January 1990

Research Project Summary (July 1989 - December 1990)

Utah Water Research Laboratory

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Foreward

The Research Project Summaries for the Utah Water Research Laboratory (UWRL), the Utah Center for Water Resources Research (UCWRR), the departments of Civil and Environmental Engineering (CEE) and Agricultural and Irrigation Engineering (AIE), the International Irrigation Center (IIC), and the Cooperative Fisheries and Wildlife Research Unit (CFWRU) contains short reports of projects in progress during July 1, 1989 – December 31, 1990. Only those publications produced during this period are referenced in the reports. Detailed project descriptions can be obtained either through project publications or from the individual principal investigator(s).

The short summaries in this report are grouped into the areas of hydrology, ground water, water resources planning and management, agricultural and irrigation engineering, international programs, water quality, waste management, environmental analysis, fisheries, hydraulics and fluid mechanics, resource information systems, water information and education, and technology transfer. Overviews of the research areas and of the program as a whole are synthesized and supplemented with goal statements for the coming year in a companion UWRL Annual Report. The purpose of this report is to give additional information to bridge the gap between the generality in the overview report and the specifics found in the many referenced project publications.

In addition to this document and the UWRL Annual Report, the UWRL has available a complete list of project publications and brochures. To obtain this information, contact Publications, Utah Water Research Laboratory, Utah State University, Logan, Utah 84322-8200; phone: 801-750-3155; FAX: 801-750-3663; TELEX: 3729283.
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<td>Agricultural Experiment Station</td>
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<td>AFB</td>
<td>Air Force Base</td>
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<td>AGU</td>
<td>American Geophysical Union</td>
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<td>Agricultural and Irrigation Engineering</td>
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Research Report Summaries—
The Utah Water Research Program

Research Administration

From every side we hear of new threats to our water supply. Carcinogens, droughts, dam failures, global warming, hazardous wastes, deforestation, overpopulation, liability, and an aging infrastructure become household fears; this list grows longer and more foreboding to the average citizen. Some of these threats are real, while others are imaginary. Some we know how to overcome and others we can find ways to overcome, yet, for some, we are still helpless.

The strength of a university lies in its success in stimulating inquisitive minds in critical examination of the problems of the world. People sense hope as experts find answers. People find better lives as those answers are applied.

University research works best as an open book set before people with problems. The project summaries in this document describe attempts to present ideas to people with needs. We want the water research program in Utah to be a cooperative effort in which faculty interact with citizens to define problems, generate ideas, test the validity and effectiveness of these ideas, translate good ideas into practical measures, monitor results, and recycle new ideas for the next round. By producing new effective measures as rapidly as society produces new problems, we can gain confidence in ourselves. Our present sense of foreboding can be turned into challenges met and victories won.

Sometimes problem-solving research must go all the way back to the fundamentals. In many cases, we are not even able to define what it is that we do not understand. At the danger of sounding irrelevant to people looking for quick answers, researchers dig to scientific depths and express what they see in terms of complex mathematical formulations.

Some projects presented in this report have these much needed theoretical and exploratory bents. All they can offer is to provide information that others can synthesize with the growing body of human knowledge in an expanding sequence of pieces heading towards practical management solutions. Others lie at the other end of the spectrum and find answers, while most research projects lie somewhere in between.

A research program is more than projects, it also includes efforts to distribute research findings through technology transfer, information dissemination, and water education. Specialists present findings to the technical community, inform people about current water issues, and prepare educational materials for use in the public schools.

Research users wear many hats. An irrigator may be faced with a water shortage or soil salinization. A manager of a water utility may find his water sources being depleted or polluted. A citizen becomes concerned with preserving ecologically productive wetlands.

When people expound on their ideas as solutions, whether the solution is a marvelous home water purifier or a new law to protect aquifers from hazardous wastes, the public faces decisions. People need to know whether an idea is technically sound, will produce benefits that justify their efforts, bends with the natural environment, and can earn legal, social, and political acceptance.

Finding and supplying priority answers to water questions is the role of the Utah Water Research Laboratory (UWRL) in a world in which there is never enough funds and expertise. Priorities are established by first
asking how important is the problem? Then, how likely is research to help? The first question can best be answered by people experiencing water problems and who are responsible for overcoming them. For this purpose, the UWRL uses a Citizen Advisory Council. The second question can best be answered by people familiar with what research can produce; the UWRL also has a University Water Resources Council of research administrators who work with a peer review process through which opinions are obtained from experts in specialty areas.

This process of research identification is assisted by a cooperative program with the U.S. Geological Survey (USGS) and administered in Utah through the Center for Water Resources Research (UCWRR) which is housed at the UWRL. Research needs are identified by compiling problems through talking to people involved in water resources management around the state and selecting the most important needs based on the broad experience of advisory council members. The UCWRR distributes statements on needs to interested researchers on the Utah State University (USU) campus, at the University of Utah, Brigham Young University, and Weber State University.

Researchers then respond to these statements. Limited USGS funding supports three or four small projects annually. Most of the other funding is obtained through proposals to federal agencies, state and local governments, and the private sector. In addition to the help that these studies give in addressing state priority items, funded research helps in program building by:

- Supporting a broader base of expertise and facilities that are available and ready to be turned to solving problems in Utah;
- Delivering information that helps solve problems in Utah without having to pay for the work with Utah funds;
- Promoting interactions in which federal, state, and local governments and the private sector work together in the public interest; and
- Expanding the coverage of graduate student training.

Program Statistics

One hundred and eleven research projects active during July 1, 1989 through December 31, 1990 are described in this report. This includes studies performed at the UWRL, by the Cooperative Fisheries and Wildlife Research Unit (CFWRU), elsewhere on the USU campus as administered through the UCWRR, by colleagues in the Departments of Agricultural and Irrigation Engineering (AIE) and Civil and Environmental Engineering (CEE), College of Engineering, and by the International Irrigation Center (IIC).

Of the 111 projects presented in this report, eight were funded through the UCWRR. A total of 103 others were funded by 13 other major sources (federal, state, and private) external to the appropriation provided the UWRL by the State of Utah. Seven of these projects were provided matching funding from the state; 67 studies of priority problems in Utah were also funded through state money. Fifteen projects were funded by providing miscellaneous services to various entities. Two projects were funded within AIE, seven within the IIC, and two within the CFWRU.

The Utah Water Research Program is large and is continually growing. The total UWRL and UCWRR research expenditures amounted to $5,409,358 in fiscal year 1990 (compared with $3,581,834 in fiscal year 1988). Expenditures on other projects covered in this report amounted to approximately $55,739 in AIE, $12,426 in the CFWRU, and $376,433 in the IIC, for a grant total of $5,853,966. The combined UWRL and UCWRR expenditures for fiscal year 1990 were divided as follows: $783,773 for program management and
development, $69,757 for technology transfer and information dissemination, $110,467 for water education, and $4,445,361 for research. Of the research total, $3,527,002 was received from contracts with 13 agencies or organizations, including approximately $658,463 from private sector sources. The remaining $918,359 was budgeted by the State of Utah through USU for studies on problems judged important to Utah.

Approximately 261 individuals were involved in research projects during July 1, 1989 through December 31, 1990. This includes 76 faculty and professionals and 33 research support staff working at the UWRL or with CEE; three CFWRU faculty and professionals and four research support staff, 11 AIE faculty and professionals and seven support staff, and nine IIC faculty and professionals and two support staff. In addition, approximately 108 graduate and eight undergraduate students, throughout the departments, were involved in research projects. The remaining research personnel came from cooperating universities, government agencies, and private industries throughout the U.S.

The faculty involved in the research projects have appointments in academic departments campus wide. These departments include Agricultural and Irrigation Engineering, Biology, Civil and Environmental Engineering, Economics, Geology, Plant and Soil Science and Biometeorology, Mathematics, Chemistry, Fisheries and Wildlife, Meteorology, Electrical Engineering, Mechanical Engineering, Sociology, and Education.

Conclusion

The synergism of this many people working interactively in advancing water science solves water resource management problem and advances capabilities that will benefit Utah, the U.S., and other nations for years to come. Research is an investment in knowledge; knowledge is our hope for the future.
Hydrology
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Study of Water Yields in Semi-arid Environments Under Projected Climate Changes

Principal Investigators:
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Gail E. Bingham (PhD), Meteorology
V. V. Dhruva Narayana (PhD), Civil and Environmental Engineering
Donald T. Jensen (PhD), Civil and Environmental Engineering

Student Assistants:
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Problem and Research Objectives
An adequate and reliable water supply is critical to continued life in the semi-arid west. Anticipated climate changes resulting from man-induced change in the composition of the atmosphere could directly affect western water availability through a change in precipitation quantity or its temporal distribution and increased average temperatures.

While current Global Climate Models (GCMs) cannot predict, with any accuracy, the effects of climate change on particular regions of the semi-arid west, they do indicate a range of possible scenarios. Using these scenarios and currently available water-yield relationships, we can begin to calculate the magnitude of the impact of climate change on western water systems. In addition, the magnitude of the secondary effects (humidity, temperature, and changes in the vegetation regimes of watersheds) on the accuracy of the existing water-yield relationships can be identified. By improving the relationships used to predict water yield, our ability to plan for the effects of climate change, once the GCMs become more reliable, will be greatly increased.

We will review the currently predicted changes in climate (precipitation, temperature, and humidity) being developed by existing GCMs for the semi-arid west. Given this information, we will make an initial estimate of the potential climate change and its significance on western agriculture. As this information is developed, we will develop a hydrologic response model to improve our impact assessments.

Improvement of the water-yield relationships used in the management of semi-arid regions will involve the collection of existing information on aspect, elevation, temperature, and atmospheric humidity effects on evapotranspiration. Once this information is collected, it will be summarized in a model which can be validated using existing data from instrumented watersheds, such as those within the Weber Basin.

Basic inputs to the model include temperature, precipitation, radiation (cloud cover), and humidity. We anticipate that, ultimately, these inputs will be provided by the GCMs; until that capability is realized, appropriate time series of the input data will be assumed to study the sensitivity of the hydrologic response functions to both temporal and spatial changes in the climatic input parameters.

The hydrologic model will include fundamental hydrologic relationships to represent the storage locations and transport processes for the system. Spatial relationships will account for topographic features (degree and aspect of slope and elevation differences) and differences in soil, vegetative cover, and groundwater storage characteristics.

Considerable success has been achieved at USU in identifying hydrologically similar areas on mountain watersheds using imagery data from satellites and other remote sensing devices. In the model, changes in watershed vegetation will be simulated as a result of climate change, evapotranspiration, surface runoff, soil moisture levels, groundwater storage quantities, and groundwater outflows.

As currently anticipated changes in western climates do not exceed the extremes of existing natural variations, we expect that the model will provide reasonable results. Some additional measurements might be needed to "patch holes" in the existing database of the study watershed(s). We can then apply the improved hydrologic model to a particular area, such as the Weber Basin, and conduct sensitivity investigations and "what if" studies on the basis of GCM predicted scenarios.

Accomplishments
1. On the basis of an extensive review of GCMs, we have written, reviewed, and finalized a report in which much currently available information on global climate change effects and GCMs is summarized.
2. We are continuing workshops and seminars on the topics of general circulation and hydrologic modeling.
3. We are conducting work on a model that will generate synthetic climate input data for the river basin hydrologic model, the Geographical Universal Climate Date Synthesizer (GUS).
4. Through cooperative efforts with USBR personnel in Denver, Colorado, we are: a) developing a linkage between the GCM and GUS models; and b) obtaining and processing satellite imagery for the Weber Basin as a whole and for the Causey subwatershed in detail.
5. We are assembling available hydrologic and meteorologic data for the Weber Basin and other nearby gauged watersheds. We will use the data to test and verify the hydrologic model.
6. Through cooperation with USU's Department of Forestry, we have initiated efforts to incorporate changes in watershed vegetation characteristics which result from short and long-term climate changes to the hydrologic model.
7. We are conducting negotiations with USBR personnel in Provo, Utah, to install a minimum number (at least five) of meteorological and runoff stations on the Causey subwatershed during the summer of 1991.

Publication

Project Number: AFS-409
Sponsor: USBR
Project Duration: April 1990 - September 1991
Project Status: Research in Progress
Distributed Hydrologic Modeling Using Digital Topographical and Geographic Data

Principal Investigator:
David G. Tarboton (PhD), Civil Engineering

Problem and Research Objectives
In using detailed physically-based hydrologic models, problems arise due to insufficient data or knowledge of the natural heterogeneities present. The increasing availability of distributed geographic data and increasing computer power leads to apparently attractive opportunities for physically-based hydrologic modeling. GIS provide a way to systematically use this data.

The objective of this research is to develop physically-based hydrologic modeling procedures within the framework of a GIS. The appeal of a physically-based distributed approach has led to the development of sophisticated distributed models such as the Systeme Hydrologique Européen (SHE) model and the Institute of Hydrology Distributed Model (IHDM).

There are fundamental problems in the application of physically-based models for practical prediction in hydrology. These problems result from limitations of the model equations relative to heterogeneous reality and the lack of a theory of subgrid scale integration for obtaining meaningful effective parameters at the grid scale. To address these issues, an improved theoretical understanding of spatial variability and how various properties scale and interact is necessary. This is required to properly integrate processes up to the required scale of interest or grid.

Potential Impacts of Climate Change on the Hydrology of the Great Salt Lake Basin

Principal Investigator:
Upmanu Lall (PhD), Civil Engineering

Student Assistant:
Taiye Sangoyomi (MS), Civil and Environmental Engineering

Problem and Research Objectives
Current projections of global climate change induced by greenhouse gas emissions may lead to hydrologic imbalances with particularly severe impacts in the arid Western U.S. Identification of controls and variations of regional climate is important not only geographically but over long time scales. Closed basins, and in particular closed basin lakes, are an excellent location for developing a fundamental understanding of the hydro-climatic interactions in arid regions. Closed basin lakes integrate the basin's hydrologic response and represent it over a variety of time scales through level, salinity, and sediments.

Accomplishments
This work will focus on the generation of runoff from rainfall and snowmelt. The estimation of runoff from rainfall can loosely be separated into estimating the quantities and timing of runoff. The quantity of runoff, usually expressed as a proportion of precipitation or snowmelt, is hardest to estimate or model, so focus is on the estimation of runoff quantity and mechanisms for runoff generation.

Accomplishments
Modeling for this project will be done within the framework of a GIS to increase the effective management of distributed geographic data, such as Digital Elevation Model data and land use or satellite data. We have acquired the GIS GRASS (Geographic Resource Analysis and Support System), developed by the U.S. Army Corps of Engineers. This system was chosen because it is public domain and the source code is available. Additionally, the building blocks for hydrologic models, namely the analysis of flow paths based on topography, are available.

Recent work in distributed hydrologic modeling has been reviewed. In this research, a model will be developed, based on a few state variables, that describes the moisture conditions at each grid cell. Hydrologic processes such as snowmelt, infiltration, and evaporation will be driven by the weather but controlled by these state variables and the local topography and vegetation so that a spatially distributed description of moisture conditions in a basin can be simulated.

When complete, this work could be used to analyze the spatial distribution of water within river basins and the effects of land use and climate changes on water supply.

Potential Impacts of Climate Change on the Hydrology of the Great Salt Lake Basin

The GSL is the fourth largest terminal lake in the world; its climatic trends are apparently well correlated with regional trends, and its fluctuations have a high economic impact and are representative of the basin's—and possibly the region's—hydro-climatic interactions over long periods of time. In this project, we intend to use dynamical analysis techniques to identify the dominant mechanisms relating climatic and hydrologic variables pertaining to the GSL. It is hoped that a fundamental basis for characterizing changes in basin hydrology due to climatic changes at short and long time scales will emerge upon the conclusion of the project.

Accomplishments
The historical and paler time series of the GSL were analyzed from a nonlinear dynamical systems perspective. Our preliminary work suggests that deterministic, chaotic behavior may be present. Work was done to identify climatic regions from meteorologic and lake data. Work to develop predictive models is in progress.
Dynamic Analysis of Hydrologic Systems in the Closed Basins of Western Utah

Principal Investigators:
Upmanu Lall (PhD), Civil Engineering
Christopher J. Duffy (PhD), Groundwater Hydrology

Support Personnel:
Craig Forster (PhD), Geology
Stan Williams (PhD), Mathematics

Student Assistant:
Douglas Oliver (BS), Civil and Environmental Engineering

Problem and Research Objectives

The development and implementation of mathematical models for the circulation of water, solutes (e.g., salts, pollutants), and geothermal heat flow in the mountain and desert basins of Western Utah are emphasized in this project. Our objective is to model the large scale (basin-scale and larger) behavior of these processes.

Modeling results for the coupled nonlinear equations for both heat and dissolved salts demonstrate extremely complex flows which depend upon the buoyancy contrast between recharging and discharging groundwater. Specific objectives are to:

- develop an inexpensive, easy-to-use computer animation package for analysis of coupled nonlinear systems behavior and for simultaneously viewing the complex time changes of pressure, concentration, and temperature in two-dimensional fields; and

- examine climate-topography relations in mountain and desert basin terrain to provide a framework for hydrologic modeling studies such as: time distribution of precipitation with elevation, groundwater circulation resulting from mountain recharge, and haline convection near salt lakes.

Accomplishments

Recent research in the field of nonlinear partial differential equations suggests that complex or even “chaotic” conditions may arise in natural systems subject to strong convective effects (e.g., where fresh and saltwater meet or geothermal waters mix).

It has recently been shown that mountain topography has a fractal or “self–similar” character. Our approach to this problem deals with the relation of “self–similar” topography to the hydrologic processes acting on this topography.

An animation program has been implemented and is being used to produce “animated” movies of the pressure and salinity contours for buoyancy–driven convection of dissolved salts in a closed basin. The animations are proving to be particularly useful in examining the role of anisotropy and heterogeneity on the flow system.

Comparison of periodically stratified basin sediments with the homogeneous–anisotropic system shows an equivalence in the large-scale features of the solutions; for the same effective permeability, the position of the salt nose is the same. However, the stratified system produces local pressure fluctuations not observed in the equivalent homogeneous–anisotropic case. The Rayleigh number, describing the basin-scale balance between mountain recharge and playa discharge, is extended to include the periodically stratified–anisotropic situations.

The role of self–similarity is examined in the second part of the project as a framework for studying the hydrology of mountains in Western Utah. A PhD student is exploring the idea that topography provides a framework for the study of dynamic hydrology of the mountain and basin region of Northwest Utah.

The animation software will allow us to study in greater detail the likely effects of climate change on the hydrology and salinity of closed–lake basins. The implications for palaeoclimatic studies will also be examined since the time scale for development of the free convection cell is on the order of 10,000 years, according to our preliminary simulations.

The fractal study will involve software development and analysis of topographic–hydrologic relationships for the Great Basin region. The research will continue to focus on software development, implementation, and applications which emphasize visual analysis and problem solving.

Publications


Real-time Monitoring of River Flows for Water Supply and Rights Management

Principal Investigator:
Daniel H. Hoggan (PhD), Civil Engineering

Problem and Research Objectives
Remote-sensing instrumentation output linked to high-speed computers by radio and satellite transmission systems enable the real-time monitoring of river flows and reservoir levels for a variety of water management purposes. Flood forecasting, water supply, and water rights administration are some of the major purposes for which successful real-time monitoring systems have been developed.

Computer simulation models of the system being monitored utilize the real-time data to project system response in terms of flows and reservoir levels at various locations and times. These models are also used to analyze the effects of different management alternatives that might be imposed on the system. Graphic display of monitoring system output greatly facilitates the use of real-time data in water management; this, coupled with rapidly advancing display electronics technology, has made graphic displays a topic of current research interest. The objectives of this project are to: 1) determine the state-of-the-art and availability of large (wall size) displays that would have the capability to indicate key conditions of a water system, and 2) seek funding from a water management agency to build a prototype graphic display that could be used within that agency for water information and management purposes.

Accomplishments
A limited review of product literature was made to determine what types of display equipment are available and approximate prices. Discussions were held with an electronic engineer and a computer graphics software specialist to explore computer hardware interfacing and graphics software availability. Preliminary discussions were also held with the Hydrology Section of the Sacramento District of the U.S. Army Corps of Engineers about their interest and requirements for developing a prototype display system. The district has expressed interest in developing a wall display; discussions are continuing.

It was found that some of the most sophisticated displays that have been developed are used in routing ambulances and other emergency vehicles in responding to calls. These are very expensive with costs ranging as high as $250,000 per unit. Some of the tracking features on such systems may be more than is necessary for a water system display.

A menu-driven graphics system operated from a personal computer and projected onto a wall screen would be a relatively inexpensive yet versatile system. Such a system would, of course, have all of the graphics capabilities of the computer monitor and graphics software employed.

The display could be customized to the configuration of the water system with local markers and legends. Flow statistics and level changes could be shown, and the areas of the system could be divided into quadrants for greater detail.
The Role of Climate and Topography on Groundwater Circulation in Hydrologically Closed Mountain and Basin Terrain

Principal Investigator:
Christopher J. Duffy (PhD), Hydrology

Student Assistants:
Ying Fan (MS/CE), Hydrology/Civil Engineering
Douglas Oliver (BS), Civil and Environmental Engineering
Kim McCleary (MS), Civil and Environmental Engineering

Problem and Research Objectives

Present-day environmental fluid flow problems focus on making predictions over large space and time scales in systems which have sparse information. In this research, the complex dynamics of groundwater flow in a topographically closed and undrained playa-lake system is examined through the use of idealized numerical experiments. Research is supported by simple field observations and specific hydrological experiments.

Our broad objective is to conduct numerical simulations of the idealized groundwater flow in a hydrologically closed basin; these simulations will then be used as a basis for studying the dynamics and forces driving flow in these systems.

Accomplishments

In this, the third year of the study, substantial achievements were made in computational-numerical simulation and field experimentation. In an MS thesis (McCleary, 1989), the role of basin or recharge asymmetry, periodic permeability stratification, and anisotropic permeability is examined. A PhD dissertation by Ying Fan, The Effect of Climate and Topography on Regional Groundwater Flow and Solute Transport in the Great Basin, is in the final stages.

Douglas Oliver, an MS student in the CEE Department, is finalizing a field experiment on Pilot Valley playa. In this experiment, space and time changes of the salinity-density gradients on the margin of playa are being examined. Mr. Oliver has installed many observation wells along the western margin of the Pilot Valley playa. His goals are to map the salinity-density gradients on the margin of a saline playa and to determine the time fluctuations of the salinity. Analysis of the data is providing an indication of the length scales for mixing from buoyancy and diffusive-dispersive processes.

A symposium on the subject, The Dynamic Hydrology and Geochemistry of Closed Basin Saline Lakes, was chaired by Dr. Duffy at the 1989 Fall AGU meeting. In addition, Dr. Duffy presented an invited paper at a Penrose Conference, Flow and Associated Transport in Basins: Driving Forces, Coupling, and Geologic Control.

Publications


The Western U.S. Mountain Weather Generator

Principal Investigators:
David S. Bowles (PhD), Civil and Environmental Engineering
Gail E. Bingham (PhD), Meteorology
Upamanyu Lal (PhD), Civil and Environmental Engineering
David Tarboton (PhD), Civil and Environmental Engineering

Support Personnel:
Mohammad Al-Adhami (PhD), Agricultural and Irrigation Engineering
Donald T. Jensen (PhD), Civil and Environmental Engineering
Gregory McCurdy (MS), Soil Science and Biometeorology

Student Assistants:
David L. Martens (BS), Arts and Sciences
Enan F. Jaycoosi (MS), Civil and Environmental Engineering
Cemalina Purzalan (MBA), Business Administration
Vasant A. Shimi (EE), Computer Engineering

Problem and Research Objectives

In the Western U.S., few meteorological observations exist in high elevation areas where USFS properties are located. Therefore, a procedure for estimating climatological variables in mountainous areas is needed to apply the Water Erosion Prediction Project (WEPP) procedure in these regions. Our purpose, through this cooperative agreement with the USFS, is to develop a Western Mountain Climate Generator (MCI1GEN) similar in function to the existing WEPP Climate Generator (CLIGEN). Additionally, we are developing a Western U.S. snowpack simulation model for inclusion in the USFS adaptation of WEPP.

We are utilizing a physically-based approach, using an expanded and improved orographic precipitation model. The model will use radiosonde and lightning data to simulate convective storms. We will represent climatological sequences, synthesized at ungaged locations, using stochastic models, similar to the approach used in the existing CLIGEN; model parameters will be available to users based on latitude, longitude, elevation, slope, and aspect. By using these models, WEPP users will be able to synthesize climate sequences for input to WEPP.

The MCI1GEN will be capable of providing three climate “event types” as input to WEPP: initial snowpack water equivalent on a specified date; melt period climate—precipitation, temperature, and solar radiation characteristics; and winter and summer storms—duration, intensity, and amount. These “event types” are accessible in three “event forms”: design events—associated with various occurrence frequencies or return periods; continuous simulation of climate for up to 20-year periods using stochastic methods; and selected representative historical events or sequences (e.g., average, dry, and wet).

To develop MCI1GEN, we are creating an orographic precipitation model (Model A) which is modified to include convective precipitation in mountainous regions. This will provide a physically-based approach for estimation of precipitation at ungaged mountain sites using gaged site and radiosonde data. The model will be supplemented with the capability for simulation of other climatological variables (e.g., solar radiation, maximum and minimum air temperature, and dew point temperature). When precipitation is in the form of snow, its spatial distribution on the ground will be determined with Model B. Model B takes into account the effects of wind and local topography on snow delivery.

At times of the year when snowpack is present, we will use climate inputs to drive a snowpack simulation model (Model C). The principal purpose of this model will be to provide estimates of water delivery to the top of the soil. These estimates will be input to the hydrology model (Model D, to be developed by the USFS) when snowpack is present. When snowpack is absent, Model C will be bypassed and climatological inputs will be transferred directly to Model D. Model D will drive the WEPP erosion model (Model J).

During the development phase, the sequence of Models A, B, C, D, and J will be applied to gaged sites in selected regions. If sufficient data are not available to calibrate and validate the hydrology and erosion models, only Models A, B, and C will be applied. The scale of resolution for Model A will be coarse, which, for our purpose, is defined to be on the order of a 2 to 10 km grid. Model B will provide a much finer scale of resolution, 60 to 90 m, depending on the availability of topography from a Digital Terrain Model (DTM) or topographical maps.

Climate sequences from Model A will be modeled using stochastic techniques (Model E), and stochastic model parameters will be mapped. Adjustment procedures will be developed for obtaining (fine-scale) Model B output from stochastically generated sequences of (coarse-scale) Model A output. The procedures will be designed to take into account the effects of local topography and shading. Additionally, the capability for representing the effects of regrowth after logging will be included.

Accomplishments

Three developmental phases have been defined for this project: Phase I: Climate data evaluation and generator design, Phase II: MCI1GEN coding and evaluation at representative sites, and Phase III: Generalization to entire Western U.S. Work undertaken so far has been part of Phases I and II. Specifically, we have conducted a literature review, key issues identification, and design and some initial coding of MCI1GEN. Considerable effort has been invested in building the USU project team. This has been necessary due to the complexity of the project and the need for close coordination between the hydrology and meteorology disciplines. Preliminary evaluation of mountain rainfall statistics has been conducted, coding of the orographic precipitation model has been completed, and model verification is underway.

Publications

Distributed Modeling for Hydrologic Simulation

Principal Investigator:
L. Douglas James (PhD), Civil Engineering

Support Personnel:
David G. Tarboton (ScD), Civil Engineering

Student Assistants:
Chi-Chung Lau (PhD), Civil and Environmental Engineering
Yang Ma (BS), Civil Engineering
Zhida Song (PhD), Civil and Environmental Engineering
Selgo Yamashito (BS), Civil Engineering

Problem and Research Objectives

The estimation of runoff (flood and low flow) from un-gaged watersheds has long been a major challenge facing engineering hydrology. Continuous hydrologic simulation seemed to offer great promise as a way to overcome this challenge when the Stanford Watershed Model was first developed over 25 years ago. However, the promise has not been fulfilled because of difficulty in developing relationships between the measurable physical characteristics of catchments and model parameters.

The difficulty lies in two directions:

1. scale changes in which hydrologic processes are most influential in determining streamflow cause a parameter used to calibrate a given sort of flow to mean different things at different scales, and
2. measuring the variability of a physical characteristic of a catchment is extremely difficult.

In this study, a parametric stochastic model is being tried at different scales to determine an optimal scale and variability to use in modeling.

As the next step, the measurements obtained by modern catchment surveillance methods (such as remote sensing) are being evaluated for how well they represent catchment characteristics at this scale. The linkage from remote sensing to model parameters will hopefully make a significant contribution towards improving flow simulation from un-gaged catchments.

Accomplishments

Hydrologic simulation, used to determine an optimal scale for catchment representation, was applied to small catchments in the Piedmont Mountains of Virginia, the coastal mountains of Central California, and the San Gabriel Mountains above the Los Angeles Basin. A Utah catchment was not used in this initial study to avoid the added complexity of having to model snowmelt. A U-curve relationship between the objective function and scale showed that catchment division into 9 to 25 units, each covering about 0.75 square miles, was about optimal.

Remotely sensed and other mapped data are being accumulated from governmental agencies to estimate the spatial distribution of the characteristics of two of these catchments. Preliminary results show a strong correlation with model parameters.

This modeling is expected to add to our understanding of the rainfall-runoff process from small catchments while suggesting a scale to use in analysis. It will also indicate a reasonable scale to use in collecting physical data on catchment characteristics from remote sensing and other mapping sources.

Publications


Flood Risks from Mountain Snowmelt

Principal Investigator:
L. Douglas James (PhD), Civil Engineering

Student Assistant:
Cort H. Lambson (BS), Civil and Environmental Engineering

Problem and Research Objectives
Some of the most valuable real estate in Utah is located on basin margin areas at the foot of the Wasatch Range. The series of wet years in the early 1980s brought severe flooding, and studies were instigated on how to ameliorate the hazards. One contribution was a series of modeling efforts to quantify the hazards of snowmelt flooding and debris deposition below the mouths of the mountain canyons.

One of the main obstacles encountered in simulating streamflow, landslides, and sediment loads was the difficulty in tracking spatially variable snowmelt between north and south-facing mountainslopes with several thousand feet difference in elevation. Most hydrologic models use temperature to index snowmelt and ignore differences in the radiation budget on slopes of varying steepness, aspect, and exposure.

Accomplishments
In this study, field measurements were applied to verify a model of mountain radiation and temperature. The model provides a continuous simulation of the net radiation at catchment points of differing slopes, aspects, and exposures. These radiation differences are then used to model adjustments to basic rates of snowmelt determined from temperatures.

The simulation of direct radiation agreed with values measured in November and December while the results for diffuse radiation under cloud cover were poor, largely because of the lack of reliable information for quantifying cloud characteristics. Temperature readings in the valleys, the mountain canyons, and ridge tops were used to determine lapse rates in summer and winter and during stormy and clear periods.

This radiation simulation was then linked with a continuous streamflow generation model. One step here was to study the sensitivity of the model to the grid density used to express point radiations. About 22 out of 95 possible points were selected, and points with middle elevations were found most critical. The simulations were good for snowmelt at the higher elevations (8000 feet) but did less well at mid elevations (6000 to 7000 feet). This may be tied with a need to use different lapse rate for canyon bottoms than for mountain tops.

This radiation model improves simulation of the risk of water and sediment flood flows caused by snowmelt. These geomorphological processes are essential to understanding the risk of flood and sediment damages to urban property.

Publications
Determination of Regional Evaporation from Measurements of the Atmospheric Boundary Layer

Principal Investigator:
Lawrence E. Hipps (PhD), Soil Science and Biometeorology

Student Assistants:
Edward Swiatek (BS), Meteorology

Problem and Research Objectives

Evaporation is a critical component at all scales of the hydrologic cycle. It is also the largest exchange of energy between the earth’s surface and atmosphere. Although study of evaporation has been done for local scales, little has been done in assessing regional scale evaporation. This is particularly true for semi-arid ecosystems such as the Great Basin.

Since large scale climate models are very sensitive to surface energy fluxes such as evaporation, an improved understanding of the regional scale fluxes of evaporation is necessary to successfully model the global climate. In addition, such information will be valuable for large scale hydrology studies and water management in semi-arid regions.

In this project, the feasibility of predicting the regional scale evaporation of a semi-arid region from measurements of the atmospheric boundary layer will be assessed. Specific goals are to:

- Make a series of soundings of the atmosphere, using balloons and radiosondes, over a semi-arid region during several study periods. A set of measurements of evaporation at four surface sites will also be made.
- Calculate the short-term values of regional evaporation using several theoretical approaches.
- Compare the above estimates with measurements made at the surface. Evaluate the predictions made by each approach and examine the hydrologic implications of the results.

Accomplishments

Field studies have been completed for this project. During the summer and fall of 1990, several experiments were carried out in Goshute Valley, Nevada. This is a typical closed desert basin in the intermountain region of Eastern Nevada. The valley has an area of 940 km² and an elevation of 1400 m. The main plant species are Sarcobatus vermiculatus (greasewood) and Artemisia tridentata (sagebrush). In terms of vegetation, the valley is very typical of the region. The studies were conducted during two one-week periods, one in early July and one in early October.

For each radiosonde, the virtual potential temperature, and specific humidity values versus height will be plotted. This will allow determination of the planetary boundary layer (PBL) height. In addition, the mean temperature and humidity values in the mixed layer will be calculated.

When combined with the wind data, the above will allow calculation of the regional scale sensible heat and evaporation fluxes using similarity theory. From the height of the PBL and values of temperature and humidity in the mixed layer the regional fluxes can be estimated from the conservation equation.

The above approaches will be used to estimate the regional fluxes for each sounding and the daily totals for each study day. The surface flux values will be averaged to obtain the “regional value” for each 30 minutes. The spatial variation between the study sites will also be examined and reported.

Comparison of the evaporation and sensible heat flux values between the surface measurements and those recovered from the radiosondes will be made for each day. In addition to checking estimate agreement, analysis will be conducted to examine how this agreement varies with atmospheric conditions.
Flows in Mountain Streams

Principal Investigator:
J. Paul Riley (PhD), Civil and Environmental Engineering

Student Assistants:
Philippe Zgheib (CE), Civil and Environmental Engineering
Mohammad Hegazy (MS), Civil and Environmental Engineering

Problem and Research Objectives
This project was developed to relate flow and sediment movement in mountain streams to energy conditions.

Accomplishments
In this project, an attempt was made to define and quantify the flow characteristics which surround large bed elements, such as large boulders, in tumbling flow in steep mountain streams.

Flume studies were conducted in which the flow characteristics were observed by pressure measurements and by injecting dye into the water. Records were made by using a small pitot tube and a video camera.

Characterization of flow mechanisms, pressure gradients, force fields, and velocity profiles around large bed elements is needed to further understanding of energy mechanisms and for application of these mechanisms to stream morphology, soil conservation, and fish habitat requirements. Philippe approached the problem from an experimental aspect by using a flume, pressure measurements, and data recording facilities available at the UWRL, including a video recorder. Studies were done using large bed elements of various sizes and shapes to identify differences in flow characteristics which might result from the shape of the bed element.

Publication

Leaching During Irrigation

Principal Investigator:
J. Paul Riley (PhD), Civil and Environmental Engineering

Student Assistants:
Mohammad Hegazy (MS), Civil and Environmental Engineering

Problem and Research Objectives
This project was developed for the study of chemical transport in irrigated fields.

Accomplishments
This research involves the development, testing, and calibration of a computer model for predicting 1) the rate of chemical movement from a soil horizon through the leaching process, 2) the required leaching component of irrigation applications to maintain a salt balance in the soil profile, and 3) the rate of movement of chemicals to the groundwater reservoir and, thus, the rate of deterioration (if any) of groundwater quality.
Studies of Drainage Basin Composition and Scale

Principal Investigator:
David G. Tarboton (PhD), Civil Engineering

Student Assistants:
Anirudha Shimpi (BS), Computer Science
Ramanprasad Kari (BS), Civil Engineering

Problem and Research Objectives
This research is part of an ongoing effort to understand the relationship between landscape geomorphology and the hydrologic processes that form the landscape. Currently, our understanding of landscape forming processes is encoded in governing equations based on physical principles. Computer simulations based on these equations give channel networks structures that are qualitatively similar to natural channel networks. Our objective is to quantitatively compare basin scales and scaling properties of simulated landscapes with real landscapes as obtained from digital elevation data.

Drainage density, the length of channels per unit area, is a fundamental length scale associated with the degree of dissection of the landscape by the channel network. The objective determination of drainage density is problematic because it is usually dependent on map resolution. However, recent work has suggested that the break in scaling associated with a switch in the mechanism dominating sediment transport from stabilizing diffusive processes to unstable processes can be used to determine drainage density. This is possible because the stability threshold appears as a break in the scaling of slope with contributing area, something that is readily extracted from digital elevation data as well as simulated landscapes.

We intend to verify this using simulated landscapes. In addition, we intend to develop an explanation of the scaling of slope with contributing area in the unstable channelized region. Here, digital elevation data has suggested multifractal structures; these need to be understood.

Accomplishments
A proposal has been submitted, in collaboration with Rafael Bras, MIT, to the USGS. In addition, experimental work is planned, and a proposal has been submitted to the NSF to support experimental investigations using the rainfall simulator and test bed at the UWRL.

We have developed a numerical model to simulate the evolution of landscapes given a parameterization of the sediment transport function. This model is unique in that it is sensitive to small perturbations and, thus, the theoretical stability limits predicted by Smith and Bretherton (1972). This is achieved by having the flow directions stochastically assigned at each time step with the probability of drainage in each downward direction proportional to slope. Some preliminary results are shown in Figure 1.

Next, we will analyze results from this model to test whether the drainage density obtained compares to that predicted by theory.

Reference

Figure 1. a) Initial conditions showing smooth landscape; and b) simulated landscape after 500 time steps on a 10 x 10 matrix showing the development of instabilities, the precursors of valley and channel networks.
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Anaerobic Biotransformation and Fate of Heterogeneous Pollutants in Ground Water

Principal Investigators:
Sam Ghosh (PhD), Civil and Environmental Engineering
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Ursula Trueman (BS), Civil and Environmental Engineering
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Bibi H. A. Rashid, Civil Engineering
Dinesh R. Setty (BS), Civil Engineering

Problem and Research Objectives
Almost two-thirds of the public water supplies in Utah are derived from groundwater, and 90 percent of the rural residents depend on it for their domestic water needs. Groundwater is commonly polluted by heterogeneous organic pollutants that reach aquifers from landfills, septic tanks, animal feedlots, municipal and industrial waste lagoons, hydrocarbon wastes from gasoline or diesel fuel, and other sources.

Our overall objective was to develop a better understanding of the mode and mechanism of anaerobic microbial transformation of heterogeneous organic pollutants (landfill leachate of a hydrocarbon mixture) in the groundwater environment. Specific attention has been given to:

- kinetics of deoxygenation and associated changes in redox potentials;
- effects of fluid flow, DO input, and pollutant, nutrient, and organism concentrations on deoxygenation and biotransformation;
- sequential anaerobic transformation of pollutants;
- mathematical simulation of the biodegradation and transport processes; and
- estimation of model coefficients.

Accomplishments
Simulated laboratory aquifers were filled with a homogeneous isotropic medium, and data were acquired on deoxygenation, biotransformation, and pollutant and catabolite transport. Major tasks were: design and installation of a laboratory aquifer, determination of acclimated culture, assessment of deoxygenation kinetics under selected conditions of temperature and pollutant flow-through rates, delineation of biodegradation patterns and monitoring the movement of pollutant and degradation products, estimation of biokinetic constants, and development and calibration of a mathematical model to match the observed movements.

The following tasks have been completed:

- Design, fabrication, installation, testing, and modification of a simulated one-dimensional flow aquifer—16-ft. long.
- Characterization of the granular aquifer material for grain-size distribution, specific gravity, moisture content, porosity, void ratio, and hydraulic conductivity.
- Development of break-through curves using a conservative tracer for the determination of selected hydraulic properties (hydraulic conductivity, dispersion coefficient, linear velocities, and flow-through rates at different hydraulic gradients) of the laboratory aquifer.
- Collection and chemical characterization of a heterogeneous pollutant (landfill leachate).
- Development of a psychrophilic (10°-15°C) culture for use in seeding the aquifer.
- Completion of a baseline and seven test continuous-flow aquifer runs.

Completed work shows that deoxygenation of aquifers can occur quickly even under the favorable conditions of low temperature (which supports a higher DO), dilute waste, and high aquifer flow rate (which brings in a higher DO mass input). We are continuing our research in the area of hydrocarbon pollutants even though USGS funding has expired.

Publications
Evaluation of Hydraulic Interconnections in Heterogeneous Multi-aquifer Systems

Principal Investigators:
Marian W. Kemblowski (PhD), Hydrology
Upmanu Lall (PhD), Civil Engineering

Student Assistants:
Susan Eyzequirre (BS), Civil Engineering
Carolyn Murphy (MS), Mathematics

Problem and Research Objectives
State agencies in Utah are working on long-term groundwater development and quality protection plans for the major aquifers in the state. Current and future groundwater development is likely to be curtailed by the degree and location of aquifer contamination.

The Utah Department of Health is particularly concerned with the likelihood of contamination of water supply wells in the principal aquifers—and/or restrictions on the development of groundwater supply in the area to avert well contamination. UWRL investigators are assisting the Utah Department of Health in addressing this issue. Specifically, the degree of aquifer inter-connection and its likely impact on groundwater cross-contamination are being examined.

Standard aquifer tests that are used to determine the properties of a confining layer are not applicable in all situations. Thus, there is a need to develop new approaches for the cases where the standard tests are inappropriate.

Our principal objectives in this study are as follows:
1. Using spectral theory and numerical modeling, we shall analyze the applicability of standard aquifer tests to multi-aquifer systems characterized by the spatial variability of the confining layer’s properties.
2. We shall develop new aquifer test methods and associated solutions to evaluate the hydraulic parameters of such systems, in particular, the spatial distribution of the confining layer’s transmissibility.
3. In collaboration with the Utah Division of Environmental Health and the USGS, we shall apply the results of this study to the Salt Lake Valley groundwater system.

Accomplishments
1. Pump test behavior in leaky aquifers with radially-symmetric heterogeneities in the leaky layer–time domain has been analyzed. A finite difference code was developed, tested, and used to analyze this problem.
2. The Adomian Decomposition Method was applied to simulation of groundwater flow in leaky aquifers with a stochastic leaky layer. The results indicate that even large fluctuations in the transmissibility distribution result in relatively small changes in drawdown. This indicates that standard pump tests are not suitable for heterogeneous leaky aquifers. This work will be submitted for publication in Water Resources Research.
3. An analytical solution was developed to analyze pump test data in heterogeneous leaky aquifers.
4. A numerical solution to pump test scenario was developed using the frequency domain. A finite-element algorithm was derived. This approach will be submitted for publication in a professional journal, most likely Ground Water.
Spreading and Mixing of Soluble Contaminant Plumes in Self-similar Porous Media

Principal Investigators:
Marian W. Kemblowski (PhD), Hydrology
Gilberto Uroz (PhD), Civil Engineering
Joe Koebbe (PhD), Mathematics

Student Assistants:
Jet-Chau Wen (MS), Civil and Environmental Engineering
Joan Oana (BS), Mathematics
Ching-Min Chau (MS), Civil and Environmental Engineering

Problem and Research Objectives

Improved understanding of the transport and fate of contaminants in groundwater has been designated by the USGS as a priority research interest for the Water Resources Research Program. Our research deals with two aspects of this problem: 1) the spreading and mixing of a contaminant plume in groundwater, and 2) the oxygen-limited biodegradation of such plumes. These phenomena are being explored for aquifers that have a fractal (self-similar) log-permeability (logK) distribution. For such aquifers, we cannot assume a finite range of correlation for logK.

Our principal objective is to determine how the self-similar nature of the logK distribution influences the spreading and mixing of contaminant plumes. There is a distinct difference between spreading and mixing. It is of particular interest to investigate how the fractal properties of the logK distribution, namely its fractal dimension in the vertical and horizontal directions, and its intrinsic variance impact the spreading (usually called dispersivity in the groundwater literature) and the mixing coefficients.

We are using spectral methods, stochastic analysis, and numerical and analytical modeling to solve the stochastic differential equation that governs the transport of soluble plumes in heterogeneous formations. In particular, we are analyzing this process for self-similar distributions of logK. No simplifying assumptions are being made regarding the fractal dimensions of logK distribution. Specifically, we are allowing the fractal dimension to be anisotropic, i.e., different in the vertical and horizontal directions.

The results of this study should be of value to researchers and practitioners interested in the soluble plume fate and transport in groundwater. Results will also be of particular interest to the groundwater hydrologists and environmental engineers who work on the fate of contaminant plumes whose degradation is limited by oxygen transport.

Accomplishments

1. Analysis of plume spreading in stratified soils with fractal distribution of hydraulic conductivity was performed. The results indicate a strong impact of the fractal dimension on the dispersion process. These results were presented last year at a conference on new approaches in stochastic hydrology held in Warsaw, Poland. A summary of the results will be sent to the Journal of Hydrology.

2. Three-dimensional analysis of plume spreading in soils with fractal distribution of log-permeability was performed. The results are currently being reviewed and analyzed and will be submitted for publication in Water Resources Research.

3. One-dimensional and three-dimensional stochastic analysis of unsaturated flow and transport in soils with fractal distribution of log-permeability was performed. The results were presented at a conference on stochastic analysis of unsaturated flow in Tucson, Arizona, in April, 1991.
Estimation of the Space and Time Variability of Non-point Source Groundwater Contamination

Principal Investigators:
Upmanu Lall (PhD), Civil Engineering
Ken Bosworth (PhD), Mathematics

Student Assistants:
Wesley James, Computer Science
Yong Il Moon (BS), Civil and Environmental Engineering
Jinghui Niu (MS), Civil and Environmental Engineering
Akin Owosina (BS), Civil and Environmental Engineering
Sylvain Sardy (BS), Mathematics

Problem and Research Objectives
Non-point source pollution (due to irrigation, septic tanks, leaking gasoline reservoirs, and leakage from waste storage sites) is a widespread cause of poor groundwater quality. Extensive groundwater quality sampling activities are being conducted across the country to identify the degree of non-point source pollution of ground water. A very important aspect of groundwater monitoring (for regulation or mitigation efforts) is to accurately infer from collected data the extent and movement of contaminants over space and time. Non-parametric regression techniques are being developed to simultaneously quantify the variability in contaminant concentration over space and time.

Industrial Groundwater Pollution

Principal Investigators:
Marian W. Kemblowski (PhD), Hydrology
Upmanu Lall (PhD), Civil Engineering

Support Personnel:
Gilberto Urroz (PhD), Civil and Environmental Engineering

Student Assistant:
Jet-Chau Wen (MS), Civil and Environmental Engineering

Problem and Research Objectives
Our major objective was to provide technical assistance to the Utah Department of Health in assessing the impact of Sharon Steel on groundwater quality.

Accomplishments
A database with over 300 citations on nonparametric density estimation, regression, and time series has been compiled. In addition, an annotated bibliography has been prepared to help summarize the mathematical properties, features, and relative strengths and shortcomings of different nonparametric methods (e.g., kernel, nearest neighbor, projection pursuit, variable kernel, series, and smoothing spline estimators) for density estimation and regression. Software was developed for kernel, nearest neighbor, and variable kernel density estimation and for kernel regression.

Comparative tests of kernel regression estimators, multi-quadratic surface estimators, and splines were performed with spatial data. Issues related to model robustness, bias, and confidence intervals were investigated.

Applications of the methods with a broad spectrum of synthetic data have been performed and are underway. Data sets from Salt Lake County were acquired, and applications of the techniques studied with this data are also underway.

Accomplishments
1. Development of a research plan for field investigation and modeling of the subsurface conditions at Sharon Steel. A phased approach to this problem was proposed.
2. Participation in meetings between the Utah Department of Health, the U.S. EPA, U.S. EPA’s contractor (CDM), and Sharon Steel’s contractor (ABC). A technical evaluation of the contractor’s work on this project was performed.
3. Review of the Site Assessment and Corrective Action Plan prepared by CDM for the U.S. EPA.
Groundwater Pollution by Mining

Principal Investigators:
Upmanu Lall (PhD), Civil Engineering
L. Douglas James (PhD), Civil Engineering
Marian W. Kemblowski (PhD), Hydrology

Student Assistant:
Zhida Song (PhD), Civil Engineering

Problem and Research Objectives
The mining activities of Kennecott Utah Copper at their Bingham Canyon site have allegedly led to the contamination of ground water in a large area of the aquifers in Southwest Salt Lake County. The State of Utah is interested in assessing the extent and nature of this contamination and its impact on aquifer yields and proposed remediation methods. Our objective is to assist the Department of Environmental Health perform such an evaluation.

Groundwater Study of the Stewart Lake Waterfowl Management Area Near Jensen, Utah

Principal Investigators:
J. Paul Riley (PhD), Civil and Environmental Engineering

Student Assistant:
Kyle H. Kirchner (MS), Civil and Environmental Engineering

Problem and Research Objectives
The Stewart Lake Waterfowl Management Area (WMA) is located south of Jensen, Utah, along the Green River. The land around Stewart Lake is primarily used for growing hay and for pasture. Between 1974 and 1979, the USBR installed subsurface drains in the areas north and west of Stewart Lake to lower the water table and allow the area to be put into more productive agricultural use. These drains provide most of the inflow to Stewart Lake. A number of seeps or springs that discharge along the northern shore of the lake, and groundwater inflow within the lake, supply additional water.

During 1986 and 1987, the USGS conducted a reconnaissance investigation on the water quality and biota of the Stewart Lake WMA to determine if there were possible toxic levels of selenium and boron present in the lake and/or wildlife. The investigation showed that water quality in two of the five drains was consistently above the Utah Wildlife Protection Standard of 50 μg/L for selenium and that significant levels were contained in the waterfowl and fish. These findings prompted the USGS to proceed with a more detailed study of the area to identify the sources of the selenium and to locate positions within the drainage system where the selenium concentration was at significant levels.

The scope of the UWRL investigation focused on the shallow groundwater system at the Stewart Lake WMA. The groundwater flow regime was investigated, including water quality, flow gradients, and possible source area(s) of selenium. The USGS limited their study to the water quality within the underground drains and the surface runoff in an attempt to trace the flow paths along which the selenium is conveyed. The specific objectives of the UWRL investigation were to: 1) define the local direction(s) and gradient(s) of the shallow groundwater system contributing to Stewart Lake, 2) analyze the chemistry along groundwater gradients for changes in selenium concentrations, 3) estimate the rate of groundwater flow along the gradients, and 4) attempt to identify any suspected source area(s) of selenium within the region.

Accomplishments
Available hydrogeological information was used to develop estimates of the aquifer area contaminated in terms of various chemical constituents. Existing pumping test information was used to develop estimates of aquifer transmissivity and storativity. These estimates, together with recharge estimates and water rights information, were used to develop estimates of the impacted yield. Proposals to remediate the contaminated area were also evaluated.

Publications
Confidentiality agreements prevent us from listing publications at this time.
Movement of Pesticides in the Subsurface

Principal Investigators:
R. Ryan Dupont (PhD), Environmental Health Engineering
R. D. R. Parker (PhD), Public Health
H. M. Deer (PhD), Environmental Health/Industrial Hygiene

Student Assistant:
G. Don Summit (MS), Environmental Engineering

Problem and Research Objectives
Tebuthiuron (Spike®) is widely used for the control of undesirable woody shrubs on rangelands in the Intermountain West. This herbicide is more water soluble (2.5 g/L) and persistent (τ₉₀ > 12 to 15 mo) than most herbicides and is currently on the U.S. EPA's priority list of leachable pesticides. While the manufacturer of tebuthiuron indicates that it does not move greater than two feet in a three year period, Johnsen and Morton (1989) detected tebuthiuron as deep as 42 inches 11 years after its application in Arizona. This study was undertaken to provide long term fate data for tebuthiuron in soils in the Intermountain western soils, based on a growing concern for the protection of groundwater quality from non-point sources of agricultural pollution.

Accomplishments
Six field sites were identified where known tebuthiuron applications were carried out over the past nine years. Soil cores, to five feet, were collected and composited in six to 12-inch lifts at three locations at each application site. Tebuthiuron concentrations in each composite sample were quantified via HPLC analysis following Tissuemizer extraction/Kuderna–Danish concentration procedures.

Tebuthiuron concentrations were detected in soils from Hill AFB and Shivwitz, Utah, Malad, Idaho, Bosler, Wyoming, and Walden, Colorado to depths of 48 inches. Due to unusually high precipitation, a worst-case for leaching in the region existed between the times of application of tebuthiuron and the times of sampling at these field sites. Mass balances yielded estimated disappearance times of tebuthiuron from these soils which ranged from 3.3 years at Shivwitz, Utah, to 8.6 years at Bosler, Wyoming. The persistence of tebuthiuron in these soils was found to be dependent upon temperature. Based on these mass balance calculations, biodegradation rather than leaching was the likely cause of tebuthiuron loss from the soils at five of the six test sites. Estimations for the Lander field site were im-
possible since no residual tebuthiuron soil concentrations were detected in Lander soils. At the Lander site, leaching was the likely cause of tebuthiuron loss from the upper five feet of the soil. The fate of the tebuthiuron applied to the Lander soils was not determined; however, the fate of tebuthiuron in soils at the other sites was found to depend upon the soil clay contents and CEC values.

Two mathematical models (VIP, Utah State University, and CMLS, University of Florida) were used to aid in the evaluation of field data collected. Both models have been designed to provide estimates of the fate and persistence of organic contaminants in the vadose zone, but they differ significantly in their conceptual development, input requirements, and output provided.

Neither model predicted peak tebuthiuron concentrations observed in the field soils, using tebuthiuron partition coefficients available in the literature. However, increasing the organic carbon normalized distribution coefficients, Kₐₒ, to 400 resulted in more accurate model predictions of peak tebuthiuron concentrations. It was demonstrated in this study that, with the input of appropriate partition coefficients and soil and climatic data, reasonable estimates of the fate and persistence of tebuthiuron may be obtained from the VIP and CMLS models. The VIP model was the more robust of the two models in its application to the wide variety of sites investigated in this study.

Reference

Publications


Groundwater Contaminant Transport Using Boundary-fitted Coordinates

Principal Investigator:
Gilberto Urroz (PhD), Civil and Environmental Engineering

Problem and Research Objectives
Solution of flow and contaminant transport equations for aquifers having irregular boundaries can be simplified by transforming the physical coordinate system into one in which the boundaries constitute constant coordinates. The governing equations are subsequently transformed and solved in the new coordinate system.

Accomplishments
A proposal was written in which boundary-fitted coordinates were to be used to transform the physical domain of an aquifer with irregular boundaries to solve the flow and contaminant transport governing equations. A two-dimensional aquifer, such as that underneath Cache Valley, was to be simulated. The proposal included the implementation of conservative and non-conservative contaminants.

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Water Resources Planning and Management
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Utah Water Research Program Coordination

Principal Investigators:
L. Douglas James (PhD), Civil Engineering
David S. Bowles (PhD), Civil and Environmental Engineering
R. Ryan Dupont (PhD), Environmental Health Engineering

Problem and Research Objectives

The Utah Center for Water Resources Research (UCWRR) works with its Citizen Advisory Council to establish water resources research priorities for the State; the Utah Director works with the Directors of the other institutes in the Pacific Southwest to establish regional research priorities. These priorities are then compared with the active studies in the Utah research program, and State and USGS funds made available through a cooperative program help support topics that are not receiving adequate attention or that offer promise for building larger research programs.

The current priority topics are protection of waters from contamination, conjunctive water supply management, water use transfers in river basin management, basin-wide water quality management, and flood control and floodplain management. The four projects active within this program are:


2. Economic Incentives for Managing Groundwater Pollution in Salt Lake County—Terrence F. Glover, Principal Investigator;

3. Evaluation of Hydraulic Interconnections in Heterogeneous Multi-aquifer Systems—Marian W. Kemblowski, Principal Investigator; and


Through the UCWRR, interactions with the other states in the region and nationwide are sponsored to foster interuniversity and interdisciplinary projects and to work with the other institutes in research program building and in cooperative interactions between the states and the federal agencies. All of these opportunities are brought to the attention of the university researchers in Utah in research program building.

Accomplishments

The four research projects listed above are within one year of completion. Each one is proving successful in addressing its targeted problems. Descriptions of project accomplishments for these projects are contained within this Technical Report.

The UCWRR Director is actively working with other center directors in updating the list of research priorities and in organizing cooperative research projects involving two or more states in the region. The states are also cooperating in studies on severe—sustained drought in a project involving a number of federal, state, and local agencies, and on the remediation of polluted aquifers through interactions with the Department of Energy. We will be organizing a new four-year research program to start in July 1992.
The Use of Remote Sensing to Management of Snow Removal and De-icing Operations on Highway Systems

Principal Investigators:
J. Paul Riley (PhD), Civil and Environmental Engineering
William J. Grenney (PhD), Civil and Environmental Engineering

Student Assistants:
John Bjerregaard (MS), Civil and Environmental Engineering
Ravi Kumar Penmetsa (MS), Civil and Environmental Engineering

Problem and Research Objectives
Successful highway de-icing and snow removal operations depend on their being undertaken at the appropriate locations in time and space. On-site meteorologic and hydrologic parameters are transmitted from remote highway locations by microwave and satellite relay networks. In this research, measured meteorologic and hydrologic parameters will be coupled with field experience to improve the efficiency for managing de-icing and snow removal operations on highway systems. A satellite relay procedure will be added, if possible, to test its reliability in comparison with the microwave system.

An existing model, developed by Surface Systems, Incorporated (SSI), will be used to make short-term predictions of future conditions at the site on the basis of the measured hydrologic and meteorologic parameters and weather data provided by the NWS. In addition, an "expert systems" component will be developed and incorporated into the SSI model. This will provide the capability to include "judgmental" considerations of an experienced highway maintenance engineer in forecasting and recommending courses of action.

Accomplishments
A literature review of related research has been completed and documented. We have obtained the SSI computer program to predict highway surface temperatures, and some preliminary testing of this software package has been carried out.

In addition, we have developed and tested a procedure for data storage and retrieval on the computer systems at USU. This system was patterned after one used for storage and retrieval of data received through a satellite down-link.

We are conducting a study to improve the prediction of road-surface temperatures at remote locations in mountainous terrain. Because of the mountainous terrain in Utah which produces marked changes in highway elevations in relatively short distances, and because climatological stations—including SSI monitoring (RPU) sites—are often spaced at considerable distances, improved procedures are needed for predicting road-surface conditions at intermediate locations. In an attempt to meet this objective, we are examining the possibility of providing a user interface with data obtained directly from the NWS. In addition, we will add a meteorological model to the system which is capable of predicting local weather patterns in mountainous terrain.

A report on these investigations is being prepared by John Bjerregaard as an MS thesis.

We are developing software for a knowledge based program to assist dispatchers and other users in implementing snow and ice removal operations. We anticipate that this system will be capable of including much of the operational knowledge which otherwise would require many years of experience for a dispatcher and/or operator of the snow and ice removal program.

A weather station and highway monitoring equipment (SSI) are being installed at a specific site in Sardine Canyon near Logan. Some of the meteorological sensors and microwave transmission equipment has been installed at this site. However, the road sensors were not received by the UDOT in sufficient time to be installed in the highway for the 1989-90 winter season. Because of this, there will be no data from the Sardine Canyon site during that period of the project. This deficiency will cause some slight changes in the objectives of the study.

Data transmission networks (microwave and perhaps satellite) will be installed and tested for the Sardine Canyon location. As indicated above, we have installed the microwave system, but have not yet generated data for transmission from this location. Because the road sensors were not installed, we will not install a satellite transmission system at this site.

The results of this study will contribute to the management of highway de-icing and snow removal operations throughout the State and in other locations of the country. The addition of the knowledge based software and the user interface will enable NWS data to be directly received by the operator. It is suggested that a micro-meteorological model be added to improve the prediction of highway surface temperatures in mountainous terrain at intermediate locations between existing meteorological observation points.

Publications

Project Number: NDSU
Sponsor: North Dakota State University
Project Duration: October 1988 – September 1991
Project Status: Research in Progress
Urban Water Resources Management

Principal Investigator:
L. Douglas James (PhD), Civil Engineering

Student Assistants:
Thomas Jackson (MS), Civil and Environmental Engineering
Yang Ma (BS), Civil and Environmental Engineering
Zhida Song (PhD), Civil and Environmental Engineering

Problem and Research Objectives

The City of Pasadena has joined with adjacent communities in Southern California in planning the development and use of Arroyo Seco, a stream which carries runoff from the San Gabriel Mountains to the North. Devil’s Gate Dam was built on the stream about 70 years ago for flood and debris control and to augment recharge of the Raymond Groundwater Basin, the oldest and still a major source of water supply for the highly urbanized area. Streamside areas below the dam are the site of the Rose Bowl and related recreation and aesthetic development that have made a major contribution to the character of the city.

Recently, the dam has been declared unsafe; help has been sought for the area on what has become known as the Devil’s Gate Multiple Use Project (DGMUP) for refurbishing the dam to safety standards and also for improving the reservoir to receive imported water from Northern California to enhance groundwater recharge within a recharge program that also enhances the urban environment. Streamside areas below the dam are the site of the Rose Bowl and related recreation and aesthetic development that have made a major contribution to the character of the city.

Project sponsors envision their community taking innovative leadership in finding ways to restore the natural character of a stream in a highly urbanized environment. They want to continue the traditional purposes of water resources management while enhancing the quality of urban life. The purpose of this project is to help in conceptualizing the project and quantifying its benefits for use in raising financial support from a variety of sponsors.

Accomplishments

The development program was subdivided into seven purposes, three locations, and six types of impact. The classification by purposes selected by the project sponsors covered:

1. Flood control (handling sediment-laden stream flows during major storms and after upland fires).
2. Water resources (managing water storage in lakes and flows in streams within a recharge program that also enhances the urban environment).
3. Recreation (parks, play fields, and trails).
4. Habitat (riparian and mountain areas restored to near natural conditions in a highly urban setting).
5. Reclamation (managed aquifer recharge and withdrawals to enhance local water supplies).
7. Human resources (jobs for people servicing the facilities and educational and natural areas).

The classification by geographical area covers:

1. The tributary watershed.
2. The area around the dam and reservoir.
3. The floodplain along the Arroyo Seco downstream to its confluence with the Los Angeles River.

The classification by type of impact distinguishes:

1. Impacts on property values near aesthetically attractive facilities, taken as within 0.25 mile.
2. Impacts on property values within the community as a whole as the quality of life is uplifted.
3. Recreation by people from the Pasadena area.
4. Tourism by people coming to see such attractions as a science museum or restored natural environments.
5. Direct economic gains to the community from expenditures and jobs.
6. Indirect and secondary gains to the community as money spent flows through the local economy.

The development program for each geographical area will be separately formulated to pursue the seven purposes. Its economic impacts will then be estimated.
Principal Investigators:
David S. Bowles (PhD), Civil and Environmental Engineering
Loren R. Anderson (PhD), Civil Engineering
Terrance F. Glover (PhD), Agricultural Economics

Student Assistants:
Daniel Asante-Duah (PhD), Civil and Environmental Engineering
Wan-Fang Chang (MS), Civil and Environmental Engineering
Evan Nixon (MS), Engineering Management
Mark Woodbury (BS), Civil and Environmental Engineering

Problem and Research Objectives
There has been a growing interest in the development and application of methodologies for systematically assessing risks associated with various types of engineering projects. Applications include dam safety improvements, hazardous waste site remedial actions, and nuclear power plant siting and design.

Such risk assessment methodologies begin with risk factor identification and estimation. These initial steps are then followed by an iterative evaluation of various risk aversion alternatives leading to the basis for the recommendation of an alternative expected to achieve an acceptably low level of risk. This last step can involve public participation, but ultimately is made by the decision makers who must shoulder the responsibility for their decision. A continuing program of risk management is then implemented. Such a program can include inspections and training.

Several investigators at USU have been actively involved in developing risk assessment techniques for a variety of water-related and engineering systems. Research includes:

• Assessment of various geological hazards such as liquefaction potential mapping (1980–present).
• Development of approaches to risk assessment of dam systems and presentation of results for dam safety decision making (1978–present).
• Development of software for performing risk assessment for dam safety evaluation (1987–present).

Accomplishments
Current activities in risk–benefit assessment are directed toward the following goals:
1. Identification of practical uses of risk assessment in dam safety decision making.
2. Improved methods for estimation of system response probabilities.

To achieve these goals, we are focusing on the following tasks:

• Results of previous research will be disseminated;
• Investigators will keep current with the state-of-the-art in risk assessment;
• State-of-the-art will be advanced through new research projects for risk assessment and management methodologies for water-related problems; and
• Investigators will assist in the application of risk assessment procedures.

To disseminate the results of previous research, articles are being prepared and submitted to refereed journals. Also, several invited papers, lectures, workshops, and seminars have been presented.

The framework for risk assessment of dams developed at USU is being incorporated into a computer software package. The package is expected to include the capability for specification of probability and consequence relationships, including those based on hydrologic and seismic analyses, utilization of an historic dam failure database, basic risk assessment computations for individual dams and dam systems, post-processing of results for various alternatives, and graphical and tabular display of results.

Benefits associated with various diking projects or pumping to the West Desert to mitigate flooding damages around the GSL have been evaluated. These evaluations were performed for the UDWR in connection with their submission of technical recommendations to the Utah State Legislature, as a part of the Environmental Impact Study for the West Desert Pumping by Bio-West, Inc., Logan, Utah, and for the U.S. Army Corps of Engineers, Sacramento office.

In addition, there has been a continual dialogue with representatives of the State of Utah, the USBR, and the U.S. Army Corps of Engineers on the subject of risk assessment of dams. UWRL faculty have served as expert consultants on the risk assessment of several major existing dams and have presented a series of workshops on this subject within the U.S. and overseas.

Publications


Economic Issues in Water Resources Planning

Principal Investigator:
L. Douglas James (PhD), Civil Engineering

Student Assistants:
Melanie Bengston (MS), Civil and Environmental Engineering
Hongbing Yin (MS), Civil and Environmental Engineering

Problem and Research Objectives

In water resources planning, uncertain alternatives are compared in an evaluative process. The more streamlined the process, the more alternatives can be compared and planners can be given greater assurance that the best course of action has been examined. Also, because water resources planning sets a course of action for the future, planners deal in uncertain predictions that are better expressed in a probability distribution of net benefits than a single deterministic estimate.

Benefits are more difficult to project than costs. In irrigation planning, the prices of project outputs can be quite volatile. In addition, the year-to-year variability of the climatic and hydrologic inputs of precipitation and sunshine and the agronomic factors impacting crop production and farming costs cause profits to be highly variable.

Benefit and cost estimation can be streamlined by the use of parametric models that estimate quantities at a large scale. Less information is required, and the computations go more rapidly. The estimation of construction quantities can be completely avoided by deriving costs directly from deterministic parameters when indexing the physical characteristics of the site. In each simplification, one loses accuracy for a particular dam and increases the probability of minimizing overall costs by being able to compare more alternatives.

Accomplishments

The ability to use stochastic techniques to estimate the probability that a project will be economically and financially viable is often a much more valuable piece of information than the benefit-cost ratio alone. To quantify the uncertainty in forecasting future time streams for benefits and costs, the properties of the historical sequences were examined to estimate important stochastic parameters. These were then used with Monte Carlo techniques to simulate reservoir operation and outputs over the project life. For example, crop production costs and prices are simulated from their historical variabilities as measured by year-to-year changes in the CPI. Other variables can be added, based on local situations, with respect to the deterministic and stochastic parameters; project performance can be simulated through numerous scenarios. The results can then be used to quantify the uncertainties and to estimate the probabilities that the benefits will exceed the costs in various situations.

Reliable methods for unbiased comparison of more alternatives can make water resources planning more cost effective. Computerized access to verified information makes the analysis quicker and simpler. The planner can review more options and spend more time reflecting on uncertainties.

Publication

The Water Rights Transfer Process as a Management Option for Meeting Changing Water Demands

Principal Investigators:
J. Paul Riley (PhD), Civil and Environmental Engineering
Ray J. Davis (LLD), Law, Brigham Young University

Student Assistants:
Paul G. Hansen (MS), Civil and Environmental Engineering
Chris C. Hogge (MS), Civil and Environmental Engineering

Problem and Research Objectives
Water is a vital element in the development of society. A legal system has evolved to protect water users and provide them with specific rights with respect to water quantity and quality; however, continuing development and changing social needs have also made a water rights transfer system necessary. Water rights transfers are broadly defined as transactions involving legally-binding alterations in the right to water usage.

The potential methods of water rights transfer in Utah were reviewed in conjunction with an analyses of available data to provide a perspective on the overall transfer process. Water rights transfers can be separated into those requiring the State Engineer's approval and those which do not. Both types of transfer occur regularly within the State, but consistent and readily available records are only available for those which require the approval of the State Engineer. These records, maintained by the Division of Water Rights, were analyzed in depth for the 1975-1987 period.

In an attempt to identify the factors which drive or inhibit the transfer process, climate, time to decision, nature of use, status, population, hydrologic basin, and water source were examined. Specific cases were researched to identify costs, types of applicants, reasons for protest, and the effects of the State Engineer's policies.

The exchange (replacement water) process was also studied to identify its administrative origins and the hydrologic, economic, and social factors which influence and drive it.

Accomplishments
In this project, we have ascertained the level and kind of water transfer activities in six western states. The major legal and institutional factors influencing efficiency and equity in these transfer activities have been determined, and the transaction costs imposed on water transfer activities by the legal requirements of each state have been measured. We have compared findings from the six states and have evaluated the transfer processes in terms of efficiency and equity.

Numerous issues and trends relating to the water transfer process in each state have been identified. In addition, we have indicated the additional information needed to further examine and improve the process.

Government administrators at all levels (Federal, State, County, and Water District) will be able to utilize the project reports in obtaining statistics on present water transfer activities in Utah and the other five Western states covered by the study. In addition, guidelines are suggested which provide useful information concerning legal and administrative procedures which might be implemented to improve the efficiency of the water rights transfer process. In this respect, those in the legal profession, and legislators who are concerned with implementing and improving water rights administrative procedures, will be able to utilize project reports.

Publications
Water Conservation in Industry

Principal Investigator:
L. Douglas James (PhD), Civil Engineering

Support Personnel:
Chun-Peng Tang (BS), Chemical Engineering

Student Assistant:
Chaohsien Liaw (MS), Civil and Environmental Engineering

Problem and Research Objectives

For many years, an average amount of agricultural water use was judged reasonable. However, average farmers can waste water, and the criterion for good management shifted to an absolute standard based on the amount of water required biologically to grow crops to maturity.

The shift has not occurred in industry because water use has been too small to be of much concern to factory management because their water bill has been small. It has not been of much concern to water utilities or water resource planners because most water was used for other purposes. The urbanization of the economy is changing both situations, and absolute standards can also save water in industrial uses.

It is now becoming important to shift the standard from water used per unit of production or per employee to an estimate of real need. Scientific principles can be applied to determine how much water is needed. Just as laws of plant biology can be used to estimate crop water requirements, other laws provide bases for estimating reasonable industrial water use. Through this research, this approach is being initiated.

Accomplishments

The conceptual model used for industrial water conservation was to balance savings in water and wastewater treatment costs against the added cost of conservation programs. Examination of the water-use practices in automotive, chemical, food processing, petroleum, and textile plants found in data from the U. S. and China identified the four major water-use categories: process water, heating/cooling water, support water, and construction water. These categories were divided into 14 functional uses, and each of these was examined to determine the principles that control how much water is required. These principles can also be used to determine a minimum water use that may be zero if the water used can be eliminated, such as by air cooling or dry cleaning.

The water use with minimum cost will be optimal in a given context. These contexts vary from case to case and need to be carefully considered in setting a reasonable industrial water use. Conditions change over time as new technologies make water conservation less expensive, full resource utilization makes water supply more expensive, and water quality standards become more rigid.

The classification of ways to conserve water use are: controlling leaks, improving operating efficiency, installing water reuse systems, process modernization or modification, and the extreme of closing the plant. The five main barriers to implementing effective programs are a lack of attention by management, technical know-how, manpower, training, and cost.

A scientific method for estimating industrial water use offers great promise in setting objective standards for water conservation and water rights monitoring. This will help industrial management and regulatory agencies. The research has attracted some interest from overseas, and steps are being taken for coordination with groups conducting related research in the U. S. and Canada.
Operation of Multi-purpose Reservoirs

Principal Investigator:
Trevor Hughes (PhD), Civil Engineering

Student Assistants:
Deren Le (MS), Civil and Environmental Engineering
Beiping Gu (MS), Civil and Environmental Engineering

Problem and Research Objectives

Within this program area, effort is being devoted to the analysis of a multi-objective compromise between economic efficiency and environmental quality related to the operation of major peaking mode hydropower reservoirs. This problem is receiving considerable coverage in the national press because of environmental and recreation interests' perception that Glen Canyon Dam operations are causing serious damage to the Grand Canyon. Controversy is focused on two parameters: 1) the allowable minimum flow rates, and 2) the allowable rates of change in flow rates.

Environmental quality is perceived as being proportional to increases in minimum flow (which causes related decreases in maximum flows) and decreases in allowable rates of change. Economic efficiency (the value to society of energy production), on the other hand, varies inversely to these same parameters.

The value of daytime energy is several times that of nighttime energy—hence, the economic objective is to minimize releases at night so that high releases are possible during peak demand hours.

Our objective is to analyze the economic cost to society of operational changes which are being proposed by environmental interests.

Accomplishments

A conceptual framework for predicting the impact on peak and off-peak period releases due to any possible future increase in minimum release rate has been developed. This framework is based upon statistical analysis of the historic relation between minimum release policy and actual hourly releases as a function of monthly release targets. The quantitative results of testing this hypothesis are underway.

Dr. Hughes is a member of a committee of the Office of Science and Water Technology. This committee is reviewing the research results of the ongoing Grand Canyon Environmental Studies program of the USBR and the National Park Service. Preliminary work under this project has already had an impact on the way in which the Western Power Administration simulates the economic environmental tradeoff.

Publication

Coping with Severe Sustained Drought in the Southwestern United States

Principal Investigators:
L. Douglas James (PhD), Civil Engineering
Frank Gregg (PhD), Natural Resources, University of Arizona
David Tarboton (ScD), Civil Engineering
Donald Kendall (PhD), Civil Engineering, Metropolitan Water District of Southern California
Benjamin Harding (BS), Civil Engineering, WBLA, Inc.
Henry Vaux (PhD), Natural Resource Economics, University of California, Riverside
Duncan Patten (PhD), Botany/Ecology, Arizona State University
Timothy Modde (PhD), Biology
Richard Krannich (PhD), Sociology
David Getches (LJD), Law, University of Colorado

Support Personnel:
Bonnie G. Colby (PhD), Agricultural Economics, University of Arizona
Hanna Cortner, University of Arizona
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Thomas B. Hardy (PhD), Civil and Environmental Engineering
William B. Lord (PhD), Forest Economics, University of Arizona
David Meko, University of Arizona
Phyllis Nash (BS), Mathematics, University of California, Riverside
Elizabeth A. Payton (MS), WBLA, Inc.
Charles W. Stockton (PhD), Hydrology, University of Arizona
Robert A. Young (PhD), Agricultural Economics, Colorado State University

Problem and Research Objectives
Federal, state, and local agencies in the Southwestern United States have built massive storage and conveyance systems to store and trade water. The system is managed to overcome seasonal and multi-year shortages and supply projected demands. The economy of the region was built by establishing a reliable water supply in a largely arid land, and the institutional fabric of the area has grown by supporting water resources development. Regional water management systems now link the water resources of the Colorado River, Central Arizona, Northern California, the Wasatch Front of Utah, the Front Range of Colorado, and Northern New Mexico.

Tree ring and other historical records suggest that a 20-year period in the late 16th century experienced a much worse drought than any this century, and several other periods were drier. Management of this vast water supply system has not had to face major drought and is poorly prepared to implement the kinds of cooperation that can get the maximum benefit from water supply during periods of shortage. Increasing population and growing anthropogenic demands on land and water resources increase the potential drought severity and magnify the probable losses during a sequence of drought years.

Accomplishments
The cooperating universities in the Colorado River Basin States have assembled an interdisciplinary team of hydrologists, water resource engineers, economists, lawyers, ecologists, sociologists, anthropologists, and experts in government and political science to structure drought scenarios and management reactions that appear reasonable in the light of events during the last 500 years but more severe than any this century. We are defining and reviewing their impacts to identify opportunities for greater management effectiveness through cooperation. Our goal is to find ways that will help decision makers use limited water supplies to gain maximum benefits by making provisions within the existing management system.

The results of this study will be useful to water resources management, policy makers, river users, and scholars who are concerned with the increasing complexity of water system management in the face of potential shortages. We are trying to provide greater institutional flexibility for coping with changing resource management needs.
Organizational Elements in Water Resources Development

Principal Investigator:
Jay M. Bagley (PhD), Water Resources/Hydrology

Problem and Research Objectives
Policy analysis and program evaluations were conducted as requested by the Policy Studies Division, U.S. Army Corps of Engineers. Issues examined include the institutional, legal, and organizational elements of resource development and management as affected by the Water Resources Development Act of 1986. Results will take the form of reports, manuals, guides, or presentations, as appropriate to Corps of Engineer needs.

Accomplishments
An Army Science Board study of water management at military installations was reviewed and assessed. An approach to systematically analyze supply and management options at individual military reservations and to develop long-term water management strategies was formulated. This involved not only the identification of appropriate technologies, but also of internal and external linkages or interfaces of an organizational/institutional/legal nature. Additionally, ways to minimize encumbrance on the strategizing process were discovered.

Digests of water laws of selected western states were prepared with material organized to correlate applicable elements of law with specific water supply options that might be implemented for a given military installation over time. Expanded to cover all states, such digests serve as permanent and ready references for contemplated system changes or enlargements.

Policies generated by requirements of the 1986 Water Resources Development Act were reevaluated and modified. In particular, the impact of new cost-share provisions on cooperative arrangements for planning and financing of projects was studied. Potentials for reallocating water to various purposes at existing reservoirs and establishing equitable charges for each purpose were also studied. The influence of state water laws on this reallocation question was explored. In addition, the influence of state water laws on U.S. Army Corps of Engineers' requirement to prepare drought contingency plans and operating release rules at all storage facilities was analyzed. Results are being used to prepare official army regulations and guidance manuals to be distributed to regions, districts, and army installations.
Agricultural and Irrigation Engineering
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Surface Irrigation Control and Decision Support Systems

Principal Investigator:
Wynn R. Walker (PhD), Irrigation Engineering

Support Personnel:
Gary R. Merkley (PhD), Irrigation Engineering
Blair Stringham (BS), Agricultural Engineering

Problem and Research Objectives

Our principal objective is the development of an integrated and comprehensive package of software for the operation and management of surface irrigation projects. Included in the definition of software are the sensors, communication systems, and control devices which provide the capability to collect and transmit system data and allow, where desirable, the control of the system based on the outcome of the data analysis.

Specific objectives are to:
1. critically establish the availability and capacity of sensors, communication linkages, and remotely controlled actuators applicable to irrigation system management and, if necessary, develop new monitoring and control systems;
2. develop an integrated sensor and control system capable of real time evaluation and operation of the components of irrigation projects ranging from the field to the reservoir;
3. develop microcomputer-based software for a real-time management system which provides either decision support for irrigation personnel or actuator support for automatically operated systems; and
4. implement the results of the first three objectives in an irrigation project in Utah as a means of demonstrating the technology and providing a pilot area for other projects for observation in route to adding computer assisted water management capabilities of their own.

Accomplishments

Project research is focused in three areas: 1) the development and testing of an integrated sensor and control system for real-time operation of irrigation canal systems; 2) the development and testing of microcomputer software for both real-time operation and decision support applications at the distribution level of the irrigation system; and 3) the development and verification of software for real-time evaluation and control of the irrigation system at the field level.

During the summer and fall of 1990, two automatic canal control gates were purchased and installed at the initial bifurcation of the Benson Canal near Logan, Utah. This bifurcation supplies the two major divisions of the system and represents a situation where automatic control will be very useful. The company agreed to allow project personnel to install the new gates and operate them via radio telemetry from the USU campus. Associated with gate installation was the installation of water level sensors, a solar power system, and gate activators. This work is being undertaken by a M.S. student supported by project funds, Mr. Blair Stringham.

The development of the canal network software continued with the completion of a steady state package, complete with user interface, and a revised hydrodynamic package without the full interface. The hydrodynamic research effort has been summarized in three technical papers.

Software to determine field infiltration characteristics and determine operational setting of automated surface irrigation systems nearing completion in 1990. The basic algorithm was published by Walker and Busman (1990); a Ph.D. student is preparing an improved user interface for the algorithm, developing internal optimization code, and verifying the software with field data. To date, the interface and internal optimization are complete with field verification schedules in 1991.

Publications


Field Verification of Irrigation Management Models for Integrated Water Quality Management and Energy and Water Conservation

Principal Investigator:
Robert W. Hill (PhD), Civil and Environmental Engineering

Support Personnel:
L. Niel Allen (MS), Agricultural Irrigation Engineering

Student Assistants:
John Proegger (MS), Agronomy and Soils
Abu Awad Ahmad (MS), Soils and Irrigation
Assad Safadi (MS), Soils and Irrigation
Marvin Lewis, Agricultural and Irrigation Engineering
Erik Merkely, Agricultural and Irrigation Engineering

Problem and Research Objectives
Meetings held in recent years with irrigators throughout the State of Utah have focused on how to cope with reduced water supplies as the result of drought. Irrigators have expressed concerns about managing saline waters and limited water supplies to profit in agricultural operations. The need for more intensive field studies (with better control on the data gathering process) focused on managing irrigation waters, particularly in saline areas, has become apparent from these meetings.

There is a need for consistent crop water use estimates throughout Utah and all state and federal agencies to accurately estimate possible deep percolation under the present and projected future management practices. A possible deep percolation estimate will be used to impute a potential groundwater contamination opportunity from agriculture chemicals. It is important that the estimate be accurately determined so irrigated agriculture is not unnecessarily burdened with restrictive management practices.

State and local agencies will be required to implement field level practices for minimizing potential groundwater contamination from agriculture chemicals. Fundamental to the implementation of approved practices is an accurate determination of the water budget for a given field. In Utah, the principle component of the water budget is estimated crop water use or evapotranspiration.

The methods currently in use by SCS, Utah Divisions of Water Rights and Water Resources, and USU Extension do not necessarily agree as to the magnitude of the evapotranspiration. There is considerable difference among the various methods currently in use. Previous and proposed research activities under this project (AES-796) can help implement state–of–the–art evapotranspiration calculation methods in the State of Utah and bring about an agreement among the various agencies involved in water management implementation practices.

In this project, we will study the effects of salinity and water management on crop yield under experimental and farm conditions. The data will be used to adapt previously developed crop yield and irrigation scheduling models to the farm situation. Resulting field verified models will be used to develop water management alternatives for irrigators.

Our main objectives are to: 1) develop crop water production functions from observed crop responses in lysimeter and farm field experiments with varied irrigation amounts, water salinity, and fertility levels; 2) modify existing models to improve the simulation of soil water and salinity effects on crop yield; use these models to develop improved irrigation management practices; 3) continue field vegetative water–use experiments in previously established lysimeters; and 4) adapt previously developed river basin hydrologic and ET simulation models to evaluate the effect of improved water–use estimates on streamflow depletion and water resource management.

Accomplishments
Crop water–use estimates were provided statewide based on the electronic weather system network. Irrigation management information was provided for 81 fields involving 37 growers in five Northern Utah counties as part of a program co–sponsored by the Utah Departments of Agriculture and Energy. Thirty–three irrigation systems were evaluated, including surface, wheel line, and center pivot sprinklers. Field irrigation application efficiencies varied from 33–84%. Pumping plant tests were conducted with efficiencies ranging from 37–82 percent, and energy cost per acre–foot varied from $4.00 to $44.00.

A study of sweet corn yields as influenced by irrigation amount and salinity in 32 (2.4 x 6.1 m) lysimeters included six irrigation levels of fresh water (EC = 33 ds/m) and four salinity levels (EC = 33, 1.48, 4, and 10.2 ds/m) at two leaching fractions. At zero leaching, yields were reduced 8% and 28% with EC's of 4.0 and 10.2 ds/m. At 32% leaching, yields loss was at 4.0 and 22% at 10.2 ds/m. Vegetable squash, cucumbers, and sweet corn yield response to varying irrigation was obtained from a line–source sprinkler plot, trickle (with and without plastic mulch), and trickle irrigation on 32 (2.4 x 6.1 m) lysimeters. Yield increased with increasing available irrigation water but declined at excess amounts. Squash and cucumber yields varied 3.5 to 83 t/ha and from 1. to 74 t/ha, respectively. Preliminary calibration of the CRPSM model to squash resulted in very close agreement between simulated and actual relative yields.

Potential nitrogen movement and potato yield response was studied with four varieties and three nitrogen levels with line–source sprinkler experiments near Enterprise and McCormick, Utah. Evidence of nitrate–nitrogen movement below the root zone correlated with the degree of excess irrigation and corresponding potato yields. A second full season of data was obtained from the phreatophyte water–use study of cattails, bulrushes, and willows along the alfalfa and turf grass. Water use was 88 mm, 99 mm, 570 mm, 800 mm, and 680 mm, respectively, for a growing season of June through September.

Publications
# International Programs

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The International Irrigation Center (IIC) was established in 1980 as part of the AIE Department. The Center was created in response to an increasing need for providing training and research to enhance the capabilities of professionals, scientists, and technicians abroad to improve irrigated agriculture in their countries.

The IIC currently offers 12 short courses for international participants on the USU campus. All of these are offered in English, and 10 of the 12 are offered, concurrently, in Spanish. All of the courses are interdisciplinary in nature and involve cooperation with the departments of Agricultural Education; Biology; Economics; Forest Resources; Plants, Soils and Biometeorology; Range Science; Sociology and the UWRL. In addition, three study tours are offered for those who want to become acquainted with irrigated agriculture and the management of soil and water resources in the western and mid-western U.S.

In addition to these regularly scheduled courses, IIC personnel prepare and present special courses to meet the specific needs of oversees clients. From July 1, 1989, through December 31, 1990, 557 participants were trained in 19 short courses in such countries as Bolivia, Brazil, Guatemala, Honduras, India, Pakistan, the Philippines, and Sri Lanka. During this same period, 303 participants attended 26 short courses taught at USU.

The IIC promotes applied research to contribute to the general knowledge base of irrigation and water management. Staff of the IIC and it's parent organization, the AIE Department, are involved in extensive research with emphasis on computer modeling and software development.
Computer Applications in Irrigation Shortcourse (Pakistan)

Principal Investigator:
R. Kern Stutler (MS), Irrigation Engineering

Support Personnel:
Carlos Martinez (MS), Irrigation Engineering
Edwin C. Olsen (PhD), Irrigation Science

Problem and Research Objectives
Our objective was to provide and/or enhance computer skills of the officers of the different provincial Command Water Management Programs in Pakistan. The training course focused on the development of small programs specifically designed for applications in water management, hydraulics, and sprinkler and surface irrigation; focus was also on the use of software packages applied in the same field.

Irrigation I: On-farm Water Management Training Course

Principal Investigators:
R. G. Allen (PhD), Civil Engineering
R. Kern Stutler (MS), Irrigation Engineering

Problem and Research Objectives
Course objectives were to:

1. enhance understanding of the underlying physical theory and concepts of irrigation processes to improve the abilities of water management staff to modify and manage irrigation systems and water course administration in Pakistan and to provide improved services to water users and farmers;
2. strengthen skills in practical applications of irrigation theory, field evaluation, and analyses techniques and instruct on improved procedures for accurate data collection and analyses; and
3. introduce practical methods for developing irrigation scheduling programs and advisories in Pakistan.

In this course, a “hands on” approach to irrigation system evaluation and data collection was encouraged. In addition, the importance of quality data and the need for management staff to personally conduct and/or supervise the collection of field data were emphasized. Simplified and practical approaches to irrigation scheduling that fit Pakistani conditions and needs were presented.

Accomplishments
Twenty-nine participants from the staff of the Command and On-Farm Water Management Projects of four provinces received training and acquired skills in the use of DOS, Quattro-Pro, WordPerfect 5.0, and the fundamentals of QuickBasic.

Publication

Irrigation I: On-farm Water Management Training Course

Principal Investigators:
R. G. Allen (PhD), Civil Engineering
R. Kern Stutler (MS), Irrigation Engineering

Problem and Research Objectives
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On-farm Drainage Course

Principal Investigators:
Lyman S. Willardson (PhD), Agricultural Engineering
Gaylord V. Skogerboe (MS), Civil Engineering

Problem and Research Objectives
The goal of this training course was to enhance the technical competence of selected professional staff in the Command and On-farm Water Management Projects in designing on-farm drainage facilities. The objectives of the course included:

- providing a common theoretical foundation to the participants;
- analyzing and designing on-farm drainage; and
- providing participants with hands-on experience under actual field conditions.

Accomplishments
Twenty-six staff members of the Command and On-farm Water Management Projects attended the course. They received formal coursework in basic elementary soil physics and porous media flow and instructions in the collection and interpretation of field data and design procedures. Participants learned and practiced these skills in a four-day field exercise.

Publication

On-farm Water Management, Evaluation, and Design Training

Principal Investigator:
R. Kem Stutler (MS), Irrigation Engineering

Support Personnel:
Carlos A. Martinez (MS), Irrigation Engineering
E. C. Olsen (PhD), Irrigation Science
Lyman S. Willardson (PhD), Agricultural Engineering

Problem and Research Objectives
The course objective was to provide trainers, extension personnel, and project beneficiaries with sufficient knowledge and training to perform the necessary activities to develop and efficiently operate on-farm irrigation systems. To achieve this objective, participants were to acquire an understanding of soil-water-plant relationships and crop water requirements, seepage losses from watercourses and canals, and the principles and calibration of water measurement devices. In addition, participants were to gain a knowledge of the design and implementation of watercourse improvements and land leveling; concepts for scheduling amount, timing and methods of irrigation; sprinkle and surface irrigation diagnostic analysis; the concepts of irrigation system evaluation; and skills development for field data collection.

Accomplishments
Twenty-four participants from various Honduras government agencies received training in the following subjects:

- Use of Programmable Calculators
- Soil-Water-Plant Relationships
- Water Requirements and Irrigation Scheduling
- Applied Hydraulics
- Water Measurement
- Evaluation of Surface and Pressurized Irrigation Systems
- Agricultural Research and Demonstration
- Evaluation and Improvement of Field Channels
- Social Sciences in Irrigated Agriculture

Classroom lectures were supplemented with hands-on field exercises.

Publication
Training Support Program for Achieving a Visible Success Story at the Tirague-Punata Irrigation Projects in Bolivia

Principal Investigator: Gaylord V. Skogerboe (MS), Civil Engineering
Support Personnel: R. Kern Stutler (MS), Irrigation Engineering
G. P. Merkeley (PhD), Irrigation Engineering

Problem and Research Objectives
During the week of June 26-30, 1989, extensive discussions were held among representatives of PRAY, GTZ, USAID, and IIC on potential training activities to support the development of the Tirague-Punata Irrigation Projects. In addition, the representatives visited each project.

The existing croplands have been irrigated for a very long time, but with very limited water supplies. The construction of facilities is nearly completed and the irrigators have received some project waters in recent years, but there should be a significant increase for the 1990-91 irrigation season.

The funding for the construction of new facilities and many complementary activities within the irrigated areas of the projects have been funded almost entirely by GTZ. This proposed training support program has resulted from the joint discussions mentioned above. IIC hopes that USAID can support this program with possibly some funding from GTZ.

The intent of this proposed training support activity is to complement other on-going project activities so that in the next three to six years a significant "visible success story" that combines both hardware and software development has been created. If successful, this process can be repeated at other irrigation projects in Bolivia.

Accomplishments
A three-week training course on "Maintenance of Irrigation Projects" was conducted July 30 - August 17, 1990. One trainer was from the IIC and two trainers were from the staff of the Tirague-Punata Irrigation Projects (TPIP). A second course for Extension staff and water users was held August 13-17. The course schedules were:

First Week: Maintenance Training on Main System
1. Introduction to the M & O Learning Process
   a. Operations phase
   b. Maintenance phase
2. Maintenance of Facilities
   a. Physical and social phenomena causing maintenance problems
   b. Solutions to maintenance problems
3. Field Maintenance Surveys
   a. Maintenance survey of flow control structures
   b. Diagnostic "walk-thru" maintenance survey
4. Maintenance Plans
   a. Normal maintenance
   b. Essential structural maintenance
   c. "Catch-up" maintenance
   d. Preventive maintenance

Second and Third Weeks: Completion of Field Work and Preparation of Maintenance Plan
5. Preparation of Maintenance Plan
   a. Preparation of outline
   b. Group assignments for writing
   c. Writing of first drafts
   d. Review of first drafts
   e. Groups revise first drafts
   f. Compilation of maintenance plans

Third Week: Maintenance Training on Tertiary Systems
6. Introduction to the M & O Learning Process
   a. Operations phase
   b. Maintenance phase
7. Maintenance of Facilities
   a. Physical and social phenomena causing problems in tertiary systems
   b. Solutions to maintenance problems in tertiary systems
8. Field Maintenance Survey and Recommendations
   a. Diagnostic "walk-thru" maintenance survey in tertiary systems
   b. Preparation of recommendations to the Water Users Association (WUA)

The first course was attended by 17 irrigation staff while the second course was attended by five WUA members and seven staff from TPIP and other irrigation projects.
Irrigation Operations and Maintenance Training

Principal Investigator:
Gaylord V. Skogerboe (MS), Civil Engineering

Support Personnel:
G. P. Merkley (PhD), Irrigation Engineering

Problem and Research Objectives
In-country training courses not only provide training for the attendees, but also provide a means to acquire usable field data for subsequent operational improvements at Parakrama Samudra, Kaudulla, Minneriya, and Giritale—four irrigation schemes in Sri Lanka. Data collected from the training courses will be used for implementing steady-state hydraulic modeling of the irrigation conveyance and delivery canals at these schemes. In addition, these training courses will result in the formulation and writing of an operations plan for each of the four schemes.

After completion of the training courses in Sri Lanka, Dr. Gary Merkley traveled to Polonnaruwa on March 9, 1990, to establish a computer operations capability for the irrigation schemes. Data collected from the training courses will be entered into the microcomputer for use in simulating the operation of the irrigation systems.

Computer simulations will be performed on a model developed at the IIC. This model is an updated and expanded version of the Gal Oya model developed by Glenn Dearth and is capable of simulating the irrigation conveyance and delivery system operation and predicting crop water requirements through irrigation scheduling methods. Following these, the recently collected field data will be transferred to the computer model. Dr. Merkley will assist the trained Sri Lankans to place the operations plans for the four schemes on the microcomputer; additionally, he will instruct Sri Lankan counterparts in the use of the steady-state hydraulic and evapotranspirations model so that a sustainable capability is established.

Accomplishments
A total of 61 Sri Lankans received training in the Hydraulic Operation of Irrigation Delivery Systems. The intention of this training course was not only to provide technical skills to the participants, but also to acquire the necessary field data for subsequent operational improvements at the irrigation schemes. Course objectives were to: 1) develop discharge ratings for the flow control structures, and 2) measure channel losses in all of the reaches of the irrigation channel network above the field channels. For each scheme, the final product was a detailed report, “Hydraulic Operations Field Data for the Irrigation Scheme.”

A total of seven participants in Sri Lanka were given training and hands-on experience in “Computer Operation of Irrigation Delivery Systems.” A microcomputer operations capability was established for the irrigation schemes at Ridi Bendi Ela, Parakrama Samudra, Kaudulla, Minneriya, and Giritale. Data collected from the field training courses were entered into the microcomputer for use in simulating the operation of the irrigation systems.

The microcomputer simulations are performed using an updated and expanded version of the steady-state model presently being used for the Left Bank Canal at the Gal Oya Irrigation Scheme. The model is easy to use and very practical for field applications; thus, it is appropriate for implementing operational improvements in Sri Lanka.

Publication
Water Management Training Courses

Principal Investigator:
Gaylord V. Skogerboe (MS), Civil Engineering

Problem and Research Objectives
A common problem in irrigation systems around the world, as well as in the Philippines, is the continual cycle of irrigation system construction, deterioration because of inadequate maintenance, rehabilitation (which ends up being major re-construction), and deterioration. This significantly inhibits the development of irrigated agriculture.

As irrigation channel networks deteriorate, the capability of delivering water equally throughout the system is decreased. The adequacy and dependability of the irrigation water supply decreases for some farmers, depending upon their location; thus, they are less likely to risk other expensive agricultural inputs such as fertilizer. The consequence is very slow progress in agricultural development.

Accomplishments
The Irrigation Maintenance and Operations (M&O) Learning Process provides one approach for effectively sustaining an irrigation network over a long period of time. This process emphasizes:

- maintaining rather than rehabilitating;
- improving financial management and accountability in maintenance documentation;
- using existing flow control structures in irrigation channels for water measurement;
- developing a more detailed physical knowledge about what is occurring within the system;
- increasing sensitivity about operating the system to meet the needs of farmers; and
- documenting irrigation system improvement needs and costs.

Training was carried out in cooperation with National Irrigation Administration counterparts on water management training under the Irrigation Operations Support Project (IOSP). The IOSP is jointly funded by the Government of the Philippines, World Bank, and USAID. Training programs were conducted April 26, May 2-4, May 8-10, May 14-19, May 21-26, May 28-June 2, June 4-15 and June 18-29.

The training course, Irrigation Water Management in Local Subsystems, was given twice in May to train-the-trainers. Each region sent one person working with farmers’ organizations, one Civil Engineer, and one Agricultural Engineer or Agriculturist. These three trainers will conduct this course in their respective region.

Essential Structural Maintenance Plan for Flow Control and Water Measurement was conducted with 11 field staff, three headquarters staff, and the 21 trainers that had attended the Irrigation Water Management course.

The second course, Essential Structural and Deferred Maintenance, was conducted for seven small irrigation systems. There were 14 field staff, three headquarters staff, and 19 trainers (17 of the trainers had attended the Irrigation Water Management course May 21-26). A single “catch-up” Maintenance Plan was completed that contained each of the seven irrigation systems.

Through this project, a total of 278 participants received training in eight seminars, workshops, and short courses.

Publications

International Water Resources Division

Principal Investigators:
J. Paul Riley (PhD), Civil and Environmental Engineering,
Division Head
David S. Bowles (PhD), Civil and Environmental Engineering
David K. Stevens (PhD), Civil and Environmental Engineering

Problem and Research Objectives

Some of the most challenging opportunities for applied research in water resources development and systems operation around the world are overseas. The UWRL and the USU CEE Department have considerable expertise to contribute; this expertise can be enhanced through experiences gained in meeting these challenges. The proposals required to enter this arena tend to be large and costly to prepare. The investment in effort is large, but the payoffs are tremendous.

Through a Program Support Grant from USAID, we have developed an organizational structure, the International Water Resources Division, through which proposals are submitted for providing assistance on overseas water resources planning projects. We are also able to provide training of foreign professionals to improve their skills in planning and operating water resources projects. The head of the International Water Resources Division is Dr. J. Paul Riley.

Through this division, research is funded which contributes to solving problems associated with overseas water resources planning projects and provides opportunities for participation of USU graduate students in the planning and operation of such projects overseas. As these opportunities are realized, the division will supplement and strengthen the research and academic programs in water resources engineering at USU.

A major source of program funding is USAID. Proposals have also been sent to other international funding agencies and, in some cases, directly to foreign governments.

The International Water Resources Division of the CEE Department and the UWRL was formed just over four years ago. Current and recently completed contracts are for training, technical assistance, and research in Egypt, India, Thailand, and West Africa.

Dr. Bowles, a principal investigator in the International Division, stated that "Faculty associated with the Division have been highly successful in obtaining international projects. Our faculty have much to offer the developing world. Although international work inevitably involves time away from campus, we believe that carefully selected international projects strengthen our faculty and research and academic programs." He added that "International extension activities are a recognized part of the mission of USU as a land grant university."

Our program objective is to strengthen the International Water Resources Division. It is envisioned that the division projects will address multi-purpose water management problems at a large-scale or river basin level. This will complement on-farm and distribution system levels of water management emphasized by the AIE Department and the IIC, both at USU.

Accomplishments

In Egypt, we are developing software for a telemetry system that will feed real-time data into a computer model for operating main system canals. We are also associated with a Consortium for International Development (CID) project for assisting the Egypt Water Research Centers (EWRC). The Central Training Unit (CTU) for River Basin Planning, which we are assisting India's Central Water Commission in establishing, was officially opened on October 27, 1988. The CTU, located east of Bombay in Pune, provides in-service training to officers of State and Central government agencies throughout India.

In West Africa we are associated with two multinational river basin development schemes. In addition, we completed on a project with the Asian Institute of Technology in Thailand to investigate the performance of a welded wire retaining wall constructed on a soft clay foundation and using a low quality backfill material. The project was sponsored by USAID through the Asian Institute of Technology.

Detailed descriptions of projects in India, Egypt, and West Africa are contained in reports XCEW-043, XCEW-50, and XCEW-52, respectively.

We maintain an involvement in seeking additional opportunities in both training and technical activities. Training programs in water resources systems analysis, economics of water resources, sedimentation engineering, hydrology, remote sensing, dam safety evaluations, and integrated river basin planning and management have been presented to engineers from various developing countries. These presentations have been made both at USU and in the developing countries themselves.

Opportunities exist for building on these training and technical assistance experiences and for expanding these programs, particularly into the Eastern European region. For example, together with other disciplines at USU, we are proposing to develop a proposal to USAID on the subject of Agricultural Water Resources Management (AWRM) Throughout the World. Our experiences in integrated river basin planning and management have provided us with a knowledge base and training materials ideally suited to a proposal of this nature.

The efficient operation of large water supply projects and of multiproject systems is one of the major challenges for water resources research worldwide. As the International Water Resources Division participates in these programs, our research teams will be at the forefront in providing answers to a wide variety of important management questions.
NATO Advanced Study Institute on Recent Advances in the Modeling of Hydrologic Systems

Principal Investigators:
David S. Bowles (PhD), Civil and Environmental Engineering
P. Enda O'Connell (PhD), Civil Engineering (University of Newcastle)

Support Personnel:
Chris Gunter, Staff Assistant
Colleen A. Riley (MS), English

Student Assistant:
Randy Foltz (MS), Civil Engineering

Problem and Research Objectives

The relationship between rainfall and runoff has been one of the central themes of hydrological research for many years; quite apart from its scientific importance, current knowledge and understanding of this relationship underpins the whole water resources management process. In the 1960s and 1970s, research hydrologists recognized the potential which mathematical modeling offered in studying the behavior of hydrological systems and developing a predictive capability for uses such as flood forecasting and water resources management. While considerable progress was achieved in this era of development, towards the end of the 1970s recognition emerged that too much attention was being paid to refining existing models at the expense of obtaining a better scientific understanding of the behavior of hydrologic systems.

Apart from the importance of this scientific quest in its own right, new and pressing real world problems were emerging. These demanded new modeling approaches founded on a more rigorous physically-based description of the movement of water in space and time within river basins. Notable among these problems was the need for reliable models for predicting the transport and fate of pollutants and sediments within river basins. Pollution from distributed sources such as nitrates and acid rain and reservoir sedimentation generated by deforestation and subsequent soil erosion pointed to the need for spatially-distributed modeling approaches which could predict the impact of measures taken to protect water resources. Another research demand is the need to couple global circulation climate models to hydrological models which could define water fluxes at the land–atmosphere interface.

In the past five years, there has been a major response to these problems and needs by the international hydrological research community. The role of spatial scale in determining the response of hydrological systems to rainfall has been identified as a key research area. The role of spatial variability is related to the scale issue in determining hydrological response and the modeling problem. There is a need to gain a better understanding of the behavior of rainfall in time and space at relevant scales, and several research groups are engaged in developing space–time models of rainfall at the present time. Research on physically–based distributed modeling has led to the emergence of a new generation of models and modeling systems such as the System Hydrologique Européen—the result of a Danish–French–UK collaborative effort.

This research endeavor has been greatly supported by contemporary technological developments in such areas as computing, artificial intelligence, and remote sensing. High speed parallel processors are opening up new computational frontiers, particularly in solving the governing sets of partial differential equations, while sophisticated color graphics are being used to assimilate the large amounts of information being produced by the new generation of models. The role of artificial intelligence in interfacing complex models with users is also being explored, and the ever-increasing computational power of microcomputers is continually being exploited in bringing modeling to bear on real world problems.

Accomplishments

The Special Programme Panel on Global Transport Mechanisms in the Geo–Sciences of the NATO Scientific Affairs Division sponsored an Advanced Study Institute (ASI), Recent Advances in the Modeling of Hydrologic Systems. A NATO ASI is a high–level scientific meeting of a clear tutorial nature. It is intended for participants normally at the post–doctoral level with the purpose of promoting the release and exchange of information not available in standard university courses, imparting knowledge and experience to young scientists, and facilitating professional contacts among scientists from NATO countries. The overall objective of the NATO ASI was to present a systematic review of the current state–of–the–art in comprehensive hydrologic modeling, current modeling issues, technological trends which are influencing advances in the field, and potential future directions.

Dr. David Bowles, Professor and Associate Director of the UWRL, served as the North American Co–director for the NATO ASI. The ASI was held in Sintra near Lisbon, Portugal from July 10–23, 1988. Professor P. Enda O'Connell, University of Newcastle, England, served as European Co–director. One hundred hydrologists from fifteen of the sixteen NATO countries in North America and Europe, and from five non–NATO countries, participated in the two–week ASI.

Sixteen lecturers provided a structured scientific program. The program covered a historical perspective, the current state–of–the–art in modeling components of the hydrologic cycle, supply– and demand–side influences on hydrologic modeling, special considerations for applying hydrologic models in different geological and climatic settings and to water resources and quality problems, and applications. One senior U.S. participant described the ASI as the “most valuable professional” meeting in his twenty–one year career. In addition to the professional benefits of the ASI, having so many nationalities together for two intensive weeks provided a rich personal experience.

A book containing the lectures presented at the ASI is being published by Kluwer in 1991. It is expected that it will be the most current comprehensive reference on the state–of–the–art in hydrologic modeling available. Anyone interested in obtaining a copy should contact Dr. Bowles.

Publication

Integrated River Basin Planning and Management, India

Principal Investigators:
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J. Paul Riley (PhD), Civil and Environmental Engineering

Supporting Faculty:
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Trevor C. Hughes (PhD), Civil Engineering
Andrew Keller (PhD), Irrigation Engineering
Jack Keller (PhD), Agricultural and Irrigation Engineering
Bradley W. Parlin (PhD), Sociology
William Rahmeyer (PhD), Civil Engineering
Wynn R. Walker (PhD), Agricultural Engineering

Collaborating Faculty:
Yacov Y. Haimes (PhD), Civil Engineering, University of Virginia
Warren A. Hall (PhD), Civil Engineering, Colorado State University
D. Peter Loucks (PhD), Civil Engineering, Cornell University
Ken Strzepek (PhD), Civil Engineering, CADSUES, Boulder, Colorado
William W. G. Yeh (PhD), Civil Engineering, University of California at Los Angeles

Problem and Research Objectives

USU is working in India with Harza Engineering Company, Chicago, to provide training in integrated river basin planning and management to state and national agency planners and engineers. This training supports the water resources management program of the Central Water Commission (CWC). The UWRL is providing an academic base; Harza is providing practical applications.

Water resources development in India is a state responsibility. The Central Government provides technical review and support and facilitates developments that join more than one state or require international financing. Thus, the CWC is responsible for the integration of investment in water development and water resources management at the national level and has sought expatriate assistance to build the necessary cadre of experts.

Each state prepares its own set of water resources development projects according to its own perceived needs, priorities, and capabilities. The National Planning Commission outlines a Five-year Plan for water resources development and provides some support in the national budget. The CWC serves as a technical review and coordinating authority. In addition, the substantial existing water resources infrastructure requires a program of planned maintenance and efficient operations. The Harza/USU program provides state-of-the-art river basin planning skills to help Indian professionals become better able to effectively respond to past, present, and future needs.

Accomplishments

Through this program, an operating Central Training Unit (CTU) has been established on the campus of the Central Water and Power Research Station near Pune, west of Bombay.

Three introductory river basin training programs (3.5-month) and one Advanced Course (9-month) have been taught to about 100 engineers. USU faculty shared responsibility for the lectures, practicums, and case studies with Harza engineers and Indian counterparts. Each program ended with a study tour where trainees could interact with experienced planners in the U.S. In addition, a program for training faculty so that the CTU can continue providing a quality course in India after the expatriates leave was well received. The Indian faculty gave the third introductory course almost entirely on their own.

This program will benefit India, Harza, and USU. For India, some 200 engineers from various states will pass through training programs and assume duties as river basin planners. For Harza, the university tie adds a strong academic component to a long-established practical training capability. Perhaps the greatest contribution is in the opportunity and incentive given academics and practicing engineers to work together in developing practical procedures for integrating water resources planning and management at the river basin scale that others can use for a long time to come. In addition, academic and research programs at USU will be strengthened through exposure of USU faculty to new water resources problems and interactions with colleagues at other universities. Later, these courses can foster continuing training programs in the U.S. and overseas. Lecture notes have been developed for the following courses:

P1. Computer Usage—William Rahmeyer
P2. Surface and Groundwater Hydrology—David S. Bowles
P3. Agricultural Science—J. Paul Riley
P4. Probability and Statistics—David S. Bowles
P5. Applied Sociology—Bradley W. Parlin
P8. Concepts of Modelling and Optimization—Yacov Y. Haimes
S1. Introduction to Integrated River Basin Planning and Management—L. Douglas James
S2. Information and Display Systems—D. Peter Loucks
S3. River Basin Irrigation Systems—Andrew Keller
S4. River Basin Hydrology—David S. Bowles
S5. River Basin Water Resources Engineering—J. Paul Riley
S7. Social Analysis—Bradley W. Parlin
S10. Integrated Systems Operation—William W. G. Yeh
Managing the Water Resources of the Senegal River

**Principal Investigators:**
- J. Paul Riley (PhD), Civil and Environmental Engineering
- William J. Grenney (PhD), Civil and Environmental Engineering
- John E. Keith (PhD), Economics
- Craig Caupp (PhD), Civil and Environmental Engineering

**Problem and Research Objectives**

The Senegal is one of the largest rivers in Africa. It rises in the north of Guinea, crosses the western part of Mali, and then, for the rest of its course to the Atlantic Ocean, forms the border between Mauritania and Senegal (Figure 1). The average annual discharge of the river at Bakel is 771 m$^3$/second, and the 100-year peak flow is 10,700 m$^3$/second. The average monthly discharge at Bakel varies between 3423 m$^3$/second in September and 10 m$^3$/second in May.

Because of wide variations in discharge, benefit can be obtained through regulation to make more water available for beneficial use during the dry period of the year. For an international river, however, an integrated development plan is required which will benefit each of the participating countries with each country paying a fair and equitable share of the cost.

The agreement also covered construction of a salt water barrier dam (Diama) at the river mouth near St. Louis to prevent the intrusion of ocean water into the lower channel of the Senegal River. Benefits would result from 1) generation of hydroelectric power, 2) irrigation during the dry season, 3) navigation on the river, and 4) flood control. The main objective of this study is to propose and test a procedure for use by the governments of the three countries for allocating the costs of the project on the basis of estimated economic benefits.

**Accomplishments**

A river basin management model has been developed in which project benefits are estimated and joint costs are allocated among the three countries. Through use of the model, it is possible to examine the effects of difficult to forecast variables such as the rate at which the farmers in this rather backward agricultural system will adopt irrigation technology, economic feasibility, and cost allocation. A users' manual describing the cost allocation computer model was prepared, and OMVS personnel are being trained to use and modify the model as needed.

Four commonly accepted cost allocation methods were examined, and an adjusted separable-costs-remaining benefits method was recommended for application to the proposed Senegal River development program. The computer model is programmed to estimate the economic benefits of the development program for each of the various uses (power, irrigation, navigation, and flood control). The joint costs are estimated, allocated to the four use sectors, and finally allocated to the three participating countries.

![Figure 1. Location of the Senegal River Basin and isohyetal lines of average annual precipitation (in millimeters).](image-url)
With these principles in mind, three of the countries (Senegal, Mauritania, and Mali) formed what is called the Organization for the Development and Management of the Senegal River (OMVS). The OMVS agreed to construct a storage reservoir (the Manantali Dam) on one of the main tributaries, the Bafing River, to provide a minimum river flow of 300 m³/second at Bakel and to generate 100 megawatts of firm power.

Since 1978, development of the model has continued as OMVS needs have become more clearly identified. In addition, the model has enabled the OMVS to focus on data required by the study. This evolving process has resulted in a series of six reports; the fifth sets forth two cost allocation alternatives, one of which was adopted at an extraordinary meeting of the Council of Ministers of the OMVS in Dakar on May 5 and 6, 1981. On the basis of this cost allocation, the required funding for the construction of the Diama and Manantali Dams was committed by the donor countries at a meeting in Paris during the week of May 15, 1981.

The most recent in the long series of projects since January 1974 was initiated in early 1989 as a subcontract with the consulting engineering firm of Dames and Moore. The main objectives of this current project are to:

- update the cost allocation model in terms of flexibility and user friendliness and the capability to function on a PC computer;
- recompute the cost allocation preparations (key) based on updated data;
- continue to train OMVS personnel in the model operation and evaluation of the results;
- examine the implications of retroactive application of the key; and
- update the computing equipment at the OMVS headquarters in Dakar, Senegal.

During the summer of 1989, a disagreement occurred between Mali and Senegal, thus delaying the project. Because of this, current project objectives have not yet been completed. However, the first phase of the project was completed and a report issued in October, 1990. Negotiations are underway to reach an agreement for completion of the second, and final, phase and, perhaps, to extend the work to include extensive training of OMVS personnel in use of the model.

The results of earlier projects have been extensively applied in the negotiation of loan agreements between OMVS countries and donor nations. The results of the current project will also be extensively used in the implementation and operation phases of the Senegal River basin project. In addition, the model is generally applicable to many other problems in cost allocation and loan management for large water projects in developing countries.

**Publications**


Irrigation Management Systems
Project, Main Systems Management Component, Egypt

Principal Investigators:
J. Paul Riley (PhD), Civil and Environmental Engineering
C. Earl Israelsen (PhD), Hydrology

Support Personnel:
Ronald V. Canfield (PhD), Statistics
Delmar A. Dyreson (PhD), Mathematics
Ralph A. Sausedo (BS), Electronics

Problem and Research Objectives

The Irrigation Management Systems (IMS) project is intended to strengthen the capabilities and capacity of the Egyptian Ministry of Public Works and Water Resources (MPWWR) in the areas of planning, design, operation, management, and maintenance of the irrigation system in Egypt. Ten major components are included in IMS, one of which is Main System Management (MSM). The primary purpose of the MSM Component is to provide real-time stream flow data which can be used by Ministry and Government Directorates to improve irrigation water management within Egypt. Specific objectives of the MSM component are to:

- install a real-time data collection system using telemetry technology;
- provide a data management system to allow decision makers and other IMS components easy access in a format that will be usable for their respective purposes;
- install a voice communication system that can be used throughout the Ministry's twenty directorates;
- establish improved water measurement capabilities including equipment, procedures, and trained staff;
- establish an Operation and Maintenance Organization that is equipped and trained to operate and maintain the various systems provided under this component;
- implement a canal automation scheme within one pilot canal command; and
- provide staff training that encompasses all of the above activities.

USU, under its subcontract with Harza Engineering Company, will:

- provide field staff to fill the positions of Software Engineer, Instrumentation/Electrical Technician, and Training Specialist;
- provide temporary duty and home office staff to fill the positions of Instrumentation/Electrical Technician, Agricultural Economist, Water Resources Systems Engineer, Water Measurement Engineer, miscellaneous people to meet special or short-term needs as they arise, sufficient home office coordination and secretaries, and graduate research assistants as needed; and
- arrange for technical visits, short-term training, and graduate training for MS and PhD students at USU and other U.S. institutions as appropriate.

Accomplishments

Ronald V. Canfield spent 12 months in Egypt and returned in August, 1990, after a successful mission. He was replaced by Delmar A. Dyreson who is currently serving with Ralph A. Sausedo as a member of the project field staff. Mr. Jeff May (formerly an Engineer with the USGS) was hired by USU early in the project and has been functioning as the Water Measurement Engineer on an as needed basis since that time. With respect to the training component of the program, three MS candidates are currently studying at USU. Alaa Hassan arrived from Egypt in early January 1990, and is now working on a MS in CEE, specializing in Hydrology and Water Resources Management. Osama Meslihi and Abou El-Seoud Ahmed arrived in September 1990; Osama is working on a MS in Electrical Engineering, specializing in Communications, and Abou is working on a MS in CEE, specializing in Hydrology and Water Resources Management. Work is progressing on schedule.

The results of this project will have direct application to water resource systems management in Egypt and could considerably increase the efficiency of water use in that country. Because Egypt is currently utilizing almost all of its available water supplies, the only way in which irrigated areas can be increased is through improved irrigation efficiency. The results of the study could also have direct application to irrigation system management, remote data acquisition, and training practices in many other countries of the world.

Publication

Water Quality
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Economic Incentives for Managing Groundwater Pollution in Salt Lake County .......................................................... 55

Phosphorus Bioavailability in Hard Water Rivers ......................................................... 56
Economic Incentives for Managing Groundwater Pollution in Salt Lake County

Principal Investigators:
T. F. Glover (PhD), Agricultural Economics
Herbert H. Fullerton (PhD), Economics
Richard C. Peralta (PhD), Engineering

Support Personnel:
Howard M. Deer (PhD), Toxicology
R. D. Ramsey (PhD), Geography and Information Systems

Student Assistants:
Oscar Daza (MS), Engineering
Shu Takahahi (MS), Engineering
Gertrudes Brito (MS), Economics
Gover Barja (BS), Economics

Problem and Research Objectives

1. Demonstrate a crop production/contamination management model (vertical saturated flow) that will optimize on-farm net returns subject to pesticide movement constraints.

2. Demonstrate the potential reduction of groundwater contamination by pesticides in the Salt Lake County area through optimal water and chemical management.

3. Demonstrate the maximum possible spatially distributed, sustained yield, groundwater extraction rates in the Salt Lake area without considering protection from pesticide contamination.

4. Present a methodology for linking on-farm and regional tradeoffs between net revenue and groundwater quality protection.

5. Demonstrate how to develop and quantify incentives, based on shadow prices computed from the completion of Objectives 2 and 3, to protect groundwater from agricultural NPS contamination due to pesticides.

6. Present a unified methodology for integrating computed incentives within Utah NPS guidelines and water resources development policy.

7. Disseminate information on optimal on-farm and chemical management to users and on possible incentive plans to water agencies.

Accomplishments

A model for obtaining maximum sustained yield groundwater extraction rates has been developed to obtain information on alternative pumping intensity and the impacts on the aquifer in the Salt Lake County area. Bounds on heads of wells in the area have also been derived, and information on all wells operating in the county has been collected. In general, as pumping is increased aquifer flow to the Jordan River is reduced; flows to the GSL are also reduced.

The objective function of the model is being modified to include economic net returns and pollution reduction incentive forms. In addition, the constraint set is being altered to include alternative groundwater standard constraints. Various water quality control mechanisms such as the Pigou Tax, alternative irrigation levels and technology, and input standards are being investigated. These will be imposed on the model to assess their potential in enhancing groundwater quality. Tradeoffs between water quality control and returns to on-farm enterprises will be further developed using the model framework.
Problem and Research Objectives

During the performance of research concerning the transport and fate of phosphorus available to algae (bioavailable phosphorus) in the Bear River (see project WG-402), it became obvious that precipitation of phosphate with calcium and other hardness ions in alkaline water could, potentially, severely limit the growth of algae in the water. In algal bioassays of hard, alkaline water from the Bear River and its tributaries where pH increased, algal growth did not increase linearly in response to added phosphate even though other nutrients were present in excess of growth requirements. In many of these assays, no measurable growth of algae occurred. These results indicate that Bear River system waters may not support algal blooms in reservoirs where it may be impounded.

Observations of local Bear River system reservoirs, however, indicate that algal blooms frequently occur in these reservoirs. In addition, empirical models of lake and reservoir eutrophication, based on normalized total phosphorus loading to the lake, predict eutrophic conditions in Hyrum Reservoir and in proposed reservoirs in the Bear River basin. This apparent conflict between bioassays and empirical data in predicting the eutrophication potential for proposed Bear River system reservoirs called for more information about the behavior and bioavailability of phosphorus in hard water streams and lakes. This project involved an in-depth literature review and data analysis concerning phosphorus bioavailability, phosphorus cycling, algal production, and eutrophication in hard water systems.

Accomplishments

Literature concerning phosphate aqueous chemistry, sediment and water column phosphorus cycling, and observations of algal growth in lakes and reservoirs that contain hard, alkaline waters was reviewed. A critical review of the literature is being prepared. Findings in the literature indicate that while considerable amounts of phosphorus may precipitate in hard, alkaline lakes and reservoirs, internal cycling of phosphorus due to microbial solubilization of calcium phosphate minerals in the sediments and water column and low phosphate sorptive capacity of calcareous sediments can provide adequate bioavailable phosphorus to support algal blooms.

Managers of water quality in lakes and reservoirs, especially in hard water systems, will benefit from the analysis of existing information to be provided by this project. Direct application of the findings of this work in planning proposed reservoir developments on the Bear River system in Utah and Idaho is expected.

Publication

Waste Management
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Biodegradation of Organopollutants in Bench Scale Reactors by a White Rot Fungus

Principal Investigators:
David K. Stevens (PhD), Civil and Environmental Engineering
John A. Bumpus (PhD), Biotechnology

Student Assistant:
Guyoung Kong (MS), Civil and Environmental Engineering

Problem and Research Objectives

Currently available technology for the biological treatment of wastewater is sometimes insufficient to decontaminate wastewater containing certain hazardous, environmentally persistent chemicals such as four- and five-ring polycyclic aromatic hydrocarbons (PARs), pentachlorophenol (PCP), and N,N,N',N,N'-hexamethyl-para-aramine (crystal violet). The white rot fungus, Phanaerochaete chrysosporium, shows promise for degrading contaminants that are structural analogues to its primary nutrient source, lignin. In this project, we are studying the degradation of these chemicals in batch suspended growth microcosms and in a fluidized bed continuous flow reactor that is suitable for scale-up to field scale.

Our objectives are to: 1) study the kinetics of fungal growth and xenobiotic degradation by P. chrysosporium, 2) develop a practical wastewater treatment system to degrade environmentally persistent chemicals in such water, 3) determine optimum conditions that promote biodegradation, 4) determine if toxic or recalcitrant reaction intermediates are formed, and 5) determine if biodegradation can be accelerated by adding supplemental biodegradable enzymes (lignines) to these biodegradation systems.

Degradation of two representative PAHs (benz[a]pyrene and phenanthrene), p-cresol, PCP, and crystal violet is being studied in bench scale reactors. In biodegradation studies that are just beginning, the disappearance of the parent compound and mineralization to CO₂ will be used as monitors of process efficiency. Metabolite formation will also be checked, and the process will be corrected for volatilization.

Accomplishments

Three series of experiments were done to study the behavior of tracer in a bioreactor. Results obtained without packing material are shown in Table 1.

<table>
<thead>
<tr>
<th>Run</th>
<th>Aeration</th>
<th>Recycle</th>
<th>θ (min)</th>
<th>τ (min)</th>
<th>σ²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yes</td>
<td>No</td>
<td>177.94</td>
<td>141.29</td>
<td>1690.45</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>Yes</td>
<td>208.50</td>
<td>154.60</td>
<td>15351.60</td>
</tr>
<tr>
<td>3</td>
<td>No</td>
<td>No</td>
<td>103.58</td>
<td>144.44</td>
<td>4745.03</td>
</tr>
</tbody>
</table>

It was observed that the bioreactor behaved as a completely mixed reactor in Runs 1 and 2. In Run 3, it behaved as a plug flow followed by a CSTR. In Table 1, it can be observed that the τ/θ values obtained were less than 1 in Runs 1 and 2. It may be expanding liquid volume by aeration or high recycle ratio. In Run 3, the τ/θ ratio was higher than in Run 1.

In Figure 1, the adsorption of crystal violet is shown based on pooled experimental data at various pH levels, since pH did not affect adsorption at equilibrium. In Table 2, the specific experimental results for the adsorption isotherm study are shown. The oxygen transfer coefficients, saturated oxygen concentration, and oxygen uptake rate were estimated by non-linear least squares. The parameter estimation results are summarized in Table 3. Under aerobic conditions, the coal biosolubilization rates were negligible. Under anaerobic conditions, the solubilized carbon was too oxidized to be of any energetic value.

![Figure 1. Crystal violet adsorption equilibrium test at various pH.](image)

Table 2. Summary of adsorption equilibrium study for the crystal violet.

<table>
<thead>
<tr>
<th>Conc.</th>
<th>Freundlich Isotherm Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>n</td>
</tr>
<tr>
<td>mg/l</td>
<td>LCL</td>
</tr>
<tr>
<td>5.0</td>
<td>.140</td>
</tr>
</tbody>
</table>

LCL: lower 95% confidence level
UCL: upper 95% confidence limit

Table 3. The summary of oxygen transfer study.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Kₓₓ (25°C), min⁻¹</th>
<th>Cₛ (25°C), mg/l</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCL</td>
<td>Mean</td>
<td>UCL</td>
<td>LCL</td>
</tr>
<tr>
<td>DDW¹</td>
<td>.048</td>
<td>.052</td>
<td>.056</td>
</tr>
<tr>
<td>Shake</td>
<td>.041</td>
<td>.047</td>
<td>.052</td>
</tr>
<tr>
<td>Culture²</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LCL: lower 95% confidence limit
UCL: upper 95% confidence limit
1: clean water test using distilled deionized water
2: dirty water test using White Rot Fungus (WRF) suspension

Project Number: BUMPUS
Sponsor: USGS
Project Duration: September 1989 - August 1992
Project Status: Research in Progress

59
Biosolubilization of Low Rank Coal

Principal Investigator:
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Student Assistant:
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Problem and Research Objectives
In this experimental program, we focused on the development of a clean coal technology using biosolubilization.

Accomplishments
We have evaluated anaerobic bacterial systems and aerobic fungal bioreactors. Results suggest that biosolubilization under either anaerobic or aerobic conditions do not yield significant amounts of soluble carbon species.

Under anaerobic conditions, the coal biosolubilization rates were negligible. Under aerobic conditions, the solubilized carbon was too oxidized to be of any energetic value.

Project Number: EC-1192
Sponsor: Vice President for Research/Mineral Leaçe Funds
Project Duration: July 1990 - June 1991
Project Status: Research in Progress
Modeling and Field Verification of Soil Vacuum Extraction/Enhanced Bioremediation of Fuel Contaminated Soils

Principal Investigators:
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David K. Stevens (PhD), Civil and Environmental Engineering

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Student Assistants:
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Problem and Research Objectives
Soil venting, or vacuum extraction, provides the removal of volatile and semivolatile compounds from the unsaturated zone through the application of a vacuum to subsurface soils. The low pressure area developed within the vadose zone is used to collect the extracted soil gas containing volatile contaminants which can be recovered or removed from the gas stream via carbon adsorption, incineration, etc., before the soil gas is vented from the site.

Soil venting to enhance subsurface biodegradation (enhanced bioventing) entails the use of soil gas as an oxygen transport mechanism to enrich the oxygen level in the subsurface. This stimulates aerobic biodegradation of semi- to non-volatile organics that remain following soil vacuum extraction. While this technology appears to have great potential for cost-effective remediation of contaminated soils, only limited experience with bioventing has been reported.

Soil venting is characteristic of remedial alternatives that provide permanent solutions and significantly reduce the mobility, toxicity, and volume of hazardous materials. The ability to mathematically model complex physical, chemical, and biological soil/waste interactions, and to physically test the validity of these models using field and laboratory-scale experiments, is needed to permit more effective extrapolation of results to new field-scale situations. Our primary objectives are to:

1. develop and verify, through laboratory scale experiments, a fate and transport model which describes soil/vapor interactions and contaminant vapor transport as affected by physical/chemical and biological processes taking place in the subsurface;
2. assess the significance of soil, contaminant, and environmental properties on model parameters and vapor transport and fate characteristics through model sensitivity analysis and laboratory studies; and
3. field test a design and operations model for the soil vacuum-enhanced bioventing process for use in future full-scale applications.

Accomplishments
Vacuum and vent gas composition data have been collected on a continuous basis at a full-scale soil vacuum extraction site at which a JP-4 jet fuel spill has been remediated. These data were collected to allow detailed comparisons to be made between field, laboratory, and model results so that effective field validation of the proposed model can be conducted. Discrepancies between model predictions and field data will be analyzed to assess the need for model improvement, additional data requirements, and further model calibration.

Laboratory experiments and treatability testing are currently underway. These small-scale laboratory microcosm experiments are being conducted in conjunction with model development and aquifer system studies to allow detailed determination of the effect of moisture and nutrient management on biodegradation of contaminants in the test soil systems.

Larger pilot-scale simulated aquifers will be constructed during the second year of the research to simulate one dimensional flow fields which are analogous to radial flow in the vicinity of a vent well. Initial experiments will be used to describe the pressure/flow field which develops within model aquifers as a function of vacuum applied to the system.

Pressure/flow experiments will be conducted for three aquifer materials at four vent flow rates under air-dried conditions. These assessments of pressure field development and equilibrium values over a variety of soil vacuum and moisture content conditions will provide a range of realistic pilot-scale operating data essential for validation of the flow field portion of the process model.

Following verification of the flow field model, pilot-scale assessment of the solute transport aspect of the model will be carried out. Final soil vapor concentrations will be collected, and mass balance calculations will be made for test compounds based on soil vapor and off-gas measurements, respiration products, and final soil concentrations.

Results from these laboratory-scale aquifers will provide information that will allow the validation of the pressure/flow field aspect of the proposed venting model and the interaction of these pressure/flow and moisture conditions on the distribution and degradation of test compounds in the model aquifers under simulated field conditions. These results will shed light on the mechanisms controlling vapor distribution, movement, and degradation in the subsurface under reduced pressure conditions and will improve the adequacy of contaminant fate assessment and prediction during soil vacuum extraction.

Publications

Biological Hazardous Waste Management Using White Rot Fungus: Bioreactor Engineering, Design, and Operation

Principal Investigators:
Ronald C. Sims (PhD), Biological and Agricultural Engineering
Michael J. McFarland (PhD), Biological and Agricultural Engineering

Student Assistant:
Xiu Gin (MS), Civil and Environmental Engineering

Problem and Research Objectives

The use of aerobic composting engineered to optimize the performance of the hazardous waste degrading microorganism, Phanerochaete chrysosporium, a white rot fungus, is a promising alternative treatment technology for accomplishing destruction and detoxification of organic hazardous chemicals for on-site remediation of contaminated soils and ground waters. This fungus is able to degrade a wide range of structurally diverse organic compounds to carbon dioxide. Many of these compounds are considered to be human and environmental health hazards and are resistant to biodegradation by most microorganisms.

P. chrysosporium, a naturally occurring microorganism, is a successful competitor with other microorganisms when cultured on wood-based products. Information concerning the technical feasibility, engineering design and operational aspects, and cost effectiveness of aerobic composting using P. chrysosporium for the treatment of hazardous chemicals present in complex wastes found in soil systems is being generated.

Objectives of the research effort include:

- determination of treatment feasibility (i.e., destruction and detoxification) of hazardous constituents in complex waste-contaminated soil, specifically those impacted with wood preserving wastes and coal gasification residues;
- determination of engineering design and operational information for optimizing destruction and detoxification of hazardous constituents;
- determination of the economic feasibility for application of the technology on a full-scale basis; and
- evaluation of a pilot scale aerobic composting unit for treatment of wood preservative-contaminated soil.

Accomplishments

During the first year of the study, research focused on determining engineering feasibility. During the second and third years of the project, reactor design and operational variables are being investigated. These variables include:

- temperature;
- moisture;
- free airspace;
- oxygen concentration; and
- concentration of P. chrysosporium.

Additionally, research efforts in the third year will focus on determination of the economic feasibility of the process. A comparison of the economics will be developed for three levels of achievable treatment, as defined by the results of the previous project efforts.

During the last year of the research project, a pilot-scale composting system will be designed, constructed, and operated, based on the results of the technical feasibility, engineering design and operation, and economic feasibility studies. The operating experience gained in the application of the pilot-scale system will be used in analysis of scale-up factors for full-scale design and operation of the process.

This project is part of a program project of the USU Biotechnology Center to develop hazardous waste treatment systems based upon the biodegradative capacity of white rot fungi. It is an interdisciplinary, interdepartmental program. The project is funded as part of the Superfund program to clean up uncontrolled hazardous waste sites. Research results will be utilized in the remediation of soils and ground waters contaminated with hazardous organic chemicals.

Publications


Hill Air Force Base—Soil Venting System Monitoring/System Optimization

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Darwin L. Sorensen (PhD), Soil Microbiology

Support Personnel:  
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AiHe Zhou (MS), Civil and Environmental Engineering

Student Assistants:  
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Anis Ahmed (MS), Civil and Environmental Engineering  
D. Kennanahalli Padmanabha (MS), Civil and Environmental Engineering

Problem and Research Objectives

Contamination of subsurface environments by hazardous organic compounds from surface spills, leaking underground storage tanks, and uncontrolled releases from impoundments, pipelines, and surface waste deposits has resulted in surface and groundwater contamination at literally thousands of sites throughout the U.S. It was estimated that some 75,000 to 100,000 petroleum storage facilities were leaking in 1985; this number was expected to increase to 350,000 by 1990. The U.S. Air Force has identified over 1,000 sites on Air Force facilities with known or suspected soil and groundwater contamination. The most common constituents of the contamination are waste fuels and chlorinated solvents.

Soil vacuum extraction (SVE) has found wide application in the in situ treatment of fuel and solvent contaminated soils. However, SVE has not generally been applied to heavier fuels (diesel or JP-4 jet fuel) and fuel oils because of the large fraction of high boiling point, high molecular weight compounds they contain. Although these high molecular weight constituents are not volatile, they are amenable to biodegradation.

A JP-4 jet fuel spill occurred at Hill AFB, Utah, in January, 1985, due to the failure of an automatic shut-off valve. This resulted in the release of approximately 27,000 gallons of JP-4, approximately 2,000 gallons of which were recovered as free product. The balance of the spill migrated away from the tank and contaminated an area of approximately one acre, 50 feet. Initial soil total petroleum hydrocarbon (TPH) concentrations reached 15,000 mg/kg with average TPH levels of 1500 mg/kg. Our objectives were to: 1) assess the potential for using the gas transfer capability of vacuum extraction systems, in conjunction with nutrient and moisture management, for the optimization of in situ biodegradation; and 2) yield an enhanced bioventing system at a field-scale JP-4 spill site capable of degrading residual fuel organics not amenable to SVE treatment alone.

Accomplishments

Before initiation of the full scale venting system, the fuel tanks were excavated, refurbished, and installed in a concrete cradle above ground, and a venting system was installed. Twenty-one pressure monitoring points (PMP) were installed at various depths throughout the site to provide point measurements of subsurface pressure and soil gas conditions. A background well was placed approximately 700 feet north of the site in the same geological unit and at the same depth as the vent wells to provide a control for basal soil respiration levels during the study.

Prior to our study, the SVE system was operated under a conventional mode to maximize the recovery of volatile JP-4 components through volatilization. Venting was initiated on December 18, 1988, at a rate of 26 acfm, and gradually increased to approximately 1500 acfm as the hydrocarbon levels in the vent gas decreased over time. This high-rate operating mode was maintained from December 18, 1988, through September 15, 1989, during which time approximately 300,000,000 acf of soil gas were extracted from the site.

A total of three field tests were conducted from September 1989 to November 1990, representing different levels of management at the site, i.e., prior to management at the site, following moisture addition, and following moisture and nutrient addition. Three in situ respiration tests were conducted during the high rate venting operating period following vented air volumes of 42,000 acf, 540,000 acf, and 45,000,000 acf. Further field studies were initiated to evaluate the potential for enhancement of biodegradation under modified site management conditions.

Significant biological activity was indicated at the field site. Without enhancement, a total of 15 to 25% of the recovered JP-4 could be attributed to biodegradation reactions. This increased to greater than 80% with enhancement, resulting in an additional 17,000 pounds of total petroleum hydrocarbons degraded during the bioventing portion of the study. Additionally, it was found that moisture addition (25 to 50% field capacity) statistically accelerated respiration at the site. However, nutrient addition generally did not statistically increase the degradation rates of residual JP-4 constituents.

Bioventing appears to be a feasible option for the in situ degradation of residual fuel contaminants not amenable to recovery by SVE alone. Methods to reduce vapor extraction rates and maximize vapor retention times in the soil are compatible with enhancing biodegradation reactions through moisture management. These procedures result in minimizing volatilization, potentially eliminate the need for vent gas treatment, maximize the utilization of oxygen in situ, and provide a framework for the development of truly optimized in situ biological treatment systems in the future.

Publications


Evaluation of the Use of Plants for Stimulating PAH Degradation in Soil

Principal Investigator:
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Support Personnel:
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James Herrick (MS), Chemistry

Student Assistants:
ATi Ferro (PhD), Biochemistry
Jeffrey Watkins (BS), Forest Service

Problem and Research Objectives

A well-managed and monitored soil treatment system offers industry a means of ultimate safe disposal of wastes through the controlled application of hazardous constituents. With controlled application, a waste can be made less hazardous, or non-hazardous, by degradation, transformation, or immobilization processes occurring on or in the soil.

For soil treatment to be used as an ultimate disposal technology, however, the treatment site, at the end of its useful life, must undergo a closure process. Closure procedures are designed to control, minimize, or eliminate any potential for damage to human health and the environment. One means of closure involves the stimulation/augmentation of in situ treatment processes to further degrade and detoxify soil-incorporated waste to regulatory-acceptable levels as well as to stabilize soil surfaces.

The use of deep-rooted prairie grasses to stimulate degradation and detoxification of toxic and recalcitrant organic chemicals at low soil concentrations may represent a low-cost, effective, and low-maintenance means of waste management during the closure of hazardous waste facilities. Stimulation of treatment of recalcitrant toxic compounds may be accomplished through several proposed mechanisms of plant/soil interactions, including:

- improvement of physical and chemical properties of a contaminated soil;
- increase in cometabolic potential through use of root exudates by microorganisms; and
- increase in contact between microbes associated with roots and toxic organic compounds in a contaminated soil.

Prairie grasses are perennial plants, so their use would provide an easily maintained, highly competitive plant community capable of displacing undesirable or noxious plant species.

Accomplishments

After seven months of incubation, concentrations of PAH compounds in soil at a low loading rate had decreased by 81 percent in vegetated columns but only 72 percent in a non-vegetated column. Similar trends were observed for PAHs initially loaded at a higher loading rate. Significant statistical differences in decreases between the vegetated and non-vegetated columns were observed. Toxicity analyses of leachate samples from the columns, as measured by the Microtox™ assay, indicated that toxicity was not present in any sample tested. PAH compounds were not detected in leachate samples. Also, once the grasses had established sufficient shoot and root mass, losses of water from the system in the form of leachate ceased while leachate continued to be generated in non-vegetated columns.

Further laboratory studies are being conducted with additional classes of chemicals, including formic acids, and with soils from active waste treatment and disposal sites. Following completion of the laboratory evaluation of site-specific soils, experimental plots will be established at operating waste treatment units. Study of these plots will address the variable conditions of climate, sunlight, temperature, water stress, and management practices.

Publications


Experimental Work for Winter Root Zone Treatment of Municipal and Industrial Wastes

Principal Investigator:
David K. Stevens (PhD), Civil and Environmental Engineering

Student Assistant:
Joy Emory (BS), Civil and Environmental Engineering

Problem and Research Objectives

The treatment of wastewaters in cold climates is a significant problem for small communities where mechanical treatment plants are prohibitively expensive to build and operate and most non-mechanical treatment alternatives are effective only during warmer weather. The Root Zone Method (RZM) is an artificial wetland process that uses common reeds, *Phragmites australis*, and provides effective treatment during cold weather. This is accomplished by virtue of the reed's active oxygen transport mechanism and the use of its root zones, rather than soil interstices for wastewater passage and microbiological colonization and treatment.

The RZM has been effective in Europe, but has yet to be introduced in the U.S. where the wastewaters are of quite different quality and strength. The unique characteristics that make the RZM effective require detailed study so that process effectiveness can be optimized.

The RZM of land application of wastewater is an engineered treatment using the soil (as opposed to a treatment and disposal process) that does not suffer from the drawbacks described above. The process is similar to an artificial wetland in that an impervious liner is placed in the soil below the treatment level and a suitable soil is placed on top of the liner. However, unlike the wetland which is operated with a 4 - 8-inch surface water depth, in the RZM the wastewater is applied underground at the upstream end of the soil through which it flows without surfacing to the downstream end. It is then collected and discharged.

Pond reeds, *Phragmites australis*, are planted, covering the ground surface such that their roots grow down to the level of the liner and provide oxygen to the bacteria growing at the root surface and within the root zone. The wastewater passes through these root zones where the organic matter and nitrogen in the water are mineralized and removed. Aerobic, facultative, and anaerobic organisms are all present in the soil at various distances from the root surface so that pollutants are exposed to several organisms types, increasing the probability that they will be removed.

Our objectives are to:

- demonstrate the technical and engineering feasibility of the RZM of wastewater treatment in cold climates in the U.S., and
- investigate, on a pilot scale, the important mechanisms controlling the removal of contaminants, including chemical and biochemical reactions, oxygen dynamics, bed hydraulics, and the mass transfer process.

Accomplishments

The work is being carried out in two phases. The first phase is on a controlled small pilot-scale at the UWRL using wastewater from a cheese processing plant as feed. The second phase will be on a larger pilot-scale using industrial wastewater on-site.

The pilot RZM has been operated continuously since Fall, 1989. Reeds obtained from a natural wetland near Perry, Utah, were planted, and clean water was passed through the system to allow the transplanted reeds to take root. Wastewater flow was begun, and the process was periodically sampled to observe system behavior.

Measurements are being made for BOD<sub>5</sub>, COD, suspended solids, nitrogen, phosphorus, alkalinity, calcium, and pH. Initial results show that the process is capable of removing up to 95% of the BOD<sub>5</sub> and suspended solids and 80% of the COD. Nitrogen and phosphorus are only removed in small amounts. The alkalinity increases significantly due to dissolution of the calcareous soil used in the bed, and the pH drops slightly, probably due to nitrification and the production of organic acids at anaerobic microsites.

Interest in the project has been shown by a private group. A preliminary design has been prepared for a small-scale system for this group.

Project Number:
WA-119

Sponsor:
State Appropriation Funds

Project Duration:
July 1986 - June 1991

Project Status:
Research in Progress
Isolation of Coenzyme F420 from Anaerobic Sludge and its Use in Whey Waste–treatment Evaluation

Principal Investigator:  
R. Ryan Dupont (PhD), Environmental Health Engineering

Student Assistant:  
Ying Bian (MS), Civil and Environmental Engineering

Problem and Research Objectives

Anaerobic reactors have been unreliable due to a lack of complete understanding of the complex microbial and biochemical reactions and interactions taking place within them. Their performance has been evaluated using measurements of reactor products or reactants, including COD, VSS, pH, volatile acids, gas production, and methane gas content.

Performance evaluation has not been directed toward enumeration of the methanogenic bacteria responsible for organic waste stabilization in these reactors. This is due to the difficulty in their reliable detection and quantification. Biomethane production potential is one method for the indirect determination of the level of methane producers in anaerobic reactors. However, this is somewhat time consuming and difficult to implement.

The development of direct methods for the quantification of methanogen populations and/or methane production potential is needed for bench–scale process selection and optimization, as well as for process monitoring in full–scale reactors. Development of such a method was our primary goal.

Our specific objectives were to:

- determine optimal procedures for the isolation of coenzyme F420 from an Upflow Anaerobic Sludge Blanket (UASB) reactor granular sludge treating whey permeate;
- correlate coenzyme F420 measurements with other indicators of methane potential using conventional indicator parameters; and
- conduct a treatability assay for whey permeate wastewater and evaluate the feasibility of application of coenzyme F420 for treatability determinations and for the assessment of methanogen inhibition and recovery from toxic inputs.

Research Project Accomplishments

Coenzyme F420 is only contained within microorganisms which produce methane under anaerobic conditions. These organisms are critical in the successful stabilization of complex organic matter anaerobically; therefore, quantification of the coenzyme F420 content of a reactor provides some indication of the methane production potential within that system.

Methods for the separation of coenzyme F420 from granular sludge from a UASB reactor and its isolation, concentration, and purification have been carried out. Conditions for the optimization of separation and purification procedures in terms of optimal preparatory and separation procedures, elution methods, and storage and quantification procedures have been identified.

This optimal method consisted of a modified Binot (1981) method entailing the following: tap, distilled and physiological saline water rinse; distilled water dilution prior to heating to 95°C for 20 minutes; high speed (10,000 rpm) centrifugation for approximately 10 minutes; ethanol addition and mixing for one hour; an additional 10 minute high speed centrifugation; rotary distillation at a temperature of between 90 and 95°C; use of QAE–Sephadex A–25 media and ammonia acetate gradient elution to provide coenzyme F420 separation from the concentrated centrate; and further purification using a Sephadex G–15 column and distilled water elution.

From the treatability assays of whey permeate waste, optimal nutrient conditions were found and problems of limited treatability of whey permeate waste in anaerobic reactors were solved.

The observed inhibition of sodium, ammonia–nitrogen, and uncontrolled pH conditions to the municipal secondary digester sludge provided information that can be used to further improve UASB operation. The addition of trace metals resulted in inhibition to the biomass, while pH control and a suitable C:N:P ratio were shown to be the key for stable whey permeate treatment.

Coenzyme F420 changes in batch reactors were shown to closely follow methane production rates. Coenzyme F420 was found to provide a sensitive detection technique for impending digester failure. It is an effective index of methanogen inhibition and recovery that can be further developed for use in reactor design and recovery scheme development.

The development of a sensitive, direct measurement technique of methanogen content and viability provides a powerful means of monitoring anaerobic digester stability. This method will enable improved anaerobic reactor design and operation. Continued refinement of such a monitoring method will provide design and operating personnel a tool for the effective control of anaerobic system loading, increase understanding of the effects of operating and loading variables on methanogen activity and survival, and should allow the continued expansion of anaerobic systems for efficient and cost effective waste treatment.

Reference


Publications


Bioprocess Engineering Program Development

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Thomas Hardy (PhD), Civil and Environmental Engineering
Michael J. McFarland (PhD), Biological and Agricultural Engineering
Darwin L. Sorensen (PhD), Microbiology
David K. Stevens (PhD), Civil and Environmental Engineering

Support Personnel:
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Mary Randolph (PhD), Microbiology

Problem and Research Objectives
A bioprocess engineering program has been developed as a cooperative effort between the EE Division and the AIE Department. This program provides students with a BS in engineering or biological sciences. Specialized coursework and research experience in bioreactor processing of environmental materials and engineering scale-up of biological-based environmental reactions are offered at the graduate level.

Accomplishments
Available areas of specialization include:
• biologically-based hazardous waste treatment technologies for contaminated subsurface environments;
• waste-to-energy processes;
• fermentation;
• composting;
• industrial and agricultural waste reuse, recycle, and minimization technologies based on biological processes; and
• engineering optimization of aquatic habitats.

Studies to Determine Phosphates and Nitrogen Groundwater Inputs to Deer Creek Reservoir

Principal Investigator:
Roland W. Jeppson (PhD), Fluid Mechanics

Student Assistant:
Scott Koram (MS), Civil and Environmental Engineering

Problem and Research Objectives
Deer Creek Reservoir in Heber Valley, Utah, supplies approximately 65 percent of the water distributed to Salt Lake County, the population center of the State of Utah. To maintain the quality of Deer Creek Reservoir and to limit its eutrophication, “best management practices” for surface waters have been implemented. These practices have significantly improved the quality of surface streams flowing into the reservoir. However, recent data for amounts of phosphorus and nitrogen in groundwater inflows to the reservoir are several times larger than predicted. There is concern that cleaning surface inflows by spreading treated sewerage on land, retaining dairy wastes in lagoons, etc., have only delayed the arrival time of harmful chemicals. These chemicals have the potential for transmittal through groundwater recharge.

Accomplishments
Our objective is to obtain data on chemicals entering the groundwater, with emphasis on phosphates and nitrogens, from lands where treated sewerage from Heber Valley is spread as well as that from liquid manure lagoons at dairy farms. Project tasks consist of:

1. The installation and collection of data from unsaturated-saturated zone (vadose zone) samplers that extract water from the partially saturated soil at six sites (with two samplers at different depths at each site). These sites are within the land where the sewerage is disposed and adjacent to two liquid manure lagoons at dairy farms. Chemical analyses from water samples, including common nutrient determinations, are being obtained on a monthly or bi-monthly basis.

2. Laboratory sorption studies on soil columns acquired in an undisturbed state from the six sites in the sewer farm.

3. Development of a computer transport and dispersion model of nutrients through the saturated groundwater system into the Heber Reservoir.

4. Study of denitrification processes taking place in the Heber Valley.

Publication
Optimization of Processes in the Destruction of Pathogens: Storage of Sludge

Principal Investigators:
Darwin L. Sorensen (PhD), Microbiology
R. Ryan Dupont (PhD), Environmental Health Engineering

Support Personnel:
Wayne Aprill (MS), Agronomy

Student Assistant:
Anis U. Ahmed (PhD), Civil and Environmental Engineering

Problem and Research Objectives

The Bureau of Water Pollution Control, Utah Department of Health, has sought to encourage beneficial use of sludge through distribution and marketing. Their current regulation for sludge distribution programs requires that sludge be stored for one year after it has been digested and dewatered. This regulation is intended to minimize the risk of infectious disease from sewage sludge; however, no direct measurements of pathogen destruction during storage of dewatered sludge have been made to support this regulation. Current U.S. EPA proposed sludge disposal regulations emphasize the need for achieving temperatures greater than or equal to 53°C for five days or more to assure the destruction of pathogens.

This project was organized to demonstrate the pathogen destruction potential of dewatered sludge storage and to investigate the possibility that the occasional turning of sludge storage piles to incorporate oxygen might enhance pathogen destruction. If pathogen destruction could be made to be equivalent to thermophilic composting, storage, or storage with occasional sludge pile mixing might be proposed to meet federal criteria for distributed and marketed sludges.

Accomplishments

Sludge storage piles seeded with pathogenic bacteria, viruses, and helminth eggs were studied in field investigations for one year. Laboratory experiments were performed for another six months to complement findings from field investigations. Major findings from this work include the following:

- Simple storage of digested and dewatered sludge, mixed twice per month, has the capacity of meeting or even exceeding the U.S. EPA proposed criteria of 53°C.
- Pathogenic bacteria (Salmonella typhimurium, Campylobacter jejuni, Yersinia enterocolitica), enteric viral indicator bacteriophage (F2), and Ascaris suum eggs were all destroyed during the one year storage time.
- In laboratory experiments, the rate of microorganism destruction increased with increasing temperature.
- In laboratory incubations, the presence or absence of oxygen made no difference in the destruction of pathogens at higher temperatures.
- At any given temperature, the time for pathogen destruction in sludge was a function of initial concentration of microorganisms.

A computer model was developed that will help municipal wastewater treatment plant managers and operators determine the potential of their plant’s sludge for autoheating, how to treat and handle the sludge for optimal heating, and the length of time sludge should be stored to achieve a standard reduction of pathogens.

Research results can help the Utah Department of Health promulgate sludge regulations for the treatment and ultimate disposal of sludge. Written guidelines and the mathematical model can aid wastewater treatment plant managers and operators in processing their sludge for distribution and marketing with the assurance that the risk of public exposure to pathogens has been eliminated.

Publications


Evaluation and Control of Mechanisms of Microbial Alteration and Humification of PAHs for Water Quality Management

Principal Investigators:
Ronald C. Sims (PhD), Biological and Agricultural Engineering
Darwin L. Sorensen (PhD), Microbiology
Michael J. McFarland (PhD), Biological and Agricultural Engineering

Support Personnel:
William J. Doucette (PhD), Chemistry
Judith L. Sims (MS), Soil Science/Environmental Biology

Student Assistants:
Carolyn Abbott (BS), Biology
Hun Seak Park (MS), Environmental Engineering
Gene Whelan (MS), Civil Engineering

Problem and Research Objectives
Polynuclear aromatic hydrocarbon (PAH) compounds are present in high concentrations in creosote wood preservative wastes that have contaminated ground and surface waters through contact with contaminated soils at over 1,100 sites in the U.S. Understanding the microbial alteration and fate of biological transformation products of high molecular weight PAH compounds may provide a basis for the control of transformation for accomplishing destruction, detoxification, and removal of PAH compounds to protect water supplies.

The fate of PAH transformation products, including water soluble and mutagenic species, in unsaturated soil systems is being investigated. The potential for biological coupling of transformation products to humic materials is also being investigated. The study involves the use of creosote-contaminated soils in laboratory microcosms. Radiolabelled-PAH compounds (benzo(a)pyrene, B(a)P, and pyrene) are being used.

Accomplishments
Experimental results have shown a trend of increasing association of PAH compounds with the soil solid phase in both poisoned and non-poisoned samples. This suggests that chemical humification processes may be responsible for covalent binding of PAHs, and perhaps polymerization of PAHs, resulting in a more stable (immobile) soil–PAH complex. This observation of an increased association of PAHs with the solid phase of soil has led to the design of experiments to analyze the humic and fulvic acid fractions versus the residual humin to determine the site of PAH binding to soil as well as to the mechanism(s) of binding (i.e., biological, chemical, or a combination of both).

Water soluble extracts of contaminated soil microcosms were evaluated for toxicity using the Microtox™ toxicity assay. There was excellent correlation between the percent of radiolabeled carbon in water extracts and Microtox™ toxicity, indicating that toxicity in the water-soluble phase of the contaminated soil could be monitored using the Microtox™ assay. These results were consistent for both B(a)P and pyrene over a 200-day incubation and analysis study.

The relationship between PAH transformation products and toxicity to algae and daphnia, as well as to fish, is currently being investigated. This approach will indicate implications for biomagnification through the food chain of water to algae to daphnia to fish. Chemical intermediates in the water soluble and organic extract phases for both poisoned and non-poisoned soil samples are being analyzed and identified.

Research results have implications with respect to the long-term behavior of high-molecular weight hydrocarbons in soil and aquifer media. Humification of PAHs may render these compounds immobile and non-toxic in the solid phase. Also, the use of simple assays like the Microtox™ assay may be useful in monitoring the leaching of contaminated water through a contaminated site.

Publications
Bioresactor Composting Using White Rot Fungus

Principal Investigator: Michael J. McFarland (PhD), Biological and Agricultural Engineering
Student Assistants: Xiu Jin Qiu (MS), Civil Engineering
Corey Radtke (BS), Biology

Problem and Research Objectives
This experimental program focused on the development of soil bioreactors using the white rot fungus *P. chrysosporium*.

Accomplishments
Preliminary results demonstrated that *P. chrysosporium* could effectively remove benzo(a)pyrene during composting operations. Most of the contaminant carbon was not mineralized; it was apparently incorporated into the soil matrix as part of the soil humus.

Publications


Bioremediation of the Vadose Zone Under Methanotrophic Conditions

Principal Investigator: Michael J. McFarland (PhD), Biological and Agricultural Engineering

Problem and Research Objectives
The focus of this research is on cometabolic biotransformation of benzo(a)pyrene by methanotrophic bacteria in the soil. Research objectives include:

1. Perform a mass balance on benzo(a)pyrene in the soil system. A mass balance would allow estimation of the biodegradation, humification, mineralization, and sorption of the contaminants.
2. Estimate benzo(a)pyrene removal rates with and without methane amendments.
3. Quantify the methane uptake in soil microcosm reactors.

Accomplishments
Research data suggests that methane stimulation of soil is ineffective in enhancing benzo(a)pyrene removal.
Subsurface Vapor/Solid Interactions

Principal Investigator:
David K. Stevens (PhD), Civil and Environmental Engineering

Student Assistant:
Claudia H. Gaeddert (MS), Civil and Environmental Engineering

Problem and Research Objectives
The removal of organic contaminants from the subsoil can, under proper circumstances, be accomplished using soil vacuum extraction. This is a process where air is drawn through the vadose zone and volatile contaminants are stripped from the soil and from pools of hydrocarbons. The mechanics of this process are not completely understood, so the usual assumption made in describing the system is that the concentration of the contaminants in the vapor phase is always equivalent to its vapor pressure, that is, the volatilization of the contaminant is assumed to be in equilibrium.

Under actual process conditions, however, mass transfer limitations may exist where the rate of volatilization cannot keep up with the rate of removal by the air and the concentration is reduced below the vapor pressure equivalent. This has been proven in pulse testing in the field where the vapor phase contaminant concentration has been shown to increase considerably after the vacuum source is stopped.

Our objectives were to:
- characterize the partitioning behavior of the contaminant toluene in soil with an “oil” phase (dodecane);
- observe the dynamics of the stripping of toluene from three binary (air/soil, soil/dodecane, and air/dodecane) systems and the ternary (air/soil/dodecane) system using a Carberry-type particle characterization reactor which uses soil micro-columns at three flow rates;
- estimate the values of the two mass transfer coefficients in a plug-flow mass transfer model as functions of the flow rate for comparison with published correlations; and
- test the mass transfer model in a larger soil column to verify the model form and mass transfer parameter estimates.

Accomplishments
This project was completed in January, 1991. The experimental results showed that the partitioning behavior of the air/soil and dodecane/soil systems could be described by the BET and Freundlich isotherms, respectively. Experimental difficulties precluded determination of the form of the air/dodecane partitioning relationships.

Dynamic studies in soil micro-columns showed that the soil system was mass transfer limited at the velocities and that the mass transfer coefficient was proportional to the Reynolds number raised to the one-third power. This is consistent with published results from other workers. The mass transfer model, which includes internal and external transport resistance, fit the data quite well at medium and high air flow velocities and less well for low velocities. The model verification study in a longer soil column showed that the model has difficulty in predicting the large peak in breakthrough concentration but correctly simulates the salient features of the experimental curve.

Publication

Microbial Ecology and the Use of Gene Probes

Principal Investigator:
Darwin L. Sorensen (PhD), Microbiology

Student Assistant:
Anis U. Ahmed (PhD), Civil and Environmental Engineering

Problem and Research Objectives
Gene probe technology, the use of DNA homology to identify specific genes in organisms or in communities of organisms in environmental samples, has opened a broad range of new possibilities in microbial ecology. Through this project, gene probe analytical capability has been established in the EQL at the UWRL.

Accomplishments
The gene probe capability established will be initially used to monitor the amount of nitrogen fixation related genetic material (nif genes) in subsurface, contaminated soil environments. It may also be used to monitor the amount of toluene (and related compound) degradation related genetic material (tol gene) in soil samples.

Initial application of this analytical capability will be in projects in which the biodegradation of petroleum hydrocarbons in subsurface contaminated soils and the role of nutrient availability in stimulating degradation are investigated.

Project Number: WR-174
Sponsor: Mineral Lease Funds
Project Duration: July 1990 - June 1991
Project Status: Research Completed

Project Number: WR-183
Sponsor: Mineral Lease Funds
Project Duration: January 1990 - June 1991
Project Status: Research in Progress
In Situ Treatment of Hazardous Waste: Cooxidation of Polynuclear Aromatic Hydrocarbons in Soil Systems

Principal Investigator:
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Support Personnel:
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Judith L. Sims (MS), Soil Science/Environmental Biology
Darwin L. Sorensen (PhD), Microbiology

Student Assistants:
Carolyn K. Abbott, Biochemistry
John Keck, Environmental Engineering
Hun Seak Park (MS), Civil Engineering

Problem and Research Objectives
Polynuclear aromatic hydrocarbons (PAHs) are compounds that are difficult to remove from waste streams, slowly degrade in the natural environment, possess the potential for bioaccumulation, and have been demonstrated to have carcinogenic and mutagenic properties. PAHs are present in a variety of waste types, including petroleum refinery and creosote wood preserving wastes.

PAHs containing four and five rings—compounds resulting in the greatest degree of chronic toxic effects—are sparingly water soluble and are especially difficult to degrade. However, if the microbial enzymes that act to degrade PAHs (i.e., oxygenases) can be induced during the degradation of other substances, four- and five-ring PAHs can also be degraded through a cooxidation process.

In this project, cooxidation was investigated as a possible means of accomplishing biodegradation of PAH compounds in contaminated soil systems. Specific objectives of the research included:

- determination of the rate and extent of biodegradation of parent PAH compounds and of metabolic intermediate products and the rate and extent of volatilization of intermediates under cooxidation conditions;
- determination of the rate and extent of detoxification of PAH compounds and intermediates associated with soil solids and leachate solutions under cooxidation conditions using a battery of bioassays; and
- determination of the effect of oxygen tension on the rate of biodegradation of PAH compounds and intermediates under cooxidation conditions.

Accomplishments
Methane, a potentially effective management tool in introducing a growth substrate to soils contaminated at depth, was used as the cooxidation growth substrate to induce the oxygenase enzyme. The extent of apparent loss of a selected PAH compound, benzo[a]pyrene (B[a]P) through time, as determined in laboratory microcosm studies, was significantly greater in a microbially active soil amended with methane than in active soil without methane or in a sterile soil amended with methane.

Studies utilizing radiolabeled B[a]P showed that association (i.e., partitioning) of B[a]P with soil organic and inorganic materials may also be an important apparent loss mechanism for PAH compounds in soil systems.

Generation of polar intermediates, more soluble than parent B[a]P, was demonstrated through analyses of aqueous soil extracts. The production of intermediates resulted in an increase in aqueous extract toxicity.

Research on the effects of oxygen tension on the extent of biodegradation of PAH compounds under cooxidative conditions was also conducted. The supply of dissolved oxygen available for microbial activity appears to be an important factor limiting biodegradation. Oxygen, through depth in the soil, is consumed by biological activity at a rate greater than it can be replenished by diffusion from the soil surface. Soil incubation studies using selected radiolabeled PAH compounds under various oxygen levels and amended with methane were conducted.

This project was part of a research program sponsored by the Office of Exploratory Research of the U.S. EPA, Washington, DC. Results may be used by engineering consulting firms in design of remediation plans for soils contaminated with polynuclear aromatic hydrocarbons.

Publications
Hydrocarbon Venting

Principal Investigator:
Marian W. Kemblowski (PhD), Hydrology

Student Assistant:
Kdra Kamil (MS), Civil Engineering

Problem and Research Objectives
Our principal objectives are to: 1) assist EG&G in designing a hydrocarbon venting system for an Air Force Base in Michigan, and 2) design a soil-vapor tracer test and analyze the test's results.

Accomplishments
The initial phase of the venting system was completed in August, 1990. The tracer test was designed during the summer of 1990. However, the work on the venting project was unexpectedly suspended due to the lack of funding last summer. Also, due to technical problems, the field experiment on tracer transport was not performed as planned and is now scheduled for the coming spring.

Hydrocarbon venting accomplishments are as follows:
1. Consultation to EG&G regarding various remediation approaches to the study site.
2. Analysis of the boiling point distribution curves for monitoring wells.

Biotransformation Studies of Organic Substances

Principal Investigators:
Ronald C. Sims (PhD), Biological and Agricultural Engineering
Michael J. McFarland (PhD), Biological and Agricultural Engineering

Support Personnel:
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Mary Randolph (PhD), Microbiology
Michael E. Wright (PhD), Chemistry

Student Assistants:
Jon Ginn (MS), Civil and Environmental Engineering
Ari Ferro (PhD), Biochemistry

Problem and Research Objectives
In 1987, in response to the need for a better understanding of the release, transformation, transport, and fate of organic compounds associated with the electric utility industry's past, present, and future operations, EPRI initiated the Environmental Behavior of Organic Substances (EBOS) project. As part of this project, the UWRL, in conjunction with Cornell University and Atlantic Environmental Services, is conducting research that addresses quantification of natural biotransformation reactions/mechanisms involved in the release and transformation of selected organic compounds, specifically polynuclear aromatic hydrocarbons (PAHs), in the subsurface environment.

Phase I of the study primarily involves laboratory studies. Specific research objectives include:
- development of experimental approaches for determining biotransformation rates of PAHs under field conditions;
- development of methods to screen for biotransformation potential in field samples; and
- finalization of experimental designs required to understand processes controlling biotransformation rates under field conditions so that realistic predictions of the fate of PAHs in the subsurface can be made.

In Phase II, experiments will be conducted at multiple field sites to generate a database of transformation rates and to develop mathematical relationships to be used in the generation of models.

Accomplishments
Soil core samples from a contaminated site have been obtained. Studies are being initiated to develop and evaluate:
1) chemical methods used to measure biotransformation of PAH compounds (including the use of deuterated tracer PAH compounds), and 2) assays and protocols to determine the rate and extent of PAH degradation, transformation to intermediate products, and mineralization.
Environmental Analysis
Environmental Analysis

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Biological Mercury Removal Using Whey Permeate

Principal Investigators:
David K. Stevens (PhD), Civil and Environmental Engineering
Conley Hansen (PhD), Nutrition and Food Science

Problem and Research Objectives
A study was carried out to determine the kinetic behavior of the microorganisms responsible for the reduction of Hg\(^{+\,+}\) to Hg\(^{0}\) and the effect of mercury concentration on those growth kinetics.

Accomplishments
Steady-state experiments were carried out at four mean cell retention times and three influent Hg\(^{+\,+}\) levels. Feed to the system consisted of whey permeate supplemented with nutrients and designed concentrations of Hg\(^{+\,+}\) at flow rates designed for preselected mean cell residence times. Steady-state COD, VSS, Hg\(^{+\,+}\), and total Hg measurements were made and averaged over the steady-state period. The results are shown in Figure 1.

The results were analyzed in concert with standard design equations based on mass balances assuming unstructured biological growth following Monod-type growth kinetics and assuming that the influent to the system contained no biomass. The steady-state equations based on this analysis are:

\[
S = \frac{K_x [1 + b\theta_c]}{\theta_c (\mu_{\text{max}} - b) - 1}
\]

\[
X = \frac{Y(S_o - S)}{1 + b\theta_c}
\]

where S\(_o\) and S are the influent and effluent COD concentrations (mg/L), \(X\) is the biomass concentration (mg VSS/L), \(\mu_{\text{max}}\) is the specific growth rate of the microorganisms (hr\(^{-1}\)), \(K_S\) is the half-saturation coefficient (mg COD/L), \(Y\) is the yield coefficient (mg biomass/mg COD), and \(b\) is the decay coefficient (hr\(^{-1}\)) which was assumed to be negligible for this preliminary analysis.

The data were used to estimate the values of the constants \(\mu_{\text{max}}\) and \(Y\) under the assumption that \(K_S\) is equal to 6000 mg COD/L. From the data in Figure 1, it is apparent that a proportion of the COD in the whey permeate was not degradable (approximately 1200 mg/L).

From this observation, the first equation was modified to \(S' = S + S_{\text{ND}}\). Non-linear least-squares regression estimates (± 95% confidence interval for \(\mu_{\text{max}}\), \(Y\), and \(S_{\text{ND}}\) are 2.0 day\(^{-1}\) (0.9), 0.032 g VSS/g COD (0.008), and 1,200 mg/L (137), respectively. The model is plotted with the data from Figure 1.

Based on these results, it appears that the organisms grow very rapidly with a low yield. The non-degradable portion of the influent COD is estimated to be about 30%.

Figure 1. Plot of steady-state kinetic data and fitted model for mercury reduction on whey permeate kinetic experiments.
Pesticide Sorption/Desorption to Groundwater Aquifer Materials: The Role of Chemical Structure and Sorbent Properties

Principal Investigators:
Joan E. McLean, (MS), Soil Chemistry
William J. Doucette (PhD), Water Chemistry

Student Assistants:
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Pi-Hsia Su (BS), Chemical Engineering
Jasmail Singh Brar (BS), Civil Engineering
Xiaoden Sun (MS), Civil and Environmental Engineering

Problem and Research Objectives

Pesticides are widely diverse in their structure and properties. The sorption of various pesticides by soil and clay minerals involves a variety of mechanisms, including: 1) ion exchange, 2) protonation, 3) water bridging, 4) cation bridging, 5) ligand exchange, 6) hydrogen–binding, 7) van der Waals interactions, and 8) hydrophobic partitioning.

The sorption coefficient, \( K_d \), of a neutral hydrophobic compound between the sorbent and aqueous phases has been shown to be primarily dependent of the lipophilicity of the compound as expressed by its octanol/water partition coefficient \( K_{ow} \) and on the organic carbon content \( f_{oc} \) of the sorbent. Mathematical relationships between \( K_d/f_{oc} \) (the sorption coefficient normalized for organic carbon content, \( K_{oc} \)) and \( K_{ow} \) have been derived for various classes of nonpolar compounds.

The applicability of the \( K_{ow}-K_{oc} \) correlation to ionizable organic compounds, including pesticides, has been questioned. The high correlation between \( K_{ow}, K_d, \) and \( f_{oc} \) for hydrophobic compounds is expected since the hydrophobic sites of soil organic matter will be the dominate mechanism of sorption. As the hydrophobic character of a compound decreases, other mechanisms of sorption may become important, especially in systems with low organic matter.

The simple partitioning model used to describe the sorption of nonionic, hydrophobic organic chemicals to soil organic matter is not generally applicable to compounds which are fully or partially ionized at natural pH levels in the environment. When dealing with sorption of hydrophobic compounds containing functional groups which may ionize or strongly interact with various organic and inorganic constituents of soil, sorption mechanisms such as ion exchange, ligand exchange, hydrogen bonding, protonation, etc., must be considered in addition to simple partitioning.

Not only is the hydrophobic characteristic of the chemical important when considering the applicability of estimation techniques, but consideration must also be given to the hydrophobic nature—the organic matter content—of the sorbent. In soils having low organic carbon content, the mineral surface will have a greater impact on sorption.

In this project, we will examine the sorption/desorption behavior of several pesticides, with a variety of physical/chemical properties (aqueous solubility, \( K_{ow}, pK_a, \) etc.), in artificial sorbents made by combining various proportions of soil, clay mineral, and sand. Batch equilibrium and column approaches will be utilized. The information obtained from the sorption/desorption studies will be used to define the limitations of current estimation techniques and to develop a more appropriate method, relating chemical structure and experimental soil properties, for estimating the sorption of pesticides to materials low in organic carbon.
Structure-activity Relationships

Principal Investigator:
William J. Doucette (PhD), Water Chemistry

Support Personnel:
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Student Assistants:
Doug Donnelly (BS), Chemical Engineering
Joe Frazier (MS), Civil and Environmental Engineering
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Mark Holt (BS), Civil and Environmental Engineering

Problem and Research Objectives

Quantitative Structure Property Relationships (QSPRs) are increasingly recognized as rapid, practical, and inexpensive methods with which values of some constant or properties necessary for fate assessment models can be estimated. QSPRs are defined as methods by which data or information on the properties of a chemical can be inferred or calculated from a knowledge of the molecular structure.

In most cases, more than one estimation method is available for a particular input parameter. Estimation methods, however, have widely varying accuracies; indiscriminate use of these techniques can result in large errors.

Selection and application of QSPRs require varying degrees of expertise depending on the structure of a particular chemical of interest, knowledge of the mechanism of the process, the extent of the data base used to develop the QSPRs, and the complexity of the structural analysis required to relate structure to the property. For example, some QSPRs are broader than others in the range of chemicals that are covered, and some methods have been established with a better understanding of the mechanisms or properties involved.

In many cases, estimation methods are developed from empirical or semi-empirical correlations. The success of the correlation is dependent on many factors, including the type and number of compounds used to develop the correlation.

Our main objective is to examine the relationship between chemical structure and properties to better predict the environmental behavior of contaminants.

Accomplishments

QSPRs, utilizing molecular structural descriptors such as Molecular Connectivity Indices (MCIs) and Total Molecular Surface Area (TSA), have been developed to estimate several properties used in environmental fate modeling including: aqueous solubility (S), octanol/water partition coefficients (Kow), organic carbon normalized soil sorption coefficients (Koc), and vapor pressure (Pv).

QSPRs can be used to quickly and economically estimate values of properties necessary for input into fate assessment models.

Analysis of Environmental Organic Contaminants

Principal Investigator:
William J. Doucette (PhD), Water Chemistry

Support Personnel:
Wayne April (MS), Agronomy
James Herrick (MS), Organic Chemistry
Linda Krywy (BS), Biology
Joan McLean (MS), Soil Science
Nancy Messner (MS), Environmental Engineering
Mike Walsh (BS), Chemistry
Yan Lu Zhai (BS), Agricultural Engineering
Ai-He Zhou (MS), Environmental Engineering

Problem and Research Objectives

The Organic Analysis Section of the Environmental Quality Laboratory (EQL) is involved with the identification and/or quantitation of organic compounds in environmental field samples or in samples derived from laboratory experiments. Methods for the analysis of environmental contaminants, such as pesticides, polycyclic aromatic hydrocarbons (PAHs), and industrial chemicals, are developed using a combination of wet chemistry and instrumental techniques.

Major instrumentation available in the EQL includes: two High Performance Liquid Chromatographs (HPLC), five Gas Chromatographs (GC), and one Gas Chromatograph/Mass Spectrometer (GC/MS).

Accomplishments

Analytical methods utilizing HPLC, GC, and GC/MS have been developed for a wide variety of organic compounds in water, soil, and air samples.

The results of analytical method development are used by research projects and/or for the analysis of field samples provided by miscellaneous clients not affiliated with USU.
Investigating the Sorption Behavior of Pesticides in Western Soils Containing Low Organic Matter for Modeling the Subsurface Transport of Agricultural Chemicals

Principal Investigators:
Joan E. McLean (MS), Soil Science
William J. Doucette (PhD), Water Chemistry

Student Assistants:
Xiaoden Sun (MS), Civil and Environmental Engineering
Pi-Hsia Su (BS), Chemical Engineering
Jasmail Singh Brar (BS), Civil Engineering
Steven Thomas Hicken (BS), Geology

Problem and Research Objectives
Regulatory agencies responsible for the protection of groundwater resources often use mathematical models to predict the fate and transport of organic contaminants, such as pesticides, in soil and subsurface systems. The soil-water sorption coefficient, $K_d$, often expressed on the organic carbon ($K_{oc}$) basis, is one of the key input parameters used in these models. Because the experimental determination of $K_d$ is difficult and expensive, estimated values are often used.

While various estimation techniques have been developed, the application of these methods to polar or ionizable organic compounds, and for soils characterized by low organic carbon content such as subsurface materials and Western surface soils, has been questioned. To use these estimation techniques, it is also necessary to assume that all soil organic matter has identical physical and chemical properties regardless of its origin. Improved estimation techniques which take into account the interaction between polar or ionizable chemical functional groups, mineral surfaces, and organic matter chemistry need to be developed.

In this project, we will examine the sorption behavior of several pesticides, both neutral and ionizable, in a variety of sorbents low in organic carbon. We will use the information obtained from the sorption studies to define the limitations of current estimation techniques and to develop a method relating chemical structure and experimental soil properties that may be more appropriate for estimating the sorption of pesticides to materials low in organic carbon.

Accomplishments
A series of nine sorbents, ranging from 0.41 to 6.32% organic carbon and 9 to 87% clay content, were prepared by blending an air-dried and sieved (2 mm) rangeland mollisol with various amounts of acid-washed sand and/or clay. Atrazine solutions were prepared in DDW containing 0.01M CaCl$_2$. The concentrations of atrazine used in the sorption study ranged from 0.5 to 50% of the aqueous solubility (0.15, 0.5, 1.0, 2.0, 5.0, and 15 mg/L). The atrazine solutions were spiked with approximately 4500 DPM of [ring-UL-14C]-atrazine (Sigma Chemical Co., St. Louis, Missouri).

A total of 12 sorbent materials, the nine soil mixtures along with 100% soil, clay, and sand, were used in a batch sorption study of atrazine. All sorption studies were performed in triplicate. A 4g sample of each sorbent type was placed in a 50 ml teflon centrifuge tube and the atrazine solutions added in sufficient volume to minimize head space in the tubes.

The tubes were weighed before and after addition of the solutions to determine the volume added to each tube. Then they were placed in an end-over-end shaker housed in a 20±1°C incubator. Following equilibration, the samples were centrifuged at 10,000 rpm for 30 minutes. The supernatant was removed, placed in a clean centrifuge tube, and centrifuged again at 10,000 rpm for 15 minutes to remove additional suspended material.

Using a Beckman 1400 Liquid Scillation Counter (LCS), a 1 ml aliquot of the supernatant was removed for counting. The remaining soil was placed in a petri dish and allowed to dry overnight. Two lg portions of the dried soil were combusted using a Harvey OX400 Biological Oxidizer, and the evolved CO$_2$ was collected into a trapping solution of 10% monoethanolamine, 40% methanol, and 50% Ready Gel® scintillation cocktail (Beckman). The trap solutions were then analyzed by LSC.

For selected samples, atrazine concentrations in the soil and solution phases were determined using high performance liquid chromatography (HPLC). Soils were analyzed for organic carbon content, cation exchange capacity, pH, and exchangeable cations. Total surface area was determined using ethylene glycol monoethyl ether, and the hydrometer method was used for determining particle size distribution.

Project Number: WAG-428
Sponsor: University of California
Project Duration: April 1990 - July 1991
Project Status: Research in Progress

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Environmental Contaminant Property Estimation Using QSARs in an Expert System

Principal Investigators:
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Ronald C. Sims (PhD), Biological and Agricultural Engineering

Support Personnel:
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Student Assistants:
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Doug Denne (BS), Chemical Engineering
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Problem and Research Objectives
To assess the potential impact of the accidental introduction of an organic chemical into the environment, information is needed concerning its environmental fate. The fate of an organic chemical in the environment depends on a variety of physical, chemical, and biological processes. Mathematical models which attempt to integrate these processes are widely used to predict the transport and distribution of organic contaminants in the environment.

Use of these models requires a variety of input parameters which describe site and contaminant physical-chemical and biological characteristics. Several important contaminant properties used to assess the mobility and persistence of a chemical are aqueous solubility, octanol/water partition coefficient, soil/water sorption coefficient, Henry's Law constant, bioconcentration factor, and transformation rates for biodegradation, photolysis, and hydrolysis.

One major limitation to the use of environmental fate models has been the lack of suitable values for many of these properties. The scarcity of data, mainly due to the difficulty and cost involved in experimental determination of such properties, has resulted in an increased reliance on the use of estimated values for many applications.

Quantitative Structure–Property Relationships (QSPRs) and Quantitative Property–Property Relationships (QPPRs) are methods by which properties of a chemical can be estimated from a knowledge of the molecule's structure or another more easily obtained property. Selection and application of the most appropriate QPPRs for a given compound is based on several factors, including the availability of required input, the methodology for calculating the necessary topological information, the appropriateness of a correlation to the chemical of interest, and an understanding of the mechanisms controlling the property being estimated.

This project was designed to develop a microcomputer-based decision support system utilizing QSPRs or QPPRs, to estimate physical-chemical properties of an organic chemical necessary to model its environmental fate. The program will provide estimated values for the following specific properties considered essential in modeling environmental transport and behavior: aqueous solubility (S), vapor pressure (Pv), soil/water partition coefficient (Kp), and Henry's Law constants (H).

Accomplishments
Chemical property data were compiled for over 700 compounds from a variety of literature sources and computerized databases. Only experimentally measured properties were used. Using this information, a chemical property database was created and used for developing MCI-property and property-property relationships; these relationships were then incorporated into a prototype microcomputer-based property estimation program (PEP).

The PEP is a decision support system, developed using HyperCard™ software, which utilizes MCI-property, property-property, and UNIFAC modules to provide the user with several approaches to estimate physical properties. The current version of PEP provides estimates of the following properties: aqueous solubility, octanol/water partition coefficients, vapor pressure, Henry's Law constants, organic carbon–based soil sorption coefficients, and bioconcentration factors.

Currently, the three property estimation modules are implemented, and the MCI module is approximately 90 percent complete. The UNIFAC and property–property modules are approximately 50 percent complete.

Publications


Study of Space Operations Facilities
Photographic Developer Waste Discharge Site Soils

Principal Investigators:
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Problem and Research Objectives
Between 1962 and 1982, Ag, Cd, Cr, and Pb were discharged in photographic developer wastewaters from four x-ray buildings at Thiokol Corporation. The metal-containing wastewater contaminated soils were near each of these four buildings. Concerns for the migration of these contaminants to groundwater resources underlying the Thiokol property have been raised.

Our objective is to evaluate whether the metals of concern are likely to migrate from the wastewater discharge areas to the uppermost aquifer at each site. We are evaluating the present extent of downward migration of these metals, the potential for future mobility of the metals in the soil, and soil properties—including soil moisture available to leach the metals—that will affect the migration potential of these metals.

Accomplishments
Laboratory analyses are nearly complete, and data analyses are being conducted. A final report is in preparation.

The results of the study will be used by Thiokol and the Utah Bureau of Solid and Hazardous Waste to design and implement closure of the wastewater disposal sites. It is anticipated that the study approach and results will be useful in other studies of metals mobility in semi-arid area soils.

Publication
Colorado Squawfish

Bonytail Chub

June Sucker

Fisheries
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Cooperative Fisheries and Wildlife Research Unit —
Director's Report .......................................................... 85

Behavioral Responses of Utah Chub and Rainbow Trout to Rotenone .................................................. 86

Isolation of Water Velocity Induced Stress Variables within Rainbow Trout ................................................. 87
The CFWRU is a program representing a union of natural resource interests among state land grant universities, state conservation agencies, and the U.S. Fish and Wildlife Service. Each cooperative element provides support to accomplish the mission of directing graduate student research in fisheries and wildlife oriented science. This research addresses the needs of both the Fish and Wildlife Service and the host state. In Utah, the CFWRU is housed in the Fisheries and Wildlife Department at USU but administers research projects conducted in the Colleges of Agriculture, Engineering, and Natural Resources.

In the aquatic component of the Utah CFWRU, the maintenance and management of threatened and endangered species, as well as recreational fishery resources, are addressed. Components of both activities are being investigated at the fisheries facility at the UWRL. The water lab facility has long been a repository for sensitive native species, including the Colorado squawfish and June sucker.

Because of its declining numbers in Utah Lake, the only location it exists naturally, the USU June sucker population will serve as the source of a culture effort for enhancement of the species. Other work associated with endangered species also includes investigations of the factors inducing sexual development in Colorado squawfish.

Studies funded by both the UDWR and the USBR are directed toward recreational fishery resources. One such study is associated with the massive rotenone treatment of Strawberry Reservoir. Relative to the proposed renovation is the question of fish behavioral responses to the applied chemical. CCFWRU personnel, in cooperation with UWRL staff, are determining the types and extent of fish responses to rotenone and its carrier substances to determine the optimum application strategy.

The CFWRU is also involved with energetic studies of rainbow trout as influenced by temperature and discharge. As part of a series of studies relating to the microhabitat use of fisheries in the Green River below Flaming Gorge Dam, rainbow trout stamina relative to diet, velocity, and temperature is being investigated in simulated river conditions in the fisheries facility.
Behavioral Responses of Utah Chub and Rainbow Trout to Rotenone

Principal Investigator: Cheryl C. Courtney (PhD), Fisheries and Wildlife
Student Assistants: Dwight Applenalp, Fisheries and Wildlife
Jon Draper, Fisheries and Wildlife
Roger Mellenthin, Fisheries and Wildlife

Problem and Research Objectives

An overabundance of rough fish can have a detrimental affect on stocked trout populations. The use of piscicides to decrease nongame fish can increase trout survival. Fish are thought to avoid rotenone, the most widely used piscicide in the U.S. However, there have been no controlled studies testing this assumption. If fish do exhibit an avoidance to rotenone, this could reduce the effectiveness of partial chemical treatments with this piscicide.

The primary objective of this project was to experimentally determine whether Utah chub (*Gila atraria*) and rainbow trout (*Oncorhynchus mykiss*) exhibit an avoidance response to the substances associated with both the emulsified and powdered forms of rotenone.

Accomplishments

A 200 x 38 x 18 behavioral trough was used to test fish response to three treatments: liquid rotenone, powdered rotenone, and a rotenone-only mixture (only the active ingredients in rotenone). Four concentrations of each treatment were tested: 0.0 (liquid carrier, inert powder, or water), 0.045, 0.075, and 0.15 mg/l of rotenone. At the beginning of each experiment, an individual fish was placed in the center of the behavioral trough and acclimated for 30 to 60 minutes (depending on the species). The time spent in each of the six cells of the behavioral trough was recorded before and after introduction of a treatment with video equipment (color video camera and VCR) and the data stored on VHS video cassettes. The measure of avoidance used in this study was a significant decrease in the amount of time spent in treated water compared to that in untreated water. A repeated measures design was used to analyze data from this study.

Utah chub and rainbow trout showed quite different responses to the treatments. For both species, there was a significant treatment effect as well as an effect of rotenone concentration. An avoidance response was not shown by Utah chub to liquid or powdered rotenone. In contrast, rainbow trout avoided rotenone, and the response was stronger for the emulsified formulation compared to the powdered preparation. Presence of the carrier, piperonyl butoxide, in liquid rotenone may be a key factor in the initiation of the behavioral response. Both Utah chub and rainbow trout avoided liquid carrier.
Isolation of Water Velocity Induced Stress Variables within Rainbow Trout

Principal Investigators:
William T. Helm (PhD), Fisheries and Wildlife
Timothy C. Modde (PhD), Biology

Student Assistant:
Keith P. Lawrence (BA), Fisheries and Wildlife

Problem and Research Objectives
During high flow tests in February of 1982, facing velocities for both adult and juvenile trout increased with discharge. This suggested that, at some level of discharge, energy expenditures needed to maintain position may exceed energy available from ingestion of food and from fat reserves.

During the 1982 test flows and shortly after, juvenile trout disappeared from the Green River tailwater while adult trout remained in seemingly undiminished numbers. The level of winter discharge sustainable by adult trout is, therefore, undefined. Since initiation of the 1985 management plan implemented by the Division of Wildlife Resources, the adult population has increased more than five-fold.

As a result, the standing crop of adult trout has increased dramatically. The proposed rewind and upgrade of the Flaming Gorge Dam generations, however, is likely to alter the operational criteria and, thus, tailwater conditions; maximum discharge will increase from approximately 4,200 to 4,800 cfs at reservoir elevations above 6,000 feet. This will increase the magnitude of fluctuations in discharge and, during years of high reservoir inflow, may increase mean monthly discharge.

To adequately assess the effect of the rewind on the tailwater sport fishery, it is necessary to evaluate whether the increase in discharge will cause a significant increase in trout facing velocity. Our approach was to describe the physiological reaction of trout subjected to varying temperatures and velocities.

Accomplishments
Fish subjected to velocities of 30 cm/s did not exhibit significant mortality in either constant or fluctuation flow tests, and anatomical differences between survivor and mortality groups could not be determined. At a maintenance ration, during low temperature tests, exercise tended to reduce weight greater than in control groups without exercise. Mesentery fat loss was observable in both fluctuation and constant flow treatments but was highest with constant flow. Fat loss was less consistent in tests where trout fed at a growth enhancement level.

Significant deterioration in the various necropsy characteristics was not observed during any test; the only exception was a significant increase in hemorrhaging in the thymus. Hematological changes, when they occurred, were not consistent between tests.

This project is one of several studies being pursued in a multi-agency effort to identify the potential influence of increased winter flows upon the trout fishery in the Green River below Flaming Gorge Reservoir. Trout have been exposed to a combination of flows and temperatures under controlled conditions and monitored to determine both the physiological response as well as their ability to maintain position in the water column. Results will be utilized to predict the ability of trout to adapt to changing discharge conditions in the Green River.
Hydraulics and Fluid Mechanics
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Hydraulic Model Studies and Testing

Principal Investigator:
William Rahmeyer (PhD), Fluid Mechanics

Student Assistants:
Kelvin Anderson (MS), Civil and Environmental Engineering
Blake Tullis (BS), Civil and Environmental Engineering

Problem and Research Objectives
The design of hydraulic structures and the development of hydraulic machinery and equipment are too complicated to complete without the assistance of experimental data. The UWRL is frequently contacted to assist with the design and/or conduct model studies of various hydraulic structures to verify and improve performance and reduce cost. Agencies negotiate contracts with the UWRL to conduct tests on new equipment and machinery to verify that it meets required specifications. This type of testing is done for manufacturers, engineering firms, state and local agencies, and federal agencies. The UWRL has unique facilities for conducting hydraulic testing and research.

Accomplishments
Numerous testing projects and model studies have been completed for a variety of clients. These studies have been useful in verifying, and in some cases improving, the design of the structure or equipment. The cost of the model study is usually more than offset by cost savings developed by modifications to the initial design. The model is also able to identify potential problems and develop appropriate solutions to prevent them from occurring in the prototype. Typical projects which involve modeling and/or testing at the UWRL are:

- Flow Meters
- Valves
- Dam Structures
- Spillways and Stilling Basins
- Pumping Pits
- Sediment Transport
- Scour Studies
- Transients
- Cavitation
- Surge Tanks
- Pipeline Design and Testing

Erosion Control Studies and Testing

Principal Investigators:
C. Earl Israelsen (PhD), Hydrology
Gilberto Urroz (PhD), Civil and Environmental Engineering

Support Personnel:
Eugene K. Israelsen (MS), Civil Engineering

Problem and Research Objectives
Worldwide degradation of the environment is beginning to attract international attention; in the U.S. this has prompted the enactment of numerous federal and state laws for decreasing air and water pollution and for controlling soil erosion. Erosion of soil by wind and water is a particularly serious problem resulting in polluted streams, lakes, and reservoirs; clogged storm sewers and drainage channels; and muddy streets.

Several manufacturers in the U.S. and in some foreign countries have developed various kinds of products which they recommend for controlling soil erosion. However, performance standards are needed to protect buyers.

The UWRL has a rainfall simulator, a tilting test flume, a wind generator, a sunlight simulator, and a high velocity test flume. Together these provide a unique capability for measuring the effectiveness of a wide variety of erosion control materials including vegetative, chemical, and synthetic products. Companies, individuals, and agencies frequently contract with the UWRL to compare the operational performance of their erosion control products with other leading brands on the market.

Project Number: S-02
Sponsor: Various
Project Status: Ongoing

Accomplishments
Numerous erosion control product tests have been completed for a variety of clients. These tests provide data which are utilized by the client to modify and improve a particular product for use in the erosion control industry.

A semi–permanent, high–velocity test flume was in almost continual use during the past year. This facility evaluates the effectiveness of materials that are used for lining channels and drains where flows of up to 20 feet/second might be expected to occur. Many of the leading products on the market have been tested in the UWRL test flume during the past year, and additional ones are regularly included.

The rainfall test facility has enabled the testing of numerous products where the parameters of rainfall rate and duration, soil type, slope steepness, wind, and sunlight can each be separately controlled. Dozens of different kinds of products have been evaluated during the recent past, and new ones await their turns.

These two unique facilities might be selected for developing product testing standards for the erosion control industry throughout the U.S.

Project Number: S-07
Sponsor: Various
Project Status: Ongoing
Analysis of Hydro-electric Power Systems

Principal Investigators:
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Man-Kit Koo (MS), Civil and Environmental Engineering

Problem and Research Objectives

In this program area, systems analysis approaches to both of the principal modes of hydropower systems have been addressed. During 1986 and 1987, a Run-of-River type system design was modeled using non-linear optimization techniques. In addition, methods of analyzing and improving reservoir operation (multi-purpose, but with focus on hydropower production) were developed during 1988 and 1989. These methods used both simulation and optimization approaches.

Accomplishments

Run-of-River research results were summarized by Hsu (1987) and Hughes and Narayanan (1987). The product of this research is a generalized model for selecting capacities of penstock and turbine combinations which will maximize benefits (hydropower revenue) minus costs. This optimization approach avoids the very cumbersome conventional method of arbitrarily selecting a pipe diameter and turbine size, applying a simulation model, observing the result, and then trying another combination of capacities (which may or may not improve the result) until a good result is obtained.


The U.S. Army Corps of Engineers has expressed interest in applying the Run-of-River model in its small scale hydro program. In addition, the results of the reservoir operating rule model are being used as part of the Office of Water Science and Technology's review of the impact of the operation of Glen Canyon Dam on the Grand Canyon environment.

References


Hydraulics of Aeration

Principal Investigator:
William Rahmeyer (PhD), Civil Engineering

Student Assistant:
Mathew Johansen (MS), Civil and Environmental Engineering

Problem and Research Objectives

A one-year initiation grant was awarded to study the effect of aeration on the scour and erosion process. The effect of aeration is recognized as a fundamental factor in the scour and erosion from hydraulic structures; however, it is one of the least understood and studied variables in erosion. This study was limited to the study of the effect of aeration on a one-inch vertical jet.

Accomplishments

A model setup was developed that was able to control factors such as water discharge, air intake, initiation of scour, sediment size, and tailwater depth. A unique method for controlling the amount of air that mixed into the water discharge was used. Basic relationships between the effect of aeration and the scour process were formulated from the test results.

The results of this study have formed a foundation and background for several proposals submitted to the funding agencies of NSF and the U.S. Army Corps of Engineers.
Sediment and Debris Flows

Principal Investigator:
William Rahmeyer (PhD), Civil Engineering

Student Assistants:
Keith Denos (BS), Civil and Environmental Engineering
Steve Schlenker (MS), Civil and Environmental Engineering

Problem and Research Objectives
In this project, we have addressed the development of new sediment research and the application of results from a combination of USU projects on hydraulic models and scour research.

Accomplishments
Our results have provided the basis for several large proposals prepared for UDOT and NCHRP in the areas of bridge pier scour. A record number of 44 bridges were destroyed in 1988 due to bridge pier scour. Discussions with the Army Corps of Engineers and UDOT have resulted in new interest in the sedimentation research program at the UWRL.

Additionally, our results have provided the basis for proposals to the U.S. Army Corps of Engineers, Sacramento, California, and Horrocks/Corollo, Engineers of American Forks, Utah. The proposals were for sediment investigation of the flooding of Millcreek in Salt Lake City.

Basic laboratory research will focus on the development of a transport model for steep mountain streams.

Publications

Effects of Aeration

Principal Investigator:
William Rahmeyer (PhD), Civil Engineering

Student Assistants:
Steve Schlenker (MS), Civil and Environmental Engineering
Eduardo Pauwels (MS), Civil and Environmental Engineering

Problem and Research Objectives
The effect of aeration is one of the most misunderstood and least studied factors in the erosion process. There is an immediate, if not critical, need to re-evaluate past research and correct it to account for the effect of aeration.

Aeration is also a fundamental variable in the application of physical model studies. Little is known about the scaling effect due to aeration. In this project, a more detailed and fundamental understanding of scour and erosion caused by hydraulic structures will be developed.

Accomplishments
Several papers were presented at the 1990 ASCE National Symposium on Scour, and a Master's thesis and a plan B report on the effect of aeration were completed. The establishment of related research in the area of scour from energy dissipators is one product of this project.

Publications
Reinforced Concrete Plunge Pool Energy Dissipator

Principal Investigator:
J. Paul Tullis (PhD), Civil Engineering

Student Assistant:
Ben Anderson (BS), Civil and Environmental Engineering

Problem and Research Objectives
When a hydraulic system is designed, it is critical to determine the cost and performance of alternative designs to provide a basis for making decisions. Resources can often be conserved by the use of a more efficient design. The type of design selected by the engineer is based on many different aspects such as soil type, flow rate, velocity, pressure, and frequency of operation.

The purpose of this research is to explore the design requirements of a reinforced concrete plunge pool energy dissipation structure that is to be used in connection with a flip-bucket spillway system. The use of this particular structure is being investigated in connection with a model study performed by the UWRL for the Lake Alan Henry spillway located near Lubbock, Texas. The design of this structure will allow it to be compared to other alternatives so the best design can be selected.

Accomplishments
Pressures were measured with a pressure transducer at several locations on the model structure to determine the distribution of the dynamic loading. These loading patterns were recorded over a specific range of flow rates to ensure that every anticipated loading was considered.

The loading on the structure was calculated using measurements from the model. The forces scaled up from the model measurements were somewhat larger than theoretical loads. A structural analysis was performed to determine the required strength of the various parts of the structure using a uniform soil pressure distribution to obtain the net loads. After finding the required strength, the design of the structure was completed to the extent that a cost estimate could be made.

This research allows for a comparison of economic feasibility of the energy dissipation structure to other design alternatives. It shows that it may be risky to use theoretical loading to design hydraulic structures because of vibrations and dynamic loadings. In addition, useful information was generated through this research that helps the engineer better understand situations where this design may be advantageous.

Mechanism and Computation of Scour Under the Oblique Impinging Jet

Principal Investigator:
J. Paul Tullis (PhD), Civil Engineering

Student Assistants:
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Kwang-Ik Son (MS), Civil and Environmental Engineering

Problem and Research Objectives
Prediction of scour below flip-bucket spillways is one of the most important parts in designing stilling basins because of the amount of damage caused to dam structures through scour. Two approaches, rational—based on the study of basic forces—and empirical, are used in predicting scour in noncohesive bed materials under jet flow.

Several empirical equations have been developed to predict the depth of scour under the free jet. However, the range of prediction is very wide. For this reason, additional research is necessary to check if some fundamental variables are not included in the previous studies.

Accomplishments
In this study, we are concentrating on the significance of additional variables such as the impact angle of the jet and the effect of jet aeration. Existing studies using a rational approach on scour under jet flow could not be found. Therefore, a rational approach–based study is necessary to understand the scour mechanism under the oblique impinging jet. Forces acting on an individual particle and the stability of each particle will be studied in detail.
Closed Conduit Hydraulics

Principal Investigator:
William Rahmeyer (PhD), Civil Engineering

Student Assistants:
Mufeed Odeh (PhD), Civil and Environmental Engineering
Lisa Houston (BS), Civil and Environmental Engineering

Problem and Research Objectives
In this project, we have focused on cavitation, control valve application, stability of control elements, and transients from pump shutdowns. We have involved physical and computer modeling of hydraulic phenomena.

Accomplishments
We have gained international and national recognition for the UWRL in the research area of closed conduit flows from the results of this project. Federal agencies, power utilities, and private firms have requested proposals and advice on related topics.

Hydraulic Structures

Principal Investigator:
J. Paul Tullis (PhD), Civil Engineering

Support Personnel:
Steven L. Barfuss (MS), Civil and Environmental Engineering
Student Assistant:
Blake Tullis (BS), Civil and Environmental Engineering

Problem and Research Objectives
General guidelines are available from the USBR and the U.S. Army Corps of Engineers for providing preliminary design requirements for various types of hydraulic structures. These guidelines are based on a large number of previous model studies and represent a reasonable starting point for the design. They do, however, tend to be conservative, and it is possible, through additional analysis and proper hydraulic modeling, to reduce the size—and therefore the cost—of many hydraulic structures.

Accomplishments
Computer analysis and physical modeling have been completed on several dam spillways and energy dissipators to reduce size and cost and to improve hydraulic performance. A primary goal of these studies has been to integrate numerical, or mathematical, modeling with physical modeling. This combination provides maximum benefits from an experimental study. The mathematical model enables a wide variety of flow conditions to be quickly evaluated, and the experimental results provide calibration data for the mathematical model.

The results of these studies have resulted in cost savings and improved hydraulic performance of a number of hydraulic models that have been studied at the UWRL.
Refinement of Hydrologic Models for Practical Application

Principal Investigator:
Daniel H. Hoggan (PhD), Civil Engineering

Problem and Research Objectives
Computer simulation models are mathematical abstractions of real-world phenomena. To simulate physical processes with mathematical expressions, parameters, coefficients, and data used to define the physical system must be determined. Because of the complexity of most modeling problems, simplified assumptions are frequently made for determining the values to be used. Thus, there is an opportunity to examine and analyze the way physical phenomena are represented in the modeling process and to investigate ways of more fully and accurately determining the model parameters and other components.

The effectiveness and accuracy of models are also greatly affected by the level of understanding of the user with regard to the theoretical basis of the model, the simplifying assumptions involved, and the correct preparation and execution of the required input data. The development of improved demonstration and training materials related to model characteristics and applications is another opportunity that can lead to the enhancement of computer simulation modeling.

The objectives of this project are to:
1. make improvements in selected hydrologic and hydraulic simulation models so that they can be used more effectively and accurately in practical applications, and
2. develop improved demonstration and training materials for users.

Accomplishments
One of the major uses of one-dimensional water surface profile simulation programs, such as HEC-2, is to compute profiles through bridges to obtain bridge design information and to determine the effect of existing bridges in obstructing potential flood flows. Contraction and expansion coefficients in the model are one of the means of adjusting the computations to account for the significant two-dimensional flow that occurs through bridges.

Research indicates that very little information is available for selecting these coefficients. A proposal was developed in fiscal year 1990 to gain more information on the characteristics of flow through bridges and provide a better basis for selecting contraction and expansion coefficients. The proposed approach was to compare two-dimensional model results with one-dimensional model results for a number of basic bridge-flow configurations.

Another research approach was subsequently considered for this problem. A physical modeling component could be added so that results of bridge model tests conducted in a flume could be compared with the results of two-dimensional and one-dimensional computer simulation models. A review of the literature on physical modeling was initiated to determine what work has been done on this aspect of bridge flow.

A complete set of illustrated lecture notes (handouts) and slides was developed for courses in floodplain hydrology and water surface profile computations. These materials will be used in short courses for practicing engineers and in civil engineering courses at Utah State University.
Flow and Sediment Routing through Mountain Streams

Principal Investigator:
Gilberto Urroz (PhD), Civil and Environmental Engineering

Student Assistant:
Phillipe Zgheib (MS), Civil and Environmental Engineering

Problem and Research Objectives

Mountain streamflow is characterized by the presence of bed elements of a size comparable to the flow depth. These are called Large Bed Elements (LBE). To better understand flow and sediment transport mechanisms due to the presence of such elements, a research program was carried out using a laboratory-size flume and naturally-occurring and man-made LBEs. Our purpose was to identify energy dissipation mechanisms in the transition from supercritical to subcritical flows around a single large bed element.

Accomplishments

The main energy dissipation mechanism identified was the formation of a three-dimensional jet above and around the single LBE. Three types of jets were characterized according to the main direction of the jet flow: forward, backward, and standing. Occurrence of each jet type is apparently related to the value of a Froude number based on the LBE width.

More tests are required, however, to obtain a definitive conclusion. Jet height above the flume bed is a measure of the energy dissipated by the LBE. A relationship between jet height and the flow Froude number was obtained for both naturally-occurring and man-made LBEs. Details on these relationships are presented in project publications.

Publications


A Model for Ice-jam Equilibrium and Flow

Principal Investigator:
Gilberto Urroz (PhD), Civil and Environmental Engineering

Problem and Research Objectives

Conditions for equilibrium and flow under ice jams occurring in river bends are not yet well understood. The analysis of river bend ice jams is complicated by the highly three-dimensional character of the flow underneath the jam and of the ice transport within. Effects of bend ice jams on river bedforms are of interest.

An important issue in understanding ice-jam equilibrium is the quantification of the shear stresses within the granular ice mass, also known as ice rubble. Based on experiments conducted at the Iowa Institute of Hydraulic Research, characteristics of bend ice jams in rigid and movable bed channels are described. These include quantification of ice rubble shear strength, description of ice accumulation and river bedform geometry, and description and quantification of the flow field underneath the ice jam.

Accomplishments

Bend ice-jam experiments were performed using a large bend flume and plastic beads to simulate ice flows. A barrier across the top of the channel forced the initiation of the jam. Ice-jam geometry was found to be such that the jam was thicker towards its toe and towards the inner bank. In many respects, jam-thickness distribution was found to be analogous to alluvial bed topography. Additionally, flow in the jam-covered bend flume was found to develop a double helicoidal flow pattern which resembled mirror-image combinations of flow field associated with open water flow in alluvial bends.

During this study, a series of points requiring further clarification for the development of a bend ice-jam model were identified. These served as the bases for a proposal submitted to the National Science Foundation. Details of study results are provided in the project publications.

Publications


Erosion Control Testing: Rainfall and High-velocity Channels

Principal Investigators:
C. Earl Israelsen (PhD), Civil and Environmental Engineering
Gilberto Urroz (PhD), Civil and Environmental Engineering

Student Assistants:
Tanveer Anjum (BS), Civil and Environmental Engineering
Issam Jardaneh (MS), Civil and Environmental Engineering
Ali Vessal (BS), Civil and Environmental Engineering

Problem and Research Objectives

At a time in which soil conservation concerns are growing, UWRL investigators are providing the erosion control industry with state-of-the-art means of testing the performance of innovative products. Two main pieces of equipment constitute the UWRL erosion control testing capabilities:

1. Rainfall Simulator. This consists of rainfall and sunlight simulators and an erosion basin. The rainfall simulator allows the side-by-side testing of different erosion control materials under the same rainfall and slope conditions. Additionally, plant growth is tested under simulated sunlight.

2. High-velocity Flume. This permits the testing of erosion control mats and roving materials at flow velocities up to 20 fps.

The testing experience at the UWRL is helping to set testing standards through the IECA Standards Committee. Dr. Urroz has been a member of this committee since 1989.

Accomplishments

Numerous testing programs have been carried out upon the request of different manufacturing companies. These programs are designed to test the effectiveness of new products against already existing products. Among the products tested under simulated rain and sunlight conditions are hydro mulches, erosion control mats, soil binders, and polymers. Erosion control and revegetation mats, turf-reinforcement mats, and roving materials have been tested under high-velocity conditions. Test results are detailed in project publications.

The rainfall simulator is being renovated to keep it working smoothly as it has done in the last fifteen years.

Publications


source Conservation, Central Soil and Water Conservation Research & Training Institute, Dehradun, U.P., India.


Jet and Scour Characteristics of Flip-bucket Spillways

Principal Investigator: Gilberto Urroz (PhD), Civil and Environmental Engineering
Student Assistant: Nosratollah Amanian (MS), Civil and Environmental Engineering

Problem and Research Objectives
Erosion mechanisms at the foot of flip-bucket spillways are not well understood. It seems that air-entrainment plays an important role in determining the depth of erosion beneath the plunge pool. Model tests are the best way to approach the understanding of the phenomena.

Accomplishments
A program of tests has been started to elucidate the variables affecting scour depth at the foot of a flip-bucket spillway.

Numerical Simulation of Spillway Flows

Principal Investigator: Gilberto Urroz (PhD), Civil and Environmental Engineering

Problem and Research Objectives
Simulation of turbulent flow over spillways can lead to better estimates of energy losses particularly for tall-dam spillways. Because the flow over a spillway is essentially two-dimensional, boundary-fitted coordinates can be easily implemented for its solution. As a first step, a potential flow solution can be obtained.

A complication in the spillway flow simulation is that the location of the free-surface is not known a priori; this requires continuous correction of the free-surface position as the potential flow is solved. Once a potential flow solution is implemented, the turbulent flow solution can be attempted by using the well known k-ε turbulence model.

Accomplishments
A solution of potential flow over a spillway made up of circular segments and with known free-surface was accomplished. The next step is to program such a solution for an ogee spillway.
Resource Information Systems
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A Remote Sensing and Computer Modeling Technique for Estimating Temporally and Spatially Dependent Subsurface Watershed Soil-moisture Conditions

Principal Investigators:
Robert W. Gunderson (PhD), Electrical Engineering
J. Paul Riley (PhD), Civil Engineering

Student Assistant:
Scott D. Lindsey (MS), Civil and Environmental Engineering

Problem and Research Objectives
The partial area approach provides a promising concept for watershed runoff modeling. Unfortunately, it has remained essentially a theoretical "text-book" approach because of the excessive amounts of traditional field work and investigations required. However, a number of recently published articles have speculated that it may be possible to put the partial area methodology into the practicing field hydrologists' hands by combining the concept with satellite and ground-based remote sensing techniques.

The basic aim of this research has been to develop a simulation model which uses currently available remote sensing platforms as data inputs for estimating temporally and spatially variant watershed soil-moisture conditions. Specifically, our goal has been to develop a method for obtaining spatially and temporally dependent estimates of subsurface soil moisture over large mountainous watersheds. Our objectives were to:

1. Use Landsat satellite data, registered to digital terrain models, to identify a minimal number of prototypical ground sites within the watershed where the field hydrologist could concentrate a measurement program;
2. Develop and calibrate a "point" simulation model to accurately and reliably predict subsurface soil-moisture conditions for the selected points in mountain watersheds from discrete-time field and meteorological measurements; and
3. Develop a mathematical technique to accurately transfer soil-moisture estimates from prototypical ground sites over the rest of the watershed to achieve the desired spatially-distributed and continuous-time estimates of subsurface soil-moisture conditions.

Accomplishments
To accomplish our objectives, we are following the methodology summarized in Figure 1. All steps have been completed, with the exception of the final model evaluation block.

Specific accomplishments are:

1. Mountain Soil Moisture in Arid Climates (MSMAC) Model—The soil-moisture model was based on the ERHYM-II range herbage and water yield model developed by the ARS, Boise, Idaho. Several major changes were required to adapt the rangeland ERHYM-II to a mountain watershed environment.
2. Remote Sensing Data Imaging Personal Computer Package (REMPD)—Although REMPD was specifically written to meet the objectives of this project, it should be equally valuable for many other hydrologic investigations. The primary function of REMPD is to register satellite TM data to digital terrain models of the study watershed.
3. FCVPC—This package allows both supervised and unsupervised classification of watershed ground pixels (units) on the basis of hydrologically meaningful data measurements and variables.

Through this investigation, we have shown that remote sensing techniques make it possible to obtain satisfactory spatial and temporal estimates of subsurface soil moisture based on point simulation models installed at a limited number of sites on a mountain watershed. Remote sensing technology has been successfully combined with traditional field measurement methods to provide a practical method for obtaining temporally and spatially dependent estimates of large mountain watershed subsurface soil-moisture conditions.

Figure 1. Development of a Mountain Watershed Subsurface Soil Moisture Simulation Model.

Publications
Blandon, F. A. Application of a point snowpack model to the Tony Grove Lake watershed. Unpublished master's thesis, Utah State University, Logan, UT.


Project Number: JER-585/VA-413
Sponsor: USGS/State Appropriation Funds
Project Duration: July 1988 – June 1990
Project Status: Research Completed

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Environmental Quality Analysis

Principal Investigators:
William J. Doucette (PhD), Water Chemistry
Darwin L. Sorensen (PhD), Microbiology
Joan E. McLean (MS), Soil Science

Support Personnel:
Ivonne Harris (BS), Political Science

Problem and Research Objectives
The EQL provides personnel and facilities to support UWRL and other USU research efforts. Environmental analytical services are provided to miscellaneous clients not affiliated with USU when the work requested is compatible with current laboratory activities. For example, gas chromatography/mass spectrometry analyses are frequently performed for hazardous waste research projects, and similar analyses can be readily done for other concerns. The EQL personnel operate a gas chromatograph/mass spectrometer, an inductively coupled plasma emission spectrometer, an atomic absorption spectrophotometer, an ion chromatograph, gas chromatographs, high pressure liquid chromatographs, and a carbon analyzer.

Accomplishments
EQL personnel can:
- provide centralized laboratory facilities for research projects;
- perform analyses for UWRL and USU research projects;
- maintain a comprehensive QA/QC program to ensure collection of reliable data, use of standard operating procedures, and maintenance of laboratory instruments;
- maintain Utah Department of Health accreditation as a certified environmental chemistry and microbiology laboratory; and
- operate a safety education program for students and technicians.

The results of the testing are used by research projects or clients to provide factual descriptions of environmental conditions. This information aids in problem solving, management and/or regulation.
Development of U.S. EPA Soil Transport and Fate Database

Principal Investigators:
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Judith L. Sims (MS), Soil Science/Environmental Biology

Support Personnel:
James Herrick (MS), Chemistry

Student Assistants:
Karyn Dinerstein, Civil Engineering
Stephanie Toombs, Civil Engineering

Problem and Research Objectives

The Soil Transport and Fate (STF) Database 2.0 provides qualitative and quantitative information concerning soil fate and behavior of organic and inorganic substances that have been designated as hazardous by the U.S. EPA. The chemicals included in the database are characterized for soil chemical processes using literature data and data generated in U.S. EPA research projects. Soil chemical processes characterized include: 1) degradation; 2) transformation; 3) partitioning among the water, soil, air, and oil phases that comprise a soil system; 4) toxicity; and 5) tendency to bioaccumulate. Data on chemical properties and literature citations are also included.

Accomplishments

The STF Database is a menu driven program containing seven database files and five HELP memos. The database files include:

1. Identification—an alphabetical listing of STF names and the Chemical Abstract Services (CAS) numbers of over 400 chemicals currently included in the database;

2. Chemical characteristics—physical and chemical characteristics of the chemicals included in the database;

3. Immobilization—the partitioning, immobility, and transport of the chemicals in a soil environment;

4. Transformation/Degradation—the degradation and transformation processes of the chemicals in a soil environment;

5. Toxicity—the toxicity of the chemicals;

6. Bioconcentration—the potential of the chemicals to bioaccumulate; and

7. References—bibliographic data for the information cited in the database.

The user can access data by selecting the chemical for which information is required from the Identification file. A “filter” mode may also be used to search for and access subsets of information or data, or to find identification numbers for chemicals of interest.

The database can link directly with the Vadose Zone Interactive Processes (VIP) and the Regulatory and Investigative Treatment Zone (RITZ) models. The models are included as part of the STF Database 2.0 system.

The STF Database is a tool for U.S. EPA personnel involved with contaminated site assessment and remediation activities. It is used to provide input data concerning degradation rates, partition coefficients, and chemical property data for mathematical models simulating the behavior and fate of chemical constituents in contaminated surface and subsurface soils.

The information presented in the database provides assistance in determining treatment potential at contaminated sites using in-place treatment techniques. Chemicals may be evaluated with respect to the importance of natural processes in controlling persistence and transport potential, and therefore susceptibility to degradation or retardation within a subsurface environment.

The STF Database 2.0 has been distributed to regulatory personnel at all ten regional offices of the U.S. EPA and is being used in permitting processes for hazardous waste treatment units and in contaminated site remediation assessments. A training course on the use of the database was held at the U.S. EPA headquarters office in Washington, DC, in August, 1989. A video on the use of the STF Database 2.0 has also been prepared.

Publication


Principal Investigators:
Trevor Hughes (PhD), Civil Engineering
A. Bruce Bishop (PhD), Civil Engineering
Herbert H. Fullerton (PhD), Economics

Student Assistant:
I. Tsou (MS), Civil and Environmental Engineering

Problem and Research Objectives
Methods of projecting municipal water demand have historically varied from a simple gallons per person per day constant, multiplied by projected population, to more recent modeling approaches which separate residential use from commercial and industrial uses. These apply various employment or other multipliers for each class of standard industrial codes (SIC). The use of colored transparent electronic maps (GIS) to disaggregate water demand spatially into many more categories than previously feasible is being tested in this study.

Accomplishments
This UWRL sponsored effort is supplemental to a much larger project sponsored by the UDWR, underway since July, 1987. During the first year, methodology was developed and applied to a case study in two cities in the Salt Lake Valley (Sandy and West Jordan). During the second and third years, Salt Lake, Davis, and Weber County models were completed.

Our objective has been to develop a tool for which all assumptions are both visible and easily changeable by the user, thereby allowing quick evaluation of the effect of changing any assumption with which the user does not agree. The data base for demand projections includes very disaggregated population estimates of both single and multiple family dwellings. Employment by SIC category is also included. These data are provided annually in electronic form by the responsible state and/or regional governmental agencies.

This study has been closely coordinated with the UDWR staff, and the model is operational in their office. They are using the model to make major planning decisions related to the timing and scale of possible future imports of water into the Salt Lake Valley. The Salt Lake County Water Conservancy District also plans to have the model operational in their office. The USBR is now participating in the project and anticipates applying the model outside of Utah.

Publication
Alternative Specifications of Operating Objectives on Multiple Purpose Projects

Principal Investigators:
Herbert H. Fullerton (PhD), Economics
Trevor C. Hughes (PhD), Civil Engineering

Problem and Research Objectives

Lake Powell and the Glen Canyon Dam comprise the largest reservoir facility on the mainstem of the Colorado River and are a very significant part of the Colorado River Storage Project (CRSP). The use and regulation of reservoir water are critical elements in the lives, industry, and recreation of a large segment of the Western U.S. and Mexico. The Glen Canyon Dam is the key regulatory feature on the Upper Colorado River.

The USBR's control and operation of CRSP control structures is based on a forecast of reservoir inflow, available storage volume, and water use requirements. The operation of hydroelectric power generation from the dam can be altered more readily than storage and delivery obligations. However, alteration is limited by the inaccuracy of forecasting the inflow and hydraulic release capability of the power plant. Through quantitative measures, improved accuracy in forecasting inflow was obtained. These measures were in terms of increases and decreases in hydropower revenues and predetermined 10-year targets for storage and delivery.

Accomplishments

A deterministic dynamic programming model was developed to find the optimum set of monthly releases in which hydropower generation, in consideration of the firm power requirement assigned to the Glen Canyon Dam, was maximized within a 12-month period. A comparison was drawn between values of optimal energy produced under different inflow prediction methods. The first value was based on historic mean values of monthly inflow; the second was based on regression estimates of monthly inflow using real time data on precipitation and snowpack within the Upper Colorado River drainage. Model results demonstrated that when real time regression estimates are used to forecast reservoir inflow, spills are reduced by approximately 60 percent (3.2 compared to 8.2 maf) over the 10-year data period. Average power revenues are increased by approximately 2.8 million dollars.

No direct application of this research has been made for Glen Canyon operations. However, current high interest in CRSP operations at that site, and an EIS which is to be prepared in tracing the impact of an uprating of the Glen Canyon power generating facility and potentially modified minimum release options, should benefit from the availability of this model.

Publication

Wasatch Front Water Demand/Supply Planning Model

Principal Investigators:
A. Bruce Bishop (PhD), Civil Engineering
Trevor C. Hughes (PhD), Civil Engineering
Herbert H. Fullerton (PhD), Economics

Student Assistants:
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Christopher Erickson (BS), Civil and Environmental Engineering
Umesh Limaye (MS), Civil and Environmental Engineering
Ming-Daw Su (PhD), Civil and Environmental Engineering
I. Tsou (PhD), Civil and Environmental Engineering
Yu-Min Wang (MS), Civil and Environmental Engineering

Problem and Research Objectives

Methods of projecting municipal water demand have varied from a simple gallons-per-person-per-day constant, multiplied by projected population, to more recent modeling approaches which separate residential from commercial and industrial use. This study extends the capability to disaggregate water demand using a Geographic Information System (GIS) approach. The use of colored transparent electronic maps provides this capability. The model is being applied to the Wasatch Front region of Utah.

Accomplishments

This UDWR sponsored effort has been underway since July, 1987. During the first year, the GIS methodology was developed and applied to a case study in two cities in the Salt Lake Valley (Sandy and West Jordan). During the second year, the balance of the Salt Lake Valley was modeled. In the third and fourth years, Davis and Weber Counties are being added to the model. Work is also underway on Utah County.

Our objective is to develop a tool for which all assumptions are both visible and easily changeable by the user, thereby allowing quick evaluation of the effect of changing any assumption with which the user does not agree. The database for demand projections includes very disaggregated population estimates of both single and multiple family dwellings. Employment by SIC category is also included. These data are provided annually in electronic form by the responsible state and/or regional governmental agencies.

This study has been closely coordinated with the UDWR staff, and the model is operational in their office. Their intention is to use the model to make major planning decisions related to the timing and scale of possible future imports of water into the Salt Lake Valley. The Salt Lake County Water Conservancy District also plans to have the model operational in their office. The USBR is also participating in the project (application in Davis and Weber Counties) and anticipates applying the model outside of Utah.

Publications


Project Number: WG-401
Sponsor: UDWR
Project Duration: July 1987 - June 1992
Project Status: Research in Progress
Cooperative Agreement for Developing Real-time Computer Models and Maintaining Computer Facilities to Support Data Collection Platforms

**Principal Investigators:**
- J. Paul Riley (PhD), Civil and Environmental Engineering
- Gail E. Bingham (PhD), Meteorology
- V. V. Dhrup Narayana (PhD), Civil and Environmental Engineering
- Donald T. Jensen (PhD), Civil and Environmental Engineering

**Student Assistant:**
- Gregory McCurdy (MS), Soils and Biometeorology

**Problem and Research Objectives**

Our objective is to provide data users throughout Utah with access to virtually real-time data through satellite transmission facilities and data storage and retrieval programs. In particular, water users in the Sevier Basin are interested in this system for improving water management practices. Other potential users include various state agencies such as the Utah Division of Water Rights, the UDWR, and water conservancy districts throughout the state.

The system consists of a data collection platform which transmits data through a GOES satellite to the NWS at Wallops Island, Virginia. From this point, the data are re-transmitted to a domestic satellite from which a signal can be received using small and easily installed antennas at any desired location. USU has the responsibility to provide data collection, storage, and retrieval facilities on university computers. Data can then be accessed through telephone linkage by any potential user in the state.

**Accomplishments**

Under this procedure, we are developing a computer program to move data from a data readout terminal (DROT) to disk operation systems (DOS) computers. As indicated above, the DROT can be established at any desired location. Terminals will be set up at various locations in the Sevier River Drainage Basin, and users will be trained to access data from the satellite. In this way, water conservancy districts in the Sevier River Basin will be able to obtain data without going through USU computers.

After completion of this system, we will undertake an effort, subject to the availability of funding, to develop a streamflow routing model for real-time basin management in the Sevier River Basin. This model would receive input data directly from the DROT computer terminal and would route river flows between reservoirs within the Sevier Basin.

The results of this project will have broad applicability to research and water resources management projects throughout the state. Because of the real-time capabilities of the system, it will have direct application to management problems which require real-time data such as those involving flooding and flow routing. It is anticipated that state agencies such as the Water Rights Division, the UDWR, and the UDOT will find this system highly useful.
Water Resources Data Management Center at Utah State University

Principal Investigator:
J. Paul Riley (PhD), Civil and Environmental Engineering

Support Personnel:
Gail E. Bingham (PhD), Micrometeorology
A. Bruce Bishop (PhD), Civil Engineering
Robert W. Hill (PhD), Agricultural and Irrigation Engineering
L. Douglas James (PhD), Civil Engineering
Kim A. Marshall (GS), Computer Science
Paul A. Wheeler (PhD), Electrical Engineering

Problem and Research Objectives
The advent of the space age technology of satellite imagery and communication capability has opened up new vistas of natural resource monitoring that have previously been impossible. Earth-orbiting satellites capable of remotely sensing spatially distributed resource data are rapidly becoming the source of information for natural resources management. Through the geostationary satellite system, data collection platforms read and store local data from on-site sensors and periodically (generally every three or four hours) transmit it to receiver sites for analysis, use, and permanent storage.

USU has been one of the nation's leading institutions in instrumentation research. It has executed more NASA space shuttle experiments than any other university in the nation. When this development is coupled with USU's position of world-wide recognition in water related education, research, and out-reach programs, an unparalleled capability for water instrumentation development—including data collection, storage, and retrieval—exists.

Accomplishments
Researchers at USU have established an education and research program for applying space-age technologies to real-time monitoring and water resource systems control. In establishing the program, significant assistance has been given by local Cache Valley industrial firms, recognized as world leaders in the manufacture of environmental monitoring equipment.

The Center was formed for the development and testing of equipment required to meet the demand for real-time monitoring and water resource systems control and for fostering the broad water resources research and educational objectives of USU. Specifically, the Center is:

- providing a sound research base for long range development, testing, and utilization of state-of-the-art hard and software systems for natural resource applications in data management, data relay technology, on-site sensor development, hydrologic system control, and hydrologic modeling; and
- establishing and maintaining state-of-the-art physical facilities for the acquisition, transmission, storage, and retrieval of data.

A software system, a satellite receiving dish, and several field stations have been purchased and deployed. The system transmits data from remote field stations via a geostationary satellite to USU's computer for analysis, storage, and retrieval by users.

With the capability of real-time monitoring and control provided by the satellite data acquisition equipment, water resources systems management is enhanced in a real-time sense. For example, the system was used to monitor meteorological conditions, salinity levels, and water levels associated with the evaporating pond in Utah's West Desert. The data were directly accessed from the USU computer by the UDWR, the agency responsible for operating the pumping project. At the present time, approximately 65 climatological and hydrological stations throughout the State are providing data to the USU computer; these data are accessible by anyone interested.

Water conservancy districts in the Sevier River Basin are using these data to monitor stream and canal flows and reservoir levels for the operation of water supply reservoirs and other facilities. Data are usually accessed through telephone modems and user computers. The number of users on the system are continuing to expand each year and now includes: 1) the State Climatologist; 2) the USU Extension Service, which provides a service to farmers on when to irrigate and the quantity of water to apply; 3) the USBR; 4) the UDWR; 5) various water conservancy districts; and 6) research projects at USU which involve the acquisition of data from remote locations. It is expected that users such as the State Division of Water Rights and other Utah conservancy districts will be added in the future.
Water Information and Education
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Principal Investigator:
Kitt Farrell-Poe (PhD), Civil and Environmental Engineering

Problem and Research Objectives
1. Provide an avenue for educating the rural public about the nature of groundwater, its interaction with surface water, the effects of land use on water quality, and how human activities can impact groundwater quality.
2. Provide training and educational materials to county extension agents to aid them in conducting safe drinking water clinics to the rural population.

Accomplishments
Through “Safe Drinking Water Workshops,” 244 domestic and livestock water supplies were tested for pH, hardness, nitrate, iron, and fluoride. The workshops were held in Box Elder, Cache, Garfield, Millard, Salt Lake, Tooele, Wasatch, Wayne, and Weber Counties and the Uintah Basin. More than one-third of the state has had a Safe Drinking Water Workshop.

County Extension Agents received Hach nitrate test kits (provided by the Utah Department of Agriculture) at the EDNET satellite training. Through independent screening, 376 additional water supplies were tested for nitrate. Of these 620 nitrate screens, only eight samples were above 8 mg/L NO₃-N, the predetermined level at which further action should be taken.

Four schools have been visited and 120 students, grades K–8, provided with classroom experience on nonpoint source issues.

In cooperation with Dr. Leona K. Hawks, presentations and workshops were designed and presented.

Teacher Inservice Training
Through the Davis County Soil Conservation District, 25 teachers were taught about nonpoint source pollution. The teachers also participated in two activities. In addition, each teacher received three lesson plans/activities.

Professional Presentations
Four professional meetings—Industrial Waste Conference, Purdue University; two meetings of the American Society of Agricultural Engineers; and the Utah Nonpoint Source Conference—were attended. Two papers were presented.

Television and Radio
A presentation was made on KSL TV’s “Focus” program. The presentation focused on household hazardous waste. In addition, I was interviewed live by KSL and a Logan radio station reporter on safe drinking water.

Other Environmental Education Efforts
I am participating with the League of Cities and Towns in educating Utah’s municipalities on their environmental responsibilities. Additionally, I am the treasurer for the Utah Society of Environmental Educators.

Publications


Project Number: EX1-1
Sponsor: Utah Department of Agriculture
Project Duration: June 1990 – May 1991
Project Status: Research in Progress
Non-point Source Pollution Education

Principal Investigator:
Kitt Farrell-Poe (PhD), Civil and Environmental Engineering

Problem and Research Objectives

1. Provide training tools for educating farmers about groundwater and sources of contamination. Provide training opportunities that make use of these materials to educate agency personnel and others about groundwater and Non-point Source Contamination (NPS).
2. Raise awareness levels by providing information about Utah NPS to elementary and secondary school students and teachers in the state.
3. Raise the general public's awareness of NPS issues and concerns and the importance of maintaining water quality.
4. Educate groups that have a special interest in NPS programs, including technical agencies, land management agencies, landowners, and others.

Accomplishments

Slide/tape Development
Preparations for a slide/tape presentation concerning groundwater and non-point source pollution in Utah are underway. The audience for the presentation will be farmers, homeowners, ranchers, and the general public. Completion date: May 1991.

Revision of Utah NPS Water Quality Handbook
The original handbook will be separated into two volumes: Volume 1—Education/Training/Awards, and Volume 2—Technical Information. Volume 1 will contain NPS background information, three sample one-hour presentations, a directory of organizations and coordinators, the Governor's Water Quality Awards with suggestions for a successful Water Quality Program, and the Utah Non-point Source Task Force Newsletters. The sample presentations will include lists of appropriate audio/visual presentations, topics to be covered, and possible speakers. New material will be added to each section as needed. Completion date: March 1991.

Volume 2 will contain technical reference material, data, maps, etc. New material will be added to each section as needed. Completion date: September 1991.

Educational Materials Development
A teacher's resource guide will be developed on NPS fact sheets, slide/tape sets, and other media forms. It will be included in the Utah NPS Water Quality Handbook, Vol. 1. Completion date: March 1991.

Five NPS lesson plans with activities for grades K-8 will be developed. Four activities have been developed and used in the classroom. Completion date: May 1991.

A workbook on NPS and related environmental concerns for 4-H and FFA students (aimed at grades 9-12) will be developed. Completion date: May 1991.

Inservice Training and Classroom Activities
Five teacher inservice training or classroom presentation activities will be conducted. One teacher inservice training and eight classroom presentations have been conducted.

Video Development
One 12-minute video on NPS Pollution in Utah will be developed for presentation at meetings and field days. The intended audience will be the general public. Completion date: Summer 1991.

Revision of the Governor's Water Quality Awards
In cooperation with Dr. Richard Peralta, county Water Quality Task Force organizational meetings have been conducted. All but two counties will have had a meeting by the end of March. The Governor's Water Quality Awards format will be revised by the end of March 1991.
International Office for Water Education

Principal Investigators:
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Rex Curtis (MA), Science Education
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Support Personnel:
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Kathryn Farrell-Poe (PhD), Civil Engineering
Jennifer Gale, Elementary Education
Virginia Jensen, Water Education/Conservation Coordinator, Utah Division of Water Resources
Colleen A. Riley (MS), English

Problem and Research Objectives
In 1983, the IOWE was organized at USU and headquartered in the UWRL. IOWE promotes water education through:

- development of comprehensive water education curricula;
- provision of effective in-service training for users of IOWE curricula;
- promotion and implementation of adult water education;
- production and marketing of water educational materials;
- provision of special services to individuals or groups who have water-related interests and needs; and
- development of a coordination and information resource center for national and international water education programs and needs.

Accomplishments
The IOWE provides water education to all segments of society. Its initial emphasis was at the elementary school level. A series of one- and two-page water education lesson plans were published in two soft-bound publications, Water Education K–6 (Daugs & Israelsen, 1985) and Water Education ... with emphasis on Deer Creek Reservoir – Provo River Drainage Area (Daugs, Israelsen, & Parrish, 1990). These lessons correlate with Utah's 1987 Core Curriculum. In addition, the IOWE has produced the Water Education Grades K-6 Equipment Kit for use with specified activities.

Training for elementary school teachers has been provided through introductory in-service and pre-service workshops and 12 and 30-hour graduate credit university courses.

The IOWE annually co-sponsors the Governor's Conference on Water Education and Water Education Month (October). In connection with these events, students may enter the IOWE sponsored Young Artists' Water Education Poster Contest. More than $580,000 in prizes are awarded annually to Young Artists' Water Education Poster Contest winners. Past themes are:

- "The Wonders of Water" (1989)
- "Water: Our Most Valuable Resource" (1990)

Numerous school assemblies were conducted by IOWE personnel in connection with the annual water education month and water education poster contest. Special water education workshops have been provided for gifted and talented class groups. Many tours for elementary students have been conducted at the UWRL and water treatment plants. Professional presentations concerning the IOWE and its programs have been delivered by the directors.

The IOWE co-sponsors a statewide Water Education Speaker's Bureau and has distributed more than 30,000 copies of the bureau directory during the past three fiscal years. Affiliation is maintained with a number of professional and special interest organizations for the purpose of encouraging water education, including the Utah Science Teachers' Association, Alliance for Environmental Education, Association for Environmental and Outdoor Education, Utah Adult Education Association, and Utah Association for Supervision and Curriculum Development.

IOWE personnel are currently writing secondary school material. Additionally, the IOWE is working with the College of Engineering at Utah State University in introducing high school students to water-related careers. More than 1,600 high school students have been hosted on the Utah State University campus for tours of the UWRL and other university facilities.

In 1990, 161 high school students attended USU's first Engineering State, a week-long program designed to introduce junior-level high school students to engineering, both as a field of study and practice. Each earned three university credits and scholarships. The successful program is being expanded college-wide in 1991 to accommodate 350 delegates.

Public understanding of the fundamentals of water science is basic to solving present and future water-related problems. Unfortunately, most people are only vaguely aware of the role water plays in their economic well-being. It is anticipated that educating the youth will one day result in better informed leaders who will be able to make wiser decisions regarding water distribution and use.
Remediation of Contaminated Soils—Fundamentals and Applications Short-course

Principal Investigators:
R. Ryan Dupont (PhD), Environmental Health Engineering
Ronald C. Sims (PhD), Biological and Agricultural Engineering

Support Personnel:
William J. Doucette (PhD), Water Chemistry
Joan McLean (MS), Soil Science
Judith L. Sims (MS), Soil Science/Environmental Biology
Darwin L. Sorensen (PhD), Microbiology
David K. Stevens (PhD), Environmental Engineering

Problem and Research Objectives

Selection of technically and cost-effective treatment technologies for remediation of hazardous waste contaminated soils has historically been done with insufficient knowledge of soil–water processes and site characterization requirements. There is a national need for provision of a more rational basis for evaluating and selecting management options and for conducting risk assessments at hazardous waste sites.

In response to this need, a short-course, Remediation of Contaminated Soils—Fundamentals and Applications, has been developed. Based on eight years of research and field experience, faculty at USU designed the course in the area of subsurface processes and treatment technologies for subsurface contamination. Presentations address the transport, fate, and cleanup of hazardous wastes in the subsurface. The course is currently sponsored by the U.S. EPA Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma.

Accomplishments

A summary and application of soil fundamentals critical to the understanding and management of the fate and transport of hazardous materials in soil systems are presented in this course. The application of chemical, physical, biological, and soil sciences to the development and implementation of remediation strategies for hazardous waste sites is emphasized.

Topics addressed include:
- soil chemical, physical, and biological process fundamentals;
- remediation techniques;
- transport and fate modeling;
- field sampling and measurement methodologies;
- field and laboratory QA/QC requirements; and
- waste treatability studies.

Discussion sections of the course are used to integrate laboratory and field data with treatment demonstration studies, the design of experimental approaches, and analysis of results.

The short-course is designed for individuals involved in the management, development, evaluation, and/or selection of physical, chemical, and biological processes for the remediation of hazardous waste contaminated soil. Course participants gain an understanding of the technical issues chemists, microbiologists, soil scientists, and engineers encounter and of the methods available for addressing the issues.

The course was offered at USU, August 14–18, 1989, and August 13–17, 1990. Participants enrolled represented academics, the U.S. EPA, consulting firms, and state government organizations. The course was given to U.S. EPA Superfund staff at the U.S. EPA Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma, February 21–23, 1990, and at the U.S. EPA Region IV in Atlanta, Georgia, October 23–25, 1990. It will be offered on a continuing basis upon request from each U.S. EPA Regional Office. In addition, the course will be offered at USU, August 12–16, 1991.

Publication

USU/EPA. (1989). Course notebook: Remediation of contaminated soils—fundamentals and applications. Published by the Robert S. Kerr Environmental Research Laboratory, Ada, OK (Mr. John E. Matthews, Project Officer).
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Information Transfer

Principal Investigator:
Colleen A. Riley (MS), English

Support Personnel:
Betty J. Hansen, Senior Secretary
Paul Jarvis, Senior Graphics Technician
Karen L. Pulsipher (BS), English
Jane M. Sorenson, Principal Composer
Arthur L. Rivers (MS), Instructional Media

Problem and Research Objectives

Our Publications group produces professional documents for the academic, professional, and lay audiences. We publish research reports and papers, brochures, proposals, presentations, and newsletters. Through these mediums, we communicate and disseminate the research information of the UWRL and its faculty.

The technical reports and papers, written by UWRL principal investigators, provide information on research projects. Our brochures give an overview of UWRL facilities, capabilities, research projects, and graduate programs. And through our proposal efforts we are able to continue our water research projects, thereby promoting knowledge and expertise in the field. Additionally, the presentations we create enable us to share our ideas and technologies.

Accomplishments

This year we have developed an annual report aimed at a wider readership; it provides UWRL capabilities, highlights recent research projects, and outlines financial information. As a supplement to the annual report, we have compiled annual technical summaries of all UWRL recently completed or ongoing research projects.

Perhaps one of our most consistent forms of communication is our "Aquarius" newsletter, developed to clearly communicate Utah and UWRL water research and water concerns. Additionally, the "Aquarius" keeps its readership informed about new projects within the UWRL, water research conferences (either within the State of Utah or presented by UWRL personnel), and UWRL personnel changes. A major objective of the "Aquarius" is to maintain a communication link between the UWRL and other water research centers throughout the nation and across the world.
Utah Water Atlas

Principal Investigators:
C. Earl Israelsen (PhD), Hydrology
Gaylen L. Ashcroft (PhD), Soil Science/Biometeorology
Darwin L. Sorensen (PhD), Microbiology

Cooperating Agency Scientists:
Lloyd Austin, Utah Division of Water Resources
Dennis Burns, Division of Parks and Recreation
Lee Case, U.S. Geological Survey
Gary Christenson, Utah Geological and Mineral Survey
Glen Davis, Division of Wildlife Resources
Roy Gunnell, Bureau of Water Pollution Control
Jerry Olds, Utah Division of Water Rights
Roland Palmer, Bingham Engineering
Jack Ralls, Utah Division of Water Resources
William Schlotthauer, Division of Water Rights

Support Personnel:
Larry Anderson, Utah Division of Water Resources
Paul Jarvis, Graphics Design
Colleen A. Riley (MS), English
Art Rivers (MED), Instructional Media

Problem and Research Objectives
In 1968, a Hydrologic Atlas of Utah was prepared and published by the UWRL in cooperation with the UDWR. This new project will update and add to the data and information contained in the earlier publication and will provide a full-color Water Atlas of Utah.

Accomplishments
An advisory committee to guide the scope and content of the Atlas is functioning. They have decided to prepare the Atlas with a maximum use of maps, graphs, and charts, and a minimum of narrative material. Content outlines of the several chapters have been prepared and reviewed by the committee. The most recent section and chapter headings are:

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Base maps of the state (1:1,000,000) have been acquired, the materials for the several chapters developed, and the cartography digitized in preparation for the color mock-up needed for final approval by the committee. The weather history section has been developed by a graduate student as part of his Master's thesis which was supervised by the History Department.

The Atlas will be a source book for water data and information and will be useful for planners, engineers, hydrologists, administrators, and others who are interested in water development and management. It will also benefit students and occasional users as a reference publication on the state's water resources.
Soil Vacuum Extraction/Bioventing

Principal Investigator:
R. Ryan Dupont (PhD), Environmental Health Engineering

Problem and Research Objectives

Soil vacuum extraction (SVE) removes volatile and semi-volatile compounds from the unsaturated zone through the application of a vacuum to subsurface soils. It is a highly cost effective soil remediation alternative that provides permanent solutions and significantly reduces the mobility, toxicity, and volume of hazardous materials at a contaminated site by the collection and treatment of hazardous constituents that volatilize from the contaminated soil matrix.

SVE application to the treatment of semi-volatile to non-volatile compounds is limited, however, since SVE system efficiency is limited by the volatility of the contaminants being extracted from the soil. It is, however, a very efficient means of transferring oxygen to the subsurface and can be effectively used to enhance subsurface biodegradation through enriching the subsurface in oxygen to stimulate aerobic biodegradation of semi- to non-volatile organics that remain in the subsurface following soil vacuum extraction. Our purpose is to investigate the connection between SVE and subsurface biodegradation of semi-volatile and nonvolatile hazardous constituents and to support field and laboratory SVE projects currently underway in the area of enhanced bioventing.

Accomplishments

Cooperative work has been carried out between the UWRL and the U.S. EPA Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, in the area of SVE laboratory and field scale treatability design and field testing methodologies. A joint effort guidance paper was presented in May 1990 (DiGiulio et al., 1990), and the Environmental Quality Group at the UWRL has been awarded a research project to design and conduct treatability studies, including SVE and bioventing treatability analyses, at Superfund sites throughout the U.S.

Invited participation (Dupont, 1990a) in a joint API/EPA working group on “Field Monitoring of Biodegradation in Unsaturated Zones” allowed the presentation of UWRL research activities in the soil remediation/soil bioventing area. This participation also allowed the incorporation of this information into research programming and development of request for proposals for both API and EPA Office of Underground Storage Tanks (OUST), Washington, D.C.

Application of research findings in the areas of soil bioremediation and soil vacuum extraction from research conducted at the UWRL to concerns of federal and state environmental regulators has been carried out through invited presentations at a national UST meeting in November, 1990 (Dupont, 1990b) attended by 300 state UST regulators, and in January, 1991 (Dupont, 1991) for the Utah Department of Health, Division of Underground Storage Tanks and Remedial Response.

This technology transfer and information dissemination effort is on-going in support of research activities that are taking place within the Environmental Quality Group at the UWRL.

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Research Faculty, Professional, and Support Staff

Utah Water Research Laboratory and the Department of Civil and Environmental Engineering Faculty and Professional Staff

Anis Ahmed (PhD), Post-doctoral, UWRL
Loren R. Anderson, PhD, Department Head, Professor, CEE
Muini Baasiri, PhD, Visiting Research Professor, UWRL
Jay M. Bagley, PhD, Professor Emeritus, CEE/UWRL
Steven L. Barfuss, MS, Research Engineer, USU Foundation
Brent Bartz, MS, Research Engineer, CEE
A. Bruce Bishop, PhD, Dean, College of Engineering, Professor, CEE
David S. Bowles, PhD, Associate Director, UWRL, Professor, CEE/UWRL
Robert Cantfield, PhD, Software Engineer, Mathematics/UWRL
Winfred O. Carter, PhD, Professor Emeritus, CEE
Duane G. Chadwick, MS, Associate Professor, EE/UWRL
Vance T. Christiansen, PhD, Professor, CEE
Calvin G. Clyde, PhD, Professor Emeritus, CEE/UWRL
William A. Cordon, PhD, Professor Emeritus, CEE
Kenneth Rex Curtis, BS, Education Specialist, UWRL
William J. Doucette, PhD, Associate Professor, CEE/UWRL
R. Ryan Dupont, PhD, Assistant Director, UWRL, Associate Professor, CEE/UWRL
Delmar Dyreson, PhD, Software Engineer, UWRL
Christopher J. Duffy, PhD, Adjunct Associate Professor, CEE/UWRL
Irving S. Dunn, PhD, Professor Emeritus, CEE
Kitt Farrel–Poe, PhD, Environmental Specialist, USU Extension/UWRL
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Robert W. Gunderson, PhD, Affiliate Faculty, EE
Christine Gunter, Business Manager, UWRL
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