B., and R.K. Waddell, 1984. Finite-element simulation of groundwater flow in the vicinity of Yucca Mountain, Nevada-California, U.S. Geological Survey Water-Resources Investigations Report 84-4349, 38 p.

10. Waddell, R.K., 1984. Evaluation of a Surficial Application of Limestone and Flue Dust in the Abatement of Acidic Drainage: Jonathan Run Drainage Basin at Interstate 80, Centre County, Pennsylvania, Ph.D. Thesis, The Pennsylvania State University, 301 p.

11. Waddell, R.K., 1984. Hydrologic and drill-hole data for test wells UE-29a#1 and UE-29a#2: Fortymile Canyon, Nevada Test Site, U.S. Geological Survey Open-File Report 84-142, 25 p.

12. Waddell, R.K., 1984. Solute-transport characteristics of fractured tuffs at Yucca Mountain, Nevada Test Site: A preliminary assessment, Geological Society of America, Abstracts with Programs, 16(6): 471.

13. Waddell, R.K., and J.R. Erickson, 1984. Transport experiments in fractured tuff at Yucca Mountain, Nevada Test Site, EOS, 65(16): 206.

14. Waddell, R.K., J.R. Erickson, and D.L. Galloway, 1984. Inferences about anisotropy of hydraulic conductivity based on fracture orientations, Yucca Mountain tracer site, Nevada Test Site, presented at 29th Annual Midwest Groundwater Conference, Lawrence, KS (October 1-3).

15. Waddell, R.K., J.M. Robison, and R.K. Blankennagle, 1984. Hydrology of Yucca Mountain and vicinity, Nevada-California: Investigative results through mid-1983, U.S. Geological Survey Water-Resources Investigations Report 84-4267, 72 p.

16. Waddell, R.K., 1982. Two-dimensional, steady-state model of groundwater flow: Nevada Test Site and vicinity, Nevada-California: US Geological Survey Water Resources Investigations Report 82-4085, 72 p.

17. Waddell, R.K., 1981. Modeling of regional groundwater flow near potential nuclear-waste repository: Nevada Test Site and vicinity, Geological Society of America, Abstracts with Programs, 13(7): 574.

18. Dixon, G.L., W.E. Wilson, W.J. Carr, F.E. Rush, and R.K. Waddell, 1981. Status of geologic investigations for Nuclear Waste Disposal at the Nevada Test Site, *Proceedings 1981 National Waste Terminal Storage Program Information Meeting*, of the DOE/NWTS-15, 26-27 pp.

19. Bassett, R.L., S.G. Perkins, and R.K. Waddell, 1980. Preliminary data describing the distribution of fluoride and silica in the Ogallala Aquifer on the High Plains of Texas, U.S. Geological Survey Open-File Report 80-349, 109 p.

20. Iman, R.L., H.P. Stephens, J.M. Davenport, R.K. Waddell, and D.I. Leap, 1980. Sensitivity study on the parameters of the regional hydrology model for the Nevada Nuclear Waste Storage Investigations, *Proceedings of the 1979 Department of Energy Statistical Symposium, Gatlinburg, Tennessee*, CONF-791016, 44-61 pp.

21. Waddell, R.K., R.R. Parizek, and D.R. Buss, 1980. The application of limestone and lime dust in the abatement of acidic drainage in Centre County, Pennsylvania, Commonwealth of Pennsylvania, Department of Transportation, Research Project 73-9, 235 p.

22. Waddell, R.K., 1977. Environmental geology of the Helotes, Texas quadrangle, with emphasis on the recharge to the Edwards Aquifer, unpublished Master's Thesis, University of Texas at Austin, 150 p.

23. Turk, L.J., E.G. Fruh, R.L. Landers. and R.K. Waddell, 1972. Water quality and geological studies, summary report to San Antonio Ranch Water Quality Review Board, Open-File Report, San Antonio Ranch, Ltd., 112 p. plus appendices.

JAMES W. MERCER, Ph.D.

President, GeoTrans, Inc.
Principal Hydrogeologist

Professional Expertise:

Numerical simulation
Groundwater hydrology
Groundwater pollution and aquifer water quality
Solute & heat transport
Multiphase flow in porous media
Hazardous waste disposal
Radioactive waste disposal
Remedial actions
Seawater intrusion
Geothermal reservoir analysis

Education:

Ph.D., Geology, University of Illinois, 1973
M.S., Geology, University of Illinois, 1971
B.S., Geology, Florida State University, 1969
A.S., Gulf Coast Jr. College, Panama City, Florida, 1967

Professional Experience:

October 1979 - Present
President and Principal Hydrogeologist, GeoTrans, Inc., Sterling, Virginia.
Specializes in all phases of geohydrologic transport analysis including groundwater flow, heat and solute transport in porous media for a wide range of applications such as aquifer resource analysis, aquifer thermal storage, geothermal energy development, radioactive waste storage, seawater intrusion, and hazardous waste problems. Experience in the following U.S. Environmental Protection Agency programs: RCRA, CERCLA/SARA, UST, and UIC. Involved in the conduct of both Remedial Investigation/Feasibility Study (RI/FS) and RCRA Facility Investigation/ Corrective measures Study (RFI/CMS). Management responsibilities include supervision of approximately 50 professionals and serving as principal investigator on several contracts. Daily project work involves overseeing data collection, data management, and analysis. Projects involve a variety of chemicals including organics, metals, and radionuclides. Processes considered include advection, hydrodynamic dispersion, diffusion, biodegradation, multiphase flow, dissolution, and volatilization in fractured and porous media. Various tasks include modeling, training, and expert witness testimony.

June 1971 - October 1979
Hydrologist, U.S. Geological Survey, Water Resources Division, Reston, Virginia.
Planning and conducting research in groundwater hydrology to predict the effects of specified stresses on groundwater systems using finite difference and finite element techniques to develop and test numerical models for describing and predicting mass and energy transport in multiphase, multi-dimensional groundwater systems. Problems examined include transport related to high- and low-level radioactive waste storage, geothermal reservoir analysis, seawater intrusion in coastal aquifers, and multifluid flow in reservoirs.

Teaching and Lecturing Experience:

Participated in American Petroleum Institute's Workshop on Comparative Evaluation of Groundwater Biodegradation Models, Fort Worth, Texas, May 8-9, 1995.

Participated in Stevens Institute of Technology's Seminar on Remediation of NAPL Contaminated Sites, Hoboken, New Jersey (March 14-15, 1994) and Boston, Massachusetts (April 5-6, 1994).

Participated in U.S. Environmental Protection Agency Seminar on Characterizing and Remediating Dense Nonaqueous Phase Liquids at Hazardous Sites, taught at all ten Environmental Protection Agency regional offices, Spring - Summer, 1993.

Taught short course on "Practical Contaminant Modeling" as part of the 1993 Spring meeting of the American Institute of Hydrology on May 16, 1993 in Washington, D.C.

Participated in workshop to Identify Barriers to In Situ Ground-Water Remediation sponsored by the U.S. Environmental Protection Agency; served as group spokesperson (June 24-25, 1992).

Participated in Subsurface Restoration Conference sponsored by the U.S. Environmental Protection Agency, presenting a talk entitled, "Site Characterization: Use of Site Characterization Data to Select Applicable Remediation Technologies" (June 21-24, 1992).

Participated in workshop entitled, "Introduction to Ground Water Modeling" at the National Water Well Association meeting in Washington, D.C. (October 21-23, 1991).

Participated in workshop entitled, "Dense Nonaqueous Phase Liquids," sponsored by the U.S. Environmental Protection Agency, presenting a talk on "Monitoring and Modeling DNAPLs" (April 16-18, 1991).

Participated in symposium on Radioactive Waste Repository Licensing, sponsored by the Broad on Radioactive Waste Management of the National Research Council, September 1990.

Taught "Modeling of Ground-Water Flow" as part of the 1990 Spring meeting of the American Institute of Hydrology on March 14, 1990 in Las Vegas, Nevada.

Participated in U.S. Environmental Protection Agency Seminar on Site Characterization for Subsurface Remediation, taught at all ten EPA regional offices, Fall 1989 - Spring 1990.

Participated in RSKERL-Ada Technical Assistance Program: Oily Waste-Fate, Transport, Site Characterization, Remediation, Denver, Colorado, May 17-18, 1989.

Taught short course (3-1/2 days) on Hydrogeology and Groundwater Pollution at the U.S. Department of Energy, Grand Junction, Colorado compound, November 28 - December 2, 1988.

Participated in short course on Risk Assessment and Management for Hazardous Materials: From Cradle to Grave at The Center for Risk Management of Engineering Systems of the University of Virginia, October 25-26, 1988.

Taught seminar in advanced hydrology (including well testing and modeling) at the George Washington University, Spring Semester 1979; Spring Semester 1983; Spring Semester 1985; Spring Semester 1987; as an Associate Professorial Lecturer in Geology.

Participated in the U.S. Geological Survey training courses in groundwater modeling, advanced groundwater hydrology, and salt water-fresh water relationships.

Participated in a short course held at the University of Southern California on recent advances in reservoir simulation, July 5 - 9, 1977.

Taught groundwater modeling short courses at the Holcomb Research Institute, Butler University, Indianapolis, Indiana, April and June 1980; May and June 1981; August 1982 (with Dr. Jacob Bear); March 1983; March 1984; March 1985; March 1986; March 1987; March 1988; March 1989, April 1989.

Included in the U.S. Geological Survey Centennial (1979) lecture series made available to Sigma Xi chapters.

Taught introduction to groundwater modeling short course at EPA Headquarters, Washington, D.C., March 1980, and EPA Region IV, Atlanta, Georgia, November 1981; taught groundwater modeling short course using personal computers at EPA Region IV, Atlanta, Georgia, February 1985. Taught a groundwater modeling short course at Georgia Southwestern College, Americus, Georgia, July 1982.

Taught a groundwater modeling short courses to St. Johns River Water Management District, Palatka, Florida, October 1982 and October 1983; and to South Florida Water Management District, October 1983 and February 1986; and to Southwest Florida Water Management District, October 1984 and July 1986.

Included in the University of South Florida's seminar on pesticides in groundwater, May 1984.

Professional Certification:

Certified Professional Geologist,
State of Delaware, No. 309, State of Indiana, No. 341, State of Virginia, No. 273,
State of South Carolina, No. 562, State of Florida, No. 275
American Institute of Professional Geologists, Number 6020
American Institute of Hydrology - Professional Hydrogeologist, No. 886

Professional Affiliations:

Society of Petroleum Engineers, Member
American Geophysical Union, Member
Geological Society of America, Fellow
National Ground Water Association, Member
American Society of Civil Engineers, Member
International Association of Hydrogeologists, Member
American Institute of Hydrology

Honor Societies and Awards:

Phi Beta Kappa
Pi Mu Epsilon
Sigma Xi
Summa Cum Laude
Chevron Senior Scholarship
NDEA Title IV Fellowship
Who's Who in Frontier Science and Technology
ASCE 1985 Wesley W. Horner Award
NWWA 1987 Distinguished Seminar Series
26th Henry W. Shaw Lecture in Civil Engineering (North Carolina State University)
1994 AIH C.V. Theis Award

Committees:

Member, U.S. Air Force DNAPL Expert Panel, Wakulla Springs, FL, Aug 2-3, 1995.

Session Leader, International Containment Technology Workshop, Baltimore, MD, August 29-31, 1995.

Member, National Sciences Foundation's Advisory Committee for Earth Sciences, 1992 - 1993.

Member, National Science Advisory Committee, Desert Research Institute, University and Community College System of Nevada, 1992.

Member, Water Science and Technology Board Study Group providing *A Review of Ground Water Modeling Needs for the U.S. Army*, 1992.

Core Consultant, U.S. Environmental Protection Agency Science Advisory Board (SAB) Environmental Engineering Committee (EEC), 1992-1993; Member, 1993 - 1995.

Cochairman, Water Science and Technology Board Committee on Ground Water Cleanup Alternatives, 1991-1993.

Member, Desert Research Institute - University of Nevada Science Advisory Working Group (SAWG), 1991.

Member of the U.S. Environmental Protection Agency Workshop on Dense Non-aqueous Phase Liquids, April-Sept., 1991.

International Association of Hydrogeologists, Vice President for Institute Development, 1990 - 1993.

Member of the U.S. Environmental Protection Agency Solid Waste Management Units (SWMUs) Stabilization Workgroup, September, 1990.

Member of the U.S. Department of Energy Peer Review Team for Unsaturated Zone Hydrology (at Yucca Mountain, Nevada), April - September, 1990.

Member of a mission to the Donana National Park, Spain, Sponsored by the International Union for Conservation of Nature and Natural Resources (IUCN) and ADENA, the Spanish affiliate of the Worldwide Fund for Nature (WWF), November, 1988.

Member of the site visit committee of the Natural Sciences and Engineering Council of Canada. Site visit was to the University of Waterloo to review proposal on "Field behavior of dense solvents in groundwater," July 27, 1988. Continued on committee until 1991.

Member of Water Science and Technology Board Committee on Ground Water Modeling Assessment, 1987-1989.

Member of the Water Pollution Control Federation's Groundwater Committee, 1987-1989.

Member of the Laboratory Director's Annual Review Committee, Earth Sciences Division, Lawrence Berkeley Laboratory, University of California, 1987.

National Research Council's Water Science and Technology Board, 1986 - 1989.

Secretary of the Hydrology Section of the American Geophysical Union, 1986 - 1988.

Co-convener of the American Geophysical Union Chapman Conference on Microbial Process in the Transport, Fate and In-situ Treatment of Subsurface Contaminants, Snowbird, Utah, October 1986.

Member of the U.S. Department of Energy Radionuclide Migration (RNM) Project Peer Review Committee, 1986.

Member of the U.S. Environmental Protection Agency Ground-Water Modeling Study Group, February 1986 - May 1986.

Co-convener of the American Geophysical Union Symposium on Saturated/Unsaturated Ground-Water Flow Systems: Measurement and Estimation of Parameters. Baltimore, Maryland, May 1985.

Member of the Ground-Water Research Subcommittee of the Science Advisory Board of the U.S. Environmental Protection Agency, December 1984 - June 1985.

Co-convener of the American Geophysical Union Symposium on Miscible and Immiscible Transport in Ground Water, Cincinnati, Ohio, May 1984.

National Research Council Panel on Groundwater Contamination (1983).

Advisory panel for the Office of Technology Assessment (Congress of the United States) on national groundwater contamination (1983).

International technical advisory committee of the International Ground Water Modeling Center (1983 - 1985).

Co-convener of the American Geophysical Union Symposium on the Role of the Unsaturated Zone in Radioactive and Hazardous Waste Disposal, Philadelphia, Pennsylvania, May 1982.

Co-convener of the Gordon Conference on Fluids in Permeable Media: Mathematics of Modeling and Simulating, Andover, New Hampshire, July 1980.

Co-convener of the American Geophysical Union Symposium on the Unsaturated Zone as a Barrier in Waste Disposal, Washington, D.C., May 1979.

Co-convener of the Geological Society of America Penrose Conference on Heat Transport Processes in the Earth, Vail, Colorado, November 1978.

Member of the Editorial Board for Journal of Contaminant Hydrology (1985 - 1992).

Member of the Editorial Board for Ground Water (1980 - 1984; 1992 - 1995).

Member of the Editorial Board for Geology (1979 - 1982).

Member of the 1982 - 1985 American Geophysical Union Ground Water Committee.

Member of the 1978 - 1983 American Geophysical Union Committee on Water in the Unsaturated Zone.

Member of the 1977 - 1978 ERDA Geothermal Exploration, Modeling and Reservoir Assessment Committee.

Publications:

Publications in Water Supply:

1. Andersen, P.F., R.M. Cohen, and J.W. Mercer, 1984. Numerical modeling as a conceptual tool to assess drawdown in a multiaquifer system, symposium on Practical Applications of Ground Water Models, sponsored by National Water Well Association, Columbus, Ohio.

Publications in Vadose Zone Evaluation:

1. Huyakorn, P.S., J.W. Mercer, and D.S. Ward, 1985. Finite-element matrix and mass balance computational schemes for transport in variably-saturated porous media, *Water Resources Research*, 21(3):346-358.

2. Mercer, J.W., P.S.C. Rao, and I.W. Marine, (Eds.), 1. Role of the unsaturated zone in radioactive and hazardous waste disposal: Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 339 pp.

3. Mercer, J.W., and C.R. Faust, 1976. The application of finite-element techniques to immiscible flow in porous media, presented at the International Conference on Finite Elements in Water Resources, Princeton University.

Publications in Wetland Hydrology

1. Hollis, T., P. Heurteaux, and J.W. Mercer, 1989. The implication of groundwater extractions for the long term future of the Donana National Park, report of the WWF/IUCN/ADENA Mission to the Donana National Park, May, 60 pp.

Publications in General Groundwater:

1. Moore, J.E., A. Zaporozec, and J.W. Mercer, 1995. *Groundwater, A Primer*, American Geological Institute, Alexandria, VA, 53p.

2. Mercer, J.W., R.R. Rabold, and W.R. Waldrop, 1991. Practical technology resulting from MADE research, *Proceedings of the International Symposium on Ground Water*, American Society of Civil Engineering (July 29 - August 2), Nashville, TN, pp. 113-119.

3. Faust, C.R., and J.W. Mercer, 1984. Evaluation of the skin effect in slug tests, *Water Resources Research*, 20(2):504-506.

Publications in General Modeling:

1. Mercer, J.W., 1991. Common mistakes in model applications, *Proceedings of the International Symposium on Ground Water*, American Society of Civil Engineering (July 29 - August 2), Nashville, TN, pp. 1-6.

2. Mercer, J.W., 1988. Standards of performance for investigative methods used in assessing groundwater pollution problems with emphases on the use and abuse on numerical models, *Proceedings of the Workshop on Groundwater Quality Protection*, Water Pollution Control Federation Annual Conference Workshop, Dallas, Texas.

3. Konikow, L.F., and J.W. Mercer, 1988. Groundwater flow and transport modeling, *Journal of Hydrology*, 100:379-409.

4. van der Heijde, P.K.M., P.S. Huyakorn, and J.W. Mercer, 1985. Testing and validation of groundwater models, Symposium on Practical Applications of Ground Water Models, pp. 14-31.

5. Mercer, J.W., and C.R. Faust, 1981. *Ground-Water Modeling*, National Water Well Association, Columbus, Ohio, 60 pp.

6. Faust, C.R., and J.W. Mercer, 1980. Ground-water modeling: Recent developments: *Ground Water*, 18(6).

7. Mercer, J.W., and C.R. Faust, 1980. Ground-water modeling: Applications: *Ground Water*, 18(5).

8. Faust, C.R., and J.W. Mercer, 1980. Ground-water modeling: Numerical models: *Ground Water*, 18(4).

9. Mercer, J.W., and C.R. Faust, 1980. Ground-water modeling: Mathematical models, *Ground Water*, 18(3):212-227.

10. Mercer, J.W., and C.R. Faust. 1980. Ground-water modeling: An overview, *Ground Water*, 18(2):108-115.

11. Wells, R.B., C.R. Faust, and J.W. Mercer, 1976. A Cross-Section Plotting Program (CSPP) for Gridded (MAP) Data, U.S. Geological Survey, *Open-File Report 76-689.*

12. Faust, C.R., and J.W. Mercer, 1976. An analysis of finite-difference and finite-element techniques for geothermal reservoir simulation, *Proceedings of Fourth Society of Petroleum Engineers Symposium on Numerical Simulation of Reservoir Performance*, Los Angeles, California, February 19-20.

Publications in Geochemistry:

1. Li, T.M.C., J.W. Mercer, C.R. Faust, and R.J. Greenfield, 1978. Simulation of geothermal reservoirs including changes in porosity and permeability due to silica-water reactions, presented at the Fourth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California.

Publications in Optimization Techniques:

1. Maddock, T., III, J.W. Mercer, and C.R. Faust, 1982. Management model for power production from a geothermal field: 1. Hot water reservoir and power plant model, *Water Resources Research*, 18(3):499-512.

2. Maddock, T. III, J.W. Mercer, C.R. Faust, and E.D. Attanasi, 1979. Management model for electrical power production from a hot-water geothermal reservoir, Reports on Natural Resources Systems, No. 34, University of Arizona, Tucson, Arizona, 114 pp.

Publications in Sea Water Intrusion:

1. Andersen, P.F., H.O. White, Jr., and J.W. Mercer, 1988. Numerical modeling of saltwater intrusion at Hallandale, Florida, *Ground Water*, 26(5):619-630.

2. Huyakorn, P.S., P.F. Andersen, J.W. Mercer, and H.O. White, Jr., 1987. Saltwater intrusion in aquifers: Development and testing of a three-dimensional, finite-element model, *Water Resources Research*, 23(2):293-312.

3. Andersen, P.F., H.O. White, J.W. Mercer, A.D. Truschel and P.S. Huyakorn, 1986. Numerical modeling of ground water flow and saltwater transport in Northern Pinellas County, Florida, *Proceedings of FOCUS Conference on Southeastern Ground Water Issues*, National Water Well Association, Dublin, Ohio, pp. 419-449.

4. Mercer, J.W., B.H. Lester, S.D. Thomas, and R.L. Bartel, 1986. Simulation of saltwater intrusion in Volusia County, Florida, *Water Resources Bulletin*, 22(6):951-965.

5. Huyakorn, P.S., J.W. Mercer, and P.F. Andersen, 1986. Seawater intrusion in coastal aquifers: Theory, finite-element solution, and verification tests, VI International Conference on Finite-Elements in Water Resources, Lisbon, Portugal.

6. Faust, C.R., and J.W. Mercer, 1982. Preliminary analysis of ground-water development and brackish water upconing at Virginia Beach, Virginia, Special Publications: Number 1, Georgia Southwestern College - *Studies of the Hydrogeology of the Southeastern United States:* 1981, B.F. Beck (ed.), pp. 30-37, pp. 797-818.

7. Mercer, J.W., S.P. Larson, and C.R. Faust, 1980. Simulation of salt-water interface motion, *Ground Water*, 18(4):374-385.

8. Mercer, J.W., S.P. Larson, and C.R. Faust, 1980. Finite-difference model to simulate the areal flow of salt water and fresh water separated by an interface, U.S. Geological Survey, *Open-File Report 80-407*, 88 pp.

Publications in Groundwater Contamination and Hazardous Waste Disposal:

1. Cohen, R.M., J.W. Mercer, and R.M. Greenwald, 1995. Design guidelines for conventional pump-and-treat systems, U.S. Environmental Protection Agency Ground Water Issue, Ada, OK.

2. Jordan, D.L., J.W. Mercer, and R.M. Cohen, 1995. Review of mathematical modeling for evaluating soil vapor extraction systems, U.S. Environmental Protection Agency Report EPA/540/R-95/513, Cincinnati, OH.

3. Jordan, D.L., J.W. Mercer, and R.M. Cohen, 1995. Review of mathematical modeling for evaluation of SVE applications, presented at EPA's 21st Annual RREL Research Symposium, April 4-6, Cincinnati, OH.

4. Cohen, R.M., A.H. Vincent, J.W. Mercer, C.R. Faust, and C.P. Spalding, 1994. Methods for monitoring pump-and-treat performance, U.S. Environmental Protection Agency publication EPA/600/R-94/123, Ada, Oklahoma.

5. Mercer, J.W. and R.M. Cohen, 1994. The limitations of pump-and-treat systems in ground-water remediation, *Pollution Prevention in South Carolina,* 11(1): 18-21.

6. Cohen, R.M., J.W. Mercer, and I. Star, 1993. Delineating subsurface DNAPL using direct and indirect methods, Air & Waste Management Association Annual Meeting, Denver, Colorado, June 14-19, 1993.

7. Cohen, R.M., and J.W. Mercer, 1993. *DNAPL Site Evaluation*, C.K. Smoley, Boca Raton, Florida.

8. Mercer, J.W. and R.K. Waddell, 1993. Contaminant transport in groundwater (Chapter 16) in *Handbook of Hydrology*, D.R. Maidment (Ed.), McGraw-Hill, New York.

9. U.S. Environmental Protection Agency, 1992. Dense Nonaqueous Phase Liquids -- A Workshop Summary, Dallas, Texas, April 16-18, 1992, EPA/600/R-92/030 (Contributing author).

10. Mercer, J.W., R.M. Parker, and C.P. Spalding, 1992. Use of site characterization data to select applicable remediation technologies, Presented at Subsurface Restoration Conference, Dallas, TX, June 21-24.

11. Mercer, J.W. and R.M. Cohen, 1992. Site characterization for DNAPL control/restoration, *Proceedings of the Water Environment Federation Pre-Conference Seminar on Detection and Restoration of DNAPLs in Groundwater at Hazardous Waste Sites*, New Orleans, LA, September 20.

12. Ward, D.S., J.W. Mercer, and L.L. August, 1992. Analysis of groundwater flow and injection fluid transport in the Floridan Aquifer near Pensacola, Florida, *Ground Water*, 30(3): 403-414.

13. Mercer, J.W., and C.P. Spalding, 1991. Chapter 2 Site Characterization Overview; Chapter 3 Geologic Aspects of Site Remediation; Chapter 4 Characterization of Water Movement in the Saturated Zone; Chapter 5 Characterization of the Vadose Zone; and Chapter 6 Characterization of Water Movement in Saturated Fractured Media, in Site Characterization for Subsurface Remediation, U.S. EPA Seminar Publication EPA/625/4-91/026, Cincinnati, Ohio, 259 p.

14. Mercer, J.W., and D.C. Skipp, 1990. Considerations in the design of pump-and-treat remediation systems, *Superfund '90: Proceedings of the 11th National Conference*, HMCRI, 720-725.

15. Mercer, J.W., and R.M. Cohen, 1990. A review of immiscible fluids in the subsurface: Properties, models, characterization and remediation, *Journal of Contaminant Hydrology*, 6(2):107-163.

16. Mercer, J.W., D.C. Skipp, and D. Giffin, 1990. Basics of pump-and-treat groundwater remediation, U.S. Environmental Protection Agency EPA/600/8-90/003, Ada, Oklahoma, 31 p.

17. Mercer, J.W., 1990. Don't gamble on a real estate purchase: An environmental assessment can separate winners from losers, American Society of Appraisers, *Valuation*, 35(1):116-121.

18. Faust, C.R., J.H. Guswa, and J.W. Mercer, 1989. Simulation of three-dimensional flow of immiscible fluids within and below the unsaturated zone, *Water Resources Research*, 25(12):2449-2464.

19. Mercer, J.W., D.A. Giffin, Jr., J.C. Herweijer, and P. Srinivasan, 1989. Groundwater contamination: Processes, characterization, analysis, and remediation, International Workshop on Appropriate Methodologies or Development and Management of Groundwater Resources in Developing Countries, Hyderabad, India, Feb 28 - Mar 4, 1989.

20. Bouwer, E., J. Mercer, M. Kavanaugh, and F. DiGiano, 1988. Coping with groundwater contamination, *Journal Water Pollution Control Federation*, 6(8):1414-1428.

21. Srinivasan, P., and J.W. Mercer, 1988. Simulation of biodegradation and sorption processes in groundwater, *Ground Water*, 26(4):475-487.

22. Faust, C.R., R.R. Rabold, and J.W. Mercer, 1988. Modeling remedial actions at S-Area, Niagara Falls, NY, *Proceedings of the Seminar on Impact of Hazardous Waste Facilities on Water Utilities*, American Water Works Association Annual Conference, Orlando, Florida.

23. Mercer, J.W., C.R. Faust, A.D. Truschel, and R.M. Cohen, 1987. Control of Groundwater Contamination: Case Studies, *Proceedings of Detection, Control, and Renovation of Contaminated Ground Water*, American Society of Civil Engineers, Environmental Engineering Division, pp. 121-133.

24. Duffield, G.M., D.R. Buss, D.E. Stephenson, and J.W. Mercer, 1987. A grid refinement approach to flow and transport modeling of a proposed groundwater corrective action at the Savannah River Plant, Aiken, South Carolina, *Proceedings of the Conference on Solving Ground Water Problems with Models*, National Water Well Association, Dublin, Ohio, pp. 1087-1120.

25. Ward, D.S., D.R. Buss, J.W. Mercer, and S.S. Hughes, 1987. Evaluation of a groundwater corrective action of the Chem-Dyne Hazardous Waste site using a telescopic mesh refinement modeling approach, *Water Resources Research*, 23(4):603-617.

26. Ward, D.S., T.D. Wadsworth, D.R. Buss, and J.W. Mercer, 1986. Analysis of potential failure mechanisms pertaining to hazardous waste injection in the Texas Gulf Coast Region, *Journal of the Underground Injection Practices Council*, 1:120-152.

27. Buss, D.R., B.H. Lester, and J.W. Mercer, 1986. A numerical simulation study of deep-well injection, *Current Practices in Environmental Science and Engineering*, 2:93-117.

28. Mercer, J.W., C.R. Faust, R.M. Cohen, P.F. Andersen, and P.S. Huyakorn, 1985. Remedial action assessment for hazardous waste sites via numerical simulation, *Water Management and Research*, 3:377-387.

29. Mercer, J.W., C.R. Faust, R.M. Cohen, P.F. Andersen, and P.S. Huyakorn, 1984. Remedial Action Assessment for Hazardous Waste Sites Via Numerical Simulation, Seventh Annual Madison Waste Conference on Municipal & Industrial Waste, University of Wisconsin, Madison, Wisconsin.

30. Mercer, J.W., C.R. Faust, and L.R. Silka, 1984. Groundwater flow modeling study of the Love Canal area, New York, *Groundwater Contamination*, Bredehoeft, J.D. and T.M. Uesselman (Editors), National Research Council, Studies in Geophysics, pp. 109-119.

31. Cohen, R.M. and J.W. Mercer, 1984. Evaluation of a proposed synthetic cap and concrete cut-off wall at Love Canal using a cross-sectional model, Fourth National Symposium and Exposition on Aquifer Restoration and Ground-Water Monitoring, Columbus, Ohio.

32. Andersen, P.F., C.R. Faust, and J.W. Mercer, 1984. Analysis of conceptual designs for remedial measures at Lipari landfill, New Jersey, *Ground Water*, 22(2):176-190.

33. Mercer, J.W., L.R. Silka, and C.R. Faust, 1983. Modeling groundwater flow at Love Canal, New York, *ASCE Journal of Environmental Engineering*, 109(4):924-942.

34. Silka, L.R. and J.W. Mercer, 1983. Evaluation of remedial actions for ground-water contamination, presented at the 3rd National Conference and Exhibition on Management of Uncontrolled Hazardous Waste Sites, Washington, D.C.

35. Mercer, J.W., L.R. Silka, C.R. Faust, and A.G. Kretschek, 1981. Draft final report on EPA test problems for groundwater model evaluation, GeoTrans Report No. 072-00K-01, 92 pp.

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3. Mercer, J.W., and C.R. Faust, 1980. The physics of fluid flow and heat transport in geothermal systems, *Sourcebook on the Production of Electricity from Geothermal Energy*, Joseph Kestin (ed), U.S. Department of Energy DOE/RA/4051-1, pp. 121-135.

4. Mercer, J.W., and C.R. Faust, 1979. A review of numerical simulation of hydrothermal systems, *Hydrological Sciences Bulletin*, 24(3):335-343.

5. Mercer, J.W., and C.R. Faust, 1979. Geothermal reservoir simulation 3: Application of liquid- and vapor-dominated hydrothermal modeling techniques to Wairakei, New Zealand, *Water Resources Research*, 15(3):653-671.

6. Mercer, J.W., and C.R. Faust, 1979. Reservoir engineering and evaluation, presented at the Geothermal Resources Council Symposium on Geothermal Energy and Its Direct Uses in the Eastern United States, Roanoke, Virginia.

7. Faust, C.R., and J.W. Mercer, 1979. Geothermal reservoir simulation 2. Numerical solution techniques for liquid- and vapor-dominated hydrothermal systems, *Water Resources Research*, 15(1):31-46.

8. Faust, C.R., and J.W. Mercer, 1979. Geothermal reservoir simulation 1. Mathematical models for liquid- and vapor-dominated hydrothermal systems, *Water Resources Research*, 15(1):23-30.

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10. Faust, C.R., and J.W. Mercer, 1977. Version I, A finite-difference model of two-dimensional, single- and two-phase heat transport in a porous medium, U.S. Geological Survey, *Open-File Report 77-234.*

11. Faust, C.R., and J.W. Mercer, 1977. A theoretical analysis of fluid flow and energy transport in hydrothermal systems, U.S. Geological Survey, *Open-File Report 77-60.*

12. Mercer, J.W., and G.F. Pinder, 1975. A finite-element model of a two-dimensional, single-phase heat transport in a porous medium, U.S. Geological Survey, *Open-File Report 75-574,* 115 pp.

13. Mercer, J.W., and C.R. Faust, 1975. Simulation of water- and vapor-dominated hydrothermal reservoirs, presented at 50th Annual Fall Meeting of Society of Petroleum Engineers of AIME, Dallas, Texas.

14. Faust, C.R., and J.W. Mercer, 1975. Mathematical modeling of geothermal systems, presented at the Second United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, California.

15. Mercer, J.W., G.F. Pinder, and I.G. Donaldson, 1975. A Galerkin finite-element analysis of the hydrothermal system at Wairakei, New Zealand, *Journal of Geophysical Research*, 80(17):2608-2621.

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17. Mercer, J.W., and G.F. Pinder, 1974. Finite-element analysis of hydrothermal systems, Oden, J.T., et al. (ed), *Proceedings of International Symposium on Finite-Element Methods in Flow Problems*, Swansea, Wales, UAH Press, pp. 410-414.

18. Mercer, J.W., and G.F. Pinder, 1973. Galerkin finite-element simulation of a geothermal reservoir, *Geothermics*, 2(3 & 4):81-89.

19. Mercer, J.W., 1973. *Finite-element Approach to the Modeling* of Hydrothermal Systems, Ph.D. Thesis, University of Illinois, 106 pp.

RUH-MING LI

President
Simons, Li & Associates, Inc.

Professional Expertise:

Hydrologic and hydraulic modeling
Water resources planning
Habitat mitigation planning and design
Environmental permitting
Litigation support

Education:

Ph.D., Civil Engineering, Colorado State University, 1974
M.S., Civil Engineering, Colorado State University, 1972

Professional Experience:

Dr. Li has more than 27 years of experience in engineering consulting, design, and construction supervision and is recognized as a leader in the fields of hydrology, hydraulic, sediment transport, and mathematical modeling of watershed and river systems. In 1979, he received the Walter L. Huber Award for outstanding research in civil engineering from the American Society of Civil Engineers. As the President and Principal Engineer of Simons, Li & Associates, Inc. (SLA) since 1984, he has been responsible for technical supervision of all completed and ongoing projects. Dr. Li has conducted and/or managed over 500 projects. His principal fields of expertise are hydraulics, hydrology, erosion and sedimentation, mathematical modeling, river mechanics, water resource, system planning, water and sewer distribution system, environmental impact study, mitigation planning and design, hydraulic structures, water quality studies, storm drain design, and real estate development.

Prior to SLA, Dr. Li was an Associate Professor of Colorado State University (CSU) from 1974 to 1980. Dr. Li has conducted extensive research of rainfall-runoff and sediment-transport phenomena using both mathematical simulation approaches and physical model studies. He has prepared over 250 technical papers and reports in the fields of hydrology, hydraulic, water resource development, and sediment transport. The results of his research and developments in sediment-transport analysis are commonly used for characterization of watershed and river stability and design erosion and sedimentation control measures. Before joining CSU, Dr. Li was a civil engineer with Taiwan Power Company. His duties included design and construction supervision of circulating water systems for thermal power plants, pump houses, drainage systems, cable conduits, generator foundations, freshwater wells, water supply systems, booster stations, and reservoirs.

Relevant Project Experience:

Hydrology/Hydraulics/Sediment Transport
State of California
Santa Clara River and Major Tributaries, Los Angeles County; Amargosa Creek, Los Angeles County; Santa Clara River, Ventura County; Callegues Creek, Ventura County; San Diego Creek, Orange County; Trabuco/San Juan/Oso Creek, Orange County; Santa Ana River, San Bernardino/ Riverside/Orange counties, Santiago Creek, Orange County; San Antonio Creek, Santa Barbara County; San Jacinto River, Riverside County; Santa Margarita River, San Diego County; San Luis Rey River, San Diego County; Lytle Creek, San Bernardino County; Santa Gertrudes Creek, Riverside County; Temescal Wash, Riverside County; and Dry Creek/Russian River, Somona County; Dry Creek/Cirby/Linda Creeks, Placer County. All streams and watersheds draining to the California Coast from Mexico Boarder to Dana Point; Orange and San Diego Counties.

State of Arizona
Salt River, Maricopa County; Agua Fria River, Maricopa/Yavaipi counties; New River, Maricopa County; Gila River, Maricopa County; Skunk Creek, Maricopa County; Santa Cruz River, Pima County; Rillito River, Pima County; Tanque Verde Creek, Pima County; Pinal Creek, Pinal County; Colorado River, Mojave County; Arizona Diversion Canal, Maricopa County; and Pantano Wash, Pima County.

Other
Unnamed Wash, Nevada; Rio Grande River, New Mexico; Tennessee-Tombighee Waterway, Alabama; Red River, Louisiana; Pearl River, Mississippi; Yazoo River, Mississippi; Colorado River, Colorado; Bitterroot River, Montana; Niger River, West Africa; Ohio River, Indiana/Kentucky; Onichita River, Louisiana; Kansas River, Kansas; Columbia River, Washington; Mississippi River, Tennessee/Mississippi/Louisiana; Tansui River, Taiwan; Kelung River, Taiwan.

Major Flood Control Facilities
Santa Ana River All River Flood Control Project, San Bernardino/Riverside/Orange counties, California; San Diego Creek Flood and Sediment Control Plan, Orange County, California; Flood Control Facilities for Development of Irvine Bioscience Center, Irvine Center and West Park, Orange County, California; Keelung River All River Flood Control Plan, Taiwan; Tansui River Flood Control System, Taiwan.

Water Resources Planning
Low Water Weir for City of Topeka, Kansas; Stormwater Conservation for Groundwater Recharge, Los Angeles County, California; Flood Control Planning for Arizona Community, Arizona; Seven Oak Dam Water Supply Study, California; Watershed Management Study for City of Boulder, Colorado; Water Resources Planning for the City of Encampment, Wyoming; Water Resources Planning Guideline for Republic of China, Taiwan.

Environmental Permitting/Environmental Impact
Environmental Impact Report for Dawson Canyon, Sand and Gravel Mining Permit; 404/1603 Permit Application for Irvine Bioscience Center Project, Orange County, California; Environmental Impact Statement for Reudi Reservoir Water Supply Study, Colorado; Kern River Hydroelectric Project Relicensing, Kern County, California. Environmental Impact Report for Sand and Gravel Mining Permit, Ventura County, California; Technical Support to Office of Surface Mining for Reviewing Surface Mining Permit Applications; Environmental Impact Report for Development of 110-acre site in Hacienda Heights, Los Angeles County, California.

Habitat Mitigation Planning and Design
Santa Ana River 92-acre Salt Water Marsh Restoration, Orange County, California; Irvine Bioscience Center Habitat Mitigation Design, Orange County, California; Salt Water Marsh Mitigation for San Joaquin Corridor, Orange County, California; Ballona Lagoon Enhancement Plan, Los Angeles County, California.

Fate of Contaminant Transport/Water Quality Studies/Hazardous Waste Remedial Investigation and Feasibility Study
Remedial Investigation/Feasibility Study for Altas Coalinga, Asbestos Mine Sites, Coalinga, California; Non-Point Source Pollution Simulation Model for U.S. Environmental Protection Agency; Assessment of Toxaphene Mitigation and Risk in the Yazoo River Basin, Mississippi; Hazardous Material Identification for Installation Restoration Program at Buckley Air National Guard Base, Colorado; Tansui River Basin Pollution Clean-up Master Plan, Taiwan; Er-Jen Creek Pollution and Toxic Substance Clean-up Master Plan, Taiwan; Stormwater Pollution Prevention Plan for Silver Belt Heliport, Arizona.

Roadway Design/Site Drainage
Highway 18 Improvement, Apple Valley, California; Central Road Improvement, Apple Valley, California; Adams County Regional Airport, Adams County, Colorado; Valmont Road Improvement, Boulder County, Colorado; Country Club Road, Tucson; Storm Drains for Etiwanda Heights Development, Rancho Cucamonga, California; Fairview Creek Ranch and Resort, Fairview Valley, California; Apple Valley Estates, Apple Valley, California; Town Center, Apple Valley, California; Vista De Lomas, Hacienda Heights, California; Corona National Housing Tract, Corona, California; 19th Avenue Landfill Storm Drain, Phoenix, Arizona.

Real Estate Development
Fairview Creek Ranch & Resort, Fairview Valley, California; Apple Valley Town Center, Apple Valley, California; Vista De Lomas, Hacienda Heights, California; Walnut Hills II, San Marcos, California; Etiwanda Heights, Rancho Cucamonga, California, Apple Valley Estates, Apple Valley, California; Hsi Lai Temple, Hacienda Heights, California; Sunbow II, Chula Vista

Litigation Support (Expert Witness Services)
El Niguel Country Club Storm Drain Case, Orange County, California; Kelso Creek Flooding Case, Kern County, California; Roseville Flooding Case, California; Alviso Flooding Case, California; Redondo Beach Flooding and Subsidence Case, Los Angeles County, California; Reserved Water Right Issue, Colorado; Saltwater Marsh Wetland Case, Orange County, California; San Diego River Bridge Failure Case, Maricopa County, Arizona; City of Gilroy Uvas Creek Flooding Case, California; Ohio River, Indiana/Kentucky State Boundary Dispute, Indiana; United Nuclear Company, Church Rock Mine Case, New Mexico.

Professional Certification:

Registered Professional Engineer, California (#36777)
Registered Professional Engineer, Colorado (#23417)
Registered Professional Engineer, Nevada (#7111)

Professional Affiliations:

American Society of Civil Engineers
American Geophysical Union

RICHARD L. DeGRANDCHAMP, Ph.D.

Principal Toxicologist
Director of Toxicology and Risk Assessment
GeoTrans, Inc.

Professional Expertise:

Human Health Risk Assessments
Toxicological Expert Witness Testimony
Toxic Tort Litigation Support
Monte Carlo Simulation Analysis
Biochemical Toxicology
Statistical Analyses
Pharmacological Toxicology
Project Management
Neurotoxicology
Design and Interpretation of Toxicological and Pharmacological Studies
Computer Modeling of Biokinetic and Exposure Parameters

Education:

Ph.D., Toxicology, University of Michigan, 1986
National Institutes of Health Fellow in Physiology,
University of Colorado, School of Medicine, 1988-1991
Research Associate, Pharmacology
Cornell University, School of Medicine, 1987-1988
Postdoctoral Fellow, Toxicology
Rutgers University, School of Pharmacy, 1986-1988
B.S., Biochemistry, Eastern Michigan University, 1978

Professional Experience:

February 1996-Present
Principal Toxicologist, Director of Toxicology and Risk Assessment, GeoTrans, Inc., Boulder, Colorado
Currently provides expert witness testimony in several toxic tort and hazardous waste litigation cases. Dr. DeGrandchamp heads a task-force of expert scientists for the Department of Defense (DOD) (Navy) that is responsible for developing risk assessment methodology for all Navy bases being investigated in the state of California. Prepares Navy policy documents that will be used to evaluate background conditions at all Navy installations in California for in human health and ecological risk assessments.

February 1992-November 1995
Principal Toxicologist, Toxicology and Atmospheric Science Discipline Leader, PRC Environmental Management, Denver Colorado.
While managing a staff of toxicologists and atmospheric scientists, Dr DeGrandchamp either conducted or reviewed approximately 300 human health risk assessments under the Comprehensive Environmental Response Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA). In addition, Dr. DeGrandchamp provided oversight to EPA Region 8 for all chemical risk assessments and radionuclide dose assessments conducted at Rocky Flats Nuclear Weapons Plant and to DOE for all risk assessments at the Savannah River Site. Dr. DeGrandchamp conducted risk assessments and prepared position papers for DOD. Provided expert witness testimony for several toxic tort litigation cases.

May 1991-February 1992
Senior Toxicologist, PTI Inc., Bolder Colorado
Dr. DeGrandchamp conducted human health risk assessments and developed experimental paradigms to evaluate the bioavailability of heavy metals.

March 1988-May 1991
National Institutes of Health Fellow in Physiology, University of Colorado Medical School, Denver, Colorado.
Dr. DeGrandchamp held a non-tenure tract faculty position conducting toxicology/physiology research, trained medical students and Ph.D. candidates, and directed technical staff.

January 1987-1988
Research Associate, Cornell University School of Medicine, New York City, New York.
Dr. DeGrandchamp conducted neurotoxicological/pharmacological studies and trained Ph.D. candidates.

May 1986-March 1988
Postdoctoral Fellow, Rutgers University School Pharmacy and Toxicology, Piscataway, New Jersey.
Dr. DeGrandchamp conducted experiments involving nerve damage, regeneration, and heavy metals, trained Ph.D. candidates and managed laboratory staff.

1985-1986
Consultant to EPA Neurotoxicology Division, Research Triangle Park, North Carolina.
Dr. DeGrandchamp developed an animal model to study the effects of pesticides and nerve agents on the peripheral nervous system.

1980-1986
Research Assistant, University of Michigan School of Public Health, Ann Arbor, Michigan.
Dr. DeGrandchamp conducted Neurotoxicology studies and was a consultant for Monsanto, General Electric, and Stouffer Chemical company.

Relevant Project Experience:

Dr. DeGrandchamp is a principal toxicologist and director of toxicology and risk assessment which has more than 16 years professional experience in biomedical research and toxicological consulting. He has been a principal investigator and principal author of many scientific studies focusing on the toxic environmental pollutants, industrial chemicals, pesticides, radionuclides, and neurotoxic compounds. Dr. DeGrandchamp conducted extensive research in biochemistry, physiology, pharmacology, and toxicology at three leading medical schools where he also trained many medical and graduate students.

Dr. DeGrandchamp has applied his scientific expertise as a consultant for major chemical and pharmaceutical companies including Monsanto, General Electric, and Stouffer Chemical as well as EPA's neurotoxic division in Research Triangle Park, North Carolina. He has conducted many human health risk assessments for sites regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) sites. Dr. DeGrandchamp oversees all phases of remedial investigations and feasibility studies. Dr. DeGrandchamp is responsible for developing the comprehensive strategy for remedial investigations and coordinates the activities of many different technical disciplines.

He has represented potentially responsible parties (PRPs), EPA, DOE, DOD in over a hundred meetings and negotiations. In this role, he has participated in binding arbitration and dispute resolutions at many CERCLA and RCRA sites.

Dr. DeGrandchamp testifies as an expert witness in tort litigation cases and provides pre-trial legal support on issues involving toxicology, chemical fate and transport, risk assessment and risk management, and environmental laws and regulations.

Dr. DeGrandchamp is currently providing expert witness testimony in several toxic tort litigation cases for a potentially responsible party at a chrome-plating facility in Texas. His responsibilities include reviewing medical records, preparing pretrial reports, giving depositions, giving presentations to defense lawyers and plaintiffs, preparing trial exhibits, preparing guardian ad litem documents, and testifying at trials. At this site, Dr.

DeGrandchamp has already participated in cases involving over 100 plaintiffs who have reported myriad medical symptoms at this site.

Dr. DeGrandchamp is currently heading a task force consisting of nationally-recognized toxicologists and statisticians for DOD. The objective of the task-force is to develop a scientifically tenable statistical approach to evaluate background conditions at California Navy bases. He is responsible for preparing the document that will become the Navy's official policy paper.

Dr. DeGrandchamp served as the toxicological expert in a toxic tort case filed against a major pesticide manufacturer that involved potential exposure to a pyrethroid pesticide. Following careful review of exposure conditions and medical records, all charges were successfully challenged and the case dropped.

Dr. DeGrandchamp provided litigation support for a toxic tort case to a potentially responsible party in Montana involving potential exposure to petroleum products. His responsibilities included developing the overall scientific strategy and designing a sampling plan for the defense. The case was successfully settled out of court.

Dr. DeGrandchamp provided technical expertise on wide-ranging issues to EPA's RCRA/CERCLA program as part of a technical enforcement support (TES) contract. As part of the TES contract, he provided EPA Region 8 with toxicological and statistical support on the ongoing remedial investigation of Rocky Flats Nuclear Weapons Plant (RFP). He has been involved in all aspects of the investigation pertaining to the analysis of human health risks from both chemical and radionuclide contaminants. He provided scientific oversight on data quality objectives, computer modeling, hot spot analysis, risk assessment methodology, statistical analysis, sampling and analysis plans, and chemical and radiological fate and transport modeling. He compiled a data base for conducting Monte Carlo simulations. He also developed a risk assessment template for EPA Region 8 that was used at each individual operable unit at Rocky Flats. Dr. DeGrandchamp conducted independent studies for EPA to verify that DOE's results and conclusions were consistent with the International Commission on Radiation Protection (ICRP) and Nuclear Regulatory Commission (NRC) methodology. He has assisted EPA in settling numerous disputes between EPA and DOE and has recently been a participant in a workgroup of nationally recognized experts in binding arbitration involving statistical analyses. He also serves in a technical advisory capacity to the EPA to oversee the activities of several scientific panels specifically focussing on RFP-related health issues and community relations. Dr. DeGrandchamp has served as the technical expert in a risk communication symposium presented to the public as part of the community relations program. He has been selected as a member of an interagency committee that included the Colorado Department of Natural Resources, Colorado Department of Health, Colorado Fish and Wildlife Service, EPA, and DOE to scope, design, and implement a comprehensive site-wide human health and ecological risk assessment for Rocky Flats.
Dr. DeGrandchamp provided scientific support to DOE on toxicological and risk assessment issues at the Savannah River Site (SRS) in South Carolina. He was responsible for reviewing risk and dose assessments conducted for numerous SRS sites He also participated as part of a task force to develop a statistical background strategy for human health risk assessments and to derive cleanup levels. He has given risk assessment presentations to EPA Region 4, DOE, and the South Carolina Department of Health risk managers and toxicologists.

Dr. DeGrandchamp provided DOD with technical expertise and negotiation support in their Navy CLEAN program. He was a member of a program-wide technical panel that developed innovative remediation strategies to streamline the CERCLA process for all Navy bases scheduled for closure or transfer. He prepared position papers, developed the Navy's overall remediation strategy and negotiated with local, state, and federal regulation agencies.

Dr. DeGrandchamp conducted the baseline risk assessment at Naval Air Station (NAS) Lemoore in California. This was a comprehensive base-wide risk assessment that involved fate and transport modeling of contaminants coupled with the analysis of current and potential future health risks. On this project, he managed and organized the activities of engineers, hydrogeologists, and geochemists. He was responsible for all negotiations with federal and state regulators. All regulators concurred with the results and it was accepted in draft form with no necessary corrections. He is currently developing a strategy for remediation of NAS Lemoore based on the results of the baseline risk assessment.

Dr. DeGrandchamp conducted all risk assessments and coordinated feasibility studies for NAS Moffett Field in California. For this project, he carried out a future land use analysis that was used to focus risk mitigation strategies based on the probable future land use. The land use analysis was also used to develop human health risk-based concentrations for clean up. He negotiated all aspects of the risk assessment approach with state and federal regulatory agencies. The Navy requested Dr. DeGrandchamp's assistance in order to avert formal dispute resolution that was considered for several operable units.

Dr. DeGrandchamp conducted risk assessments for NAS Alameda in California. He was responsible for developing the overall risk assessment approach and negotiating all technical aspects of the project on behalf of the Navy with local, state, and federal regulators. He was also tasked with preparing position papers for the Navy on issues of background, preliminary remediation goals, and data aggregation using NAS Alameda as a pilot site.

Dr. DeGrandchamp provided oversight to DOD for risk assessments for NAS China Lake.

Dr. DeGrandchamp developed a comprehensive risk-based strategy to remediate Navy petroleum sites. He authored a policy paper for the Navy that was subsequently approved by local, state, and federal agencies and is currently being implemented at leaking underground storage facilities and spill sites.

Dr. DeGrandchamp provided technical expertise to the State of Massachusetts for radionuclide risk assessments, compliance, and cleanup standards. His expertise was used to develop state guidance for remediation of all Department of Defense and Nuclear Regulatory Commission sites within the state.

Dr. DeGrandchamp provided oversight and technical support to the EPA Region 8 (Montana office) RCRA division for remediation of oil refineries in Billings, Montana, Mandan, North Dakota, and Commerce City, Colorado. He oversaw all phases of the RCRA process involving preliminary investigations and corrective measures studies. His expertise was used to establish health-protective cleanup levels, facility permitting, and remediation enforcement. Together with Colorado Department of Health officials, he worked to negotiate remediation goals and a cost settlement.

Dr. DeGrandchamp provided EPA Region 8 with technical oversight for all remedial investigations and risk assessments for F.E. Warren Air Force Base in Wyoming, and Tooele Army Depot in Utah.

Dr. DeGrandchamp conducted an emergency response risk assessment for off-site residents at F.E. Warren AFB. This investigation focused on actual exposure to groundwater contaminated with chlorinated solvents and involved modeling exposures for all direct and indirect chemical contact.

Dr. DeGrandchamp lead the human health and environmental risk assessment for EPA Region 6 to evaluate the health effects associated with emissions from several incinerators in Midlothian, Texas. This investigation was prompted by strong public concern about adverse health effects on humans and livestock. In this evaluation, Dr. DeGrandchamp analyzed the potential for dioxin to produce birth defects, spontaneous abortions, and diverse effects on humans that have been reported.

Dr. DeGrandchamp provided legal support for the Montana Solvent Site. He also served as the technical advisor on community relations for this project. He was responsible for directing the development of fact sheets and all interactions with the U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry (ATSDR).

Dr. DeGrandchamp was the program manager for the U.S. Geological Survey (USGS) risk assessment contract. His responsibilities included managing the contract, overseeing and conducting risk assessments at CERCLA and RCRA for USGS throughout the United States.

Dr. DeGrandchamp investigated the human health risks associated with RCRA facilities in southern California. He conducted the risk assessment for the onsite human receptors as well as the surrounding community after developing an innovative approach to determine the potential risks to pregnant woman from benzene, arsenic, and cadmium in ground water more specifically, the risks assessed to pregnant women and their fetuses through *in utero* exposure via ingestion of home-grown produce. At another RCRA facility, he conducted a risk analysis to determine potential risks associated with arsenic from fly ash used as landfill material.

Dr. DeGrandchamp designed experimental paradigms to study the bioavailability of mineralogical forms of heavy metals, such as arsenic and cadmium from mining tailings for a CERCLA site in Montana. This physiological information was used to evaluate the applicability of EPA's standard default approach. Monte Carlo simulations were also incorporated into this analysis to model exposure parameters.

Dr. DeGrandchamp worked on a project for the National Institutes of Health to investigate the neurophysiological mechanisms of strychnine poisoning. In this capacity, he coordinated a team of experts and managed all technical personnel in a multifaceted research program to elucidate the steps that result in central nervous system damage.

Dr. DeGrandchamp, in collaboration with other toxicologists, investigated the neurotoxic mechanisms associated with exposure to mercury and acrylamide. This information was incorporated into the data base used by EPA and the Occupational Safety and Health Administration to set regulations and define safe exposure concentrations for workers.

Dr. DeGrandchamp, together with other experts, investigated the neurotoxic effects of alcohol on the developing nervous system which produces the fetal alcohol syndrome. He was responsible for developing new research methodologies and approaches to investigate subtle molecular changes in the brain. He was additionally responsible for training staff scientists, and medical and graduate students.

Dr. DeGrandchamp, in collaboration with other leading toxicologists, developed and modified the neurotoxic esterase *in vivo* enzyme assay, which has become a standard EPA methodology to screen neurotoxic compounds in the chemical industry. He also developed a correlative animal model for EPA to quantify chemical-induced neuropathies associated with exposure to pesticides and nerve agents.

Publications:

1. DeGrandchamp, R.L., and H.E. Lowndes. 1990. Early degeneration and sprouting at the rat neuromuscular junction following acrylamide administration. Neuropathol. Appl. Neurobiol. 16:239-254.

2. DeGrandchamp, R.L., K.R. Reuhl, and H.E. Lowndes. 1990. Synaptic terminal degeneration and remodeling at the rat neuromuscular junction resulting from a single exposure to acrylamide. Toxicol. and Appl. Pharmacol. 105:422-443.

3. DeGrandchamp, R.L., and R.J. Richardson. 1994. Degeneration of rat muscle spindles induced by organophosphorus compounds. (in preparation).

4. McNiven, A.I. R.L. DeGrandchamp, R.L., and A.R. Martin. 1990. Conductance properties of glycine-activated chloride channels depend on cytoplasmic chloride concentration. Abstract, Biophysical Society.

5. McNiven, A.I. R.L. DeGrandchamp, and A.R. Martin 1990. Effects of cytoplasmic chloride on glycine-activated chloride channels. Proc. of Rocky Mountain Regional Neuroscience Group, Fort Collins, Colorado.

6. DeGrandchamp, R.L., and H.E. Lowndes. 1988. Early degenerative and regenerative changes at the neuromuscular junction (NMJ) in acrylamide neuropathy. The Toxicologist 8:244.

7. Walewski, J.L., M. Okamoto, and R.L. DeGrandchamp. 1988. An *in vivo* model demonstrating the synaptotoxic effects of chronic perinatal ethanol exposure. Proc. of the Society of Physiology 1988. Society of Physiology, Washington, DC.

8. DeGrandchamp, R.L., S.F. Matheson, and H.E. Lowndes. 1987. Decreased *de novo* Ache synthesis following axotomy. The Toxicologist 7:53.

9. Halleck, M.M., B.G. Gold, R.L. DeGrandchamp, M. DeJesus, K.R. Reuhl, and H.E. Lowndes. 1987. Neuropathology of trimethyl lead in the rat. The Toxicologist 7:27.

10. DeGrandchamp, R.L. 1986. Organophosphorus-induced delayed neuropathy in the rat. Thesis. University of Michigan, Ann Arbor, Michigan.

11. DeGrandchamp, R.L., R. Gray, and R.J. Richardson. 1983. Assessment of neuronal damage in TOCP-dosed hens: a quantitative neurohistochemical approach using horseradish peroxidase. The Toxicologist 3:123.

12. Dudek. B.R., R.L. DeGrandchamp, and R.J. Richardson, R.1981. Neurotoxic esterase in developing chick embryo brain. The Toxicologist 1:15833

Project Descriptions

CERCLA Remedial Design and Remedial Action for Groundwater

Client:
Confidential

Start:
January 1990

Completion:
Ongoing

Project Value:
Confidential

Project Features:

- Groundwater Remedial Design and Remedial Action
- Characterization of fractured aquifer
- GIS
- Flow and transport model development
- Strategic and regulatory support

Background: In accordance with the Consent Decree, a potentially responsible party (PRP) group will finance, take the lead on technical efforts, and manage the remediation of the Whitmoyer Laboratories Superfund Site. Arsenic, aniline, and volatile organics are the principal contaminants of concern. GeoTrans provided technical analyses in support of negotiations among the U.S. EPA and the PRP group regarding the Consent Decree for site remediation. We developed the conceptual design for the phased approach to remediation of the groundwater. We also developed the field data collection program and utilized numerical models to design and implement the extraction/recharge system.

Scope of Work: GeoTrans was engaged to develop, design, and manage the remedial design for the groundwater Operable Unit (OU) #6. This consisted of:

- Geophysical logging of all existing wells to characterize the lithology, bedrock structure, and fracture orientation and density.
- Performance of fracture trace analysis to identify potential zones of enhanced aquifer hydraulic conductivity.
- Developing an information management system using a Geographic Information System (GIS).
- **Developing site-wide groundwater flow and transport models used to design the field program and extraction/recharge system.**
- Implementing the field data collection program that included installation of monitoring wells, collection of bedrock cores, aquifer testing, and groundwater sampling.
- Designing the groundwater extraction/recharge system.
- Installing and operating a package treatment system to treat water generated during investigation activities.

Outcome: GeoTrans developed remedial design strategies to implement the groundwater remediation program in phases. Phase I consists of using an initial small set of wells targeted toward hot-spot extraction and plume containment, whereas Phase II consists of supplemental wells, as needed. The phased approach will allow information gained during Phase I to be used to design an expanded Phase II system. This approach will also result in the identification of attainment versus nonattainment aquifer zones for application of groundwater cleanup goals, thus resulting in an optimized, more cost-effective, technically practical remedial design. The selection of treatment technologies for this system is being evaluated in conjunction with the operation of the 20 gpm treatment system. The pilot treatment system has effectively treated over 300,000 gallons of water to date.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

Groundwater Flow & Transport Modeling Conducted in Support of an Environmental Impact Report (EIR)

Northern Wisconsin

Client:
Foth and Van Dyke

Start:
November 1993

Completion:
Ongoing

Project Features

- Groundwater flow and transport
- Regulatory compliance
- Database development
- Geographic information system

Background: GeoTrans, Inc., was retained by Foth and Van Dyke, an engineering firm in Green Bay, Wisconsin, to develop groundwater models to predict the effects of mining an underground zinc deposit in Northern Wisconsin.

Scope of Work: The objectives of the project were to quantify impacts for both operational and regulatory concerns. Specifically, the modeling addressed:

- Quantification of water flow into the mine during a thirty year operational period.
- Effect on regional groundwater levels in the glacial overburden overlying the mined deposit.
- Effect on surface water levels (lakes, streams, wetland) of mining operations.

Solute transport modeling addressed:

- Compliance of the tailings management area with state regulatory groundwater quality standards.
- Compliance of the mined area, following reflooding of the mine, with state regulatory groundwater quality standards.

Outcome: An extensive database was developed and used in the analysis. In addition, the screening of the database suggested the necessity of collecting data to quantify the competence and continuity of lakebeds and the connection between the orebody and the glacial overburden. GeoTrans designed appropriate data collection programs, including an electromagnetic geophysical survey and a sixteen day pump test. GeoTrans analyzed the pump test with standard curve matching techniques and a localized model using inverse techniques. Following analysis of these tests, the data were incorporated into a complex regional flow model. The model, consisting of seven layers and a total of 160,000 nodes, was developed using Geographic Information System technology.

Following calibration with a steady-state time period and two transient events, the model was run in a predictive mode to obtain best engineering judgment and practical worst case results. A cross-sectional solute transport model was also developed and applied in a predictive mode. The results of both models were incorporated into an Environmental Impact Report.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

Bear Creek Uranium Mill Tailings Impoundment-Hydrogeologic and Geochemical Transport Analyses

Converse County, Wyoming

Client:
Union Pacific Resources

Start:
October 1994

Completion:
September 1995

Project Features:

- Numerical Modeling
- Groundwater and Geochemical Characterization
- ACL Application

Background: The Bear Creek Uranium mill processed ore in Converse County, Wyoming from 1977 until 1986. The milling process dissolved ores using sulfuric acid, a process that releases hazardous metals from the ore and produces a low pH fluid. Seepage from the tailings pond to the shallow aquifer led to the installation of a seepage recovery system, which was operated from 1986 to the present. Union Pacific Resources contracted GeoTrans to perform an analysis of the remediation and the potential for future migration of constituents. The analysis will be used to determine the effectiveness of the remediation and to support the development of an ACL amendment application for the facility, if appropriate.

Scope of Work: The objectives of the study are:

- Evaluate geochemical controls on the migration of license-specific constituents;
- Estimate the ultimate downgradient movement of the low pH plume and its rate of movement; and
- Predict the movement and concentrations of hazardous constituents at the Point of Compliance (POC) and Point of Exposure (POE).

Outcome: A combination of groundwater flow and geochemical modeling was successfully used to predict the long-term effectiveness of the seepage-recovery system and hazardous constituent transport. The primary constituents of concern for transport were radium, uranium and nickel. All other constituents were predicted to be irreversibly coprecipitated as a result of neutralization processes and thereby removed from future transport. The peak concentrations of radium, uranium and nickel were predicted to occur at the POC after a period of about 80, 100 and 260 years, respectively. Continued use of the seepage-recovery system for the next 3 to 5 years to remove low pH water from the tailings impoundment would reduce the peak concentrations at the POC by about 8 to 38 percent.

San Gabriel Valley PRP Steering Committee Allocation Support

Los Angeles County, California

Client:
Confidential

Start:
December 1994

Completion:
Ongoing

Project Value:
Confidential

Project Features:

- Numerical Modeling
- GIS Database Development
- Allocation Support
- Groundwater and Geochemical Characterization

Background: The San Gabriel Valley in Los Angeles County covers more than 170 square miles and consists of residential, commercial and industrial developments. In 1979 groundwaters contaminated with VOCs were discovered within the San Gabriel Basin. A more extensive investigation of the basin revealed that groundwater contamination was widely distributed across the entire basin. A total of seven RI areas within the basin have been delineated since 1979 with four of the areas included on the National Priorities List. GeoTrans was contracted to provide technical support to a PRP steering committee group for the development of allocation costs. The primary contaminants of concern in the area are chlorinated organic solvents, consisting of TCE, PCE, carbon tetrachloride, 1,1,1-TCA, 1,1-DCE, and 1,2-DCA.

Scope of Work: The objectives of the study are:

- Provide technical assistance to the steering committee for the development of PRP allocation costs;
- Develop a three-dimensional groundwater flow model of the basin, with particle tracking, to evaluate pre-design remedial alternatives and to analyze contaminant transport rates and directions;
- Use linear-programing optimization techniques to minimize pump and treat remedial costs while maintaining plume capture;
- Develop a comprehensive and fully integrated GIS database system that includes all soil, soil vapor and water sample analyses, and facility site features, such as storage units, process units, waste disposal practices and site history;
- Perform data analyses and prepare data summaries for steering committee members.

Outcome: GeoTrans successfully developed a three-dimensional groundwater flow model, with particle tracking to evaluate the remedial alternatives proposed in the ROD. Previous models developed for the basin did not accurately incorporate the effects of anthropogenic stresses in the basin and the potential impacts of a hydrologic fault barrier on contaminant transport. The GIS database is currently being used to assist the steering committee members in the development of allocation costs for PRPs. Work for this client is projected to be completed in 1996.

Nevada Test Site 3D Regional Flow Model
Nevada

Client:
U.S. Department of Energy

Start:
June 1995

Completion:
Ongoing

Project Value:
$275,000

Project Features:

- Numerical Modeling
- Groundwater Characterization

Background: Underground testing of nuclear weapons has been conducted at the Nevada Test Site (NTS) over the past 40 years. A significant number of tests were conducted at or below the water table, and an extensive investigation is currently being conducted to characterize the potential for migration of the contaminants and evaluate the risk to potential receptors. In support of this effort, GeoTrans was tasked with constructing a regional 3D flow model. The model, which included the NTS, covered approximately 3500 km^2 of the Death Valley groundwater flow system.

Scope of Work: The regional flow model developed for this project is one of the most complicated and extensive models ever produced. Water levels within the model ranged from approximately 1200 meters in the northeastern section of the model, to several hundred meters below sea level in the southwestern corner. In addition to the complicated flow regime, the amount of material that needed to be incorporated into the model, including the regional geology (divided into 20 distinct hydrostratigraphic layers), recharge rates and distribution, and characterization of boundary fluxes, was immense. Seventeen hydrologic model layers were necessary to accurately represent hydrogeologic properties of the volcanics and carbonates present within the system. Programs and batch files were written to automate as much as possible the creation of input data sets for each model run in order to facilitate Quality Assurance (QA) procedures. Model resolution was greatest in the weapons testing areas to facilitate future development of near-field flow and transport models. Particle-tracking was conducted to identify flow paths in support of regional transport modeling

Outcome: GeoTrans successfully developed a three-dimensional groundwater flow model of an extremely large and complicated flow system. Particle tracking was used to identify flow paths for far-field transport modeling, which is currently being conducted: results from the modeling will be incorporated into risk evaluation. Fluxes from the model will be used as boundary fluxes for near-field modeling in weapons-testing areas. Projected completion date for remaining tasks is January 1997.

GeoTrans, inc.

Groundwater Flow and Transport Model for the Western Processing Superfund Site

Kent, Washington

Client:
Western Processing
Mr. Paul Johansen

Start:
February 1995

Completion:
Ongoing

Project Features:

- 1D and 3D Flow and Transport Modeling
- Degradation of Organics
- Technical Impracticability

Background: The Western Processing Superfund site is an industrial waste processing and recycling facility that operated from 1957 to 1983. Drum removal and contaminated soils excavation began in 1983. A groundwater remediation system has been operating from 1989 to the present. The site trustees are currently completing a site-closure plan petition, which includes a technical impracticability waiver, for submittal to EPA and Washington Department of Ecology. GeoTrans was retained to construct a flow and solute transport model of the facility as part of the closure petition.

Scope of Work: The groundwater flow and solute transport model was designed to address the following issues: 1) characterization of the pre- and post-remediation site and regional hydrogeology; and 2) the extent of future contaminant transport under several potential site closure scenarios. The model was complicated by the fact that it had to encompass the regional area, while maintaining a fine-enough grid spacing in the vicinity of the site to predict effects of closure scenarios on both local and regional transport. The model area covered approximately 4 square miles of the Green River Valley, including the Green River from S. 212th St. on the south to approximately S. 180th St. on the north.

The modeling was divided into three tasks. The first task consisted of developing a three-dimensional (3D) groundwater flow model using the USGS parameter estimation code MODFLOWP (Hill, 1991). Use of the parameter estimation code resulted in optimal parameter selection by minimizing the subjective selection of parameter values encountered in traditional model calibration. The flow model was calibrated to both pre-remediation and remediation conditions. A particle-tracking routine was used to determine well locations and minimum extraction rates necessary to maintain inward and upward gradient controls at the site for a proposed closure scenario that included slurry wall and low-permeability cap. The second task consisted of the development of a 3D transport model for prediction of the effectiveness of different closure scenarios. Following calibration of the transport model to pre-remediation conditions for three metals and trichloroethene (TCE), the model was used to predict migration of the contaminants under three different closure options for containment. The final task consisted of modeling TCE and its degradation products, cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride (VC), using the 1D transport code MC_TRANS (GeoTrans, Inc., 1995). The 1D transport model incorporates both matrix diffusion, which is important in layered deposits with variable hydraulic conductivities, and production of VC from degradation of TCE and cis-1,2-DCE. The 1D code was used both to predict transport of the organics under the various closure scenarios, as well as to predict cleanup times at the site assuming continued operation of the current remediation system. The latter analysis was used in support of a technical impracticability waiver included as part of the petition.

Outcome: The modeling indicated that contaminant cleanup-time would be dictated by the organcis. Timeframe analyses indicated that the current remedial system would have to be operated for a 20 to 30 year period prior to reaching MCLs for TCE and VC. This is a conservative estimate since it does not take into account rebound effects following cessation of pumping. Modeling results further indicated that long-term maintenance pumping at the site for gradient control would be protective, and would involve pumping at about 5 percent of the current withdrawal rate.

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GeoTrans, inc.
GROUNDWATER SPECIALISTS

A Three-Dimensional Groundwater Flow and Solute-Transport Modeling Investigation of Hydrocarbon Contamination

California

Client:
Confidential

Start:
April 1990

Completion:
Ongoing

Project Value:
$200,000

Project Features

- 3-D flow and transport modeling
- Hydrocarbon contamination
- Development of well recovery/ containment design

Background: Oil refinery spills of hydrocarbon products dating back to the early 1940's have resulted in localized contamination of the uppermost regional aquifer in the West Coast Basin, near Los Angeles, California. The refinery is surrounded by other firms who may also be contributors to the hydrocarbon plume, complicating the assessment of liability with respect to remediating the plume.

Scope of Work: GeoTrans, Inc. was contracted primarily to develop a well-recovery/containment design through the use of a numerical-flow model.

Most of the West Coast Basin was simulated so that proper hydrologic boundaries could be used. Moreover, the model included the Gage/Gardena down to the Silverado aquifers to incorporate the regional and historical pumping and injection stresses on water levels near the refinery.

The flow model was performed with the USGS's MODFLOW. It became apparent from the model that the client was not the sole contributor to the plume. The USGS's particle-tracking code was used as an inexpensive preview to the full transport model. Particle tracking simulates only the advective part of transport and can be run forward to observe movement to the plume or backwards to estimate the origin of a particle. This can be used to demonstrate, in part, the source of the plume. For this project, the backwards option was used to estimate the capture area of proposed remedial wells. GeoTrans' Geotrack was used to display movement of the particles through time and in three-dimensions. Real-time rotation of the display is also available. Geotrack is able to make numerical-modeling results easily understood by a non-technical audience.

The well-recovery/contaminant design was created using GeoTrans' MODMAN (MODFLOW MANagement). This automated numerical optimization routine assisted in the estimation of the number of wells, their placement, and the pumping distribution to achieve hydraulic containment of the plume. This solution allowed the client to reduce its pump and treat costs by 20 percent.

Because the refinery operations require large volumes of water which the client pumps from deep aquifers below the site, the model was also used for water supply. The model was used to recommend locations for the water-supply wells that would minimally impact the shallow recovery containment system.

Outcome: The model is currently being operated to reflect the new data which has been collected since the original work was completed in 1990.

A Two-dimensional, Finite-difference Flow Model Simulating the Effects of Withdrawals to the N-aquifer

Arizona

Client:
Peabody Coal Company

Start:
August 1986

Completion:
Ongoing

Project Features

- Groundwater Modeling
- Regulatory Compliance/ Permitting

Background: Peabody Coal Company operates two adjacent coal strip mines, the Black Mesa and the Kayenta Mines, in an area of approximately 100 square miles. Coal is moved from the Black Mesa Mine to an electric power plant near Laughlin, Nevada via a 273-mile long slurry pipeline which utilizes groundwater extracted from the N-Aquifer. Both the Navajo and Hopi Indian Reservations occupy the entire Black Mesa area and operate community wellfields. The combination of both Tribal community and mining withdrawals have caused water levels to decline in wells located throughout this area. GeoTrans, Inc. conducted a modeling study to determine the effect of withdrawals (from Peabody's leasehold and the Tribal communities) on water levels in the aquifer and on spring discharges in the surrounding Black Mesa area from the year 1956 to 2054.

Scope of Work: In 1986, GeoTrans, Inc. conducted a study of the N-aquifer in northeastern Arizona for compliance with the Office of Surface Mining, Reclamation and Enforcement (OSMRE) permit regulations which require a Cumulative Hydrologic Impact Assessment (CHIA) to be performed. A groundwater flow model was developed using least-squares parameter estimation techniques, and calibrated for both pumping and non-pumping conditions. Particular attention was paid to developing consistent and useable estimates of future Tribal pumpage. The model initially was used to estimate the long-term effects to the N aquifer from mining related pumpage and can now be used as a resource management tool.

In 1994, GeoTrans was asked to numerically assess and compare the reliability of the previous modeling efforts. The Tribes were still not confident in the model's results, some of the input parameters, or its use as a tool to predict drawdown. Using MODFLOWP, a parameter-estimation code developed by the USGS (Hill, 1992), GeoTrans assessed the certainty in model calibration parameters and evaluated model calibration sensitivity to input parameters, such as hydraulic conductivity, recharge, and transient leakance from the overlying confining bed. Results from this exercise and other related geochemical and biological studies demonstrated thar the MODFLOW model was an appropriate and reliable tool to use for evaluating the regional effects to the N-aquifer.

Outcome: GeoTrans continues to conduct groundwater modeling in support of Peabody's operating permit applications. Ongoing work includes refinement of the model and incorporation of new hydrologic data as it becomes available.

Groundwater Modeling and Litigation Support for a Confidential CERCLA Site

Client:
Confidential

Start:
August 1990

Completion:
Ongoing

Project Value:
$220,000

Project Features:

- Groundwater Flow Modeling
- Analysis of Interim and Remedial Measures

Background: This confidential site has been on the National Priorities List (NPL) for several years. There have been several property owners over the history of site operations; industrial activity at the site has resulted in contamination impact to soil, groundwater, and surface water. Litigation is pending over the recovery of response costs and the division of liability between the potentially responsible parties.

Scope of Work: GeoTrans is providing confidential technical services in support of anticipated litigation at the site. A three-dimensional groundwater flow model and particle transport analysis has been performed to support legal arguments on the division of liability between potentially responsible parties. Work on this project has included:

- Development of a regional and site-specific three-dimensional groundwater flow model;
- Analysis of particle migration and transport times under varying site conditions;
- Numerical analysis of hydraulic response actions taken at the site;
- Conceptual analysis of immiscible and miscible phase contaminant transport at the site;
- Review of documents and reports for relevance to anticipated litigation.

Outcome: Litigation is still pending on this case. GeoTrans staff have been named to provide expert testimony. We continue to provide expert technical consultation relating to the division of liability among the potentially responsible parties.

Characterization of Ground-water Flow and Transport in the General Separations Area

South Carolina

Client:
E.I. duPont de Nemours and Company

Start:
October 1985

Completion:
December 1986

Project Value:
$495,306

Project Features

- 3-D flow and transport modeling
- Site characterization
- RCRA Part B permit engineering feasibility study

Background: The Savannah River Laboratory (SRL) prepared an Environmental Impact Statement (EIS) to address the operations of the Savannah River Plant (SRP) on hydrogeologic settings and types of disposed waste materials. An Environmental Information Document (EID) was prepared for 26 functional groups to address the nature of disposal, the hydrogeologic setting, the waste site closure and management alternatives, and the environmental impacts.

Scope of Work: GeoTrans, Inc. provided technical services related to quantifying the fate and transport of potential contamination from the 45 km General Separation Area (GSA) which contains a majority of the existing and closed waste sites. A variety of flow and transport models were employed for these assessments. The quasi-three-dimensional regional flow and transport model for the GSA consisted of a vertical sequence of four aquifers and three aquitards which covered approximately 45 km. An automatic parameter estimation code (HYPER 3-D) was used to estimate hydraulic conductivities and leakance coefficients. A solute transport model was constructed with SWIFT II to estimate concentration in groundwater and flux to two bounding streams.

A two-dimensional flow and solute transport model was constructed in a vertical cross-section configuration through the H-Area Seepage Basin No. 4. The SATURN finite-element code was used to simulate the flow of water and dissolved chemical constituents within the variably-saturated zone beneath the bottom of the basin. The purpose of the simulations was to provide an assessment of the hydrologic behavior of the variably-saturated zone related to the chemical constituent migration and to provide a benchmark analysis for other quantitative analyses being performed on waste sites at the SRL.

As part of a RCRA Part B permit engineering feasibility study, 3-D, finite-difference flow and solute transport models were constructed for both the F and H Area Seepage Basins to evaluate the effectiveness of groundwater extraction/injection systems proposed for each facility.

Outcome: A cost effective treatment of the contaminant transport was accomplished by telescoping grid refinement from the large regional model.

Open-end Contract for Architectural - Engineering Services

St. Louis, Missouri

Client:
US Army Corps of Engineers

Start:
1993

Completion:
1994

Project Features:

- Watershed Investigations

Background: The Wappapello Dam is located on the St. Francis River in Wayne County, Missouri. The Wappapello Reservoir provides for the downstream flood control and is part of a comprehensive plan for protecting the St. Francis River Basin in conjunction with channel improvements and leveed floodways. Other objectives of the reservoir include recreation, fish and wildlife, forest and lease land management, and hydropower production.

Scope of Work: The St. Louis District of the US Army Corps of Engineers retained GeoTrans/Tetra Tech to conduct comparison between the surveys of 1947, 1964 and the 1993 resurvey. The purpose of this investigation was to determine the amount and distribution of the sediment entering the reservoir, and the trap efficiency and rate of the storage depletion.

Outcome: The study documented the watershed characteristics, climate conditions, reservoir operations, reservoir inflow characteristics, type and scope of sediment surveys and reserves method of sediment computations, sediment quantities, and trap efficiency of the reservoir.

Application of Modified Generalized Planning Model to Investigate Pesticide Transport

Iowa

Client:
U. S. Environmental protection Agency

Completion:
1984

Project Features:

- Model Calibration

Background: The generalized planning model (GPM) is a cause-effect simulation model based on mathematical descriptions of watershed physical processes related to nonpoint-source pollution. A pesticide transport module, including an adsorption/desorption mechanism and degradation of pesticide constituent, is implemented with the existing GPM system. The modified GPM system is then used as a tool to evaluate the transport of pesticide applied was the watershed on land surface and its distribution in the sail moisture profile.

Scope of Work: The modified GPM model is composed of the following major components:

1. Soil-plant-atmosphere water moisture adjustment simulation,
2. Kinetic wave surface-water-routing component,
3. Hydraulically based sediment size distribution model,
4. Subsurface flow component,
5. Nutrient routing based on particle partition coefficient method to simulate nitrogen and phosphorous compounds transformation, and
6. Pesticide transport module including adsorption/ desorption and degradation mechanisms.

Outcome: The modified GPM model was applied to the four Mile Creek watershed in Iowa for calibration and verification.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

Remedial Investigation of Coalinga Asbestos Superfund Site (Npl 260)

Coalinga, California

Client:
Southern Pacific Land Company

Completion:
1989

Project Features:

- Hydrologic and Hydraulic Analyses

Background: The Coalinga Asbestos Mill Site is located in the upper portion of Los Gatos Creek watershed, a tributary to the Arroyo Pasajero. The Site is located approximately one-half mile downslope from the New ldria Formation, which is a large, massive natural source of asbestos. The New ldria Formation and other natural resources have been contributing asbestos-rich sediment to the Arroyo Pasajero alluvial fan throughout geologic history.

Scope of Work: GeoTrans/Tetra Tech (GT/Tt) was retained by the Southern Pacific Land Company, to evaluate (1) the Site's relative contribution of asbestos in comparison with background levels, to air and water quality in the Arroyo Pasajero watershed, and (2) the degree of public health risk, if any, presented by release of asbestos from the Site in relation to releases from background areas of the Arroyo Pasajero.

The EPA's primary concerns for the site focused on two transport mechanisms. First, EPA was concerned about relative Site Contribution to the levels of asbestos found in the air in Huron and Coalinga. Second, EPA was concerned about potential asbestos contributions of the Site to the California Aqueduct.

GT/Tt conducted a detailed engineering analysis which included:

I. HEC-1 hydrologic analysis to determine the surface runoff in and adjacent to the Site.
2. Soil erosion analysis to determine the soil loss due to surface runoff.
3. Recommendation for the establishment of a Regional Soil Sampling Program to characterize off-site asbestos-rich sediment source.
4. Sediment source analysis to estimate sediment production rates from various asbestos-rich sediment source areas.
5. Hydraulic analysis of various tributaries in the Arroyo Pasajero watershed,
6. Sediment transport, deposition and scour in the main water courses and floodplain.

Outcome: The study concluded that any environmental or health risk potentially attributable to the incremental contribution of the Site to airborne asbestos in the region was insignificant compared with the contribution of other regional sources. In addition, it was found that the asbestos-containing sediments of the Site to the California Aqueduct is far less than the contribution of the Site to the Arroyo Pasajero watershed alone. Thus, the potential environmental or health risk attributable to Site is insignificant.

BIO1D Modeling Code Profile

BIO1D

Overview

BIO1D, developed by P. Srinivasan and J.W. Mercer is a one-dimensional modeling code which simulates biodegradation and sorption in contaminant transport. The objective was to provide an interactive, user-friendly microcomputer software package to serve as an educational tool for understanding the relative importance of various physicochemical and biochemical processes.

Applications

BIO1D may be applied to solute transport problems involving a reactive substrate. The reactions may include aerobic and anaerobic degradation and/or adsorption described by a linear, Freundlich or Langmuir isotherm. Figure 1 shows the simulation of organic transport involving aerobic biodegradation at a waste site in Conroe, Texas, and is based on an earlier study by Borden, *et al.* (1984).

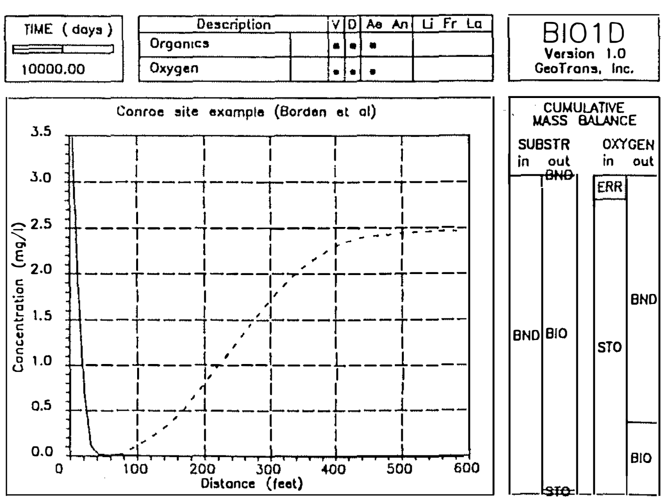


Figure 1. Simulation of aerobic biodegradation at Conroe site, Texas

The code may be used in a conceptualization mode for many applications to help determine the importance of transport processes. The applications can involve a number of reactive substrates such as organic solvents and petroleum products. In addition, because anaerobic degradation is considered, non-organic solutes, such as radionuclides with decay can be simulated. The code will be especially useful for analyzing laboratory data from column experiments.

Model Features

- Advective and dispersive transport of a hydrocarbon and an electron acceptor (e.g. oxygen)
- Aerobic biodegradation using modified Monod function
- Anaerobic biodegradation using Michaelis-Menten kinetics
- First-order degradation for both substances
- Linear, Freundlich, and Langmuir adsorption isotherms for both substances
- Dirichlet, Neumann, and Cauchy boundary conditions modified to include first-order degradation
- Cumulative mass balance report

Limitations

- Transport is one-dimensional.
- The flow field is uniform (constant velocity).
- Material properties of both substances are uniform throughout the medium.
- Only one reactive substrate is considered per simulation.
- Microbial density is assumed constant.

Governing Equations

A summary of the equations solved in BIO1D is presented below.

$$D\frac{\partial^2 S}{\partial x^2} - V\frac{\partial S}{\partial x} - B(S,O) - \{1+A(S)\}\frac{\partial S}{\partial t} = 0 \qquad (1)$$

$$D\frac{\partial^2 O}{\partial x^2} - V\frac{\partial O}{\partial x} - F.B(S,O) - \{1+A(O)\}\frac{\partial O}{\partial t} = 0 \qquad (2)$$

where

S substrate concentration in the pore fluid (ML^{-3});
O oxygen concentration in the pore fluid (ML^{-3});
D longitudinal hydrodynamic dispersion coefficient (L^2T^{-1});
x distance (L);

V	interstitial fluid velocity (LT^{-1}), assumed uniform;
$B(S,O)$	biodegradation term ($ML^{-3}T^{-1}$), expressed as a function of the dependent variables S and O;
F	ratio of oxygen to substrate consumed;
$A(S)$	substrate adsorption term;
$A(O)$	oxygen adsorption term; and
t	time (T).

Aerobic Biodegradation (Monod function)

$$B(S,O) = Mk \frac{S}{k_S + S} \frac{O}{k_O + O} \frac{S - S_{min}}{S} \qquad (3)$$
$$= 0 \text{ for } S \le S_{min} \text{ or } O \le O_{min}$$

where

$B(S,O)$	aerobic biodegradation term, a function of substrate and oxygen concentration ($ML^{-3}T^{-1}$);
M	microbial mass (ML^{-3}) assumed constant;
k	maximum substrate utilization rate per unit mass of microorganisms (T^{-1});
k_S	substrate half-saturation constant (ML^{-3});
k_O	oxygen half-saturation constant (ML^{-3});
S_{min}	minimum substrate concentration that limits growth and decay (ML^{-3}); and
O_{min}	minimum oxygen concentration that limits growth and decay (ML^{-3}).

Anaerobic Biodegradation (Michaelis-Menten kinetics)

$$B(S) = M_n K_n \frac{S}{k_{Sn} + S} \frac{S - S_{min}}{S} \qquad (4)$$

where the terms, M_n, k_n, and k_{Sn} are counterparts of M, k and k_S under anaerobic conditions. As a special case, M_n, k_n, and k_{Sn} may be set equal to M, k and k_S, respectively.

First-Order Decay

$$B(S) = \mu_S S \qquad (5)$$

where μ_S is a first-order degradation coefficient (T^{-1}).

Linear Adsorption Isotherm

$$A(S) = \rho_b K_d / \phi \qquad (6)$$

where

ρ_b	bulk mass density of the porous medium (ML^{-3});
ϕ	effective porosity; and
K_d	distribution coefficient (L^3M^{-1}).

Freundlich Adsorption Isotherm

$$A(S) = \rho_b n K_f / \phi \; S^{n-1} \qquad (7)$$

where

K_f	rate constant; and
n	Freundlich isotherm exponent

Langmuir Adsorption Isotherm

$$A(S) = \frac{bK}{\phi(1 + bS)^2} \qquad (8)$$

where

b	constant; and
K	maximum sorption capacity of solid.

Uncoupled Simulation Option

When the biodegradation option is not used, the equations (1) and (2) are uncoupled and may be solved simultaneously. Two sets of input values are used for all parameters except those defining the grid and time steps. This permits a wide range of possible comparison studies. Some are listed below.

- Different velocities. This is an indirect way of comparing the effect of two hydraulic conductivity values. Figure 2 illustrates a field application of BIO1D where the predicted breakthrough curves are bracketed with two estimates of clay permeability. Similarly, hydraulic gradients may also be used for comparison.

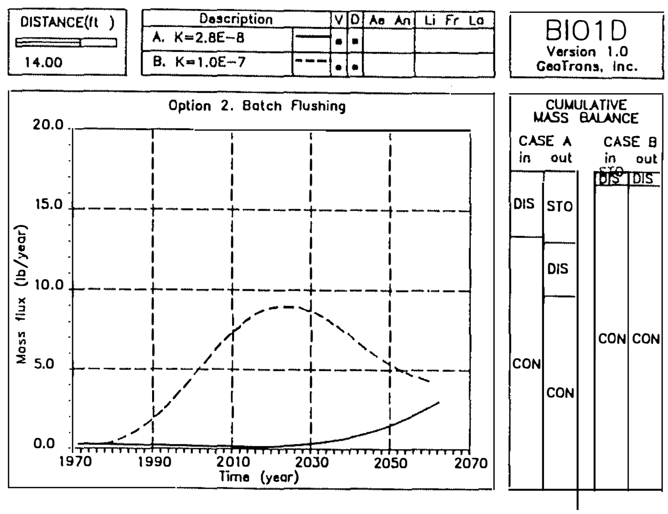


Figure 2. Varying clay permeability.

- Different dispersion coefficients.
- Different adsorption rates. BIO1D is an excellent tool for comparing two isotherms, or varying coefficients of the same isotherm. Figure 3 illustrates a study on varying Freundlich isotherm exponent.
- Different first-order decay rates. As a special case, one of the decay rates may be set to zero.
- Different boundary conditions. Three types of boundary conditions with built-in first-order degradations are available. In field situations, boundary conditions are not always clearly understood. Thus the importance of assumptions made at the boundary may be studied.

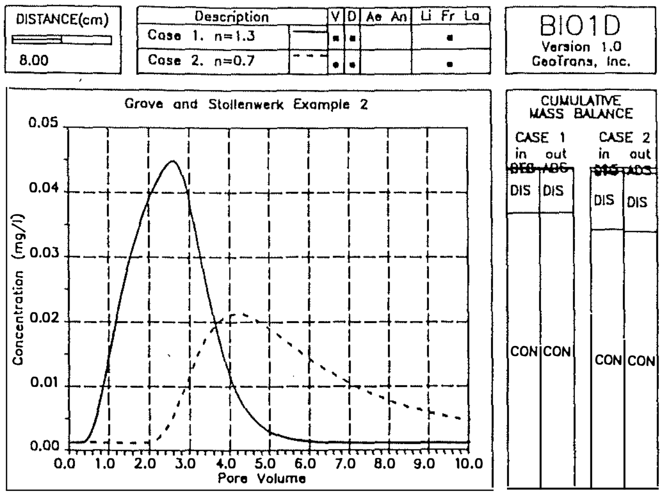


Figure 3. Uncoupled simulation option:
Varying Freundlich isotherm exponent.

Interactive Preprocessor

A preprocessor has been built into BIO1D which enables the user to prepare input data interactively. The preparation includes features such as inputting new data and storing them in a disk file, or reading data from a disk file and editing them. The preprocessor has built-in error recovery procedures to forgive most input errors made by a user during interaction.

For first-order decay and linear, Freundlich, or Langmuir adsorption isotherms, definitions found in the literature are not always uniform. The preprocessor provides the user with alternative definitions, and the user may select the one that is most familiar. Figure 4 illustrates the definitions available for linear isotherm. The user may define the isotherm in terms of linear isotherm coefficient, distribution coefficient and bulk density, or retardation factor. Many such useful features may be found throughout the interaction.

```
BIO1D            6. LINEAR EQUILIBRIUM ISOTHERM              SCREEN 33
                      Substance: Benzene
  Linear equilibrium isotherm may be defined using one of the following
  definitions. Choose the one you are familiar with for entering data.
     Definitions:     (1)        (2)          (3)      Choose one:   3
                       Kl       ρb . Kd
           A(S) =    ----- =   --------- = Rf - 1       (φ =   .20 )
                       φ           φ
Defn 1.     Linear isotherm coefficient (Kl):    12.820
Defn 2.                  Bulk density (ρb):  not known   [ compatible
              Distribution coefficient (Kd):  not known  [   units
Defn 3.              Retardation factor (Rf):    65.100
SCREEN OPTION        (<RETURN>:continue, 1:edit, 2:previous screen): _
```

Figure 4. BIO1D data preparation:
Alternative definitions.

Run-Time Options

Taking advantage of the single-user microcomputer environment, many simulation options are provided at run-time. A *run-time monitor* as illustrated in Figure 5 is displayed and updated constantly as the simulation progresses. The user may run the simulation for a certain time period, monitoring its behavior, and then choose a different set of run-time options for the rest of the simulation. The options include printing concentrations, cumulative mass balance information, and selecting plotting intervals. Advanced debugging options such as iteration information, nodal mass balance tables, displacement matrices, and matrix solver monitors are also available at run-time. These options can be useful when the processes simulated are highly nonlinear, or if the results of the simulation show unusual behavior.

```
BIO1D                      RUN-TIME MONITOR                    SCREEN 10
   SIMULATION OPTIONS        |   PRESENT STAGE      |   STOP WATCH
Final time:   20000.   days  | Time:   1150.0  days |  Elapsed time
First DELT:   10.000   days  | DELT:   5.0000  days |   3.10 minutes
Total time steps:  2000      | Time step:  115      |
Max. iterations :    10      | Iteration:   1       |
        STATUS INFORMATION FROM PREVIOUS TIME STEP
                                   Organics         Oxygen
 Maximum error (mg/l )           .53066E-04       .46142E-04
          occurred at node            4                8
 Cumulative mass balance error (%)  -.71791E-02    -.62351
           LAST MESSAGE FROM TIME STEP #   108
 WARNING: Diverging S(  5) at iteration   4
          DELT halved to    5.0000     days          Press RETURN: _
```

Figure 5. BIO1D run-time monitor.

The advanced debugging options may also be used by students learning numerical methods. Every step of the nonlinear iterative solution scheme used in BIO1D may be monitored by the user. The *Peclet* and *Courant* stability numbers are displayed automatically during data preparation, and a *stop watch* (Figure 5) is activated to measure the CPU time during the simulation. These features are useful in understanding the effects of varying the input parameters such as, grid spacing, time step size, and convergence criteria which are associated with the numerical solution.

Plotted Results

Concentration vs. distance at a certain time, or concentration vs. time (or pore volume) at any node may be plotted. Concentration may be plotted in linear or log scale. Figures 1, 2 and 3 illustrate these options. Plots may be previewed on the screen and sent to any of the plotters listed under *Hardware* (page four). For comparative studies, hard copy plots from uncoupled simulation runs (eg. Figures 2 and 3) can be readily used in reports.

Verification Tests

The features available in BIO1D have been tested in a systematic manner. A variety of problems have been selected to test major options in biodegradation, adsorption, and boundary conditions. The data files for the above problems have also been carefully prepared to test many of the minor options (grid spacing, plotting, etc.) available in BIO1D. Table 1 shows the features tested by the problem sets A through F.

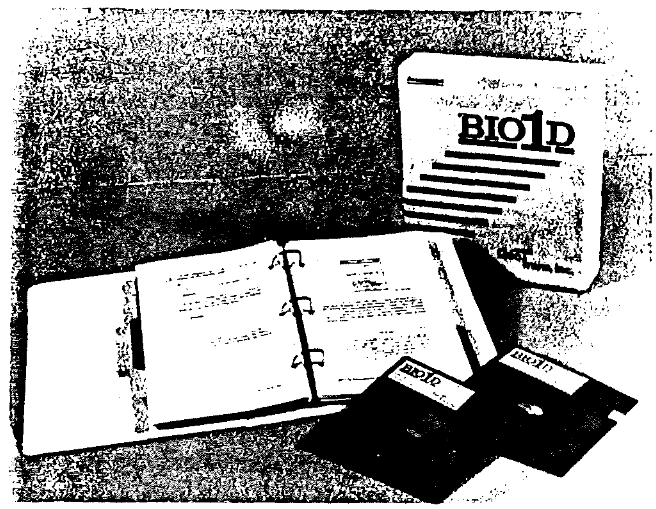
Table 1. BIO1D features tested.

FEATURES		PROBLEM SETS
advection/dispersion		A B C D E F
degradation	- *aerobic*	F
	- *anaerobic*	F
	- *first-order*	B F
uncoupled simulation		D
adsorption	- *linear*	B C
	- *Freundlich*	D
	- *Langmuir*	E
boundary (*: pulse)	- *Dirichlet*	A C* D* E* F
	- *Neumann*	
	- *Cauchy*	B*
solution	- *tridiagonal*	A B C E
	- *pentadiagonal*	D F
grid	- *uniform*	A B C D E
	- *variable*	F
plots	- *C vs. X*	A F
	- *C vs. T*	B
	- *C vs. PV*	C D E

Features that are not yet tested may also be identified from this table. A description of each test along with a complete list of corresponding input and output files of the BIO1D simulations are presented in the BIO1D documentation.

Documentation

The documentation for BIO1D is believed to be the most comprehensive ever for a groundwater code, setting new standards for the industry. It is divided into two major parts. The first part covers the theoretical aspects of BIO1D which include: derivation of the mathematical model; development of the numerical solution; and verification tests. The second part serves as the *user's manual* for the code. The sections included are: step-by-step installation instructions; three *guided tours* to familiarize the user with the data preparation, simulation, and plotting of the results; detailed input data instructions; interpretation of output; and error conditions and handling.



Hardware

BIO1D runs on an IBM PC, XT or AT compatible microcomputer with 640K memory. A numeric coprocessor (8087 or 80287) is required. CGA, Hercules monochrome or EGA graphics card is needed for screen graphics. HP 7440A, 7470A, 7475A, 7550A, 7580B, 7585B, 7586B plotters; HI DMP-51, 52, 56 plotters; Enter SP-600, 1200 plotters; EPSON FX, RX, MX, LQ, and JX series printers; IBM Proprinter, PC Graphics printer; Okidata ml 92/93, 182/192/193 printers; Centronics GLP printer; and HP Laserjet series laser printers are supported for hard copy plots. Examples shown in this brochure were made using the HP 7475A 6-pen plotter.

Availability

An executable version of the BIO1D software along with the documentation is priced at **$250** and is available from GeoTrans. For further information, please call P. Srinivasan at (703) 444-7000.

GeoTrans, inc.
GROUNDWATER SPECIALISTS
46050 Manekin Plaza, Suite 100
Sterling, VA 20166
Phone: (703) 444-7000