Water Research Consortium

U.S. Department of Energy
Grant Award Number DE-FG02-05ER64132

Final Technical Report

For Period Beginning: 15 September 2005
And Ending: 31 December 2009

Report Date: 16 March 2010

Project Directed by Steven R. Billingsley, Executive Director,
Inland Northwest Research Alliance, Inc. (INRA)

I. Executive Summary

This report summarizes the activities of the INRA Water Research Consortium (IWRC) for the period beginning September 15, 2005 and ending December 16, 2010. This report compares accomplishments to project objectives, documents the activities associated with this project, and lists products developed during the course of the project.

Rationale

Arid western regions are especially susceptible to impacts of water shortages. In our naturally water-limited area, drought affects both water quantity and water quality. Understanding the complex interaction of anthropogenic and natural factors that affect the water cycle, and the resultant impacts on water resources within our geographically dispersed region, requires expertise in many disciplines, including agriculture, climatology, chemistry, geography, geology, hydrology, engineering, ecology, economics, forestry, sociology, environmental science, and watershed management. Water shortages associated with wide-spread drought conditions impact energy supplies, municipal and agricultural water supplies, recreational activities, and ecological needs of fish and wildlife.

INRA member institutions are tasked with training the next generation of professionals who will tackle these complex problems. Future workers will need both depth of understanding created by earning graduate degrees in areas such as climatology, hydrology, or ecology; and breadth of understanding created by exposure to all of the pertinent social and scientific disciplines along with the issues confronted by policy makers. A similar INRA model has already achieved success in the subsurface sciences.

Public Benefit

The public will benefit from the enhanced understanding, the multi-disciplinary training of our next generation of professionals, as well as from the establishment of the INRA Constellation of Experimental Watersheds (ICEWATER) network. The ICEWATER network facilitates study of these topics in a regional context such that integrated assessments can be brought to bear on regional water resource management issues. The ICEWATER network fosters the holistic understanding of water resources in the intermountain region through the following activities aimed at stimulating synthesis and integration across multiple experimental watershed and aquifer sites.

Through this program, a regional Scientific Needs Assessment has been performed, and a Research Plan and an Education Plan have been developed based on the issues brought forth in the Scientific Needs Assessment. Twenty-One research projects have been conducted, and in integrated cyber-infrastructure, known as the ICEWATER Network and ICEWATER Central Website. The ICEWATER Network and ICEWATER Central Website continue to be developed although the project has concluded. The National Science Foundation’s (NSF) CUAHSI (Consortium of Universities for the Advancement of Hydrologic Science) Program provided the “backbone” for the Hydrologic Information System that has been developed, and these efforts continue to be integrated.

II. Accomplishments Compared to Objectives

A. Year 1 Objectives
1-A. Scientific Needs Assessment
1-B. Draft Regional Scientific Research Plan
1-C. Design Multi-Disciplinary Graduate Degree Program

B. Year 2-3 Objectives
2-A. Finalize Needs Assessment
2-B. Final Regional Scientific Research Plan
2-C. Final Education Plan
2-D. Select and Fund Research Projects

C. Year 4-5 Objectives
3-A. Provide infrastructure for ICEWATER information system and define watersheds to be included.
3-B. Produce an informational website to link to the data gathering and data dissemination infrastructure defined in 3-A.
3-C. Make investments to assist research efforts between and amongst the constellation watersheds.

D. Year 1 Accomplishments
1-A. Scientific Needs Assessment – Draft Completed
1-B. Draft Regional Scientific Research Plan – Draft Completed
1-C. Design Multi-Disciplinary Graduate Degree Program – Draft Education Plan Completed

E. Year 2-3 Accomplishments
2-A. Finalize Needs Assessment – Completed (see section IV for description and Appendix A for Needs Assessment)
2-B. Final Regional Scientific Research Plan – Completed (see section V for description and Appendix B for Scientific Research Plan)
2-C. Final Education Plan – Completed (see section VI for description and Appendix C for Education Plan)
2-D. Select and Fund Research Projects – Completed (see section V for description and Appendix B for Project Abstracts)

F. Year 4-5 Accomplishments
3-A. Provide infrastructure for ICEWATER information system and define watersheds to be included – Completed (see Section VII for description, and Appendix D for Poster highlighting the infrastructure).
3-B. Produce an informational website to link to the data gathering and data dissemination infrastructure defined in 3-A – Completed (see Section VII for description – the website is http://icewater.inra.org)
3-C. Make investments to assist research efforts between and amongst the constellation watersheds – Completed (see Section V for description, and Appendix B for Research Plan and Project Abstracts)

III. Administrative Activities

For the first 3 years of the project, the IWRC steering committee met via teleconference twice per month to administer the project, and to assure that progress was made on the regional needs assessment, the scientific research plan, and the education plan. For the final two years of the project, the steering committee met once per month, while a newly established cyber-infrastructure committee also met once per month via teleconference. The steering committee met to assure progress was made with the ICEWATER cyber-infrastructure and the research projects, while the cyber-infrastructure committee concerned itself with the technical aspects associated with implementing the web-site, hydrologic information systems, and hardware and software concerns.

At the end of the project, the steering committee members were:

Boise State University (BSU)	Dr. James McNamara (vice-chair)
Boise State University	Dr. Warren Barrash
Idaho State University (ISU)	Dr. Bruce Savage
Idaho State University	Dr. Daniel Ames
Montana State University (MSU)	Dr. Lucy Marshall
Montana State University	Dr. Brian McGlynn
University of Alaska Fairbanks (UAF)	Dr. Douglas Kane
University of Alaska Fairbanks	Dr. Amy Tidwell
University of Idaho (UI)	Dr. Jan Boll
University of Idaho	Dr. Patrick Wilson
University of Montana (UM)	Dr. Sarah Halvorson
University of Montana	Dr. Nancy Hinman
Utah State University (USU)	Dr. Mac McKee
Utah State University	Dr. David Tarboton
Washington State University (WSU)	Dr. Michael Barber (chair)
Washington State University	Dr. Jonathan Yoder
INRA	Mr. Steven Billingsley

IV. Needs Assessment Activities Report (Year 1 of Project)

The Needs Assessment was completed, and the final document is presented in Appendix A. This product was carried out by social science faculty in five INRA institutions (one per INRA state). The lead author was Dr. Douglas Jackson-Smith of Utah State University. The intent of the Needs Assessment was to obtain perspectives of applied water resource managers in the INRA region, and use their feedback to identify priorities for future INRA research and education programs that would contribute to the IWRC program.

The recommendations identified in the report reflect what the participating constituents most need in their work. Constituents surveyed include respondents who are working on water quantity and water quality issues, including Local, State, Federal and Tribal government leaders and staff; watershed groups and water conservancy districts; and nonprofit and private sector representatives.

All respondents were asked what the largest challenge is to them being able to perform their jobs. The overall findings identified respondents' "biggest" challenges in the natural science sector (37% of respondents), social science sector, including law and policy matters (38%), management challenges (18%), and systems associated with sharing and gathering basic data on water (7%). The full report (Appendix A) goes into much greater detail.

Research needs were identified in natural science areas, including a need to develop basic understanding with respect to integrated hydrologic systems studies, including groundwater – surface water interactions, and climate and drought modeling. Applied science needs included research directed toward understanding the impacts of social and economic change on water demand; understanding the impacts of changing water use patterns on water resources; and a need to develop biophysical models linking human behavior and water quality parameters. Social science needs included requirements for studies on water consumption patterns and conservation behavior; data on socioeconomic trends and conditions; techniques for changing public behavior; and assessment of effectiveness of alternative policy approaches.

Education needs suggested that although the status of natural sciences and engineering training was solid, that graduates needed to have better technical skills, better interdisciplinary or cross-disciplinary training, and needed more opportunities for "real-world" experiences. Other topics indicated that students exiting the university and entering the workplace would benefit from better oral and written communications skills, as well as having a better understanding of Western water law and policies.

The core recommendations of this Needs Assessment will be prioritized by the steering committee to include long-, mid-, and short-term research needs; high, medium, and low priority research needs; and align these with the various technical capabilities within the INRA universities. The core recommendations are:

- Encourage investments in water monitoring and data collection infrastructure;
- Invest in basic science studies on groundwater – surface water interactions and climate and drought modeling;
- Invest in applied natural science research to assess the impact of social and economic changes on water supply and quality; and
- Encourage more human dimensions research, focusing on understanding human drivers of change.

V. Research Activities

As part of an INRA-wide assessment of current capabilities related to water resources management, we have identified 81 University Research Centers and 316 University Faculty that have current research interests in disciplinary fields associated with water resources management. These include: Atmospheric sciences; climatology, ecology, geosciences, hydrology, policy and public issues, soil science, and others.

Nine research projects were initiated during the second year of the project, and twelve more were initiated during the fourth year of the project. The research plans for the Year 2 and Year 4 projects are presented in Appendix B, along with the twenty-one project abstracts, and any recent reports. Some reports will be published in peer-reviewed journals, and these are listed in Section VIII, but are not reproduced in Appendix B. Each funded research project required collaboration amongst INRA member schools, and required support for a graduate student.

In summary, the funded research projects included:

1. Boise State University—Dr. Jennifer Pierce, in collaboration with Dr. Nancy Glenn (ISU), Dr. Colden Baxter (ISU), and Dr. Cathy Whitlock (MSU)—*Drought, Fire and Timing of Snowmelt in Central Idaho.* [Year 2 Project]
2. Boise State University—Dr. Warren Barrash, Dr. James McNamara, in collaboration with Dr. David Tarboton (USU)—*Surface Water-Groundwater Interaction at the Boundary and Interior of a Range Front Mountain Block; Research, Infrastructure Strengthening, and Collaboration.* [Year 4 Project]
3. Idaho State University—Dr. Amy Marcarelli, in collaboration with Dr. Jim McNamara (BSU), Dr. Shawn Benner (BSU), and Dr. Michelle Baker (USU)—*Coupling Management of Water Quality and Quantity: How do Hydrology and Biological Activity Interact to Control Nutrient Concentration and Export in an Impaired Intermountain Watershed?* [Year 2 Project]
4. Idaho State University—Dr. Bruce Savage, in collaboration with Dr. Blake Tullis (USU)—*Increasing Data Accuracy, Reliability and Accessibility to Improve Basin-Wide Water Resources Decision Making.* [Year 4 Project]
5. Idaho State University—Dr. Benjamin Crosby, in collaboration with Dr. Larry Hinzman (UAF), Dr. Douglas Kane (UAF), and Dr. Jim McNamara (BSU)—*Tools for Monitoring Arctic River Processes and Fluxes.* [Year 4 Project]
6. Montana State University—Dr. Brian McGlynn, in collaboration with Dr. Tamao Kasahara (USU), Dr. Matt Baker (USU), Dr. Tim Link (UI), Dr. Jim McNamara (BSU), and Dr. Scott Woods (UM)—*Linkages Between Climate, Watershed Structure, Land Cover, and Snow Runoff Dynamics: Initiation of the ICEWATER Regional Experimental Watershed Constellation.* [Year 2 Project]
7. Montana State University—Dr. Cathy Whitlock, in collaboration with Dr. Jennifer Pierce (BSU), Dr. Jim McNamara (BSU), Dr. Wayne Wurtzbaugh (USU), and Dr. Glenn Thackray (ISU)—*Long-Term Ecohydrologic Variability in the Sawtooth Region of Central Idaho: Establishing a Baseline for Assessing Water Resource Issues.* [Year 2 Project]
8. Montana State University—Dr. Brian McGlynn and Dr. Lucy Marshall, in collaboration with Dr. Geoff Poole (MSU), Dr. Wyatt Cross (MSU) and Dr. Daniel Ames (ISU)—*Watershed Structure, Landuse/Land Cover, and Snow Runoff Dynamics: Montana State ICEWATER Constellation.* [Year 4 Project]
9. University of Alaska Fairbanks—Dr. Amy Lovecraft, in collaboration with Dr. Chuck Harris (UI), Dr. Liz Shanahan (MSU), Dr. Douglas Jackson-Smith (USU), and Dr. Philip Wandschneider (WSU)—*Freshwater Social-Ecological Systems: Analyzing Alaska's Institutional Capacity for Water Security and Hydrological Change.* [Year 2 Project]
10. University of Alaska Fairbanks—Dr. Douglas Kane, in collaboration with Dr. Bethany Neilson (USU)—*UAF Research Contribution to ICEWATER.* [Year 4 Project]
11. University of Idaho—Dr. Chuck Harris, in collaboration with Dr. Jonathon Yoder (WSU)—*INRA UI-WSU Complementary Water Resources Research.* [Year 2 Project]

12. University of Idaho—Dr. Jan Boll, in collaboration with Dr. Michael Barber (WSU)—*Modeling Hydrological Responses from Watersheds.* [Year 4 Project]
13. University of Idaho—Dr. Patrick Wilson, in collaboration with Dr. Sarah Halvorson (MSU)—*Defining and Implementing a Common and Equitable Vision Across Communities Connected to Watersheds.* [Year 4 Project]
14. University of Montana—Dr. Joel Harper, in collaboration with Dr. John Bradford (BSU)—*Contribution of Glacial Melt to Water Resources in NW Montana: Past, Present and Future.* [Year 2 Project]
15. University of Montana—Dr. Joel Harper, in collaboration with Dr. John Bradford (BSU), Dr. Jim McNamara (BSU), Dr. Mark Greenwood (MSU) and Dr. David Tarboton (USU)—*Impact of Climate Variability and Change on Snowmelt from Montana's Mountain Ranges.* [Year 4 Project]
16. University of Montana—Dr. David Shively and Dr. Sarah Halvorson, in collaboration with Dr. Patrick Wilson (UI)—*Flathead Basin Investigation – Human Dimensions of Water Use.* [Year 4 Project]
17. University of Montana—Dr. Nancy Hinman and Dr. William Woessner—*Milltown Surface Water – Groundwater Interactions – Groundwater Modeling.* [Year 4 Project]
18. Utah State University—Dr. Tamao Kasahara, in collaboration with Dr. Brian McGlynn (MSU)—*Analyzing the Effect of Watershed Topography on Water Residence Time and Hydrologic Scaling in Semi-Arid, Alpine Catchments.* [Year 2 Project]
19. Utah State University—Dr. Bethany Neilson, in collaboration with Dr. Douglas Kane (UAF)—*Understanding Processes Affecting Instream Temperatures in the Arctic.* [Year 4 Project]
20. Washington State University—Dr. Joan Wu, in collaboration with Dr. Jan Boll (UI), Dr. Erin Brooks (UI), and Dr. Donald McCool (USDA-ARS-PWA)—*Snow Redistribution and Water Storage at a Watershed Scale: Field Investigation and WEPP Simulation.* [Year 2 Project]
21. Washington State University—Dr. Michael Barber, Dr. Jennifer Adam and Dr. Jonathan Yoder, in collaboration with Dr. Jan Boll (UI)—*ICEWATER Projects – Spokane Valley – Rathdrum Prairie Aquifer and Pataha Creek.* [Year 4 Project]

VI. Education Plan Activities

The education plan was finalized, and is included in Appendix C. The primary purpose of the education plan was to implement a cross-institution program in "interdisciplinary water resources" to equip prospective water resources professionals with the skills needed to contribute to the solution of water resources problems in the intermountain region. The education plan can target needs identified in the Needs Assessment, which include needs for: more interdisciplinary courses; more systems-level or integrated water science courses; more "real-world" experience; better communications skills; and a greater awareness of the social, economic and political dimensions of water resource management problems.

The education plan indicates that these needs will best be met through a graduate level program targeted at interdisciplinary problem solving, developing communications skills and technical skills. The objectives of this program would be for students to: demonstrate depth in their disciplinary field; demonstrate ability to synthesize and solve problems, individually and in teams; develop skill with key common scientific and engineering tools (GIS, mathematics, statistics); demonstrate the ability to communicate effectively through reports and presentations; and, as indicated above, finally to develop awareness of social, economic and political dimensions of water problems.

Funding was sought for Year 4 activities that would have included initiating the Education Program, but funding that was provided was sufficient only to implement the ICEWATER Network activities, and the Year 4 Research Projects. Should funding become available for it, the Education Plan is ready to be implemented.

VII. ICEWATER Network Activities

The work that established and supported the INRA Water Resources Consortium Constellation of Experimental Watersheds, (ICEWATER) Information System Network was performed by Utah State University. The ICEWATER Information System Network is a distributed network of Servers built using the Consortium Of Universities For the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS) technology to publish and integrate the data holdings from ICEWATER. Experimental watersheds in the INRA region span a number of climate, human development and disturbance gradients. Integration of data from these watersheds will facilitate cross-site comparisons and large scale studies that synthesize information from diverse settings, making the network as a whole greater than the sum of its parts. The sharing of data in a common format is one way to stimulate interdisciplinary collaboration. The goals of the ICEWATER Information System network are:

- Establishment of a common information system for data sharing, analysis and archiving, building upon the CUAHSI Hydrologic Information System
- Establishment of a common modeling framework, potentially around systems such as OpenMI (http://www.openmi.org/) to facilitate sharing and model interoperability.
- Establishment of common base characterization datasets such as digital elevation models (DEMs) from LIDAR, land cover and land use from remote sensing, that provide detail beyond nationally available information.

The ICEWATER Information System comprises a centralized functionality, referred to as ICEWATER Central, managed from Utah State University, and a network of servers, one at each INRA university, that support the data services hosted by that university. Utah State University led and managed the establishment of the network, drawing upon its participation in development of the CUAHSI Hydrologic Information System technology being used. The ICEWATER Central Website is located at http://icewater.inra.org. A poster, presented at the American Geophysical Union (AGU), is provided in Appendix D.

Programmers at Idaho State University assisted with the development of software tools for simplifying and streamlining interaction with HIS web servers deployed within the INRA ICEWATER Network. Specifically work to enhance and build upon the HIS Desktop application prototyped by University of Texas – Austin HIS collaborators was performed. This tool, HydroDesktop (http://hydrodesktop.org), is a map/GIS based, standalone, client side software application that includes specific functions for browsing online catalogs of HIS nodes, exploring libraries of spatially distributed hydrologic observation data contained in these servers, searching for specific data sets – relevant to selected areas of study; and visualizing these data through graphical plots, and tabular views. Additionally, the software allows users to conduct exploratory statistical analyses such as correlation analysis, as well as exporting retrieved datasets to commonly used file formats, including Excel and CSV. While this project has built upon existing HIS tools, it has been tailored to uniquely fit the needs of the ICEWATER collaborators through a feedback process using online software development collaboration tools (shared code repository, discussion forum, and bug tracking system). The software developed under this effort is fully compatible with other tools developed in the broader ICEWATER project, and help ensure meeting the needs of researchers and students at the participating ICEWATER institutions.

VIII. Products

Publications

Kunkel, M.* **Pierce, J.L.,** Hamel, J.,** Kramer, T.,** and Mooney, S., Effects of Climate-induced changes in the timing of snowmelt on barley yields (*in progress*).

Kunkel, M.* and **Pierce, J.L.,** Reconstructing Snowmelt in Idaho's Watershed Using Historic Streamflow Records**,** *Journal of Climatic Change* (*In press*).

Svenson, L.,* Pierce, J.L., Wilkins, D., and Perkins, D., Fires and Droughts in Lodgepole Pine-dominated Forests of Central Idaho. *In preparation for* Forest Ecology and Management.

Whitlock, C., Briles, C.E., Fernandez, M.C., Gage, J., Holocene Vegetation, Fire, and Climate History of the Sawtooth Range, Central Idaho, USA, *Quaternary Research* (*in review*).

Gillan, B. J., **J. T. Harper**, and J. N. Moore (2010), Timing of present and future snowmelt from high elevations in northwest Montana, *Water Resources Research*, 46, W01507, doi:10.1029/2009WR007861.

Qiu, H., **J.Q. Wu**, D.R. Huggins, M.E. Barber, and D.K. McCool, Effects of surface residue conditions on snow redistribution and soil water storage, *Trans. ASABE*, 2010. (in submission)

Gardner, K.K. and **B.L. McGlynn**. 2009. Seasonality in spatial variability and influence of land use/land cover and watershed characteristics on streamwater nitrate concentrations in a developing watershed in the Rocky Mountain West. *Water Resources Research*. DOI: 10.1029/2008WR007029.

Jencso, K. J., **B. L. McGlynn**, M. N. Gooseff, S. M. Wondzell, and K. E. Bencala. 2009. Hydrologic Connectivity Between Landscapes and Streams: Transferring Reach and Plot Scale Understanding to the Catchment Scale, *Water Resources Research*. DOI: 10.1029/2008WR007225.

Pacific, V., K. Jencso, **and B.L. McGlynn**. 2010. Variable flushing mechanisms and landscape structure control stream DOC export during snowmelt in a set of nested catchments. *Biogeochemistry*. DOI: 10.1007/s10533-009-9401-1

Smith, T. J., and **L. A. Marshall**. 2008. Bayesian methods in hydrologic modeling: A study of recent advancements in Markov chain Monte Carlo techniques, *Water Resources Research*, 44, W00B05, doi:10.1029/2007WR006705.

Smith, T. J., and **L. A. Marshall**. 2010. Exploring uncertainty and model predictive performance concepts via a modular snowmelt-runoff modeling framework, *Environmental Modeling & Software*, (*In press*).

Web-Sites
A. http://icewater.inra.org
B. http://hydrodesktop.org tools were updated to integrate the ICEWATER Network with the existing Hydrologic Information System being developed by CUAHSI.

Networks
A. The ICEWATER Network was established (see Section VII) – the Functional Specifications for the Network are listed in Appendix E.

Patent Applications
None

Other Products

Poster – **Boll, J.**, J.W. Machala, E.S. Brooks, and A. Edstrom. 2009, Localized climate change scenarios using a downscaling methodology with a distributed hydrology model, *Eos Trans. AGU, 90(52)*, Fall Meet. Suppl., Abstract U13B-0056.

Poster – **Horsburgh, J. S., D. G. Tarboton, K. Schreuders, D. P. Ames, J. P. McNamara, L. A. Marshall, B. L. McGlynn, D. L. Kane, A. Tidwell, J. Boll, N. W. Hinman, M. E. Barber** (2009), INRA Constellation of Experimental Watersheds: Cyberinfrastructure to Support Publication of Water Resources Data, *Eos Trans. AGU*, 90(52), Fall Meet. Suppl., Abstract H51H-0858. (See Appendix D)

Presentation Proceeding – **Ames, D. P., Horsburgh, J.**, Goodall, J., Whiteaker, T., **Tarboton, D.**, Maidment, D. (2009). "Introducing the Open Source CUAHSI Hydrologic Information System Desktop Application (HIS Desktop)": AMES_MODSIM_HIS_Desktop.pdf. *18th World IMACS/MODSIM Congress*, Cairns, Australia 13-17 July 2009. http://mssanz.org.au/modsim09

Presentation Proceeding – Moore, J. N., **J. T. Harper**, W. W. Woessner, and S. Running (2007), Headwaters of the Missouri and Columbia Rivers WATERS Test Bed site: Linking Time and Space of Snow Melt Runoff in the Crown of the Continent, *Eos Trans. AGU*, 88(52), Fall Meet. Suppl., Abstract H13A-0964.

Presentation Proceeding – Reardon, B. A., **J. T. Harper**, and D. B. Fagre (2008), Mass Balance Sensitivity Of Cirque Glaciers In The Northern U.S. Rocky Mountains, Montana, U.S.A, in Workshop on mass balance measurements and modeling, edited by J. O. Hagen, et al., pp. 1 ‐ 5, International Glaciological Society, Skeikampen, Norway.

Thesis – Brown, Joel (in prep) "Social Vulnerability and Perceptions of Drought in the Flathead River Basin, Montana." University of Montana, MS Thesis.

Appendix A
Needs Assessment Report

Inland Northwest Research Alliance
Water Resources Research Consortium

WATER RESOURCES MANAGEMENT RESEARCH NEEDS ASSESSMENT PROJECT

FINAL TECHNICAL REPORT

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October 2007

Acknowledgements

This project was made possible by a grant from the U.S. Department of Energy, through the Inland Northwest Research Alliance.

Field interviews were conducted and interview transcripts were developed by several graduate students working with the principal investigators. These included:

Scott Hoffman *(Utah State University)*
Michael Halling *(Utah State University)*
, (University of Alaska-Fairbanks)
, (Montana State University)
, (University of Idaho)
, (Washington State University)

Critical assistance with data coding, interpretation, and analysis was provided by

Analysts
Brian Jennings *(Utah State University)*
Joyce Mumah *(Utah State University*

The authors also wish to thank the many people who participated in the interviews.

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EXECUTIVE SUMMARY

Background

The Water Resources Research Needs Assessment team received funding from the Inland Northwest Research Alliance Water Resources Steering Committee to facilitate a structured needs assessment process that could provide a basis for future targeted research efforts to improve regional water resources management in the Inland Northwest region. The original INRA proposal specifically mentions the need to conduct a detailed assessment of the information and research needs of policy makers and water user groups during a period of increasing competition for scarce water supplies. A particular focus of this assessment would be to understand what types of research might facilitate water resource management during periods of drought.

The specific goals of the Needs Assessment project were to:

- Quickly ascertain the perceptions of diverse stakeholders in this region, and
- Condense this complex information into a format that can be shared with the INRA scientific panel, and
- Develop of a realistic set of research needs & priorities that can shape future INRA-funded research activities.

Methods

The Needs Assessment research team developed lists of water resource management key informants in each state. These lists included administrators, technicians, staff and representatives from a diverse arrange of public and private groups and agencies. Key informants were chosen to provide a diverse array of geographic, topical, and organizational experience. A total of 160 key informant interviews were conducted in the fall of 2006.

Results of the key informant interviews were summarized in written narrative reports and then analyzed using standard qualitative analysis approaches. The analysis focused on the identification of related themes or content clusters for each of the major research topics. These themes were then used to organize the results summarized in this report.

Key Findings

(insert)

Conclusions & Recommendations

(insert)

1. BACKGROUND & METHODS

1.1 Background

The Inland Northwest Research Alliance (INRA) is a consortium of 8 universities in the US Western region who received funding from the US Department of Energy to initiate a research and educational program related to drought and water resource management in this 'inland northwest' region. Among other tasks, the INRA Water Research Consortium has facilitated coordinated research and education programs related to the complex interactions between climate change, watershed and landscape changes, water supply and quality; ecosystems, and humans.

The current project was designed to identify high priority topics for future INRA research. Specifically, we gathered information from policymakers, elected officials, water users, and others with a stake in the Western water debates to identify their most pressing data and information needs. This structured needs assessment process is designed to provide a basis for future targeted research efforts to improve regional water resources management in the Inland Northwest region. Because of the recent years of low water supply in the West, one focus of our needs assessment was targeted toward an understanding of what types of research might facilitate water resource management during periods of drought.

The specific goals of the Needs Assessment project were to:

- Quickly ascertain the perceptions of diverse stakeholders in this region, and
- Condense this complex information into a format that can be shared with the INRA scientific panel, and
- Develop of a realistic set of research needs & priorities that can shape future INRA-funded research activities.

1.2 Methods

Identifying Key Informants

Cooperating social science faculty were identified from one INRA institution in each of the 5 INRA states during the summer of 2006. The participating universities included the University of Alaska-Fairbanks, the University of Idaho, Montana State University, Utah State University and Washington State University. Together this team developed formal research protocols for identifying and contacting a representative group of key informants in their respective states (Appendices I and II). A semi-structured interview schedule was developed and used by all interviewers involved with the project (Appendix III).

Prior to the fieldwork and interviews, project teams in each state conducted a review of the literature related to water resources and recent management activities. The purpose of this document was to begin identifying key contacts, current water management needs, geographic areas, and priorities. This 'water narrative' created a summary document for each state and helped to identify categories of key informants that needed to be represented in each state.

Key informants for the fieldwork were identified by each state from a master list of potential groups and organizations with links to water. Project teams first constructed a master sampling frame of potential key informants designed to encompass the breadth and depth of groups in conjunction with the water narrative. From this master sampling frame, a subset of individuals was selected for fieldwork interviews that were considered to be representative of water users in each state. Selecting this subset of individuals involved identifying diverse individuals who are knowledgeable about water issues and/or actively involved in water resource management in this region.

Potential individuals and/or groups to be included in the sample included knowledgeable agency or organizational representatives (analysts, staff, and decision-makers) as well as key stakeholders, including elected officials and representatives of relevant organizations. The list is broad in order to take into account variation across states. Example 'categories' span multiple levels of government, underscoring the breadth and depth noted above. General categories include Federal Agencies such as the Bureau of Reclamation and Fish & Wildlife Service; State Government divisions such as Water Resources Agencies (e.g. state engineers & water rights staff, water planning agencies, and water quality agencies), State Agriculture Department staff, and State Economic Development staff; and regional governments such as water conservancy districts. Additional governmental categories include county governments (e.g. county associations, county commissioners & executives, county water advisory boards, and county planners), city governments (e.g. city associations, city mayors & council members, and city planners, water departments, environmental departments), and tribal governments.

In addition to governments, the list included examples of non-governmental organizations and water users groups that were equally broad-ranging with regard to levels of interaction. Examples in this grouping include regional organizations like hydropower utilities (e.g., Pacificorp), and environmental, wildlife, and recreational organizations (Audubon/birders, Ducks Unlimited, Salmon groups, river rafters, lake boaters, etc.). Other examples include state non-governmental organizations (e.g. associations of water users like irrigation/canal groups and agricultural organizations like the Farm Bureau), and local organizations like irrigation districts, canal companies and local Chambers of Commerce. The master list was tailored to each state in order to take into account variation in governance among other criteria; thus these lists served as a general organizing frame.

As noted above, a subsample of individuals was selected from this master list in order to create the list of individuals we refer to as 'key informants.' Project leaders in each state began by identifying key contacts in important statewide and regional agencies and organizations from a variety of sources, form personal contacts with university colleagues to internet searches of agency/organization website listings for staff & administrators. In many instances, snowball sampling was used, where we proceed through intra-agency/organization filters and asking those interviewed for additional contact information.

Where appropriate, we used purposive sampling. For example, for some categories (e.g. federal agencies, regional water conservancy districts, and county and city governments), we needed to identify a subset of the total universe of possible people (or places) that met our criteria. This strategy met the goal of having a sample that covered the diversity or range of water resource management challenges within each state. In taking into account variation across states, we selected a subset of places/people in order to maximize coverage related to 1) previously identified key issues, 2) geographic regions, 3) examples of places with well-known debates or historical uniqueness, and 4) links with other intersecting dynamics (e.g. urban/rural interests and problems, agricultural vs. non-agricultural interests, government vs. non-governmental perspectives, Tribal vs. non-Tribal interests and problems, and economic vs. environmental perspectives).

The interviews thus proceeded in a series of stages, where teams strategically prioritized groups from these lists multiple times to yield state-specific lists of interviewees. From the master list, we prioritized specific names from organizations that were used in a first round of interviews. From the first round of interviews, a second round of contacts was selected to complement the first round.

Our interviews included detailed questions on the following topics:

- What are your greatest challenges for water resources management?
- What are the largest information gaps you encounter when managing water resources, and what are the most important research priorities for future water-resource research?
- What are the most important educational needs for people seeking to work in this area?
- Who are your most important partners for working on water resource management?
- What are your most important sources of information as you manage water resources?

Key informant interviews were conducted in the late summer and fall of 2006. Contact was first made with each informant in a phone call, email, or letter. Background to the project and a copy of the key informant consent document was provided to each interviewee, a request was made to participate in the study, and – if the respondent was willing to participate – a time and place was determined for the interview. Most interviews were conducted with individual respondents, though in some cases small groups of persons working in the same department, agency or organization were interviewed at the same time. In total, interviews were completed with 160 key informants. The distribution of responses by state is shown in Table 1.2.1.

Table 1.2.1: Number of Interviews Completed by State and Major Topic

		Total # Cases Reporting Information on Each Major Topic				
State	Overall # Interviews	Greatest Challenges	Research Needs	Education Priorities	Partners	Information Sources
Montana	22	18	18	22	19	19
Alaska	30	30	28	29	29	29
Idaho	53	52	46	52	51	50
Utah	27	27	27	26	26	26
Washington	28	28	25	27	28	27
Total	160	155	144	156	153	151

In addition to information about water resource management challenges and needs, the key informants were asked a small number of structured questions designed to characterize their work organization, their role or responsibilities, and their background and expertise in this subject matter. A profile of the respondent characteristics is included in Table 1.2.2 below.

Table 1.2.2: Characteristics of Respondents

	Number	Valid Percent
Job Description		
Elected Official	2	1.4%
Administrator/Director	80	55.2%
Technical Staff	31	21.4%
Outreach Staff	6	4.1%
Member of Organization	3	2.1%
Other	23	15.9%
Total Known	145	100.0%
Organization Type		
Federal Agency	34	21.5%
State Agency/Board	40	25.3%
County Government/Board	17	10.8%
City Government/Board	8	5.1%
Tribal Government	8	5.1%
Nonprofit Organization	15	9.5%
Private Company	23	14.6%
Other	13	8.2%
Total Known	158	100.0%
Scale of Responsibilities		
Local/County	47	30.1%
Multi-County	33	21.2%
Statewide	58	37.2%
Multi-state region	14	9.0%
Other	4	2.6%
Total Known	156	100.0%
Self-Described Expertise on Topic		
Very Knowledgeable	71	47.7%
Knowledgeable	38	25.5%
Moderately Knowledgeable	28	18.8%
Slightly Knowledgeable	11	7.4%
Not Knowledgeable	1	0.7%
Total Known	149	100.0%
Education Level		
< BS	11	8.0%
BS	57	41.3%
MS/MA/MPA/MBA	55	39.9%
PhD or JD	12	2.9%
Other	3	5.8%
Total known	138	2.2%
Years of Experience		
Under 5 years	30	20.8%
5 to 9 years	24	16.7%
10 to 19 years	29	21.5%
20+ years	57	41.0%
Total Known	140	100.0%

By design, most of our key informants were career water resource management professionals. For example, 80 (or 55 percent) were administrators or directors of an organization or agency that addresses water issues in this region. Another 21 percent were technical staff in these groups. We did not select many elected officials to participate in this project because we believed that the views of applied managers would be most relevant for identifying key scientific research needs or topics.

Most of the respondents worked for public agencies – with 22 percent from federal agencies, 25 percent from state agencies or boards, and 16 percent from county or city government. A total of 8 interviews were conducted with tribal government representatives. Nonprofit groups and private companies comprised another 24 percent of our total respondent sample. Not surprisingly, our key informants worked on water issues across a variety of scales. Just over half worked at the local, county or multi-county level. Another 37 percent worked at the statewide level, with a small minority working at larger scales.

After each interview was completed, our field staff made a subjective assessment of the level of expertise or knowledge that each respondent seemed to have regarding water resource management issues. Three-quarters of all respondents were classified as knowledgeable or very knowledgeable.

By the same token, almost all respondents had higher education degrees. Almost 43 percent had a BS degree, another 37 percent had a masters degree, and 9 percent had a PhD or JD degree. Most respondents also had a significant number of years of work experience dealing with water resource management issues. Over 60 percent had worked for 10 or more years in this area.

Analysis of Interview Data

Interviews were summarized in a structured narrative form (see Appendix IV) and sent to Utah State for consolidation and analysis. The analysis strategy involved careful review of interview narratives and summary sheets submitted by each cooperating state. Interview information was transferred to spreadsheets and NVIVO 7®, a qualitative analysis software that allows interactive coding and memoing of key themes in the narratives.

The respondent answers to these key questions were coded into clustered topics or themes using an inductive thematic coding process (Strauss and Corbin 1998; Flick 1998). This process involved identifying preliminary clusters of similar answers, then reviewing the resulting coding scheme for internal consistency, theoretical coherence and applicability to the overall research project goals. Several investigators and their graduate students reviewed the coding schema and individual answers were coded and recoded several times before producing the final version.

The coding schemas developed for each major type of question were summarized in descriptive statistical tables to identify the frequencies of major categories of answers. The answer patterns were also examined within important subgroups of respondents (state, type of respondent, type of agency where person works, etc.).

1.3 Important Water Resource Issues in Each State

As part of the preliminary work to prepare for interviews with key informants, the research team in each state spent time gathering published reports, informal documents, web resources, and other information. This information was used to develop a list of important water resource issues for each state, and was summarized in a short narrative. These narratives provide a snapshot of the most prominent water resource challenges and issues faced by managers across this region. Condensed versions of narratives for three of our participating states are summarized below.

In sum, understanding water resources and issues requires an approach that acknowledges generalities as well as contextual differences that convey past, present, and future challenges for water professionals and practitioners. For instance, while physical features of locations such as geography, climate, and size are integral to understating natural resources and their availability and spatial distribution, of integral importance also are understanding how other issues intersect with these physical features, including population changes, pressures for economic development, and various legal influences linked with supply and demand. Indeed, a complex chain of mutually reinforcing issues, actors, and agencies can be identified, as can interrelations that posit unique causal pathways.

Water in Alaska

Understanding water in Alaska requires situating it within other characteristics that make it unique—including its vast size, physical separation from the contiguous 48 states, population composition and distribution, environmental attributes, and climate. Comprising over one-third of all of the fresh water in the US, water is abundant in Alaska. Yet in spite of its profusion, many issues exist that intersect in varied ways with its past, current, and future availability, use, and allocation. More specifically, Alaska has over 12,000 rivers and streams that total over 365,000 miles, at least 170 million acres of wetlands, over than a million lakes larger than five acres, and more than 44,000 miles of coastal shoreline.[1] And even in the so-called last frontier, interactions between natural resources and human populations can be noted, from issues related to development and recreation uses. Climate change holds the potential to uniquely influence Alaska's prolific water resources as well, through thawing of the permafrost and its resulting impacts such as an increase in wetlands in unanticipated areas and other bodies of water and waterways linked with them, all of which hold the potential to influence human populations and settlements (Hinzman et al. 2005). Moreover, this change does not take into account dramatic seasonal effects related to water availability and use which is only imperfectly understood given various unique aspects of Alaska's climate, linked especially with its vastness and numerous uncharted waters.

In many respects, water use remains highly concentrated in Alaska, as freshwater resource use occurs mainly in two major urban centers, Anchorage and Fairbanks, thus posing further challenges for smaller municipalities, rural villages (about 300), and Native villages (about 70), many of which do not have access to potable water distribution systems. Thus, coordination issues are considered to be focal, as spatial dynamics interact with these human-environment interactions.

[1] Governor Tony Knowles. October 2, 2002. "Administrative Order no. 200. " Retrieved from http://www.gov.state.ak.us/admin-orders/200.html on November 22, 2006.

For various legal reasons, water management issues continue to evolve, as a result of its history as a territory and also due to various natural resource-related sections of its constitution in 1956, prior to officially becoming a state in 1959. For instance, the Alaska Water Use Act, passed in 1966, applied to all surface and ground waters of the state (not subject to federal rights), and gave statutory definition to the prior appropriation doctrine (effectively converting all previously existing riparian rights to prior appropriation rights). As a result, under this act, water law is simple and straightforward, as a water source in Alaska is defined as a "substantial quantity of water capable of being put to beneficial use." Interactions and legislation related to water management issues take place at a various scales including federal, state, borough and local levels of government, with considerable variation both across and within scales reflecting further complications to understanding water in Alaska.

Water in Montana

As was true in describing water in Alaska, understanding water in Montana requires a nuanced approach that enables researchers to take into account various local conditions, including geography and climate, and interactions with pressures from human populations and settlements as well. In addition, a recent period of drought in the state has further strained both water quality and quantity. Generally speaking, describing water is complicated by a number of factors.

Agriculture, domestic and commercial consumption, recreation, natural ecosystems, and industrial uses such as cooling water for energy generation or dust abatement at mine sites, are the primary water needs in Montana. Agriculture is the largest consumptive use category in the state. Irrigation is highly dependent on snowmelt runoff in the Rocky Mountains, which has been further complicated by loss of snow-pack over the last half century (Inland Northwest Research Alliance Water Research Consortium, 2005). Generally, almost half of the annual long-term average total precipitation falls from May through July, resulting in Montana as one of the largest producers of dryland grain crops (Western Regional Climate Center, n.d.). Additionally, Montana's primary water source comes from surface water (rivers, streams, and lakes) as opposed to groundwater (US Global Change Research Program). Regions of the state exhibit wide climatic variation, from wet in the west to arid in north central Montana, with the driest section in the state situated along the Clark Fork of the Yellowstone River in Carbon County (average precipitation for a 16-year period is only 6.59 inches).

Water quality and quantity issues are germane in Montana. According to the USGS, seven major issues concerning water resources in Montana are inextricably linked with consumption in various ways. These issues include both from human dimensions such as rapid population growth in western and southcentral Montana (in areas surrounding Bozeman, Missoula, and Kalispell) and development effects like those of abandoned or inactive mines in various places throughout the state and coalbed methane (CBM) development, especially drilling.

In addition, other issues pertain to gathering more detailed data and understanding of existing waters (e.g. stream-channel geomorphology and hydraulic analysis), improving and increasing surface water monitoring activities, hydrologic changes linked with fires, and dealing with drought in general (the most recent drought occurred for seven consecutive years from 1999 to 2005.

Water in Utah

As was the case with Alaska and Montana, understanding water resources and water issues in Utah requires situating it within various contextual factors. Both environmental and population dynamics make Utah unique relative to other states in the intermountain West. In average annual rainfall, for example, Utah ranks as the second driest state in the nation (after Nevada). Utah is also currently experiencing one of the highest population growth rates in the Intermountain West (ranking fourth) due to natural increase and migration. Utahns used an average of 4.76 billion total gallons of water each day in 2000, with around 81% used for irrigation (for agricultural purposes). With regard to municipal water consumption on a per capita basis, the average Utahn used 293 gallons of water per day, around 65% of which was used outdoors (Utah Foundation 2004).

Water issues in Utah are varied and complex, and further complicated by various geographic attributes such as size, location, and topography, meaning that climates throughout the state are highly variable. For instance, average precipitation across the state ranges from five inches in desert regions to 60 inches or more in the higher mountainous regions, most of which comes from snowfall. As a whole, the state averages just thirteen inches of precipitation per year.[i] In addition to climate-related supply difficulties, Utah experienced a six-year drought between 1998 and 2004, placing further demands and strains on its water supply.[ii]

To address questions of water use and supply, in 2001 the Utah Department of Water Resources developed a plan calling for:

1) increased conservation from both agricultural and municipal users;
2) the transfer of agricultural water to municipal purposes as zoning changes from rural to urban; 3) the development of access to new water sources and rights that Utah has claims to; and
3) the maintaining and advancing of water storage techniques.[iii]

These mutually influencing forces make issues regarding water utilization, water quality, and water conservation salient for all involved with water in Utah.

More specific examples of water issues in Utah include, for example, water development projects, water quality issues, and newsworthy items that demonstrate further complexities related to water resources, as many waterways cross state borders. With regard to water development projects, in 2006, state government legislation concentrated on two major projects: The Lake Powell Pipeline and the Bear River Project. The former would secure additional water resources that would be targeted toward use for Utah residents, potentially alleviating pressure placed on management of water resources during prolonged periods of drought, such as those recently experienced in Utah. The second project also focuses on water supply, seeking to redistribute a proportion of water from the Bear River to four other conservancy districts in the state.

Given existing issues of natural resource-human population interactions, issues related to water quality are key concerns in the state. In addition to population growth dynamics mentioned earlier, issues of water quality highlight other development-related pressures that have consequences for natural resource availability and utilization. Examples include clean-up projects designed to mitigate previous groundwater contamination from various sources, including industrial sites, mining operations, and agricultural practices.

The final category mentioned above underscores how these issues cross natural and artificial boundaries in ways the further complicate understanding natural resource availability and use. Water rights issues are prominent with regard to appropriations and allocations, and have consequences beyond state borders as watersheds are not always neatly contained within a given state's boundaries.

2. RESULTS

2.1 GREATEST CHALLENGES

OVERVIEW

As the previous section suggests, various geographic attributes and unique characteristics of physical environments combine with a variety of other factors. These unique constellations of forces mean that water professionals face a number of challenges in their work. As might be expected by the broad range of concerns intimated by the state-based water narratives, individuals involved in water-related positions and professions echo many of these topics in the interviews conducted in this research. After asking about their background characteristics, respondents were asked a battery of questions related to water management challenges and information needs.

> ***"What are the 3 greatest issues or challenges for water resource management that you face in your work?"***
>
> *For each of these three issues, the following questions were asked:*

i. ***"Let's focus on (****Issue X****). In what ways is this issue challenging?***
ii. ***How has this issue changed in recent years?***
iii. ***What kinds of information are most critical to your ability to address this issue?***
iv. ***What are the most important sources of information you use to address this issue?***
v. ***How adequate is the existing information?***
vi. ***In what ways could this information be made more useful?***
vii. ***What new kinds of information would be most helpful to you as you address this issue?***

The following analyses presents the most common responses recorded in the interviews. Cumulatively, 471 responses were recorded from 159 interviews (See Table 2.1.1). As shown in the table, the largest number of interviews were completed in Idaho (32.7 percent of the total), and a large proportion of the greatest issues or challenges come from these interviews (a total of 167 needs, or 35.5 percent of the total, come from the Idaho interviews).

We begin our discussion of these results focusing on the aggregated responses in order to discern whether similar patterns can be identified regarding greatest issues or challenges across the five states. Following this discussion, we disaggregate them by state to highlight similarities and differences across the study areas in biggest challenges. This approach also allows us to see how information from the 'water narratives' intersects with the practice of water research, as communicated by respondents in this research.

Table 2.1.1. Number of Interviews Completed and Greatest Challenges Identified by State

	Overall # Interviews	Total Reporting Any Greatest Challenges	(%)	Total Challenges Identified	(%)	Avg. # Challenges Reported / Interview
Montana	19	18	11.3%	54	11.5%	3.0
Alaska	30	30	18.9%	84	17.8%	2.8
Idaho	53	52	32.7%	167	35.5%	3.2
Utah	27	27	17.0%	99	21.0%	3.7
Washington	30	29	18.2%	67	14.2%	2.3
Total	159	156	100.0%	471	100.0%	3.8

The 471 total greatest challenges identified in the individual interviews were analyzed for common themes and patterns. This permitted their subsequent organization into four major categories:

- Challenges related to Natural Science Topics
- Social Science Issues and Challenges
- Management Challenges
- Information-related Challenges, like data quality and dissemination issues

The total number of responses in each major category (as well as several subcategories, are listed in Table 2.1.2. Taken proportionally of all challenges identified by respondents, of foremost concern are natural science topics and social science issues and challenges, followed by management challenges, and, finally, those related to information or data issues.

Table 2.1.2. Distribution of Greatest Challenges by Four Major Categories

		Frequency		Percent	
Topic	Subtopic	Topic	Subtopic	Topic	Subtopic
Natural Systems Challenges		174		36.9	
	Water Quantity		89		51.1
	Water Quality		61		35.1
	Climate and Drought		16		9.2
	Other Natural Science Data		8		4.6
Human Dimensions Challenges (Social Science)		176		37.4	
	Legal Challenges		34		19.3
	Policy Challenges		35		19.9
	Funding Challenges		27		15.3
	Sociological Challenges		16		9.1
	Educational Challenges		36		20.5
	Challenges of Population Dynamics		28		15.9
Management Challenges		89		18.9	
	Personnel/time/logistical challenges)		23		25.8
	Management needs in general		21		23.6
	Management Strategies		41		46.1
	Program Effectiveness		4		4.5
Information/Data Quality and Dissemination		31		6.6	
	Data collection standards & quality		18		58.1
	Data dissemination mechanisms		13		41.9
Total		471		100	100

Natural Systems Challenges (36.9%)

Water professionals find topics related to natural systems to represent some of the greatest challenges that they face in their work. More than one-third of all greatest challenges identified fell into this category. Within this classification, four subtopics were identified: water quantity, water quality, climate and drought, and other natural systems concerns. Each of these categories can be subdivided into groupings that are more detailed as well. Because of the generality in the phrasing of the question, responses ranged quite broadly; thus we focus chiefly on summary statistics but also include examples from the interviews for illustrative purposes.

The most frequently cited subtopic in the natural systems challenges section involved water quantity topics, comprising slightly more than half of all responses. While we recognize that issues of water quantity are prominent for water professionals and are germane especially in the Intermountain West region, we also acknowledge that respondents did receive some background information related to our study involving a short discussion of the water resource management issues in the region, with a particular focus on water supply and drought. That noted, however, since challenges related to natural science and social science are quite similar as proportions of the total, we do not anticipate that the background information primed the respondents in a manner that would question the results, given this roughly equal distribution.

Water Quantity Challenges

The water quantity subtopic issues were further subdivided into four subgroups, three of which were parsed into additional layers. These were overall water quantity assessments, groundwater challenges, groundwater/surface water interactions, and water availability and demand.

Overall Water Quantity Data/Assessments

The first subgroup included challenges representing overall water quantity data, assessment, and issues, comprising roughly 2.5 percent of all responses. Nearly all of the remarks dealt with issues of how the absence of data posed a challenge in various ways, from knowledge-based reasons to historical questions to specific projects related to water diversion. Some specific challenges included:

- “Knowing enough about how much water there is to allocate,”
- “Lack of data—groundwater and surfacewater,”
- “Water supply data”

A subtopic within this category included specific challenges related to stream gauges and flows, comprising roughly 3.4 percent of all responses. A time element was also apparent in some comments related to day-to-day, and both short-term and long-term planning. In addition to the absence of data posing a challenge, flow data were also linked with particular aspects of water like seasonal effects and downstream effects for fish populations and other bodies of water. Flow depletions were also mentioned. Some examples are as follows:

- “Estimating the timing of snow melt and stream flows,”
- “How to balance instream flow needs and consumptive use demands,”
- “Water measurement of large water flows.”

Groundwater Challenges

Challenges related to groundwater were mentioned in a few interviews, representing fewer than two percent of total challenges. Subtopics within this group included general groundwater data and assessments and aquifer resources.

Another subtopic mentioned as a challenge was groundwater/surface water interactions. These ideas comprise one and a half percent of all challenges mentioned.

Water Availability and Demand

About ten percent of the challenges identified were subsumed under the category of water availability and demand, which included a subclassification related to historical issues and allocation. Some responses focused on issues related to water use either in and of themselves, or linked with other changes such as those in land use generally and more specifically related to agriculture, municipalities or processes of urbanization.

Specific challenges for suggestions for water availability and demand included the following examples:

- “Water availability due to changing climate and demographics, and recent drought,”
- “The changing needs of water resources - moving from agriculture to recreation and residential development uses,”
- “Changing land use and uncertainties related to water right conversions,”
- “Changing water uses related to changing land use,”
- “Trying to determine how much water is actually available,”
- “Inefficient use of water for agricultural production,”
- “Finding new sources of water,”
- “Dealing with urbanization of rural areas,”
- “Water use efficiency for environmental concerns,”
- “Adequate municipal water supply given population growth-conversion of ag land to residential and effects on water supply,”
- “Insufficient water supply for current and future demands (population growth) ,”
- “Adequacy of water infrastructure and supply to meet multiple and competing demands by 2036,”
- “Water supply-maintaining it,”
- “Availability of water,”
- “Creating water resources to meet growth demands,”
- “Water demand is increasing via urbanization,”
- “Urbanization and the need for domestic commercial municipal and industrial water,”
- “Summer time and meeting peak demand, as agriculture puts a heavy load on existing infrastructure,”
- “Water accounting accuracy,”
- “Adequate information concerning water resources,”
- “Accuracy on water usage,”
- “Forecasting of water availability,”
- “Increased pressure on the resource (water).”

Water Quality Challenges

Like those linked with water quantity, water quality challenges were further subdivided into a number of additional layers. These five groups include better data, research on pollutants, relationships to the surrounding ecosystem, links with development processes, and how policy affects water quality. In total, water quality issues represent more than a third of total challenges within the natural science classification.

Data Issues

Representing three percent of total challenges, data issues linked with water quality focused on improvements that could be made to existing data from groundwater to surface water to drinking water. Also noted were challenges related to consistency issues regarding data already in place in numerous agencies that also represent various locations. Quality concerns included those linked with health of waters, the influence of temperature, and waterways generally in terms of baseline data.

Research on pollutants

A second subcategory related to water quality challenges dealt with contaminants in a broad sense and various pollutants linked with specific activities such as agriculture, livestock, mining, and particular types of companies (e.g. pharmaceuticals). Particular pollutants were also mentioned within this subset including nitrates, acidity from mining activities, toxic metals, and iron. These challenges represented four percent of the total. In many respects, these concerns were localized, linked with a specific organization or issue.

Relationship to surrounding Ecosystem

The third group in this subheading related to how water quality linked with the surrounding ecosystem, comprising only 1.3 percent of total challenges conveyed by the respondents. For instance, interrelationships among agricultural operations, land cover, and wetlands with respect to water quality could be noted in the responses.

Development's Impacts on Water Quality

Processes related to development were mentioned as challenges in about three percent of all challenges. Land use issues tended to be expressed in these responses, in some instances also taking into account intersections and interactions with population shifts. Municipal concerns were also reported, in addition to general processes of urbanization.

Policy Effects on Water Quality

As 1.7 percent of the total challenges, how policy affects water quality were also responses related to various challenges water professionals reported facing in their work. These comments vary widely with regard to the scale of the policy, from federal regulations to watershed-based concerns to issues linked with infrastructure that can intersect in various ways with the above.

Climate and Drought Challenges

Aside from water quantity and quality topics within the overall category of natural systems challenges, climate and drought issues were also mentioned as posing some of the greatest challenges for water professionals in their work in about nine percent of this group overall. As a whole, these comprised less than three percent of the total. The three subgroups are drought effects on water resources as pertains to management decisions, climate change factors and resulting effects, and general concerns linked with modeling climate change. As examples, comments subsumed under these headings included:

- "Water scarcity related to climate change (reduced storage via snowpack)"
- "Not as much snow cover, moisture—how do we adjust and compensate,"
- "variable climate regimes,"
- "Drought and the pressures put on managers due to water shortages,"
- "Forecasting precipitation events,"
- "Climate change and the problems this creates for long-term planning."

Other Natural Systems Challenges

Though mentioned in fewer interviews as posing a substantial challenge, a handful of other responses represent overall data on natural systems in a general sense. In many respects, these responses did not fit neatly into the other categories, yet needed to be incorporated into the analysis and discussion. Responses included a number of data absence concerns related to consistency of data gathering across time and space, the absence of specific types of data, navigational questions, and issues of scale (e.g. how watersheds intersect with other data gathering techniques and measurements).

Human Dimensions or Social Science Issues and Challenges (37.4%)

As the largest category proportionally of greatest challenges, topics related to human dimensions were prominent for water professionals. More than one-third of responses citing greatest challenges related to issues pertaining specifically to social science topics, or 176 comments out of the total of 471. Put another way, 3.7 out of ten challenges mentioned related to these issues. Within this classification, six subtopics were identified (count following type in parentheses): legal challenges (34), policy challenges (35), funding challenges (27), sociological challenges (16), educational challenges (36), and challenges of population dynamics (28). As percentages within this category, they represent 19.3 (legal), 19.9 (policy), 15.3 (funding), 9.1 (sociological), 20.5 (educational), and 15.9 (demographic), respectively.

How these groupings were further subdivided is detailed below. We address each in turn. As was noted earlier, because of the generality in the phrasing of the question, the responses ranged quite broadly; thus we focus primarily on summary statistics but also include examples from the interviews for illustrative purposes as appropriate.

Legal Challenges

Water professionals noted a number of legal challenges that they face while involved with their work. Two main subgroupings emerged: those linked with water laws (14) and those linked with water rights (20). With regard to the former, comprising three percent of total challenges named, issues related to enforcement of existing water laws, knowledge of existing statutes related to various groups (e.g. irrigated landowners, agency managers, public), and information dissemination strategies generally designed to communicate technical and legal language in a format easily grasped by all groups involved. Issues related to coordination and interpretation were also expressed.

Some examples include:

- "Helping the public to better understand water law,"
- "Communication of the complexities of state water laws to the general public,"
- "Enforcement of water laws."

In terms of the latter, water rights, these comprised slightly more than four percent of all challenges verbalized. Enforcement issues were also raised, as were expressions related to knowledge in general terms and under specific circumstances (unfulfilled water rights and treaties). Some comments also illustrated how water rights are communicated and understood by various groups, including the general public and other users. Data concerns regarding completeness and accuracy of rights were also noted.

- "Water rights adjudication,"
- "Trying to get a handle on water rights,"
- "Capacity of the agency to deliver service regarding water rights to the public,"
- "Lack of knowledge of water rights by the public."

Policy Challenges

As a group, policy challenges comprise 19.9 percent of human dimensions challenges, and represent 7.5 percent of total challenges expressed in the interviews. Thus, they represent the second largest subcategory of human-dimensions related responses. Three subcategories were noted in the coding (count, percent of total challenges): adequacy (9; 1.9%), political/community dynamics (13; 2.8%) and regulatory issues (13; 2.8%). Adequacy concerns linked with regulatory aspects related to public officials in a general sense and also with government structures overall and those associated with specific economic facets. One noted a general disjuncture between perceptions of the public, specific public policies, and water law. Another focused on planning or vision capacities of agencies.

Political and community dynamics illustrate, in various ways, how different groups perceive the actions and intent of others involved with a particular issue as linked because of a certain shared resource. Some examples include responses relaying how local landowners mistrust the government, a mismatch between existing data and political expectations, how resource conflicts emerge and are effectively played out in different arenas, how politics are infused in issues of water use and distribution, and water politics in general.

The third subgroup includes responses that communicate how compliance with regulations takes place related to state and federal guidelines, including existing and newly introduced ones. Planning concerns were also expressed in relation to compliance with current and future laws and how to accomplish such goals in the face of uncertainty.

Funding Challenges

As a whole, resource or funding related challenges comprised 5.7 percent of total challenges across all mentions in the interviews. From general expression of funding to funding limitations or a lack of funds, including those linked with projects generally, others mentioned ties to specific activities and projects. For instance, some responses included:

- "Funding resources required to meet new regulation standards and time frames,"
- "Lack of funding not allowing expertise in field to be developed,"
- "Finding funding to pursue the projects the community needs,"
- "Funding for data management and data collection."

Sociological Challenges

The subcategory of sociological challenges includes two further subgroups: organizational or institutional dynamics linked primarily with agencies (11; 2.3%) and managing with consideration given to social components (5; 1.1%). Combined, they represent just under 3.5 percent of total challenges mentioned. These responses describe interrelations among various actors (e.g. municipalities, county agencies and private water companies), along with people in the industry overall. Other examples include fostering links among government, universities and local populations, and encouraging practitioners to find ways to communicate. Other concerns include management issues that cross state and federal boundaries and span various scales of interaction. Some remarks also called for taking multiple perspectives into account in decision-making processes.

Educational Challenges

Taken as a group, educational challenges comprised 7.9 percent of total challenges across all mentions in the interviews, and 20.5 percent within the human dimensions subgroup. As such, they represent the largest segment of human dimensions-related challenges. Two additional layers to this category emerged: public education and community outreach (17; 3.6%) and conservation education (19; 4%). Examples related to public education and community outreach can be considered in the following two groupings. The first related to general interactions and highlights information and involvement challenges:

- "Dealing with the public,"
- "Public ignorance, or lack of willingness to get involved,"
- "Lack of public participation,"
- "Lack of understanding about water by public,"
- "Adequately informing the public on what needs to be done concerning water resource protection,"
- "Public buy-in-convincing/educating the public that certain actions need to take place."

A second sub-grouping highlights resource and outreach issues:

- "Public outreach, (e.g. water management, grazing issues, recreational use of lands, and the affordability of technology),"
- "Question of how to reach all the varied groups of water users in the region, and how best to develop tools that are effective at reaching the different groups,"
- "Lack of outreach regarding incentive and rebate programs,"
- "Community outreach and awareness about the watershed and water quality,"
- "Getting resources out to the villages,"
- "Education and outreach on connection of people's daily lives to health of the watershed,"
- "Promoting use of safe water in Native communities,"
- "Lack of public education about farming due to financial burden (advertising) and current biased info that public receives,"
- "Creating awareness of Nitrate Priority Areas,"
- "Public education of environmental protection and restoration,"
- "Getting landowners to listen to all sides of the issues."

Challenges of Population Dynamics

As a whole, these demographic challenges comprise just under 6 percent of total challenges noted by our survey respondents. Six subgroups were identified: population and growth projections (10; 2.1%), population change and water demand (8; 1.7%), population change and consumption patterns (2; .4%), population change and flooding (1; .2%), population change and culture (4; .8%), and other growth-related topics (3; .6%).

Management-related Challenges and Concerns (18.9%)

The third broad group of greatest challenges that emerged from the qualitative analysis of the interviews related to management challenges and concerns. As a whole, they represent nearly nineteen percent of the total challenges relayed by those in our sample of survey respondents. Within this group, although we show four subcategories in Table 2.1.2 (personnel/time/logistical challenges, general management needs, management strategies, and program effectiveness), in the original analyses, seven subcategories were identified. These subgroups were personnel and time management/logistical challenges, management needs in general, management regimes (e.g. restoration, stormwater, storage, etc.), biological/wildlife management, holistic management, and program effectiveness.

Challenges subsumed under the first category include those of staffing like hiring processes, a general lack of resources for getting things accomplished, attempts at efficiency gains, establishing links among diverse user groups, and various demands placed on organizations that highlight difficulties associated with existing resources and the utilization of existing channels. Time management issues and person-power issues were also comments made regarding this subcategory. These constituted nearly five percent of the total challenges.

Related to the second subcategory, management needs in general, various responses were conveyed suggesting knowledge gaps, how to contend with issues of communication and coordination, and general sustainability concerns. Representing four and a half percent of total challenges, these responses include a mix of local and more expansive scales, illustrating complexities related to management strategies over particular spatial arrangements and institutional realms.

Conjunctive management challenges were mentioned 11 times, representing 2.3 percent of the total. Responses included general issues related to conjunctive management (e.g. uncertainty linked with it), as well as more specific applications and general groundwater/surfacewater interrelations. Similarly, management regimes, with 10 comments, were 2.1 percent of the total, including restoration, stormwater, storage, and general data concerns, sometimes linked with specific events like floods.

Biological and wildlife management challenges also reflected broad-based and locally-specific concerns, and represent 2.5 percent of total challenges. For example, fish passage related to hydropower was mentioned generally, as were more specific examples of salmon populations including how such efforts link with the Endangered Species Act. Holistic management challenges incorporate those related to competing groups and achieving balance in complex decision-making environments, comprising under two percent of the total. Rounding out this category are four responses linked with program effectiveness and specifically economic analyses conducted to determine such impacts.

Concerns with Information, Data Quality & Dissemination (6.6%)

The final category related to the greatest challenges that water professionals face included responses that link with how existing data is gathered, organized and disseminated. Representing 6.6 percent of the total, these challenges focused on data collection standards and quality, data dissemination mechanisms, and conveying information in formats that make them accessible to the lay public, and were relatively equally split among these concerns, as shown in Table 2.1.2.

Generally, these suggestions are not focused on a need for new data, but instead highlight strategies for communicating and integrating existing sources in a manner that improves accessibility and has a potentially broader audience. 31 responses were categorized into this topic, which included four subtopics: utilization of existing data or the creation of a central repository, a lack of adequate or high quality data, specific types of data needs, and formatting issues related to conveying materials to the general public.

Examples of responses in the first subtopic focused on issues of data management, particularly in terms of having it be centralized to improve its accessibility. A standardized database was suggested that would serve as a repository for data that has already been collected in order to facilitate information transfers. This data sharing would involve various groups involved with water-related issues, such as agencies, universities and the lay public. A web-based delivery system was also advanced as a possible centralized, data storage location.

The second subtopic's responses concentrated on issues related to the absence of particular types of data, data quality concerns, and a general lack of data collection. Comparability of data was also expressed in relation to the number and frequency of data points being gathered. Concerns related to data standards were also included, along with the issue of the absence of historical data availability. Maintaining high quality data standards over time were also included.

A subset of responses within the broader category of information, data quality and dissemination focused on specific types of data like the need for real time data and how geological factors shape the ability or inability to gather proper data. One response linked specifically with how fire impacts soil hydrologic functioning. A final challenge related to gathering data at the watershed level as a concern.

The final cluster of responses in this category honed in on issues related to data accessibility. Examples included calls for more efforts to translate technical scientific data into terms and products that are applicable to a range of audiences such as extension agents, managers, stakeholders, and the lay public. These challenges cut across various outputs, from written reports to particular programs, with one calling for a reduction in jargon in order to facilitate information transfers within and between agencies, academia, and the public.

State Differences in Reported Biggest Challenges

In examining the greatest challenges by state in order to discern whether particular patterns may be notable, we found a number of intriguing results. For instance, using the four broad categories of data, natural systems, human dimensions, and management, the distribution of responses across and within states, shown in Table 2.1.3, a perusal of the frequencies suggests similarities as well as differences.

Though differing in actual percentages, the patterning of responses is similar in Montana, Idaho and Washington. In Montana, for example, natural systems challenges comprise the largest category of responses with 60 percent, followed by human dimensions challenges (19.2 percent), management (13 percent), and data with less than 8 percent. In Idaho, natural systems challenges represent 39 percent of all challenges reported by respondents, with human dimensions (33.6 percent), management (14.9 percent) and data (7.2) following, respectively. For Washington, though the patterning is the same, the percentages differ, as natural systems and human dimensions are quite similar (at 46.3 and 43.4 percent respectively), followed by management with 9.0 and data with only 1.5 percent.

Greatest challenges differ in Utah and Alaska, though both focus on human dimensions challenges represent the largest category in both states. For instance, in Utah human dimensions constitute the largest category with half of responses, followed by management (25.3 percent), natural systems (20.1 percent), and general data (4 percent), respectively. An even different proportional ranking can be seen for Alaska, as even though human dimensions represent the greatest number of challenges by responses, they are only 37 percent of the total, followed by natural systems (31 percent), management (20.3 percent), and data with 11.9 percent.

Table 2.1.3. Greatest Challenges Water Professionals Face by State

Type of Topic	AK	ID	MT	UT	WA
Data collection standards & quality	8.3	6.0	5.6	2.0	0.0
Data dissemination mechanisms	3.6	1.2	1.9	2.0	1.5
Data Subtotal	*11.9*	*7.2*	*7.7*	*4.0*	*1.5*
Water Quantity	9.5	22.2	22.2	13.1	28.4
Water Quality	16.7	10.8	33.3	3.0	13.4
Climate and Drought	1.2	4.2	5.6	3.0	3.0
Other Natural Science Data	3.6	1.8	0.0	1.0	1.5
Natural Systems Subtotal	*31.0*	*39.0*	*60.1*	*20.1*	*46.3*
Legal Challenges	1.2	4.2	5.6	5.1	26.9
Policy Challenges	10.7	13.2	1.9	3.0	0.0
Funding Challenges	11.9	4.2	1.9	6.1	4.5
Sociological Challenges	3.6	2.4	3.7	5.0	3.0
Educational Challenges	6.0	3.6	3.7	17.2	9.0
Challenges of Population Dynamics	3.6	6.0	1.9	14.1	0.0
Human Dimensions Subtotal	*37.0*	*33.6*	*19.2*	*50.5*	*43.4*
Personnel/time/logistical challenges	6.0	3.0	3.7	9.1	3.0
Management Needs in general	6.0	3.6	5.6	5.1	3.0
Management Strategies	8.3	8.3	3.7	7.1	3.0
Program Effectiveness	0.0	0.0	0.0	4.0	0.0
Management and Other Subtotal	*20.3*	*14.9*	*13.0*	*25.3*	*9.0*
TOTAL	100	100	100	100	100

2.2 RESEARCH NEEDS

OVERVIEW

After asking about the challenges they face in managing water resources in their job, respondents were asked:

> *"Thinking back over the last 5 years, can you think of any specific instances in which you did not have the information you needed to make good decisions about water resource management? If you can think of several, pick the most important or most common type of situation."*
>
> *and*
>
> *"Of all the specific types of information gaps that you've mentioned, could you rank each one as a potential focus for future university research, with "1" being the highest priority area?"*

The most common responses were recorded and used in the analysis below. All told, 547 responses were recorded from 144 interviews (See Table 2.2.1). The largest number of interviews were completed in Idaho (32 percent of the total), and each Idaho interview recorded an average of almost 7 key research needs (a total of 314 needs, or 57 percent of the total, come from the Idaho interviews). While some of the results discussed below include the aggregated totals form all interviews, we also examine patterns by state to highlight ways in which the priorities and perceived needs differ across the study areas.

Table 2.2.1. Number of Interviews Completed and Research Needs Identified by State

	Overall # Interviews	Total Reporting Any Research Needs	(%)	Total Needs Identified	(%)	Avg. # Needs Reported / Interview
Alaska	30	28	19.4%	61	11.2%	2.2
Idaho	53	46	31.9%	314	57.4%	6.8
Montana	19	18	12.5%	44	8.0%	2.4
Utah	27	27	18.8%	84	15.4%	3.1
Washington	30	25	17.4%	44	8.0%	1.8
Total	159	144	100.0%	547	100.0%	3.8

The 547 total research needs identified in the interviews were analyzed for common themes and patterns, and then organized into four major categories:

- Need for better data coordination and dissemination
- Need for Natural Science Research
- Need for Social Science Research
- Need for Management Resources and Strategies

The total number of responses in each major category (as well as several subcategories, are listed in Table 2.2.2.

Table 2.2.2. Distribution of Research Need Priorities by Major Categories

		ALL REASONS LISTED				ONLY TOP 3 REASONS			
		Frequency		Percent		Frequency		Percent	
Topic	Subtopic	Topic	Sub-topic	Topic	Sub-topic	Topic	Sub-topic	Topic	Sub-topic
Data Quality and Dissemination		**60**		**11.0**		**29**		**8.2**	
	Data collection standards & quality		26		4.8		15		4.3
	Data dissemination mechanisms		34		6.2		14		4.0
Natural Science Research		**328**		**60.0**		**221**		**62.8**	
	Water Quantity		131		23.9		89		25.3
	Water Quality		94		17.2		64		18.2
	Climate and Drought		70		12.8		43		12.2
	Watershed data		21		3.8		16		4.5
	Other Natural Science		12		2.2		9		2.6
Human Dimensions Research		**144**		**26.5**		**89**		**25.2**	
	Conservation Behavior		7		1.3		4		1.1
	Consumption Patterns		37		6.8		16		4.5
	Sociological factors		48		8.8		29		8.2
	Political factors		32		5.9		25		7.1
	Economic factors		20		3.7		15		4.3
Management Approaches, Etc.		**15**		**2.7**		**13**		**3.7**	
	Management needs (general)		3		0.5		1		0.3
	Management training		7		1.3		7		2.0
	Funding concerns		3		0.5		3		0.9
	Other		2		0.4		2		0.6
Total		**547**		**100.0**	100.0	**352**		**100.0**	100.0

Because some states allowed many respondents to list more than three top research priorities, we also ran an analysis that limited the data to the first three responses per person. The results are shown in the right half of Table 2.2.2. While there are some modest shifts in proportions of answers in specific categories, the overall patterns remain substantively the same. This suggests that multiple responses from certain respondents (or states) are not driving the patterns in our research needs database. In the sections below, we will be reporting on results from the full dataset that includes all suggested research needs and priorities.

Ensuring Data Quality & Dissemination (11%)

The first major category included all of the responses that emphasized ways to better gather, organize, and disseminate existing types of scientific data about water resources. Just over 10 percent of the total research needs fell into this topic category. In a sense, most of these suggestions do not call for new basic or applied scientific work, but rather organizational and institutional innovations that might make existing scientific knowledge more accessible and widely used. The 60 responses in this category were broken into two subtopics – requests for better data quality, and requests for systems to better disseminate the available data.

Examples of responses in the first subtopic included a call to standardize data collection and reporting protocols (to enable comparisons of data across time and space). This was particularly true for water quality datasets. There were also concerns that basic types of water resource data (particularly stream flows, climactic events, water quality measurements, and reservoir/lake levels) should be made available to resource managers in real-time.

The responses in the second subtopic focused on problems related to the access, sharing, and dissemination of existing water resource datasets. There were three main types of suggestions. Most common was a request for some type of digital data clearinghouse (cited by 18 respondents) where researchers and managers could go to get systematic data across a range of parameters. Examples of the types of data that would be appropriate include:

- "centralized database with links to climate and population data,"
- "…database to store all agency-collected water data,"
- "Coordination techniques for consistent monitoring and evaluation data collection…and the creation of a database to store collected monitoring data," and
- "Establishment of an aerial photo library or guide to accessing historical aerial photos."

Some of those interested in a data clearinghouse pointed at the need to develop techniques or software that can inventory and integrate disparate types of water data from multiple sources. Others sought direct links to mapping software that help display spatial patterns and relationships.

Other responses in the data dissemination subtopic addressed institutional changes that are required to better facilitate data sharing and communication across different government agencies, and between universities and public or private water resource managers. One Montana respondent called specifically for "Universities to help agencies develop: 1) analytical techniques, 2) better monitoring and efficiency in monitoring system design, 3) richer data, 4) partnerships with universities to provide more research angles, 5) sampling designs, and 6) hardware."

The final cluster of responses in this category included calls for more efforts to translate technical scientific data into terms and products that are accessible to politicians, managers, and the lay public. These responses echo some suggestions for better public education that will be discussed in more depth in the sociological research section below.

Natural Science Research (60%)

By far the most common suggestion for further university research addressed natural biophysical science topics. Sixty percent of the total research needs fell into this category. Because of the diversity of the specific suggestions, we divided this category into four major subtopics (which, in turn, can be subdivided into more detailed groups). Before examining each subtopic, it is worth noting that most of our natural science research suggestions did not specify a particular discipline or basic science topic, but rather were phrased as applied scientific questions focused on particular management problems.

As such, our four subtopics include: Water Quantity data and research, Water Quality data and research, Climate and Drought data and research, and a final group of diverse other topics.

Water Quantity Research Needs

The most frequently cited subtopic in the natural science research needs category involved water quantity topics. Almost a quarter of all responses mentioned issues in this category. Because the background on our study provided to respondents involved a short discussion of the water resource management issues in the region, with a particular focus on water supply and drought, it is not surprising that respondents directed a large share of their attention toward these topics.

The water quantity subtopic suggestions were further subdivided into several different subgroups (see Table 2.2.3). These were titled: surface water, ground water, surface and groundwater interactions, and studies of water availability and storage.

Surface Water Research

The first subgroup included data on surface water conditions (roughly 6 percent of all suggestions). Almost all of these identified a need for better streamflow data monitoring and reporting systems. Specific suggestions included:

- "Increased monitoring and gauging,"
- "More stream gauging data," or "Greater coverage of streamflow gauges"
- "Increased flow data, inclusive measurement of low stream flows…timing of peak flows,"
- "Timely stream and canal flow measurements,"
- "In-stream flow data… and inflow forecast anomalies"
- "Timely site specific stream flow and precipitation gauges to model storm events."

Other suggestions for surface water research included better data on stream channel dynamics, improved understanding of the ecosystem impacts of changes in streamflows, and development of technologies that make more efficient use of surface water resources.

Table 2.2.3: Detailed Water Quantity Research Needs

Type of Research Need	**Number of Respondents**	**Percent of Water Quantity Suggestions**
Water Quantity Research Needs	131	
2.11 Overall water quantity data, integrated hydrologic assessments	***15***	***11.5%***
2.12 Surface water data	2	1.5%
2.121 Stream gauges and flows	20	15.3%
2.122 stream channel dynamics	2	1.5%
2.123 Ecosystem effects of flows	6	4.6%
2.124 More efficient uses of surface waters	1	0.8%
Subtotal (surface water data)	***31***	***23.7%***
2.13 Ground water data	17	13.0%
2.131 Groundwater withdrawals	8	6.1%
2.132 Aquifer models	15	11.5%
2.133 Spring flows	3	2.3%
2.134 Recharging models	6	4.6%
Subtotal (ground water data)	***49***	***37.4%***
2.14 GW and SW Interactions	**15**	**11.5%**
2.15 Water availability, utilization and storage	1	0.8%
2.151 Est. water availability	5	3.8%
2.152 Water storage and conjunctive management	13	9.9%
2.153 Flood control	2	1.5%
Subtotal (water availability and storage)	***21***	***16.0%***

Groundwater Research

The most common subgroup in the water quantity subtopic involved suggestions for more research on groundwater availability and dynamics. Almost 50 responses (or 10 percent of all research needs) fell into this area.

Specific suggestions for groundwater research topics included the following examples:

- Increased data on groundwater levels
  - "More groundwater monitoring locations dealing with depth to water table,"
  - "Research on the location of groundwater resources,"
- More detailed data on groundwater usage and withdrawals
  - "Better measurement of groundwater usage (quantity and efficiency),"
  - "Determination of adequate spacing between domestic wells,"
  - "Long-term measurement of groundwater withdrawals,"
  - "Policies for regular reporting of pumping records, diversions and return flows,"

- “A statewide study of the net impact of domestic wells,”
    - “Regulation and monitoring of domestic and agricultural groundwater use.”
- Improved basic understanding of aquifer resources and dynamics
    - “Map aquifers,” “Aquifer mapping,” “Aquifer data,” “Delineate aquifers,”
    - “Assess the size of groundwater reservoirs and the quantity of useable water within the reservoirs,”
    - “Research the extent, boundaries, and behavior of aquifers”
    - “Long-term sustainability of aquifer (quantity level to sustain),”
    - “Technical information to create broad conceptual model of the aquifer,”
- Better understanding of aquifer recharge dynamics
    - “Identify aquifer recharge locations,”
    - “Transmittivity of aquifer recharge and timing of discharge”
    - “Assessment of key locations for aquifer recharge so that flood control can take advantage of subsurface storage of excess flows,”
    - Identification of natural recharge locations (both shallow and deep aquifers) and identification of potential enhancement locations.
- Better understanding of spring flows

Interactions of Surface and Groundwater Resources

The third subgroup in this section included suggestions for more research explicitly targeted at understanding the interactions between surface and groundwater resources. Cited by almost 6 percent of respondents, examples of the suggestions included:

- Better basic science understanding of these interactions
    - “Increased understanding of surface/groundwater interactions”
    - “Modeling of ground and surface waters in tributary valleys,”
    - “Development of groundwater and surface water models”
    - “Basic understanding of groundwater – assessing where and how groundwater is recharged by surface water and creating a model that takes into account both ground/surface waters that will enable better predictions of water levels,”
- Applied science understanding the impacts of water use on ground and surface waters
    - “Groundwater pumping and how it affects surface water flows in the pumping timeline,”
    - “Better understanding of the interrelations of ground and surface waters, accounting for diversions and pumping,”
    - “Tributary underflow, return flows from canals, and precipitation in non-irrigated lands and their relationships to groundwater-surface waer models,”

Water availability, utilization and storage

The final subgroup of water quantity topics included applied studies of water availability and options for increasing storage capacity for sustained water use. Examples of suggestions in this section included the following:

- Estimates of water availability
    - "Quantification of how much water is potentially being used, and how much actually exists,"
    - "Better tools and methods for water supply forecasting,"
    - "Determine the yields (sources) and uses of water, and address the question: 'where is water coming from and how is it being managed?'"
- Studies of water storage alternatives
    - "Is there more water available for more dams?"
    - "Assessments of the current status of dams (need to fix or alter to increase capacity – including assessments of sedimentation, toxicity, and potential removal and reuse projects."
    - "Study of the storage needs to meet requirements for agriculture and wildlife,"
    - "How to secure water (storage) for supplemental use during shortages and recharge,"
- Scientific studies to support conjunctive water storage management approaches
    - "Data to assist conjunctive management,"
    - "Better understanding of conjunctive management,"
    - "Techniques for integrated water management,"
    - "Policy strategies for conjunctive management,"
    - "How to conjunctively manage ground and surface water users' rights,"

Climate and Drought Research

Aside from water quantity topics emphasizing the study of ground and surface water resources, many respondents identified climate and drought topics as a high priority for future university research. In total, we classified 70 research needs (or 12.8 percent of the total) into this subtopic category.

While it was difficult to draw clearcut lines, the specific suggestions for research in this area fell into the following major topic areas:

- Improved data on climate and weather
- Drought specific research topics
- Studies of climate change
- Prediction and modeling of climate and drought
- Studies of Policies and BMPs designed to address climate change and drought

Improved data on climate and weather

A sizeable group of key informants felt that the development of a better system of baseline data on climate and weather would be a priority for future INRA work. Examples of comments included people who indicated a desire for the following types of data:

- "Basic hydrological data including snow pack, precipitation cycles, soil moisture, lake levels, climactic influences, and streamflow,"
- "better data on solar radiation,"
- "increased quantity and accessibility of SNOTEL sites,"
- "historic snowpack and climate conditions," "snowmelt rates," "understanding snowpack levels," "additional research on snowpack and meteorological data and their interpretation,"

Drought science

Because many states in this region have experienced recent prolonged periods of drought, the research instrument asked all respondents whether or not they felt there was adequate scientific information regarding the prediction and impacts of droughts on water resource management. Suggestions included research that would lead to: "better definitions of drought," "understanding the precursors of drought," and "developing a new way to determine soil moisture."

Climate Change Science

Given the intense public and scientific attention to the topic in recent years, it was not surprising that a number of our respondents felt that more research should be done on the nature, causes, and impacts of global warming and climate change. Of particular interest to these informants would be further study of the following topics:

- "Impact of climate change on water resources," "Effects of global climate change on hydrology," "Analysis of the impacts of global warming on water availability," "Global warming research, especially impacts on drinking water sources," "Climate change effects on water supply,"
- "Global warming research as it relates to fish and waterways,"
- "Predictive modeling of vegetative structure changes related to climate change,"

Modeling and Forecasting Science

Aside from better data on weather, climate, drought, and climate change impacts, many key informants identified a need for better climate models that help predict changes and provide short- and medium-term forecasts to assist water resource planners. Suggestions included:

- "Better weather and climate forecasting," "Improved weather predictions,"
- "Development of better forecasting models," "Greater spatial and temporal resolution of weather predictions,"
- "Increased accuracy and timeliness of weather and water supply predictions,"
- "Increased accuracy of weather predictions to reduce the uncertainty in water supply and shortages (e.g., water use, flooding, and drought),"
- "Models with increased capabilities to incorporate wind and solar radiation data."
- "Better drought management predictions,"

- "Knowledge as early as possible regarding the conditions (drought or surplus) of the coming year,"
- "Better long-range drought forecasting,"
- "Predictions of the effects of drought on the water supply,"
- "Early drought predictions and the provision of that information to farmers,"
- "Linking groundwater data to stream flow data in drought predictions."

Policies and BMPs to address Climate Change and Drought

The final cluster of research needs in this section relate to specific management or technological solutions to climate change and/or drought. Specific suggestions were:

- "Development of a response plan for drought," "Collaborative watershed plans for drought management,"
- "Methods/tools/policies to plan for multiple drought years (fish and irrigation) with an emphasis on leaving water in-stream during drought
- "Unified, statewide public awareness of drought and water quantity issues,"
- "Development of drought tolerant crops," "Development of drought management Best Management Practices (BMPs) that are holistic,"
- "Cloud seeding research," "What is the impact of cloud seeding in the basin? Do we know what we are doing?"

Water Quality Research Needs

Although studies of water quantity dominated the natural science research needs in our interviews, there were a sizeable group of respondents (17% of all suggestions) who felt that more research should be done on water quality issues.

Water Quality Monitoring

As with water quantity topics, a large number of suggestions focused on ways to improve the general monitoring infrastructure and data reporting network. Specific comments included:

- "More and better water quality monitoring data,"
- "Baseline data on water quality parameters," "Baseline water quality data to understand influences at multiple scales"
- "A network of water quality monitoring stations – specifically designed to make determinations of beneficial use for the TMDL process"
- "Data on surface water quality," "Data on nutrients, temperature, and sediments in surface waters,"
- "more sediment gauges on rivers,"
- "Temperature data from USGS gauging stations," "Assessment of current stream temperatures with quantification of the effects of human activities on stream temperatures."

Sources, impacts and dynamics of specific pollutants

Other suggestions focused on enhancing our understanding of the processes associated with particular types of water pollutants.

Some suggested the need for an overall assessment of the relative levels and impacts of different types of pollutants as a first step. Typical comments were:

- "Which are the worst bodies of water and why? Chemicals, nutrients, sediments, pharmaceuticals?"
- "Technologies to better define and isolate TMDL problems," "Applications of current technologies (e.g., GIS) to better understand and holistically plan the management of TMDLs."
- "Localized research of discharge (e.g. temperature, metals and nutrients) on impacts on aquatic species and downstream water users"

Others identified particular pollutants as a specific priority for future research. Among these, the most commonly mentioned were:

- Nutrients & sediments
- Metals
- Pharmaceuticals, personal care products, and other inert ingredients

Relationships between land use changes and water quality impacts

While the above suggestions focused on measurements of water quality parameters, there were a cluster of suggestions that suggested a broader data collection approach designed to link changes in the larger landscape to changes in water quality in surface and groundwater resources. Examples included studies of the impacts of the following changes in land uses:

- Logging
- Off-road vehicle use
- Septic systems
- Urban development and construction activity
- Stormwater runoff
- Wastewater and stormwater

Development of technologies to mitigate water quality problems

A final cluster of water quality suggestions focused on engineering, management, and technical innovations that might provide solutions to water quality problems. Again, the particular water quality issues of interest to our respondents were quite diverse, so their suggestions represented a wide sweep of potential Best Management Practices (or BMPs). Examples included:

- Better erosion and sediment control techniques
- Better water treatment options – particularly with emphasis on treating nitrogen & phosphorus in wastewater
- Assessment and quantification of the pollutant reductions associated with specific BMPs already on the shelf
- Development of tools to support water resource management approaches that incorporate a wider range of water quality issues into decision-making

<u>Other Natural Science Research Needs</u>

While water quantity and quality issues dominated the natural science research suggestions among our respondents, we did gather a number of responses that did not fit neatly into any previous category. The two largest examples in this group include studies of watershed scale dynamics, and studies of fisheries. In the case of watershed studies, there were several respondents who identified a need for better fine-grained spatial datasets at the watershed scale. These data might be used for a variety of interrelated purposes, including

- Delineation of basin and subbasin boundaries
- Mapping changes in terrain and erosion
- Improved land classification systems that reflect water uses
- Data on human modifications of water systems that facilitate comparisons of natural and human modified flows
- Development of historic vegetative data sets at the watershed scale
- Securing funding for integrated multi-disciplinary and long-term studies of selected watersheds

In the case of fisheries research, most of the emphasis focused on (a) salmon enhancement and recovery issues, and (b) stream restoration techniques with an eye toward re-establishing fish habitat.

Social Science Research (26%)

Human dimensions issues were directly or indirectly mentioned in a number of the natural science research topics listed above, but were also the primary focus for a large cluster of suggestions in this section. Overall, topics classified as social science research comprised roughly a quarter of all research needs suggestions. These were then broken into four major categories (see Table 2.2.4):

- Conservation & consumption – (8%)
- Sociological (sociological baseline data; community & stakeholder relationships, educational programs, institutional/organizational factors) – (9%)
- Political (water rights, water law, policy impacts on water resources) – (6%)
- Economic (CBA/prices) – (4%)

Table 2.2.4. Detailed Description of Human Dimensions Research Needs

Type of Research Need	Number of Suggestions	Percent of HD Suggestions
Human Dimensions Research Needs	147	
3.1 Water Conservation and Consumption		
3.11 Conservation practice effectiveness	2	1.4%
3.12 Development of new conservation practices	5	3.4%
3.13 Improved/standardized data on water consumption	16	10.9%
3.14 Ag vs domestic water use studies	8	5.4%
3.15 Water use demand info and data	6	4.1%
3.151 Population growth impacts on water demand	7	4.8%
Subtotal (water consumption and conservation)	***44***	***29.9%***
3.2 Sociological Research		
3.21 Basic Socioeconomic data	13	8.8%
3.22 Stakeholder input & public information dissemination	4	2.7%
3.221 Soliciting input from public & stakeholders	4	2.7%
3.222 Public education efforts	10	6.8%
3.23 Public ed/research on best ed approaches	18	12.2%
3.24 Organizational Dynamics	1	0.7%
Subtotal (sociological processes)	***50***	***34.0%***
3.3 Policy Research		
3.31 Water rights issues	11	7.5%
3.32 Legal concerns	7	4.8%
3.33 Understanding impacts of policy on water resources	6	4.1%
3.34 Political influence on science and policy	9	6.1%
Subtotal (political processes)	***33***	***22.4%***
3.4 Economic Research		
3.41 Cost benefit analyses	14	9.5%
3.42 analysis of market prices and solutions	6	4.1%
Subtotal (economic processes)	***20***	***13.6%***

Water Conservation and Consumption Patterns

Research needs associated with water consumption patterns were difficult to categorize. We grouped 44 suggestions into a water conservation and consumption category that included calls for the following types of research:

- Research into new technologies to reduce water demand,
- Improved approaches to measuring different types of water use, including a desire for
    - Better historical data,
    - Better metering, and
    - More remote sensing data,
- Standardization of reporting techniques related to water use data (several people emphasized problems with comparing estimates of per capita water use across states and jurisdictions),
- Detailed studies of agricultural irrigation water use (including a focus on whether or not changing irrigation technologies and pricing systems affect irrigators' water use behaviors),
- Detailed studies of urban water use, including
    - a focus on the impacts of different settlement patterns and types of growth on residential water use, and
    - better projections of water demand needs associated with population growth
- Detailed studies of the rate and character of transferring water rights from traditional agricultural uses to new urban/domestic consumption uses.

Sociological Research

A significant number of respondents identified human dimensions problems that we classified as "sociological" in nature. These fell into two main categories:

- Better socioeconomic data, and
- Improved techniques for working with the public.

Examples of suggestions in the first subcategory emphasized the importance of more accurate population projections and more detailed (finer-scale) socioeconomic data. Several respondents indicated a desire to know more about where development is most likely to occur, and what this growth will mean for water demand. In addition, there was an interest in more research into cultural attitudes toward water and water use. In every case, these forms of sociological research were designed to help

Most of the sociological research suggestions were in the second category. Examples fell into three clusters – public input and participation, public education, and behavioral modification strategies. Some illustrative phrases used in the interviews were:

- Ways to increased public involvement in decisions
    - "Acquisition of skills to successfully incorporate public involvement,"
    - "Ways to incorporate communities into the research being done there,"
    - "Negotiations of how society should respond to drought,"
    - "Increased public involvement in water quality rule-making,"
    - "Public assessments of technical information regarding aquifer status,"
    - "Getting input from all parties and stakeholders in making management decisions."

- Ways to better get information out to the public
    - "Communication to and education of the public on research trends'"
    - "What are the most effective training programs for teaching regulated entities what is expected of them?"
    - "Unified statewide public awareness of water quality issues,"
    - "Information dissemination to the public about contaminants,"
    - "Communication strategies for effective dialogue when resources cross state or jurisdiction boundaries,"
- Behavioral modification strategies
    - "How to convince people not to over-irrigate,"
    - "Public education and promotion of conservation / reuse methods and tools,"
    - "Education and training on conservation measures,"
    - "Best ways to educate the public about conservation."
    - "Education and communication strategies to inform irrigators of conservation practices,"
    - "Determining a way to improve how people use water."

Policy Research

Roughly 6 percent of responses identified legal and policy issues as an area where further research was warranted. Many of these suggestions focused on the unique aspects of water rights law in the American West that shape the management of water resources. Others emphasized a need to understand the impacts of specific policies on water resources.

Some specific examples of policy research suggestions include:

- Water rights and other legal issues
    - "Real time water rights accounting data,"
    - "Mapping of water rights into a GIS database,"
    - "Development of technologies that better display existing water rights,"
    - "More information about what water rights are available and how they are used,"
    - "Development of a water rights manual to inform the public,"
    - Finding an alternative to Western Water law,"
    - "Need for research to support the strengthening of water quality law,"
    - "Clarity of the management of irrigation canals and ditches,"
    - "Management of regional water systems for salmon recovery under ESA,"
- Policy assessments
    - "Research to determine policies for holding power companies accountable for environmental and recreational damages caused by dam operations,"
    - "Sociological analysis of water rights holders behaviors under different forms of regulation,"
    - "Cost sharing alternatives and the political/legal frameworks of water administration across states/national jurisdictions,"

A final cluster of suggestions reflected concerns that politics (and perceived "biases") play too much of a role in water management research, and thus the 'need' was to have more unbiased and apolitical research.

Economic Research

About 4 percent of the suggested research needs identified topics focused on the economics of water use and water policy. These mainly fell into two clusters – cost/benefit analysis of alternative programs and policies, and studies of market-based solutions to water management challenges.

Examples of economic research topics that respondents would find useful include:

- Cost-benefit analyses
    - "Risk evaluations to prioritize spending scarce dollars,"
    - "Economic analysis of most appropriate forms of regulation to encourage conservation,"
    - "Expectancy-value studies that result in behavior changes related to water consumption."
    - "Costs and benefits of moving toward larger economies of scale,"
    - "Clarification of benefits water user receive by adopting conservation practices,"
    - Better analysis of cost-feasibilities for water reduction and conservation programs,"
    - "Cost-benefit analysis of xeriscaping,"
    - "Develop cost effective approaches to effecting changes in water use behaviors,"
    - "What are the costs and benefits of water development? Will bringing water to the community bring more money to local governments?"
- Market solutions
    - "Studies of the successes made by other states in terms of water valuation using market prices,"
    - "New economic analyses of tiered water rate structures,"
    - "Research on water marketing"
    - "Case study assessments of market trading policies and strategies,"
    - "Pricing of water,"
    - "Predictions of future resource markets."

Management Research – (3%)

The final group of suggestions were management systems needs, most of which focused on a desire for better guidance in making well-informed decisions on water resources management. This section also included several comments indicating frustration with the adequacy of funding and staffing resources for water resources management at various scales. Some of the more useful suggestions (for prioritizing INRA research efforts) might be:

- "Techniques for how to make better decisions with not enough information,"
- "Education and training on the technical aspects of water operations,"
- "Water resource planning research (tools, model development, interactive models, adaptive management models, modeling scenarios),"
- "Application of more recent research and analysis tools,"
- "Development of a funding database,"
- "Development of infrastructure (such as gauging stations) and methods for sustainable funding for such projects,"

Research Needs Priorities by State

Because of the diverse biophysical, socioeconomic, and policy settings across the five INRA states, it was expected that there would be some particular research topics that would rise (or fall) in prominence in the different states. The results in Table 2.2.5 below reflect the percent of respondents in each state who suggested research topics in each of the major categories discussed above.

Table 2.2.5: Research Need Priorities by State

Type of Topic	AK	ID	MT	UT	WA	Total
Data collection standards & quality	4.9	5.7	4.5	3.6	0.0	4.8
Data dissemination mechanisms	1.6	8.0	2.3	4.8	6.8	6.2
Data Subtotal	*6.6*	*13.7*	*6.8*	*8.3*	*6.8*	*11.0*
Water Quantity	**31.1**	**24.2**	**18.2**	**21.4**	**22.7**	23.9
Water Quality	**14.8**	**14.6**	**43.2**	**20.2**	6.8	17.2
Climate and Drought	**11.5**	**12.7**	**13.6**	7.1	**25.0**	12.8
Watershed data	**11.5**	3.2	0.0	0.0	9.1	3.8
Other Natural Science Data	6.6	1.3	0.0	1.2	6.8	2.2
Natural Science Subtotal	*75.4*	*56.1*	*75.0*	*50.0*	*70.5*	*60.0*
Conservation Behavior	0.0	1.0	0.0	4.8	0.0	1.3
Consumption patterns	0.0	8.9	4.5	7.1	2.3	6.8
Sociological factors	6.6	9.6	6.8	**11.9**	2.3	8.8
Political factors	1.6	5.7	2.3	6.0	**15.9**	5.9
Economic factors	1.6	3.5	2.3	8.3	0.0	3.7
Social Science Subtotal	*9.8*	*28.7*	*15.9*	*38.1*	*20.5*	*26.3*
Management needs (general)	0.0	0.3	0.0	1.2	2.3	0.5
Management training	4.9	1.0	0.0	1.2	0.0	1.3
Funding concerns	1.6	0.3	0.0	1.2	0.0	0.5
Other	1.6	0.0	2.3	0.0	0.0	0.4
Management and Other Subtotal	*8.2*	*1.6*	*2.3*	*3.6*	*2.3*	*2.7*
TOTAL	100	100	100	100	100	100

The findings suggest that natural science research is the overwhelming priority for water resource managers in Alaska (over 75 percent of suggestions were in this category) and Washington (71 percent). Social science research is perceived as a higher priority in Idaho and Utah, where 29 and 38 percent of suggestions, respectively, highlighted human dimensions research as a top priority. Within these broad categories, it is clear that water quality research was an unusually strong priority in Montana, while climate and drought research and water rights law were much more common themes in Washington. Concerns about the adequacy of the water resources data infrastructure were highest in Idaho, since it was cited at nearly double the rates in most of the other states.

Research Needs and Priorities by Respondent Characteristics

A final analysis was conducted that examined possible relationships between the type of organization where a respondent worked and the types of research needs that they perceive as high priority. The results are shown in Table 2.2.6 below.

Table 2.2.6: Major Research Needs by Type of Organization

	Type of Organization Where Respondent Works			
Major Type of Research Need	Federal Agencies	State Agencies	Local City or County Government	Other (Private, Tribal, Nonprofit)
Basic Data Infrastructure	12.8%	7.8%	6.9%	13.5%
Natural Science Research	71.6%	70.2%	61.1%	47.0%
Human Dimensions Research	11.9%	19.1%	27.8%	37.8%
Management Challenges	2.8%	2.1%	4.2%	1.7%
Total observations	(109)	(141)	(72)	(230)

The results suggest that Natural Science research topics are viewed as higher priorities by persons who work in state and federal agencies. By contrast, human dimensions research topics were more frequently cited as higher priority needs by persons working in local government, tribal government, or in the private nonprofit or business sector. There was a notably higher level of concern about the adequacy of the water resources data infrastructure among federal agency staff and persons working in the private sector.

2.3 EDUCATION NEEDS

OVERVIEW

After being asked about the challenges they face in managing water resources in their job and information needs related to their employment, respondents were asked a number of questions related to educational needs. In particular, respondents were queried about INRA University Consortium's plans to develop a training program for graduate students in "integrated water sciences" that related to the following seven questions.

a. *What do you feel are the most important skills someone in your position should have?*
b. *If you were to do it over, what training or skills do you wish you had received while in college/graduate school?*
c. *Are there any water resource management topics on which you would like to receive updated training or knowledge?*
d. *How successful has your agency/organization been at identifying & hiring qualified people with the skills needed to work on water resource issues?*
e. *Do you feel that people graduating from regional universities have the right mix of education and skills to work well in this area?*
f. ***What are the specific types of knowledge, training, or skills that are most lacking among recent graduates?***
g. ***Are there any other suggestions you might have for INRA universities regarding the training of water resource management professionals?***

The discussion here focuses especially on f and g above. Responses to these questions were aggregated from each state and interview texts were inductively analyzed in order to determine common themes.

We identified two broad areas of educational needs:

- Those related to **traditional skills** learned in water resource management-related science fields, and
- Those related to **non-traditional skills** not commonly included as formal components of water-resource training programs (i.e., communication skills, social science training, and administrative skills).

Our analysis focuses on these two broad subcategories, as well as three subareas within each subcategory (natural science training, technical skills, real world experience, in the first instance; and communication skills, social science training, and administrative skills in the second). Table 2.3.1 shows the breakdown of responses as a percentage within the two broad subcategories (first column of percentages) and as a percent of all responses (the second column of percentages). While educational needs are broad-ranging, in the following paragraphs we provide detail about each category to show how respondents view these areas in conjunction with one another.

Table 2.3.1 Areas where Increased Education and Training would be Useful

Types of Educational Needs	# responses	% of subcategory	% of total
Traditional Water Resource Manager Skills	**302**	**100.0%**	**53.6%**
Natural Science Training (overall)	**137**	**45.4%**	**24.3%**
Hydrologic Sciences	38	12.6%	6.7%
Interdisciplinary Science Training	31	10.3%	5.5%
Disciplinary Basic Natural Sciences	28	9.3%	5.0%
Engineering	20	6.6%	3.6%
Applied Natural Sciences	16	5.3%	2.8%
Other	4	1.3%	0.7%
Technical Skills (overall)	**104**	**34.4%**	**18.5%**
Decision-Making Skills	26	8.6%	4.6%
Research Design and Analysis	21	7.0%	3.7%
Computer Skills	21	7.0%	3.7%
General technical knowledge	17	5.6%	3.0%
Math/Statistics	15	5.0%	2.7%
Other	4	1.3%	0.7%
Real World Experience (overall)	**61**	**20.2%**	**10.8%**
Real World Experiences	31	10.3%	5.5%
Internships	26	8.6%	4.6%
Field Smarts	4	1.3%	0.7%
Non-Traditional Water Resource Manager Skills	**261**	**100.0%**	**46.4%**
Communication Skills (overall)	**122**	**46.7%**	**21.7%**
Communication Skills	65	24.9%	11.5%
Public Education	26	10.0%	4.6%
Teamwork	18	6.9%	3.2%
Conflict Management	13	5.0%	2.3%
Social Science Training (overall)	**89**	**34.1%**	**15.8%**
Water Law and Policy	59	22.6%	10.5%
Other social sciences	30	11.5%	5.3%
Administrative and Management Skills	**27**	**10.3%**	**4.8%**
Miscellaneous	**23**	**8.8%**	**4.1%**
Total	**563**		**100.0%**

Traditional Water Resource Manager Training (54%)

Natural Science Training (24% of total)

Interestingly, only about 24 percent of respondents identified natural science training as a problem in current regional graduate training programs. The general sense from the interviews was that natural science training is critically important, and provides important background for water resource managers. However, most felt that the available natural science training programs were providing an adequate disciplinary science base for their graduates.

Just over half of the natural science educational needs focused on two topics: deeper training in hydrology and hydrogeology, and broader interdisciplinary training that integrates the various disciplinary sciences.

Hydrological sciences was a diverse category, including basic knowledge of hydrology, a focus on complete hydrologic systems, awareness of the role of water law, water conservation behaviors, water storage and availability, etc. Some specific examples of educational needs that we coded as "hydrology" included:

- basic understanding of hydrology,
- better understanding of surface and groundwater interactions,
- hydrogeology, and
- fluvial geomorphology

Examples of interdisciplinary training needs were diverse. Some focused on the integration of the natural sciences. Others emphasized the need to bridge the basic sciences, technical skills, and social and legal forms of knowledge. A sample of specific comments include:

- "Cross-discipline training," "Interdepartmental training," "Multidisciplinary approaches," and "Interdisciplinary education,"
- "A general understanding of biology and chemistry for engineers, and a better understanding of basic engineering principles for scientists and a better understanding of policy for all,"
- "Multidisciplinary nature, need the technical (ecological, engineering) as well as the social,"
- "Broad background/perspective (technical, economic, political, and social expertise),"
- "Solid training in physics, chemistry, surface and ground water quality, and hydrology,"
- "Integration of policy, hydrology, ecology, engineering,"
- "Solid foundation in technical/natural/biological sciences, and water law, legislation, and regulation,"
- "Knowledge in soils, physiology, hydrology, sociology, economics, psychology, biology, botany, natural science, anthropology, GIS, Remote sensing, water law," and
- "Technical knowledge and skills (hydrology, hydraulic engineering, geomorphology, riparian botany, aquatic ecology, fish biology)."

About 6 percent of all educational needs listed specific disciplines in the natural sciences, while 4 percent cited engineering training as a priority. A set of 'applied' natural sciences – including irrigation technology, watershed management, and public health topics included 16 suggestions.

Technical Skill Training (19% of the total)

While there is obvious overlap with the "applied" and "interdisciplinary" natural sciences listed above, we grouped 104 responses in a 'Technical skills training" category. About half of the suggestions in this category addressed the development of applied research and data analysis skills. For example, many respondents indicated that recent graduates needed to receive better training in applied research design, data collection, data management and data analysis skills. One respondent remarked that it's being able to "…see the forest, not the tree." Other comments mentioned the need to develop an ability to:

- "conduct experiments and write up results,"
- "understand and synthesize available data,"
- "critically evaluate data," or "discriminate important from unimportant information,"
- "make defensible estimates,"
- "critical thinking and analytic/reasoning skills"
- "make science applicable to decision-making"
- "ability to problem solve with limited information"
- "decision-making skills,"

At the same time, there were numerous general suggestions calling for more "basic technical skills" or "technical education, coursework, and knowledge." Some specific types of technical skills that were mentioned by significant groups of respondents as areas where graduate education could be improved include:

- GIS skills
- math and statistical skills
- practical water use knowledge
- water use measurement techniques

Real World Experience (11%)

A sizeable number of respondents felt that graduates of regional universities had insufficient real world experience to be effective in their water resource management roles. As such, there were many who wanted more "real world experiences" to be integrated into graduate training. These experiences range from hands-on skill building, practical field training and experience, and formal internships with public and private sector clients.

A flavor for the 61 comments in this section an be captured in the following quotes:

- "Ability to address real life concepts,"
- "Analysis of real world case studies,"
- "field experiences," "field classes," "hands-on experience"
- "practical experience" or "practical application of basic science skills,"
- "knowledge of agriculture, water use groups, utility industry,"
- "a desire to work in the field,"
- "field smarts," "field techniques,"
- "internships," "partnerships," "professional work-related practical experiences," and "on-the-job experiences gained outside the classroom."

Non-Traditional Water Resource Manager Skills (46%)

Our results suggest that training in natural sciences disciplines, research and technical skills, and real world applied experiences are all areas where improvements can be made in regional graduate school programs. However, these topics are common parts of most undergraduate and graduate training programs and the suggestions reflect incremental refinements and modest curriculum design changes.

By contrast, roughly forty six percent of suggested educational program improvements identified topics that are not as commonly found in standard university training programs. These 'non-traditional' skills are broken into three broad categories: communication skills, social science training, and administrative or management skills.

Communication Skills (22%)

The largest non-traditional category, communication skills, was suggested by almost one-fourth of all respondents. In addition to basic verbal and written communication skills, it consists of various subcategories, such as teamwork, conflict management, and public education skills.

The largest subgroup in this category was "basic communication skills," This category included general suggestions for "better communication skills", as well as people whom specifically identified non-technical writing and public speaking as particular skills that were lacking in many recent graduates. The focus of most comments was to emphasize the need for water resource management staff to be able to communicate their work with their colleagues, policy-makers, key stakeholders, or the general public. One respondent's reply succinctly put it into words as "…being able to communicate at a range of technical levels, from a farmer in a field to a researcher at a university." A similar response was, "…to be able to communicate with both peers and academics, as well as with water users."

A related, though distinct, subcategory was public education. Suggestions in this subtopic were specifically geared toward techniques for disseminating information to broader audiences through public relations plans, as well as educating the public on technical issues related to water use, conservation, and management. A smaller subset of this section included the need for better training in techniques for 'stakeholder assessment' and 'public input' processes.

Two subtopics in this section emphasized the need for better teamwork and conflict management skills. The first reflects interpersonal skills necessary for working in multi-disciplinary teams and/or projects that require professional scientists to work closely with persons who have less formal training. The second involves learning techniques for managing public discussions or meetings on contentious topics. In both cases, it appears that some recent graduates have not been exposed to or trained in modern techniques for these types of group processes.

Social Science Training (16%)

The category social science training taps into water law and policy in addition to general social science, business and economic dimensions, and city and regional planning.

The largest component of this subtopic emphasized training in water law and policy. The suggestion was frequently made that technically trained graduates of regional universities do not often have a sophisticated understanding of the legal issues surrounding water resource management in the west. Similarly, they have little understanding of the perspectives of various competing water user groups, and the sensitive cultural and political aspects of making water resource allocation decisions. A handful of comments also identified parallel issues with respect to the legal and social context of water quality regulations and programs.

Some illustrative quotes on these topics include:

- “Introductory water law course,” “water law and water rights,” “Legal knowledge,”
- “Indian water law,”
- “Ability to understand the effects of politics in water management,”
- “Appreciation for policy and regulatory development,” “Understanding government structures,”
- “Broad-based understanding of current laws, standards, and regulations,”
- “Clean Water Act information,” “Endangered Species Act,”

Other social science training that was felt to be lacking included the ability to “…understand the big picture”, or the “unique constellation of science, politics, and public policy,” in applied water resource management. More specific suggestions illustrated training programs that enhanced student’s understanding of the following topics:

- “The role of Indian tribes in water resource management,”
  “The social dynamics and cultural sensitivity of water use in the west,”
- “Knowledge of the social, legal, and historic aspects of the human-water interface,”
- “Training in the socioeconomic aspects of working with water resources,”
- “Business and economic aspects of water resource management,”

Administrative and Management Skills

A final set of suggestions emphasized the need for some graduates to have better administrative or management skills, comprising roughly five percent of the total. The main examples included:

- Public administration
- Project management and project administration
- Financial skills and fiscal management
- Management skills (personnel, finances, construction and facilities)
- Organizational skills (including multi-tasking)

Education Needs by State

A final analysis of the educational needs of INRA-region university graduates disaggregated the responses by state. The results are shown in Table 2.3.2 below.

Table 2.3.2: Perceived Education or Training Needs by State

Type of Education Need	**AK**	**ID**	**MT**	**UT**	**WA**	**Total**
Natural Science Training	**32.9**	**22.4**	**20.0**	**26.5**	**21.4**	**24.3**
Technical Skills	**17.1**	16.4	**24.6**	**20.4**	**17.9**	**18.5**
Real World Experience	**15.9**	8.2	10.8	11.5	11.9	10.8
Subtotal Traditional	*65.9*	*47.0*	*55.4*	*58.4*	*51.2*	*53.6*
Communication Skills	9.8	**26.5**	**32.3**	**19.5**	15.5	**21.7**
Social Science Training	13.4	**17.4**	6.2	14.2	**23.8**	15.8
Administration and Management	8.5	5.5	3.1	2.7	3.6	4.8
Miscellaneous	2.4	3.7	3.1	5.3	6.0	4.1
Subtotal Nontraditional	*34.1*	*53.0*	*44.6*	*41.6*	*48.8*	*46.4*
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0

Top three needs for each state are noted with bold text.

The overall patterns did not vary dramatically by state, suggesting that the development of new educational programs or initiatives throughout the region might emphasize a similar set of issues. The main differences noted here are that water resource managers in Alaska were more focused on improving natural science training skills than in the other states. By contrast, respondents in Idaho and Washington had higher rates of concern about the adequacy of training in the social sciences, especially water law and policy issues.

2.4 Partners and Information Sources

OVERVIEW

Respondents also were asked to think of the kinds of water resource management work that they had done over the previous year and to name the three sources of information they used most frequently in their work. A total of 427 responses were received, which were organized into eight major categories and 43 subcategories (see Appendix V).

The respondents also were asked to report the three partners, agencies, groups or stakeholders with whom they had interacted most frequently during the same period when working on water resource management issues. A total of 436 responses were received, which were organized into eight major categories and 19 subcategories (see Appendix VI).

Information Sources

As Table 2.4.1 shows, nearly half of the kinds of information sources cited by respondents across all of the states were categorized as public officials/staff personnel (45%), followed by double-digit proportions of responses indicating published data sources (nearly 14%), literature/publications/reports (over 13%), and Internet sources (nearly 12%). Roughly 10 percent of respondents cited groups and associations as major sources of information, while less than three percent cited meetings, conferences, legal advisors, or the general public.

The results suggest that applied water resource decision-makers and managers rely on personal contacts in state or federal agencies as sources of basic information more frequently than on published data sources, peer-reviewed publications, or the internet. This suggests that senior agency staff (as were more likely to show up in our interview samples) rely heavily on individuals to serve as a conduit for scientific data and information regarding water resource management decisions. For university scientists seeking to get existing scientific findings into the hands of senior managers, it is worth devoting time to figure out the appropriate people working at different levels who might be important parts of the information chain.

Table 2.4.1: Most Frequently Mentioned Information Sources (Frequencies and Percentages).

Type of Information Source	Frequency	Valid Percent
Public officials, staff, personnel	191	44.7
Published data sources	59	13.8
Literature, Publications, and Reports	56	13.1
Internet sources	49	11.5
Groups & Associations	43	10.1
Meetings, conferences, forums	11	2.6
Legal sources	9	2.1
General Public, Local Communities	9	2.1
Total	427	100

An analysis by state (Table 2.4.2) indicates that the largest proportion of category of important information sources for all states surveyed was public officials/staff personnel (between 42 and 49%). Published data sources were also reported as an important kind of information source in Montana, as were literature/publications/reports (17%); the general public and local communities (at nearly 4%) were mentioned as sources at a proportion twice that of Idaho (a little over 1%).

Groups/associations were much more important as sources in Utah (27%) than in any other state (especially Montana, where these received less than 1% of mentions as an information source). Utah respondents also mentioned published data sources, literature/publications/reports and Internet sources much less frequently.

In contrast, literature/publications/reports were frequently mentioned in Alaska (17%) as key information sources, along with the Internet (at much greater proportions than in either Montana or Utah); in those states, these kinds of sources were mentioned in higher proportions than in any other state. Also important in Alaska were published data sources (10%).

Respondents in Idaho were the most likely to mention all of the information sources, with particular importance placed on published data sources (nearly 20%) and Internet sources (nearly 12%) as sources of information. Also reported in Idaho was a relatively higher proportion of groups/associations (8%), with a lesser proportion of mentions of meetings/conferences/forums (over 2%) and the lowest proportion of any state in its mentions of general public/local communities (1.5%).

Table 2.4.2. Percentages of Most Frequently Mentioned Information Sources, by State.

	Percent by State						
Type of Information Source	AK	ID	MT	UT	WA	Total %	Total #
Public officials, staff, personnel	49.4	41.6	41.5	45.2	47.1	44.7	191
Published data sources	10.4	19.7	30.2	2.7	6.9	13.8	59
Literature, Publications, and Reports	18.2	9.5	17.0	8.2	16.1	13.1	56
Internet sources	13.0	11.7	5.7	9.6	14.9	11.5	49
Groups & Associations	6.5	8.0	1.9	27.4	6.9	10.1	43
Meetings, conferences, forums	0.0	2.2	0.0	2.7	6.9	2.6	11
Legal sources	0.0	5.8	0.0	1.4	0.0	2.1	9
General Public, Local Communities	2.6	1.5	3.8	2.7	1.1	2.1	9
Total N	77	137	53	73	87		427

Important Partners

The vast majority of partners cited by respondents across all of the states were categorized as agencies/public officials, followed by nearly one-fifth of the responses indicating that private/quasi-public groups were key partners (Table 2.4.3). Given that most of our respondents were public officials, it is perhaps not surprising that they would consult with one another on water issues. However, the relatively low frequency of regular working partners outside of the state or federal agencies might lead to a degree of insularity and prevent water resource managers from regular contact with stakeholders and/or the university research community.

Table 2.4.3. Most Frequently Mentioned Partners (Frequencies and Percentages).

	Frequency	Valid Percent
Agencies, Public Officials	312	71.6
Private or Quasi-Public Groups	77	17.7
NGOs, Environmental Groups, Professional Organizations	15	3.4
Irrigators, Water Companies	12	2.8
General Public	11	2.5
Consultants	6	1.4
Lobbyists	1	0.2
Media	2	0.5
Total	436	100.0

However, the most frequently mentioned kinds of partners varied noticeably among the states (see Table 2.4.4). The types of partners most frequently mentioned by respondents in Utah, for example, were almost evenly split between public agency officials and private or quasi-private water groups (mainly water districts and utilities). In Utah fairly small proportions (nearly three percent) also were reported for irrigators/water companies, consultants, and NGOs/environmental groups/professional organization, and just over one percent for the media and the general public.

Table 2.4.4. Percentages of Most Frequently Mentioned Partners, by State.

	Percent by State						
	AK	ID	MT	UT	WA	Total %	Total #
Agencies, Public Officials	88.0	77.3	76.5	42.9	69.0	71.6	312
Private or Quasi-Public Groups	6.0	12.1	19.6	46.8	10.7	17.7	77
NGOs, Environmental Groups, Professional Organizations	3.6	0.7	0.0	2.6	10.7	3.4	15
Irrigators, Water Companies	0.0	4.3	2.0	2.6	3.6	2.8	12
General Public	1.2	2.8	2.0	1.3	4.8	2.5	11
Consultants	1.2	1.4	0.0	2.6	1.2	1.4	6
Lobbyists	0.0	0.7	0.0	0.0	0.0	0.2	1
Media	0.0	0.7	0.0	1.3	0.0	0.5	2
Total	83	141	51	77	84		436

In contrast, nearly all of the kinds of partners reported in Alaska (88%) were agencies/public officials, with only six percent reported for private/quasi-public groups and over three percent for NGOs/environmental groups/professional organizations.

In Montana, the vast majority of the kinds of partners reported (79%) were agencies/public officials as well, with over 19 percent reported for private/quasi-public groups and two percent found for irrigators/water companies and the general public. Idaho's respondents reported somewhat similar proportions as Montana’s for agencies/public officials and private/quasi-public groups, but nearly double the proportions found for other states in terms of Idaho’s mentions of irrigators/water companies (over 4%) and of the general public (nearly 3%). In addition to consultants, the media and NGOs/environmental groups/professional organization, less than one percent also reported lobbyists.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

As outlined above, this needs assessment project was designed to identify high priority topics for future INRA research and to inform the design of new educational programs. The overriding objective was to document the perspectives of policymakers, elected officials, water users, and others with a stake in the Western water debates.

Because the vast majority of water scholars and research scientists tend work in academic settings, it is easy for university training programs and scientific research projects to loose touch with the realities of water resource management decision-making at the local, state and federal levels. Like anyone, university faculty members respond to the incentives and rewards provided by their departments, institutions, or professional organizations. These incentives tend to reward the pursuit of basic scientific questions, the development of core theories and conceptual models, and the publication of scientifically rigorous, peer-reviewed journal articles.

While this system of scientific research is critical to the continued development of our understanding of hydrologic processes and trends, the results may not always be easily applied to the practical problems faced by water resource managers in the West. The Inland Northwest Research Alliance Water Resources Research Consortium was created to help bridge this gap by taking several important steps:

1) To encourage the sharing of the latest scientific findings with the applied water management community,
2) To facilitate the development of new research programs designed explicitly to help answer critical questions and fill information gaps that prevent the effective and efficient management of water resources, and
3) To develop innovative educational initiatives for both undergraduate and graduate degree programs to help train future professional water resource managers and scientists.

The results presented above provide some general guidance and specific suggestions for areas that might be fruitful targets for future INRA research and educational initiatives. These suggestions reflect the expert judgment of the needs assessment team and are based on both the statistical summaries presented above as well as a comprehensive evaluation of the detailed interview narrative transcripts. However, they are intended to stimulate further conversation and exploration, and should be tempered by the expertise, experience, and perspectives of the water research scientific community and the public and private actors who are making day-to-day decisions regarding the allocation and management of water in the American West.

Understanding the Challenges Facing Water Resource Managers

When asked what obstacles and challenges they face in their current jobs, water resource managers were equally likely to cite natural science and social science topics. The natural science challenges reflected a diverse set of topics (ranging from water quantity, water quality, climate and drought, to other natural systems concerns). Social science topics included challenges linked with water rights law and policy, inadequate funding resources, and pressures associated with rapid population growth and change. In many ways, these challenges overlap and intersect, posing future challenges, necessitating further scrutiny.

While most managers identified limitations in the available scientific research base as key challenges, they also discussed the importance of improving management systems and the challenges associated with maintaining an effective water data collection and analysis infrastructure. Not surprisingly, for many respondents, improving existing types of water data and working to standardize and disseminate existing information are as important as developing new scientific models or understandings.

Some state-based differences were notable. Respondents in Montana, Idaho and Washington identified had relatively balanced sets of challenges (natural systems, human dimensions, management and data). In contrast, though human dimensions challenges were the largest category in both Utah and Alaska, the rank ordering for the other three categories differed. These similarities and differences should be explored in more depth in future studies.

Understanding Research Needs and Priorities

Overall, while basic natural science topics were not uncommon in our interviews, the dominant research priorities focused on more applied water science questions, including efforts to develop a better water monitoring and data collection infrastructure and the development of scientific models that can help explain impacts of human behaviors on the hydrologic system.

In the first instance, it is clear that there has been inadequate investment in the development and maintenance of water resource monitoring systems. Many respondents felt that they had to make decisions in the context of inadequate basic data about local water use, water supply, and water quality conditions. Specific criticisms were lodged at the problems of inconsistent measurement techniques and schedules, uncoordinated data storage systems, a lack of locally specific data, irregular data collection schedules, and long time lags between data collection and the availability of the information.

Secondly, it is clear that many of the natural science puzzles – such as better information about the interactions between surface and groundwater systems – are most important to decision-makers in the context of applied water management problems. Most of these problems are linked directly to social, economic, and land use changes associated with rapid population growth and the transfer of water from traditional agricultural sectors to urban or rural residential and commercial uses. Our interviews suggest that there is still a great deal that is not understood about human-driven changes taking place on the landscape and their associated effects on water use, water demand, and water quality in this region. Many of the research priorities summarized under the ‘Human Dimensions of Water’ label above fit into this category.

Many respondents did identify conventional basic natural scientific research as a priority, though a large fraction of these people emphasized that the greatest need was in the intersections of traditional scientific disciplines – including interdisciplinary, cross-disciplinary, and systems-level research. In some cases, these intersections involve various natural science fields; in others, they involve integrating social science perspectives and methods into studies of natural science phenomena.

A significant number of our interviewees had responsibilities to education the public about water quantity and quality issues. In most cases, these people felt that they would benefit from a deeper understanding of the techniques and tools available for communicating with the public. These tools might involve strategies for understanding the goals and experiences of diverse stakeholders, as well as efforts to change the behaviors of a broader mass of citizens.

A final insight from the research needs inventory is that there is considerable room for improving the quality and quantity of information that can be exchanged between the academic scientific community and the water resource managers included in our interviews. While not strictly a research priority, we believe that the feedback from interviews suggests that institutional barriers to interaction and communication across these two social fields are higher than they need to be.

In sum, understanding water resources and issues requires an approach that acknowledges generalities as well as contextual differences that convey past, present, and future challenges for water professionals and practitioners. For instance, while physical features of locations such as geography, climate, and size are integral to understating natural resources and their availability and spatial distribution, of integral importance also are understanding how other issues intersect with these physical features, including population changes, pressures for economic development, and various legal influences linked with supply and demand. Indeed, a complex chain of mutually reinforcing issues, actors, and agencies can be identified, as can interrelations that posit unique causal pathways.

Education Needs

Interview participants were asked to evaluate whether the training received by students in INRA universities is adequate to prepare them for work in typical non-academic settings. Overall, most respondents felt that the eight INRA institutions were providing an excellent scientific and technical foundation for applied water resource management in this region. However, a significant number of respondents identified areas where additional training or education might be useful.

Among natural science topics, the main emphases for improved education reflected a desire for (a) more interdisciplinary or systems-level integrated science training, and (b) more applied and hands-on experiences that make basic science knowledge more relevant for addressing actual water resource management problems and challenges. At the same time, there was a call for more technical skills in research design, data collection and analysis, statistics, and GIS.

One of the most striking patterns in the interviews was the strong emphasis on the need for training in more ‘non-traditional’ topics. Specifically, the lack of adequate communication skills among natural science program graduates is seen as a serious problem by a wide range of interviewees. Similarly, there is a desire to expose science and engineering students to the complexities of water law and policy debates in the West before they arrive on the job market.

Core Recommendations

Research Priorities:

Some basic recommendations for INRA research priorities based on the needs assessment include the following broad topics:

- **Encourage investments in the water monitoring and data collection infrastructure.** While this may or may not include a role for INRA university institutions, there is likely a considerable in the needs of the water resource management and the scientific research communities for better water resource monitoring systems.
- **Encourage interdisciplinary and applied scientific research** designed to illuminate the dynamics of water quantity and quality in the context of human-impacted environments.
- **Help predict the impacts of future population growth, land use changes (such as the shift from agriculture to residential uses), and different water policies on patterns of consumption of and demand for water resources.**

A much more detailed list of more specific research priorities were summarized above, though many of the substantive suggestions fit into these three categories.

Changes in the research priorities on INRA university campuses will be complicated by the fact that all universities are organized around traditional disciplines and there are strong career disincentives for students or faculty to engage in interdisciplinary or highly applied research.

However, seed monies and targeted research initiatives to attract this type of innovative research might well be required to fill some of the information gaps identified in our interviews. Similarly, investments in better communication between university and non-university actors is clearly required to ensure that state-of-the-art scientific knowledge is made readily available to decision-makers (and that the problems faced by decision makers are communicated to public research scientists).

Education Priorities

The core educational needs that could be addressed by INRA might include:

- More interdisciplinary courses
- More systems-level or integrated water science courses
- More real world experience
- Better communication skills
- More awareness of social, economic and political dimensions of water problems

While it is easy to identify areas where new educational programs should be developed, it does not follow that universities are well positioned (or even well advised) to undertake a dramatic reshuffling of their educational missions. For instance, it is important to recognize that many graduate programs are designed to train future academic scientists/professors. Similarly, many graduates of these programs may go on to different types of careers in the public or private sector. In each instance, broadening course requirements or changing training approaches may have inadvertent impacts on other groups of students.

It is encouraging that many INRA campuses are engaged n conversations about creating integrated water science degree programs or other interdisciplinary training programs that encourage or require students to build a broader understanding of the various water-related sciences as part of their training. There are also efforts to increase opportunities for students to get hands-on, real-world experiences through internships and partnerships with public and private organizations. It would seem appropriate to target some of INRA's resources to support these initiatives.

APPENDIX I: Sampling Protocol

SUGGESTED SAMPLING METHODOLOGY

Needs Assessment Interviews of
Elected Officials, Policy Makers and Major Water Stakeholders

Dr. Charles Harris & Dr. Douglas Jackson-Smith
July 12, 2006 version

Purposes of Fieldwork:

1. **Identify research and information needs** to address regional problems of drought, water shortages and water supply in the face of regional growth and changing demands for water; assess current situations and patterns of change in water availability, demand and use.

2. Conduct focused interviews to **elicit specific researchable topics** towards which INRA Water Resources Consortium research efforts can be directed

Fieldwork Procedures

1. **Conduct a review of literature** on water resource issues for each state and recent water management activities -- to begin identifying key contacts, current water management needs, geographic areas and priorities.

2. **Construct a master sampling frame** of potential key informants. This sampling frame list will be used to select a subset of individuals for the fieldwork interviews. This involves identifying diverse individuals who are knowledgeable about water issues and/or actively involved in water resource management in this region.

    a. These will include knowledgeable agency or organizational representatives (analysts, staff, and decision-makers) as well as key stakeholders, including elected officials and representatives of relevant organizations. Example 'categories' that were outlined in our original proposal include:
        - Federal Agencies
            - Bureau of Reclamation
            - Fish & Wildlife Service
            - Others?
        - State Government
            - Water Resources Agencies
                - State engineers & water rights staff
                - Water planning agencies
                - Water quality agencies
            - State Agriculture Department staff
            - State Economic Development staff

- Regional Governments
    - Water conservancy districts
    -
- County Governments
    - Association of counties
    - County commissioners & executives
    - County water advisory boards
    - County planners
- City Governments
    - Association of cities
    - City mayors & council members
    - City planners, water departments, environmental departments
- Tribal Governments
- Non Governmental Organizations and Water User Groups
    - REGIONAL?
        - Hydropower utilities (e.g., Pacificorp)
        - Environmental and Wildlife Organizations
            - Audobon/birders, Ducks Unlimited, Salmon groups,
        - Recreation Organizations
            - River rafters, lake boaters, etc.
    - STATE?
        - Associations of water users (irrigation/canal groups)
        - Agricultural organizations (Farm Bureau, Others)
    - LOCAL?
        - Local irrigation districts and canal companies
        - Local Chambers of Commerce
    - Others?

b. Begin by identifying key contacts in important statewide and regional agencies and organizations – Agency, NGO, etc.
    i. Use university colleagues & other key individuals to identify who are important actors/players within each category
    ii. Supplement these lists with internet searches of agency/organization website listings for staff & administrators
    iii. Use snowball sampling ---
        1. Begin by contacting a person high up in an organization or agency and ask them to identify the individuals in their organization who are the best resource people for our purposes
        2. As we conduct interviews, be sure to conclude each interview by asking the informant if they can think of other individuals who would be good to contact

c. For some categories, we will need to identify a subset of the total universe of possible people (or places) that meet our criteria. The goal would be to have a sample that covers the diversity or range of water resource management challenges within each state.
    i. Examples of situations where we will need to purposively sample include:
        1. Regional water conservancy districts
        2. County governments
        3. City governments
        4. Local irrigation companies or water user groups
    ii. In cases where there are many potential people or places that qualify, we will select a subset of places/people that maximize the following things:
        1. Ensure coverage of the full diversity of current, recent or potential water supply/demand and water management issues in each state; this means picking at least one place that is a good representative of each type of issue
        2. Ensure coverage of diverse geographic regions (represent the full diversity of current recent or potential water supply/demand and water management issues
        3. Include examples of places where there are well-known water-resource policy debates or water resource data needs, or that are engaged in significant water management efforts (e.g., comprehensive basin planning, conservation programs, etc.); these areas would include cities and counties, as well as larger watersheds and basins.
        4. Where possible, consider balancing the selected places to ensure that we learn about the different data / research needs of places that are:
            a. Urban vs. rural interests and problems
            b. Agricultural vs. non-agricultural interests
            c. Government vs. non-governmental perspectives
            d. Tribal vs. non-Tribal interests and problems
            e. Economic vs. environmental perspectives

3. **Prioritize which key informants to contact first**. Once we have a master frame of potential informants in each state, we should prioritize specific names to use in a first round of interviews. Based on the results of this first round of interviews, we can then strategically pick a second round of contacts to complement those already completed.

APPENDIX II: Key Informant Interview Contact Protocol

INTERVIEW & ANALYSIS METHODOLOGY

Needs Assessment Interviews of
Elected Officials, Policy Makers and Major Water Stakeholders

Douglas Jackson-Smith & Chuck Harris
July 14, 2006 version

ARRANGING INTERVIEWS

Once you have a set of names selected for interviews, you will need to contact these potential informants and arrange a time to conduct the interview. We suggest a progressive contact approach that might include all or some of the following steps:

1. Send a pre-contact letter

   Before each interview, it is desirable that every respondent know a certain amount about the goals of our project, be made aware of any risks or benefits associated with the research, and have a chance to think about the specific questions we intend to ask. As such, it makes sense to try to send every potential respondent a precontact letter and a copy of the "Informed Consent Information Sheet" that you developed for your particular state/institution.

   A copy of a draft cover letter and the Utah version of the informed consent sheet are appended below. Note that the cover letter includes examples of the key questions we might ask.

2. Contact key informant by telephone, arrange the interview

   The goal of the telephone contact is to (a) answer any questions the informant might have about the study, and (b) make an appointment for the actual interview. Tell them that interviews should take between 30 minutes to an hour (we may change this estimate after some fieldwork experience…!)

   Depending on your situation ($$, travel logistics, etc.) you might arrange any of three kinds of interviews:
   - individual face to face interview
   - individual telephone interview
   - group interviews

   It may even be best for the respondent to conduct the interview during your initial phone contact, and you should be prepared to accommodate them if it makes sense.

CONDUCTING INTERVIEWS

Each interview situation might be a little different, but the basic steps involved will include several steps. However, there are general principles of effective interviewing that might be worth reviewing. These include:

THE INTERVIEWER'S REPERTOIRE

- preparation = key (know your instrument inside and out)
- have answers prepared to common questions (why are we doing this…?)
- think about probes ahead of time
- strategies for eliciting details (when you get initial short/shallow answers)
    - the anticipation pause (wait 10 seconds to create mildly uncomfortable silence)
    - the simple probe (say "…go on"..) -- echoing (convey you are hearing what they say)
    - the assertive probe (say "can you say more about that?")

TEN COMMANDMENTS OF INTERVIEWING

1. Never begin an interview cold (warm up with small talk)
2. Remember your purpose (keep your eyes on the prize, stay on track)
3. Present a natural front
4. Demonstrate aware hearing (sit up, look at them, respond to their comments with appropriate body language or verbal cues)
5. Think about appearance
6. Interview in a comfortable place (quiet, confidential, uninterrupted)
7. Don't be satisfied with monosyllabic answers (see strategies above)
8. Be respectful
9. Practice, practice, practice
10. Be cordial and appreciative

SPECIFIC GUIDELINES

1. Personal interviews (face to face with an individual)
    - Confirm appointment by phone, email or mailed letter (if possible)
    - Record the interview (with the permission of the informant) for future reference and analysis
    - Write rough notes during the interview
    - Synthesize the interview notes as soon as possible (using a word processor) in the formats suggested below.

2. Telephone interviews (with an individual)
    - Confirm appointment by phone, email or mailed letter (if possible)
    - Record the interview (with the permission of the informant) for future reference and analysis – you may need special equipment to record a telephone call
    - Write notes during the interview
    - Synthesize the interview notes as soon as possible (using a word processor) in the formats suggested below.

3. GROUP interviews
    - BACKGROUND & WARNINGS
        - Only use these if there are significant advantages (in terms of travel logistics, scheduling people, or unique opportunities to get access to multiple people at a pre-arranged event).
        - Note that formal 'focus group' methodology requires that the participants be relatively homogenous or similar in most important respects. The point of a focus group is to encourage informants to feed off of one another's comments, and to gain greater depth in their answers. To be successful, it helps to
            - have folks who share certain types of experience (most likely relative to water resource management), AND
            - have a group that does not include people who have different status or rank relative to one another – specifically avoid situations where some of the participants might be reluctant to speak openly because of the presence of another particular person in the room
    - LOGISTICS
        - Confirm date/time of the meeting with all participants in advance (if possible)
        - Review the confidentiality agreements & ground rules for the group interview before you begin
            - Note that you will be the moderator & notetaker
            - Tell them to be respectful of one another
            - encourage everyone to participate equally
        - Record the session (if everyone gives permission) for future reference
        - Write up your notes in a way that allows you to distinguish between different individual participants in the group (with particular attention to the individuals' key attributes or job/role as it might affect our interpretation of their feedback)
        - Synthesize your notes and type up using one of two forms
            - A set of separate individual interview summaries, or
            - An amalgamated 'group' summary

EXAMPLE PRE-CONTACT COVER LETTER

DATE

XXXXXXX
Address
City, ST Zip

Dear XXXXXX,

You have been recommended (by _____) as someone able to offer some insights into water resource management in this region. I am writing to ask if you are willing to be interviewed as part of a study of funded by the U.S. Department of Energy that seeks to **identify high priority data and information needs for water resource management** in this area. Researchers at 5 public universities in Alaska, Idaho, Montana, Utah and Washington are collaborating on this study. The results will help direct future research dollars to high priority areas.

We particularly are interested in your views on the challenges faced by those trying to manage water resources during periods of drought, climate volatility, population growth, and economic transformation, and your suggestions for what kinds of new information or data could improve management of water resources in this region.

I will be contacting you by phone in the next week to arrange a time for an interview.

To help you prepare for the interview, we thought it would be helpful if you knew some of the questions that we will be asking. These include:

- What are the greatest issues or challenges for water resource management that you face?
- What kinds of data or information do you regularly use to address these issues? How adequate is the existing data or information?
- What new kinds of data or information would be most helpful as you address this issue?
- Thinking back over the last 5 years, can you think of any specific instances in which you did not have the data or information you needed to address this issue?
- Do you feel that people graduating from regional universities have the right mix of education and skills to work well in this area?
- What specific types of knowledge, training, or skills do recent graduates lack?

I want to emphasize that **participation in this study is voluntar**y and if you agree to participate in this study, your comments and opinions will be kept **strictly confidential**. You are able to stop the interview at any time or refuse to answer any questions that might make you uncomfortable. No names or information that identifies study participants will be included in any findings reported from this project without the expressed permission of the participant.

Again, I look forward to contacting you by phone in the next week to see if we can arrange a time for an interview.

Sincerely, XXXXXXXXXXXX,

INFORMED CONSENT STATEMENT

Water Research Needs Assessment

Inland Northwest Research Alliance Water Research Consortium

Overview of the Study

This project is being conducted by researchers at 5 Western Universities: Utah State University, the University of Idaho, Washington State University, the University of Alaska-Fairbanks, and the Montana State University. The project is sponsored by the Inland Northwest Research Alliance (INRA) -- a consortium of 8 universities in the region who received funding from the US Department of Energy to initiate a research and educational program related to drought and water resource management in this 'inland northwest' region. Over the next few years, the INRA Water Research Consortium will perform research related to the complex interactions between climate change, watershed and landscape changes, water supply and quality; ecosystems, and humans.

The current project is designed to identify high priority topics for future INRA research. Specifically, we plan to consult with policymakers, elected officials, water users, and others with a stake in the Western water debates to identify their most pressing data and information needs.

How were you chosen?

You have been recommended as someone able to offer some insights into water policy issues in this region, with a focus on the challenges faced by those trying to manage water resources during periods of drought, climate volatility, population growth, and economic transformation in the American West. We hope to interview 30-40 people per state for this project.

What kinds of information do we want to gather?

We will gather information about the important water resource management issues in your area. Of particular interest will be your ideas regarding the adequacy of existing data and information resources, and your recommendations for high priority areas toward which future water-related research might be directed. We are also interested in learning about the job skills and competencies that might be required of future graduates from our institutions seeking employment in the water management area.

Information will be gathered in personal and group interview settings using a semi-structured interview schedule. Interviews may take from 30-120 minutes.

Is your participation required?

Your participation in this study is entirely voluntary. Specifically, you have the right to terminate participation for any reason at any time without penalty. In addition, you have the right to refuse to provide specific information or answer questions that you are not comfortable sharing with us.

Possible risks and benefits associated with the study

We believe there are very minimal risks associated with participation in this project. None of the topics listed should be sensitive, and efforts will be made to respect your privacy.

Throughout our work, we will take steps to ensure that your identity is kept confidential. . Respondent answers will be recorded using written notes and (with permission) audiotape recordings. The audiotapes will used to verify any quotations used from the interviews, and facilitate possible graduate thesis or dissertation research on water research needs in this region (under the supervision of one of the principal investigators). Individual respondents will be tracked using ID numbers, rather than names or other identifying information. If we do wish to use direct quotes from your responses, **we will contact you for permission before using your name or identity in any of our reporting of the results**. All of our original interview notes and tapes will be will be stored in a secure manner and will not be shared with any other researchers, organizations, or agencies. To further protect respondents, we will destroy the list of participant IDs within 1 year, and the audiotapes within 3 years.

The benefits of this project could be significant. The information you provide will help us determine how to target future research and educational programs to be most useful to water managers, officials, and water user groups in this region. We strongly believe that the voices of potential data users & stakeholders should shape the prioritization of future research efforts and the design of innovative educational programs. We hope that our efforts will lead to the development of actual resources that can assist your own work on water issues.

A summary of the findings from this study will be provided to you at the conclusion of the project if you would like.

Contacting the researchers

If you have any questions or concerns about this study at any time, we encourage you to contact the scientists who are leading this project. The lead investigator in Utah is:

Utah State University
Dr. Douglas Jackson-Smith
ph: (435) 797-0582
email: douglasj@hass.usu.edu

If you wish to directly contact the Utah State University Institutional Review Board regarding this project, you should call or write to: True Rubal at (435) 797-1821, 1450 Old Main Hill, Logan, UT 84322, or by email at true.rubal@usu.edu.

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By signing below, the lead researchers agree to abide by the terms of this document. Your participation in this interview will be treated as evidence that you have read the above information and are willing to participate in this study under these terms.

____

Dr. Douglas Jackson-Smith

APPENDIX III: Key Informant Interview Instrument

INRA Water Research Consortium
Needs Assessment Project

KEY INFORMANT INTERVIEW SCHEDULE

FINAL VERSION

Information about our project to be read (or summarized) to the respondent before each interview

This project is being conducted for the Inland Northwest Research Alliance – a Consortium of 8 public universities in Alaska, Idaho, Montana, Utah, and Washington.

The group was created by Congress to conduct coordinated multidisciplinary research on water resource management challenges facing this region, with particular interest in the impacts and management of periodic droughts.

A critical component of this project is a "Research and Information Needs Assessment."

This Needs Assessment involves detailed conversations with policy makers, elected officials and diverse water user groups to determine the information and data needs that future INRA research could address.

The results of our assessment will help determine priorities for the allocation of future research dollars & identify specific data or information needed to improve water resource management in this region.

We will also use your feedback to help design an multi-institutional graduate training program at the INRA universities that will focus on integrated water sciences.

Before we start, do you have any questions about this project?

2. **<u>Background & Context</u>**

a. **What is your position or official job title?**

b. **How would you describe your own work or activities with respect to water resource management** in (Alaska, *Idaho, Montana, Utah, Washington*)

c. **How long have you worked in this capacity?**

d. **How did you get into this type of work?**

e. **What types of formal and informal training have you had that has prepared you for your work with water resource issues?** *(if they don't volunteer it, also ask about their highest level of formal education and specialization)*

f. **Are you originally from this area?** (If not,) how long have you lived here?

- -

NOTE: if you are working in <u>a group interview situation</u>, you might simplify this first page by asking everyone present to go once around the group and introduce themselves by talking specifically about:

- *who they are*
- *what they do in their work*
- *what kinds of background, training or experience they have had in this area*

In these settings, you might also back off worrying about the individual demographic information in the summary templates.

When you are addressing a <u>larger meeting or group</u> (not in a formal interview context), you might limit this to asking people to briefly introduce themselves and explain what they do in their work. The core questions you might ask a large (non-interview) group are highlighted in yellow on the next two pages.

3. <u>Water Management Challenges & Information Needs</u>

a. What are the 3 greatest issues or challenges for water resource management that you face in your work?

1) ______________________________

2) ______________________________

3) ______________________________

b. Probe for each type of issue:

- **i. Lets focus on (***Issue X***). In what ways is this issue challenging?**
- **ii. How has this issue changed in recent years?**
- **iii. What kinds or information is <u>most critical</u> to your ability to address this issue?**
- **iv. What are <u>the most important sources of information</u> you use to address this issue?** *(Be sure to get as specific as possible about the type of information and the source of the information).*
- **v. How adequate is the existing information?**
- **vi. In what ways could this information be made more useful?**
- **vii. What new kinds of information would be most helpful to you as you address this issue?**

c. **Thinking back over the last 5 years, can you think of any <u>specific instances</u> in which you did not have the information you needed to make good decisions about water resource management?** *If you can think of several, pick the most important or most common type of situation.*

- **i. What was the problem you were trying to address?**
- **ii. What kinds of information did you need?**
- **iii. Where did you try to find information?**
- **iv. What did you find?**
- **v. What kinds of information were you <u>unable to find</u>?**
- **vi. Do you think this type of information exists? If so, where?**

d. *(If drought has not been discussed by this point – ask:)* **Thinking specifically about periods of drought – what are some of the most notable information gaps that affect your ability to make informed <u>drought management</u> decisions?**

e. *After reviewing all the various types of information needs mentioned by the respondent, ask….***Of all the specific types of information gaps that you've mentioned, could you rank each one as a potential focus for future university research, with "1" being the <u>highest priority</u> area?** *(for large groups:* **what are the top priorities for future university research on water resource topics?**

f. **Before I change topics, are there any other suggestions or comments that you would like to share regarding areas where better science or information sharing could improve water resource management in this area?**

4. <u>Education Priorities</u>

Preamble Aside from generating research that can meet the needs of water resource managers in this region, the INRA University Consortium plans to develop a training program for graduate students in "integrated water sciences." I now want to ask you a few questions that might help us design this training program.

a. What do you feel are the most important skills someone in your position should have?

b. If you were to do it over, what training or skills do you wish you had received while in college/graduate school?

c. Are there any water resource management topics on which you would like to receive updated training or knowledge?

d. How successful has your agency/organization been at identifying & hiring qualified people with the skills needed to work on water resource issues?

e. Do you feel that people graduating from regional universities have the right mix of education and skills to work well in this area?

f. What are the specific types of knowledge, training, or skills that are most lacking among recent graduates?

g. Are there any other suggestions you might have for INRA universities regarding the training of water resource management professionals?

5. <u>Networking and Information Sources</u>

a. Think of the kinds of water resource management work that you have done over the last year. **What THREE sources of information did you use most frequently in your work**? *(Possible sources could be individual people, agencies/organizations, sources of specific data, journals/publications, websites, etc.)*

b. **During the same period, what THREE partners, agencies, groups or stakeholders did you interact with most frequently when working on water resource management issues?**

6. **FINALLY: can you think of one or more key individuals who might be a good person for us to talk with for this project?** *(If yes – get name & contact information)*

NAME:	Contact information
____________________	______________________________
____________________	______________________________
____________________	______________________________
____________________	______________________________
____________________	______________________________
____________________	______________________________

- -

I want to thank you for taking the time to provide feedback for our needs assessment project.

Do you have any questions you want to ask me before we finish?

Would you be interested in seeing the results of our study? (We expect to have a final report in the winter or early spring).

APPENDIX IV: Key Informant Interview Narrative Summary Template

Interview Summary Information: ID#: ______

INTERVIEW NARRATIVE (1-2 pgs)

- include description of interviewee & interview context
- include discussion of challenges
- include discussion of info gaps & research priorities
- include discussion of education needs
- include discussion of info sources & key partners
- include key quotations and any other relevant info

INTERVIEW SUMMARY:
Short sentences/bullets in each category; be as specific as possible
For group interviews, note areas of agreement and disagreement

- Respondent's Role/Job (or describe all individuals in group interview):
- Biggest Challenges
- Information Gaps (Any mentioned)
- Research Needs (Rank Ordered)
- Education Priorities
- Top Information Sources
- Top Partners/Collaborators/Stakeholders

INTERVIEW CODING

Check all that apply

Total interview time: ______minutes **Was recording made?** ☐ **yes** ☐ **no**

Comments on how interview went:

____

____

____

Organization Type:

- ☐ Federal agency
- ☐ State agency/board
- ☐ County government/board
- ☐ City government/board
- ☐ Tribal government
- ☐ Nonprofit organization
- ☐ Private company
- ☐ Other: ____________________

Scale/Region of Work:

- ☐ Local/county
- ☐ Multi-county region
- ☐ Statewide
- ☐ Multi-state region
- ☐ Other: ____________________

INDIVIDUAL CHARACTERISTICS

(perhaps ignore for group interview settings)

Job Description:

- ☐ Elected official
- ☐ Administrator/Director
- ☐ Technical staff
- ☐ Outreach staff
- ☐ Member
- ☐ Other: ________________

Highest Degree and Training

- ☐ < BS
- ☐ BS
- ☐ MS/MA/MPA
- ☐ PhD
- ☐ JD
- ☐ Other: ________________

Discipline/Specialization (highest degree)

Describe: ________________________

Years experience working on WRM:

____

Our own subjective assessment of respondent's WRM expertise

- ☐ Very knowledgeable about or experienced with water management issues
- ☐ Knowledgeable or experienced on water management issues
- ☐ Moderately knowledgeable or experienced on water management issues
- ☐ Slightly knowledgeable or experienced on water management issues
- ☐ Not knowledgeable or experienced on water management issues
- ☐ Other: ________________

Appendix V: Major categories of sources of information.

Literature/Publications/Reports/Studies

- State agency
- WRRI
- DEQ
- American Water Works Association
- Libraries
- Text books
- Journals/bulletins
- In-house publications
- University publications and guides

Public Officials/Personnel/Agencies (Water-mgt-related)

- **State officials/staff**
  - State conservation coordinators
  - Engineers/hydrologists
  - Contacts
  - State agencies
    - DWR/Water agencies
    - DEQ
    - F & G
    - State Water Board/Conservation Board
    - Attorney General
    - Public Utilities Commission
- **Federal officials/staff**
  - Contacts
  - EPA
  - BOR
  - USGS
  - USDA
  - NOAA/Nat. Weather Serv./Climate Center
  - RMRS
  - NPS
- Tribal officials
- Consultants/seminars
- Centers -- Academic/Research – WRRIs
- Conferences/networking/other public sector contacts/colleagues
- County/Local planners
- Universities & faculty
- Contacts/Colleagues/Experts

Appendix V: Major categories of sources of information (continued)

Groups/Associations
- Conservation District
- Regional Water District/Water Master
- AWWA
- State Water Users Assoc.
- Tribal Consortium
- NAITI
- NGOs/Water environ. groups/Stakeholder groups
- Irrigators/water users
- Companies/Industry hydrologists

Data
- Federal
- State
- Conferences
- Own field data
- Internet
  - Weather
  - Water
- Agency data
  - BOR
  - DWR
  - USGS
- Industry
- Local/regional study
- Maps/Geospatial data

Internet
- Federal site
- State site
- Policies
- Budget
- Reports/publications
- Webinars

Meetings/forums
- Conferences
- Meetings
- Workshops

Judicial Rulings/Law reviews
- Attorneys

General Public/Locals

Appendix VI: Major categories of partners

PARTNERS

Officials/Personnel/Agencies
- **State officials/agencies**
  - State conservation coordinators
  - Engineers/hydrologists
  - Contacts/colleagues
  - State agencies
    - DWR/Water agencies
    - DEQ/DEC/DNR/Dept of Ecology
    - F & G
    - Dept. Ag.
    - Bureau of Mines & Geology
  - Legislators/Politicians
  - State Water Board
- **Federal officials/Agencies**
  - Contacts/colleagues
  - EPA
  - BOR
  - USGS
  - USDA
  - NOAA/Nat. Weather Serv./NMFS
  - Forest Service/USFS
  - DOD
  - NRCS
  - BLM
  - DOI
  - USFWS
  - BIA
  - Army Corps
- **Data generators/providers**
- **Local governments/school districts**
  - Municipalities/Communities
  - Counties
- **Health departments**
- **Universities/Centers -- Academic/Research**
- **Colleagues/Other contacts**
- **Tribal officials**
  - Consortium
  - Dept.s
  - Tribal Councils

Appendix VI: Major categories of partners (continued)

Public/Private Groups

- **Conservation/Conservancy Districts**
- **Regional/Local Water Districts**
- **National Water Assoc.'s/AWWA/NWRAssoc.**
- **State Water Users Assoc./Watershed Coordinating Council**

- **Private Industry**
  - Utilities
  - Developers
- **NAITI???**
- **Researchers (Agency)**
- **Local water boards & groups**
  - Councils/Watershed Groups
  - Working groups/teams
  - Technical Advisory Groups

Irrigators/Water Users/Ditch Companies

Consultants

General Public

- **Locals**
- **Landowners/Dischargers**
- **Stakeholders**
- **Permit holders**

Lobbyists

Media

NGOs/Environmental Groups/Professional Organizations

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[i] Utah Division of Water Resources, Long-term Water Supply Outlook
http://www.water.utah.gov/droughtconditions/WaterSupplyOutlook/default.asp July 12, 2006

[ii] Utah Center for Climate and Weather
http://www.utahweather.org/drought_is_waning.html

[iii] Utah Division of Water Resources, Utah's Water Resources: Planning for the Future
http://www.water.utah.gov/waterplan/uwrpff/TOC.htm

Appendix B
Research Plans and Project Abstracts

Year 2 Research Plan

2006 Final Research Plan

Committee Recommendation

The INRA Water Research Consortium's Regional Scientific Research Plan will integrate regional needs for water resources research in interdisciplinary scientific, social, and economic areas of water management in times of drought. The final research categories will be defined within the concept of a decision-makers' "Tool-Kit" identified as part of the Regional Needs Assessment. Although this needs assessment is currently being developed, the original proposal was predicated on our understanding of current regional needs and thus this initial seed grant request for proposals will focus on these broadly defined areas.

The goal of the initial call will be to initiate projects at all eight INRA institutions. Given the current level of resources, it is anticipated that one project will be funded at each university regardless of the number of proposals received from each university. Although INRA will send out the call, it is expected that individual steering committee members will actively solicit proposals from their respective institutions. Since the review process is intended to objectively evaluate the merit of each proposal without being overly burdensome, the proposals will be of modest length. The proposal requirements are shown in Table 1.

Table 1. Required Format and Components of Proposals

Topic	**Subcategories**	**Page**
Cover Page	Title Abstract PI contact information: Name Institution Phone E-mail	1-page
Proposal	Regional Problem Statement Project Objectives and Scope Methodology by Objective Information Dissemination Policy Implications Collaborative Features Statement of Benefits Opportunities for Competitive Grant Funding	8-page
Resume	One for each PI/Co-PI	2-page per PI
Budget Summary	By Expenditure	1-page
Budget Justification	Detailed Explanation by Budget Category	1-page
References		no limit
Support Letters	Agency or Other Potential Funding Sources	2 letters

While there is no exact formula for collaboration, in the spirit of this project it is expected that collaboration be broadly defined as "meaningful and substantial involvement by at least one faculty member from at least one other INRA university." Because of the desire to provide maximum flexibility, collaboration may mean faculty from other INRA institutions provide active participation in a single proposal, submit a companion proposal, or be involved with an existing project where the additional INRA funding clearly provides a value-added opportunity for leveraging. Other beneficial partnerships, such as those with state governments or other non-INRA institutions, are encouraged but are NOT sufficient to satisfy the collaboration requirement.

Reporting Requirements:

The committee recommends that a 1-page progress report be submitted to the Steering Committee through INRA every 6 months with a digital version of the final report being submitted within 30 days of project completion.

Proposed Timeline:

The proposed timeline for these activities is shown in Table 2. Arguably this is an ambitious schedule and Steering Committee members must adhere to all of the deadlines in order to complete it as planned.

Table 2. Schedule of Activities

Call for Proposals	**Proposals Due**	**Initial Review**	**Final Review**	**Award Notice**
August 28, 2006	October 6, 2006	October 20, 2006	November 3, 2006	November 17, 2006

Call for Proposals:

Using the approved Executive Summary of the project, a Call for Proposals will be developed by the Subcommittee by the end of July. The Call will include a statement on research priorities (i.e., regional needs as identified in opening paragraph), and will specifically stress both the scientific and social/economic/policy avenues of research. The RFP will be approved by the Steering Committee in early August so that it can be sent out according to the above timeline.

Budget:

Considerable discussions were held regarding the various alternatives and possible combinations of funding avenues for dispensing the Year 1 research money. After examining the pros and cons of each alternative and keeping in mind that our initial goals are to:

* build capacity at all INRA institutions
* promote collaborative research and education programs
* develop a procedure for proposal development, review, and award

* insure INRA has a measurable presence at all institutions
* get the program off the ground as quickly as possible
* keep all INRA institutions engaged in the process

the Steering Committee opted to fund a single project at each INRA institution during the initial grant cycle period.

The budget for each project should be $62,500 including the student stipend, tuition, health insurance and applicable university overhead. All projects must fund at least one graduate student to meet the objectives of the plan.

In subsequent years, assuming the better part of $3M were available for research and education, the process would morph into:

1. An INRA fellow at each university
2. A more competitive grant program where collaboration between institutions was encouraged but funding would simply be based on the highest ranking proposals being selected regardless of institution.

Proposal Reviews:

Initial Reviews -

Each proposal received by INRA prior to the closing date of the RFP will be distributed electronically to 3 reviewers from the Steering Committee not actively involved with the proposal (i.e., at a different university) or any collaborative feature of the proposal. Steve Billingsley will decide who gets which proposals to review. A consistent proposal review form will be developed in order to standardize ranking to the maximum extent possible. The review form will be developed by the Research Plan Team and approved by the Steering Committee prior to receiving proposals.

Final Review Panel –

A review panel consisting of the entire Steering Committee will meet face to face in Boise, Idaho to evaluate the reviews and make the final selection regarding which proposals to fund.

Award Notice:

The anticipated start date will be January 1, 2007. Having an award notice date of November will give successful proposals time to attract and identify the proper graduate student for the task. However, there is some flexibility in the start date if the PI is not ready to begin the project at this time.

THE INLAND NORTHWEST RESEARCH ALLIANCE
WATER RESEARCH CONSORTIUM

CALL FOR PROPOSALS

August 28, 2006

The Inland Northwest Research Alliance (INRA) is please to announce a request for proposals (RFP) related to the INRA Water Research Consortium's effort to conduct research related to the complex interactions between climate variability; watershed and landscape alterations; estimating basin water budget; water quality; ecosystem impact and response; demographics; and human impact and response. Proposals will be accepted from any INRA institutions. Details of the RFP are provided below.

Background

Arid western regions are especially susceptible to impacts of water shortages. In our naturally water-limited area, drought affects both water quantity and water quality. Understanding the complex interaction of anthropogenic and natural factors affecting the water cycle and their resultant impacts on water resources within our geographically dispersed region requires expertise in many disciplines, including agriculture, climatology, chemistry, geography, geology, hydrology, engineering, ecology, economics, forestry, sociology, environmental science, and watershed management. The water shortages associated with wide spread drought conditions impact energy supplies, municipal and agricultural water supplies, recreational activities, and ecological needs of fish and wildlife.

INRA, a non-profit scientific and educational organization consisting of eight Western research universities (Boise State, Idaho State, Montana State, Utah State, and Washington State Universities; and the Universities of Alaska Fairbanks, Idaho, and Montana), has developed a strategic initiative with a long-term objective to establish a multi-institutional, interdisciplinary Water Research Consortium that improves our capability to predict and monitor water shortages and provides policy makers with potential remedies to the problems created by water shortages. A program to address these problems must integrate interdisciplinary, multi-institutional research and education. This Program will facilitate sharing of expertise, facilities and information in addressing regional water resources problems. Collectively, the INRA research institutions possess the depth of understanding necessary to conduct multi-faceted, inter-disciplinary research and education activities in order to understand these complexities and to predict water shortages and to better manage our water resources. The long-term approach for this program will:

1) Create a regional scientific research plan that coordinates future INRA research on key drought and water supply issues. These issues include (among others) complex interactions between climate variability; watershed and landscape alterations; estimating basin water budget; water quality; ecosystem impact and response; demographics; and human impact and response.

2) Use the understanding synthesized and information gathered in Step 1 to develop decision-making and outreach tools for our public policy makers. Such management tools and public education efforts, informed by high-quality research and development, will assist decision makers in addressing the concerns of their constituencies during these drought cycles.

3) Help society prepare for the inevitable occurrence of drought through science education and public outreach. We will improve graduate and undergraduate training and educational outreach by accessing collective faculty expertise to meet the critical demand for a new generation of graduates and teachers, trained to address social, environmental and economic issues of drought. We will recruit undergraduate and graduate students from underrepresented groups that have a stake in drought impacts and water-resource management. This will include development of a multi-disciplinary, multi-institutional graduate degree program, distance delivery of courses, graduate fellowships, and coordination among researchers contributing to this program.

A critical need involves access to information and data that decision-makers will need for making water-resource and water-use decisions. Currently, not all data relevant to a potential decision, such as water status and trend information, are available, and if they are available, are often not accessible except to the very specific scientific discipline for which they were developed. Available data, besides being useful to only a small segment of the water resource community, are often not integrated with one another.

Another significant need for critical information is data associated with past policy decisions related to water resource management, including the processes by which decisions were made, the outcomes of those decisions, and the relative success or failure of the outcome to achieve the goal desired from the decision-making process.

The final primary need associated with information, and access to information is the current inability for various constituencies that are concerned with water resource management to successfully utilize the information. Policy makers often do not have the scientific background necessary to interpret and synthesize data provided by the scientific community. Likewise, scientists and engineers can lack the social science and policy backgrounds necessary for understanding the impacts of their research and their advice. Finally, the end users that bear the brunt of these water management decisions are often not familiar with either the policy-making or the scientific arenas. Policy-makers and researchers need to make certain that information can be utilized by those who will be implementing decisions.

Research is needed answer questions in process science, policy science and information science. The outcomes of these hypothesis-driven research projects can be incorporated into a "Tool-Kit" for decision-makers. Proposals covering a broad range of water resources related topics are acceptable although projects that transcend typical discipline-specific research are especially encouraged. The following list of priority areas was generated to demonstrate typical areas of interest:

Hydrologic Cycle o Improve process model development for complex mountain systems: water/snow, nutrient, sediment, and carbon budgets o Conduct monitoring of semiarid mountain watersheds to develop comprehensive local hydrologic data sets o Improve knowledge of spatial variability by ground-truthing remote sensing data o Improve insight of surface/groundwater interactions o Response of riparian vegetation; stream down cutting; wet meadow recharge; exotic species to changing hydrology. o Improve estimates of water requirements for fish and wildlife. o Examine temporal and spatial dynamics of water quality in streams, rivers and lakes due to drought. o Investigate how plant communities impact carbon/nitrogen recycling and sequestration relative to climate change. o Determine hydrological responses of watersheds altered by human development in the human/wildlands interface.	**Drought Mitigation** o Forecast how water scarcity affects water value and uses. o Investigate economic impacts of water allocation on society. o Improve systems for estimating and predicting water use. o Planning for growth – conservation vs. development vs. ecosystem needs. o Water allocation: legal and social issues for instream protection: water rights; transfers; water banks; and public trust. o Benefits/costs analysis of policy alterations; adoption, compliance, regulations, and incentives. o Examine the physical /economic/biological costs and benefits of water banking. o Improve understanding of aquifer storage and recovery issues: geochemistry; water law; hyporheic transport; surface/GW interaction; and riparian vegetation.
Climate Change o Examine drought in relation to projected climate change. o Investigate spatial scale of drought to determine regional variations. o Couple atmospheric, surface, and groundwater research with geospatial and remote sensing information and tools. o Improve links between global climate models and regional climate and process models. o Explore impact of global climate change on snow hydrology – diminished snow pack; aerial extent; and persistence. o Identify large-scale atmosphere patterns and modeling regional climate change at different time scales. o Evaluate ratio of snow to rain in water to human and natural ecosystem response to drought conditions.	**Fire** o Improve predictive capability of fire response to drought and climate change. o Examine trends in fire frequency as a function of drought. o Determine long-term impacts of fires on water availability. o Investigate species changes as a result of fire and climate change. o Examine trajectory of recovery within watershed. o Examine interaction between drought, insect infestation, and fire.
Social Science	**Economics**

Proposal Format

Please pay specific attention to the required format of the proposals. Proposals not strictly adhering to the format specified in Table 1 the will be rejected without being reviewed.

Table 1. Required Format and Components of Proposals

Topic	Subcategories	Page
Cover Page	Title Abstract PI contact information: Name Institution Phone E-mail	1-page
Proposal	Regional Problem Statement Project Objectives and Scope Methodology by Objective Information Dissemination Policy Implications Collaborative Features** Statement of Benefits Opportunities for Competitive Grant Funding	8-page
Resume	One for each PI/Co-PI	2-page per PI
Budget Summary	By Expenditure	1-page
Budget Justification	Detailed Explanation by Budget Category	1-page
References		no limit
Support Letters	Agency or Other Potential Funding Sources	2 letters

** Collaboration: While there is no exact formula for collaboration, in the spirit of this project it is expected that collaboration be broadly defined as “meaningful and substantial involvement by at least one faculty member from at least one other INRA university.” Because of the desire to provide maximum flexibility, collaboration may mean faculty from other INRA institutions provide active participation in a single proposal, submit a companion proposal, or be involved with an existing project where the additional INRA funding clearly provides a value-added opportunity for leveraging. Other beneficial partnerships, such as those with state governments or other non-INRA institutions, are encouraged but are NOT sufficient to satisfy the collaboration requirement.

Reporting Requirements:

All projects selected for funding will submit a 1-page progress report to the INRA Water Research Consortium Steering Committee every 6 months with a digital version of the final report being submitted within 30 days of project completion.

Evaluation Criteria

Each proposal will be reviewed by technical experts using the criteria shown in Table 2.

Table 2. Proposal Evaluation Criteria

Categories	Points
♦ Regional Problem Statement	5
♦ Project Objectives and Scope	10
♦ Methodology by Objective	25
♦ Information Dissemination	5
♦ Policy Implications	5
♦ Collaborative Features	10
♦ Statement of Benefits	10
♦ Graduate Student Involvement	10
♦ Opportunities for Competitive Grant Funding	5
♦ Budget Justification	10
♦ Support Letters	5
Total =	100

Submission Requirements and Deadlines:

Proposals, with university approved budgets, should be submitted electronically in MS Word or Adobe PDF format by **close of business October 6, 2006** to:

Michelle Rutledge
Executive Assistant
Inland Northwest Research Alliance, Inc.
151 North Ridge Ave, Suite 140
Idaho Falls, Idaho 83402

E-mail: mrutledge@inra.org

Timeline

Anticipated Schedule of Activities

Call for Proposals	Proposals Due	Initial Review	Final Review	Award Notice
August 28, 2006	October 6, 2006	October 20, 2006	November 3, 2006	November 17, 2006

Year 2 Research Abstracts

DROUGHT, FIRE AND TIMING OF SNOWMELT IN CENTRAL IDAHO

Dr. Jennifer Pierce
Boise State University
208-426-5380
jenpierce@boisestate.edu

Dr. Jim McNamara
Boise State University
208-426-1354
jmcnamar@boisestate.edu

Dr. Cathy Whitlock
Montana State University
Bozeman MT 59717
406-994-6910
whitlock@montana.edu

ABSTRACT

The proposed project will investigate relationships between hydrology, climate, and fire activity in the Sawtooth Mountains area of central Idaho. Recent studies indicate that the incidence of large fires in the western U.S. is highly correlated with changes in the timing of spring snowmelt and peak spring streamflow. The correspondence of wildfires with the timing of snowmelt is not surprising: earlier snowmelt should lead to longer dry seasons, soil moisture defects, and a longer period of successful ignitions. This project will use stream gage data, snowmelt and soil moisture data from SNOTEL sites, soil moisture data from field instrumentation, burn area data from USDA Forest Service records, and longer-term records of drought and fire to examine relationships among the timing of snowmelt, peak runoff, soil moisture, and fire in the Sawtooth region. Establishing relationships between antecedent hydrologic conditions, summer drought and fire could provide mangers with a powerful predictive tool to plan for severe fire seasons.

While meteorological data, recent fires, water shortages, and lower lake levels all provide ecological evidence of the current drought in central Idaho, records of past droughts are poorly documented. Placing the current drought within the longer-term context is critical to understanding the natural range of variability within the ecosystem. Substantial collaborations with Dr. Whitlock (MSU) will provide a longer-term context for modern relationships between snowmelt, drought and fire activity which will allow assessment of whether or not recent droughts and fires are unprecedented over millennial timescales. This proposed study will examine modern and historic relationships among streamflow, snowmelt, soil moisture and fire: Dr. Whitlock's work examines centennial to millennial records of drought and insect infestations. Parallel research by Boise State and MSU will therefore provide a history of drought and disturbance in central Idaho on annual to millennial timescales.

This project provides needed data for forest and water management. Relationships between the timing of snowmelt, peak streamflow and fire can be used to more accurately predict severe fire seasons several months in advance. This will facilitate effective resource allocation by both forest managers and communities living in fire-prone areas throughout Idaho. Second, synthesis of the timing of snowmelt from this study can be used to identify changes in the timing of the onset of spring in central Idaho. Earlier spring snowmelt related to rising global temperatures has been documented in other watersheds throughout the West. The high Sawtooth Mountains form the headwaters of the Boise, Payette, and Salmon River systems, and changes in the timing of snowmelt could significantly impact water storage capabilities and increase risks of flooding. Finally, placing recent droughts, fires, and insect infestations within a longer-term context will provide information about if and how forest management and land-use have changed disturbance regimes in central Idaho forests.

Coupling management of water quality and quantity: How do hydrology and biological activity interact to control nutrient concentration and export in an impaired Intermountain watershed?

Abstract

Many rivers worldwide are degraded by both eutrophication and altered flow regimes. However, to date these two problems have largely been addressed independently by scientists and watershed managers alike. Daily and seasonal patterns of biological activity and hydrology interact to control river nutrient concentrations and export patterns. We hypothesize that diel and seasonal cycles of dissolved oxygen and carbon caused by biological activity directly and indirectly affect cycles of nitrogen and phosphorus transported and processed within the Portneuf River. Further, we hypothesize that nutrient transport and export depend on the relative timing and magnitude of biological activity and flows. Thus, we expect future changes in hydrology (e.g., due to climate change, decreased irrigation withdrawals, etc.) may have positive or negative effects on watershed nutrient export, depending on the timing of flows relative to peaks in biological activity. To test these hypotheses, we will measure nutrient loads in relation to daily and seasonal cycles of biological activity in the Portneuf River network, including the mainstem and tributary streams, to achieve more accurate load estimates and to identify potential biological nutrient processing mechanisms. We will then combine this empirical study with hydrologic modeling to investigate the interactions between flows and nutrient processing and export. Finally, we will use hydrologic scenario modeling to predict how changes in water management may affect nutrient pollution in the Portneuf River network. This research will have important water quality management implications for the Portneuf River, and other nutrient rich, hydrologically altered rivers nationwide.

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Linkages Between Climate, Watershed Structure, Land Cover, and Snow Runoff Dynamics: Initiation of the ICEWATER Regional Experimental Watershed Constellation

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Understanding how water moves through watersheds is crucial to water resource planning. Precipitation and snowmelt entering a watershed follow a wide range of flow pathways resulting in a distribution of travel times to the stream. Consequently, stream flow at any given moment is a mixture of water from a range of watershed source areas and flow pathways. In the case of snowmelt runoff generation (spring melt), streamflow is composed of older resident soil/groundwater and new snowmelt. Isotopic techniques can be used to first separate streamflow into the current year's snowmelt contribution and past years' soil water/groundwater contributions. Additionally, estimates of the travel times (residence time) of snowmelt that makes it to the channel outlet separately from the travel time of older stored groundwater is critical to understanding the sources and controls on runoff across watersheds of varying structure and size when combined with distributed hydrometric measurements. We seek to link process scale observations from the point and plot, to semi-distributed transects across characteristic landscape positions, to the accumulated controls on streamflow source areas and travel times across nested watersheds. Our approach combines spatially and temporally intensive observation and data collection, time series analysis, and parsimonious watershed modeling. We seek to integrate multiple scales, and modes of observation and analysis, to provide information critical to maintaining and predicting sustainable water resources in the face of mounting population pressures, resulting land use changes, and a changing climate. Specific objectives to be addressed at the Tenderfoot Creek Experimental Forest include:

1. To evaluate the spatio-temporal heterogeneity in snowmelt dynamics, runoff source areas, and the impacts of terrain and forest practices through investigation of thresholds in snowmelt, soil water and water table development.
2. To separate new snowmelt runoff direct contributions to streamflow from resident (old) groundwater (GW) contributions to spring runoff across sub-watersheds, to further evaluate the residence time of new water and to build a data set to quantify the old water residence time in each of 7 watersheds.
3. To quantify the first order controls on spatio-temporal runoff dynamics and new snowmelt/old groundwater runoff partitioning through the synthesis of field observations and tracer experiments in a predictive modeling framework assessing the link between model complexity and validation.

Our goal is to link spatial and temporal scales of observation through empirical analysis and watershed modeling to aid the transfer of understanding in space and time. Feedback between observation and modeling synthesis is critical for system understanding and development of modeling approaches that are consistent with physical processes. We are working to build lasting tools and infrastructure for research and education, and to begin to address themes critical to the region including drought, snow dynamics (e.g., the relationship between SNOTEL sites and watershed scale heterogeneity), climate change, forest operations, fuels management, and streamflow forecasting. Although research in one set of experimental watersheds is valuable, regional issues are best addressed through regional scale synthesis. Therefore, we propose ICEWATER **(I**NRA **C**onstellation of **E**xperimental **WATER**sheds). Significant data resources (e.g., distributed snowpack properties; hydromet, LiDAR (ALSM) topography, and remote sensing data; stream gauges; networks of wells and piezometers; eddy flux towers; SNOTEL sites; snowmelt lysimeters; forest manipulation experiments, etc.) exist at a few experimental watersheds in the region, but no mechanism currently exists to coordinate information gathering, sharing, synthesis and comparison. Developing regional synthesis and networks of experimental watersheds is critical in the snowpack-dependent inland northwest. We will initiate a dialogue across the region via a symposium of university research groups working in experimental watersheds, land and water managers, and public policy interests. Our proposed activities leverage ongoing research and infrastructure, direct match of college and department resources, and will facilitate opportunities for integrated research and teaching.

Long-term Ecohydrologic Variability in the Sawtooth Region of Central Idaho: Establishing a Baseline for Assessing Water Resource Issues

An INRA IWRC Proposal

Submitted by

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ABSTRACT

The Sawtooth National Recreation Area (SNRA) of central Idaho has been severely disturbed by the recent drought and increased spring and summer temperatures. Water shortages can affect natural resources, disturbance regimes, recreational opportunities, and local livelihoods. The ecological manifestations of current drought are evident in the vast areas of beetle-killed forest, increased likelihood of catastrophic fires, and lowering of lake levels. Although water shortages are dramatic, the occurrence of such conditions in the past is poorly documented. Are current drought levels unprecedented, and if so, on what time scale? Have mountain pine beetle (*Dendroctonus ponderosae)* infestations occurred during other dry periods and, if so, are they always associated with large fires? Current climate projections of warming conditions in this region point to a need for more information about natural climate variability and its effects on forest health and hydrology. This study is a collaborative effort between Dr. Whitlock (Montana State University) and Dr. Pierce (Boise State University). The MSU-INRA project will examine the ecohydrological history of a small, relatively simple watershed in the SNRA to reconstruct environmental changes over the last 11,000 years. The high-resolution analysis will help determine the frequency of drought events occurring on decadal to millennial year time scales and assess the ecological response to past droughts, in terms of fire, insect outbreaks, lake-level adjustments, and vegetation changes. The BSU-INRA project will investigate modern relationships between hydrology, climate, and fire activity in the same region and provide an important calibration data set for the longer record. This part of the research is motivated by observations that recent fire years in the northwestern U.S. are associated with a trend towards reduced snowpack, early spring snowmelt, and more-severe summer drought. Our poor understanding of critical linkages between antecedent hydrologic conditions, summer drought, fire, and insect outbreaks limits management efforts that seek to consider historical range of variability and future climate projections. For example, we do not know the nature of ecohydrological thresholds that might greatly alter disturbance regimes, forest health, and key ecosystem services, such as clean water, timber, habitat, recreation, and local economic viability. The study will utilize and complement research activities underway by cooperating scientists from Montana State University, Utah State University, and Idaho State University, who are looking at the ecology and hydrology of Sawtooth lakes, streams, and glaciers. It will also build on a USDA-funded study to examine the record of recent insect outbreaks in lake sediments in the Sawtooth region. The information obtained from this project will also provide relevant teaching materials for students, teachers, and visitors interested in understanding a region currently experiencing dynamic ecological changes.

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Freshwater Social-Ecological Systems: Analyzing Alaska's Institutional Capacity for Water Security and Hydrological Change

Abstract

The water security of the far Northwest region faces particular challenges related to climate change, remote rural populations, and historical lack of policy research. This project treats Alaska's freshwater management as a social-ecological system and researches the relative fit of state institutions to provide water and information about it to policy-makers and citizens. It also examines the capacity for coordination across scales and among water managers for current and future water information sharing, resource development, and adaptive strategies for future hydrological change.

Total Project Request: $62,500

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INRA UI-WSU Complementary Water Resources Research Proposal

A Proposal for a Parallel Projects Collaborative Research Effort

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To be submitted to INRA through IWRRI

Abstract

The goal of the water resources research proposed here is to lay the foundation for a long-term research initiative that would build upon and address research needs currently being identified with the INRA assessment of water-resources research needs for the state of Idaho. Specifically, the funded research would, first, expand on and refine a protocol currently being developed at the University of Idaho (UI) for providing an integrated systems-modeling approach to linking socio-economic demand for water with groundwater and surface water supply data, and also for assessing impacts of water use on hydrologic systems and thus water supply. Second, the research would organize and coordinate a collaborative, inter-disciplinary, inter-institutional and inter-state research effort to implement this approach. The study area for the research would be the Palouse Basin, which spans parts of the states of Idaho and Washington. This project would focus specifically on the Idaho sub-basins of this larger basin, while a parallel project being proposed by collaborating researchers at Washington State University (WSU) would focus on portions of basin in the state of Washington. The proposed WSU research would examine the effect of changes in water rights and potential water policy instruments on water use and future water availability in the Eastern Washington side of the Palouse Basin. The UI's Idaho effort would parallel and complement the WSU research, emphasizing assessment of the current socio-economic as well as hydrologic conditions in the basin, and then the modeling of projected changes in demographics and climate and their impacts on water resources, based on the water balance modeling being conducted for the Palouse Basin.

Contribution of Glacial Melt to Water Resources in NW Montana: Past, Present and Future

A research proposal to
The Inland Northwest Research Alliance Integrated Water Research Consortium

ABSTRACT

More than 37 glaciers currently exist in Glacier National Park where the annual water runoff from just 1 km^2 of glacier ice is on the order of $6x10^6$ m^3. Glacier Park glaciers were significantly larger and more numerous a century ago. The reduction in the area of NW Montana covered by glacier ice has likely caused reduced late summer flows in streams, and can be expected to continue to reduce late season water resources in upcoming decades. To interpret this effect in our historical records, and to forecast its impact on future water resources and associated ecological and human issues, we must have a solid understanding of the contribution glaciers make to Montana river flows – past, present and future. We will develop and apply new methods for separating the glacier derived component of runoff from the annual hydrograph with glacier covered basins in NW Montana. We will first simulate glacier runoff in the present day by three independent methods. The three methods will allow cross checking, and importantly, calibration of a new numerical model for simulating glacier flow dynamics on a large-scale landscape. Calibration of this model will allow proper simulation of future change to glaciers and associated runoff, and reconstruction of past glaciers and their contribution to late season flows in streams. Our work will result in a new method for assessing the impact of climate change and variability on small glaciers which is important to water resources of portions of the mountain west and many regions of the world.

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Analyzing the effect of watershed topography on water residence time and hydrologic scaling in semi-arid, alpine catchments

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Abstract

Understanding how water moves through a watershed is a critical component of water resource planning. Catchment water inputs (e.g., snowfall, rainfall) follow a variety of different pathways resulting in a range of travel times. In most cases, instantaneous stream discharge is composed of both recent surface inputs (e.g., snowmelt or rainfall runoff) and older water from resident storage compartments (e.g., soil, groundwater). Thus the residence time distribution (RTD) of stream discharge is an essential parameter that provides integrated information about water sources, watershed storage capacity, and the nature of dominant flow pathways within a given catchment. The overall objective of this study is to estimate the water residence time distribution in several nested watersheds of varying size, composition, and structure located in northern Utah and to examine factors that may exert a primary control on properties of the distribution. In so doing, our goal is to provide crucial decision support information in the face of mounting population pressures, water resources development, and a changing climate. Our specific objectives may be summarized as: (1) quantify the relationship between spatial and temporal variation in the dynamics of snowmelt, runoff generation, and water residence time, (2) evaluate patterns of relationship between residence time and catchment size for scale-dependent, threshold behavior, and (3) assess the effect of a variety of topographic and geologic attributes on mean residence time to develop simple predictive relationships for ungauged catchments. Our approach combines spatially and temporally intensive data collection, as well as time series and geospatial analyses. We will use stable isotopes (^{18}O) in simple mixing and lumped parameter tracer models to separate recent from older waters and to estimate water RTDs. We will then analyze relationships between various aspects of the water RTD, watershed geology, and topographic attributes derived from a digital elevation model. Our proposed research leverages ongoing scientific efforts and infrastructure to address regional needs for improved understanding of snowmelt-discharge relationships. However, our work will be further enabled and enhanced by synergistic collaboration with active university research groups working in experimental watersheds throughout the region. Development of a regional scientific synthesis through networks of experimental watersheds is a vital step in addressing ongoing and upcoming challenges in regional water resource management.

Snow Redistribution and Water Storage at a Watershed Scale: Field Investigation and WEPP Simulation

A research proposal submitted to the Inland Northwest Research Alliance (INRA)

Abstract

The availability of water is undoubtedly the most important factor affecting agricultural production in the western US. This is particularly true for the dryland farming region of the Pacific Northwest (PNW). Current practices used to manage crops and residues often result in significant redistribution of precipitation and highly variable within-field quantities of stored soil water. Field locations where water has been removed through wind transport of snow or surface runoff often have inadequate recharge of the root zone, despite sufficient precipitation. In contrast, the capacity to store soil water is often exceeded in locations that accumulate snow or receive surface runoff or subsurface lateral flow or both. Consequences of field-scale redistribution of water include greater spatial variability of crop yield, soil erosion, soil-borne disease, anaerobic soil conditions and off-site transport of soluble agrichemicals.

Numerous watershed hydrologic models have been developed. Yet few explicitly account for both physical hydrological processes, including snow redistribution, and the biological processes of vegetation growth and residue decomposition. WEPP (Water Erosion Prediction Project), a process-based model, was developed by the USDA-ARS for use in agricultural watersheds. WEPP simulates hydrological and water erosion processes on cropland, rangeland, or forested areas. It also includes a module for snow redistribution. This module, however, has never been properly tested.

Our overall goal is to improve the understanding of snow redistribution and thus the spatial variation of stored soil water on a watershed scale, which can in turn provide key information for developing management strategies to increase the uniformity of nutrient use efficiency and overall yield potential of crops and to decrease soil quality and environmental degradation associated with an over supply of water. To achieve this goal we will: (1) evaluate the impact of different crops and residue management practices on snow accumulation and redistribution as well as soil water storage that occur on a watershed scale; and (2) evaluate and refine the WEPP model for simulation of snow redistribution and soil water storage using watershed and field-scale measurements.

Successful modeling of snow hydrology will improve our understanding of management impacts on snow transport and enable cost-efficient assessment of alternative cropping systems and residue management scenarios. Yet the utility of information generated from this study extends far beyond improving local soil water storage. Understanding the redistribution mechanisms of snow will allow us to (i) better predict flood runoff caused by rain-on-snow events and water erosion from agricultural lands by knowing the runoff source location, (ii) establish a mechanism for application of fertilizers, pesticides and herbicides in relation to water availability to improve yield potential in precision agriculture, and (iii) better comprehend the hydrologic impacts of global climate change at the sub-watershed level. Therefore, the proposed study is significant and critical to evaluating economic feasibility and enhancing agricultural sustainability in the western US.

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Year 4 Research Plan

INRA Water Research Consortium
ICEWATER 2009 Final Research Plan

The purpose of the ICEWATER network is to foster the holistic understanding of water resources in the intermountain region through various activities aimed at stimulating synthesis and integration across multiple experimental watershed and aquifer sites. Towards this purpose, the goals of the FY09 ICEWATER research program are to

1) Conduct collaborative research addressing themes identified in Section II, and
2) Test and refine the ICEWATER Hydrologic Information System by contributing diverse and complex datasets.

Approach: The FY09 ICEWATER research program will distribute funds to each university to develop projects that contribute to both goals. The steering committee has identified three themes to pursue that contribute to the aims and objectives of this research plan, capitalize on the strengths and resources of the INRA universities, and foster collaboration amongst INRA institutions. INRA representatives at each university should select a specific project or projects that

1) Contributes to at least one of the research themes identified below,
2) Identifies how the data generated will enhance the HIS,
3) Develops a plan to participate in an ICEWATER Collaborative Activity

RESEARCH THEMES
Theme 1. Snowmelt and Runoff:
In the inland northwest area winter snowpack controls regional water resources. The inland northwest snowpack is highly susceptible to climate and land cover change. Despite the outstanding need for improved understanding of the first-order controls on snowmelt runoff processes and controls, little research has been conducted in the inland northwest on the linkages between snow accumulation, snowmelt, watershed characteristics, runoff source areas, and water routing. This thematic research area will help to fill a critical, strategic niche in our understanding of the hydrologic processes that control water yield and flow regime across this complex region. The focus on snowmelt-hydrology-climate interactions is particularly relevant given that snow-dominated headwater areas generate a large component of regional water resources. These areas are subject to land cover alteration due to natural or human-induced processes such as timber harvest, mechanical thinning for fire hazard risk reduction, insect-induced mortality, and species changes. This research area will link spatial and temporal scales of observation through empirical analysis and watershed modeling to aid the transfer of understanding in space and time. The research will continue regional synthesis that will ultimately advance societal abilities to develop adaptive strategies to optimally manage water resources within a dynamic and variable climatic regime.

- The University of Montana proposes to investigate the sensitivity snow distribution in mountains to climate change.

- Montana State University proposes to take advantage of a comprehensive set of data resources in an instrumented mountain watershed to study snowmelt/streamflow dynamics. MSU researchers propose regional synthesis activities with other ICEWATER sites operated by Boise State University, University of Idaho, Idaho State University, and Utah State University.

- The University of Alaska has a long history of snow research in northern, snow-dominated watersheds. UAF researchers propose to participate in comparative studies assessing the impacts of climate change on the hydrology of cold-regions watersheds.

- Idaho State University proposes to instrument and investigate a new experimental watershed in western Alaska.

Theme 2. Groundwater/Surface Water Interactions

Rivers are central elements of natural and human water resource systems in the Inland Northwest. Rivers integrate surface and groundwater systems, yet they represent a nexus in traditionally disparate scientific and resource management fields. Improved management of water resources in the Inland Northwest requires improved understanding of the dynamics of groundwater and surface water interactions in our river systems. Three universities have proposed Groundwater-surface interaction research:

- Boise State University proposes to quantify GW-SW interactions under two important, generic settings (i.e., major river as a large-scale flow system terminus and local interactive flow system boundary, and intermittent stream(s) in mountainside watershed) in the Boise River system.

- The WSU ICEWATER Project research ideas include two surface/groundwater interaction projects; 1) continuation and expansion of the spatial recharge monitoring network in the Spokane Valley-Rathdrum Prairie (SVRP) watershed and 2) expansion of the Pataha Creek (PC) tillage practice impacts on summer base flows monitoring/modeling project.

- The University of Montana proposes to investigate the impact of the removal of the Milltown Dam on surface-water – groundwater interactions and the changes in water quality and quantity as a consequence of dam removal.

- Utah State University proposes to evaluate the uncertainty associated with quantify groundwater-surface water interactions by different methods.

- The University of Alaska Fairbanks proposes to study groundwater – surface water interaction above and below the permafrost layer.

Theme 3. Human Altered Systems

By most measures, modern human settlement of the Inland Northwest, and the entire western United States, has only been possible through our ability to manipulate ecological resources—specifically water. From a policymaking perspective any number of questions arises about our ability to sustain and maintain this ability to manage the provision of this ecological service. Perhaps the most important, is the ability of water management institutions to withstand the shock of adapting to rapid change in the underlying ecological systems. The proposals submitted by the ICEWATER members all, to some extent, address one the project's principal questions—How do human alterations coupled with water resources and management infrastructure and policies affect water quantity, water quality and the hydrologic functioning of watersheds? Some of the specific projects proposed by consortium members draw specific attention to how social-ecological systems may adapt to ecological change. These include:

- The University of Montana proposal to assess how political constraints and institutions affect watershed management in the Flathead watershed and the area affected by the removal of the Milltown dam.

- The proposal by Washington State University to study how to effectively and economically improve instream flows in two watersheds in Northern Idaho and Eastern Washington.

- Working with irrigation managers, Idaho State University proposes to conduct a field project to calibrate flow measurement devices that are used for water resources management and planning purposes.

- The University of Idaho study of the Lapwai creek watershed and how divergent stakeholders can achieve collaboration and the gap between science and policy can be bridged.

These projects are examples of the potential for collaborative research among the ICEWATER members in the area human-bonded ecosystems with a long-term goal of a better understanding of how institutions created to manage the natural environment will/will not continue to meet the demand for the most basic ecological service—water.

HIS CHALLENGES

The ICEWATER HIS, modeled after the CUAHSI HIS is designed to stimulate synthesis and integration across research sites. Currently, the HIS is well suited to and time series data. However, other forms of data, such as spatial data (DEMs, land cover, remote sensing) and specialty data, such as geophysical surveys have not to date been part of HIS. Development of the ICEWATER HIS will include enhancements to incorporate additional data types as using collaborative ICEWATER research as test cases that provide data for incorporation and sharing. One premise motivating this work is that an integrated information system provides a tool that enables and enhances collaboration.

COLLABORATIVE ACTIVITIES

Although university projects may address local water resource issues, projects must outline a plan to contribute to at least one overarching collaborative activity. Potential activities include:

1) Collaborative papers – Specific research results will be described and compared in collaborative research papers. These results may be used to produce a vision paper or series of papers that summarize state-of-the-science and future challenges in the three research theme areas described above.

2) Integrated modeling – A common obstacle inhibiting research across sites is the lack of systems that will allow for integrated modeling. Although a large undertaking, especially in light of the funding available to the initial projects, this potential collaborative activity may lend itself well to a joint proposal as described in #4. The ICEWATER infrastructure will provide the means by which such an activity may be developed for future funding. ICEWATER projects are encouraged to participate in CHyMP (Community Hydrologic Modeling Platform) activities… http://www.cuahsi.org/chymp-20090331.html

3) Inter-site comparison – The Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI) is planning to host a watershed inter-comparison workshop in October, 2009 (see workshop planning document below). Many of the proposed INRA Water Research Consortium research projects will be able to participate in the inter-site comparison activity. Cross-site conclusions can be drawn as to what data are transferable from one site to another, versus which data are site specific.

4) Joint proposal development – Research to advance the understanding of complex hydrologic processes and water resources systems increasingly requires integration of information from multiple observations or lines of inquiry. This requires collaboration and work across disciplines. Funding agencies that recognize this have released a number of integrative proposal requests, such as NSF coupled natural and human systems, Critical Zone Observatories (http://www.nsf.gov/pubs/2006/nsf06588/nsf06588.htm - this is old but there may be a new one sometime), IGERT (http://www.nsf.gov/pubs/2009/nsf09519/nsf09519.htm), CDI (http://www.nsf.gov/pubs/2008/nsf08604/nsf08604.htm), STC (http://www.nsf.gov/pubs/2008/nsf08580/nsf08580.htm), and EPA/USDA (http://es.epa.gov/ncer/rfa/2009/2009_star_ecosystem_services.html), National Institute for Climatic Change Research (http://www.niccr.nau.edu/). This list is not comprehensive. Coordinated research that supports the development of competitive joint proposals in response to these or other equivalent opportunities is encouraged.

Understanding the Dynamics of Hydrologic and Biogeochemical Stores: A Community Workshop to initiate Inter-site Comparison

I. **Background**

A fundamental purpose of CUAHSI's efforts to establish a network of hydrologic observatories is to create a platform of consistent, quality hydrologic information that transcends place. Such information would enable intersite comparisons that are currently difficult because of inconsistent data collection and quality control methods, disparate or conflicting objectives, and variable temporal consistency of data. Although a network of observatories designed from the top down, such as the proposed WATERS Network would address these issues, such a network is many years away. Furthermore, there remains a great deal of uncertainty in such a design.

A complementary strategy is to take advantage of existing experimental field sites that are maintained by university investigators. By organizing the dispersed field facilities operated by universities and agencies, we may find that we have a basis for an observatory network. Under the auspices of the CUAHSI Water Data Federation, we can determine the strengths that such a grass roots network offers and what gaps must be filled to move towards a formal network. The CUAHSI Hydrologic Information Systems and the resultant Water Data Federation have established a platform to organize a diffuse network of field sites and experimental watersheds.

We propose to hold a workshop that explores the possibility of using the Water Data Federation and the HIS as an avenue of intersite comparison. Key questions include

1. Is it feasible to establish a Water Data Federation comprised of independent, PI operated field facilities? If so, what other grass roots activities can be done to facilitate building the network? What metadata is essential to publish for a field site?

2. How can CUAHSI help organize cross-site comparison? Is it feasible to foster collaboration at low cost using various cyber-collaboration facilities?

3. How do we recruit contributors to the federation?

4. What are the example inter-comparison science questions that such a network can address and will they be engaging enough for the community to undertake without supplemental resources?

To provide focus, we propose to organize the workshop around the theme of estimating hydrologic and biogeochemical stores in catchments. Data from national-scale networks, such as the USGS NWIS and EPA STORET systems, now available through CUAHSI HIS, allow estimation of these stores through direct measurements more feasible now than in the past, but data are sparse. Experimental watersheds probably have the most complete data sets to begin to answer that question at smaller scale and beginning the estimation process at such sites would inform approaches for larger scale work. Limitations in data sets, even in these data-rich field sites, will also become apparent. The storage of water has not been typically estimated because it is difficult to do so, even in data-rich experimental watersheds. However, with new geophysical methods, like microgravity, we have additional ways to approach this problem. Furthermore, the GRACE satellite provides rough estimates (at coarse spatial and temporal resolution) across the entire globe. Further developing these estimates will require combining traditional estimation using measurements such as groundwater levels and soil moisture with new geophysical measurements and other indirect approaches, such as estimating groundwater stores from recession hydrographs.

This question provides a focus and a scientific motivation for addressing such issues as comparability of data sets, inference approaches, and metadata requirements.

Objectives

The premise of this workshop is that many existing field sites have sufficient data to estimate annual stores of water and associated solutes for many years, even many decades. The spatial and temporal patterns can potentially provide new insights into hydrologic processes and to enable hypotheses to be generated and new field measurement campaigns to be designed. Comparing the methods for deriving storage estimates from field measurements will also provide the opportunity to compare conceptual models of watershed structure across the participating sites. Although an ultimate goal is to make scientific advances concerning catchment processes, it is first necessary to determine the readiness of the Water Data Federation. Specifically,

1. What data need to be considered to quantify the stores and fluxes in a watershed,
2. What is the adequacy of data currently available to make those estimates? This question considers both density and distribution of time series of water levels, soil moisture, etc. as well as more static information such as hydrostratigraphy, mapping of soils and vegetation.
3. What is the uncertainty in these estimates?
4. How must the estimates be documented to make valid inter-annual and inter-site comparisons?

The workshop will be informed by previous intersite comparison efforts that have been done both informally and formally in catchment hydrology and biogeochemistry (e.g., Post et al., 2000; Kane and Yang, 2004; Jones, 2005) and by special sessions held at numerous professional society meetings, including the most recent Fall Meeting of the American Geophysical Union that featured 3 half-day sessions on long-term networks of experimental watersheds. *The objective of this workshop is to recruit participants in the CUAHSI Water Data Federation by developing compelling questions to inspire analysis of existing data sets in a manner to allow systematic comparison of different sites.* The broader scientific objective is to develop of a more general understanding of hydrologic and biogeochemical processes in the face of heterogeneity of geological setting, soils, vegetation, land use, and climate. Results from the first year of analysis will be presented at the CUAHSI Biennial Colloquium in the summer of 2010. New technologies, particularly CUAHSI Water Data Services, will enable access to the data sets and the derived products (such as annual estimates of stores) used in these analyses by the broader community. Other cyberservices, such as wikis, will be supported by CUAHSI to encourage broader participation.

II. Workshop Structure and Outcomes

After an initial plenary session that reviews past and current experiences with inter-site comparisons, the majority of the workshop will be in breakout sessions, broken out by subdisciplines, to develop sample community questions that build on the initial question. Example break-out sessions include:

1. *Direct, indirect, and remote-sensing approaches for estimation of stores.* Spatial extrapolation of direct measurements, such as groundwater levels and soil moisture, will be contrasted with indirect methods, such as recession analysis, and geophysical approaches such as microgravity. What are the relative advantages of different approaches? How is precision of the estimates determined for each approach?

2. *Comparison Across Scale.* How can estimates made in data-rich areas, such as experimental watersheds, help to inform estimates in data-poor areas where only monitoring networks exist?

3. *Mass Balance Approaches.* Storage of water and solutes are commonly estimated as residuals in a balance equation. This approach requires that all fluxes are known and that errors in flux estimates are minimal. Can we improve traditional mass balance approaches to estimate catchment scale storage of water and solutes?

4.

III. Workshop Products

The outcomes of this workshop will be

1. A set of questions for inter-site comparison.

2. A listing of approaches and documentation required (i.e., metadata) for estimation of stores

3. Teams derived from workshop attendees and potential other contributors assigned to each question

4. An initial assessment of the available sites and data for each question and a call for participation by other sites

5. Target presentation and manuscript titles to be presented at the 2010 CUAHSI Biennial Symposium.

6. Action item schedule for each question.

Key aspects of the workshop are the use of the CUAHSI Water Data Services to publish both the raw and the derived data products that can serve as data repositories for further analysis.

Year 4 Research Abstracts

Surface water-groundwater interaction at the boundary and interior of a range front mountain block; Research, Infrastructure Strengthening, and Collaboration

Submitted by Warren Barrash and James McNamara
Department of Geosciences, Boise State University

Abstract

Boise State University proposes a 1-year project largely focusing on (a) the thematic issue of quantifying surface water-groundwater interaction under two important, generic settings (i.e., major river as a large-scale flow system terminus and local interactive flow system boundary, and intermittent stream(s) in mountainside watershed); (b) the institutional research infrastructure strengthening issue of improving established field sites for high-level research competitiveness; and (c) developing collaborative relationships with other INRA universities (e.g., Montana State University, University of Montana, Utah State University, Washington State University) that also are conducting research at established field sites on surface water-groundwater (SW-GW) interactions.

Boise Hydrogeophysical Research Site (BHRS)
Early in the project we will add piezometers at the edge of the Boise River adjacent to the BHRS, survey their locations, and instrument these piezometers and existing in-stream staff gauge stations with transducers and self-contained data loggers for measuring head and temperature at all locations, and general water chemistry parameters at selected locations. This instrumentation, in combination with existing head sensors will provide the core capability for monitoring levels, temperature, and diagnostic water chemistry changes in the Boise River and the adjacent aquifer at the BHRS.

In addition to developing the capability for fundamental monitoring and sampling, we will use the new stations and instrumentation as critical elements in an observational experiment that will observe (a) the major springtime stage change in the Boise River (i.e., increase in stage of approximately 0.75 m) in mid-late April when flows are increased from the upstream system of dams to provide surface irrigation water in the New York canal system and (b) corresponding head changes at the edge of the rive and in the aquifer across the gravel bar at the BHRS. In addition, ground-penetrating radar reflection transects between control points (new piezometers and wells) perpendicular to the river will capture changes in capillary fringe/moisture content forced by the step rise in river level. Temperature and basic water chemistry parameters will be measured in the river, in the river-edge piezometers, and in wells.

The head and water quality changes will be modeled to quantify SW-GW interaction including river bed and river bank behavior and their appropriate parameterizations. It is known from hydrologic tests and tracer tests at the BHRS that the gravel bar aquifer is highly sensitive to the river boundary.

In addition to participants from Boise State, students and researchers from INRA institutions will be invited to participate in this experiment, and to supplement as may be appropriate.

Understanding of the SW-GW interaction at the Boise River is an important component in the range front flow system; results from this experiment will be significant for inclusion of the Boise River component in an evolving larger-scale range front hydrologic model.

Dry Creek Experimental Watershed (DCEW)

Mountain streams are important sources of groundwater recharge. Ongoing experiments in the Dry Creek Experimental Watershed are investigating groundwater-surface water interactions from scales ranging from substream sediments to mountain fronts. In this project we investigate the geomorphic features that control hyporheic exchange in stream reaches. Funds will be used to install piezometers and conduct tracer studies in selected stream reaches.

Sub-Project: Tools for Monitoring Arctic River Processes and Fluxes
Lead: Ben Crosby, Idaho State University
INRA Collaborators: UAF and BSU.
Abstract: Northern climates have experienced the most dramatic changes in temperature and precipitation in the last 50 years of meteorological record and are predicted (through global climate models) to continue to experience the largest changes in climate over the next 100 years. These changes in climate affect both the function and the stability of the arctic landscape. Melting permafrost changes both the timing and volume of precipitation and snowmelt delivery to channels and these have consequences on river bed and bank stability. Accelerated river erosion results in hillslope failure and further volatility of the Arctic landscape. This instability threatens all that inhabit this landscape, including the Inupiaq people living along these rivers. We propose to develop a small research watershed in the western arctic that will complement an existing experimental watershed in the north central Arctic (Figure 1). The existing watershed is situated on the North Slope, near at the foot of the Brooks Range. We propose to develop a research watershed in a more maritime environment. At this location, the influence of open water (ever more frequent with decreasing sea ice duration) creates unique temperature and precipitation patterns that are not represented at the existing site. Dr. Ben Crosby will lead this project and will work in direct collaboration with Dr. Larry Hinzman and Dr. Douglas Kane who have decades of experience in establishing and maintaining observational networks in the Arctic environment. An advantage of the proposed site is that it is readily and inexpensively accessed from Kotzebue, a regional hub served by Alaska Airlines. This observational network will integrate directly with a NSF grant that Crosby currently has ($250,000, 2008-2013) to work in the same region as well as complement research goals within the National Parks Service sites in the region. The site and data collected will be used by collaborators at Dartmouth University, Penn State, University of Pennsylvania and Boise State University. It will enhance the competitiveness of ISU's research program in this area and provide new opportunities for external funding regarding watershed processes in one of the most dynamic landscapes on Earth.

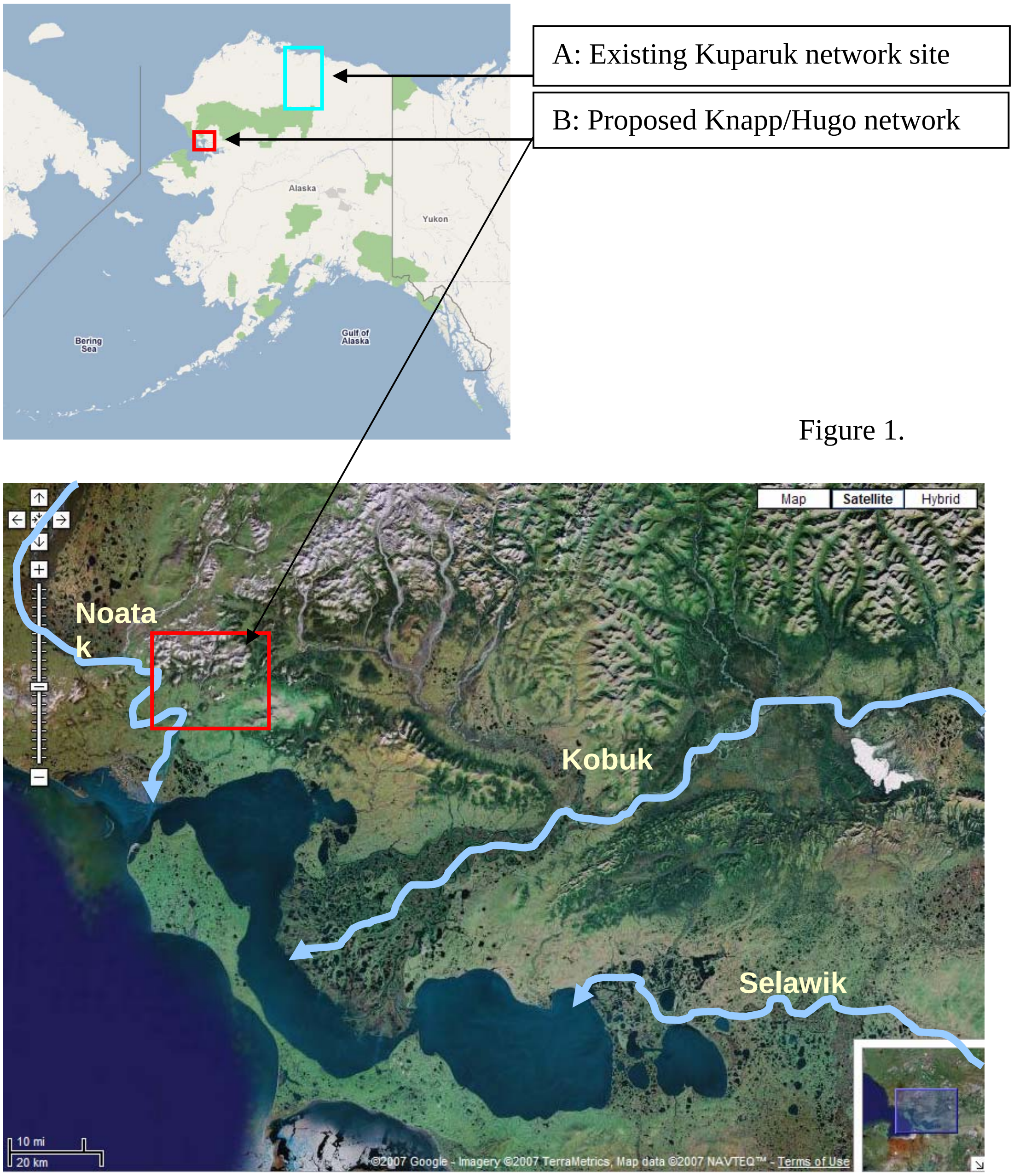
A: Existing Kuparuk network site
B: Proposed Knapp/Hugo network
Alaska
Yukon
Bering Sea
Gulf of Alaska
Map
Satellite
Hybrid
Noata
k
Kobuk
Selawik
10 mi
20 km
©2007 Google - Imagery ©2007 TerraMetrics, Map data ©2007 NAVTEQ™ - Terms of Use

Figure 1.

Sub-Project: Increasing Data Accuracy, Reliability, Accessibility, and Understandability to Improve Basin-Wide Water Resources Decision Making

Lead: Bruce Savage, Idaho State University
INRA Collaborators: USU

Abstract: To effectively manage any resource, the ability to quantify that resource, accurately distribute it, and evaluate impact or productivity is essential. Water resources are no different. Most irrigation companies and water users groups have the infrastructure in place to measure and report flow rates in canals and rivers (typically downstream of storage reservoirs). In some cases, however, weir calibrations can be inaccurate due to an incorrect reference datum, effective shorting of weir heights due to upstream sedimentation or other maintenance issues. Other issues may be due to that fact that those who perform periodic field calibrations do not understand operational procedures for the measurement equipment or they do not have access to or the ability to update the head-discharge relationships in the computer that logs the data. In other cases, telemetry systems may transmit inaccurate data or no data at all if the batteries providing power to the system are sufficiently depleted of charge. In short, in addition to having a data collection and transmission system in place, a minimum amount of maintenance, and education of users is required to insure the accuracy of the data. We propose that a project be carried out to field calibrate many of the different flow measurement devices currently in place. Calibrations will be carried out using a variety of methods including surveying the site and point velocity measurements. This work would be carried out in conjunction with local irrigation managers within the Portneuf Basin. In addition, similar work is being carried within the Bear River Drainage by Dr. Blake Tullis and other researchers at Utah State University and the Utah Water Research Laboratory. A comparative analysis of measurement structure types and common problems would provide a good educational tool in the analysis and operation of these systems. The data collected would be entered within the ICEWATER network. By having the data and commonly available and with an accurate flow measurement/distribution system in place, additional information such as local soil-moisture content and evapotranspiration rates can further assist in determining appropriate water application rates and frequencies. Dr. Bruce Savage will lead this project in collaboration with the specified Utah State University researchers.

Watershed Structure, Landuse/Land Cover, and Snow Runoff Dynamics: Montana State ICEWATER Constellation

Brian McGlynn, Associate Professor of Watershed Hydrology, MSU.
Lucy Marshall, Assistant Professor of Watershed Analysis, MSU.
Collaborators:
Geoff Poole, Assistant Professor of Fluvial Landscape Ecology, MSU.
Wyatt Cross, Assistant Professor of Stream Ecology, MSU

Significant data resources exist at a few experimental watersheds in the inland northwest (e.g. distributed snowpack properties, hydromet data, LiDAR topography data, remote sensing data, stream gauges, networks of wells and piezometers, eddy flux towers, SNOTEL sites, snowmelt lysimeters, and forest manipulation experiments, etc.), but no mechanism currently exists to coordinate information gathering, synthesis, and comparison. Therefore, development of regional synthesis network of experimental watersheds is critical in the snowpack dependent inland northwest. Our contribution to this network seeks to leverage ongoing research and infrastructure to address regional needs to improve understanding of snowmelt-streamflow relationships, watershed carbon –water cycle dynamics, and the impacts of landuse change of aquatic systems. We seek to build infrastructure and research capacity at MSU and contribute to regional synthesis in the following research proposal.

> Montana State University proposes a project building data collection, analysis, and modeling capacity at watershed scales focused on (a) hydrological linkages between landscapes and stream networks, (b) coupled carbon-water distribution and flux across environmental gradients, (c) measuring and modeling the effects of landuse change on streamwater chemistry

> The institutional research infrastructure strengthening will build on established field sites to enhance high-level research competitiveness and aid development of collaborative relationships with other INRA universities (e.g., Boise State University, University of Idaho, Idaho State University, and Utah State University) that also are conducting research at established field sites on related issues including watershed hydrology, measuring and modeling impacts of landuse change on aquatic systems, and groundwater-surface water interactions.

Montana State ICEWATER research watershed foci include the Tenderfoot Creek Experimental Forest and the Big Sky watershed of the West Fork of the Gallatin River. These watersheds are well-placed in space and foci to build capacity in integrated field hydrology, biogeochemistry, and ecology fully coupled to quantitative model development, testing, and assessment to address the following ICEWATER questions:

1. How can we predict streamflow and aquifer water levels (hydrologic responses) from watershed and climate attributes?

2. How can we predict water quality and ecological integrity from watershed and climate attributes?
3. How do human alterations and water resources and management infrastructure and policies affect water quantity, water quality and the hydrologic functioning of watersheds?
4. How can understanding of water quantity, water quality, and hydrologic functioning of experimental watersheds contribute to integrated water resources management regionally?

These broad ICEWATER questions beg multi-scale integrated research that includes hydrology, biogeochemistry, and modeling activities in both natural and human impacted research watershed sites. To begin to address these questions, ICEWATER research activities must be coupled with and contribute to the hydrological information service initiative concurrently undertaken by Regionally by INRA universities and nationally by CUAHSI HIS. Therefore, this funding will be used to improve data acquisition capabilities, data analysis and synthesis, development of innovative modeling strategies, and synergy and linkages to other INRA universities through a shared HIS data system and direct contact and natural collaboration with complementary INRA ICEWATER projects.

UAF'S RESEARCH CONTRIBUTION TO ICEWATER

Douglas Kane, University of Alaska Fairbanks

Abstract

We have two interests that we would like to propose. First, we would like to participate with those universities that are interested in examining surface water/groundwater interactions and second, those universities that are concerned with the role that snow plays in the hydrologic cycle of these semi-arid basins.

We would propose working on the North Slope of Alaska in a group of nested watersheds associated with the Kuparuk River basin (Figure 1). This north draining river originates in the foothills of the Brooks Range (Rocky Mountains) and empties into the Arctic Ocean near Prudhoe Bay. At the USGS gauging site (established in 1971) near the coast, the drainage area is 8,140 km^2. Three other watersheds are gauged in or adjacent to the Kuparuk River basin: Imnavait Creek (since 1985; 2.2 km^2), Upper Kuparuk River (since 1993; 142 km^2) and Putuligayuk River (1970-1980 and 1982-1995 by USGS; 1999-present by UAF; 471 km^2). This is an area that is underlain by continuous permafrost and is essentially treeless (although shrubs are more prevalent). The Kuparuk watershed is a combination of mountains and foothills (62%) and low-gradient coastal plain (38%). The Upper Kuparuk watershed captures all of the steepest terrain, the Imnavait catchment is representative of the foothills and the Putuligayuk basin is entirely contained on the low-gradient coastal plain. Therefore, the runoff response of each basin has different characteristics. Organic soils of varying depth (~20 cm) mantle mineral soils with alpine vegetation at higher elevations and tussock sedge tundra at lower elevations in foothills and coastal plain. Maximum summer thawing of the active layer averages about 50 cm.

This is an area where there has been considerable warming the past few decades. These trends were first evident in the warming of permafrost at depth in the 1980s. This warming trend has continued with the ice cover reductions of the Arctic Ocean (minimum summer sea ice extent record in 2007) a clear confirmation of further warming. It is not clear how these climatic warming will manifest itself in the Arctic environment. There is considerable variability year-to-year in our present data sets such that trends are not evident yet.

One element of the ICEWATER network that is common to all watersheds is that snow plays a very important role in the hydrologic cycle. The accumulation of the winter snowpack (in our case eight to nine months) represents a natural storage reservoir that can provide water during the spring season. This meltwater can be utilized by vegetation, represent groundwater recharge or produce runoff. In our case, a significant hydrologic runoff event occurs each spring for all four of the watersheds mentioned here; however, the floods of record for the smaller and steeper watersheds are rainfall. On average, 30 to 40 % of the annual precipitation is in the form of solid precipitation. We still struggle to make good measurements of solid precipitation at gauges, redistribution by wind is important in the Arctic environment and losses due to sublimation are hard to assess (estimates range from 0 to 50 % of snowpack). Snowmelt does guarantee that there will

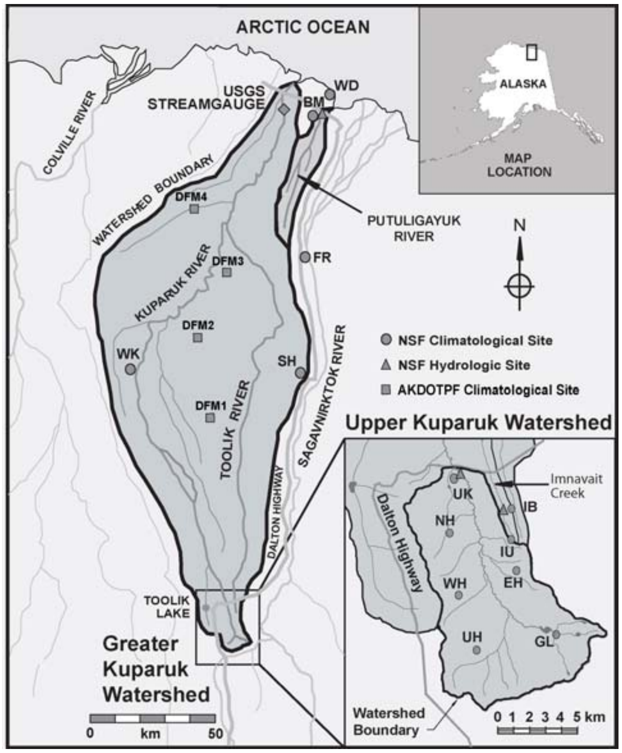

Figure 1: Map of nested watersheds presently being studied on the North Slope of Alaska with the location of various measurement sites.

be soil water available for immediate plant use. The snowpack (along with water from lakes) is used for building ice roads in winter; lakes that have been pumped during the winter for ice roads need to be recharged the next ablation period. Due to the lack of subsurface storage because of permafrost, runoff ratios are quite high during snowmelt.

I would propose that we try to compare the snow related processes in the ICEWATER network to see what regional commonalities exist. Is it possible to transfer knowledge from one area to another within the region? We have a fair understanding of present processes, but unclear about the role of snow in a changing climate.

One might conclude that because of continuous permafrost (250 to 600 m thick), surface water/groundwater interactions would not be of interest in the Arctic. However, it is clear that there are hydraulic connections between the surface and subsurface water, both below and above permafrost. Clearly, in the ICEWATER network, the Kuparuk River basin represents an extreme case of surface water/groundwater interactions with the role of subsurface storage being minimal. However, the formation during the winter months of large aufeis fields along the river drainages of the Arctic are indicative of groundwater discharge. In the Kuparuk River, age dating of this groundwater discharge shows it to be very recent, therefore it is much to young to have discharged from below the permafrost. Springs to the east of the Kuparuk basin have been age dated to be around 3000 years and it is hypothesized that this water is discharging from much older groundwater from below the permafrost.

In summary, in these permafrost basins snow hydrology is a dominant part of the hydrologic cycle and groundwater (although present), plays a minor role. Many of the other ICEWATER research watersheds have snow hydrology as a dominant component of the hydrologic cycle, but subsurface flow is also a very important process. The permafrost and shallow active layer are a poor buffer to both floods and drought; or stated another way, the amount of water storage in the active layer is minimal, therefore it is easily saturated, but it also dries out very quickly. Ponds, lakes and wetlands are the major storage reservoirs in these Arctic basins, particularly the low-gradient ones on the coastal plain. We agree to participate in any comparative studies that the INRA Consortium (or a group of INRA partners) determines is suitable with regards to snow and subsurface hydrology. With regards to subsurface storage in the hydrologic cycle, we would represent an extreme case.

Modeling hydrological responses from watersheds

Jan Boll, University of Idaho

Abstract

Hydrological responses due to climate variability (including predicted climate change) will affect water resources world-wide. In the Pacific Northwest, the major climate change impact will be on type of precipitation (rain vs snow) and the early onset of snowmelt. The hydrologic balance will be affected, including timing and magnitude of streamflow, runoff generating areas, evapotranspiration, and recharge.

In this proposal, Global Circulation Models GCMs will be selected based on their initial downscaling from a 15 km resolution supplied by the Climate Impacts Group (CIG) at the University of Washington to a 4 km resolution using interpolation techniques at the University of Idaho. We will apply another downscaling methodology to the first downscaled GCM output (monthly, 4km resolution) and create climate input to distributed hydrologic models (daily, 30m resolution). The downscaling methodology will include both min/max temperature as well as precipitation for low, medium and high climate change predictions. Simulations will be run from 2000-2100.

The geographic area of focus is northern Idaho. Detailed model testing will be done in two experimental watersheds: Mica Creek watershed and Paradise Creek watershed. Additional watersheds will be chosen in Idaho (e.g. Lapwai Creek, Benton Creek at Priest River) and in other INRA states based on data availability and research support from other INRA institutions. We will predominantly use the Soil Moisture Routing (SMR) model, and will seek model inter-comparison with the Water Erosion Prediction Project (WEPP) model, and the Distributed Hydrology Snow Vegetation Model (DHSVM). The research will focus on the use of the INRA-HIS and Web-GIS in setting up model input and model validation, and the ability of models to use readily available data so models can be applied in ungauged watersheds.

This research addresses the following ICEWATER questions:

> *How can we predict streamflow and aquifer water levels (hydrologic responses) from watershed and climate attributes?*
>
> *How will projected global climate changes be manifested regionally? How well can these regional impacts be predicted, and what are the regional consequences for water resources?*

Defining and implementing a common and equitable vision across communities connected to watersheds

Patrick Wilson, University of Idaho

Abstract

By most measures, modern human settlement of the Inland Northwest, and the entire western United States, has only been possible through our ability to manipulate ecological resources—specifically water. From a policymaking perspective any number of questions arise about our ability to sustain and maintain management of the provision of this ecological service. Perhaps the most important, is the ability of water management institutions to withstand the shock of adapting to change in the underlying ecological systems—most notably the effects of global climate change.

The focus of this project is modified from that identified in the "Project Ideas" submitted by the University of Idaho ICEWATER team. This change reflects an increased interest in the challenge of scale and how best to identify the potential for adaptability and flexibility in management institutions. In addition, the modified project scope responds to more current thinking on the best way to meet the ICEWATER objectives to promote collaborative research and brings the project more in align with a larger ICEWATER theme of the effects of global climate change. It is primarily directly at ICEWATER research question:

> *How do human alterations coupled with water resources and management infrastructure and policies affect water quality, quantity, and the hydrological functioning of watersheds.*

The increased attention to the effects of global climate change will allow this project to more easily be the foundation for or a component part of parallel ICEWATER sponsored research on the sustainability and flexibility of human-bonded ecosystems. In particular it may be possible to develop a collaborative research relationship with projects at either Washington State University or the University of Montana.

Thus, in addition to the attention on the Lapwai creek watershed, as noted in the original proposal, this research effort will also include study of the Columbia River system, both as human construct and ecosystem resource, and examine specifically the hydropower system and the past and future of the Columbia Basin irrigation project—with special attention to scale, fit, and institutional interplay. The point of departure for this research project is two interlinked questions: 1) What is the capacity for flexibility and adaptability in the basin's long-established management institutions in the face of ecological change—especially given these institutions are grounded in historical political considerations? 2) What will be the effect of institutional change on the health and availability of ecosystem resources?

Impact of Climate Variability and Change on Snowmelt from Montana's Mountain Ranges

Joel Harper   Department of Geosciences, University of Montana

Abstract

The sensitivity of snowmelt driven water supply to climate variability and climate change is difficult to assess in the mountain west, where strong climatic gradients are coupled with complex distributions of snow in the mounting topography. Further, sparse ground measurements sample climate and snow conditions in high mountain regions and significant interannual variability exists. To better understand the distribution of snow and its sensitivity to climate conditions, we are developing a modeling scheme which can be used to back-calculate the distribution of snow on the landscape based on satellite imagery and meteorological measurements. The mountain snowpack is then forced with differing melting scenarios to investigate current variability of snowmelt timing, in addition to past and future changes in timing. Our approach captures important spatial variability in steep mountain terrain yet is well suited for application to areas far greater than 1000 km^2.

In preliminary work we applied the model scheme to the Middle Fork of the Flathead Basin, a 2900 km^2 snowmelt-dominated watershed in northwest Montana (Gillan et al, in review, WRR). We found that a over 25% of the total annual snow falls above the elevation of the highest measurement station in the basin, and over 70% falls above the mean elevation of the nine nearest SNOTEL stations. Furthermore, elevation lapse rates in snow water equivalent are variable from year-to-year and are poorly described by existing ground measurements. Consequently, scaling point measurements of snow water equivalent to describe basin conditions leads to significant misrepresentation of basin snow water resources, and therefore does not necessarily reveal the snow's sensitivity to climate change. Numerical melt simulations of the basin's snow elucidated the control of temperature variability on snowmelt timing under modern climate and future climate projected by downscaled ocean- atmosphere GCM output. Typical short term temperature variability (i.e., daily to weekly weather) affects snowmelt timing on the order of 3 weeks, and plays an even larger role in a warmer climate. Timing of melt in a large snowpack year was found to be more susceptible to natural temperature variability than in a small snowpack year. On average, snowmelt timing occurs 22 days earlier in our projected future climate for the year 2100, but the range of variability is such that an overlap with conditions experienced today occurs as often as 50% of the time.

Continued research efforts will be directed towards 1) improving model representation of physical processes driving snow accumulation and melt; 2) field experiments for the purpose of model verification; 3) investigating larger regions of NW Montana, including watersheds heavily impacted by human changes in land cover; and, 3) performing improved and additional experiments using downscaled coupled ocean-atmosphere GCM output. All funding will be used to support a Ph.D. student working on the project.

University of Montana's ICEWATER
Flathead Basin Investigation – Human Dimensions of Water Use

Project Co-PI's: David Shively and Sarah J. Halvorson
Department of Geography, University of Montana

Abstract

Introduction
The UM Flathead Basin investigation proposal focuses on the physical and human dimensions of hydrology and water use in this important Columbia River tributary basin. In addition to the measurement and modeling of the basin's water yield, especially that coming from basin-wide snowpack, it is proposed to link this information to water-use perceptions and policies in the lower reaches of the basin. This document articulates more fully the methods and resource requirements associated with the human dimension of the proposal.

Research Questions
Specific research questions addressing the topics of water-use perceptions and policies outlined in the proposal include (see draft proposal for the complete list of research questions):

1. *What are current patterns of water use and water demand in the basin and forecasts for these in the future?*

2. *What are perceived and apparent policy and institutional constraints surrounding water management in the watershed? What factors and processes contribute to these constraints?*

3. *What are the perceptions of water vulnerability and risk among various water users under conditions of climate variability, drought, and climate change?*

There are two important ongoing efforts to quantify current and future patterns of municipal, industrial, and domestic water use and demand in the basin, including one associated with the reserved water right compact being negotiated between the Confederated Salish and Kootenai Tribes (CSKT) and the State of Montana and one associated with negotiations between the State of Montana and the U.S. Bureau of Reclamation (BOR) to allocate unallocated waters stored in the BOR's Hungry Horse Reservoir to downstream municipal and industrial use. The results of these efforts will be integrated into the ICEWATER investigation. These results, however, will address agricultural water use only at the most marginal level. Therefore we propose to acquire additional data that address questions 2 and 3 using the following methods.

Research Plan: Data and Analysis

Quantitative Water Resources & Agricultural Data

Agricultural data to be used in the investigation will include both quantitative and qualitative data. The quantitative data concern water deliveries by irrigation districts (assessments, volumes delivered, lands in production, etc.), water use by non-district irrigators, and on-farm costs associated with irrigation for farmers receiving district waters and for those with private water rights. These data will come from documentation compiled by the three irrigation districts that together constitute the Flathead Irrigation Project (i.e., the Mission, Jocko Valley and Flathead Irrigation Districts), from irrigators and from individual irrigators identified using the methods described below.

Qualitative Data

It was originally proposed to obtain qualitative data using semi-structured interviews conducted with farmers using private irrigation works, and those receiving water from districts. Here we propose to modify this approach by first assembling and meeting with two focus groups comprised of individuals who are representative of these groups, adding an additional focus group focusing on CSKT irrigators, and refining the list of interview questions to be used in subsequent interviews with individual farmers. The focus group and interview questions will focus on the changing dynamics of irrigated agriculture in the basin, the costs of irrigation, and perceptions concerning physical and legal water availability in the basin. We will conduct a minimum of five interviews with representatives of each of the three groups. The focus group and individual interviews will thus allow us to develop an general understanding of the perspectives of the three different major sub-populations of irrigators in the Flathead Basin which can be expanded on with future research.

Milltown surface-water groundwater interactions - groundwater modeling

Nancy Hinman, University of Montana
Bill Woessner, Co-I, Tony Berthelote (grad student), University of Montana

<u>Abstact</u>

This effort constitutes a small portion of the ICEWATER project at the University of Montana and focuses mainly on developing cyberinfrastructure capabilities while addressing the questions below. The project addresses Theme 2 - Groundwater/Surface Water Interactions through continuous monitoring of groundwater levels, temperature, and conductivity, along with periodic anion analyses, in two to four wells in an existing network.

The Milltown area has an extensive monitoring network with ongoing data collection prior to and during dam removal. However, the only remotely retrieved data are acquired by a private water-supply company who, although they will supply the data in spreadsheets, do not provide real-time data. In this project, we will add continuous access capability to existing continuous monitoring equipment.

Ongoing work by Bill Woessner's graduate student, Tony Berthelote, provides the center piece of this work. His research focuses on three questions; the following questions are taken from Berthelote's dissertation proposal.

<u>Research Questions:</u>

1. How do river valley groundwater systems respond to staged pre-dam breach reservoir draw-downs and final dam removal?

2. How do hyporheic exchange locations, magnitudes, and rates change during the dam removal and river restoration processes?

These questions frame a study beyond the scope of this proposal. This project will contribute to an understanding of groundwater flow paths and chemistry in response to river restoration. It is fortunate that continuous data are available from before the breach of the Milltown Dam, and this project offers an opportunity to more closely monitor and use, in a predictive sense, water quantity and quality parameters to determine sampling intervals.

<u>Site Description and Physical Data</u>
Milltown Dam was located below the confluence of the Upper Clark Fork River and the Blackfoot River. The valley fill is stream gravels overlying crystalline bedrock of the Belt Supergroup. Sediments from the Clark Fork River have accumulated behind the dam for over 100 years. These sediments comprise both natural river sediments and contaminated tailings from copper-mining operations in Butte, MT. The presence of the Milltown Dam diverted subsurface discharge from the Clark Fork River into the subsurface flow regime of the Blackfoot River, causing water quality issues in the nearby community of

Milltown, MT. The area has been the focus of ongoing studies by Drs. Woessner and Moore for over 30 years. Extensive pre-removal data on subsurface flow and groundwater-surface water exchange are available, including continuous and discrete water-table data, discrete water-quality data, and river discharge data. Several groundwater flow models have been used to delineate past and present subsurface flow. Interview and survey data of community perceptions are available.

Research Methods and Approach

Existing monitoring wells are instrumented with pressure transducers and thermistors that are recorded and stored on a Campbell data logger. Two to four wells will be equipped with conductivity probes and cell-phone transponders, if the sites have cell-phone access. Alternative means of transmitting data will be found if cell-phone coverage is inadequate.

Periodic (approximately monthly) sampling for anion analyses will be performed using standard methods of sample collection. Samples will be analyzed by ion chromatography at the University of Montana Murdock Environmental Biogeochemistry Laboratory. Results will be posted on the UM ICEWATER HIS site.

Understanding Processes Affecting Instream Temperatures in the Artic

Utah State University
Bethany T. Neilson
Collaborators: Doug Kane, University of Alaska Fairbanks

Introduction

The potential effects of global warming on instream temperatures and therefore, freshwater and marine fishes are varied and complex [*Wood and McDonald*, 1997]. The most obvious effects of increases in instream temperatures on water quality are related to changes in oxygen solubility and reaction rates. Additional impacts include the influence on recreational and commercial fisheries due to important aquatic species moving from lower latitudes to higher latitudes [*Carpenter et al.*, 1992]. In turn, this movement may can have an adverse affect on native Alaskans that depend on these fisheries for subsistence. Species at higher latitudes are expected to be the most impacted [*Rombough*, 1997].

To be able to quantify the impacts of climate change on instream temperature (particularly in the Artic) and potentially develop management strategies to address the associated issues, it is important to: collect process specific data; determine dominant heat sources and sinks; and further develop instream temperature models that incorporate these processes. Temperature models currently available to assist in heat load allocations have limitations in the types of heat fluxes included. Heat fluxes that are typically not considered include bed conduction, hyporheic processes, dead zone processes, and shortwave solar radiation fate in the water column and bed substrate. A data-centric approach to collecting detailed information about energy and mass fluxes in streams, including the hyporheic (subsurface exchange) and dead zone effects, was developed and used support model development and testing that incorporates these processes [*Neilson*, 2006]. Another mechanism that may influence instream temperatures are larger scale exchanges between surface water and groundwater. Quantifying the relative magnitude and direction of each of these exchanges is important in understanding both the energy and mass balances within streams and rivers. A number of different methods have been developed to assist in quantifying groundwater/surface water interactions.

Study Area

In this project, data will be collected to begin understanding the dominant heat fluxes in a small Artic stream. As shown in Figure 1, the proposed site, Imnaviat Creek, is a beaded stream on the North Slope of the Brooks Range. This creek is near the Toolik Field Station and is located within Imnaviat Creek, part of the ICEWATER network.

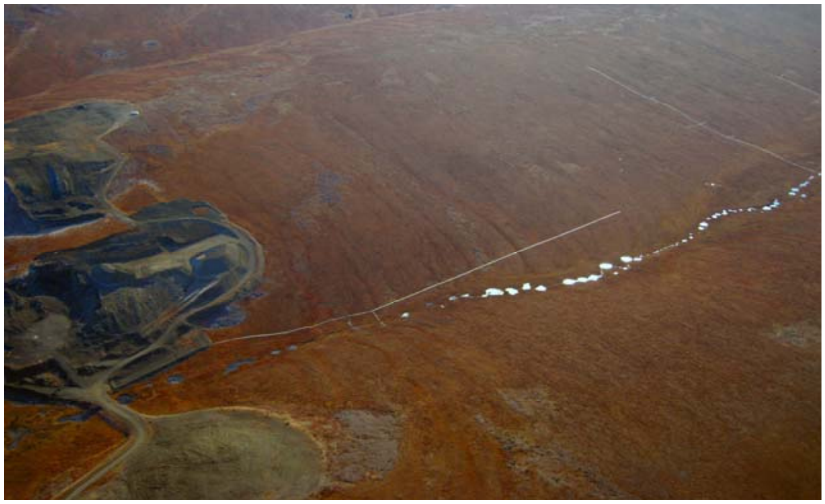

Figure 1. Imnavait Creek

Proposed Activities:

To begin addressing a subset of two research needs identified in the INRA Needs Assessment Project [*Jackson-Smith et al.*, 2007] (i.e., Climate Change Science and Water Quality Monitoring), the primary research questions will be:

1. How do instream temperatures change longitudinally in beaded systems such as Imnaviat Creek?
2. What are the significant heat fluxes in these systems?
3. How important is bed conduction in Artic systems and will the significance of this flux change as the depth to the permafrost increases?
4. Does earlier snowmelt and the resulting increase in the open water period change the instream temperature dynamics?

To address these questions, a synoptic study of approximately 1 week will be conducted to collect data in addition to those already being collected within the watershed (e.g., discharge, air temperature, wind speed, humidity, precipitation, radiation). The data collected over the synoptic study include: main channel temperatures vertically in pools and along the study reach; sediment temperatures at multiple locations and depths; shortwave radiation reflection off the water surface and penetration of the water column; and a tracer study to quantify transient storage and/or groundwater/surface water interactions. Longer term instream data may also be collected over the open water season the following summer. This data in conjunction with instream temperature modeling efforts will provide initial information on the significant heat fluxes forcing longitudinal changes in temperature. Modeling scenarios, where the depth to the permafrost table (active layer thickness) can then be investigated. Additionally, simulations to try to understand the potential influences on a longer open water season may also be conducted

Collaboration

This effort will support the ICEWATER proposal from University of Alaska, Fairbanks and will additionally utilize the data from an existing watershed that is part of the ICEWATER network. In addition to the collaboration with University of Alaska

Fairbanks, additional temperature modeling work in the Ninilchik River in Southern Alaska will be completed in collaboration with the National Weather Service (NWS) Alaska-Pacific River Forecast Center (APRFC) and the Cook InletKeeper. This project is in response to NWS identifying water temperature forecasting as a target parameter with the best chance of success and applicability in Alaska.

The collaborative activity resulting from this proposal will be the submission of collaborative papers and potentially expand this effort into a more detailed measurement/modeling effort through a joint proposal between USU and UAF.

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Washington State University - ICEWATER Project Ideas

Michael Barber, Professor, Civil and Environmental Engineering, WSU.
Jennifer Adam, Assistant Professor, Civil and Environmental Engineering, WSU.
Jonathan Yoder, Associate Professor, School of Economic Sciences, WSU.

Abstract

The WSU ICEWATER Project research plan includes two surface/groundwater interaction projects; 1) continuation and expansion of the spatial recharge monitoring network in the Spokane Valley-Rathdrum Prairie (SVRP) watershed and 2) expansion of the Pataha Creek (PC) tillage practice impacts on summer base flows monitoring/modeling project.

Spokane Valley-Rathdrum Prairie Aquifer

Groundwater modeling of the SVRP sole source aquifer is currently being conducted to assess the availability of water resources in the region. Two models have been developed, a steady-state model based on intensive groundwater and surface water monitoring conducted in 2005 and a transient model evaluating the long-term (1991-2005) response of the system. To correctly predict the outcomes of future water management decisions, the entire water balance must be understood. This includes both inflows such as flow along the model boundary via ungauged and gauged tributaries, lake seepage, groundwater/surface water exchanges, and spatial recharge as a result of precipitation as well as outflows such as pumping withdrawals and seepage out of the basin across the downstream boundaries. However, some uncertainty in the estimates still exists due to knowledge gaps in the information specifically in terms of the spatial recharge due to precipitation and infiltration.

Because of the connection between surface and ground water in this watershed, variations in recharge estimates can impact predicted stream flows by nearly 100 ft^3/s. Consequently, we have installed four weather stations throughout the watershed that include standard climate data (rain, temperature, solar, wind, relative humidity) and nested Campbell Scientific soil moisture probes at 10, 30 and 100 cm depth. In addition, earlier this year, an AgriMet station was installed near Rathdrum, ID.

We will:

1. Extend the monitoring and infiltration analysis at all four WSU sites for the duration of the INRA project,
2. Update daily evapotranspiration estimates with new data and information from AgriMet station,
3. Incorporate this into a revised surface/groundwater MODFLOW model,
4. Investigate impact on stream/groundwater interaction,
5. Add climate change modeling using VIC to predict future impacts on ET/water resources
6. Input data into ICEWATER network.

In addition to investigating surface/groundwater interactions, this information will also permit us to better explore fundamental questions regarding spatial and temporal precipitation and evapotranspiration variations.

<u>Pataha Creek</u>

The goal of the existing BPA-funded project is to investigate the potential for increasing instream flow and groundwater resources through a wider adoption of direct seeding as a best agricultural management practices. Groundwater flow is a gradual process with an extremely long duration, creating a natural mechanism of water resource enhancement. We believe the unsaturated space in the soil near the land surface and the underlying aquifers can be used to store water during winter and spring, and the water stored will flow naturally into the streams later in the summer thus enhancing base flow. The strategy offers a natural way to alter the hydrological imbalance and may have a great potential to become one of the most effective and economical options in the tributary areas. Our previous research results show that land management practice such as direct seeding considerably reduces runoff by enhancing field infiltration. Thus has a great potential for recharging these subsurface reservoirs. However, the ultimate fate of the water remains unknown.

Current tasks include conducting infiltration experiments on conventional and no-till areas using soil moisture sensors and a Guelph Permeameter, conduct field measurements of hydraulic heads along stream reaches, and develop a surface/groundwater interaction model to predict any additional base flow improvement.

We will:

1. Expand the number of locations that we can collect permeability measurements,
2. Purchase and install a continuous turbidity sensor to go with our flow stations,
3. Collect and analyze TSS samples during runoff events
4. Develop a WEPP model for the agricultural portion of the watershed.

Select Research Papers

Drought, Fire and Timing of Snowmelt in Central Idaho
Interim Report: July 2008- January 2009

Submitted by: Jennifer Pierce
Department of Geosciences
Boise State University
Boise Idaho 38725
Date: 26 January 2009

Overview:
The scope of our overall project is defined by two research areas: 1) reconstructing timing of past snowmelt from streamflow records, and 2) reconstructing the timing of past fires from fire-scar records. Since July 2008, we have submitted a manuscript entitled "Reconstructing Snowmelt in Idaho's Watershed Using Historic Streamflow Records" to *The Journal of Climatic Change* (research area 1). For research area 2 (fire history) we have established major and minor fire years from dated fire scar samples and forest stand-ages back to the 1600's, and identified fire years back to 7000 years ago from radiocarbon samples.

The summary below presents the major findings in each of these two research areas.

RECONSTRUCTING SNOWMELT IN IDAHO'S WATERSHED USING HISTORIC STREAMFLOW RECORDS
Personnel: Model development, data collection and analysis, and manuscript preparation was done by Mel Kunkel (PhD student, Department of Geosciences) and Jennifer Pierce.

Activities during this period:
We have prepared and submitted a manuscript for publication, and presented the results of our analysis at the American Geophysical Union Meeting (Fall AGU).

Plans
In the next phase of the project, we will use established final snowmelt dates to compare with collected soil moisture data for many of the sites and conduct (statistical) analysis of this data with past fire start and severity data collected within Idaho.

Results to date:
- In recent decades, a warming climate likely has accelerated the timing of spring snowmelt; however, records of the timing of snowmelt typically only extend to the 1980's. Stream gage data in snowmelt-dominated watersheds can extend records of the timing of snowmelt back to the early 1900's (Figure 1).
- We used snowpack telemetry data and historic streamflow records to test reconstructions of final snowmelt dates using Short Time Fourier Transform (STFT) wavelet analysis of hydrographs. Using STFT in well-paired basins over 1100 final snowmelt dates were calculated using streamflow records (early 1900's to today) to extend records of the timing of snowmelt from SNOTEL sites (1980's-today).
- STFT reconstructions tested against known final snowmelt dates over the last ~25 years indicate final snowmelt can be determined within ± 4 days ~95% of the time and within ± 7 days 100% of the time (Figure 2).
- Comparison of the STFT method with the center of timing method indicates that in addition to reconstructing actual snowmelt dates (as opposed to dates associated with the center of timing of streamflow), the STFT method may limit interpretation errors associated with changes in discharge not related to snowmelt.

- From 1911 - 2007, the average date of final snowmelt in Idaho's watershed has decreased from June 11 to May 31. Results show an interval of earlier snowmelt during the late 1920's to early 1940's, later snowmelt in the 1970's-mid 1980's, and earlier snowmelt from the mid-1980's to today. (Figure 2).
  Variability in the timing of snowmelt has increased in recent decades; intervals of earlier average snowmelt also appear to correspond with an increase in the variability in the timing of snowmelt. (Figure 3). For example, Results from the Trinity Mountain Site show a standard deviation in final snowmelt date of ± 10-15 days from the 1920's --late 1940's, ± 5-10 days from the1950's --early 1980's, and ± 15-23 days from the early 1980's-mid-2000's.
- A comparison between years with early snowmelt and drought reconstructions from the Palmer Drought Severity Index (PDSI) indicate a correspondence between early snowmelt and drought years (Figure 4).
- Reconstructions of final snowmelt dates in the Idaho, U.S. study area show intervals of early snowmelt (1920's-1930's), later and less variable snowmelt (1940's-1970's), and both variable and early snowmelt (~1985's-2007). Early and variable snowmelt during the last ~20 years is associated with large wildfires (Figure 5).

FIGURES (SNOWMELT RECONSTRUCTIONS):

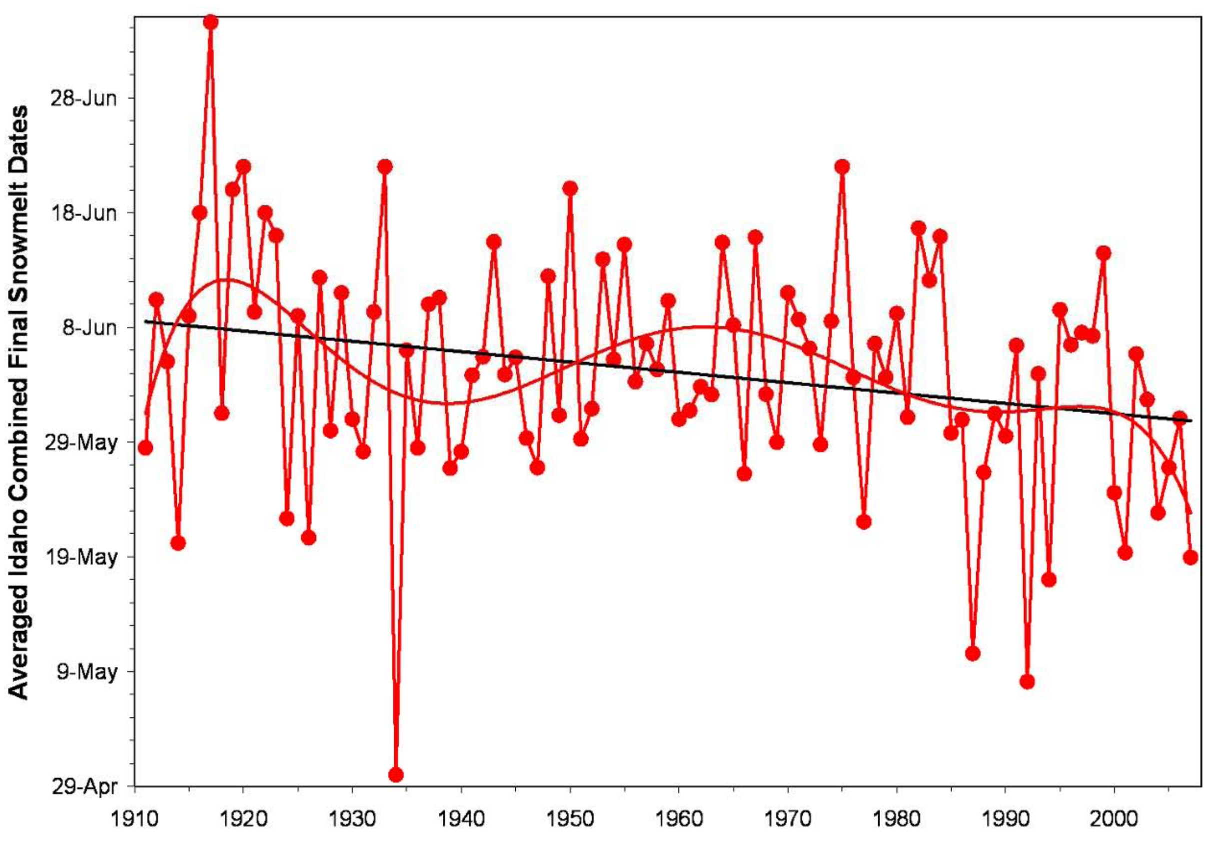


Figure 1: Plot of the averaged Idaho combined final snowmelt dates, developed by averaging all of the reconstructed final snowmelt dates for a given year. Results show an interval of earlier snowmelt during the late 1920's to early 1940's, later snowmelt in the 1970's-mid 1980's, and earlier snowmelt from the mid-1980's to today. Historic drought of 1934 very evident in the combined reconstruction

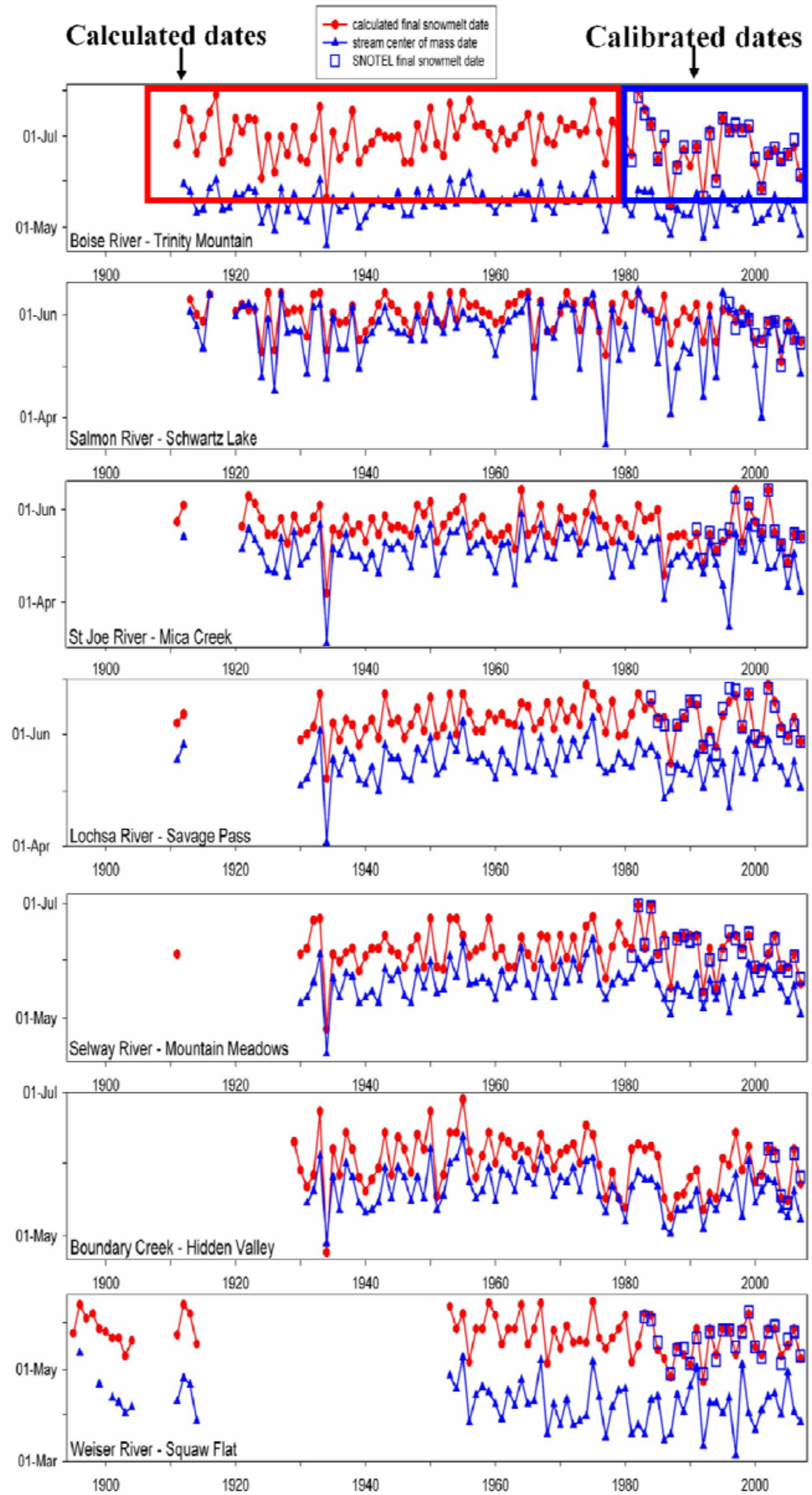


Figure 2: Example of reconstruction of final snowmelt dates (solid red circles/lines), actual final snowmelt from SNOTEL sites (open blue squares) and stream center of timing plots (solid blue circles/lines). The title on each graph indicates the stream name and the SNOTEL site name for each paired system.

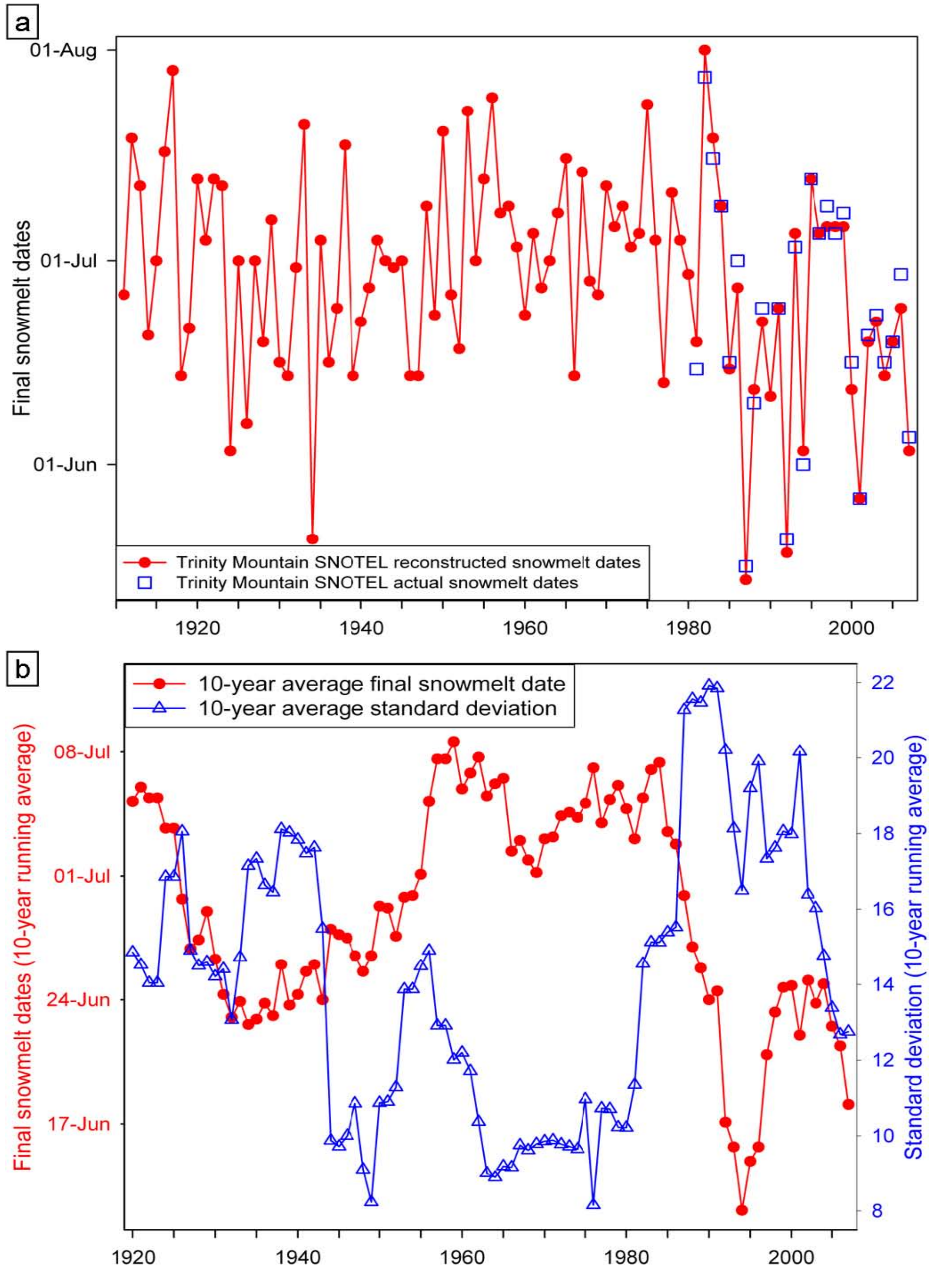


Figure 3: Variability in the timing of snowmelt has increased in recent decades; intervals of earlier average snowmelt also appear to correspond with an increase in the variability in the timing of snowmelt. Reconstructed final snowmelt dates from the Trinity Mountain SNOTEL site demonstrates this quite well. **a)** Reconstructed final snowmelt dates (red squares) compared to the actual final snowmelt dates (blue squares) at this site, and **b)** the 10-year running average of snowmelt dates and the 10-year running average in standard deviation of snowmelt dates.

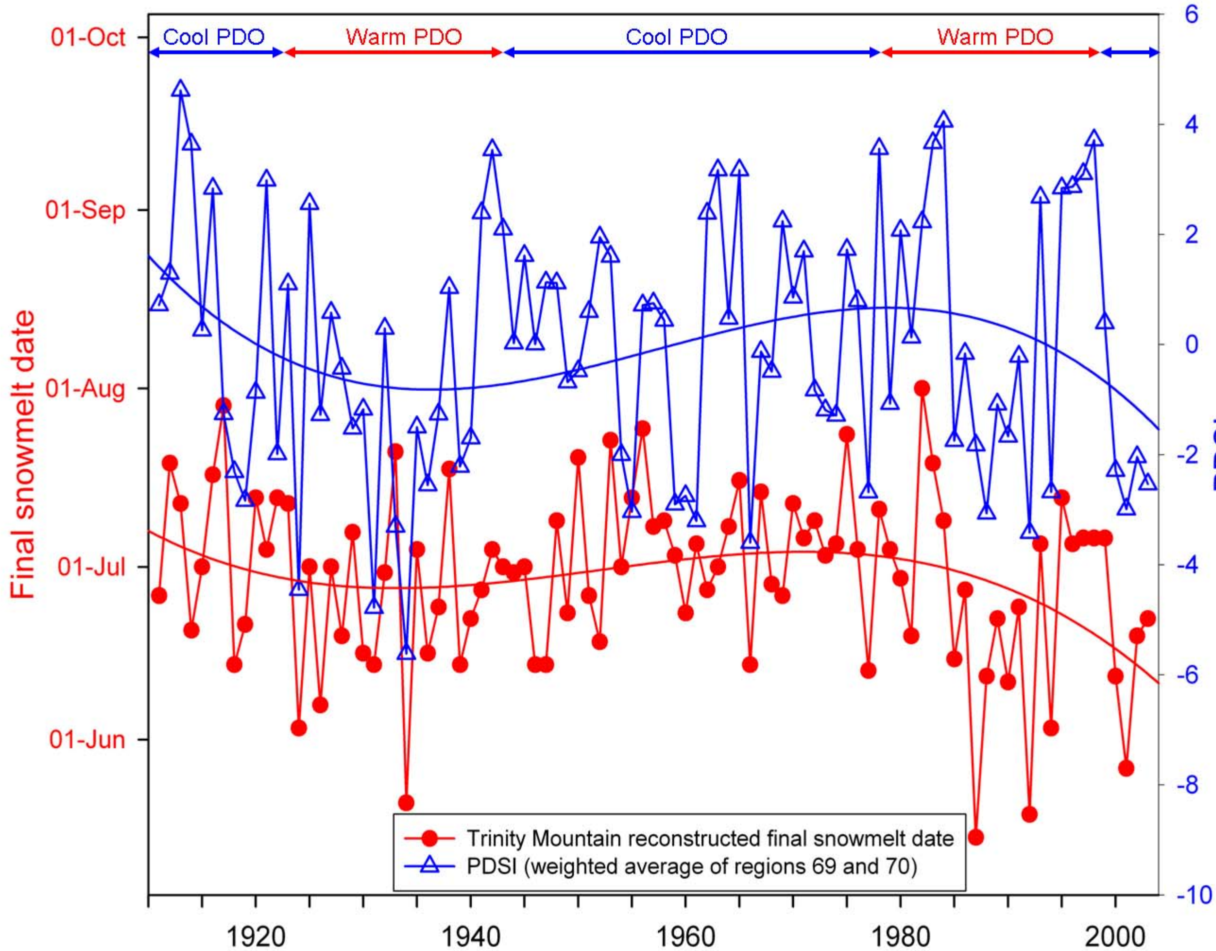


Figure 4: Reconstructed Trinity Mountain Final Snowmelt dates compared with a weighted average of the Palmer Drought Severity Index for regions 69 and 70 (NCDC, 2008). (Trinity Mountain sits between the 69 and 70 grids in central Idaho). Negative Palmer Drought Severity Index values indicate drier conditions.

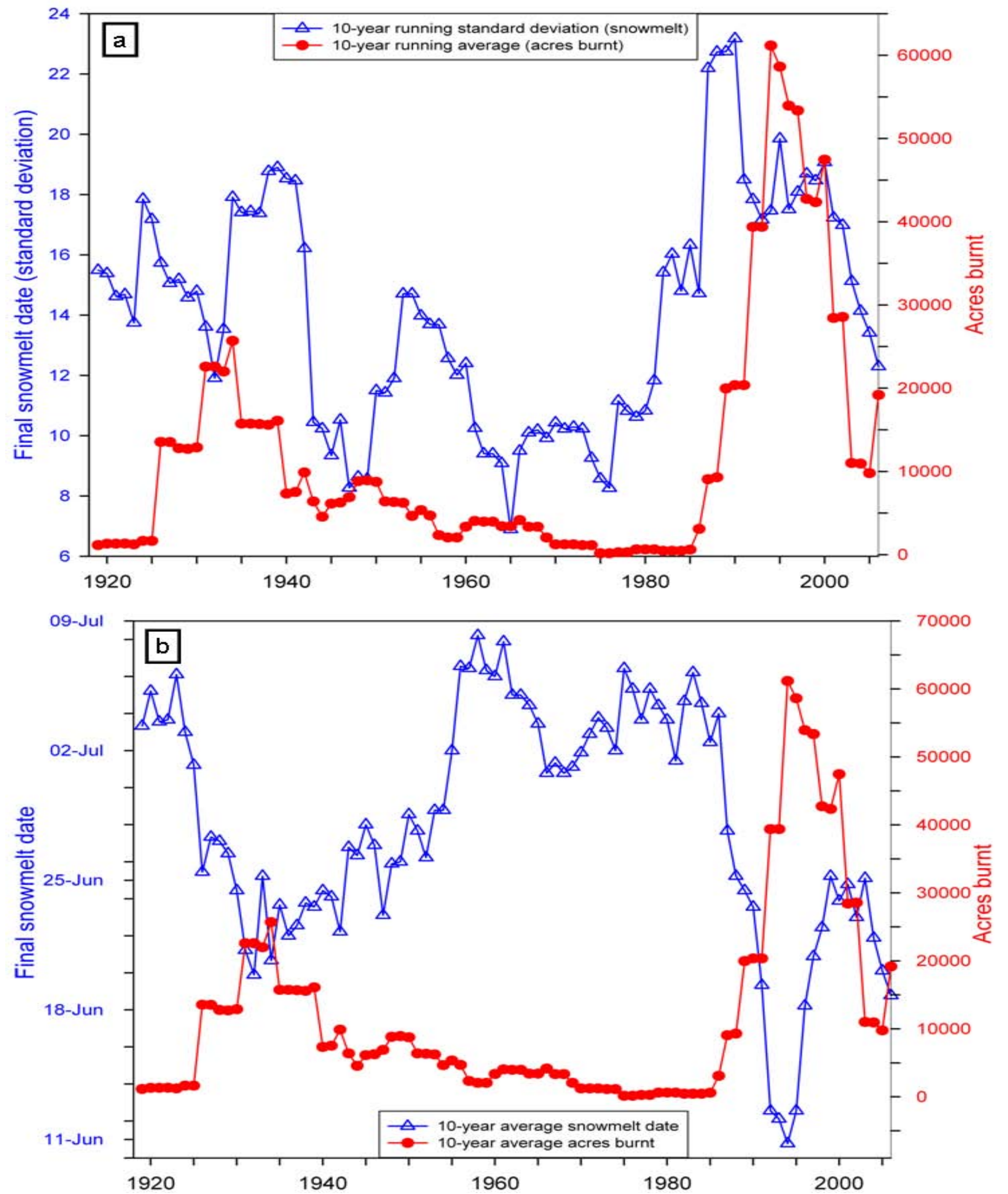


Figure 5: Comparison between final snowmelt dates and acres burned in the Boise National Forest. **a)** Comparison of the 10-year running standard deviation for the final snowmelt dates at Trinity Mountain SNOTEL site with the 10-year running average acres burned in the Boise National Forest. **b)** Comparison of the 10-year running average snowmelt dates from Trinity Mountain SNOTEL Site with the 10-year running average acres burned in the Boise National Forest. Note that in 1994 the earliest snowmelt year (June 2) corresponds with the greatest number of acres burned (61,169 acres).

Drought, Fire and Timing of Snowmelt in Central Idaho
Interim Report: July 2008- January 2009

Submitted by: Jennifer Pierce
Department of Geosciences
Boise State University
Boise Idaho 38725
Date: 26 January 2009

FIRE HISTORY RECONSTRUCTIONS:

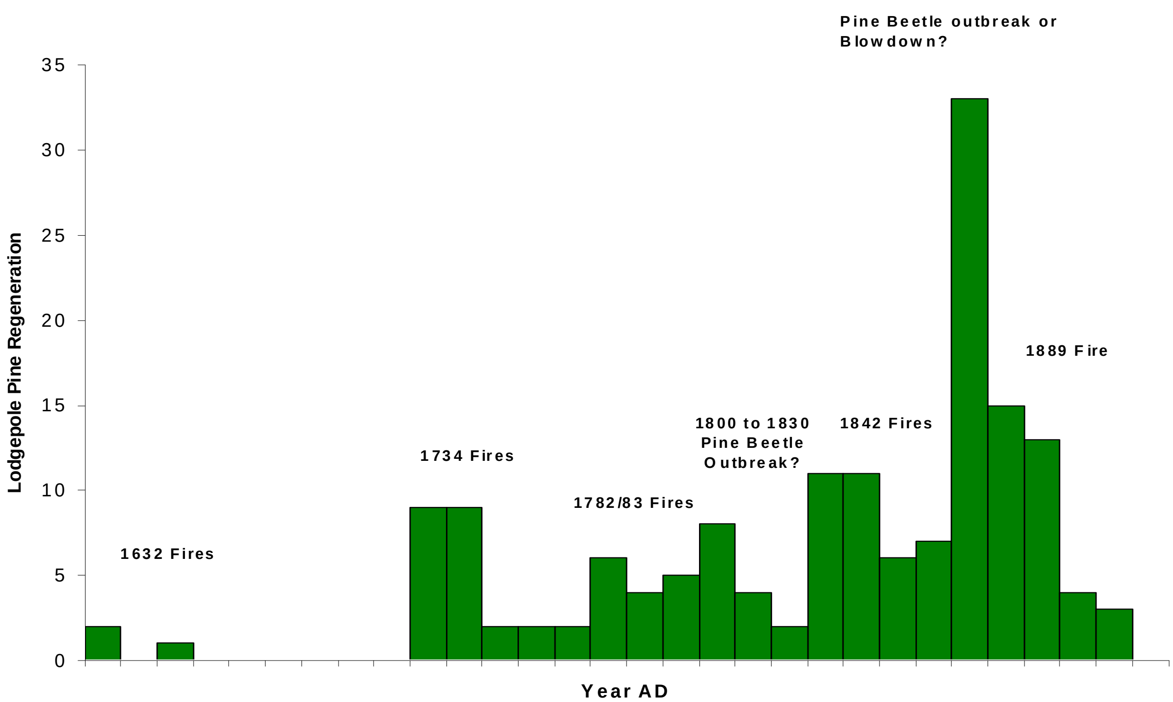
Personnel: Fire scar sampling and preparation, dendrochronological analysis, preparation of radiocarbon samples and sample analysis (at Arizona State University) has been done by Lar Svenson (MS student, Department of Geosciences) and Jeremy Whitman (Murdock K-12 scholar) and Jennifer Pierce. In addition, we are collaborating with Dr. Cathy Whitlock and students (Montana State University) to combine our recent fire chronology with their longer-term record from lake core analyses.

Activities during this period: We collected and prepared fire scar samples, and prepared and analyzed 15 radiocarbon samples. We recently received 13 of 15 radiocarbon results and should have the other two very soon. We presented the results of our study at the August and January Murdock foundation meetings, and will present results of our research at the 2009 National American Association of Geographers meeting (March, 2009).

Plans**:** In the next phase of the project, we will finish the fire history reconstructions and finalize a record of fire in the Sawtooths over the past ~400 years. We will use results of radiocarbon dating to provide a longer record of fire, to assess the utility of alluvial fan reconstructions of fire history in this area, and in conjunction with lake core records from Whitlock et al to investigate whether similar fire events are recorded in both alluvial and in lake cores. We will then begin writing up the results of this study for publication.

Results

Records of fires from fire scars indicate at least three 'major fires' (definition below) over the last 400 years in the Sawtooth Valley (1632, 1734 and 1842 AD). These years correspond with independent reconstructions of PDSI that indicate drought conditions (negative PDSI). 'Major' 'Minor' and 'Indeterminate' fire years from fire scar data are compared with lodgepole pine



stand ages to assess whether fire was the cause of stand disturbance (Figure 6).

Figure 6: Dates of lodgepole pine stand establishment, where dates indicate the timing of seedling generation following disturbance.

The tables below summarize fire years, and define 'Major' 'Minor' and 'Indeterminate' fire years.

Major fire year: At least two fire scars from different watersheds or one fire scar and one even-aged lodgepole stand from different watersheds or one fire scar within the age range of a piece of charcoal from a different watershed.

Major Fires

Year	PDSI (Palmer Drought Severity Index)
1632	-3.97
1734	-0.72
1842	-2.60

Minor fire year: A fire scar and an even-aged lodgepole stand in the same watershed or a fire scar within the age range of a piece of charcoal in the same watershed.

Minor Fires

Year	PDSI (Palmer Drought Severity Index)
1783	-4.85
1873	0.86
1889	-4.71
1934	-4.54

Indeterminate fire year: A single scar with no supporting evidence from even-aged lodgepole plots or charcoal dates.

Indeterminate Fires

Year	PDSI (Palmer Drought Severity Index)
1428	-2.74
1500	-2.51
1654	0.07
1686	-2.25
1712	-1.24
1756	-4.91
1782	-2.93
1800	-4.81
1953	1.50
1964	0.29

In most cases, fires occurred during intervals of regional drought. Except in two stand ages, most stand ages correspond with fire years, indicating fire is likely the mode of disturbance.

The spatial distribution of fire scars with the same fire dates can be used to infer relative extent of the fire (Figure 7).

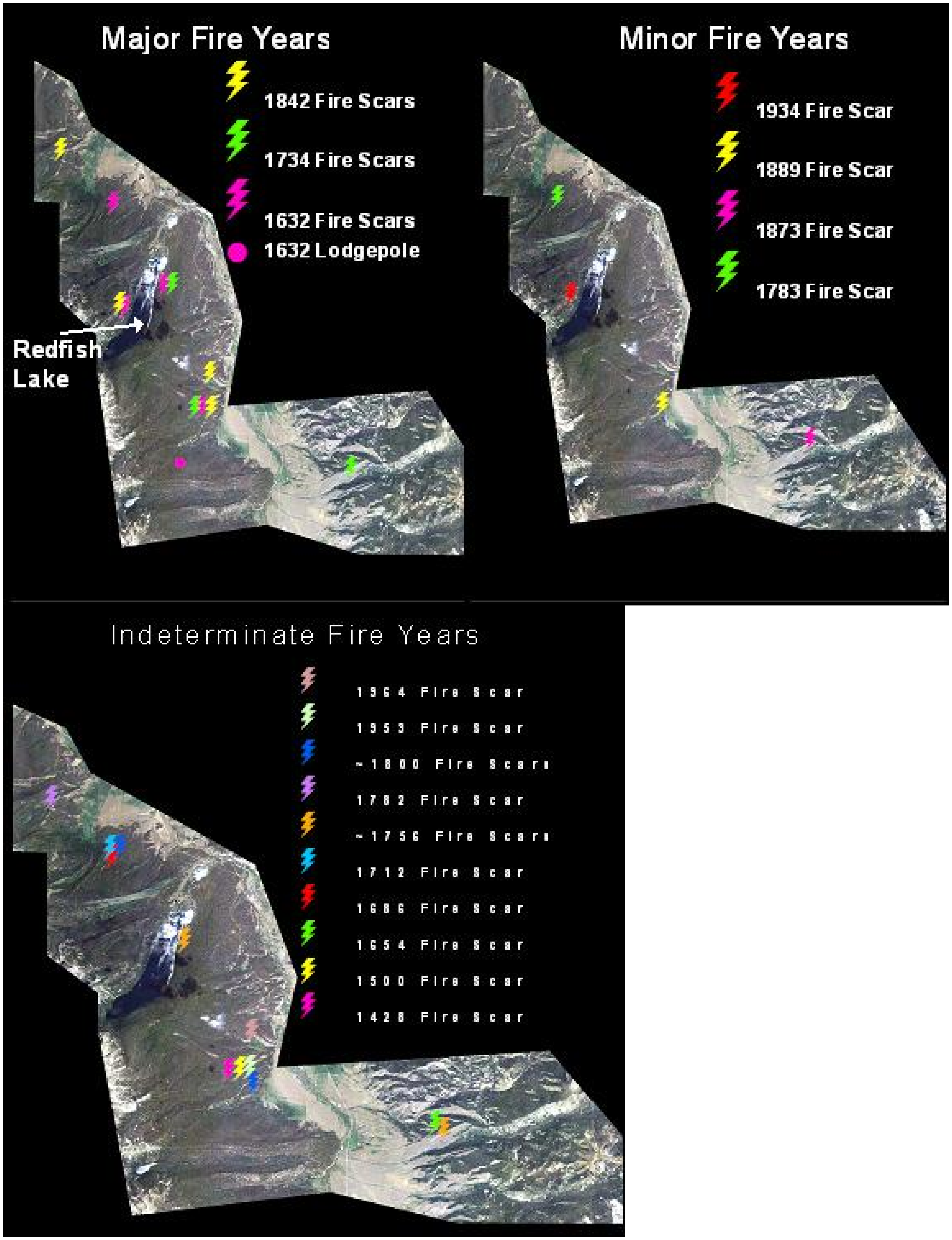


Figure 7: Major, minor, and indeterminate fire scar locations and dates of fires reconstructed from fire scars.

Long-term Ecohydrologic Variability in the Sawtooth Region of Central Idaho: Establishing a Baseline for Assessing Water Resource Issues
Interim Report: July 2008- January 2009
Task Order No. 60-5004-201

Submitted by: Cathy Whitlock
Department of Earth Sciences
Montana State University
Bozeman MT 59717
Date: 19 January 2009

Overview: Since July 2008, we have obtained three additional radiocarbon dates and increased the number of pollen samples for Decker Lake in order to develop a Holocene reconstruction of climate, vegetation and disturbance for the Sawtooth region. This interim report focuses on the personnel and data analysis activity of the last six months. We have attached a new age model and a summary figure showing all data collected at present.

Personnel: Radiocarbon sample preparation, age model development, and pollen counting have been undertaken by Dr. Christy Briles, a postdoctoral research fellow at Montana State University. Whitney Brawner, a lab tech in the MSU Paleoecology lab has prepared pollen samples. Josh Gage, a former master's student at MSU in Earth Sciences and Matias Fernandez, a graduate from Columbia University, have contributed data to the project (see past reports). In addition, we are collaborating with Dr. Jennifer Pierce and students (Boise State University) to develop a recent fire chronology from tree-ring records in the watershed. Dr. Steve Kuehn (University of Alberta) has provided tephra identifications.

Activities during this period: Analysis of the sediment cores followed the protocols outlined in the proposal. We have obtained three more radiocarbon dates (for a total of 15), and we are awaiting one more. The three new radiocarbon dates fill in gaps in the chronology. To date, we have finished all core descriptions, lithological analyses (carbon and nitrogen content, carbonate content, magnetic susceptibility), and charcoal analyses. We have also developed a preliminary vegetation history from widely spaced pollen analysis and are working toward a higher-resolution pollen record. All methods followed those outlined in the project proposal.

Results to date: Analysis based on geochemistry and shard morphology and size, conducted by Dr. Kuehn, identified two ash layers in the Decker Lake core, Mt St Helens Y (~3650 cal yr BP) and Mazama ash (~7627 cal yr BP). (Note: cal yr BP means calibrated radiocarbon years before AD 1950.) The chronology developed from these tephra ages and the sequence of radiocarbon dates suggests that Decker Lake was formed by 11,000 cal yr BP. The small lake lies in an abandoned meltwater channel on the prominent moraine complex coming from the Sawtooth Range, and thus its age is younger than the age of glacial ice recession. Decker Lake accumulated sediment at a rate of 15-30 cm yr^{-1} from 11,000 to 4500 cal yr BP and at a rate of 10-15 cm yr^{-1} from 4500 cal yr BP to the present (see Figure 1). Description of the core based on visual lithologic characterization and photography was presented in the January 2008 interim report. Charcoal concentrations and the pollen stratigraphy were described in the July 2008 report and a summary of the data and environmental reconstruction is included in the attached figures. Based on the pollen analysis, four environmental periods are registered at Decker Lake (see Figure 2):

1) 11,000 to 8500 cal yr BP. Higher-than-present summer insolation resulted in warmer conditions than today in summer. Lake productivity was low. Upland forests around Decker Lake were composed primarily of *Pinus contorta.* Fire activity was moderate, ranging between 4-6 fire episodes per 1000 years.

2) 8500 to 5600 cal yr BP. Decreasing summer insolation in the Northern Hemisphere resulted in cooler temperatures than before in the western US. Lake productivity gradually increased. Upland forests were a mixture of *Pinus contorta* and *Pseudotsuga*. The valley steppe vegetation covered a broader area than present. A significant decrease in *Pinus contorta* occurred between 8500 and 8000 cal yr BP with a corresponding increase in *Pseudotsuga* and *Artemisia*. Fire activity was slightly higher than before, ranging between 5-7 fire episodes per 1000 years. The highest fire activity in this period occurred between 8500 and 7800 cal yr BP.

3) 5600-2600 cal yr BP. Summer insolation continued to decrease resulting in cooler and likely wetter conditions than before. Lake productivity continued to gradually increase. Upland forests were primarily composed of *Pinus contorta*. *Pseudotsuga* decreased significantly and riparian areas had slightly more *Picea* and *Abies*, while the valley steppe was less developed than before. Fire activity was initially high at 7 fire episodes per 1000 years and then declined to 4 fire episodes per 1000 years after 3500 cal yr BP.

4) 2600 cal yr BP-present. The modern climate became established. Upland forests were composed primarily of *Pinus contorta*. Productivity gradually increased until present to maximum levels. Riparian species become less abundant and the valley steppe became slightly more developed than before. Fire episode frequency increased to the highest level of the record (10 fire episodes per 1000 years) at present.

The abundance of *Pseudotsuga menziesii* in the region prior to 5000 years ago is surprising since it is a relatively minor component of the low-elevation forest today. Expanded *Pseudotsuga* forests and abundant *Artemisia* steppe suggest greater seasonality (cooler, wetter winters and warmer, drier summer) than today. There was also a shift in fire regime in the last few millennia towards more frequent fires, and this was associated with the expansion of *Pinus contorta* forests.

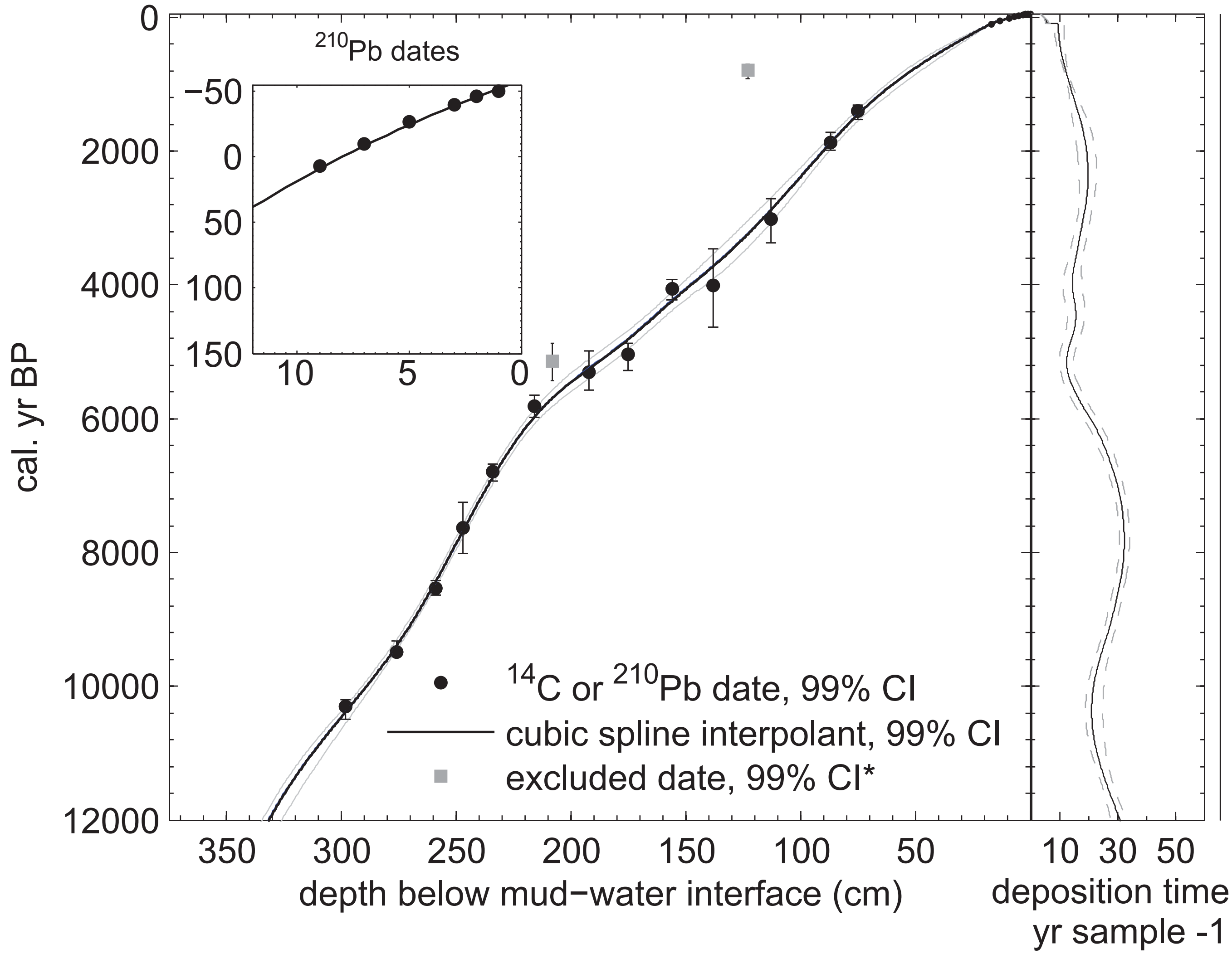
Plans: In the next phase of the project, we will finish the pollen analyses and finalize the age chronology. We will start the comparison of all datasets to reconstruct the environmental history and begin writing up the results for publication.

FIGURE CAPTIONS

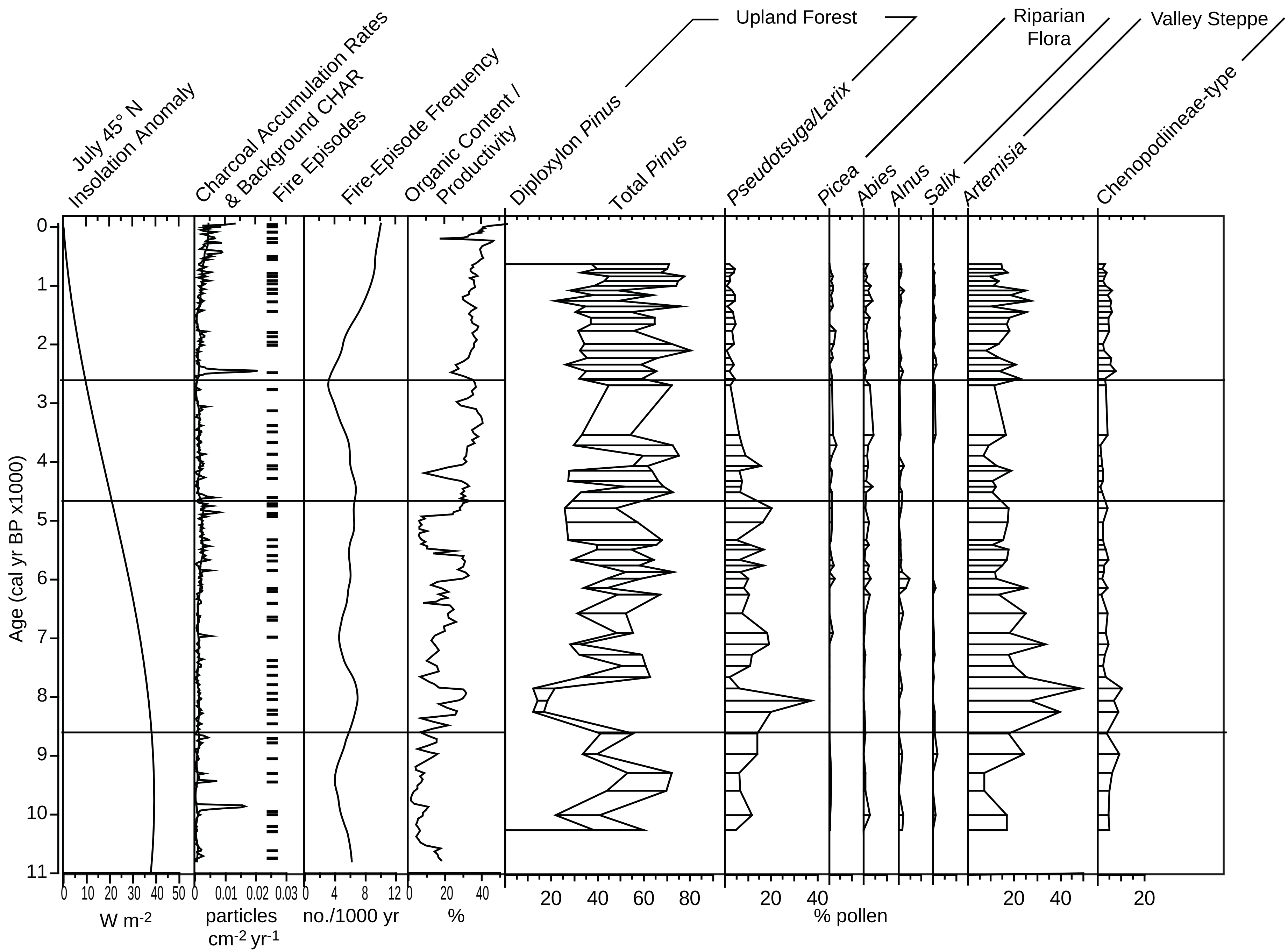
Figure 1. Age-versus-depth curves and deposition time based on radiocarbon and ^{210}Pb dates, and tephrochronology. Model was determined with a bootstrap approach. The gray band reflects the range of dates and deposition times and the black line the 50th (i.e., median age) percentile of all runs. Circles and bars reflect the 50th, 2.5th (i.e., lower age) and 97.5th (i.e., upper age) percentiles of the probability distribution function of calibrated dates. Gray squares represent dates that were excluded.

Figure 2. Environmental history of Decker Lake. Graphs from left to right include July summer insolation at 45°N anomaly relative to present, charcoal data (including Charcoal accumulation rates (CHAR), Background or slowly varying trend in CHAR, Fire episodes, and fire-episode frequency), Organic content is a measure of lake productivity, and pollen percentages for select taxa that document vegetation changes. Horizontal lines represent major changes in pollen composition and/or abundance. Charcoal analyses were performed using CharAnalysis software (http://charanalysis.googlepages.com/).

Decker Lake, Sawtooth Mountains, central Idaho
Figure 1.



Decker Lake, Sawtooth Mountains, central Idaho
Figure 2.



Progress report, for INRA sponsored "Changing Water Resources from Montana's Mountain Glaciers: Past, Present, and Future"

P.I. Joel Harper, Department of Geosciences, University of Montana

February 5, 2008

This report represents the progress after 1 year into this two year project. The last report dated July 18, 2007 focused on field instrumentation installed during the summer of 2007. This report will focus on the scientific results achieved to date.

ABSTRACT OF SCIENTIFIC ACHIEVEMENTS

Currently 37 glaciers exist in Glacier National Park (GNP), Montana, USA. These glaciers are small cirque glaciers with a maximum size of approximately 1 km^2. A century ago the glaciers in GNP were larger, up to 8 km^2 and more numerous. The runoff from glaciers in this region is an important and sometimes the only source of discharge in the typically dry summer months of July, August, and September. We present a case study of Sperry Glacier in order to investigate the changes in runoff between 1850 and present. Sperry Glacier is located on the west side of the Continental Divide and the headwall of the glacier lies at about 2800 m. The snout has retreated from an elevation of 1900 m in 1850 to about 2300 m in 2005 (Figure 1). The glacier area has been reduced over the same time period from 3.76 km^2 to only 0.84 km^2.

Direct measurements of runoff from Sperry Glacier (or any other GNP glacier) are not available. We employ two methods to compute present day summer ablation from the glacier and make the assumption that all ablation results in runoff. First, we employed a distributed energy balance model, adjusted from Brock and Arnold (2000), using data from an on-site meteorological station. This modeling supports the notion that little ablation results from sublimation or evaporation and that shortwave energy is the dominant source for melting the ice. Second, we made direct measurement of surface melt using an ablation stake network and continuous measurements of melt at a single point with a sonic ranger. Ablation measurements showed daily melt rates averaged 56 to 59 mm w.e. during summer and revealed little to no elevation gradient along the glacier. The distributed energy balance model slightly underestimated the daily melt, and had a tendency to produce a stronger elevation gradient in the melt rate than indicated by direct observations.

We examined scenarios for runoff from Sperry Glacier in 1850 by employing a numerical reconstruction of the glacier (Figure 2). We used a cellular automata technique which includes rules for surface accumulation and ablation, including snow accumulation from avalanching off the cirque walls, and down-valley mass transfer by glacier motion (Harper and Humphrey, 2003). Here we focus on one end-member scenario that considers no change in the glacier's accumulation gradient (only increased ablation due to warming) between 1850 and present. This assumption along with the modeled annual mass balance gradient yields a solution for the 1850 summer ablation along the glacier.

Total melt runoff from Sperry Glacier in 1850 is estimated to be 17 x 10^6 m^3. Our methods and assumptions suggest summer runoff from Sperry Glacier has decreased on the order of 75%, from approximately 17 x 10^6 m^3 in 1850 to approximately 4.3 x 10^6 m^3

in 2005. Such a reduction has likely had a significant impact on basin ecological systems and represents an important water resource to local downstream users in this dry summer climate regime.

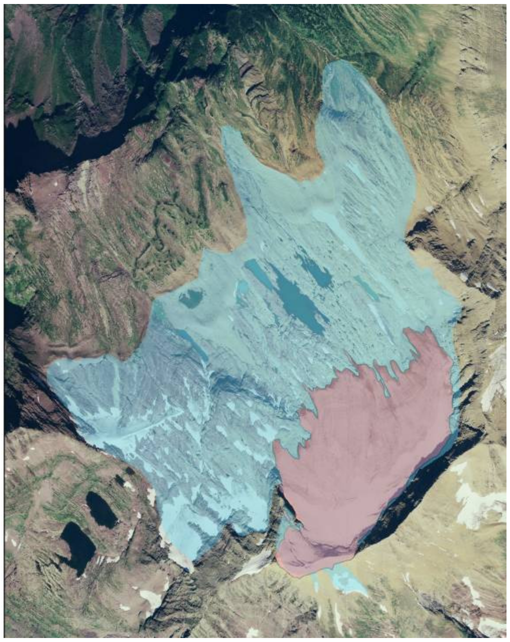


Figure 1. Satellite image of Sperry Glacier showing extent of the glacier in 1850 (blue) and 2007 (red).

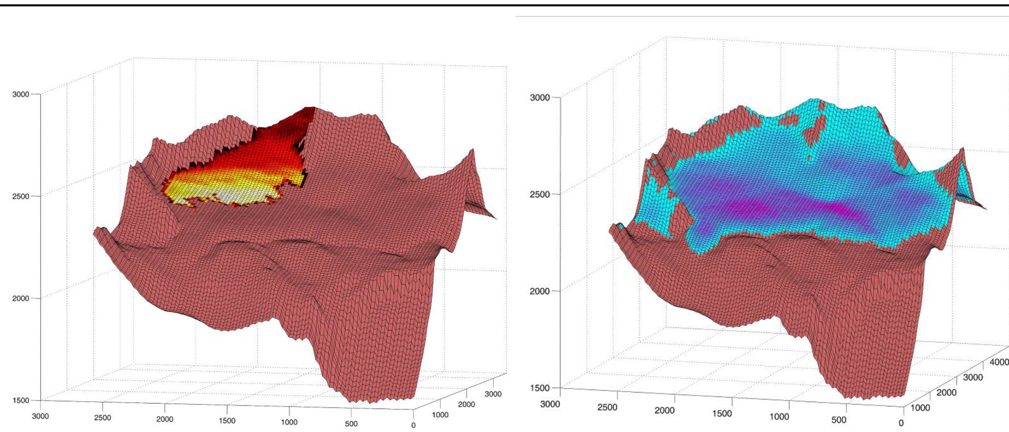


Figure 2. Modeled geometry and mass balance of Sperry Glacier. Left panel shows 2007 extent of the glacier. Colors indicate surface mass balance from a spatially distributed energy balance model. Hotter colors indicate more negative mass balance. Right panel shows 1850 geometry of the glacier from a cellular automata model and a spatially prescribed net mass balance.

ONGOING WORK

Modeling

Modeling work is focused on incorporating the retreat of the transient snowline into the spatially distributed energy balance model. Figure 3 shows that the snowline retreat is rapid and irregular; it is currently represented in the model as a steady progression upward in elevation as it typical of larger glaciers. Using time lapse images of Sperry Glacier collected during 2007 as guidance, the retreat of the snow line is currently being incorporated into the model.

Figure 3. Images from time lapse camera installed at Sperry Glacier. Retreat of the snow line is rapid and irregular, unlike the steady upward progression observed on most glaciers. This unique snowline retreat is being incorporated into the distributed energy balance model.

Field Preparations

Preparations are underway for the second field campaign of the project. Instrumentation to be installed at the Glacier during the upcoming summer is being programmed and tested and waterproof enclosures with bulkhead connecters are being constructed.

Paper Preparation

The first manuscript of the project is currently being drafted for publication in Annals of Glaciology. The target date for submission is March 15th, 2008.

Conference Presentations

The research completed thus far was presented at an international conference of glaciologists and water managers.

Kramer, M., **Harper, J.,** 2007, Historical Changes in Streamflow Related to Small Mountain Glaciers in the Glacier Park Region, Montana, USA, Workshop on Glaciers in Watershed and Global Hydrology, International Commission for Snow and Ice Hydrology, IAHS, Obergurgl, Austria, Sept. 2007.

Progress report, for INRA sponsored "Changing Water Resources from Montana's Mountain Glaciers: Past, Present, and Future"

August 3, 2008

P.I. Joel Harper, Department of Geosciences, University of Montana

Results Since The Last Progress Report

1. Mass Balance for Water Years 2005-2008

Research has focused on deriving the mass balance of Sperry Glacier during the 2005-2008 water years. Results are complete for the first two year of available data; the 2007 and 2008 water years will be completed this fall. The following highlights the results from the 2005 and 2006 water years.

The point snow depth, density and ablation measurements for the two balance years are summarized in Table 1. For the 2005 balance year, we calculated B_w to be 2.19 m w. eq., B_s as -3.41 m w. eq. and B_n as -1.22 m w. eq. For the 2006 balance year, the values were 3.12, -3.99 and -0.87 m w. eq. The accumulation/ ablation area ratio (AAAR) was 0.09 for 2005 and 0.31 for 2006.

The interpolated snow depths, ablation and specific balance values showed significant transverse spatial variability for both balance years (Figure1). For cells at similar elevations, spatial variability was greatest near the mean elevation of the glacier, where specific balances spanned over 4 m w. eq. At other elevations on the glacier, the range was typically 1.5 to 2.5 m w. eq.

The accumulation proxy showed that most years (63%) had lower snow accumulation than 2006, with 2005 accumulation among the lowest in the 1970-2006 period. The ablation proxy showed 887 and 1221 PDD for 2005 and 2006 respectively. More than half the years had lower total PDD than 2005, but only one year had a lower total than 2006.

Table 1: Sperry Glacier snow depth, density and ablation, balance years 2005 and 2006

Balance Year	Snow depth measurements: normalized date, elevation range & mean (m a.s.l)	Measured snow depth range, mean & standard deviation	Mean density, depth/ density relationship, r^2	Ablation measurements: Measurement dates, elevation range & mean (m a.s.l)	Measured ablation range, mean, & standard deviation (m w. eq.)
2005	175; 2287-2593; 2422	0-7+ m; 4.09 m; 1.3 m	563 kg m^{-3}; ρ=14.5ln(depth)+541.5; 0.99	176-252; 2362-2525; 2450	2.97-3.54; 3.26; 0.2
2006	160; 2298-2582; 2428	0-9+ m; 4.63 m; 1.46 m	594 kg m^{-3}; ρ=53.8ln(depth)+523.8; 0.933	178-271; 2362-2525; 2437	2.95-3.70; 3.46; 0.25

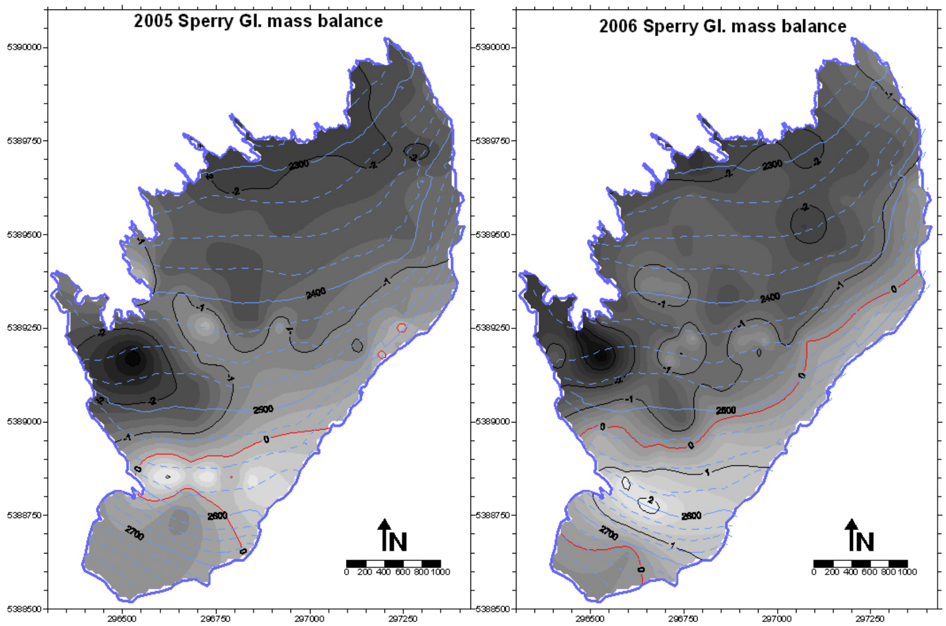


Figure 1: Maps showing elevation contours and specific balances for Sperry Glacier, balance years 2005 and 2006.

2. Ice Volume Changes 1950-2007

Digital elevation models of Sperry Glacier were constructed from two USGS topographic maps based on surveys of the glacier conducted in 1950 and 1960. A third digital elevation model was produced from data collected during a 2007 survey of the glacier's surface and surrounding rock margin. This latter survey was done with a kinematic GPS survey system utilizing an established local base station and a rover outfitted with Trimble R7 receivers. Post processing of these data allowed for cm-scale vertical and horizontal accuracy. Digital elevation models were gridded into $10m^2$ cells via a standard Kriging algorithm. The grids were differenced in order to calculate volume changes between the survey years. These results provide insight into the rate of ice volume loss of glaciers in Glacier National Park, and constitute figures from which mass balance values could be derived and then compared to current on-going field measurements. The implications of this research are highly relevant at both local and global scales. Locally, 75% of water resources in the Rocky Mountain West come from mountain snow, with glaciers filling an important niche as storage reservoirs that provide water during the late summer drought typical for the region. Global scale implications include insight into the fate of runoff from small mountain glaciers. These glaciers are the dominant contributor to current worldwide sea level rise, though the functions by which this is occurring are not yet fully understood.

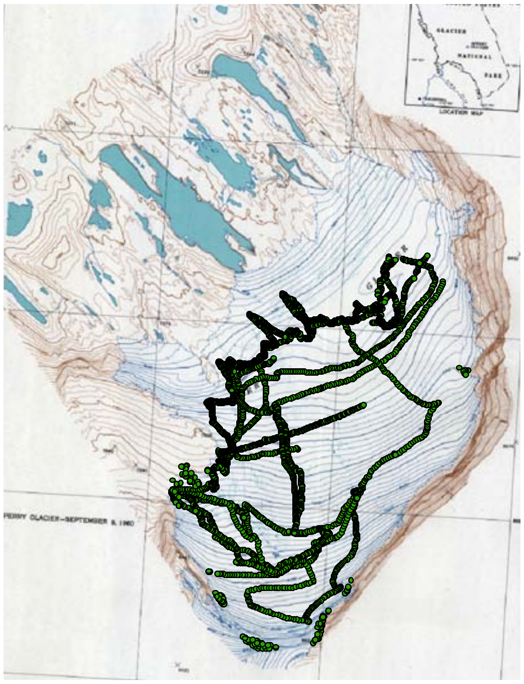


Figure 2. Survey path of GPS rover, August 2007. Note large gaps in data coverage which are being addressed during the 2008 field season.

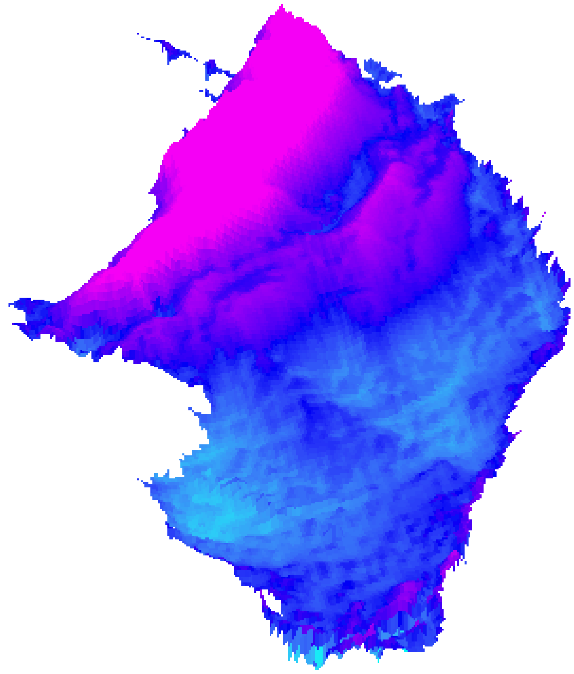


Figure 3. Magnitude of volume change between 1950-1960. High pink areas denote ice loss, low light blue areas denote ice thickening.

Work in Progress

We are in the middle of the 2008 field research season in Glacier Park. Six trips have been made to the field site so far this summer and two more are planned. We have (1) installed meteorological instruments adjacent to and on the glaciers, (2) collected winter balance data from snowpits, probing and density profiling, (3) collected precision GPS data for purposes of constructing a 2008 glacier surface, and ablation profiles, and (4) collected ice penetrating radar data for determining ice volume. The two remaining field campaigns will focus on collected surface GPS data and ice radar data.

A manuscript is in preparation for publication in the *Journal of Climate.* This manuscript focuses on long term ice volume chances of Sperry Glacier and the climatic forcing on ice volume. Data from the 2008 field season must be fully processed for inclusion in one section of the paper. We expect this to be complete and to submit the paper for review by December, 2008.

Students Involved In (And Supported By) This Research

Michiel Kramer, Ph.D. candidate, Geosciences
Blase Reardon, M.S. candidate, Geosciences
Nathan Taylor, undergraduate senior, Geosciences
James St. Clair, undergraduate senior, Geosciences and Physics

Public Outreach Involving This research

• Presentation. "Role of Ice Movement in the Response of Glacier Park Glaciers to Climate Change" Waterton-Glacier Parks Science and History Day, July 27, 2006.

• Invited guest speaker, Big Sky Science Partnership Summer Institute, June 19, 2008
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Undergradute Senior Thesis

Nathan Taylor, UM Geosciences. "Ice Volume Changes in Sperry Glacier, Glacier National Park, From 1950-2007" Completed: 5/2008

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Reardon, B.A., J.T. Harper, and D.B. Fagre, 2008, Climatic And Topographic Influences On The Mass Balance Of A Receding Cirque Glacier, Glacier National Park, Montana, Mountain Climate Research Conference, Silverton Colorado, Consortium for Integrated Climate Research in Western Mountains.

Moore, J. N., J. T. Harper, W. W. Woessner, and S. Running (2007), Headwaters of the Missouri and Columbia Rivers WATERS Test Bed site: Linking Time and Space of Snow Melt Runoff in the Crown of the Continent, Eos Trans. AGU, 88(52), Fall Meet. Suppl., Abstract H13A-0964.

Progress report, for INRA sponsored "Changing Water Resources from Montana's Mountain Glaciers: Past, Present, and Future"

P.I. Joel Harper, Department of Geosciences, University of Montana

January 8, 2008

This report represents progress since the last report dated February 5, 2008. This report focuses on results obtained during the last year, and does not include prior achievements.

1. Mass Balance for Water Years 2005-2008

1.1 Overview

The annual balance is an estimate of the total change in mass at the glacier surface over a year. For Sperry Glacier, the year is defined as the water year, which runs from October 1 to September 30. The sum of accumulated and ablated mass at a given point on the glacier surface is the point net balance b_n. The mean b_n for all points on the glacier is the annual net balance B_n. It can also be understood as the change in mass at the glacier surface divided by the glacier area.

The point net balance b_n can be calculated for any point for which both b_w and b_s are known by summing the two values. A positive sum represents a net gain in mass at the point, while a negative sum represents a net loss in mass. For Sperry Glacier, a direct calculation of b_n is possible for the ablation stake points each year. The interpolated b_w and b_s values also allow b_n to be estimated for each 10 m cell by summing the two grids. The mean value for the cells approximates the annual net balance B_n. This method for determining B_n can be used for 2005 and 2006 because there were sufficient snow depth measurements to interpolate b_w across the glacier. For 2007 and 2008, B_n is estimated by adding the scaled B_w and the B_s determined through interpolation.

1.2 Methodology

We used two methods for calculating B_n. For 2005 and 2006, grids of interpolated b_w and b_s were both available, allowing calculations of b_n for each of the 10 m cells by summing the two grids. The mean b_n value is equivalent to the B_n for the glacier as a whole. For 2007 and 2008, only one of the two grids was available, the grid of interpolated b_s values. We calculated B_n by summing the B_w value for each year derived via scaling and the B_s value for each year taken from the interpolated grid of b_s values.

1.3 Results for 2005 and 2006 water years

Maps of interpolated b_n for 2005 and 2006 show similar spatial patterns. In both years, the area with the most negative b_n values was near the west margin of the glacier, in the area of crevasses and shallow snow. The areas with the highest values were below the headwall and the cirque walls, while the headwall itself showed both positive and negative mass balances. In both years, most of the lower part of the glacier had b_n values between -1.00 to -2.00 m w.e. However, while the line where accumulation and ablation are equal – the zero contour – was at different elevations in the two years. In the basin below the headwall, the line was between 2500 and 2550 m elevation both years but in 2006 the line was lower and extended northeast under the cirque wall whereas in 2005 there were only a few patches of positive mass balance under the cirque wall.

The maps also showed that the two years had very different accumulation- area ratio (AAR). This measure is the ratio of the area in which the b_n is positive to the area of the entire glacier surface. For the glacier area in the denominator of this ratio we used the total area of the interpolated cells – 0.828 km^2 - which is slightly smaller than the actual area of the glacier - 0.841 km^2. The AAR for 2005 was 0.08, only 1/3 the of 2006 value of 0.24. Both values are well below the ratio of 0.6-0.7 considered typical of a glacier with a positive mass balance.

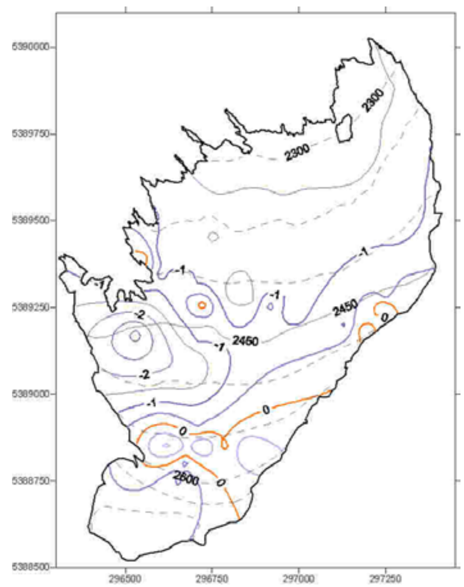

Figure 1. Contour map of 2005 calculated b_n values and surface elevations. Blue contours depict b_n in 0.5 m w.e. contour intervals, with orange line marking line of zero balance. Grey lines depict surface elevation in 50 m intervals, with solid dark line marking approximate mean elevation of glacier.

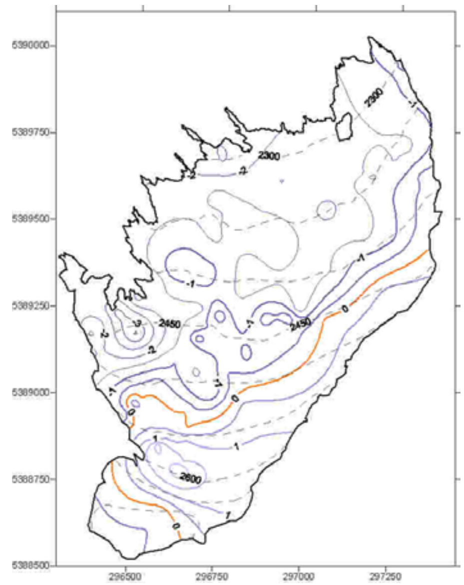

Figure 2. Contour map of 2006 calculated b_n values and surface elevations. Blue contours depict b_n in 0.5 m w.e. contour intervals, with orange line marking line of zero balance. Grey lines depict surface elevation in 50 m intervals, with solid dark line marking approximate mean elevation of glacier.

The differences between the 2005 and 2006 interpolated b_n values were greatest at the extremes. The median values for the two years were nearly identical, as were the 75th-percentile values, with the 25th percentile values similar. Thus the middle 50% of the values were both similar and similarly distributed. For the other two quartiles, particularly the uppermost quartile, the two year's values were more different. In 2005, the mean and median values were with 0.05 m w.e.; in 2006, the mean was considerably further from the median and closer to the 75th percentile.

In 2005, the glacier lost 8.88 x 10^5 m^3 water while gaining just 2.3 x 10^4 m^3, for a net volume change of -8.65 x 10^5 m^3 of water. Dividing that net change by the gridded area results in an annual net balance B_n for the year of -1.04 m w.e. That figure is slightly lower than the mean interpolated b_n due to the equation used to determine volume on the grid; the latter is likely a slightly better estimate of b_n because the math is simpler.

The volume of water lost at the glacier surface in 2006 was 8.53 x 10^5 m^3, only slightly lower than in 2005. The volume gained, however, was 1.54 x 10^5 m^3, 6.5 times greater than in the prior year. The resulting net change for the year was -6.99 x 10^5 m^3 of water, for an annual net balance of -0.84 m w.e. The mean b_n of -0.81 was slightly more positive and is again a slightly better estimate of B_n.

1.4 Results 2007 and 2008 water years

For these two years, computing the B_n required subtracting the interpolated B_s from the B_w value derived by scaling. However, the ablation stake data provided measured b_w values that could be included in the scaling, so the B_w estimate was revised (Table 1). The revised Bw values were each 0.04 m w.e. greater than the previous versions, but the increases seem reasonable. The 2005 value is still within 3% of the interpolated value, and the mean measured b_w for 2007 and 2008 are almost certainly underestimate the actual values.

Table 1	**2007**	**2008**
Scaled B_w	2.35	3.08
Interpolated B_s	-3.97	-2.36
B_w-B_s	**-1.62**	**0.72**
Mean stake b_w	2.44	3.18
Mean stake b_s	-3.97	-2.4
Mean stake b_n	**-1.53**	**0.78**
Total Grid Area (m^2)	808900	808900
Net delta Volume (m^3)	- 1309090	584952

Without interpolating values we cannot compare spatial patterns with previous years, but other comparisons are possible. Multiplying the total grid area for the B_s computations – slightly smaller than the grid used for the previous two years – by the B_n provides an estimate of net volume change for the glacier in each of the two years. In 2007, the glacier lost a net volume of 1.31×10^6 m^3 of water – 86% more than the previous year. In contrast, the glacier gained 5.85×10^5 m^3 of water.

1.5 Cumulative Balance:

Over the four years of study, an average of 10.4 m w.e. accumulated at any given point on the glacier surface, but 13.11 m w.e. was ablated over the same period (Table 2). The cumulative mass balance for the four years was -2.77 m w.e., with a mean annual balance of -0.69 m w.e. The average volume change each year was -5.72×10^5 m^3 of water, for a net volume change over the period was -2.29×10^6 m^3.

Table 2.

	2005	2006	2007	2008	Cumulative Sum	Annual Mean	Range
B_w (m w.e.)	2.18	2.79	2.35	3.08	10.4	2.60	0.9
B_s (m w.e.)	-3.18	-3.60	-3.97	-2.36	-13.11	-3.28	1.61
B_n(m w.e.)	-1.06	-0.81	-1.62	0.72	**-2.77**	**-0.69**	2.34
Net D Volume (m^3)	-864819	-698469	-1309090	584952	**-2287426**	**-571857**	1894042

2. Ice Volume Changes 1950-2007

Digital elevation models of Sperry Glacier were constructed from two USGS topographic maps based on surveys of the glacier conducted in 1950 and 1960. A third digital elevation model was produced from data collected during a 2007 survey of the glacier's surface and surrounding rock margin. This latter survey was done with a kinematic GPS survey system utilizing an established local base station and a rover outfitted with Trimble R7 receivers. Post processing of these data allowed for cm-scale vertical and horizontal accuracy. Digital elevation models were gridded into $10m^2$ cells via a standard Kriging algorithm. The grids were differenced in order to calculate volume changes between the survey years.

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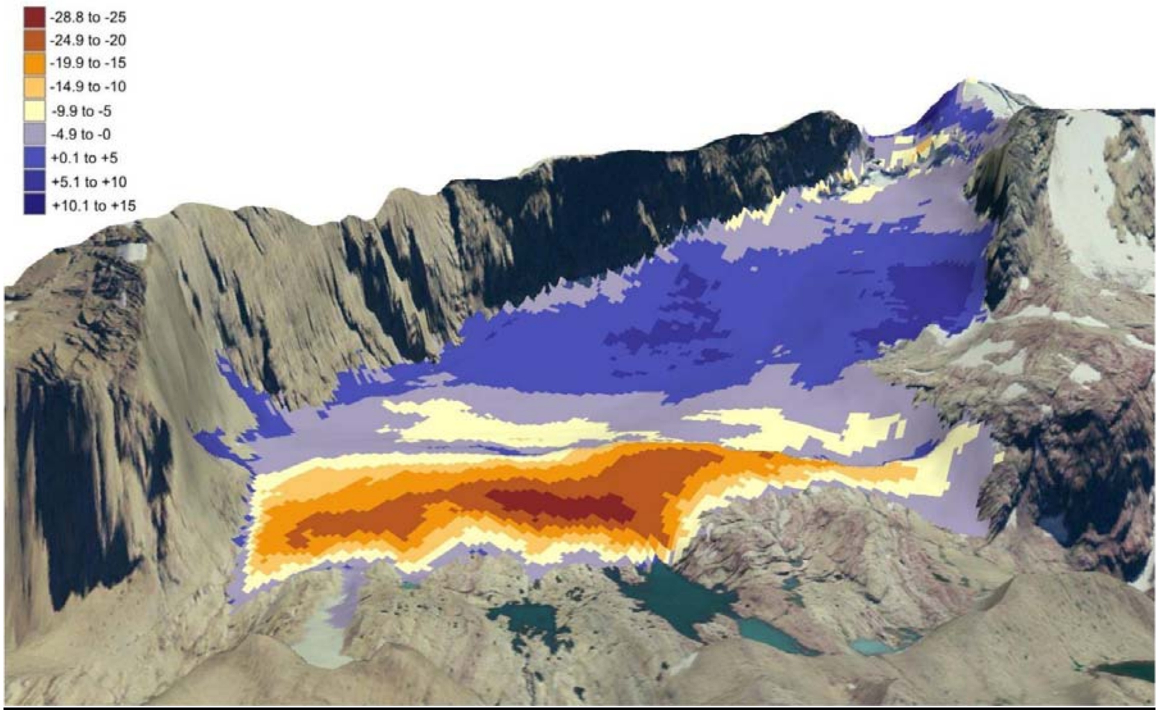

Figure 3. Ice volume change of Sperry Glacier, 1950-1960. Hot colors show areas of glacier thinning ($-5.4x10^6$ m^3); cold colors show areas of glacier thickening ($+1.4x10^6$ m^3).

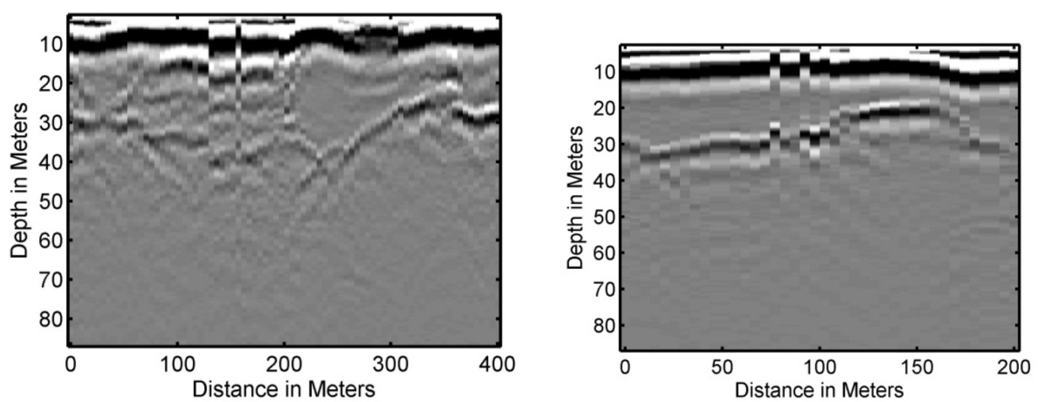

Figure 4. Example ice penetrating radar transects of Sperry Glacier collected in 2008. Radar data were used to map the glacier bed and compute the present day ice volume.

Students Involved In (And Supported By) This Research
Michiel Kramer, Ph.D. candidate, Geosciences
Blase Reardon, M.S. candidate, Geosciences
Nathan Taylor, undergraduate senior, Geosciences
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Snowmelt and Climate Change in Western Montana

Inland Northwest Research Alliance (INRA)
INRA Constellation of Experimental WATERsheds (ICEWATER)

Progress Report
2/15/10

Zachary M. Seligman
Joel T. Harper

Research under the INRA ICEWATER directive has been directed towards two main avenues. The first has been the collection and processing of data from the National Operational Hydrologic Remote Sensing Center (NOHRSC), while the second has been building and testing 5 meteorological (met) stations that will be used in the near future for continual monitoring of western Montana snowmelt processes.

NOHRSC was developed to help forecast water supply and flood warnings throughout the entire United States. The NOHRSC model incorporates satellite-derived snow-covered area, coupled with airborne snow water equivalent measurements, ground-based hydrometeorological data and numerical weather prediction model datasets into coupled snow-transfer, mass and energy balance models. The result is continuous, hourly or daily representation of various parameters including: liquid precipitation, solid precipitation, snowpack temperature, snow water equivalent (SWE), snowmelt, snowpack sublimation, blowing snow sublimation, and snow depth at 1 km spatial resolution.

NOHRSC raw data is available on-line at an FTP site where daily data for all listed parameters can be obtained beginning in fall 2003 (http://www.nohrsc.noaa.gov/archived_data/). To process the NOHRSC data for practical use involves numerous steps and lofty computational resources. For each day, there are 8 files. Hence, for one year, there is just shy of 3,000 files, which is roughly 130 GB. Each file needs to be decompressed, renamed and clipped in geographical extent as the original files are of the entire United States. Matlab code was created in order to automate these steps as much as possible. Post-processing, data is in a usable format and can be plotted.

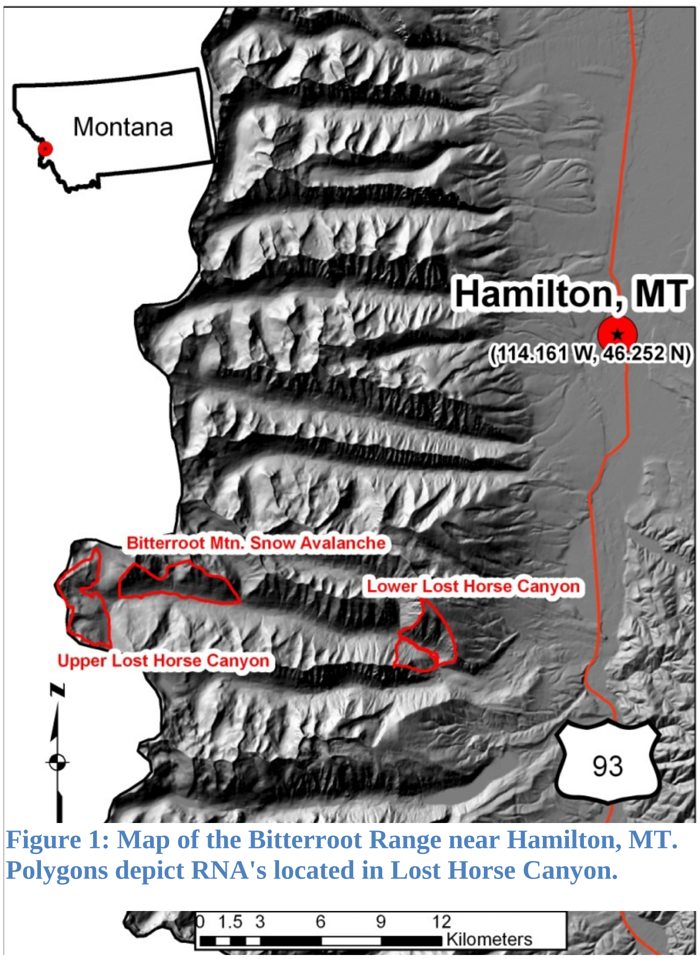

Figure 1: Map of the Bitterroot Range near Hamilton, MT. Polygons depict RNA's located in Lost Horse Canyon.

Some initial data was plotted for Lost Horse Canyon, located in the Bitterroot Range just west of Hamilton, Montana. At the top of Lost Horse Basin is the Upper Lost Horse research natural area (RNA). RNA's are a network of natural ecosystems that are managed by the Forest Service for scientific study. The Upper Lost Horse RNA is one location where we are planning to implement a field-based snowmelt study using the mentioned meteorological stations (Figure 1).

As an example, a few of the NOHRSC parameters were averaged and plotted for this small mountain watershed using 2005 data (Figure 2). The parameters follow expected cycles where SWE is highest in the spring and melt ensues, punctuated with periods of snowpack sublimation at various times of the year.

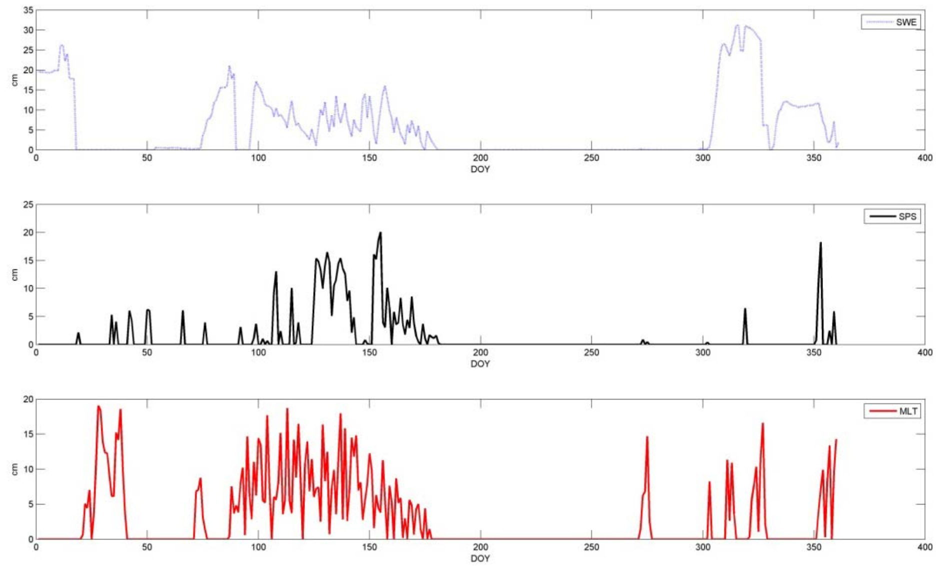

Figure 2: SWE (blue), Snowpack Sublimation (black) and Snowpack Melt (red) as determined from NOHRSC data for the Upper Lost Horse RNA, 2005. Y-axis is centimeters of water equivalent; x-axis is day-of-year.

NOHRSC provides a time series of hydrometeorological data which can be used as a potential reference to our own modeling and field evaluations. The next steps to take are continuation of downloading and processing the rest of the NOHRSC parameters all the way to the present.

In addition to obtaining the NOHRSC modeled time series, we have also been preparing for field work. A major hurdle in this direction has been to build 5 met stations from their various bits and pieces and get them functioning and ready for the field. Each met station consists of 4 instrumental components and a data-logger. The instruments used are a sonic depth ranger, a temperature probe, a solar panel and a radiation sensor. Each instrument cable was spliced, where an eight position connector was subsequently placed in the divided section. This was done so that instruments could be easily connected to the data-logger while also keeping connections water-tight and the data-logger well protected. The data logger is placed in a water-tight pelican case with four holes drilled in the side that handle the 8 position connectors for each instrument (Figure 3). All instruments are mounted on a 3-meter tall aluminum tripod to insure stability in adverse weather conditions (Figure 4).

We are now in the process of designing experiments for this upcoming ablation season that will be looking at snowmelt and sublimation rates in the alpine and sub-alpine areas of Lost Horse Basin which will employ the use of these met stations. Collected data will then be used to further develop and drive a snowmelt model for the Bitterroot Range.

Figure 3: This is a close-up of the data-logger box. 1) Male ends of the 8 - position connectors. 2) Campbell CR200 data-logger. 3) Corresponding female end for the radiation sensor (left). 4) Corresponding female end for the sonic depth sensor (right).

Figure 4: An example of one of the met stations. 1) Sonic Depth Sensor. 2) 5W Solar Panel. 3) Temperature Probe housed inside a radiation shield. 4) Radiation Sensor. 5) Data-Logger housed inside a waterproof Pelican Case.

Understanding Processes Affecting Instream Temperatures in the Arctic

Utah State University
Bethany T. Neilson
Collaborators: Doug Kane, University of Alaska Fairbanks

Introduction

The potential effects of global warming on instream temperatures and therefore, freshwater and marine fishes are varied and complex [*Wood and McDonald*, 1997]. The most obvious effects of increases in instream temperatures on water quality are related to changes in oxygen solubility and reaction rates. Additional impacts include the influence on recreational and commercial fisheries due to important aquatic species moving from lower latitudes to higher latitudes [*Carpenter et al.*, 1992]. In turn, this movement may have an adverse affect on native Alaskans that depend on these fisheries for subsistence. Species at higher latitudes are expected to be the most impacted [*Rombough*, 1997].

To be able to quantify the impacts of climate change on instream temperature (particularly in the Arctic) and potentially develop management strategies to address the associated issues, it is important to: collect process specific data; determine dominant heat sources and sinks; and further develop instream temperature models that incorporate these processes. Temperature models currently available to assist in heat load allocations have limitations in the types of heat fluxes included. Heat fluxes that are typically not considered include bed conduction, hyporheic processes, dead zone processes, and shortwave solar radiation fate in the water column and bed substrate. A data-centric approach to collecting detailed information about energy and mass fluxes in streams, including the hyporheic (subsurface transient storage) and dead zone (surface transient storage) effects, was developed and used support model development and testing that incorporates these processes [*Neilson et al.*, 2009].

With this ability to quantify the processes that drive the instream temperature dynamics, other external mechanisms that can influence instream water quality and temperatures must be considered and included if they are influential in the overall energy balance within the stream. These possible sources of heat and solutes during the summer months in most natural systems include runoff due to precipitation events and larger scale exchanges between surface water and groundwater. In the Arctic, the exchanges of subpermafrost groundwater and surface water are rare in areas of continuous permafrost [*Zarnetske et al.*, 2007] and therefore, suprapermafrost meltwater moving through the active layer [*Edlund et al.*, 1990] (or top layer of sediments that thaw annually in areas with continuous permafrost [*Hinzman et al.*, 2005]) and runoff from direct precipitation are likely the biggest concerns.

Study Area

In this project, data was collected to begin understanding the dominant heat fluxes in a small Arctic stream. As shown in Figure 1, the proposed site, Imnavait Creek, is a beaded stream on the North Slope of the Brooks Range. This creek is near the Toolik Field Station and is located within Imnavait Creek, part of the ICEWATER network.

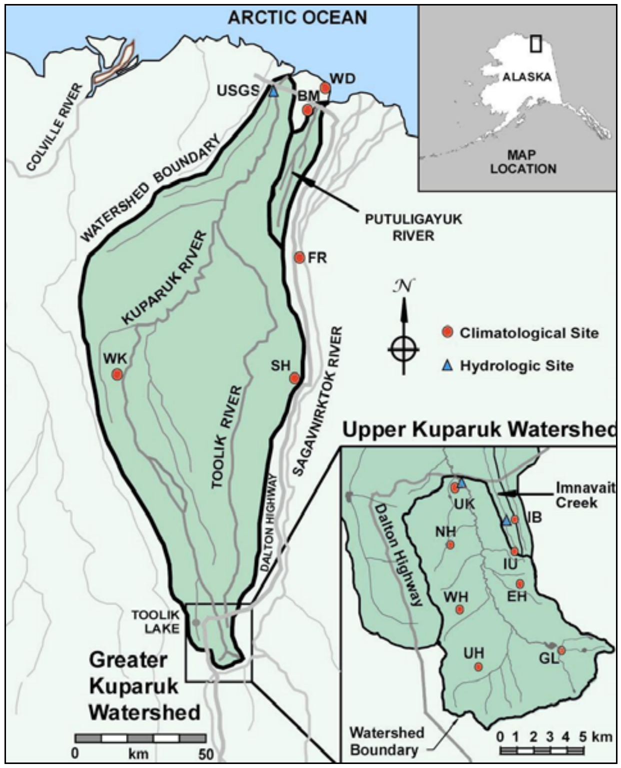

Figure 1. Imnavait Creek watershed location within the Upper Kuparuk watershed.

Completed Activities:

The primary research questions were:

1. How do instream temperatures change longitudinally in beaded systems such as Imnavait Creek?
2. What are the significant heat fluxes in these systems?
3. How important is bed conduction in Arctic systems and will the significance of this flux change as the depth to the permafrost increases?
4. Does earlier snowmelt and the resulting increase in the open water period change the instream temperature dynamics?

A synoptic study of approximately 6 days was conducted to collect almost 100 temperature time series at various locations along the study reach (Figure 2 and Table 1). More specifically, the data collected throughout the synoptic study included: main channel temperatures vertically in pools and along the study reach; sediment temperatures at multiple locations and depths; temperatures within water tracks (surface and subsurface); shortwave radiation reflection off the water surface and penetration of the water column; tracer studies to quantify travel times, transient storage, and/or groundwater/surface water interactions; and depth information at the boundary condition to establish a stage discharge relationship. Other data types are further detailed in Table 2.

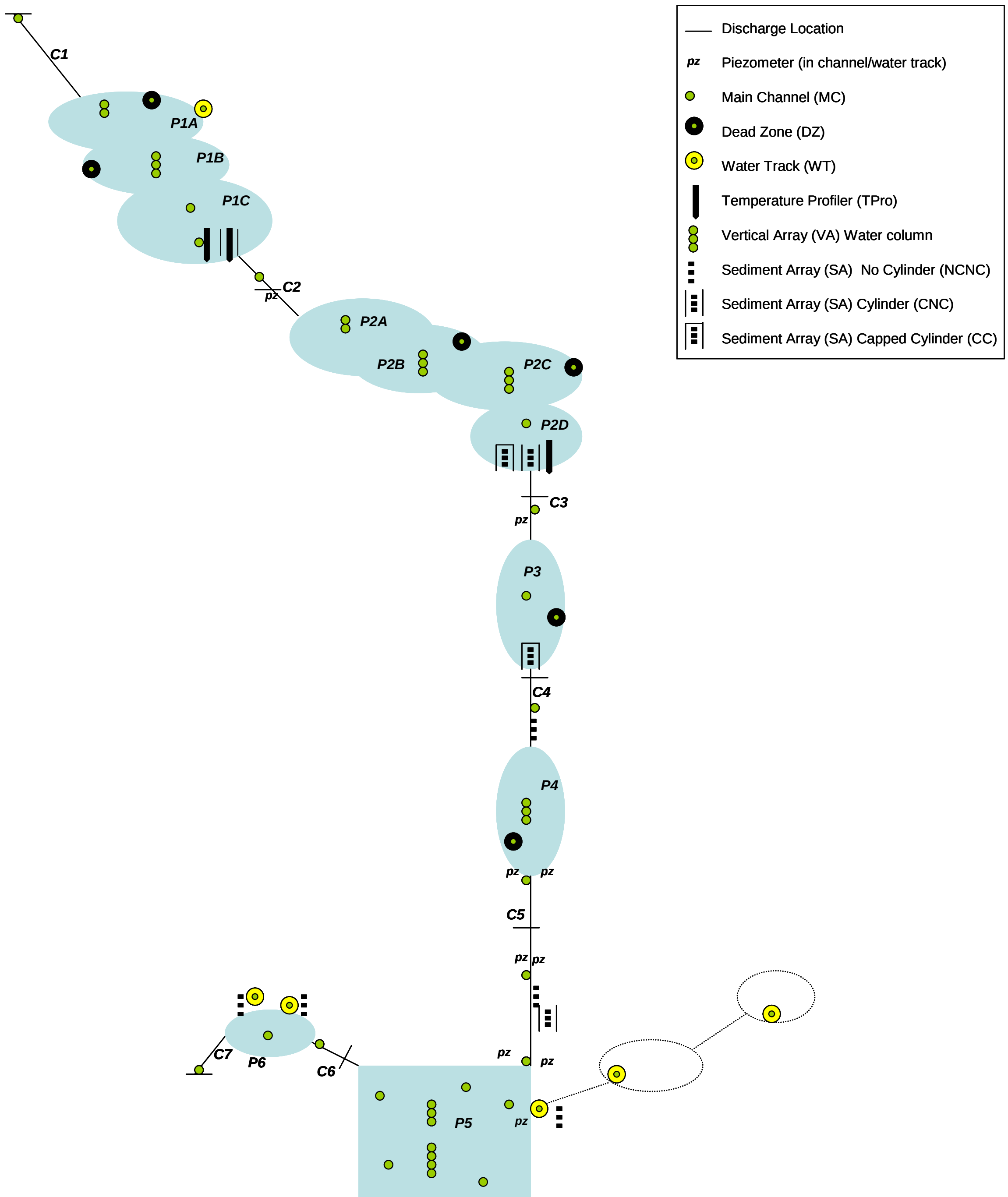

Figure 2. Diagram of data types and location throughout the Imnavait study reach.

Table 1. Data types collected in Imnavait Creek study reach in Summer 2009.

Data Type	Equipment	Frequency	Locations	Reason Collected
Temperature	Thermal profilers (thermistors) Onset Hobo thermistors	10 minutes	Chutes (x9) Pool Edges (x6) Pools vertically (x28) Water tracks (x6) Sediment (cylinder and no cylinder)(x30)	Pool stratification Bed conduction Hyporheic exchange Dead zone exchange
Discharge	Velocity meter Kane Weir	12 hours Long Term	Chutes (x6)	Net water balance Seasonal Fluctuations Boundary Condition
Land survey/Bathymetry	Survey grade GPS/Sonar		Sampling locations Perimeter	Spatial Representation
Instream vertical head gradients	Piezometers	12 hours	Pool inlets and outlets (10 cm, 20 cm) (x5) Chutes (10 cm, 20 cm) (x4)	Upwelling or downwelling
Hydraulic conductivity	Piezometers Slug test		Inlets and outlets (10 cm and 20 cm) (x5) Chutes (10 cm and 20 cm) (x4)	Subsurface potential Spatial Heterogeneity
Solar radiation	Pyronometers	10 minutes one time	Above pool (x1) throughout water column (x2)	Reflection Attenuation
Weather data	Weather station		Kane	Surface Heat Flux
Sediment core	Cylinder	one time	Chute (x1)	Thermal properties
Specific conductance	YSI Sondes	3 times	Pool inlets and outlets (x12) Pools vertically (x36) Pools longitudinally (x12) Chutes (x7) Slug Injections (x10)	Longitudinal profiles Vertical profiles Dilution Residence times

The influence of lateral inflows into streams due to surface runoff (from rainfall or snowmelt) or melt of frozen, ice-rich soils within the active layer during the were found to result in a significant heat sink and/or source of constituents (Figure 3). We found that quantifying the relative magnitude of these inflows is important in understanding the mechanisms of runoff generation in permafrost environments and both the energy and mass balances within streams and rivers.

The data collected during the synoptic event are currently being used as both forcing and calibration data for instream temperature modeling efforts. They are additionally being analyzed to further understand the influences of lateral inflows (active layer meltwater) on instream processes. As the instream temperature model is completed being developed and calibrated, the results will provide initial information on the significant heat fluxes forcing longitudinal changes in temperature in these common beaded streams within the Arctic. Additionally, modeling scenarios, where the depth to the permafrost table (active layer thickness) will be investigated.

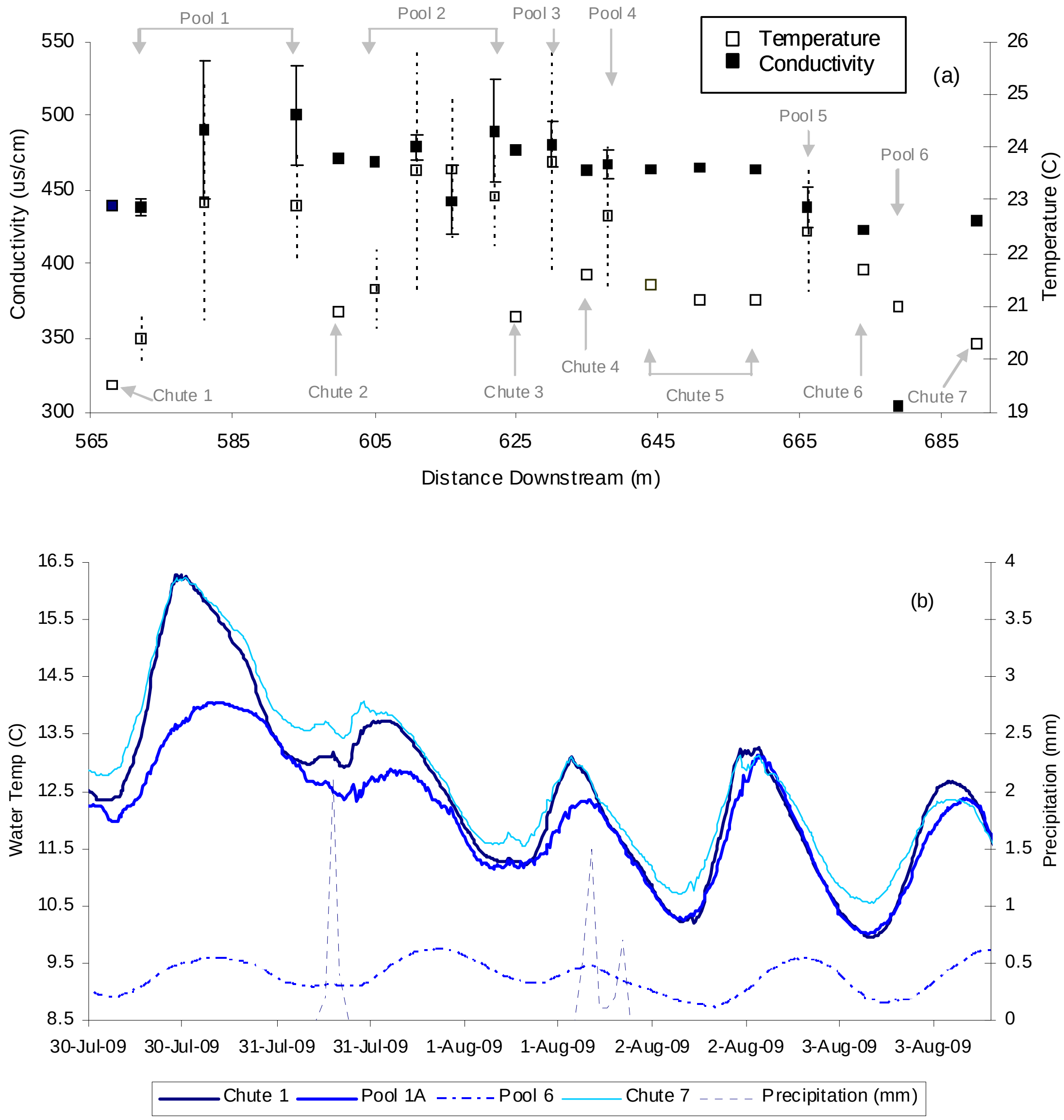

Figure 3. Example of data from Imnavait Creek in July and August of 2009 showing the variability in instream temperatures and conductivity over space (a)and time (b). (a) Longitudinal profile of temperature and conductivity under low flow conditions (July 22, 2009) and no precipitation. Larger pools (e.g., Pool 1) were measured at a number of locations longitudinally. Error bars represent the standard deviation of measurements taken within the stratified pools. (b) Time series of instream temperatures at four locations within study reach and a time series of precipitation within the Imnavait Creek watershed. Locations shown in (b) correspond to those shown in (a).

Longer term instream temperature data were also collected throughout the entire month of August 2009. A few temperature probes were additionally left in the stream and sediments throughout the winter season. Simulations to try to understand the potential influences on a longer open water season may also be conducted.

Collaboration

This data collection effort was conducted with the assistance of Doug Kane at the University of Alaska, Fairbanks. Some of the supporting data being used in the USU effort results from other data collection efforts by UAF. This collaborative activity has resulted in the submission of collaborative proposal in response to the NSF Office of Polar Programs Arctic Research Opportunities Solicitation (submitted January 14, 2009). Additionally, USU has been invited to attend the Arctic Long Term Ecological Research annual meeting to provide an overview of this research as well as preliminary findings.

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INRA Constellation of Experimental Watersheds: Cyberinfrastructure to Support Publication of Water Resources Data

Jeffery S. Horsburgh, David G. Tarboton, Kimberly A. T. Schreuders

Introduction

Over the past several years, researchers at universities affiliated with the Inland Northwest Research Alliance (INRA) have been collecting water resources datasets at a number of experimental watersheds in the western United States. Experimental watersheds in the INRA region span a number of climate, human development, and disturbance gradients, and researchers are investigating several different research themes, including snowmelt responses to climate change, groundwater - surface water interactions, modeling of hydrologic response, land use change, and arctic river processes. Integration of data from these watersheds is facilitating cross-site comparisons and larger scale studies that synthesize information from diverse settings, making the network as a whole greater than the sum of its parts.

This project focused on establishing and supporting the INRA Water Resources Consortium Constellation of Experimental Watersheds (ICEWATER) Information System Network. The ICEWATER Information System Network is a distributed network of computer servers that was built using components of the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS) technology (http://his.cuahsi.org) to publish and integrate the data holdings from ICEWATER. The goals of the ICEWATER Information System network were: establishment of a common information system for data sharing, analysis and archiving, building upon and extending the CUAHSI Hydrologic Information System; establishment of a common modeling framework to facilitate sharing and model interoperability; and establishment of common base characterization datasets such as digital elevation models (DEMs) from LIDAR, land cover and land use from remote sensing, that provide detail beyond nationally available information.

Project Summary

The ICEWATER Information System is comprised of centralized functionality, referred to as ICEWATER Central (http://icewater.inra.org), and a network of HIS Servers, one at each INRA university, that support the data services hosted by that university (see http://icewater.usu.edu for an example). In addition to hosting and publishing data on an ICEWATER HIS Server, Utah State University constructed the ICEWATER Central website and provided support to the data managers and investigators at the other INRA Universities in setting up and configuring an HIS Server on which they could publish data from their experimental sites. This included developing and delivering a 2-day, hands-on training session held at Boise State University, during which the data managers from each University were trained in using HIS Server software components. ICEWATER Central support also included email and telephone support for data managers and monthly conference calls during which data managers were able to ask questions and get feedback.

Significant enhancements to the CUAHSI HIS Server software platform were also made by USU as part of the ICEWATER project. In response to requests from data managers at the INRA universities, features were added to and bugs were fixed within existing HIS Server software like the Observations Data Model (ODM) Data Loader, the ODM Steaming Data Loader, and ODM Tools. Additionally, new HIS Server components were introduced, including the HIS Server Website, the Time Series Analyst, the HIS Server Map, and the HIS Server Capabilities database and Web services. These tools and their documentation are all available via the ICEWATER Central website. While developed specifically for the ICEWATER project, these components will all be reused as general components of the CUAHSI HIS, which has a broader impact within the Hydrologic Science Community. Anyone can now use the HIS Server components developed by the ICEWATER project to establish a new or enhance an existing HIS Server.

Finally, a significant outcome of the ICEWATER project is a set of functional requirements for supporting data organization, versioning, authorization, and access control for hydrologic data that can be incorporated within a data publication policy supported by the Hydrologic Science Community and that can be functionally supported within a data publication system like the CUAHSI HIS.

Publications and Presentations Resulting from this Project

Horsburgh, J. S., D. G. Tarboton, K. Schreuders, D. P. Ames, J. P. McNamara, L. A. Marshall, B. L. McGlynn, D. L. Kane, A. Tidwell, J. Boll, N. W. Hinman, M. E. Barber (2009), INRA Constellation of Experimental Watersheds: Cyberinfrastructure to Support Publication of Water Resources Data, Eos Trans. AGU, 90(52),Fall Meet. Suppl., Abstract H51H-0858.

Horsburgh, J. S., D. G. Tarboton, K. Schreuders, J. McNamara, D. Ames, L. Marshall, D. Kane, A. Tidwell, J. Boll, N. Hinman, and M. Barber (2009), INRA constellation of experimental watersheds: Cyberinfrastructure to support publication of water resources data, Presented at the Utah State University Water Initiative Spring Runoff Conference, Logan, UT, April 2 - 3.

Appendix C
Education Plan

Introduction

The INRA Water Research Consortium Education Plan consists of innovative educational activities primarily aimed at graduate, undergraduate, and K-12 levels, although public outreach opportunities will also be pursued. Initial investments will be targeted toward graduate-level education, drawing from the substantial expertise developed from the INRA Subsurface Science Graduate Program (SSGP).

The education plan is inextricably linked with the INRA Water Research Consortium research plan that focuses on information and decision tools for water resources and drought monitoring and management. INRA Water Research Consortium research will substantially involve students, and it is expected that these students will participate in the education activities and programs outlined in this plan.

At the graduate level we will develop a new cross-institution certificate program in "Interdisciplinary Water Resources" intended to equip prospective water resources professionals with the interdisciplinary and problem solving skills, as well as sufficient disciplinary depth, required to contribute to the solution of water resources problems in the intermountain region. Figure 1 depicts the range of subject matter knowledge, from basic sciences to applied sciences to integration with social sciences, required to address water resources problems. Figure 2 presents a preliminary summary of the categorization of responses to the education questions from the INRA needs assessment. The goal of the INRA Interdisciplinary Water Resources Graduate Level Certificate program will be to provide students with the knowledge, communications, and problem solving skills to effectively contribute in an interdisciplinary professional working environment to the solution of the region's water resources problems. This certificate program will be open to all levels of graduate study, but preliminary assessment of future needs and employment opportunities identified MS education as a critical area of emphasis.

At the undergraduate level we will make content and tools available from the Water resources toolkit for use in undergraduate courses at INRA institutions and work within appropriate departments to implement undergraduate research experiences for university credit.

At the K-12 level we will focus on educational materials and workshops for teachers that provide improved Water Resources Science content.

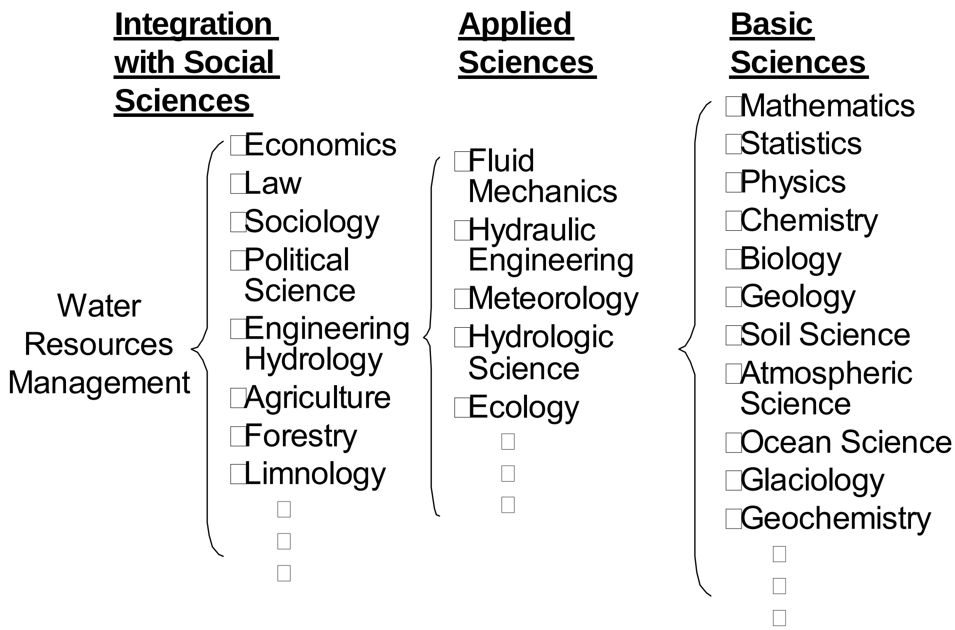


Figure 1. Intellectual ingredients for understanding, forecasting and managing water resources (Adapted from National Research Council Committee on Opportunities in the Hydrologic Sciences (COHS), 1991)

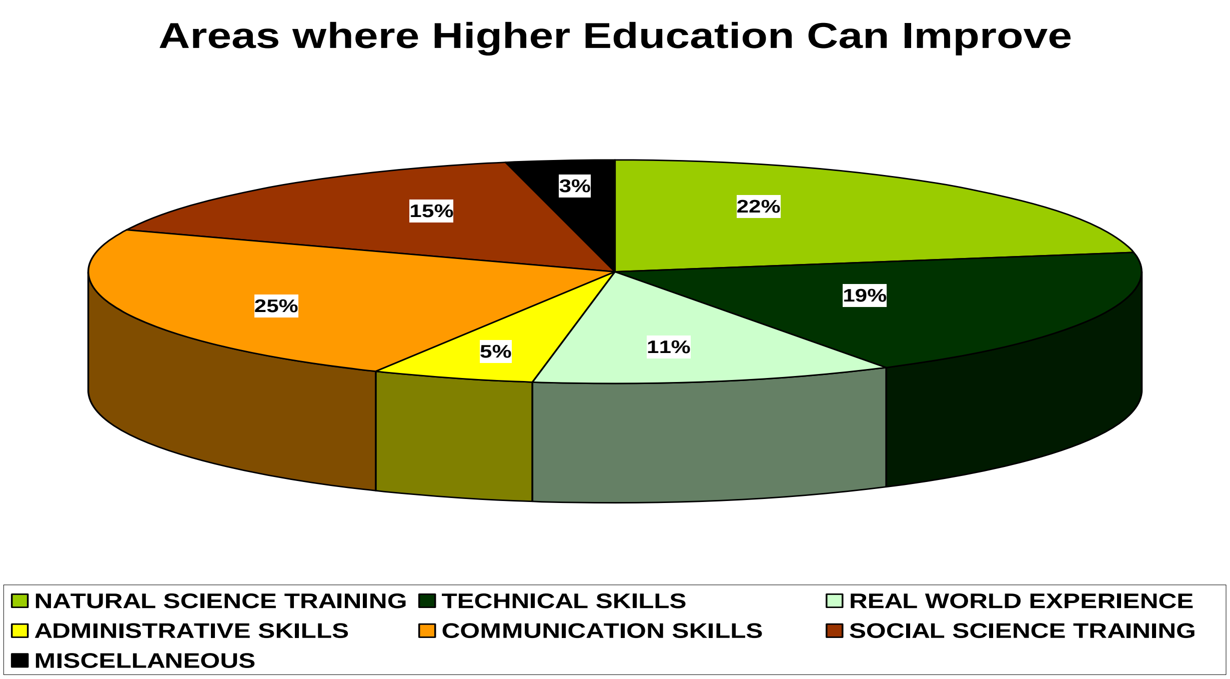


Figure 2. Preliminary summary categorization of responses on education needs from the INRA Needs Assessment (Jackson-Smith, personal communication, 2007)

Purpose and Educational Objectives

The purpose of this plan is to provide the basic outline for the content, delivery and management, of the graduate level component of the cross-institution interdisciplinary water resources program. Design of program elements to support undergraduate and K-12 levels will await the findings of the research needs assessment and further discussion.

The fundamental aim of the graduate program is to provide MS-level students life-long problem solving skills that will be needed to function productively as a professional in the water management sector in the US. While there will be some basic subject matter requirement, the educational objectives of the program revolve around the development of problem solving skills that will be needed to support the interdisciplinary nature of modern water resources management. The educational objectives of the graduate program are:

1. *Depth in a disciplinary field*. Students will have demonstrated through coursework an in-depth understanding at a professional level of their specific field of expertise.

2. *Synthesis and problem solving*. Students will have demonstrated the ability to synthesize and solve problems in their discipline.

3. *Team problem solving*. Students will have demonstrated through participation in a problem based learning course the ability to work together and solve problems on a current interdisciplinary water issue.

4. *Communication (papers, presentations, report writing)*. Students will have demonstrated through reports and presentations the ability to clearly communicate their ideas and work to both technical audiences from a different discipline and non-technical audiences.

5. *Synthesis and integration*. Students will have demonstrated the ability to synthesize diverse, conflicting and uncertain real world information including information from other disciplines into problem solutions and designs.

Program Requirements, Content, and Delivery

Requirements: Graduate students in the cross-institution interdisciplinary water resources program will be required to:

1. Fulfill the requirements for a graduate degree in their home department and home institution. This will demonstrate Educational Objectives 1 and 2.

2. Complete the Core "Interdisciplinary Water Resources Problem Solving" course (see the following section). This will address Educational Objectives 3-5. This course will be in addition to the courses required for completion of the degree in the home institution.

3. Complete a one week workshop to be held in the summer following the core course. This workshop will bring the cohort together for a week of intense work and interaction that includes field, laboratory and analytical work.

4. Complete at least one course from another INRA institution, using distance education technology, which should be part of each student's program of study to fulfill either a breadth or depth requirement. This course may, if permitted by the home institution, also count towards the course requirements for the graduate degree. The purpose of this requirement is to encourage the sharing of expertise among INRA universities.

Problem Solving Content: A problem-based-learning (PBL) course will be required that focuses on a current interdisciplinary regional water resources problem. It will be offered spring semester and should be taken by program participants in their second semester. A group of instructors will lead the class through a data-driven and extensive study of a topical issue. As a learning community, the class will learn the skills and disciplinary knowledge required through addressing the problem at hand. Classes will generally be in the form of collaborative discussion groups intended to engage students as active learners. The disparity in entering skill levels and disciplinary knowledge will be a challenge, but will provide opportunities for more knowledgeable students to develop communication skills by explaining and sharing their knowledge with students from other disciplines. Directed lectures[1] will be used to provide just-in-time educational experiences in the context of the problem at hand. These will be presented either by faculty on the instruction team (one from each institution) or a guest lecturer invited to supply expertise needed to address the problem at hand. The class will culminate in a "committee" class report that provides their collective recommendation for the solution of the problem. The course will be run by a team of instructors, comprising one instructor from each INRA institution who will be the instructor of record for that institution. This course will be divided into three blocks with each block focusing on a separate problem, or if possible related aspect of the same problem. Each block will be taught by a team of two or three faculty such that the faculty member from each institution is involved in teaching one block.

One month of salary coverage from INRA water resources consortium funds will be provided to each institution to support the instructor responsible for this class for the first two years that it is offered. This is intended to cover the additional effort of developing the course and to help ease the assimilation of such a course into departmental budgets and faculty instructional loads. From the third year on, the course is expected to become part of the regular instructional load of the university supported by tuition and other funding that universities receive for offering graduate education. In the event that some participating institutions are unable to assimilate this course into their regular offerings by the third year, it is hoped that a sufficient number of INRA institutions are able to establish and maintain the course and continue to offer it to all INRA institutions just like the regular courses provided via the distance delivery system. Student fees from the non-participating institutions (i.e., institutions that do not have a local instructor of record) would be transferred to the participating institutions using mechanisms put in place for the Subsurface Science Graduate program (see Program Administration, below).

[1] A directed lecture is a presentation targeted to a specific problem, explaining the concepts, processes and methods, limited to and within the context of the problem.

One Week Workshop Content: Physically observe a hydrologic system that has been the topic of one of the problems discussed during the core course. This could include a socioeconomic perspective. Physically measure parameters used to resolve the problem. Work with models to analyze and develop a synthesis of the problem based on the physical measurements. Discuss statistical methods, validation, and statistical significance of the interpretations. Discuss how the original outcome might have varied as a result of any new perspective gained by the workshop. The goal is to ensure that the students have some concept of how data are collected and synthesized into a form that can serve as a basis for decision making. The workshop should have a duration of 3 to 7 days depending on the site and the complexity of the problem.

Disciplinary Content: A list will be developed of courses, participating programs, and prerequisites from each institution that would be offered to other institutions using distance delivery mechanisms. Each institution should offer at least two (but more, where possible) of its regular courses via the INRA distance delivery system or equivalent. Courses offered should preferably be those that are somewhat unique and not available at other institutions. These courses will be used by students to fulfill the requirement of taking at least one course from another INRA institution.

Seminar Content: Students will be required to attend a seminar each semester they are in the program. Seminars will be offered approximately twice per month, and will be a combination of offerings from INRA institutions. One person at each university will be locally responsible for the seminar series.

Course Delivery: The course delivery facilities to enable offering of the core and disciplinary classes at each institution should have the following functionality. This is described in terms of generic functionality, rather than capabilities of specific systems. Information technology specialists need to assist with ensuring that the system chosen or developed has this functionality:

- One to many system capable of delivery up to nine sites
- Multi way voice free capability between originating and destination sites without need for operator moderation or microphone switching
- General purpose PC with high resolution screen capable of accommodating any general purpose software an instructor requests
- Tablet software for transmission and recording of note writing and sketches
- Computer desktop sharing from originator to destination classrooms
- Capability to switch display to from a destination classroom
- Sessions may be initiated by any site with no more than 2 days lead time
- Webcam video transmission between originator to destination classrooms
- Second computer display in originator classroom to monitor transmission
- Computer chat as an alternative to voice for asking questions
- Course management website that includes electronic reserve material, discussion forums, email, chat, archives of classes

This system could the existing H.323 system that was installed using funding from the Department of Energy for the Subsurface Science Graduate Program. Alternatively, Internet 2 based technology such as Access Grid Nodes, or a Personal Interface to the AccessGrid (PIG), or

MacroMedia Breeze capability could be used. Facilitation, technical support, and training for effective use of these systems needs to be provided to faculty participating in this program. Documentation on how to use the system needs to be developed and maintained.

Program Administration

Program Director: A program director with sufficient administrative assistance is required to take overall responsibility for the coordination and running of the program.

Faculty program coordinators: A faculty program coordinator is needed to be responsible for the execution of the program at each participating institution. The faculty program coordinator will also advise students in the program and coordinate with the graduate deans and program director.

Graduate Deans: The INRA Council of Graduate Deans (CGD) will assist with the development of the Graduate portion of the education program. They will interface with the registrars, department heads, deans, regents, and others as appropriate to incorporate the program into specific existing programs. The existing fee transfer arrangements[2] put in place for the Subsurface Science program will be used to transfer tuition payments between universities to cover the elective classes that students take at other institutions.

Advisory Committees: Students involved in the program who are pursuing research degrees (MS or PhD) are encouraged to take advantage of the expertise available at other INRA institutions by having one or more supervisory committee faculty members from another INRA institution. Travel funds will be set aside to assist with travel of such committee members to necessary meetings. INRA distance education facilities will also be accessible, subject to scheduling availability, for committee meetings involving faculty members from other institutions.

Admission and Fellowships: A number of INRA Interdisciplinary Water Resources Fellowships will be awarded competitively to students at each INRA institution based upon the availability of funds for students to complete the graduate certificate program. Non-Fellow students in participating programs will be eligible to apply for admission to the certificate program.

Graduate Deans will solicit nominations of potential fellows from their departments. Joint applications are required from a student and major professor, and must include a resume and personal statement from the student and a description of the research program of the major professor. At a given INRA school, the Graduate Dean will select the fellows. The selection should be based in part on whether the advisor has a suitable research program for the student to work within.

Curriculum Committee: A curriculum committee, to consist of one faculty member from each INRA university, will be formed to assemble a list of courses that the institutions volunteer to offer. The committee will examine the list for gaps and, where gaps are identified, will prepare

[2] Refer to: http://ssgp.boisestate.edu/include/elective.course.mgt.plan.pdf

an outline and student outcomes for these missing core courses. The committee will then seek faculty willing to prepare and teach these courses. A grant will be provided to faculty members who are selected to prepare such courses. Selection will be based in part on the long-term sustainability of the proposed course.

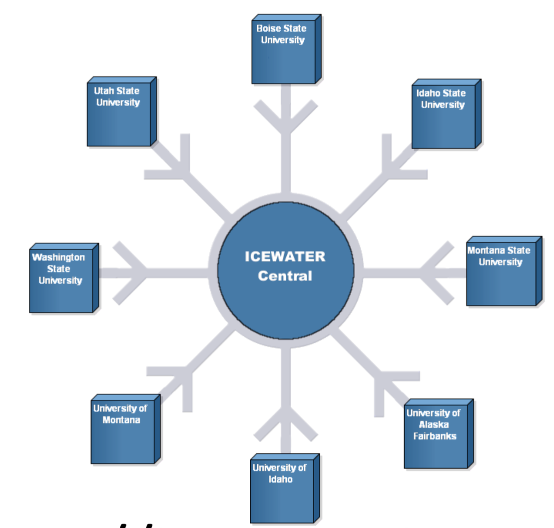
The Curriculum Committee will also prepare the curriculum for the problem-solving course, including the purpose, outline, and syllabus.

Certification: Certificates will be crafted and issued separately by each INRA university.

Reference

National Research Council Committee on Opportunities in the Hydrologic Sciences (COHS), (1991), Opportunities in the Hydrologic Sciences, Editor, P. S. Eagleson, National Academy Press, Washington, D.C.

Appendix D
ICEWATER Poster



INRA Constellation of Experimental Watersheds:

Cyberinfrastructure to Support Publication of Water Resources Data

H51H-0858

Jeffery S. Horsburgh, David G. Tarboton, Kimberly A. T. Schreuders, Daniel P. Ames, James P. McNamara, Lucy A. Marshall,
Brian L. McGlynn, Douglas L. Kane, Amy Tidwell, Jan Boll, Nancy W. Hinman, Michael E. Barber, and the ICEWATER Data Managers

http://icewater.inra.org

INRA INLAND NORTHWEST RESEARCH ALLIANCE

This work is funded by the US Dept. of Energy #DE-FG02-05ER64132

1 Abstract

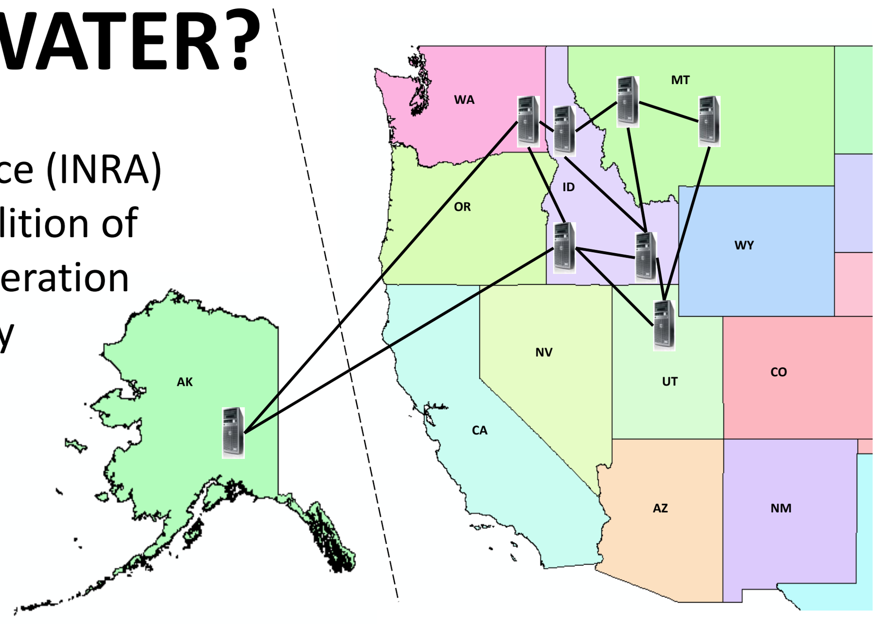
Over the past several years, researchers at universities affiliated with the Inland Northwest Research Alliance (INRA) have been collecting water resources datasets at a number of experimental watersheds in the western United States. Experimental watersheds in the INRA region span a number of climate, human development, and disturbance gradients, and researchers are investigating several different research themes, including snowmelt processes, climate change, groundwater - surface water interactions, modeling of hydrologic response, land use change, and arctic river processes. Integration of data from these watersheds will facilitate cross-site comparisons and large scale studies that synthesize information from diverse settings, making the network as a whole greater than the sum of its parts. In this presentation, we describe efforts towards establishing and supporting the INRA Water Resources Consortium Constellation of Experimental Watersheds (ICEWATER) Information System Network. The ICEWATER Information System Network is a distributed network of computer servers built using components of the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS) technology to publish and integrate the data holdings from ICEWATER. The sharing of data in a common format is one way to stimulate interdisciplinary collaboration. The goals of the ICEWATER Information System network are: establishment of a common information system for data sharing, analysis and archiving, building upon and extending the CUAHSI Hydrologic Information System; establishment of a common modeling framework to facilitate sharing and model interoperability; and establishment of common base characterization datasets such as digital elevation models (DEMs) from LIDAR, land cover and land use from remote sensing, that provide detail beyond nationally available information. The ICEWATER Information System will comprise centralized functionality, referred to as ICEWATER Central, and a network of servers, one at each INRA university, that support the data services hosted by that university.

2 What is ICEWATER?

Inland Northwest Research Alliance (INRA) Water Research Consortium - coalition of eight universities working in cooperation with the US Department of Energy

- Boise State University
- Idaho State University
- Montana State University
- University of Alaska Fairbanks
- University of Idaho
- University of Montana
- Utah State University
- Washington State University

ICEWATER – INRA **C**onstellation of **E**xperimental **WATER**sheds



CUAHSI HIS

http://his.cuahsi.org

ICEWATER: An Implementation of the CUAHSI HIS

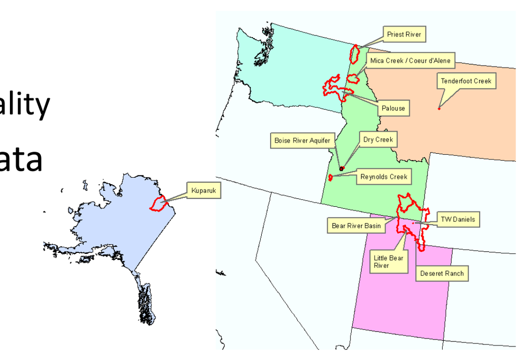
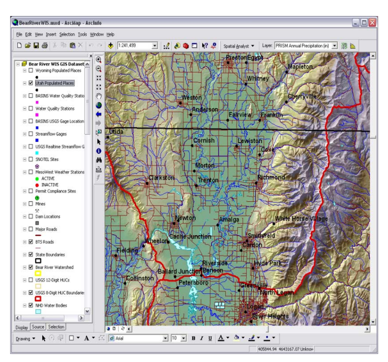
UtahState University · Boise State University · Idaho State University · Montana State University · University of Alaska Fairbanks · University of Idaho · The University of Montana · Washington State University

3 ICEWATER Data


Point Observations
- Stream gages
- Continuous water quality sampling
- Weather stations
- Soil moisture
- Snow monitoring
- Groundwater level/quality

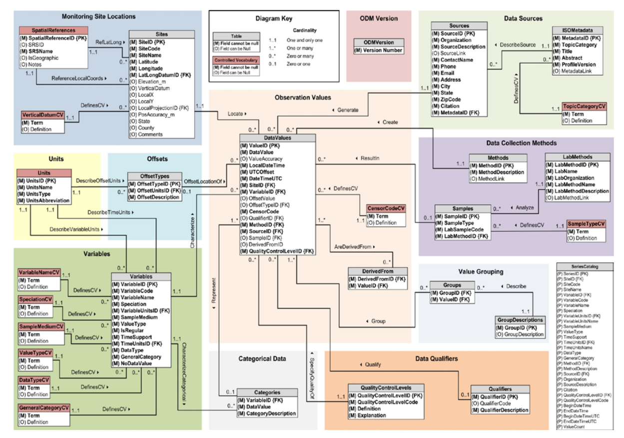
Spatially Distributed Data
- Land use/cover
- Terrain
- Hydrography



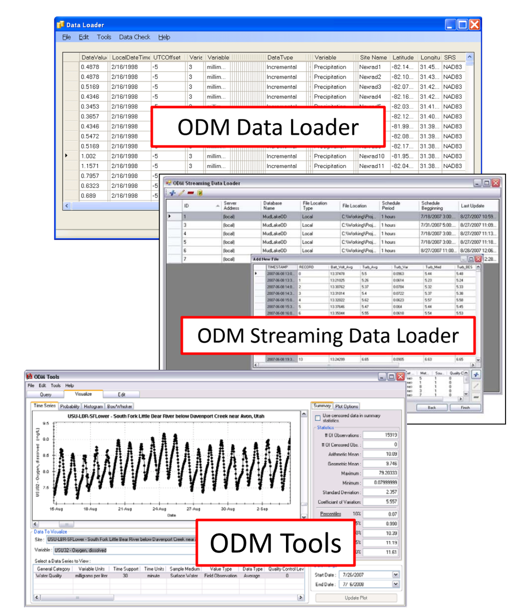




4 Publishing Data using the CUAHSI HIS Server Software Stack

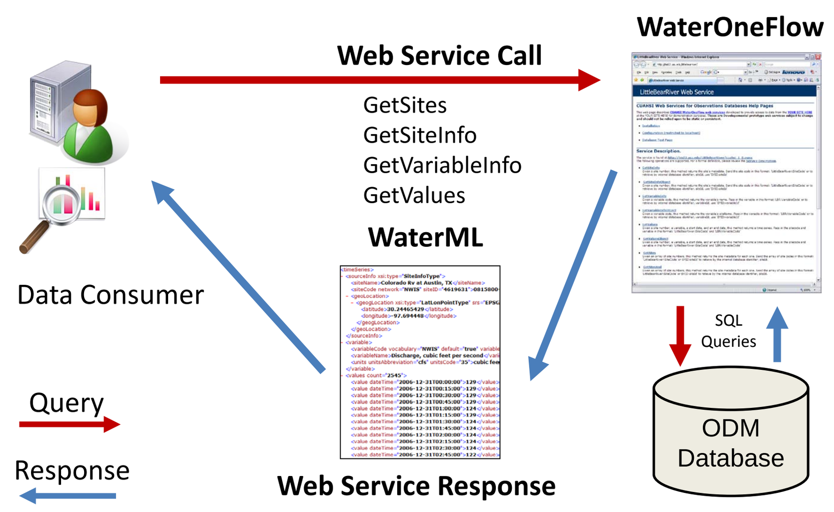
The CUAHSI HIS Server provides a standard software stack for publishing hydrologic data.



The Observations Data Model (ODM): ODM provides a standard relational model for storing and managing hydrologic observations made at points. Data managers are loading their time series data into one or more ODM databases, which are implemented in Microsoft SQL Server.

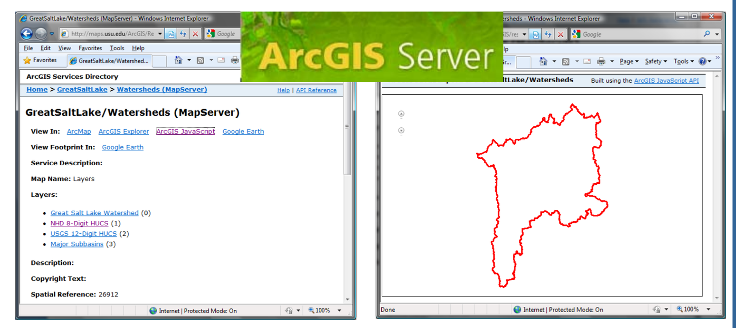


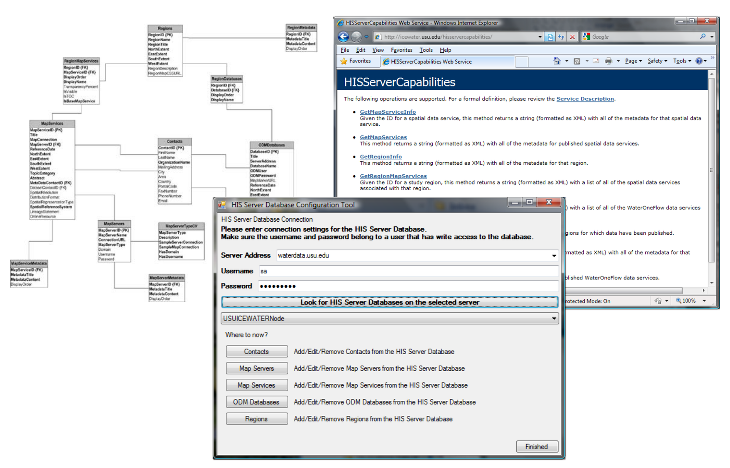
ODM Utilities: A number of software programs have been created for data managers to use to interact with ODM databases. The ODM Data Loader and streaming data loader help data managers load data. ODM Tools enables data managers to query, export, visualize, and edit data. ODM Tools provides some data QA/QC capabilities.



WaterOneFlow Web Services: The WaterOneFlow web services provide a platform, operating system, and programming language independent way of communicating data over the Internet. Data managers are publishing the contents of each ODM database using the WaterOneFlow Web Services.

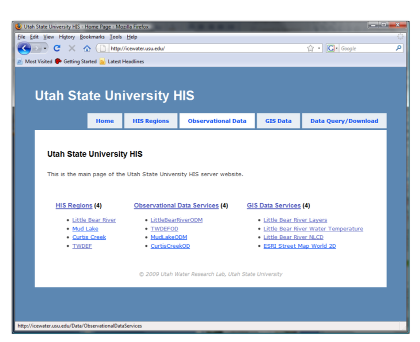
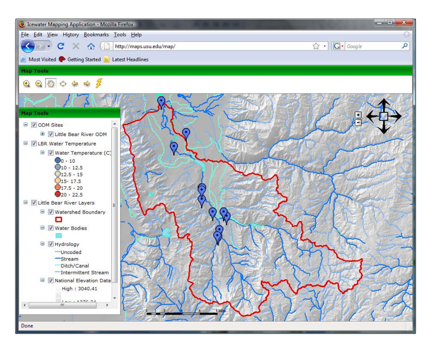
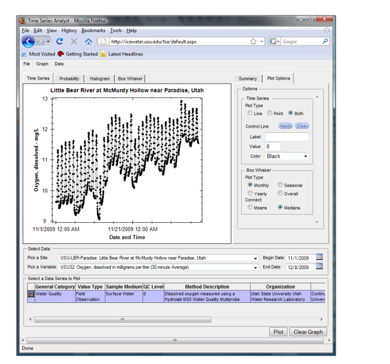
Publication of Spatial Datasets: Data managers are using ArcGIS server to publish spatial datasets for their experimental watersheds and study sites. Services are published using OGC WMS, WFS, and WCS.





HIS Server Capabilities: Each service that is published on an HIS Server is cataloged in a capabilities databases along with relevant metadata. A configuration tool is available for editing the capabilities database. Once in the database, a Capabilities Web Service publishes the capabilities of the HIS Server so that it is "self describing."

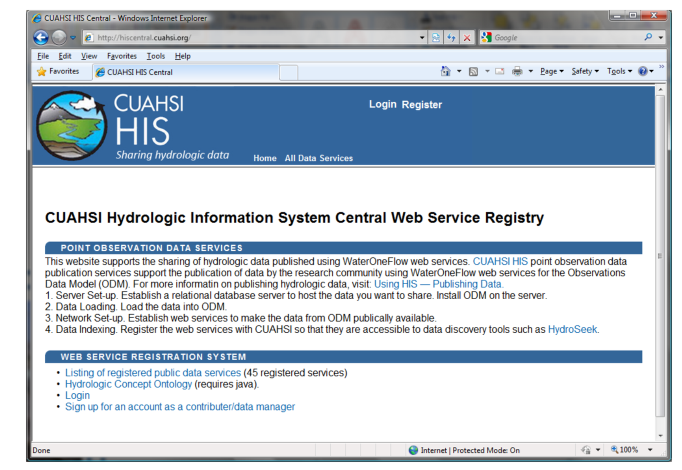
HIS Server Web Applications: Each data manager is implementing a standard set of web applications for presenting the available data and services on their HIS server as well as for providing data visualization and download capabilities. These include an HIS Server Website, an Internet Map Application, and the Time Series Analyst.

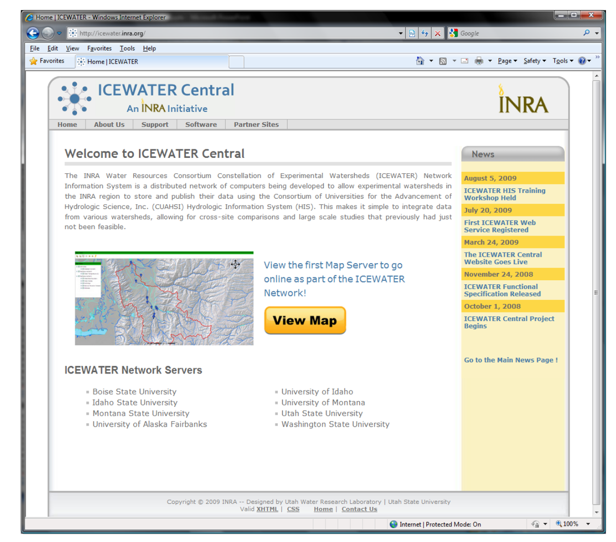




5 Discovering ICEWATER Data

CUAHSI HIS Central: ICEWATER data managers are registering their services with CUAHSI HIS Central, which is a national registry of hydrologic data services. By doing so, ICEWATER services are made public and can be discovered by client tools like HydroDesktop. HydroDesktop is a software program that enables users to search across the entire contents of HIS Central and download all of the available data.

http://hiscentral.cuahsi.org



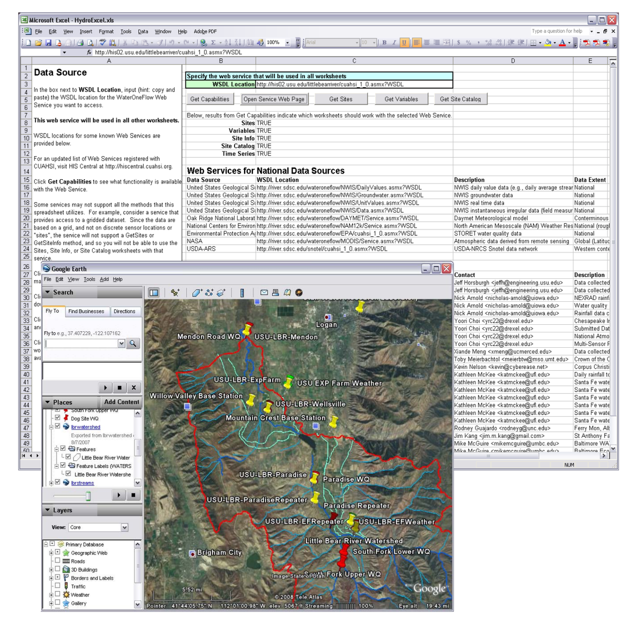


ICEWATER Central: ICEWATER Central is a website hosted at Utah State University that provides information about ICEWATER data resources, support for ICEWATER data managers, and links to all of the software used to establish HIS Servers within the ICEWWATER network. At ICEWATER central, you can discover all of the data resources available in the ICEWATER data network and you can be linked to each of the individual ICEWATER HIS Servers where you can access and download the data.

http://icewater.inra.org

6 Accessing ICEWATER Data Using HIS

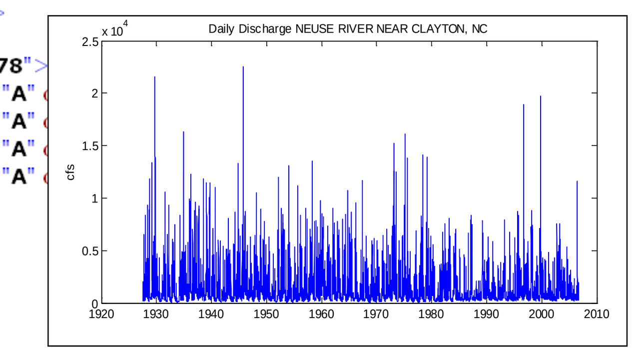
HydroExcel: Get Data Directly into Microsoft Excel



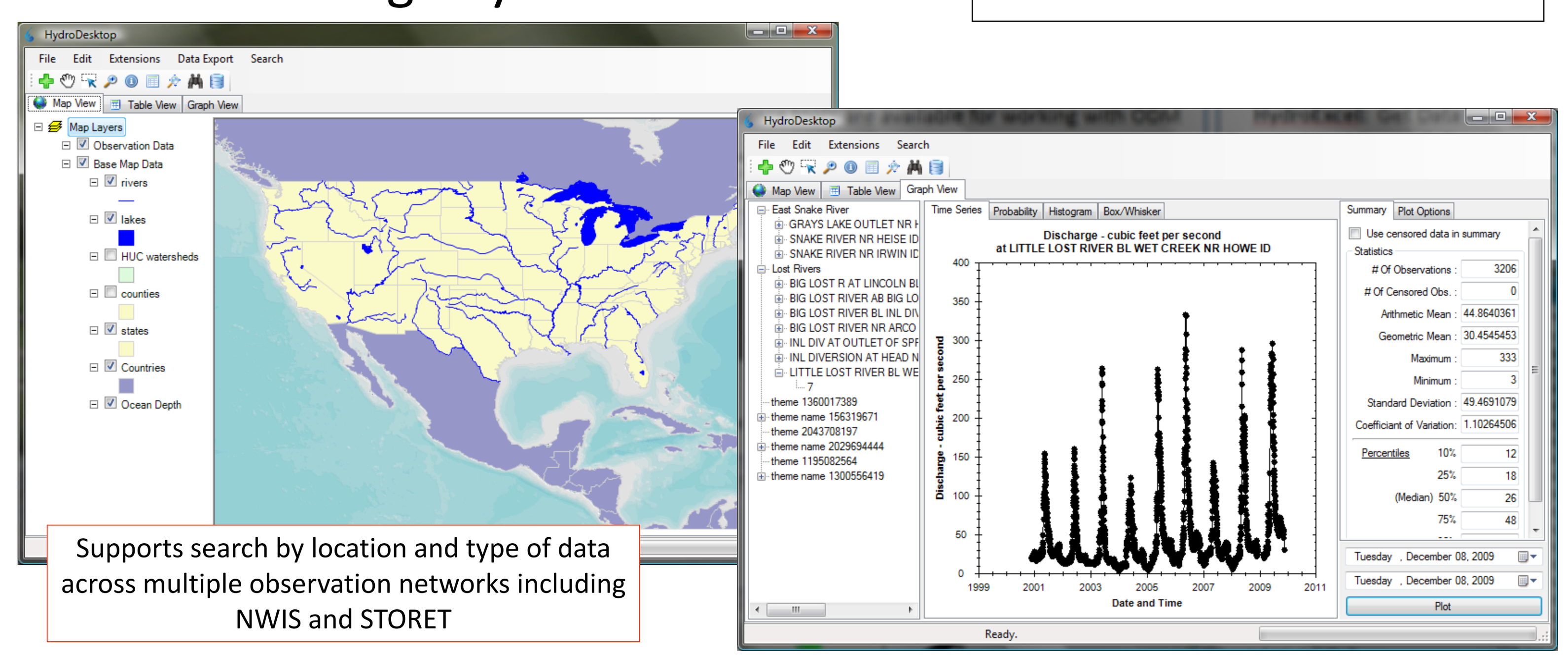
MATLAB: Get Data Directly in Your Analysis Environment of Choice

```
% create NWIS Class and an instance of the class
createClassFromWsdl('http://water.sdsc.edu/wateroneflow
/NWIS/DailyValues.asmx?WSDL');
WS = NWISDailyValues;
% GetValues to get the data
siteid='NWIS:02087500';
bdate='2002-09-30T00:00:00';
edate='2006-10-16T00:00:00';
variable='NWIS:00060';
valuesxml=GetValues(WS,siteid,variable,bdate,edate,'');
```


```
<variableCode vocabulary="NWIS" default="true"
  variableID="12578">00060</variableCode>
<variableName>Discharge, cubic feet per second</variableName>
<units unitsAbbreviation="cfs" unitsCode="35">cubic feet per
  second</units>
</variable>
- <values count="1478">
  <value qualifiers="A"
  <value qualifiers="A"
  <value qualifiers="A"
  <value qualifiers="A"
```

HydroDesktop: Get Data on Your Machine Using Keyword Searches



Supports search by location and type of data across multiple observation networks including NWIS and STORET

Appendix E
Functional Specifications for ICEWATER Network

ICEWATER Network Information System Functional Specifications

Jeffery S. Horsburgh, David G. Tarboton, and Kim Schreuders (Utah State University)

11-24-2008

Introduction

The INRA Water Resources Consortium Constellation of Experimental Watersheds (ICEWATER) Network Information System will be a distributed network of servers built using the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) Hydrologic Information System (HIS) technology to publish and integrate the experimental watershed and water resources data holdings from INRA institutions. Experimental watersheds in the INRA region span a number of climate, human development, and disturbance gradients. Integration of data from these watersheds will facilitate cross-site comparisons and large scale studies that synthesize information from diverse settings, making the network as a whole greater than the sum of its parts. The sharing of data in a common format is one way to stimulate interdisciplinary collaboration.

In this document, we describe the functional specifications of the ICEWATER Network Information System. This cyberinfrastructure will facilitate the consistent publication of observational data from any observation system or experimental watershed in the region of interest to INRA water researchers. While the focus is on experimental watersheds, the system will be open to all water resources research data that INRA institutions want to include. The ICEWATER Network Information System will comprise centralized functionality, referred to as ICEWATER Central, managed from Utah State University, and a network of data nodes, one at each INRA university, that support the data services hosted by that university. The primary functionality of data nodes is to host observational data services and supporting applications. The primary functionality of the central node is to: 1) provide a centralized website that provides information about the ICEWATER Network and directs data requests to each of the data nodes; and 2) provide functionality and resources for building the community and supporting the network of data nodes. The conceptual design of the system, showing the interconnections among components is shown in figure 1.

Because at the end of this project each university will be responsible for maintaining their ICEWATER data node, a major requirement of this effort to establish cyberinfrastructure for ICEWATER is that each university must have a fully functional and self contained data publication system at the end of this project. Given this, the following sections describe the features and functional requirements for the cyberinfrastructure components that will support the ICEWATER Network Information System.

ICEWATER Data Nodes

Features and Functional Requirements

Data nodes will host observational and other water-related data (i.e., data characterizing impact of human activities on the dynamics of the watershed hydrology) from one or more observation system/experimental watershed/location and will publish the data using components of the CUAHSI HIS. A data node is a computer server that has the capability to host web applications and their underlying databases.

Data node servers must have static IP addresses and hostnames. It is suggested that each of the data nodes adopt the following naming convention: "icewater.xxx.edu", where the "xxx" is the three letter name of the university at which the server is located (i.e., for Utah State University, the server would be named "icewater.usu.edu"). It is anticipated that data node servers will be managed by IT personnel and the designated data manager from the university at which the server is located. Each data node will be entirely autonomous (i.e., each data node server will function on its own without dependencies on other data nodes or a central node).

The following components/functionality will be available on each of the ICEWATER data nodes. This functionality will be implemented at each node so that each is autonomous and not dependent on any centralized applications for full functionality.

Data Organization and Persistent Data Storage

The CUAHSI HIS Observations Data Model (ODM) is a relational data model for storing, managing, and manipulating point observations data. Each data node will implement one or more ODM databases, depending on the number of research watersheds/locations hosted by the data node. All of the observational data for each location will be entered into an ODM database. ODM provides the persistent storage mechanism for the data. Because the ODM databases will be implemented in a relational database management system (i.e., Microsoft SQL Server 2005), they will support a variety of applications through the use of SQL queries that can be passed to the database to retrieve and manipulate data. Additionally, once data have been entered into an ODM database, they can be published using the WaterOneFlow web services. Several tools are available as resources for supporting ODM, including: ODM Tools for managing data within an ODM database; ODM Data Loader for performing bulk data loads; and ODM Streaming Data loader for automating the loading of data from datalogger files into an ODM database.

Publication of Point Observations Data

The CUAHSI HIS WaterOneFlow web services are designed to be implemented on top of an ODM database to publish observational data on the internet. The WaterOneFlow web services transmit data in Water Markup Language (WaterML) format. The WaterOneFlow web services consist of a set of methods (i.e., GetSites, GetSiteInfo, GetVariableInfo, GetValues) that can called from many different programming languages and software environments for retrieving data from an ODM database over the Internet. These methods have been implemented within a single web application that is easily installed and configured. Each data node will implement a set of WaterOneFlow web services for each ODM database that contains data to be published. This will ensure that all of the data published in the ICEWATER Network will be available on the internet in a standard, interoperable (i.e., platform and programming language agnostic) format. In addition, WaterOneFlow web services can be registered with CUAHSI HIS Central, enabling the services to be discovered and consumed by central CUAHSI HIS applications like Hydroseek (http://www.hydroseek.org).

Publication of Spatial Datasets

Through the use of ArcGIS Server 9.3, data nodes will have the capability to publish GIS datasets as GIS data services on the Internet for each of the experimental watersheds/locations for which they have data. A GIS data service is defined as one or more GIS datasets published using ArcGIS Server. ArcGIS Server 9.3 is capable of publishing vector data using the Open Geospatial Consortium's (OGC) Web Feature Service (WFS) standard and raster data using the OGC Web Coverage Service (WCS) standard. These standards are open formats that can be consumed by a variety of different GIS client software. Functionality will be provided for publishing appropriate metadata along with each published GIS data service.

Data Discovery via a Map Interface

Each data node will have an Internet map server interface to the observational data services and the GIS data services that are published at that node. The map interface will be a web application that runs in a web browser and allows users to perform simple data queries for discovering data that are published at a data node. It will be based on the ArcGIS JavaScript API and/or the Google Maps JavaScript API using the example at http://odm.usu.edu/odmmap/ as a prototype. The map server will plot the locations of monitoring sites and will provide site information and links to the data when users click on a site on the map. The map server application will dynamically generate its content (i.e., monitoring site locations, links to the Time Series Analyst, etc.) using direct SQL connections/queries to the databases that contain the observational data. The map server will be capable of presenting data from multiple published observational and GIS data services, and the list of available services will be generated from underlying database tables that can be edited by data node managers. When services are added to these tables, they will automatically appear in the Internet Map Server application.

NOTE: Although a license for ArcGIS Server 9.3 will be required for publishing GIS data services, it will not be required for using the map interface web application.

Data Preview, Visualization, and Analysis

Each data node will host an instance of the Time Series Analyst application that enables users to visualize and generate descriptive statistics for selected observational datasets. The Time Series Analyst is a web application that enables users to screen/preview datasets prior to download so that they can make sure that the data are what they want. A prototype of the Time Series Analyst is available at http://tsa.usu.edu/odmanalyst/. The Time Series Analyst will be linked to the map server so that when users click on a monitoring site on the map they will be presented with a link to visualize/summarize the available data at the selected site using the Time Series Analyst.

Data Node Website

Each data node will have a website that provides information about the data node and details for each published data service that resides at that data node. The majority of the content of this website will be dynamically generated from an underlying application database and the database(s) that hold the observational data. This will enable the website to be customized through editing a database table to add content rather than editing the code of the website. The website will contain the following components/pages:

1. An overall/opening page that describes the ICEWATER data node: This page will be customizable so that it provides data node managers with the ability to add their visual identity to the page.
2. A listing of published observational data services: This will be a web page with a dynamically generated list of published observational data services that is based on an underlying database table that can be edited by the data node managers. The underlying database table will contain information about the published data service, including information required for the web application to access the database that stores the observational data. When a new data service is added to the database table, it will automatically show up in the website. This list will have subsidiary pages or details for each published observational data service that enable users to select a published data service and then get more details about the service and access the data.
3. A listing of published GIS data services: This will be a web page with a dynamically generated list of published GIS data services that is based on an underlying database table that can be edited by data node managers. The underlying database table will contain information about the published GIS data service, including information about how to access it along with its appropriate metadata. When a new GIS data service is added to the database table, it will automatically show up in the website. This list will have subsidiary pages that will enable users to select a published GIS data service and then get more details about the service and access the data.
4. Links to the map interface and data visualization and analysis tools: When users click on a published observational or GIS data service, they will be presented with links that allow them to access the published data in an appropriate client application (i.e., a new web browser window, or the map server and Time Series Analyst described above).
5. A data query and download page: This webpage will allow users to more easily query for data from one or more published observational data service and then download the data. This page will allow users to get multiple datasets at once rather than one by one. This page will directly interface with the underlying ODM database.

Get Capabilities Web Services

Each ICEWATER data node will have a set of web services that publish the capabilities of that data node. This will include a set of web methods that return in XML format the list of published observational data services and appropriate metadata as well as the list of published GIS data services along with appropriate metadata. By doing so, an overall catalog of these services can be compiled at the ICEWATER central node. The get capabilities web services will be a web application that uses a direct

SQL connection with the data node database and will utilize the tables that list the published data services.

ICEWATER Central Node

Features and Functional Requirements

The primary functionality of the ICEWATER central node is to: 1) provide a centralized website that provides information about the ICEWATER Network and directs data requests to each of the data nodes; and 2) provide functionality and resources for building the community and supporting the network of data nodes. The following sections describe the functionality of the ICEWATER central node.

ICEWATER Central Website (http://www.icewaterdata.org)

The ICEWATER Central website will provide information about the ICEWATER Network and will provide links to each of the individual ICEWATER data nodes. The ICEWATER Central website will contain the following components:

1. A description of the ICEWATER Network and its purpose: This will be a web page that is an overall description of the ICEWATER Network.
2. A map server that identifies each ICEWATER Site: This will be a website with an embedded map that shows the locations of each of the ICEWATER experimental sites. When users click on a site on the map, they will be taken to the appropriate web page at the data node that hosts that site.
3. A description of the cyberinfrastructure implemented at each data node: This will be a description of the cyberinfrastructure that has been used to construct the ICEWATER Network. It will be provided so that additional sites can join the network if they choose to do so.
4. A catalog of available data services: This will be a web page listing of each of the ICEWATER data nodes and the services that they provide. It will be a very high level listing of available observational and GIS data services that are provided by each data node. It will be compiled and maintained by calling the capabilities web services that are hosted at each data node. Users will be able to browse this catalog, and it will direct them to request data from the appropriate website at the data node that hosts the data service.

ICEWATER Central Data Managers Discussion Group

The ICEWATER central node will host a discussion group for data managers and IT professionals at each of the INRA universities. Users will be able to post questions and receive assistance from individuals at Utah State University or from other users throughout the ICEWATER user group. This discussion group will take the form of an email forum and may be hosted using Google Groups or some other email forum hosting service.

ICEWATER Central Data Managers Support

The ICEWATER central node will provide email and phone support to data managers and IT professionals in configuring the data node servers, implementing the data node software, publishing GIS datasets using ArcGIS Server 9.3, and loading data into ODM. This support will include an email listserv and online discussion forum capability. Support managers at Utah State University will develop documentation that will address each of these tasks. It is anticipated that this documentation will cover the majority of questions that data managers and IT professionals will have in implementing ICEWATER data nodes. However, personnel at USU will field questions from data managers and IT professionals on an as needed basis.

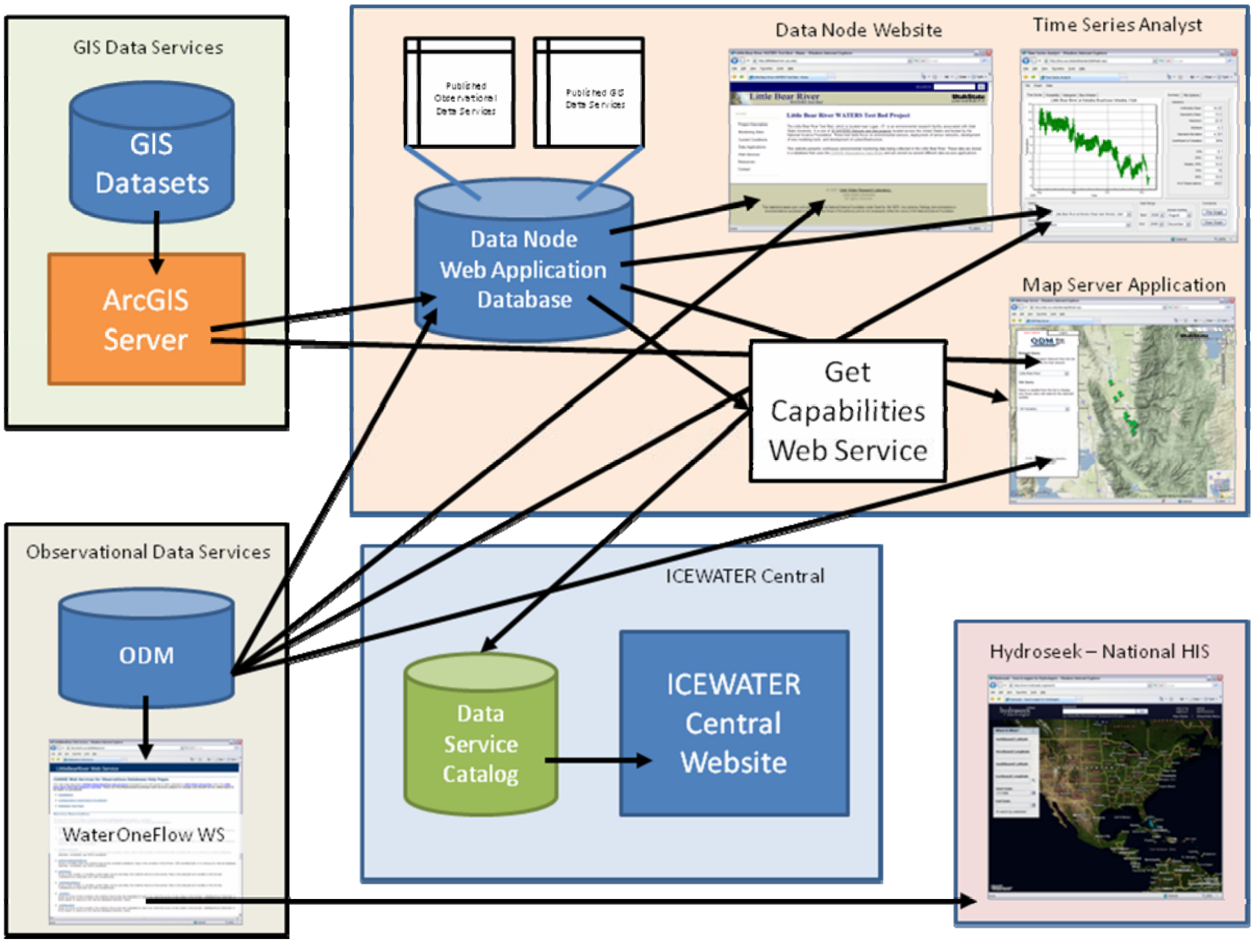


Figure 1. Icewater Cyberinfrastructure Conceptual Design

Implementation

Following are steps required for the implementation of ICEWATER

1. Establish ICEWATER CI subcommittee
2. Finalization of hardware recommendations for data nodes
3. Finalization of commercial system software recommendations for data nodes
4. Finalization of CUAHSI HIS system software recommendation for data nodes
5. Establish data manager listserv and online discussion forum
6. Development of spatial dataset publication guidelines. A document that describes how to publish spatial datasets using ArcGIS server on the HIS node server platform
7. Development of HIS node server map interface as a deployable package
8. Development of Timeseries analyst for HIS node as a deployable package
9. Development of HIS node server website as a deployable package
10. Development of get capabilities web service
11. Development of ICEWATER Central website

[Deadlines and responsible parties for each step above need to be specified]

Appendix

Specifications for Data Node Servers

Data Node Server Required Hardware

It is recommended that the ICEWATER Data Node servers have the following minimum hardware specifications:

- Dual Core Intel Processor, minimum 2 GHz
- 4 GB RAM
- 500 GB or greater hard drive
- Gigabit network adapter
- DVD Drive

Data Node Server Required Software

The following is a list of required software components that must be installed on the ICEWATER data node server to support serving observations data services:

Operating System and Server Software

- Microsoft Windows Server 2003 R2, Standard Edition
- Microsoft IIS 6.0 (part of Windows Server 2003)
- Microsoft .Net Framework 2.0 (free download)
- Microsoft SQL Server 2005 Standard Edition
- [Microsoft Visual Studio 2005 Professional. Current CUAHSI specifications call for this, but we think it is not necessary and will work on getting dependency on this, used for setting up web services removed.]

NOTE: The free version of Microsoft SQL Server (i.e., SQL Server 2005 Express) can be used in the event that a license for SQL Server 2005 Standard Edition cannot be obtained.

Internet Map Server Software

- ArcGIS 9.3 Desktop
- ArcGIS 9.3 Server

NOTE: ArcGIS server is only required for hosting spatial data services (i.e., serving GIS datasets). It is not required for publishing observational data.

Hydrologic Information System Software

- ODM Version 1.1
- ODM Tools Version 1.1
- ODM Data Loader Version 1.1
- ODM Streaming Data Loader Version 1.1
- WaterOneFlow Web Services Version 1.0
- Map Server Application for Data Discovery
- ODM Time Series Analyst

NOTE: Manuals for installing and configuring each of the HIS software components are available at http://his.cuahsi.org.

ICEWATER Data Node Software

- Get Capabilities Web Services
- Data Node Website