

Idaho Water Resources Research Institute

Annual Technical Report

FY 2004

Introduction

The Idaho Water Resources Research Institute (IWRRI) is housed at the University of Idaho. IWRRI is dedicated to supporting and promoting water and water-related research, education, and information transfer throughout Idaho. IWRRI collaborates with researchers and educators from all Idaho state universities; staff of local, state, and federal agencies; and private water interests.

The IWRRI is the only mechanism in the state that provides an autonomous statewide source of support for water research and training without regard to specific topic or discipline area. This is important because Idaho's water problems cross multiple topics and disciplines and compartmental approaches to these problems are less effective. IWRRI is relied upon by state and federal agencies and private water interests to provide the objective expertise to address the needs of the state and region.

The Institute has been a strong proponent of education and outreach for both youth and adult audiences. It is through education that the public can make informed public policy decisions concerning water. It is also through education that individual citizens become engaged in the process through adjustments of their own attitudes and lifestyles.

Research Program

The Idaho Water Resources Research Institute's research program is comprised of the following objectives: (1) To work with state and federal agencies and non-government organizations to identify water research needs of the state and region; (2) To promote water-related research relevant to state and regional needs; (3) To stimulate, coordinate, and provide leadership for water resources research within Idaho universities and collaborate with sister institutions in adjoining states; (4) To cooperate with and assist state and federal agencies and non-governmental organizations for the benefit of the citizens of Idaho and the region; (5) To encourage and facilitate public involvement in water resource programs within the state; (6) To promote water education within the state at the K-12, undergraduate and graduate levels; and (6) To develop funding for needed research and encourage cooperation with other research organizations.

Validating Meta(loid) Flux Predictions from Lake Coeur d'Alene Sediments Using Contaminated Ponds as Mesocosms

Basic Information

Title:	Validating Meta(loid) Flux Predictions from Lake Coeur d'Alene Sediments Using Contaminated Ponds as Mesocosms
Project Number:	2003ID11B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Sediments, Toxic Substances, Geochemical Processes
Descriptors:	sediments, metal contaminants, mine tailings, contaminant flux
Principal Investigators:	Matthew John Morra, Daniel Strawn

Publication

1. Finkelnburg, Douglas C., Gordon R. Toevs, and Matthew J. Morra. 2005. Metal(loid) Solubility in Persistently Reducing Mining-Impacted Wetland Sediments, In Abstracts of the 86th annual meeting of the AAAS Pacific Division Western Society of Soil Science/AAAS, Ashland, OR, pg. 55.
2. Finkelnburg, Douglas C., Matthew J. Morra, Gordon R. Toevs, and Vladimir Borek. 2005. Alkalinity Measurement in Mine-impacted Wetland Sediments Using Gas Chromatography, In Abstracts of the 15th Annual V.M. Goldschmidt Conference, Moscow, ID, abstracts online at http://www.the-conference.com/2005/gold2005/web_pdfs/G07.pdf, pg. A814.
3. Toevs, G., Polizzotto, M., Morra, M., Strawn, D., Fendorf, S., Bostick, B. 2005. Arsenic Mobilization in Mine-Impacted Sediments, In Abstracts of the 15th Annual V.M. Goldschmidt Conference, Moscow, ID, abstracts online at http://www.the-conference.com/2005/gold2005/web_pdfs/G07.pdf, pg. A617.
4. Toevs, G., M. Polizzotto, M. Morra, D. Strawn, S. Fendorf, and B. Bostick. 2004. Arsenic Mobilization as a Function of Redox Changes in Mining-impacted Sediments. In ASA Abstracts, Seattle, WA, 2004 American Society of Agronomy Abstracts on CD.

Title: Validating Metal(loid) Flux Predictions from Lake Coeur d'Alene Sediments Using Contaminated Ponds as Mesocosms

Project Number: 2003ID11B

Start Date: 3/1/2004

End Date: 2/28/2005

Funding Source: 104B

Research Category: Water Quality

Focus Categories: GEOCHE; SED; WQL

Descriptors: sediments, metal contaminants, mine tailings, contaminant flux

Primary PI: Matthew J. Morra

Other PIs: Daniel G. Strawn

Project Class:

Student Support:

Two students are currently working on the project. Gordon Toevs is a Ph.D. student funded by the Inland Northwest Research Alliance and Douglas Finkelnburg is funded by a University Presidential Scholarship. Although stipends for both students are provided by other sources, IWWRI funding has been essential to support operating and travel expenses for these students.

Publications:

Finkelnburg, Douglas C., Gordon R. Toevs, and Matthew J. Morra. 2005. Metal(loid) Solubility in Persistently Reducing Mining-Impacted Wetland Sediments, In Abstracts of the 86th annual meeting of the AAAS Pacific Division Western Society of Soil Science/AAAS, Ashland, OR, pg. 55

Finkelnburg, Douglas C., Matthew J. Morra, Gordon R. Toevs, and Vladimir Borek. 2005. Alkalinity Measurement in Mine-impacted Wetland Sediments Using Gas Chromatography, In Abstracts of the 15th Annual V.M. Goldschmidt Conference, Moscow, ID, abstracts online at http://www.the-conference.com/2005/gold2005/web_pdfs/G07.pdf, pg. A814.

Toevs, G., Polizzotto, M., Morra, M., Strawn, D., Fendorf, S., Bostick, B. 2005. Arsenic Mobilization in Mine-Impacted Sediments, In Abstracts of the 15th Annual V.M. Goldschmidt Conference, Moscow, ID, abstracts online at http://www.the-conference.com/2005/gold2005/web_pdfs/G07.pdf, pg. A617.

Toevs, G., M. Polizzotto, M. Morra, D. Strawn, S. Fendorf, and B. Bostick. 2004. Arsenic Mobilization as a Function of Redox Changes in Mining-impacted Sediments. In ASA Abstracts, Seattle, WA, 2004 American Society of Agronomy Abstracts on CD.

Project Overview:

Lake Coeur d'Alene (CDA) in Idaho is the second largest natural lake in the Inland Northwest. Over the last century Lake CDA has become a major collecting bed for As, Pb, Cd, Zn, and other contaminants. The USGS has estimated that as much as 85% of the lake bottom is contaminated with metal(loids). Despite this contamination, lake water quality typically meets regulatory guidelines. Unfortunately, the median concentrations of As, Pb, and Zn in the porewater from the lake sediments are considered chronically or acutely toxic. The overriding concern is potential release of the accumulated metal(loids) into the overlying water column. However inadequate information exists to make accurate metal(loid) flux predictions in changing redox environments. Our objective was to characterize key geochemical properties that control metal(loid) flux from sediments to the overlying water column in order to predict the impact of redox changes in altering this flux. To accomplish this goal we characterized the lake sediments and made use of a novel approach using contaminated ponds along the CDA River as mesocosms. These ponds have been contaminated by the same events that have transported contaminants to Lake CDA and thus allow us to determine how redox changes impact flux of metal(loids) to the overlying water column.

Total metals in lake and pond sediments were determined by analyses of HF-Aqua regia digest solutions using ICP-AES. Porewater trace metal concentrations were determined from ICP-MS analyses of acidified samples collected in equilibrium dialyzers inserted into the sediments and retrieved after a 4-week equilibrium period. Anion concentrations were determined using non-acidified porewater samples analyzed using ion chromatography. X-ray absorption near edge structure (XANES) spectroscopy was used to determine sulfur oxidation states and speciation. Solid phase Fe was speciated from linear combination fitting of the deconvoluted curves obtained from extended x-ray absorption fine structure (EXAFS) spectroscopy.

Maximum lake-sediment concentrations of As, Pb, Cd, and Zn were 278, 5 169, 37, and 3 686 mg kg⁻¹, respectively. Lake sediment contained from 3.9 to 10.5% Fe. Maximum As, Pb, Cd, and Zn lake-porewater concentrations were 1.21, 0.142, 0.004 and 0.530 mg L⁻¹, respectively. Fe in the lake-porewater increased with depth throughout the profile to a maximum of 53 mg L⁻¹, whereas As and Mn increased below the suboxic boundary and remained elevated throughout. The lake was oxic in the overlying water column, suboxic in the top 3 cm of sediments, and anoxic at depths below 5 cm. XANES analysis of the solid phase indicated pyrite increased with depth to comprise about 50% of the total S in the 30- to 36-cm sample. However, the Fe to S ratio indicates S does not dominate metal(loid) sequestration. EXAFS indicated siderite dominated the solid iron phase and exceeded 70% of the iron species in the 30- to 36-cm sample. Oxyhydroxides were present in the lake at the sediment-water interface.

Maximum pond-sediment concentrations of As, Pb, Cd, and Zn were 298, 14 598, 55, and 10 812 mg kg⁻¹, respectively. Pond sediment contained 7.2% to 10.1% Fe. Although the sediment contamination in the ponds significantly exceeds the lake-sediment levels, As, Pb, and Cd in the porewater was near detection limits and the maximum Zn was 0.472 mg L⁻¹. Iron in the pond-porewater increased throughout the profile to a maximum of 179 mg L⁻¹, Mn increased at the suboxic boundary and remained elevated throughout the profile. Porewater As was near or below detection limits, 0.040 mg L⁻¹. The pond was determined to be suboxic in the overlying water column and at the sediment water interface and anoxic throughout the sediment profile.

The striking difference between the Fe and As porewater concentrations in the lake and pond suggest different mechanisms of metal(loid) release, flux, precipitation and dissolution. In the lake, as the mine tailings (reduced primary minerals) accumulate at the oxic sediment-water interface they begin to oxidize, dissolution occurs, and oxyhydroxides precipitate. These oxyhydroxides act as scavengers for the metal(loids) as they diffuse toward the overlying water. This series of reactions prevents metal(loids) from entering the water column. However, as additional sediment is deposited, the oxyhydroxides and coprecipitated metal(loids) are buried and become unstable as the redox environment becomes anoxic. This accounts for the increase of Mn, Fe, and As in the lake porewater below the suboxic/anoxic boundary. The pond does not exhibit an oxic sediment-water interface, so as the primary minerals are deposited they do not undergo oxidation and subsequent dissolution and precipitation as oxyhydroxides. However, the amount of Mn and Fe in the pond-porewater indicates a significant source of oxyhydroxides, not associated with As. This project underscores the impact redox conditions have in controlling release and sequestration of metal(loids) in contaminated sediments. We suggest that the strategic development of wetlands in contaminated areas along the CDA River may be a viable part of a management strategy for decreasing metal(loid) bioavailability.

Advanced Cone Penetrometer Technology for In-Situ Measurement of Unsaturated Soil Hydraulic Properties

Basic Information

Title:	Advanced Cone Penetrometer Technology for In-Situ Measurement of Unsaturated Soil Hydraulic Properties
Project Number:	2004ID25B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	2
Research Category:	Ground-water Flow and Transport
Focus Category:	Hydrology, None, None
Descriptors:	unsaturated soils, instrumentation, soil-water characteristic curves
Principal Investigators:	Molly Maya Gribb

Publication

Final Report Synopsis

Title: Advanced Cone Penetrometer Technology for In-Situ Measurement of Unsaturated Soil Hydraulic Properties

Project Number: 2004ID25B

Start Date/End Date: 3/1/04 - 2/28/05

Funding Source: 104B

Research Category: Groundwater Flow and Transport

Focus category: HYDROL

Descriptors: unsaturated soils, instrumentation, soil-water characteristic curves

Primary PI: Molly M. Gribb, Boise State University

Project class: Research

Most groundwater contamination originates at or near the surface of the soil, where soil is often unsaturated. As a result, understanding the hydraulic properties of unsaturated soils is necessary for predicting the movement of water and water-borne contaminants to the groundwater below. Conventional field test methods for determining the hydraulic properties of unsaturated soils are commonly limited in depth of application, and can be time consuming and labor intensive. In many cases, laboratory tests do not adequately reflect the in-situ behavior of the soil, due to the small sample size and/or disturbance of the soil structure that occurs during sampling. The aim of this project was to continue development of a cone penetrometer tool, called a cone permeameter for determining unsaturated soil hydraulic properties in situ.

Project activities began with experiments to calibrate and validate a newly fabricated prototype cone permeameter. These early experiments exposed serious design

flaws that rendered the prototype unusable. As a result, a total redesign of the device was initiated. The schematic in Fig.1 shows the components of the new permeameter. The modular design allows for rapid replacement of individual components, including the cone tip, which is most susceptible to damage during use. A new prototype will be fabricated according to this design in summer 2005.

Project activities also included determining the soil-water characteristic curves for an indoor meso-scale soil test bed as shown in Figs. 2 and 3, which will ultimately be used to validate the cone permeameter and other soils instrumentation. The 1.8-m

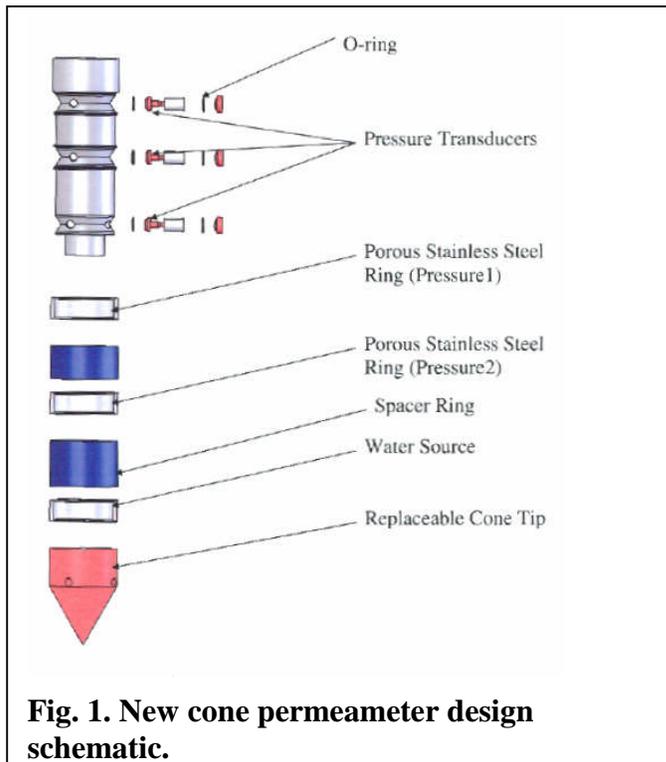


Fig. 1. New cone permeameter design schematic.

diameter by 2.1-m deep test bed was constructed in an in-ground, waterproof, concrete vault and instrumented with time domain reflectometry (TDR) waveguides and tensiometers during construction to allow for continuous measurement of soil-water content and pressure at various depths.



Fig. 2. Construction of the soil test bed and placement of tensiometers and TDR waveguides.

Data collected during wetting and drying experiments in the deposit were collected and fitted to the van Genuchten equation to determine variations in the soil-water characteristics with depth, as shown in Fig. 4. Results indicate that the bulk hydraulic properties of the soil pit change with depth, as expected. The soil-water characteristic curves have steeper slopes closer to the bottom of the deposit, likely due to the greater compaction of the lower soil layers.

In summary, testing of a prototype permeameter resulted in a total redesign of the device, which will be refabricated this summer. The soil-water characteristic curves were determined at various depths in the meso-scale soil test bed and results will be used to support undergraduate and graduate teaching, as well as provide a means for validating the performance of a new cone permeameter device as well as other soil testing equipment in the future.

Publications: A poster presentation of this work is planned at the upcoming Idaho Water Symposium. Student support: Grant funds were used to partially support two undergraduates and one graduate student. Information transfer: The meso-scale test bed and results of this work was featured in a poster presentation during the College of Engineering open house in February, 2005.

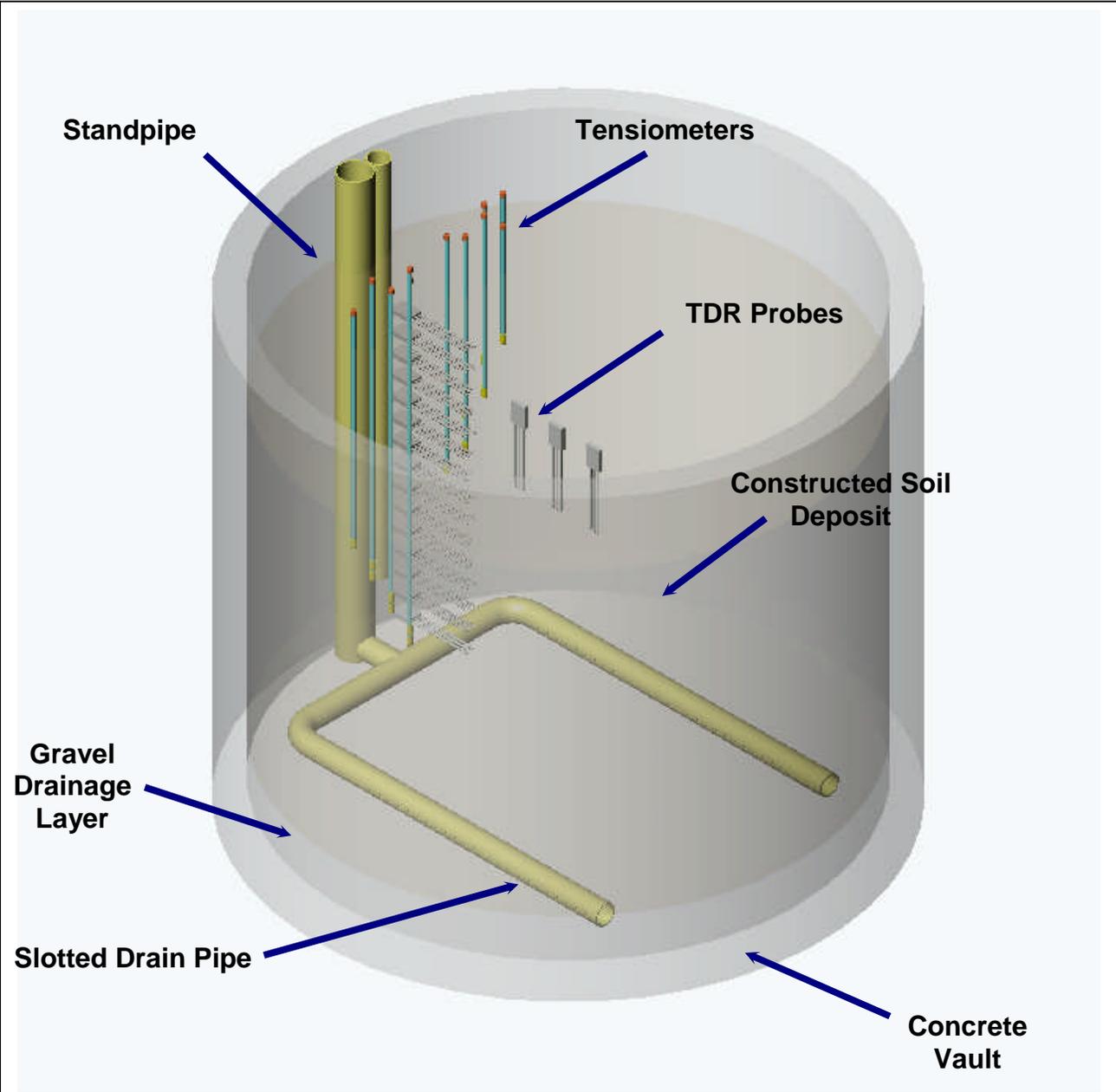


Fig. 1 Schematic of the meso-scale soil test bed.

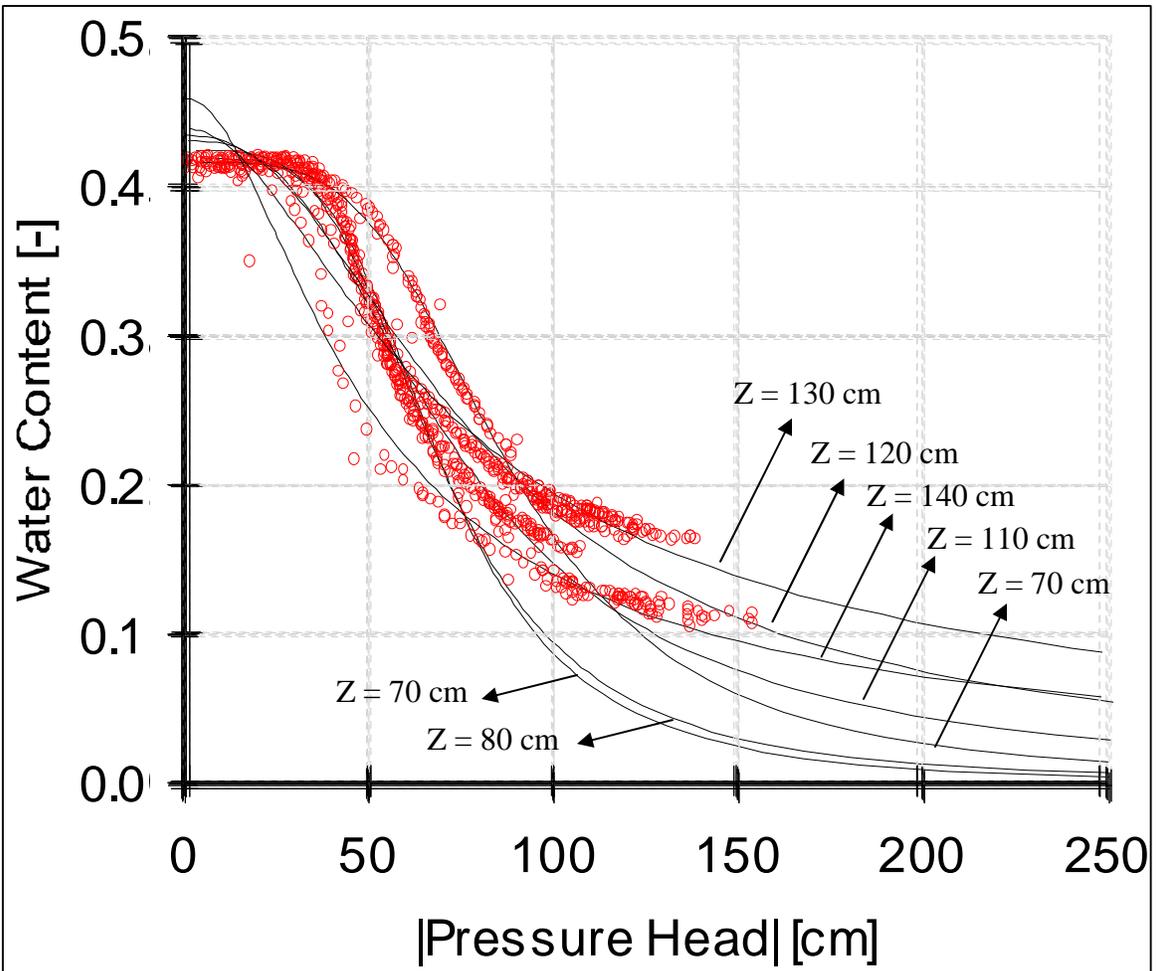


Fig. 4: Soil -water characteristic data and fitted curves generated at different distances above the gravel layer in the meso-scale test bed (Z positive upwards).

Improved Short-term Operational Streamflow Forecasting for Snow-melt Dominated Basins (Request for Year 2 funding)

Basic Information

Title:	Improved Short-term Operational Streamflow Forecasting for Snow-melt Dominated Basins (Request for Year 2 funding)
Project Number:	2004ID38B
Start Date:	3/1/2004
End Date:	2/28/2005
Funding Source:	104B
Congressional District:	1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, Models, Water Quantity
Descriptors:	
Principal Investigators:	Von P. Walden, Karen S Humes

Publication

1. Harshburger, B.J., T.R. Blandford, B.C. Moore, K.S. Humes, V.P. Walden, R.J. Qualls, and W. Zhao, 2004: Improved Short-term Operational Streamflow Forecasting for Snow-melt Dominated Basins in Idaho, Proceedings of the 2004 meeting of the Association of American Geographers, Philadelphia, PA, 14-19 March 2004.
2. Harshburger, B.J., T.R. Blandford, B.C. Moore, K.S. Humes, and V.P. Walden, 2004: Towards improved short-term operational streamflow forecasting for snow-melt dominated basins, Proceedings of the 2004 meeting of the American Geophysical Union, San Francisco, California, 6-10 December 2004.
3. Harshburger, B.J., T.R. Blandford, K.S. Humes, V.P. Walden, and B.C. Moore, 2005: Evaluation of Enhancements to the Snowmelt Runoff Model, Proceedings of the 2005 Western Snow Conference, Great Falls, Montana, 11-15 April 2005 , in press.
4. Blandford, T.R., B.J. Harshburger, B.C. Moore, K.S. Humes, and V.P. Walden, 2005: Interpolating surface air temperature for use in a semi-distributed snowmelt runoff model, Proceedings of the 2005 Western Snow Conference, Great Falls, Montana, 11-15 April 2005, in press.
5. Blandford, T.J, and K.S. Humes, 2005: Approximating the daily temperature lapse rate using the synoptic weather type, in preparation for Journal of Hydrometeorology.
6. Blandford, T.J, and K.S. Humes, 2005: Complex versus simple methods for interpolating surface air

temperature: Application to conceptual semi-distributed snowmelt runoff models, in preparation for Water Resources Research.

7. Moore, B.C., and V.P. Walden, 2005: Evaluation of NCEP downscaled and NDFD temperature forecasts over the intermountain West region, in preparation for Weather and Forecasting.

Title: Improved Short-term Operational Streamflow Forecasting for Snow-melt Dominated Basins (Request for Year 2 funding)

Project Number: 2004ID38B

Start Date: 3/1/2004

End Date: 2/28/2005

Funding Source: 104B

Research Category: Climate and Hydrologic Properties

Focus Categories: Surface Water, Models, Water Quantity

Descriptors:

Primary PI: Von P. Walden

Other PIs: Karen S. Humes

Project Class: Research

Our USGS 104(b) grant was used to initiate a project to provide hydrometeorological tools for streamflow forecasting. Through this funding, our group at the University of Idaho was able to secure additional funding from the Pacific Northwest Research Collaboratory (PNWRC) and, thus, was able to expand the original project. Below are the primary tasks that our group has accomplished.

(1) Evaluation and validation of meteorological forecasts of near-surface variables used by snowmelt models.

We have made significant progress in generating meteorological forecasts for use in our version of the Snowmelt Runoff Model (SRM). We ultimately focused on two different forecasting approaches. First, we continued our work on “downscaling” the global forecasts supplied by the National Center for Environmental Prediction (NCEP) at NOAA. As suggested by Clark et al. (2004; J. Hydrometeor., 5, 243-262), we implemented the technique of regression with forward selection for all SNOTEL and COOP meteorological stations within Idaho and northwest Montana. Regression coefficients were generated for each of these stations for each of the 14 days of forecasts. We have now automated the process of retrieving the daily 14-day forecasts from NCEP’s ftp site and then “downscaling” the forecasts to the locations of the SNOTEL and COOP stations.

Our downscaled forecasts are generated automatically each day, and the resulting forecast data are then emailed to various group members that use the data.

Secondly, we have automated the task of retrieving 7-day forecasts from the National Digital Forecast Database (NDFD) from the National Weather Service. Each day, we retrieve the NDFD forecasts, then select the particular grid cells that contain the temperature data for each of the SNOTEL and COOP stations. These data are tabulated and emailed to the group members that use the data.

We are in the process of verifying the results from both the NCEP and NDFD forecasts for the snowmelt period March through July 2005. (Data for June and July will be verified as they become available.) Our verification process compares the forecasted data with the actual measured values from each of the SNOTEL and COOP stations as they become available. We plan to submit a manuscript describing these comparisons (see reference below).

(2a) Validation of SRM on representative sub-basins using actual surface and streamflow observations.

We have provided two major enhancements to SRM: a) a new technique to assign model parameters (i.e. degree-day factor, runoff coefficients) that make use of data from SNOTEL sites located within the basin and; b) the incorporation of relative humidity and wind speed data into a new (optional) model module designed to improve model performance during rain-on-snow events. These enhancements are currently being evaluated.

Using snow-cover images from the Moderate-resolution Infrared Sounder and our meteorological forecasts of temperature, we began to forecast streamflow in the Big Wood Basin in Idaho in March 2005. This has proved to be a interesting year for hydrological forecasting with SRM because of the low amount of snowpack in the Big Wood Basin and the large amount of precipitation that occurred during the spring and early summer. We are currently evaluating SRM's performance in predicting streamflow at the Hailey, Idaho stream gauge for the snowmelt season beginning in March 2005.

(2b) Several schemes for the spatial interpolation of point-based ground temperature measurements will be evaluated.

Surface air temperature is an important meteorological input parameter for snowmelt runoff models, as well as models of other hydrologic processes. In

complex terrain, such as that found throughout much of Idaho, it is necessary for spatial interpolation techniques to specifically account for orographic effects. We have evaluated three different schemes for spatial interpolation of surface temperature in complex terrain, including a simple lapse rate method, elevationally-detrended ordinary kriging, and the use of climate interpolation models (PRISM). Each of these schemes was evaluated on their overall performance, as well as ease-of-use. It was determined that the simple lapse-rate scheme is easy to use, fast computationally, and performs well in complex terrain. Therefore, this scheme will be used to interpolate our meteorological forecasts over mountain basins. We have two papers in preparation on this topic (see references below).

(3) Development of an interface between meteorological forecast model outputs, real-time ground data, operationally available snowcover data (remotely sensed), and SRM.

We have begun to develop an expert system for improving streamflow forecasting in Idaho. We have created an Excel version of SRM that will ultimately be linked to Arc GIS. Using Arc GIS, we have automated the disaggregation of remotely-sensed, snow-cover images into the percentages of snow-covered area, which is one of the primary inputs into SRM. A user's manual has been written for our end-users. As mentioned above, we have also automated the production of temperature forecasts using NCEP and NDFD data.

- A. **PUBLICATIONS:** A list of all reports published during the reporting period as a result of projects supported using section 104 and required matching funds, including base grants, and National Competitive Grant Program awards **for which you are the lead institute**, and as a result of supplemental awards. Publications for current projects are to be entered in the "Research Project" section of the report if the publication resulted from a research project and in the Information Transfer section of the report if it resulted from an information transfer project. Publications from prior-year projects should be entered by going to the menu item labeled "Publications from Prior Projects".

Harshburger, B.J., T.R. Blandford, B.C. Moore, K.S. Humes, V.P. Walden, R.J. Qualls, and W. Zhao, 2004: Improved Short-term Operational Streamflow Forecasting for Snow-melt Dominated Basins in Idaho, Proceedings of the 2004 meeting of the Association of American Geographers, Philadelphia, PA, 14-19 March 2004.

Harshburger, B.J., T.R. Blandford, B.C. Moore, K.S. Humes, and V.P. Walden, 2004: Towards improved short-term operational streamflow forecasting for snow-melt dominated basins, Proceedings of the 2004

meeting of the American Geophysical Union, San Francisco, California, 6-10 December 2004.

Harshburger, B.J., T.R. Blandford, K.S. Humes, V.P. Walden, and B.C. Moore, 2005: Evaluation of Enhancements to the Snowmelt Runoff Model, Proceedings of the 2005 Western Snow Conference, Great Falls, Montana, 11-15 April 2005 , in press.

Blandford, T.R., B.J. Harshburger, B.C. Moore, K.S. Humes, and V.P. Walden, 2005: Interpolating surface air temperature for use in a semi-distributed snowmelt runoff model, Proceedings of the 2005 Western Snow Conference, Great Falls, Montana, 11-15 April 2005, in press.

In preparation for peer-reviewed journals:

Blandford, T.J, and K.S. Humes, 2005: Approximating the daily temperature lapse rate using the synoptic weather type, in preparation for *Journal of Hydrometeorology*.

Blandford, T.J, and K.S. Humes, 2005: Complex versus simple methods for interpolating surface air temperature: Application to conceptual semi-distributed snowmelt runoff models, in preparation for *Water Resources Research*.

Moore, B.C., and V.P. Walden, 2005: Evaluation of NCEP downscaled and NDFD temperature forecasts over the intermountain West region, in preparation for *Weather and Forecasting*.

- B. **INFORMATION TRANSFER PROGRAM:** A brief description of information transfer activities supported with section 104 and required matching funds during the reporting period.

Not Applicable to this project.

C. STUDENT SUPPORT:

	Section 104 Awards		NIWR-USGS Internship	Supplemental Awards	Total
	Base Grants	Competitive Awards			
Undergrad.					
Masters	2				2
PhD.	1				1
Post-Doc.					
Total	3				3

D. NIWR-USGS STUDENT INTERNSHIP PROGRAM:

Not Applicable to this project

E. NOTABLE ACHIEVEMENTS AND AWARDS:

Graduate Student Awards

- Best Poster at the PhD Level: Brian Harshburger, "*Improved short-term operational streamflow forecasting for snow-melt dominated basins in Idaho*", 2004 Annual Meeting of the Association of American Geographers, Philadelphia, PA.
- Best Poster: Troy Blandford, "*Interpolating Surface Air Temperature and Precipitation for Use in a Semi-distributed Snowmelt Runoff Model*", 2005 Western Snow Conference, Great Falls, MT.
- Runner-up, Student Paper Competition: Brian Harshburger, "*Evaluation of Enhancements to the Snowmelt Runoff Model*", 2005 Western Snow Conference, Great Falls, MT.

Ground water/surface water interactions in the Idaho batholith

Basic Information

Title:	Ground water/surface water interactions in the Idaho batholith
Project Number:	2004ID46B
Start Date:	4/1/2004
End Date:	12/15/2005
Funding Source:	104B
Congressional District:	1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, None, None
Descriptors:	: groundwater/surface water interactions, chloride mass balance, residence time
Principal Investigators:	J. P Mcnamara

Publication

Final Report Synopsis

Title: Groundwater/surface water interactions in the Idaho Batholith

Project Number: 2004ID46B

Start Date: 3/1/04

End Date: 2/28/05

Funding Source: 104B

Research Category: Climate and Hydrologic Processes

Focus category: GW

Descriptors: groundwater/surface water interactions, chloride mass balance, residence time

Primary PI: James P. McNamara, Boise State University

Project class: Research

1. Introduction

Mountainous regions play a critical role in the hydrology of semi-arid drainage basins. Due to orographic forcing of precipitation, especially snow, they receive much more water than lower regions, they provide most of the runoff, and they provide most of the groundwater recharge to adjacent valley aquifers. Sound groundwater management plans in mountain front communities must rely on thorough understanding of the interactions between surface water and groundwater in the mountain blocks. In mountain front aquifer systems this requires understanding how mountains and adjacent valley aquifer systems are hydraulically connected. However, groundwater recharge in mountain blocks is difficult to measure and poorly understood because shallow soils over fractured bedrock create complex flow paths.

Mountain block recharge (MBR) and groundwater/surface water interactions are important issues in the Treasure Valley. In a study assessing the groundwater recharge in the regional Valley aquifer system Hutchings et al. (2001) indicated that a key unknown in the Treasure Valley groundwater system is the extent of recharge from various sources along the Boise Front. Geochemical evidence suggests that a significant portion of recharge to the shallow aquifers in the Treasure Valley comes from the Idaho Batholith (Hutchings et al., 2001). Wood and Burnham (1987) suggest that a significant amount of water in the deep geothermal aquifer system underlying the Treasure Valley is derived from recharge into fractured granite in the adjacent mountain block. The rates of groundwater recharge in the mountain block, and the hydraulic connections between the mountain block and valley aquifer system, however, is largely unknown. Further, once water enters the fractured granite at high elevations it can return to the surface water system at any lower elevation through springs and gaining streams, or it can make it to the valley aquifer system entirely through subsurface flow paths.

Several important questions exist concerning the hydrologic relationships between the Boise Front and the Treasure Valley aquifer system. A thorough understanding of mountain recharge in the Boise Front is beyond the resources of this project. However, this project takes an important first step by asking these questions: 1) How much high elevation precipitation in the Boise Front enters the subsurface fractured granite, and 2) what is the fate of that recharged water?

The goal of this project was to contribute to understanding the hydrologic relationship between the Boise Front mountain block and the adjacent Treasure Valley aquifer system. We evaluated how much precipitation is lost to the subsurface, and estimate the mean residence time of streamflow to begin to understand when and where that lost water returns to the surface water system in the Dry Creek watershed in the foothills on the Idaho Batholith adjacent to Boise, Idaho. Specific objectives included:

1. Determine proportion of precipitation in Dry Creek that is lost to the subsurface using water and chloride balances.
2. Estimate mean residence time of stream flow at various points in Dry Creek using isotopic dating techniques.

2. Status of proposed objectives

2.1 Objective 1: Determine proportion of precipitation in Dry Creek that is lost to the subsurface using water and chloride balances.

The purpose of this objective was to take advantage of existing hydrologic infrastructure in the Dry Creek watershed in the foothills adjacent to Boise, Idaho to test the chloride and water balance approaches for estimating groundwater recharge in granitic watersheds (Figure 1). Faculty and students in the Department of Geosciences at Boise State University have been conducting hydrologic studies in Dry Creek for approximately four years. Currently, seven stream gauging stations and three weather stations are distributed throughout the 27 km² watershed. One weather station is located in a 0.012 km² watershed where we are also monitoring, hillslope overland flow, snow depth, soil moisture in 20 locations, and streamflow. This small watershed, called the Treeline watershed, is the site for this study.

Water and chloride budget investigations should be conducted over time periods that encompass one wet season. The funding period for this subcontract overlapped with the end of one wet season and the beginning of the next. Consequently, we were unable to construct current budgets as part of this grant. We are, however, continuing the sampling program and seeking further funding from other sources to construct budgets at larger scales in the Dry Creek watershed. Fortunately, water samples were collected, but unanalyzed, in previous years as part of other projects. Funds from this subcontract were used to analyze samples from previous years to complete water and chloride budgets for the Treeline watershed for the 2001 water year, and to begin a new sampling program to perform similar analyses at larger scales. Water and chloride budgets for the large watersheds will be completed after a full year of sampling is completed following the spring 2005 snowmelt period.

2.1.a Background

Research on the topic of this project is generally found in the literature category of mountain front recharge (MFR), which is defined as the contribution of mountainous regions to the recharge of aquifers in adjacent basins (Figure 2). This large scale problem involves several processes including surface runoff from mountains to the valley floor via

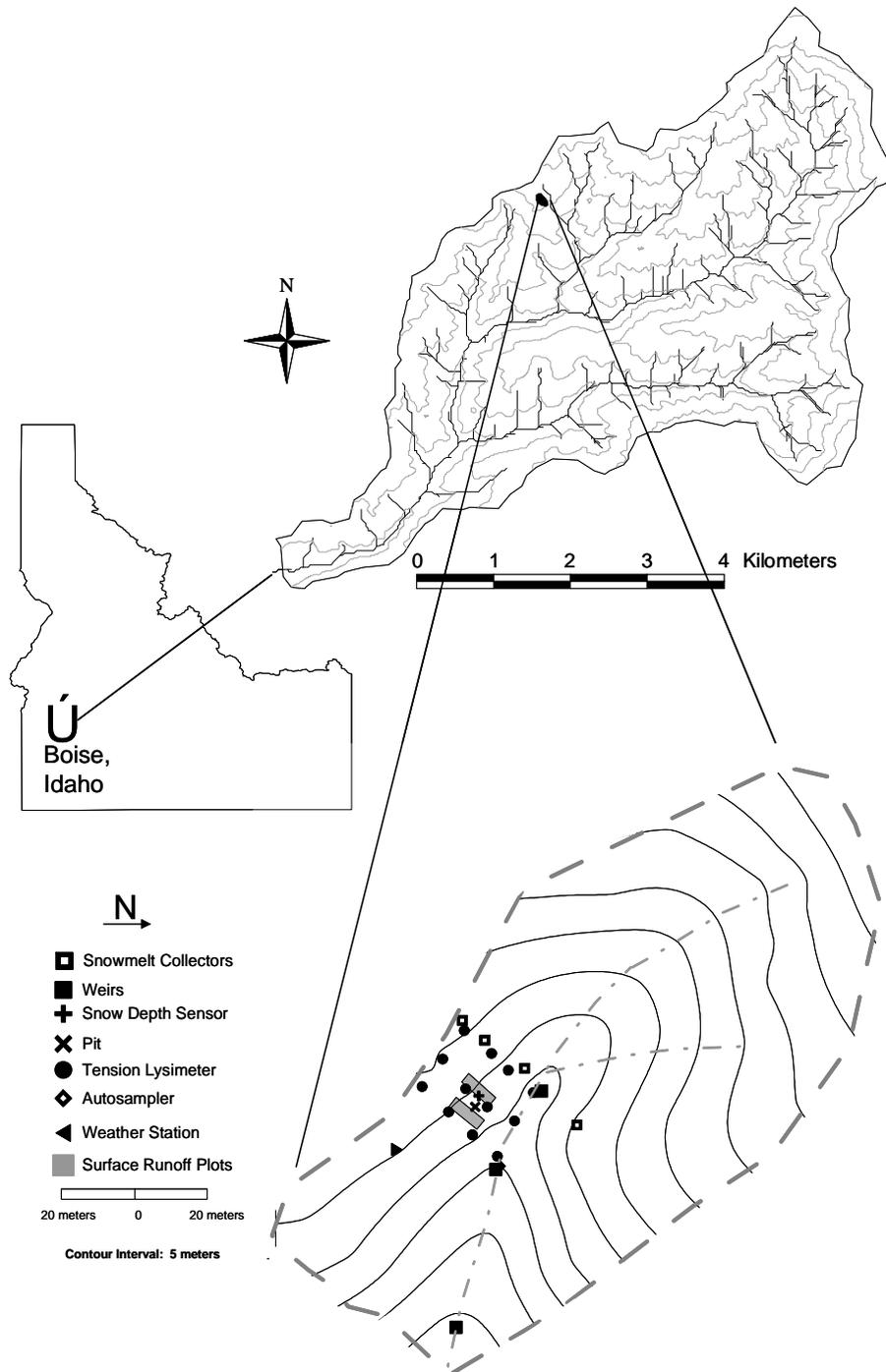


Figure 1. Location of the Dry Creek Experimental Watershed.

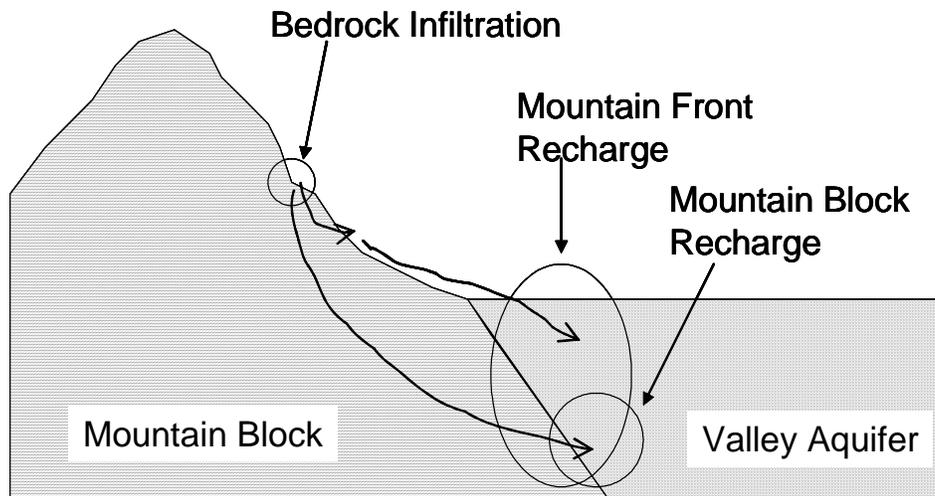


Figure 1: Schematic illustrating relationships between bedrock infiltration, mountain-block recharge, and mountain-front recharge.

streams, subsurface discharge through soils and streambeds, and subsurface contributions to valley aquifers from adjacent bedrock. This last process, called mountain block recharge (MBR), occurs via subsurface fractures and fissures. Most MFR and MBR studies take a valley-centric perspective and are primarily concerned with assessing quantities of water entering the valley aquifers. However, this current project is concerned with the other end of the flow path at the local recharge source.

Land managers that are charged with assessing impacts of land use on groundwater recharge are not concerned with the down-valley problems of quantifying subsurface discharge into valley bottom aquifers, but are interested in site-specific recharge at the other end of the flow paths in the mountains. How much of the annual precipitation over relatively small areas enters the bedrock fracture system? From this upstream perspective, it can not be said if water that enters the bedrock fracture system, henceforth called bedrock infiltration (BI), travels through the mountain block to the lower basin or re-enters streams high up in the mountains. Regardless, the starting point for MBR is BI, and it is this localized process that is of immediate concern for land managers. What happens between bedrock infiltration and mountain front recharge is a field of research that is ripe for future investigations, but is well beyond the scope of this project. For this reason this report avoids the terms mountain block recharge and mountain front recharge in favor of the term bedrock infiltration to refer the precipitation that is lost to the bedrock subsurface within a study area of interest.

Methods to assess bedrock infiltration are not well developed. Instead, methods designed for assessing deep infiltration in soils must be modified to account for the complexities of mountain landscapes. Infiltration is generally a one-dimensional process wherein water moves from the surface into the subsurface. Estimating groundwater recharge through infiltration is typically a problem of determining when vertically moving subsurface water travels beyond the evaporative demands of the climate and vegetation. Bedrock infiltration is complicated by the fact that the surface of interest is typically hidden by a

thin but complicated soil layer. For bedrock infiltration to occur, infiltrating water must survive passage through this layer while being subject to evapotranspiration and lateral throughflow to streams. Once water reaches the soil/bedrock interface it will move down slope until a fracture with sufficient conductivity is encountered. In arid and semi-arid regions dry soil can prohibit water from reaching the soil/bedrock interface for much of the year. Infrequent summer rainfall must first wet near surface soils to field capacity, but evapotranspiration typically removes this water. McNamara et al. (2005) showed that in a semi-arid watershed near Boise Idaho hillslope soils must wet to depth before they can contribute appreciable runoff to streams (Figure 3). This is also true for bedrock infiltration. Hence, the problem of estimating bedrock infiltration involves complex interactions between topography, soil moisture dynamics, climate, and bedrock geology.

Methods to Estimate Bedrock Infiltration

Several recent reviews have been written summarizing methods to estimate one-dimensional groundwater recharge (i.e. Allison et al. 1994; Gee and Hillel, 1998; Flint et al., 2002; Grismer et al., 2000; and Scanlon et al., 2002). de Silva (2004) lists the techniques as (a) lysimeter method, (b) soil water budget models, (c) water table fluctuation method, (d) watershed water balance method, (e) numerical modeling of the unsaturated zone, (f) zero flux plane method, (g) Darcy method, (h) tritium profiling method and (i) chloride profiling method (Lerner et al., 1990; de Silva, 1998; Scanlon et al., 2002). de Silva (2004) further states that all but the watershed water balance method are point estimates and that the watershed method is the least valid because of many problems associated with two dimensional flow. However, point methods are based on the idea that once vertically infiltrating water overcomes near surface evaporative demands, water continues downward as piston flow to become groundwater recharge. The problem then is simply to estimate the rate at which that water moves. However, the piston flow model is not applicable where thin sloping soils overly fractured bedrock. This report takes the opposite view of de Silva (2004) that watershed based approaches to estimate bedrock infiltration are more applicable than point based approaches in mountainous terrain. Consequently, we limit further discussion to using watershed water and solute budgets to estimating bedrock infiltration.

Water Budget

The water budget equation is based on conservation of mass which dictates that the difference between the rate that water enters a region (Q_{in}) and the rate that water exits that region (Q_{out}) over a period of time (Δt) must match of change in the volume of water stored (ΔS) in the region during that period of time.

$$Q_{in} - Q_{out} = \frac{\Delta S}{\Delta t} \quad (1)$$

Expansion of the terms in Equation 1 will vary with the spatial and temporal scales of the applications, but the basic physical concept is true for all scales over all periods of time. For example, the water budget equation can be applied to the near-subsurface in agricultural lands to evaluate water losses to deep infiltration from irrigation, or to evaluate how precipitation is partitioned between evapotranspiration, streamflow, and

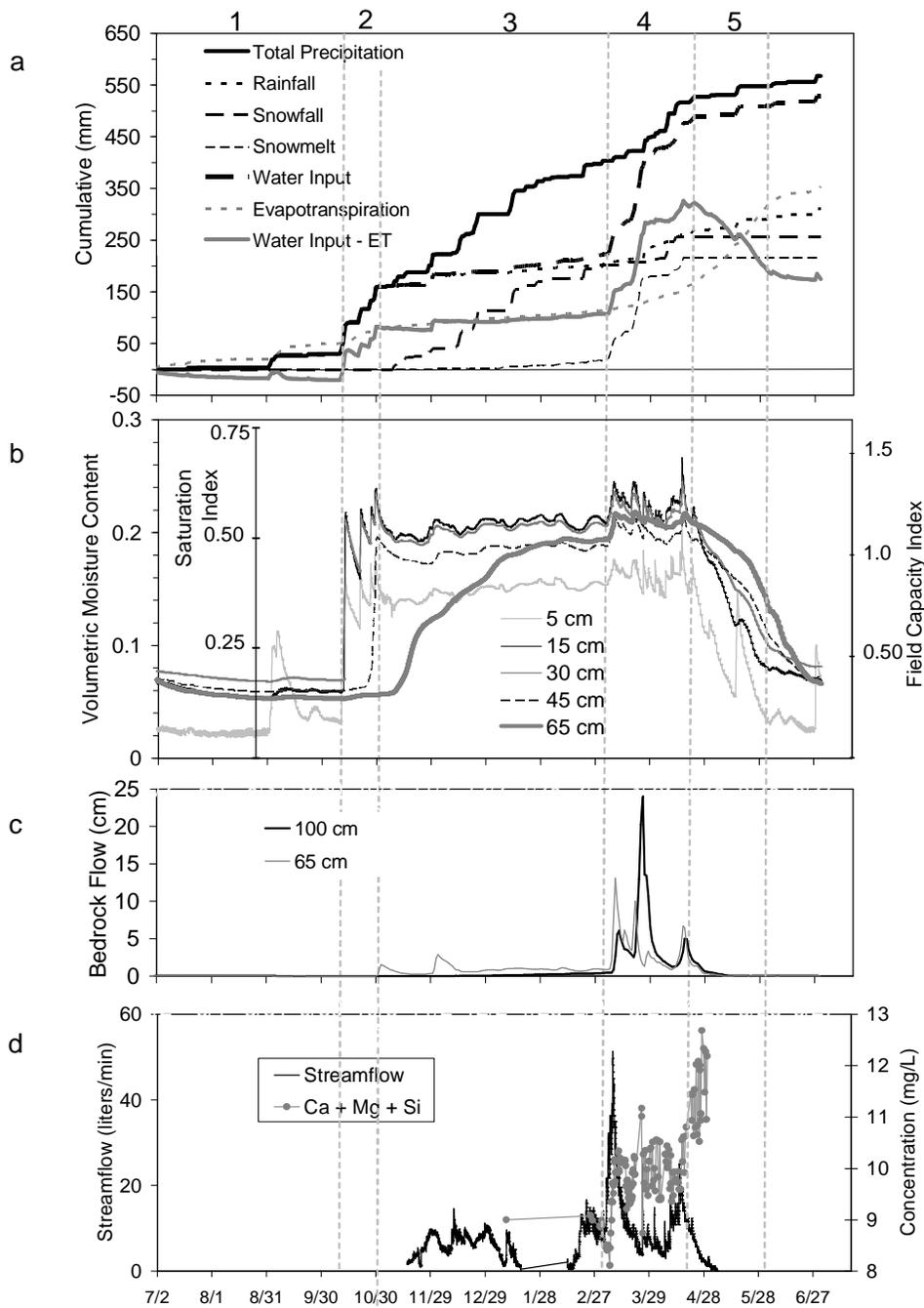


Figure 3. Timing of events during the 2001 water year a) at the land—atmosphere interface, b) in the soil column, c) at soil/bedrock interface modeled by SHAW, and d) in the stream. The numbers across the top and the gray vertical line refer to the characteristic moisture periods described by McNamara et al. (2005).

groundwater recharge in small to large watersheds. In both of these cases, the vertical movement of water to the deep subsurface, or groundwater recharge, is typically

calculated as a residual with all other components being measured or modeled.

For a watershed bounded by topographic highs and a surface water outlet, inflow terms include precipitation (P) and groundwater (GW_{in}). Outflow terms can include evapotranspiration (ET), surface runoff (R), and losses to groundwater (GW_{out}). Storage (S) can take place in the vegetation canopy (S_{can}), snow (S_{snow}), surface water ponding (S_{pond}), and soil moisture (S_{soil}). Incorporating these terms into Equation 1 results in

$$(P + GW_{in}) \Delta t = (ET + GW_{out} + R + \Delta S_{can} + \Delta S_{snow} + \Delta S_{soil} + \Delta S_{pond}) \Delta t \quad (2)$$

All components are given as rates so that a mass balance is produced when integrated over a period of time. Well known hydrologic processes such as overland flow and infiltration are not included at the watershed scale because these processes are simply internal cycling mechanisms that do not bring water into or carry water out of the watershed. Groundwater can also be an internal cycling mechanism if water enters and exits the groundwater system within the boundaries of the watershed. For groundwater recharge investigations, it is therefore important to apply the water budget equation to proper watershed scales that will provide the desired information. Bedrock infiltration only represents water that enters the watershed boundaries from the surface and leaves the watershed boundaries through the subsurface. In this application bedrock infiltration is the difference between GW_{in} and GW_{out}

$$BI = GW_{out} - GW_{in} \quad (3)$$

The difficulty of applying Equation 2 increases as time scales decrease and spatial scales increase. A common application is to evaluate Equation 2 at the annual time scale. In this case the storage terms can be considered 0 (i.e. soils hold essentially no water during the summer, become wet during the winter then return to dry conditions the following summer). For a one year period Equation 2 can then be written as

$$BI = P - ET - R \quad (4)$$

where the quantities in Equation 4 are annual total volumes. In the remainder of this report the components of the water budget equation refer to annual equivalent depths, which is the volume of water transported by the particular process in a year divided by the watershed area.

The major limitation to applying the water budget approach to any scale is that the accuracy of recharge estimates depends on the accuracy with which the other components are measured or modeled. P and R are easily measured. ET is not. This is a particular concern in areas where groundwater recharge is a small component of the water budget such as in arid and semi-arid mountain environments where ET and streamflow are high. However, the water budget method provides a rough estimate of potential losses of surface water to groundwater.

An excellent summary of the errors associated with measurements of individual components of the water budget is given in Dingman (2002). Evapotranspiration is the most difficult component to evaluate so the accuracy of the water balance approach depends largely on the accuracy of ET estimations. For example, if ET is 60% of P, and BI is 20% of P, then a 20% uncertainty in the ET estimate leads to a 60% uncertainty in BI (example modified from Wilson and Huade, 2004).

Chloride Mass Balance

A key advantage to tracking the mass balance of a conservative solute (i.e. non-reactive) that is carried by water such as chloride is that evapotranspiration can be ignored. Evapotranspiration does not transport chloride so the mass of chloride input to a watershed in a year can be accounted for by the mass that leaves as streamflow and the mass that enters the groundwater system. This is based on several assumptions including 1) there is no storage of chloride in the unsaturated zone, and 2) precipitation is the only source of chloride in the flow system.

The first assumption is easily violated if chloride balances are performed on less than an annual time scale. In arid and semi-arid climates nearly all rainfall that falls during the summer months evaporates, but strands chloride behind in the vadose zone. When fall rain and spring snowmelt travels through the soil, infiltrating water picks up the stranded chloride. Assumption 1 is strictly valid if the amount of stranded chloride during the dry season is approximately the same from year to year. The second assumption can be violated from weathering of geologic formations high in chloride or from anthropogenic activities such as road salting.

Additional assumptions must be made depending on the application. Two general classes of applications include point-based chloride profiling and watershed scale mass balances.

The chloride mass balance (CMB) approach was first developed as a one-dimensional estimation of point recharge in desert soils (Allison and Hughes, 1978). This application is commonly called chloride profiling and involves calculating the vertical mass flux of chloride then relating mass flux to water flux. The mass of chloride that flows through any region is the product of the flow rate of water (L^3t^{-1}), the concentration of chloride in that water (ML^{-3}), and the time period of interested (t). The derivation of an annual chloride budget with no annual storage of chloride follows the same logic as the annual water budget discussed above. A one-dimensional annual chloride budget can be written as

$$P * C_p = GR * C_{gr} + R * C_r \quad (5)$$

where P is precipitation, GR is groundwater recharge, and R is surface runoff. C is annual average chloride concentration in precipitation, groundwater, and runoff. A significant advantage the chloride balance over the water balance is that ET is not included in chloride balances because ET does not transport chloride. ET, however, does change chloride concentrations in the subsurface. Typically, chloride concentrations increase

with depth to the base of the root zone then remain relatively constant with depth after that (Scanlon et al., 2002). This evaporative concentration can be ignored if C_{gr} is measured well below the affected zone. Solving for groundwater recharge, Equation 5 is written as

$$GR = (P(C_p) - R(C_r)) / C_{gr} \quad (6)$$

The chloride profiling method is commonly applied to arid and semi-arid regions with little or no surface runoff and with a clearly defined water table in unconsolidated sediments (Allison and Hughes, 1978). In such environments the problem can be reduced to one dimension and Equation 4 reduces to

$$GR = P \frac{C_p}{C_{gr}} \quad (7)$$

Equation 7 can be used in reconnaissance investigations by obtaining P and C_p from publicly available data sources then sampling deep soil moisture or groundwater to estimate C_{gr} . In this way a CMB can be performed quickly without the expense and time commitment of constructing an annual water budget. Precipitation data and chloride concentrations in precipitation are available from the National Atmospheric Deposition Program. Applicable data is available for Idaho locations, i.e. Smiths Ferry station, Valley County, just south of Cascade, elevation 1442 meters and Craters of the Moon station.

Equation 7 is difficult to apply in mountainous terrain because of the thin soils and the sloping topography. The thin soils make it essentially impossible to sample C_{gr} directly below the site of interest. The sloping topography creates significant lateral flow, i.e. not piston flow, and surface drainage. Streams are not routinely monitored for chloride concentrations so it is difficult to estimate C_r without conducting a year of monitoring. Dettinger (1989) modified the chloride profiling method for application to several watersheds in Nevada. Subsequent similar studies have been conducted in Nevada by Russell and Minor, 2002 and by Thomas and Albright, 2003. Rather than using C_{gr} in a vertical profile below the sites of interest these studies use springs and wells to obtain regional average groundwater chloride concentrations. This approach provides good estimates of regional groundwater recharge rates, but it integrates large areas. Consequently, the watershed scale CMB approach is best suited to estimate mountain block recharge rather than localized bedrock infiltration.

At the point scale it is difficult to sample C_{gr} and the assumption of piston flow is violated. At the watershed scale, however, the difficulties of determining C_{gr} can be overcome if sampling locations are selected carefully to ensure that the C_{gr} represents the local recharge water, called bedrock infiltration. Proximal groundwater wells can be used if they exist. Springs must represent groundwater that has gone through the localized concentrating by evapotranspiration, but does not integrate multiple evapotranspiration

regimes. Springs, however, can not exist in the study site of interest or else the watershed is not likely to be a recharge area.

An alternate approach to estimate the chloride concentration in recharge water, C_{bi} , is to assume that all rainfall evapotranspires without contributing to recharge so that recharge only comes from melting snow. Further assume that the chloride that is stranded in the prior dry season by evapotranspiration is entirely mobilized by later snowmelt. The concentration in recharge water is therefore the mass of chloride delivered from the atmosphere during the entire year divided by the volume of water that falls as snow during the year. This is equivalent to multiplying the average annual concentration in precipitation by the ratio of annual depth of precipitation to annual depth of snow water equivalent (SWE)

$$C_{bi} = (C_p) * (P/SWE) \quad (8)$$

This approach neglects the effects that evapotranspiration might have on the snowmelt water and assumes that no stranded chloride is transported laterally to streamflow. Both of these additional assumptions are not strictly true, but the violations are likely minor and counter to each other.

Claassen et al. (1986) approached the C_{bi} problem by assuming that the chloride concentration in runoff is equal to the chloride concentration in recharge water. However, they present no data to support this assumption. Dettinger (1989) states that in most watersheds, runoff concentrations tend to be one quarter to one half of groundwater concentrations.

2.1.b Methods

The goal of the study is to compare estimations of bedrock infiltration from the Treeline watershed using water and chloride budgets for the 2001 water year. Specific objectives include

1. Quantify the annual bedrock infiltration from the Treeline watershed using a water balance approach (Equation 4),
2. Quantify the mass of chloride lost to bedrock infiltration (Equation 5),
3. Convert the annual chloride loss to bedrock infiltration rates with Equation 6 using different approaches to estimate C_{bi} including
 - a. groundwater from a proximal spring
 - b. groundwater from a proximal well,
 - c. the stranded chloride approach with Equation 8.

Combined rainfall and snowfall, P , was measured in a shielded weighing bucket gauge mounted on a post approximately 1.5 m above the ground surface. P was considered snow when the air temperature was below 0 degrees Celsius. In addition, snow depth was monitored hourly at one point by a sonic depth sensor. Occasional snow surveys are

performed to obtain basin-average snow water equivalent. SWE obtained from snow surveys compared favorably to SWE obtained from the weighing bucket gage.

Evapotranspiration (ET) and Soil Moisture: ET was calculated using the Simultaneous Heat and Water (SHAW) model (Flerchinger et al., 1996). SHAW is a comprehensive one dimensional model that simulates moisture fluxes from the atmosphere through the vadose zone. SHAW requires soil texture, vegetation type, air temperature, solar radiation, and wind speed. Soil texture was described as components of sand, silt, and clay from five samples collected from two soil pits excavated to bedrock. Meteorological variables were measured with a Campbell Scientific weather station close to the precipitation station. SHAW simulations were calibrated and verified by comparing simulated to observed soil moisture patterns. Soil moisture was monitored in two vertical profiles 100 cm (pit100) and 65 cm (pit65), 2 m apart and 15 m upslope from the stream channel on the N-facing slope. Moisture content was monitored at 15 minute intervals with Water Content Reflectometers (Campbell Scientific, Logan, UT) at depths of 5 cm, 15 cm, 30 cm, 65 cm, and 100 cm.

Streamflow, R, was monitored at a plywood v-notch weir draining 0.012 km². Stage in the pond behind each weir was monitored by pressure transducers.

Rain and snow samples were collected to determine chloride concentration in precipitation, C_p. Rain was collected during occasional storms using plastic funnels draining in polyethylene bottles. Snowcores were collected periodically throughout the cold season and melted to sample the chemical composition of the snowpack. Snowmelt pans were used to collect snowmelt at the base of the snowpack. Water samples were collected from the stream twice daily using an ISCO automatic sampler during the snowmelt period and approximately weekly during the low flow winter period. The stream does not flow during the summer. All water samples were passed through a 1 micron filter at the time the sample was taken. All water samples were refrigerated before analysis. Chloride analysis was completed by a colorimetric method at the Utah State University Analytical Laboratory.

2.1.c Results

Water Balance

Bedrock infiltration from water budget calculations (Equation 4) was 71 mm or 13% of annual precipitation (Table 1). Bedrock flow, a product of SHAW, in Table 1 is the amount of water that reaches the soil bedrock interface. Once the moisture content at this interface reaches field capacity, additional water becomes available for bedrock infiltration. Figure 3b shows that the deep soils did not reach field capacity (approximately 17%) until April suggesting that the bedrock infiltration can only occur during a brief period of the year. SHAW simulations suggest that 244 mm or 42% of total precipitation reached the soil bedrock interface. This water either travels laterally to the stream or infiltrates the bedrock. The difference between this bedrock flow and streamflow (143 mm) is 101 mm, which provides an upper boundary to potential bedrock infiltration. Actual bedrock infiltration is expected to be less, as our water budget

calculations suggest, because some moisture will remain in storage at moisture contents below field capacity.

Chloride Balance

Using annual average chloride concentrations from Table 2 and annual water fluxes from Table 1, the watershed received 4.6 Kg of chloride via precipitation and exported 2.1 Kg of chloride via streamflow suggesting that 56% of the chloride that entered the watershed left via bedrock infiltration. This supports the water budget calculation that the watershed loses water to the underlying bedrock.

Table 1. Annual and monthly water budget of the Treeline Catchment.

	Observations		Equation 4 Calculations		SHAW Simulations					
	P (mm)	Runoff (mm)	Bedrock Infiltration (mm)	BI/P	Rain (mm)	Snow ² (mm)	Snowmelt (mm)	ET (mm)	ΔS_{soil} (mm)	Bedrock Flow (mm)
Total Annual	568	143	71	0.13	311	257	217	354	5	244
July-00	3				3	0	0	17	-7	0
August-00	1				1	0	0	4	-2	0
September-00	26				26	0	0	28	2	0
October-00	130				130	0	0	29	76	0
November-00	62				22	40	0	12	10	0
December-00	78				5	74	2	8	11	0
January-01	68				8	60	7	8	5	4
February-01	29				7	22	9	8	2	8
March-01	53				35	17	164	23	4	167
April-01	77				33	44	35	54	-15	61
May-01	20				20	0	0	124	-57	3
1-Jun	20				20	0	0	41	-24	0

Table 2. Annual average chloride concentrations (mg/L), and Bedrock Infiltration calculation

	Streamflow	Precipitation	Proximal Groundwater Springs	Proximal Well (Bogus Basin)	Equation 8
Mean	0.69	0.68	1.20	1.24	1.28
Min	0.29	0.29	na	na	na
Max	1.78	1.32	na	na	na
STDEV	0.22	0.34	na	na	na
n	137	14	1	1	1
BI			241	233	226
BI/p			0.42	0.41	0.40

All three approaches to estimate C_{bi} produce strikingly similar bedrock infiltration results near 40% of precipitation. This encouraging result suggests that when wells or springs are not present, the stranded chloride approach can be used to estimate C_{bi} .

Differences between the water budget and CMB approaches can be attributed errors in ET and C_{bi} estimations. However, without a full error analysis of both approaches it is difficult to say which approach is more robust. At best, we can say that both approaches suggest that the Treeline watershed loses water to bedrock infiltration and that the magnitude of that loss is somewhere between 10% and 40% of annual precipitation.

2.2 Objective 2: Estimate mean residence time of stream flow at various points in Dry Creek using isotopic dating techniques.

This objective was designed to provide qualitative information on the fate of water that is lost to the subsurface determined in objective one. Ultimately we want to know the pathways that water takes to the valley bottom. Here, we proposed to use mean residence time of stream water to understand where and when high elevation recharged water returns to the surface water system.

The mean residence time (MRT) of streamflow is the average time water spends in the watershed before it reaches a designated point along its flow path such as a watershed outlet. More interaction with the subsurface yields higher MRT. MRT for groundwater is typically determined by measuring the concentrations of radioactive elements in water such as ^{14}C or ^3H . These methods are well known and are not described in detail here other than to say that ^{14}C is used on waters tens of thousands of years old and ^3H is generally used to date waters tens to hundreds of years old.

The MRT of streamflow can be much less than is detectable from radioisotopic methods. A less common approach is to use time series of the stable ^{18}O in precipitation and streamflow to estimate MRT's. The approach takes advantage of isotopically distinct water in precipitation that propagates in a known or assumed pattern over time through the watershed and exits with a new isotopic signature due to mixing in flowpaths. The input and output time series' are related by a convolution integral

$$\delta(t) = \int_{-\infty}^t \delta_{\text{in}}(t')g(t-t')dt' \quad (9)$$

where $\delta(t)$ is the streamflow ^{18}O signature, t' is an integration variable that describes the entry to the system, t is the calendar time, δ_{in} is the input ^{18}O signature to the system, and $g(t-t')$ is the residence time distribution or system response function, which is the travel time probability distribution for tracer molecules in the system. The MRT is obtained as a model parameter in an assumed probability distribution, $g(t-t')$. Various distribution functions have been proposed (McGuire et al., 2002).

Application of the convolution integral method to estimate MRT requires at least a one year time series of ^{18}O analyses on precipitation and streamflow at desired output locations. We will collect samples for analysis of ^{18}O at the same time and locations of our chloride sampling. At this point we have collected and analyzed approximately one year of precipitation and streamflow samples, but have not yet performed the calculations to determine MRT. A graduate student in the Department of Geoscience, Richard Friese, is conducting the analysis for his thesis. We anticipate that Mr. Friese will complete the analysis by December, 2005.

3. Outcomes

This project contributed to a journal publication (McNamara et al., 2005), provided data to prepare a second journal publication about the application of the chloride mass balance in thin soils and a third publication about the residence time of streamflow in the Dry Creek Experimental Watershed. Two graduate students were partially supported through this grant. Data from this project are providing the basis for a proposal that is currently being developed for submission to the USDA National Research Initiative, and a BSU graduate student, Bernadette Hoffman, received a \$10,000 fellowship from NASA to

investigate the geologic controls on groundwater recharge, a problem that was initiated by this project.

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Information Transfer Program

Consistent with our mandate, the Idaho Water Resources Research Institute at the University of Idaho has endeavored to promote and coordinate education and information transfer. These efforts have been in coordination with Idaho's water resource agencies and the Idaho Department of Education. The following is a list of water quality education/information transfer programs which emphasize cooperation and collaboration. These activities are not directly funded with the Section 104B USGS funding.

Project WET (Water Education for Teachers) Idaho, an interdisciplinary, supplementary water education program for Idaho educators, was active this past year. The goal of Project WET is to facilitate and promote an awareness, appreciation, and understanding of Idaho's water resources through the development and dissemination of classroom-ready teaching aids. Like other successful natural resource education programs, Project WET emphasizes teaching students how to think, not what to think. In this past year there were 12 workshops with 220 teachers participating.

The Idaho Water Resources Research Institute also participated in Water Awareness Week, Idaho Salmon and Steelhead Days, geothermal education programs, the Ground Water Awareness Projects and other ad-hoc watershed programs.

Many of the Idaho Water Resources Research Institute research projects also provide for outreach and education activities. Researchers have participated in a number of public meetings and held workshops related to their specific projects around the state. In particular, several IWRRRI researchers have been providing the Idaho Legislature's Interim Committee on Natural Resources with background information and scientific analysis to help identify the data and research needs related to supporting conjunctive management of Idaho's surface and groundwater resources.

Student Support

Student Support					
Category	Section 104 Base Grant	Section 104 RCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	0	0	0	0	0
Masters	5	0	0	0	5
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	7	0	0	0	7

Notable Awards and Achievements

Graduate Student Awards Best Poster at the PhD Level: Brian Harshburger, Improved short-term operational streamflow forecasting for snow-melt dominated basins in Idaho, 2004 Annual Meeting of the Association of American Geographers, Philadelphia, PA.

Best Poster: Troy Blandford, Interpolating Surface Air Temperature and Precipitation for Use in a Semi-distributed Snowmelt Runoff Model, 2005 Western Snow Conference, Great Falls, MT.

Runner-up, Student Paper Competition: Brian Harshburger, Evaluation of Enhancements to the Snowmelt Runoff Model, 2005 Western Snow Conference, Great Falls, MT.

Publications from Prior Projects