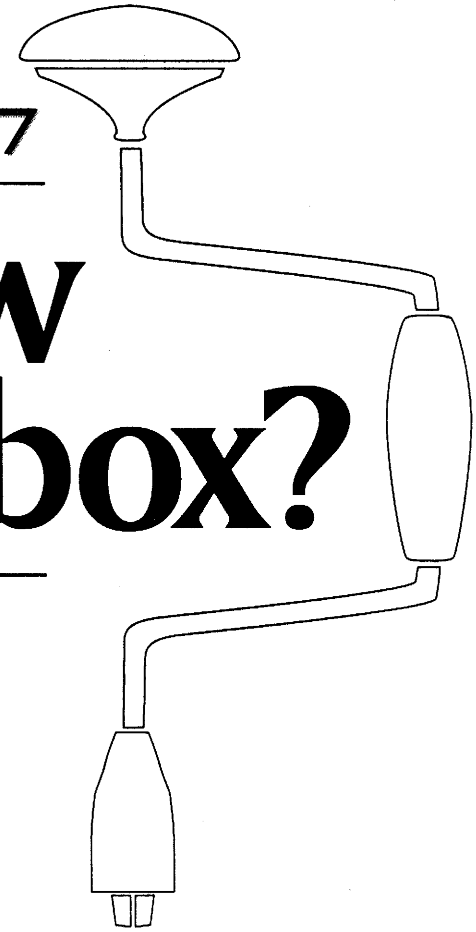
Wyoming Water 1997

What's New in the Toolbox?



Applied Research for Management of Wyoming's Water Resources: A Statewide Conference

April 21-23, 1997

Casper, Wyoming

Parkway Plaza Hotel & Convention Centre

WYOMING WATER 1997 - AGENDA

WHAT'S NEW IN THE TOOLBOX:

APPLIED RESEARCH FOR MANAGEMENT OF WYOMING'S WATER

PARKWAY PLAZA HOTEL AND CONVENTION CENTRE - CASPER, WYOMING

MONDAY APRIL 21, 1997

10:30 a.m. - Registration booth opens

11:30 a.m. - All posters must be in place

1:00 p.m. - **Introductions and Welcome - Steve Gloss, Director - Wyoming Water Resources Center**

SESSION 1: WATERSHED MANAGEMENT

MODERATOR: STEVE GLOSS

1:10 p.m. - *Assessment of Collaborative Watershed Management Approaches Used in the United States with Evaluation for Applicability in Wyoming.* Scott Mullner, Wayne Hubert, Eric Felbeck and Tom Wesche

1:30 p.m. - *The North Tongue River: A Collaborative Approach to Watershed Management.* Eric Felbeck, Tom Wesche, Scott Mullner and Wayne Hubert

1:50 p.m. - *Loco Creek Small Watershed Project.* Andy Warren and Larry Hicks

2:10 p.m. - *Muddy Creek Seeking Common Ground Project.* Larry Hicks and Andy Warren

2:30 p.m. - *The Geomorphologist's Toolbox: Analysis Tools for River Management and Restoration.* Craig Goodwin

2:50 p.m. - Break

SESSION 2: GIS APPLICATIONS IN WATER MANAGEMENT

MODERATOR: TOM KOHLEY

3:10 p.m. - *Using Geographic Information Systems (GIS) to Aid Implementation of Conservation Strategies for Native Fish.* Nick Schmal, J. Newton, and Tom Kohley

3:30 p.m. - *Integrating GIS Technology into Groundwater and Surface Water Modeling Associated with Wyoming's Cumulative Hydrologic Impact Assessment.* James Oakleaf and Jeff Hamerlinck

3:50 p.m. - *Wyoming/Utah Interstate Cooperative Water Rights Project.* Nancy McCann

4:10 p.m. - *GIS-Based Surface Water Rights Mapping in the Tongue River Basin,.* Robert Niedenzu

4:30 p.m. - *Water Div. II GIS: Prototype Toolbox for Dynamic Water Planning in Wyoming.* Jeff Hamerlinck

4:50 p.m. - Poster Session Opens

Concurrent Evening Workshops

7:30 p.m. - *Wyoming Groundwater Vulnerability GIS Computer Mapping.* Jeff Hamerlinck and Christopher Arneson ****Parkway Plaza****

7:30 p.m. - Water Information Systems and World Wide Web Technology On-line. Barry Lawrence ****Casper College - Physical Sciences Bldg. Rm. 224**** Note: Due to a Limited Number of Workstations, Separate Sign-up is Required.

TUESDAY APRIL 22, 1997

SESSION 3: WELLHEAD PROTECTION

MODERATOR: BERN HINCKLEY

8:00 a.m. - *Wellhead Protection in Wyoming: An Overview.* Kevin Frederick and Phil Stump

8:20 a.m. - *Groundwater and Wellhead Protection for Rural Drinking Water Supplies.* Floyd Field

8:40 a.m. - *"Do it Yourself" Experiment in Wellhead Protection, Elk Mountain, Wyoming.* Todd Jarvis and Benjamin Jordan

9:00 a.m. - *Utilizing Watershed Management in Conjunction With Wellhead Protection in the Cheyenne Board of Public Utilities Borie Wellfield, Laramie County, Wyoming.* Benjamin Jordan, Peter Huntoon, and Todd Jarvis

9:20 a.m. - *Identifying Ground-Water Threats from Improperly Abandoned Boreholes.* Robert Kubichek, Jerry Cupall, William Iverson, Sangsung Choi, and Michael Morris

9:40 a.m. - Break

SESSION 4: WATER QUALITY

MODERATOR: TODD PARFITT

10:00 a.m. - *Nonpoint Source Water Pollution Control: The Role of Conservation Districts.* Earl DeGroot

10:20 a.m. - *Team Approach for Protecting Groundwater Quality From Non-Point Source Pollution in Goshen County, Wyoming.* Katta Reddy

10:40 a.m. - *Ocean Lake Hydrologic Unit Area - Designs and Accomplishments.* Kirk Faught

11:00 a.m. - *Effects of Copper on Microbial Sulfate Reduction in Freshwater Sediments.* Song Jin and Patricia Colberg

11:20 a.m. - *Fate of Aldicarb and Nitrate Under Irrigation Management.* Shankar Sharmasarkar, Florence Cassel-Sharmasarkar, Renduo Zhang, and George Vance

11:40 a.m. - *Present and Future Impacts of the Big Sandy River Salinity Control Program on an Agricultural Community.* Tom Heald and Kelly Crane

12:00 p.m. - Lunch (On Your Own)

SESSION 5: WATER RESOURCE EDUCATION

MODERATOR: CHRIS GOERTLER

1:00 p.m. - *Wyoming's Approach to Multi-Disciplinary Graduate Education in Water Resources.* Tom Wesche and Chris Goertler

1:20 p.m. - *The Conserve Wyoming Program.* Donn Kesselheim and Thomas Whitney

1:40 p.m. - *The Statewide Integrated Conservation Education Program (SICEP).* Duane Keown

2:00 p.m. - *North Platte Valley Water Coalition.* Jim Merrigan

2:20 p.m. - *Shoshone Project Cultural Resources Mitigation: A Pilot Project for Irrigation Education.* Beryl Churchill

2:40 p.m. - Break

SESSION 6: WATER MODELING AND RELATED DATABASES

MODERATOR: BARNEY LEWIS

3:00 p.m. - *Assessing the Cumulative Impacts of Surface Mining and Coal Bed Methane Development on Shallow Aquifers in the Powder River Basin, Wyoming.* Kenneth Peacock

3:20 p.m. - *Cumulative Hydrologic Impact Assessments on Surface Water in Northeastern Wyoming Using HEC-1: A Pilot Study.* Anthony Anderson, Dan Eastwood, and Mike Anderson

3:40 p.m. - *A Network Model for Biofilm Growth and Its Effects in Porous Media.* Brian Suchomel, Benito Chen, and Myron Allen III

4:00 p.m. - *The Water Resources Data System (WRDS).* Barry Lawrence

4:30 p.m. - Poster Session Opens

Evening Hands-on Computer Workshop

7:30 p.m. - Water Information Systems and World Wide Web Technology On-line. Barry Lawrence ****Casper College - Physical Sciences Bldg. Rm. 325**** Note: Due to a Limited Number of Workstations, Separate Sign-up is Required.

WEDNESDAY APRIL 23, 1997

SESSION 7: RIPARIAN AREA MANAGEMENT

MODERATOR: BOB BUDD

8:00 a.m. - *Use of Beaver to Improve Riparian Areas in Wyoming.* Mark McKinstry and Stanley Anderson

8:20 a.m. - *The Effect of Three Residual-Vegetation Heights on Streambank Sediment Deposition and Vegetation Production.* Carrie Gray, Quentin Skinner, and Robert Henszey

8:40 a.m. - *Stubble Height and Function of Riparian Communities: Channel and Plant Succession.* Quentin Skinner

9:00 a.m. - *Effects of Herbivory on Willow (Salix spp.) Canopy Volume on Mountain Rangelands of Northern Wyoming.* Mark Thorne, Quentin Skinner, Mike Smith, William Laycock, and Jerry Dodd

9:20 a.m. - *Establishment Rates and Biomass Production of Willow and Grasses under Greenhouse Conditions of Variable Soil Salinity and Nutrient Concentration.* Mark Rogaczewski, Jeff Powell, Joe Hiller, and Michael Parker

9:40 a.m. - Break

SESSION 8: STREAM AND WETLAND ECOLOGY

MODERATOR: BILL DIRIENZO

10:00 a.m. - *Channel Morphology and Riparian Mosaic Changes along the Big Horn River Downstream from Boysen Dam.* Travis Bray, Tom Wesche, and Wayne Hubert

10:20 a.m. - *Use of Radiotelemetry to Define Winter Habitat Use by Rainbow Trout in the Big Horn River, Wyoming.* Darin Simpkins, Wayne Hubert, and Tom Wesche

10:40 a.m. - *Comparison of Bird Use of Adjacent Wetlands in Southwestern Wyoming.* Brian Heath and Stanley Anderson

11:00 a.m. - *Waterbird Use, Productivity, and Water Level Fluctuation.* Christopher Mason and Stanley Anderson

11:30 a.m. - Lunch (Provided)

12:15 a.m. - **LUNCHEON ADDRESS BY GOVERNOR JIM GERINGER**

SESSION 9: INSTREAM FLOWS

MODERATOR: TOM WESCHE

1:00 p.m. - *Flushing Flow Requirements of Large Regulated Rivers in Wyoming.* Tom Wesche, Travis Bray, and Wayne Hubert

1:20 p.m. - *Evaluation of Flow Duration Analysis to Establish Winter Instream Flow Standards for Wyoming Trout Streams.* Wayne Hubert, Cindy Pru, Thomas Wesche, and Travis Bray

1:40 p.m. - *Development of an Individual Based Model to Assess the Instream Flow Requirements of Stream Salmonids.* Russell Rader

2:00 p.m. - *Wyoming Water Development Commission's Role Under the Wyoming Instream Flow Law.* Bruce Brinkman

2:20 p.m. - *Ten Years Down the Road: A Wyoming Game and Fish Department Perspective on the State's Instream Flow Law.* Tom Annear

2:40 p.m. - Break

SESSION 10: WATER MANAGEMENT

MODERATOR: SUE LOWRY

3:00 p.m. - *Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S.* Steve Gloss

3:20 p.m. - *Water Management in an Unregulated River System - The Little Snake River of South Central Wyoming.* John Boyer

3:40 p.m. - **Closing Remarks - Jeff Fassett, State Engineer.**

WYOMING WATER 1997 - POSTER DISPLAYS

Citizens Network for Monitoring Groundwater Quality in Goshen County, Wyoming: An Educational and Outreach Project. Chris Goertler, Katta Reddy, Jack Cecil, Charlene Stephenson and Joe Hiller

A Pebble Count Procedure for Assessing Watershed Cumulative Effects. Gregory Bevenger and Rudy King

Instream Flow Water Rights: The Process of Appropriation. Carla Rumsey

Shoshone Project Cultural Resources Mitigation: A Pilot Project for Irrigation Education. Beryl Churchill

Determination of Spatial Precipitation Distributions for Studying Groundwater Pollution. Alexandra Kravchenko, Renduo Zhang, Steven Gloss, and Yeou-Koung Tung

Genetic Improvement of Alfalfa to Conserve Water. Dave Claypool, Ron Delaney, Ray Ditterline, and Ron Lockerman

Assessment of Copper Mobilization Resulting From Microbial Reduction of Iron Oxide. James Markwiese, Joe S. Meyer, and Patricia Colberg

Mass Balance Changes on Teton Glacier Using Historical and Contemporary Data. Kelly Elder, Melinda Laituri, Kathy Tonnessen, and Rich Greenwood

The Wyoming Annual Medic Breeding Program: Improving Water Use Efficiency and Water Quality in the Winter Wheat Agroecosystem. Robin Groose, Michael Walsh, David Claypool, Ronald Delaney, and Jim Krall

Wyoming Riparian Association . Tina Willis

A Preliminary Estimate of the Influence of North Park Colorado Irrigation Practices on the Commercial Rafting Season in Northgate Canyon, Medicine Bow National Forest, Wyoming. Harry Osborn.

Wyoming's Water Resources Data System. Barry Lawrence.

GIS Projects at the Wyoming Water Resources Center. Jeff Hamerlinck, Tom Kohley, Christopher Arneson, Jim Oakleaf, and Kevin Toohill

Water Resource Management Simulator. Sue Lowry and Wyoming Riparian Association

Wyoming Coordinated Resource Management Process (WyCRM): A Tool for Sound Resource Management. George Cleek

Surface Water Allocation Models: BESTSM - Boyle Engineering Stream Simulation Model. Erin Wilson and Jerry Kenny

American Water Resources Association - Wyoming Section. Bern Hinckley

The Total Maximum Daily Load (TMDL) Issue in Wyoming. Mark Conrad, Beth Pratt, and Todd Parfitt

The Water Resources Data System (WRDS). Barry Lawrence

Shoshone Project Cultural Resources Mitigation: A Pilot Project for Irrigation Education. Beryl Churchill

PREFACE

Welcome to Wyoming Water 1997!

Eleven years have passed since the University of Wyoming last hosted a statewide water conference focusing on applied research and current management issues. The Wyoming Water 1986 and Streamside Zone Conference was also held in Casper and highlighted papers, presentations, and discussions dealing with a critical water issue of that time period, riparian zone management.

A lot of water has "passed under the bridge," so to speak, in those eleven years. Rapid advances in Geographic Information Systems, electronic large database management, and water modeling have expanded our analysis capabilities in the water resource management field. Watershed management and wellhead protection have come to the forefront in our efforts to enhance both the quality and quantity of our water resources. Continuing research in the areas of streamside zones, instream flows and wetland ecology are providing new information for helping us enhance our quality of life while maintaining traditional water uses. These advances in technology and our knowledge base have led to ever increasing needs for improved water resource education.

The theme for Wyoming Water 1997 is, "What's new in the toolbox?" The goal of the conference is to provide the people of Wyoming a chance to talk about their water resources and learn about new findings from applied research for better management of Wyoming's water. Over 60 papers and displays will be presented over the three days of the conference, while evening workshops will be held for "hands-on" training in GIS, Water Information Systems, and World Wide Web Technology.

These proceedings are published to provide a record of these presentations both for conference participants and for those who could not attend. The papers presented herein have undergone only minor editing and in no case were the statements or intents of the author(s) changed.

We would especially like to thank Mary Yannutz for her special contributions to the completion of these proceedings. We would also like to thank Carla Rumsey, Travis Bray, and Deedee Boysen for their assistance in the review and editing process.

DISCLAIMER

COORDINATION COMMITTEE:

Chris Goertler	I&E Coordinator, Wyoming Water Resources Center
Bern Hinckley	President, AWRA – Wyoming State Chapter
Ken Peacock	Past President, AWRA – Wyoming State Chapter
Chris Ewers	Technical Editor, Wyoming Water Resources Center
Tom Wesche	Associate Director, Wyoming Water Resources Center

TABLE OF CONTENTS

SESSION 1:
WATERSHED MANAGEMENT 1

Assessment of Collaborative Watershed Management Approaches Used in the United States for Applicability in Wyoming .. 2

The North Tongue River: A Collaborative Approach to Watershed Management 7

Loco Creek Small Watershed Project 9

Muddy Creek Seeking Common Ground Project 12

The Geomorphologist's Toolbox: Analysis Tools for River Management and Restoration 15

SESSION 2:
GIS APPLICATIONS IN WATER MANAGEMENT 21

Using Geographic Information Systems (GIS) to Aid Implementation of Conservation Strategies for Native Fish 22

Integrating Geographic Information Systems (GIS) Technology into Groundwater and Surface-Water Modeling Associated with Wyoming's Cumulative Hydrologic Impact Assessment 25

Wyoming/Utah Interstate Cooperative Water Rights Project: Wyoming State Engineer's Office and Utah State Engineer's Office 34

GIS-Based Surface Water Rights Mapping in the Tongue River Basin 35

Water Div-II GIS: Prototype Toolbox for Dynamic Water Planning in Wyoming ... 38

SESSION 3:
WELLHEAD PROTECTION 43

Wellhead Protection in Wyoming: An Overview 44

Groundwater & Wellhead Protection for Rural Drinking Water Supplies 49

"Do It Yourself" Experiment in Wellhead Protection, Elk Mountain, Wyoming 51

Utilizing Watershed Management in Conjunction with Wellhead Protection in the Cheyenne Board of Public Utilities Borie Wellfield, Laramie County, Wyoming 60

Identifying Ground-Water Threats from Improperly Abandoned Boreholes 67

SESSION 4:
WATER QUALITY 73

Nonpoint Source Pollution Control: The Role of Conservation Districts 74

Team Approach for Protecting Groundwater Quality from Non-Point Source Pollution in Goshen County, Wyoming 76

Ocean Lake Hydrologic Unit Area – Design and Accomplishments 80

Effects of Copper on Sulfidogenic Activity in Freshwater Sediments 81

Fate of Nitrate and Aldicarb Under Irrigation Management 87

Present and Future Impacts of the Big Sandy River Salinity Control Program on an Agricultural Community 92

SESSION 5:
WATER RESOURCE EDUCATION 95

Wyoming's Approach to Multi-Disciplinary Graduate Education in Water Resources 96

The ConServe Wyoming Program 98

The Statewide Integrated Conservation Education Program 101

North Platte Valley Water Coalition 105

Shoshone Project Cultural Resources Mitigation 107

SESSION 6:
WATER MODELING AND RELATED DATABASES 109

Assessing the Cumulative Impacts of Surface Mining and Coal Bed Methane Development on Shallow Aquifers in the Powder River Basin, Wyoming 110

Cumulative Hydrologic Impact Assessments on Surface Water in Northeastern Wyoming Using HEC-1: A Pilot Study 111

A Network Model for Biofilm Growth and its Effects in Porous Media 118

The Water Resources Data System (WRDS) 122

SESSION 7:
RIPARIAN AREA MANAGEMENT 127

Use of Beaver to Improve Riparian Areas in Wyoming 128

The Effects of Three Residual-Vegetation Heights on Streambank Sediment Deposition and Vegetation Production 134

Stubble Height and Function of Riparian Communities: Channel and Plant Succession 139

Effects Of Herbivory On Willow *(Salix spp.)* Canopy Volume on Mountain Rangelands of Northern Wyoming. 144

Establishment Rates and Biomass Production of Willow and Grasses Under Greenhouse Conditions of Variable Soil Salinity and Nutrient Concentration. 150

SESSION 8: STREAM AND WETLAND ECOLOGY 155

Changes in Channel Morphology and Riparian Mosaics on the Big Horn River, Wyoming 156

Use of Radiotelemetry to Define Winter Habitat Use by Small Rainbow Trout in the Big Horn River, Wyoming. 161

Comparison of Bird Use of Adjacent Wetlands in Southwestern Wyoming 164

Waterbird Use, Productivity and Water Level Fluctuation 170

SESSION 9: INSTREAM FLOWS 175

Flushing Flow Requirements of Large Regulated Rivers in Wyoming 176

Evaluation of Flow Duration Analysis to Establish Winter Instream Flow Standards for Wyoming Trout Streams 180

Development of an Individual-Based Model to Assess the Instream Flow Requirements of Stream Salmonids 182

Wyoming Water Development Commission's Role Under the Wyoming Instream Flow Law 183

Ten Years Down the Road: A Game And Fish Perspective on the State's Instream Flow Law 186

SESSION 10: WATER MANAGEMENT 191

Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S. 192

Water Management in an Unregulated River System: The Little Snake River of South Central Wyoming 198

WYOMING WATER 1997 POSTER DISPLAYS 203

Citizen's Network for Monitoring Groundwater Quality in Goshen County, Wyoming: An Educational and Outreach Project 204

A Pebble Count Procedure for Assessing Watershed Cumulative Effects 206

Instream Flow Water Rights: The Process of Appropriation 207

Determination of Precipitation Spatial Distributions for Studying Groundwater Pollution 210

Genetic Improvement of Alfalfa to Conserve Water 214

Assessment of Copper Mobilization Resulting from Microbial Reduction of Iron Oxide 220

Mass Balance Changes on Teton Glacier Using Historical and Contemporary Data 221

The Wyoming Annual Medic Breeding Program – Improving Water Use Efficiency and Water Quality in The Winter Wheat Agroecosystem 222

Wyoming Riparian Association 226

A Preliminary Estimate of the Influence of North Park, CO, Irrigation Practices on the Commercial River Season in Northgate Canyon, Medicine Bow National Forest, WY. 228

GIS and the Wyoming Water Resources Center 232

Water Resources Management Simulator 233

Wyoming's Coordinated Resource Management Process (WyCRM): A Tool for Sound Resource Management 234

Surface Water Allocation Models: BESTSM - Boyle Engineering Stream Simulation Model 237

American Water Resources Association – Wyoming Section 239

The Total Maximum Daily Load (TMDL) Issue in Wyoming 240

INDEX OF AUTHORS 243

WYOMING WATER 1997 CONFERENCE PROCEEDINGS - ERRATA SHEET

Add page 22a - Figure 1. Hierarchy of watersheds that can be analyzed using GIS for Colorado River cutthroat trout range expansion priorities.

Page 51 - Change address for Weston Engineering to P.O. Box 6037, Laramie, Wyoming 82070.

Page 53 - column 2 - paragraph 2 - Change "principle sources of recharge" to "principal sources of recharge."

Page 53 - column 2 - paragraph 5 - Change "Table I" to "Table 1."

Page 56 -column 2 - paragraph 1 - Change "Tables I and II references" to "Table 1 and Table 2."

Page 56 - Change "Elm" to "Elk" in Table 1 heading.

Page 58 - Change "WYPA" to "WHPA" in Table 2 heading.

Pages 63 and 64 - Replace with revised pages.

Page 87 - column 2, last paragraph - Replace "2 = volumetric water content," with "θ = volumetric water content".

Page 88 - Replace equation 2 (top of page, left-hand column) with the following:

$$\frac{\partial \theta}{\partial t} = \left(\frac{1}{r}\right) \frac{\partial}{\partial r}\left[rK(h)\frac{\partial h}{\partial r}\right] + \frac{\partial}{\partial z}\left[K(h)\frac{\partial h}{\partial z}\right] - \frac{\partial K(h)}{\partial z}$$

Page 88 - In Equations "3b", "3d", and "3e", replace "`i" with "Γ_i"

Page 88 - Table 1. - Replace "Residual water content (2_r cm^3/cm^3)" with "Residual water content (θ_r cm^3/cm^3)," "Saturated water content (2_s cm^3/cm^3)" with "Saturated water content (θ_s cm^3/cm^3)" and "Coefficient in retention function (`` cm^{-1})" with "Coefficient in retention function (α cm^{-1})".

Pages 146 and 148 - Change "'''" to "+/-"

Page 148 - Change "0.162 " 0.118 m3" to "0.162 +/- 0.118 m^3"

Page 185 - Column 2 - After 5C, items 6 through 10 should not be indented.

SESSION 1:

WATERSHED MANAGEMENT

ASSESSMENT OF COLLABORATIVE WATERSHED MANAGEMENT APPROACHES USED IN THE UNITED STATES FOR APPLICABILITY IN WYOMING

Scott A. Mullner, Eric A. Felbeck, Wayne A. Hubert, and Thomas A. Wesche[1]

INTRODUCTION

Extensive natural resource exploitation in the Unites States since the 1800's has prompted continuous evolution of resource management agencies to conserve and administer natural resources under a multiple-use management strategy (Frentz et al. 1995). In 1949, Aldo Leopold described man's need to limit landscape modification to protect overall ecosystem quality, terming it the "land ethic." Even with foresight such as Leopold's, land use has continued to be a primary cause of changes to stream fishery resources (Meehan 1991).

Recently, fisheries managers have begun to use watershed boundaries to delineate basic management units (Taylor et al. 1995). Both state and federal agencies, as well as industry, have begun adopting the watershed as the principle management unit for water and fisheries resources (Perciasepe 1994). Watershed-scale management considers the effects from land use practices on components of the landscape and its inhabitants. Cumulative impacts upon a watershed's integrity or function caused by management decisions can be reduced by approaching upland and aquatic management decisions at a watershed scale. The necessity for watershed-scale management of fisheries is becoming apparent to agencies and managers responsible for these resources, thus raising the question of how to accomplish management at the watershed scale, over which individual management agencies may have little or no authority?

A process for collaborative watershed management can address this concern by enabling involvement of interested stakeholders to reduce individual responsibilities, promote cooperation, and improve a project's acceptance and success. Thus, agencies designated to manage fisheries resources can improve their management success through collaboration. However, the components for a collaborative process for watershed-scale management have not been fully developed and integrated into fisheries management.

Currently, Wyoming's resource managers do not have a defined approach to collaborative watershed-scale management, due partially to the difficulty of bringing together individual stakeholders within a watershed. Yet, entire watersheds are rarely owned or managed by a single government entity or private individual. Instead, they are managed by several stakeholders (private and public) each with potentially different, and sometimes conflicting, objectives (Cornett 1994, Jamal and Getz 1995).

Managing fisheries resources to the satisfaction of all stakeholders within a watershed requires a process that ensures participation by each party (Gunn 1988, Inskeep 1991). The process of collaborating to manage resources at a watershed scale is termed "collaborative watershed management" (CWM). The CWM process promotes the involvement of stakeholders and increases the likelihood of success by creating participant ownership in the process and products. Through the involvement and interaction of all stakeholders, the process becomes a collaborative process for the management of fisheries resources at the watershed scale.

Collaboration is defined by Gray (1985) as "the pooling of appreciations and/or resources...by two or more stakeholders to solve a set of problems which neither can solve individually." The optimal CWM process includes organizations and agencies considered to be outside of traditional fisheries management (e.g. agriculture, forestry, water resources, environmental quality or recreation) and spreads responsibilities and ownership of the management process to all involved stakeholders (Jamal and Getz 1995). A CWM process improves the likelihood of public acceptance of management decisions, while reducing responsibilities and expenses for single agencies or groups. The importance of public participation throughout the process is imperative, and includes developing issues and identifying direction (Thompson 1993). Historically, public involvement in the fishery resource management process generally meant simply informing stakeholders of activities and decisions that had been made by professional resource managers.

Our research evaluates watershed-scale management processes being used by agencies throughout the United States to identify the array of perspectives and ideas that constitute watershed-scale management today. The

[1] Wyoming Cooperative Fish and Wildlife Research Unit; Department of Rangeland Ecology and Watershed Management; Wyoming Cooperative Fish and Wildlife Research Unit; and Wyoming Water Resources Center, UW, Laramie, WY 82071, respectively.

necessary components of a collaborative process defined by social collaboration theory can be used to describe and develop a CWM process for application by the Fish Division of the Wyoming Game and Fish Department.

METHODS

A thorough review of peer-reviewed and agency literature was completed to identify processes for CWM in currently in use by federal agencies and private industry. A telephone survey for all the states (Kellehear 1993) was completed using a qualitative survey approach to identify CWM processes being considered or implemented by state agencies. The phone survey allowed interviews of a large number of agency personnel within a reasonable period of time.

The telephone survey consisted of three questions, each one more explicit than the prior one (Table 1). A request for corresponding documentation was made, if it was identified that the state was using collaborative watershed management. Thematic analysis (Kellehear 1993) to identify themes, concepts, and ideas (Rubin and Rubin 1995) was applied to code and categorize the information.

Table 1. List of phone survey questions

Question #	Question
1	Is your agency currently using a watershed process to assess or manage fish, water, or sediment?
Introductory statement for questions 2 and 3:	For this project I am considering collaborative watershed management to be any watershed management methodology that directly involves the stakeholders, with concerns or ownership in the watershed, in determining the state's management direction for that watershed.
2	Is your agency using a collaborative process that formally included various stakeholders?
3	What documents, handbooks, etc. are available on this process and could they be sent for my review?

Processes for collaborative watershed management were described from the documentation for the various watershed management programs being used or considered by state and federal agencies, private institutions, and industries across the United States. These CWM processes were evaluated using a four-step approach. A U. S. Department of Agriculture document (Jordan 1993) indicated differing types of planning models used by natural resource managers (Figure 1a and b), with a paradigm shift prompting the development and adoption of more collaborative style management processes (Figure 1c). The first step in our review was to evaluate and categorize each CWM as to which one of three planning models (Figure 1) most closely represented the process. If the CWM process was determined to be a collaborative process (Figure 1c), we moved to the next step.

Selin and Chavez (1995) identified four collaborative designs that occur in natural resource management: (1) appreciative planning, (2) partnerships, (3) dialogues, and (4) negotiated settlements. Appreciative planning encourages interaction of participants that share resource management goals and the expected outcome of the process is limited to information exchange. Partnerships require that participants share resource management goals and develop agreements which address those goals. Dialogues are used to resolve conflict by identifying differences in goals of participants and searching for common goals without binding agreements. A negotiated settlement produces an agreement ratified by all participants to resolve conflicts.

Our second step was to identify which of the four collaborative designs each CWM process contained. If a CWM process was identified only as appreciative planning, it was eliminated. If the process contained one of the other three designs, we retained it for step three.

Gray (1985) determined that a collaborative process consists of three phases: (1) problem-setting, (2) direction-setting, and (3) structuring. In step three, the remaining CWM processes were examined to determine if they contained any of the three phases of a collaborative process. Those that contained one or more of the collaborative phases were more thoroughly examined.

Gray (1985) determined that successful implementation of each collaborative phase requires inclusion of specific facilitative conditions (Table 2) in a CWM process. Gray (1985) identified 12 facilitative conditions for collaboration (Table 2) and we added three more to create a more complete collaborative process. The CWM processes containing any phase of collaboration were examined in step four, using the facilitative conditions listed in Table 2.

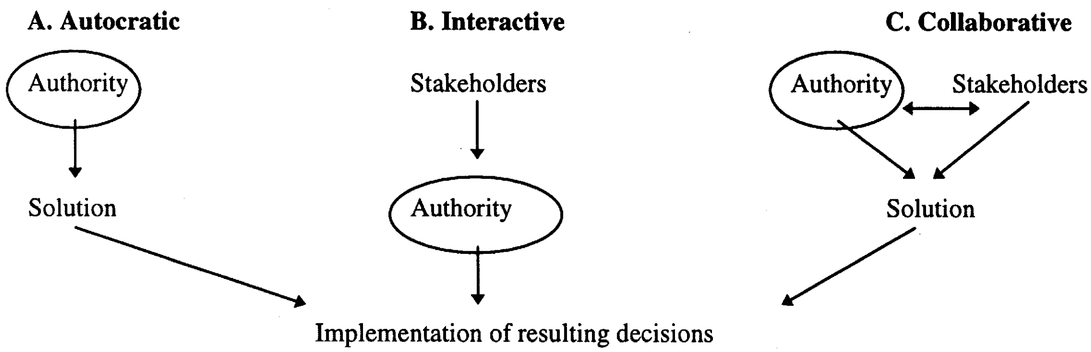


Figure 1. Planning Models (*from* The Power of Collaborative Planning, 1993).

Table 2. Facilitative conditions at each phase of collaboration (Gray 1985).
Those conditions in italics were added by these authors.

Problem-setting	Direction-setting	Structuring
Recognition of interdependence	Coincidence of values	High degree of ongoing interdependence
Identification of a requisite number of stakeholders	Dispersion of power among stakeholders	External mandates
Perceptions of legitimacy among stakeholders		Redistribution of power
Legitimate/skilled convener		
Define concensus	*Unanimity in minority group halts process*	Influencing the contextual environment
Explicit agreement on how to reach "final resolution"		
Positive beliefs about outcomes		
Shared access to power		

Themes, concepts, and ideas (Rubin and Rubin 1995) that existed within CWM processes were examined. The CWM processes that did not contain a majority of the facilitative components were considered to be "least" collaborative while those containing a majority were considered "most" collaborative. The CWM processes were classified into three groups (slightly collaborative = ≤ 5 of 15 facilitative conditions, moderately collaborative = 6 to 10 of 15, and highly collaborative = ≥ 11 to 15). The CWM processes which addressed the greatest number of components of steps one through four were most likely to be the successful collaborative management processes.

RESULTS AND DISCUSSION

All but two states were contacted during the telephone survey and 26 states indicated that they considered their watershed management processes collaborative. Four states were selected from the responses to serve as examples of the types of collaborative watershed management processes being used: Ohio, Illinois, New York, and California.

The Ohio Process for Water Resources Planning is a process that uses the autocratic and interactive planning models to develop watershed plans. This process lacks a collaborative planning model. The components are indicated in Table 3.

The Illinois Watershed Management Program used both the interactive and collaborative planning models, but the lack of any collaborative designs beyond the appreciative level of collaboration eliminated this model (Table 3). The components represented in the Illinois watershed management process are in Table 3.

The New York process for Watershed Planning for the Control of Nonpoint Source Pollution includes interactive and collaborative planning model components and the process also contains all collaborative designs except negotiated settlements. Continued evaluation of this watershed management process indicated that problem-setting and direction-setting phases were both included. Comprehensive evaluation of these phases identified five of the eight facilitative conditions for problem-setting

Table 3. Components of four states' watershed management processes.

Planning Model Type	Ohio	Illinois	New York	California
Autocratic	√			
Interactive	√	√	√	
Collaborative		√	√	√
Collaborative Design				
Appreciative		√	√	√
Partnership			√	√
Dialogue			√	√
Negotiated Settlement				√
Main Phase Types				
Problem-setting			√	√
Direction-setting			√	√
Structuring				
Facilitative Conditions				
Problem-setting				
Recognition of interdependence			√	√
Identification of a requisite number of stakeholders			√	√
Perceptions of legitimacy among stakeholders			√	√
Legitimate skilled convener			√	√
Define concensus				√
Explicit agreement on how to reach final resolution				√
Positive beliefs about outcomes			√	√
Shared access to power				√
Direction-setting				
Coincidence of values			√	√
Dispersion of power among stakeholders				
Unanimity in minority halts process				
Structuring				
High degree of ongoing interdependence				
External mandates				
Redistribution of power				
Influencing the contextual environment				
Number of Facilitative Conditions	0 of 15	0 of 15	6 of 15	9 of 15

(Table 3) and one of the facilitative conditions for direction-setting (Table 3). In all, six of 15 possible facilitative conditions were represented in this process, making it a moderately collaborative watershed management process.

The California Coordinated Resource Management and Planning process was the only one to include only the collaborative planning model. All the collaborative design phases were represented in this model, but only the problem-setting and direction-setting phases of collaboration were included in the California process. Comprehensive evaluation of the problem- and direction-setting portions of the document included nine of 15 facilitative conditions.

The extent of collaborative development in four CWM processes were compared to planning models, collaborative designs, collaborative phases, and facilitative conditions defined from social collaboration theory. These examples are only four of 26 state CWM processes evaluated, but are indicative of those used nationwide. None of the state's CWM processes contain all 15 facilitative conditions for collaboration. The problem-setting phase of the California process includes all of the facilitative conditions required for successful collaborative problem-setting as identified by Gray (1985). We have learned that these and other CWM processes can provide a pattern for development of a CWM process for Wyoming.

REFERENCES

Cornett, Z.J. 1994. GIS as a catalyst for effective public involvement in ecosystem management decision-making. Pages 337-345 *in* Remote Sensing and GIS in Ecosystem Management.

Frentz, I., P.Hardy, S. Maleki, A. Phillips, and B. Thorpe. 1995. Ecosystem management in the U.S.: an inventory and assessment of current experience. Master's Thesis. University of Michigan. Ann Arbor, Michigan.

Gunn, C.A. 1988. Tourism planning, second edition. Taylor and Francis, New York.

Gray, B. 1985. Conditions facilitating interorganizational collaboration. *Human Relations* 38:911-936.

Inskeep, E. 1991. 1991 Tourism planning: an integrated and sustainable development approach. Van Nost and Reinhold, New York.

Jamal, T.B., and D. Getz. 1995. Collaboration theory and community tourism planning. *Annuals of Tourism Research* 22:186-204.

Jordan, C. 1993. How does collaborative planning work? Pages 6-7 *in* The Power of Collaborative Planning. United States Department of Agriculture Forest Service FS-553.

Kellehear, A. 1993. The unobtrusive researcher - guide to methods. Allen and Unwin, Leonards, New South Wales, Australia.

Leopold, A. 1949. A Sand County Almanac. Oxford University Press, Oxford.

Meehan, W.R. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Perciasepe, R. 1994. EPA's watershed approach to ecosystem management. *Fisheries.* 19(4):4, 27.

Rubin, J.R., and I.S. Rubin. 1995. Qualitative Interviewing: The Art of Hearing Data. Sage Publications, Thousand Oaks, California.

Selin, S., and D. Chavez. 1995. Developing a collaborative method for environmental planning and management. *Environmental Management* 19:189-195.

Taylor, W.W., C.P. Ferreri, F.L. Poston, and J.M. Robertson. 1995. Educating fisheries professional using a watershed approach to emphasize the ecosystem paradigm. *Fisheries.* 20(9):6-8.

Thompson, J.G. 1993. Addressing the human dimensions of wolf reintroduction: an example using estimates of livestock depredation and costs of compensation. *Society and Natural Resources* 6:165-179.

THE NORTH TONGUE RIVER: A COLLABORATIVE APPROACH TO WATERSHED MANAGEMENT

Eric A. Felbeck, Scott A. Mullner, Thomas A. Wesche, and Wayne A. Hubert[1]

The North Tongue River is located on the northern end of the Bighorn National Forest, in north-central Wyoming. The stream originates on the western side of the Bighorn Mountain range at 3050-m above mean sea level (MSL) and flows east to its confluence with the South Tongue River at 2130-m above MSL. The North Tongue is a fourth order stream (Strahler, 1957) at the South Tongue River confluence, and has 97 first order, 20 second order, and 3 third order tributaries. The river drains approximately 150 square kilometers.

Paralleled for much of its length by U.S. Highway 14A, a scenic byway, the Wyoming Game and Fish Department (1987) rates the North Tongue as a Class 3 (yellow ribbon) trout stream due to its aesthetics, availability to the public, and productivity. Class 3 is defined as "important trout waters, a fishery of regional importance."

There are populations of four trout species within the North Tongue River basin. These species are brook (*Salvelinus fontinalis*), brown (*Salmo trutta*), cutthroat (*Oncorhynchus clarki*), and rainbow (*Oncorhynchus mykiss*) trout.

Underlying geology is primarily quartzo-feldsparthic gneiss, a form of granitic rock with areas of limestone, sandstone, and shale inclusions in the overlying bedrock. The majority of the drainage is classified as general soil map unit Owen Creek-Tongue River-Gateway. Nesser (1986) describes this unit as "moderately deep, well-drained soils that formed in material derived from interbedded shale, sandstone, and limestone, on mountainsides and landslide deposits." The Owen Creek soils formed in colluvium derived from interbedded shale and sandstone on mountainsides and landslide deposits, and support a big sagebrush (*Artemesia tridentata*) - Idaho fescue (*Festuca idahoensis*) grassland community. Tongue River soils formed in residuum from soft sandstone and shale on mountainsides and support a lodgepole pine (*Pinus contorta*) forest community. Gateway soils formed in residuum derived from shale and limestone on mountainsides and support Engelman spruce (*Picea engelmanii*) dominated communities (Nesser, 1986). Land uses within the drainage include roads, road construction, timber harvest, grazing (livestock and wildlife), and recreation.

The North Tongue River basin is an area of concern for many people, organizations, and entities. Limited natural recruitment occurs for all trout species in the watershed (Hubert and Wesche, 1994). A lack of suitable spawning habitat is believed to be the cause, and land uses may contribute by supplementing natural sediment levels. Sediment may reduce reproductive success by blocking water flow through spawning gravels; reducing the amount of dissolved oxygen reaching the eggs and fry. In the mid-1980's the Wyoming Game and Fish Department (WGFD) determined that virtually all stocked fingerling cutthroat trout were eliminated within 15 months of stocking. Angler harvest was the largest cause (Stewart, 1995). Processes such as naturally erosive geologic conditions, limited spawning habitat within the drainage, and disjunct distributions of habitat suitable for spawning, rearing, and adult habitat may be contributing to the problem (Hubert and Wesche, 1994). A lack of overwinter habitat for juvenile and adult fish may also be limiting in the system (Stewart, 1995).

The low trout reproductive rate has caused concern which resulted in the creation of the North Tongue Working Group in the early 1990's. The Working Group is an assembly of stakeholders who have been brought together to examine the watershed problems and develop solutions in a collaborative manner. It is composed of: the Bighorn Forest Grazing Permittee Association, Trout Unlimited; Bighorn Forest Users Coalition; Bighorn Forest Cabin Owners Association; Wyoming Game and Fish Department; U.S. Forest Service; Bighorn National Forest; and the Wyoming Department of Environmental Quality.

Gray (1985) defines collaboration as "the pooling of appreciation and/or tangible resources, e.g., information, money, labor, etc., by two or more stakeholders, to solve a set of problems which neither can solve individually." Three major steps lead to collaboration (McCann, 1983):

1) Problem setting - identification of the stakeholders and the issues which join them;
2) Direction setting - understanding of stakeholder values which drive their involvement; and
3) Structuring - recognition of interdependence among stakeholders (Gray, 1985).

Objectives of collaboration are to allow inquiry and to develop common values regarding resource use (Selin and Chavez, 1995). The assembly chooses between forms of collaboration based on motivation and desired outcomes. The four forms are:

1) Appreciative planning - This is motivated by a desire to advance a shared vision. The outcome

[1] Department of Rangeland Ecology and Watershed Management; Department of Zoology and Physiology; Department of Rangeland Ecology and Watershed Management and the Wyoming Water Resources Center; Wyoming Cooperative Fishery and Wildlife Research Unit and Department of Zoology and Physiology; University of Wyoming, Laramie, Wyoming, respectively.

is information sharing. This form can be used to lay the ground work for the remaining three forms.

2) Partnership - This requires shared goals and results in assignment of shared responsibility to stakeholders to realize the goals.

3) Dialogue - Used to set out differences and search for common ground without resulting in binding agreements.

4) Negotiated settlements - Produces a binding agreement that is ratified by all participants to resolve conflict (Selin and Chavez, 1995).

Appreciative planning most closely describes the collaborative form currently being used by the North Tongue Working Group. The stakeholders have come together with common concerns to exchange information and search for a solution. In the process of this search the group has determined that there was insufficient information to conclusively identify the cause of the low reproductive rates. To address this question, the WGFD funded a research project at the University of Wyoming, entitled "Development of an Ecosystem-Based Approach to Assessment of Watersheds for the Management of Trout Fisheries in Wyoming." The objectives of the study are to:

1) Describe the sediment delivery patterns to the North Tongue River and determine what watershed characteristics influence these patterns.

2) Determine how geomorphic feature distribution affects trout habitat and trout population distribution and evaluate Geographic Information System (GIS) support for watershed analysis.

3) Conduct a literature review and survey of state agencies to develop an approach for collaborative fisheries management at a watershed scale.

4) Test the collaborative approach and GIS support using the North Tongue River and the information developed for objectives 1 and 2.

The study began in January 1996, and is projected to be complete by the end of 1999. Research is attempting to determine the reason for the low level of trout recruitment, how much of the problem is attributable to natural conditions, and how much is attributable to land use. When the research is complete, results will be turned over to the WGFD and thus to the Working Group. They will then determine a course of action.

How the collaborative process proceeds on the North Tongue River is yet to be determined. Any of the four collaborative designs could be used depending on the outcome identified as desirable and necessary by the Working Group. If the goal is limited to information exchange only, appreciative planning may be used. Dialogue may be used if the information exposes differing views and common ground needs to be found. A partnership is possible if solid agreement is reached through appreciative planning or dialogue on the goal and the methods to reach it. The partnership would have members agreeing on roles and responsibilities for each stakeholder. A negotiated settlement could result if the working group determines that a binding arrangement, to which all stakeholders agree, is the desired end.

REFERENCES

Gray, B. 1985. Conditions Facilitation Interorganizational Collaboration. *Human Relations*, 38:911-936.

Hubert, W.A. and T.A. Wesche. 1994. Development of an Ecosystem-Based Approach to Assessment of Watersheds for the Management of Trout Fisheries in Wyoming. Proposal Submitted to Wyoming Game and Fish Department.

McCann, J.E. 1983. Design guidelines for social problem-solving interventions. *Journal of Applied Behavioral Science* 19:177-189.

Nesser, J.A. 1986. Soil Survey of Bighorn National Forest, Wyoming. U.S. Department of Agriculture Forest Service and Soil Conservation Service in Cooperation with Wyoming Agricultural Experiment Station.

Selin, S. and D. Chavez. 1995. Developing a Collaborative Model for Environmental Planning and Management. *Environmental Management* 19(2):189-195.

Stewart, B. 1995. Response of Fish Populations to a Restricted Harvest Regulation on the Upper North Tongue River and Bull Creek. Wyoming Game and Fish Department, Administrative Report 30-833-030-17. Cheyenne, Wyoming.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. *Transactions of the American Geophysical Union.* 38(6):913-920.

Wyoming Game and Fish Department. 1987. Wyoming Trout Stream Classification Map.

LOCO CREEK SMALL WATERSHED PROJECT

A. Warren and L. Hicks[1]

ABSTRACT

The Loco Creek Watershed Project has proved to be a success in small watershed restoration. The Coordinated Resource Management process was used with many individuals, groups, and agencies participating and/or contributing financial assistance. Monitoring results show substantial improvement to aquatic, riparian, and upland habitats. Macroinvertabrates analysis exhibited statistically significant improvements during the project. Stream channel morphology improved with substantial reduction in stream width to depth ratio at most sites. Stream bank water storage was shown to increase as riparian system function improved. Both woody and herbaceous key riparian species showed increases in frequency, density, and height. Biological function of the system has shown dramatic change. Re-establishment of a cold water fisheries occurred in 1995, where none had existed for many decades. In 1996 beaver activity returned to the main stem of Loco Creek.

INTRODUCTION

There are approximately 11,260 acres in the Loco Creek Watershed. Land ownership consist of 58% BLM, 34% private, and 7% state lands. The BLM administered Morgan-Boyer grazing allotment is contained almost entirely within the watershed. The allotment is a common allotment with five permittees running cow/calf operations and one permittee running sheep. In addition there is a stock drive way through the allotment where over 12,000 sheep are trailed onto and off the Medicine Bow National Forest annually. Loco Creek is utilized as a noon resting/watering site by these trailing herds.

The watershed is comprised of high plateaus at elevations of 8,000 feet and a steep canyon that bisects the watershed. Elevation at the mouth of Loco Creek is 6,700 feet. The plateaus and canyon slopes occupy 95% of the total watershed. Vegetative communities are predominantly mountain shrub and sagebrush. Average annual precipitation is approximately 14 inches.

IDENTIFIED PROBLEM

The Morgan-Boyer grazing allotment was a single pasture allotment with limited upland water. This resulted in livestock grazing in riparian areas from May through October (growing season long use). Significant removal of riparian vegetation resulted in a degraded nonfunctional riparian system. The nonpoint source pollutant in Loco Creek was silt and sediment as a result of unstable banks and condition of uplands immediately adjacent to the riparian area. Poor condition of woody riparian vegetation, to provide shading, resulted in thermal pollution with peak summer time temperatures limiting the potential for cold water fisheries.

PROJECT GOALS AND OBJECTIVES

Goal 1. Reduce silt and sediment loading into Loco Creek.

Objective 1. Reduce upland erosion.

Objective 2. Reduce silt/sediment from entering Loco Creek as a result of concentrated flows and gully erosion associated with roads.

Goal 2. Improve and enhance the riparian areas along Loco Creek.

Objective 1. Reduce livestock and wildlife impacts to riparian areas and vegetation.

Goal 3. Work towards re-establishment of self sustaining cold water fisheries as an indicator of improved water and habitat quality.

Objective 1. Reduce summer time high water temperatures.

Goal 4. Document the effectiveness of grazing Best Management Practices for control of NPS pollution.

Objective 1. Disseminate information to livestock operators and other resource user groups.

Project Participants are: Little Snake River Conservation District, Mckee Partners Ranch, USDI-BLM, Great Divide Resource Area, Cobb Cattle Company, Wyoming Riparian Association, K L Sheep Company, Natural Resource Conservation Service, Morgan Ranch, Department of Environmental Quality, Farm Service Agency, Environmental Protection Agency, USFS - CSA, Rocky Mountain Elk Foundation, and Wyoming Game and Fish Department.

PROJECT ACTIVITIES AND TOOLS

Two and one half miles of high tensil solar electric fencing consisting of six drift fences were used to divide the allotment into five pastures. In addition to the fences, herding was done more frequently than in the past. Upland water developments consisted of four springs, and three ponds.

Minor road alterations were made to move two portions of the two track road adjacent to Loco Creek farther away from the creek. Water bars were also placed on the roads adjacent to Loco Creek. A culvert was placed at one crossing of an ephemeral tributary to Loco Creek.

Approximately 2,000 acres of upland was burned in the spring and fall of 1994 in the lower two creek

[1] USDI-BLM, Great Divide Resource Area, 1300 North 3rd St., Rawlins, WY 82301 and Little Snake River Conservation District, P.O. Box 355, Baggs, WY 82321

bottom pastures. Burning was conducted by the BLM with cost share and inkind contribution by the Rocky Mountain Elk Foundation, permittees, and the conservation district.

Over 2,000 willow cuttings and 3,000 bare root riparian shrubs and trees where planted along Loco Creek between 1993 and 1996. Twelve small in-stream structure where placed in Loco Creek between 1993 and 1995 to establish grade control, elevate water tables, trap sediment, and improve fisheries habitat. Seven structures where made of logs and five where constructed with steel posts, woven wire, and geotextile material. Initially we had proposed re-introducing beaver into the system. Early on we reevaluated this activity and decided to postpone this practice and allow the habitat more time to respond. However, in 1996 beaver returned on their own and by October had started on construction of three dams on the main stem of Loco Creek.

RESULTS

Improvement in surface water quality was barley detectable. This is not to say that substantial improvements did not occur. The lack of definitive results is more a reflection of the methodology with which water column data was collected. Water quality data was collected by grab sample methodology at predetermined times of the month. This methodology only provides a point-in-time comparison for water quality parameters. Other factors such as changes in type of instrumentation, change of sampling location, and different persons conducting the sampling may have resulted in confounding the data so there were no definitive changes.

Aquatic macroinvertabrate samples were not collected until 1994, three years after the change in grazing practices. While substantial improvements in the benthic macroinvertabrate community occurred from 1994 to 1996 these changes would have been much more dramatic had macro-sampling been conducted prior to changes in grazing practices in 1991.

Total taxa "richness" statistically increased from 1994 to 1996. Number of taxa increased from 26 present in 1994 to 34 present in 1996 , a 24% increase in the total number of taxa in Loco Creek. Taxa "richness" is a component and estimate of community structure and stream health based on the number of distinct taxa. As water quality improves, taxa "Richness" increases. EPT Richness is a summary of the taxa richness within the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). These orders are considered to be sensitive to pollution. EPT generally increases with increasing water quality. There was no statistical difference in EPT richness between 1994 and 1995. However, EPT richness in 1996 compared to 1995 and 1994 was statistically better indicating an overall improvement in water quality. An aquatic macroinvertabrate community dominated by a few taxa indicates environmental stress. In 1994, Loco Creek had a dominant community value of 49.3% but improved to 25.8% in 1996.

Ecological diversity is a measure of community structure defined by the relationship between the number of distinct taxa and their relative abundance. Shannon's diversity index is widely used in community ecology. The higher the number, the greater the diversity. Shannon Diversity Index for Loco Creek showed statistical improvement from 1994 (1.78) to 1996 (2.6). Biotic indices make use of the indicator taxa concept. The most common biotic index used in the United States is the Modified Hilsenhoff Biotic Index (MHBI) where waters having 0-2 are considered clean, 2-4 slightly enriched, 4-7 enriched, and 7-10 polluted. In 1996 the MHBI was 4.1, the lowest of any year. The MHBI for all three years indicated moderate organic enrichment.

Seven stream cross sections were established, two in 1988 and five more in 1992, to evaluate channel morphology changes as influenced by natural processes and grazing impacts. Stream morphology plays an important role in providing fisheries habitat and physical water quality parameters such as water temperature. Deeper stream channels with overhanging banks provide more habitat and are less influenced by thermal radiation and water temperature fluctuations than shallow wide streams. Cross sections are primarily used to evaluate change in width to depth ratio. Five of the eight channel cross sections showed reduced width to depth ratio by 87.6%, 89.6%, 79%, and 40.5%. The other cross sections showed lateral migration of the channel or increased width-to-depth ratio resulting from down stream movement of streambed substrate.

Eight shallow stream bank water wells were placed along Loco Creek in 1992. Depth of wells ranged from 5 to 10 feet and ranged in distance from 10 to 100 feet away from the Creek Channel. Wells consisted of perforated two inch PVC pipe. The purpose of the wells was to evaluate stream bank water storage as influenced by the changing condition and function of the riparian system along Loco Creek. Several observations and conclusions can be made from the data collected from 1993-1996. First, Loco Creek directly communicates with its alluvial aquifer. The shallow stream bank water wells provide for a reliable tool in evaluating the functional condition of riparian areas as it relates to bank water storage and release.

Data from shallow bank water wells indicates that the overall function of the riparian areas for storing bank water and allowing for slow release as the season progresses is improving. In 1994 and 1996 average annual precipitation was below normal.

However, at the same stream discharge rate in 1996 bank water storage and slow release was improved. This was especially evident where the riparian areas were in better condition.

Stream bank water well data from the exclosure well demonstrates the positive effects on elevating stream bank water by construction of small in-stream structures, in this case a woven wire, steel post, and geotextile cloth structure. In July 1995, the structure was placed approximately 100 feet down stream from the existing stream bank water well. For the remainder of 1995 it maintained stream bank water elevation a minimum of 14 inches higher in the bank compared to 1993. In addition in 1996 the structure maintained bank water elevation a minimum of 19 inches higher than in 1994 at the same stream discharge rates in mid summer. Because of this elevated water table stream side vegetation at this site is showing a shift from Kentucky bluegrass to *carex* and *juncus* species which have a much higher root density providing better bank stability characteristics.

Nebraska Sedge and all *salix* species present were selected for monitoring on Loco Creek as key riparian species. Attempts were made to locate vegetative transect along the entire length of Loco Creek and in most pastures to give an overall picture of changes in these key riparian species. Both frequency and density of Nebraska Sedge increased along Loco Creek. Increases in Nebraska Sedge frequency was greatest in the middle pasture (37%), followed by the lower (28%), and upper pastures (16%). Increase in Nebraska Sedge densities were 35%, 64%, and 153% in the upper, middle, and lower pastures, respectively.

Willow regeneration transects showed an average increase in willow height of 30 inches at one of the more representative grazed sites and an average increase of 33.3 inches in the ungrazed exclosure. Another grazed site by livestock had an average increase in height of 19.3 inches while the exclosure had an average increase in height of 21 inches but the area was being utilized by beaver. It would appear that average height of willows is very similar regardless of being utilized between livestock and wildlife. It should be mentioned here that average increases in willow height are somewhat deceiving regardless of whether they are inside or outside of the exclosure. No provision in measuring willows was made for increased occurrence, regeneration through seed, or suckering. Along Loco Creek, establishment of seed borne willow was evident especially after the high flow event in May of 1993, which was in excess of a 25 year event. Some willows measuring 9 inches in 1992 grew to in excess of seven feet by 1996. In 1995 some individual willow leader lengths were measured exceeding 3 feet.

There were significant differences in the "rate of improvement" from year to year. This occurred as a result in tremendous variation in annual precipitation, stocking rates, turn out dates, and the time in which project activities occurred. All upland water projects were not completed until 1995 and the prescribed burning didn't occur until 1994. Average annual precipitation varied greatly during the 5 years of this project, 1992 and 1993 were near average (14 inches) while 1994 and 1996 were below average and 1995 was 146% of average.

Permanent photopoints document the improved function of riparian areas. The following can be seen in the photopoints.

- Sediment and gravel deposition on the banks.
- More residual vegetation left on the banks.
- Establishment of seed borne willow and cottonwood.
- Increased height of woody riparian species.
- Increase in the amount of sedge present.
- Disappearance of livestock trail on bank.
- Improved bank stability.
- Positive changes in channel morphology.
    a. decreased width-to-depth ratios.
    b. improved pool-to-riffle ratios.
    c. decreased occurrence of braided channels.
    d. defined creek banks.
    e. reduced lateral channel migration.
- Increase in base stream flows on Loco Creek and ephemeral tributaries.

MUDDY CREEK SEEKING COMMON GROUND PROJECT

Larry Hicks and Andy Warren[1]

ABSTRACT

Muddy Creek is located in south central Wyoming. This half million acre area has been identified as a principal source of sediment into the Colorado River drainage. In 1991, the local conservation district initiated the CRM (Coordinated Resource Management) process to bring together affected interests to effect ecosystem management on a watershed basis. The group has worked to reduce non-point source pollution from both upland and riparian areas using a variety of tools. These include grazing management, prescribed burning, water development, creating wetlands and other practices. Many projects were cooperative ventures involving funding, survey and design, or construction. Site-specific monitoring shows significant improvement. However, improving watershed issues like water quality, storage and flows will take a longer period of time to document. What makes this project unique is that so many diverse interests have come together to seek common ground solutions to watershed issues.

INTRODUCTION

The Muddy Creek drainage is located in south central Wyoming in the upper Colorado River Watershed. Precipitation varies from around 7 inches annually in the lower elevations to 18 inches annually at the headwaters. Saltbush, greasewood, sagebrush-grass, and juniper plant communities dominate the lower elevations while aspen, mountain shrub, tall sagebrush, and riparian plant communities dominate higher elevations. Ephemeral and intermittent drainages to the west contrast with perennial drainages to the east. Wildlife is abundant and diverse.

Muddy Creek is a major contributor of salinity and sediment into the upper Colorado River system. Livestock grazing is an important element of the local economy. Oil and gas development occurs within the watershed, with coal reserves potentially being developed in the future. Recreational use is also expanding as people look to open areas like Wyoming to get away from it all.

This diversity of resources and land use also increases the complexity for management. Some resources span large areas with no regard for land ownership or jurisdictional responsibility. These include water quality, flows, and usage, wildlife and fisheries, recreation and open space. Managing on a watershed basis provides the forum to address these kind of issues, to look at the "big picture". The Muddy Creek CRM Project encompasses nearly 300,000 acres of mixed federal, state, and private lands in Carbon County, Wyoming. The CRM group emphasizes cooperation rather than confrontation. The process involves people getting to know the land, building relationships through communication, earning trust so they can identify their common ground, and working together to achieve success. Using the philosophy of ecosystem management on a watershed basis, the CRM process was initiated in 1991 by the local conservation district to get all affected interests in the watershed working on consensus management of the natural resources. To date, there are over 25 members working on the project representing private landowners, federal, state, and local agencies, environmental and conservation organization, industry, and the public. The cooperators include AL Land and Cattle Co., Bruce Thayer, Bureau of Land Management, Carbon County Commissioners, Carbon County Cooperative Extension Service, Desert Cattle Company, Ducks Unlimited Inc., Environmental Protection Agency, Espy Livestock Company, Jack Creek Land and Cattle Company, Little Snake River Conservation District, National Fish and Wildlife Foundation, Natural Resource Conservation Service, PH Livestock Company, Salisbury Livestock Company, Snyder Oil Corporation, Stratton Sheep Company, Three Forks Ranch, University of Wyoming, U.S. Fish and Wildlife Service, U.S. Department of the Interior - Central Utah Project Completion Act, Weber Ranch, Wyoming Department of Environmental Quality, Wyoming Game and Fish Department, Wyoming Outdoor Council, Wyoming Riparian Association, Wyoming Water Development Commission, and Wyoming Wildlife Federation.

MISSION STATEMENT

To protect, enhance and conserve the Muddy Creek Watershed for healthy, sustainable use of natural resources for wildlife, livestock, energy and recreation.

GOALS OF THE UPPER MUDDY CREEK/RED RIM CRM

- Increase cooperation, coordination, and trust among landowners, permittees, agencies, and interest groups.
- Improve critical ranges for antelope, elk, and deer in the area.
- Demonstrate that properly managed livestock grazing can be compatible with consumptive and non-consumptive use of the area's multiple resources.
- Improve water quality and reduce erosion and sedimentation. Restore riparian habitats to the desired future condition, this will consist of visible changes in the plant community, stream

[1] Little Snake River Conservation Distr., P.O. Box 355, Baggs, WY 82321 and BLM, 1300 N. 3rd, Rawlins, WY 82301.

channels, and hydrologic regimes. It includes improvement of existing woody plant communities and their restoration to previously occupied sites. Re-establish Colorado River Cutthroat Trout to headwater streams.

- Manage upland habitats to improve their biodiversity and productivity for selected wildlife species and domestic livestock.

METHODS

The CRM process has been the most effective method for people to have active participation in the decision making process. It allows people with different viewpoints to reach a common or shared vision of where they are going and how to help each other to get there. It becomes a support group to tackle difficult or complex issues that one individual or agency alone could not handle. And it provides continuity of work and success if someone leaves. To implement projects on the ground, new or existing plans must simply comply with the mission statement and goals listed above.

One of the most important tools used to achieve these goals was development of water sources. Tires were obtained from coal mining operations for use as troughs. Roads are used to collect water into pits. Upland pits and reservoirs have been built to stop active headcuts or gullies in addition to creating a new water source. Where sufficient water occurs, ponds are built to support fisheries as well.

Other tools used in the project include prescribed burning, instream structures, vegetative plantings, spreaderdiking, herding of livestock, and cross-fencing using high tensile solar electric fencing.

Erosion from roads was identified as a major cause of sedimentation into Muddy Creek. Over 3,000 miles of roads exist within the watershed, less than 200 miles of those roads are actually planned and designed roads by the county or the Bureau of Land Management. This sheer number of roads not only contributes erosion into Muddy Creek, it impacts wildlife and their habitat. While technical solutions such as improving road design, culverts, wing ditches and water bars are being implemented throughout the area, this is only part of the answer.

Figures 1 and 2 illustrate the diverse funding sources and expenditures for the project.

RESULTS

The combination of upland water development, creation of smaller pastures and prescribed burning provide opportunities for more intensive livestock management. This has resulted in better distribution and shortened duration of use. At the junction of Littlefield Creek and Muddy Creek a near reversal in plant cover has occurred on the streambanks from only 5 percent in 1989 to over 90 percent in 1995. Improvement in streambank cover is an important early step to holding soil in place, improving water quality, and providing more forage and habitat for livestock and wildlife. Short duration use, in this case about one month instead of four months, has allowed the riparian habitat to heal.

Management changes on Muddy Creek have allowed plants more time to grow and stabilize streambanks. As this process continues, vegetation is encroaching into and narrowing stream channels, resulting in 30 to 50 percent reduced stream width along Muddy Creek in six years. A narrower channel and greater depth result in lower water temperatures for fish and aquatic insects. It also creates a faster current, helping to flush out sediment from the bottom and deposit it on building banks and improving water quality and channel bottom habitat. In many places gravel substrate has been observed where none previously existed. A narrower channel will fill faster during high flow events resulting in more over bank flooding which increases bank water recharge and storage for late season release, and reduces destructive energy by spreading water over a broad area.

Improved woody plant vigor has resulted in increased cover and vertical structure. These changes in riparian communities increase the diversity of animal life which depend on them. Other benefits include improved bank stability and stream shading which helps lower water temperatures for fish and aquatic insects. As woody shrubs species regain their abundance, so will beaver.

There has been approximately 14,000 acres of the watershed prescribed burned since 1985. Prescribed burning has been extremely beneficial for livestock, wildlife, and vegetation communities. Removal of those uniform stands of sagebrush releases forbs, desirable grasses such as green needlegrass and onion grass, and early successional species such as horsebrush and evergreen ceanothus. Sagebrush seedlings are able to sprout and a more diverse age class of sagebrush results. Most of the riparian aspen communities that are important for beaver are gone. Existing upland aspen stands are mature and decadent. Fire removes the sagebrush competition so that aspen regenerate and expand in both riparian and upland sites. Burning uplands also attract livestock away from riparian areas due to increased quality and quantity of forage.

Forty miles of main transportation roads and twenty-two miles of secondary access roads were improved to protect the natural resources and reduce annual maintenance costs. Five miles of roads were reclaimed and eight miles were signed for voluntary closure. Sedimentation into Muddy Creek from roads has been reduced. Road management has been a difficult issue for the CRM group. Public perception has been negative, especially when any

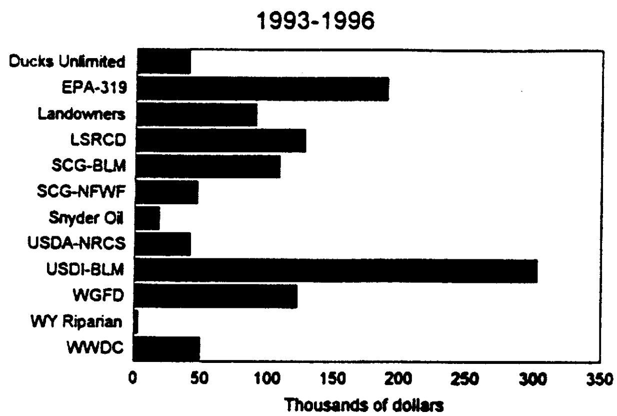


Figure 1 Muddy Creek Funding Sources

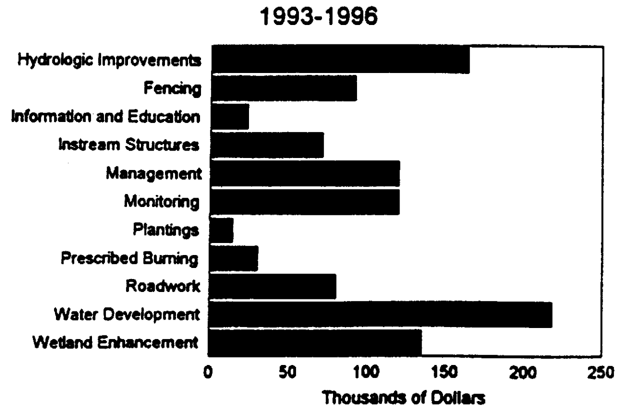


Figure 2. Muddy Creek Expenditures

type of road closures were discussed. Further public participation in travel management is needed.

Open water and brood-rearing habitat has been developed for waterfowl and other wildlife in the meadowlands above and below the George Dew spreader dike. In addition to providing gradient control and enhancing historic irrigation, over 120 new acres of diverse wetland habitats was created. These new dikes were cost-shared by a variety of agencies and organizations, including Ducks Unlimited, Snyder Oil Company, Natural Resources Conservation Service, Bureau of Land Management, and the Little Snake River Conservation District.

This important habitat has been managed for both livestock and wildlife. Forage production averages about 4 tons per acre, enough to save the rancher $100,000 annually in hay costs during the October to February period of use. Livestock grazing is balanced to maintain healthy willow communities for beaver and mule deer habitat while close grazing some grassy areas for spring waterfowl use. During high creek flow in the spring, thousands of migrating ducks and geese layover in the flooded meadows to feed on new plant growth where there is good visual security. Sufficient cover still remains in many areas for waterfowl which decide to nest and raise their young.

The CRM group is working to reintroduce the Colorado River Cutthroat trout which is a Threatened and Endangered Species candidate. Currently it occupies just 1percent of its historical range. Reintroduction and recovery of this species will represent a 32 percent increase in the number of stream miles it inhabits in the Little Snake River Enclave. Through local, voluntary actions like this the CRM group hopes to avoid additional federal mandates.

Trout are the "miner's canary" of the watershed, a biological indicator for success. Healthy riparian systems provide fish habitat in the form of cooler water temperatures, good water quality, over-hanging vegetation and undercut streambanks. Currently, numerous water column parameters are monitored including salts, turbidity, temperature, dissolved oxygen and flow. This monitoring is expensive and time consuming. However, if a healthy trout population is re-established in Muddy Creek then water quality standards would be met.

CONCLUSIONS

The accomplishments described here will hopefully show managers and politicians that although technical expertise is available to solve problems, whether success is achieved is usually dependent on people and their ability to work together. All the natural resources in the watershed have shown improvement since the initiation of the project. Numerous conservation and land management tools have been implemented to restore, enhance, and maintain the abundant natural resources in the area while maintaining the economic stability and cultural heritage of the people on the land. The ecosystem management philosophy has dictated that before any action was taken or activity implemented that all impacts and users of the area were addressed.

The Muddy Creek project is a Wyoming success story with national significance. People with a vested interest in the watershed, came together and agreed on common goals and how to achieve them. These were pro-active people who believed that local problems were best solved by local solutions. The lesson learned from the CRM group is that successful natural resource management requires an investment in people.

THE GEOMORPHOLOGIST'S TOOLBOX: ANALYSIS TOOLS FOR RIVER MANAGEMENT AND RESTORATION

Craig Goodwin[1]

ABSTRACT

During the past several decades, heightened environmental awareness has led to more environmentally sensitive river management and regulation, and in some cases, river restoration. In this paper, I propose a six-step approach for undertaking river management and restoration projects. The six steps are 1) problem identification, 2) goal setting, 3) situation analysis, 4) planning, design, and permitting, 5) project implementation, and 6) monitoring. I suggest that the third step—situation analysis—may be the most critical, since it not only establishes management or design parameters, but also may provide information suggesting reconsideration of project goals. Situation analysis requires an integrated appraisal of watershed conditions at a range of scales. In this paper, I first present some basic geomorphic concepts—including equilibrium, complex response, and the significance of spatial and temporal scale—to illustrate the complexities of natural river systems. I then describe several geomorphic analysis methods for assessing river system condition.

INTRODUCTION

A century ago when Europeans settled Wyoming and the West, they had one goal in mind: to develop the region's water, land, and natural resources to make a better life for themselves and their families. We now realize that many of the well-intentioned activities of our ancestors have had severe environmental consequences. Today, rivers and streams, their adjacent riparian lands, the fauna and flora of these areas, and even mankind may suffer the effects of water project operations, land and resource development activities, and river channelization projects. Rivers are eroding valuable agricultural and riparian lands and destroying civil works; excessive sedimentation has increased water treatment costs and destroyed aquatic habitats; altered streamflows have severely damaged aquatic and riparian ecosystems; and many flood control attempts are failing, as evidenced by flooding in recent years. We have now come to realize that for sustainable human existence and river ecosystem survival, we must become better caretakers of our rivers. Increased scientific knowledge and heightened environmental awareness have led to better and more environmentally sensitive management of river environments, including instream-flow allocation, riparian area preservation, and river restoration. Good tools must be available in order to make sound, scientifically based management decisions. Within this paper I highlight the application of geomorphology for developing solutions for management and restoration of Wyoming's rivers.

Management and restoration approaches to solve existing and prevent future river problems can be summarized in a six-step process: 1) problem identification, 2) goal setting, 3) situation analysis, 4) planning, design, and permitting, 5) project implementation, and 6) monitoring. I suggest that the third step—situation analysis—may be the most critical, for it establishes historic, existing, and potential environmental conditions; provides management and design parameters; and may furnish information recommending reconsideration of project goals. Situation analysis for river problems usually requires an integrated assessment of geomorphic, hydrologic, hydraulic, sedimentologic, and ecological conditions.

FUNDAMENTAL CONCEPTS

Watersheds are geomorphic *systems*—sets of interconnected parts that function together as a whole. Parts of the watershed system include 1) landforms, 2) processes, 3) factors that control forms and processes, and 4) interconnections including matter and energy flows, stores of matter (sediment), cycles, transformations, and feedbacks. Because of the interconnections within a system, a change made to one watershed element may have consequences throughout the watershed system. Thus, subsequent to developing a river management or restoration program, one must thoroughly understand the system. This section presents a brief overview of a few fundamental concepts of geomorphic systems.

SPATIAL AND TEMPORAL SCALE

Geomorphology is the scientific study of landforms— including their development and evolution—using structure, form, process, and time. A factor that distinguishes geomorphology from many other scientific disciplines is that geomorphic systems operate over a wide range of phenomenological scales and virtual velocities (Church 1996). Therefore, analysis of geomorphic systems usually requires that controlling factors, processes, forms, and interconnections be studied at multiple spatial and temporal scales. Temporal and spatial scales are directly related, with small elements changing during short time periods (high virtual velocity) and large elements changing slowly over long time periods (low virtual velocity). For example, very small suspended sediment moves with water at rates of meters per second. Individual river meanders move at rates of meters per decade to meters per century. At a watershed scale, the

[1] Fluvial System Consulting, 1610 East 1185 North, Logan, Utah 84341

drainage network evolves through stream migration at rates of less than meters per 100,000 years. To fully describe a complex geomorphic system like a watershed thus requires analyses over the spatial and temporal scales of the system's elements. Nested within the watershed system in a hierarchical fashion are other geomorphic subsystems including the channel network, river valley segments, hillslopes, river reaches, and individual river forms. It may be possible to define and study a specific component subsystem (a river reach, for example) at a limited range of scales. However, one must ultimately consider the larger order or whole into which the subsystem is integrated and by which its activities are constrained.

At the river reach and segment scales common to river management decision-making and restoration projects, processes occurring from 1 year to 10^3 years must be considered. The effects of past environmental conditions may still be visible and affecting present-day processes and conditions. System disturbances can take many years to manifest, and once manifested, may take many years to recover, so it is not always possible to determine the status of a system from an instantaneous snapshot of the system. For example, sediment derived from a watershed may take thousands of years to travel down a river system as it is deposited and re-eroded from alluvial deposits along the river course. River aggradation at a particular location may thus reflect watershed erosion that occurred many years or even centuries ago. Slugs of sediment were eroded from Wyoming's mountains during Quaternary glaciations that ended about 10,000 years ago. Many rivers now flow over coarse sediments deposited during glacial outwash events, but these rivers are incapable of moving the underlying sediment with their current streamflow regimes.

CONTROLLING FACTORS

For any nested subsystem within a watershed system hierarchy, elements in higher level subsystems provide the independent controlling factors for lower level subsystems. From a river reach scale perspective, independent controls are river valley slope and watershed-derived sediment and water. Watershed climate, geology, soils, land cover and use, and topography control water and sediment production; climate change, land use changes, or water projects that modify water or sediment derived from the watershed will affect downstream river conditions. Interdependent controlling factors are those that occur at the subsystem level, and which typically respond as feedback mechanisms.

EQUILIBRIUM AND THRESHOLDS

Although engineers seek river *stability*, a condition whereby a river neither moves nor adjusts laterally or vertically, rivers are naturally stable only for very short periods of time. Many rivers reach a state of *dynamic* equilibrium, a condition where individual landscape features are non-permanent, but the overall appearance may seem to be constant. In other words, a river maintains fairly constant sinuosity, slope, and channel form, but wanders about its floodplain. Two non-equilibrium states are river aggradation and degradation, which occur when sediment transported into and out of a reach do not balance. A state of equilibrium may be reached when controlling watershed factors remain stable for some extended period of time. However, in some river systems, an equilibrium state may never be attained, and for still other rivers, multiple equilibrium states may be possible. River restoration is usually based upon the assumption that an equilibrium condition can be reinstated. Because this assumption may be invalid, restoration projects can fail if located where equilibrium is not an achievable condition.

COMPLEX RESPONSES

Watersheds and their rivers are nonlinear systems that operate in diverse and complex manners. Schumm (1973) presents one example of watershed complexity that he terms *complex response*. Due to complex response, thresholds, and the vagaries of reaction and relaxation times, different parts of a watershed may be in various stages of disequilibrium. Thus, different parts of the watershed system may be out of phase with each other, with degradation occurring in some places and aggradation in others. Structural river restoration methods used to treat a degrading reach could, for example, prove foolhardy as aggradation later begins when a sediment wave traverses the reach. Because of complex watershed responses, a complete situation analysis must examine much more than just the isolated stretch of river involving the project.

GEOMORPHOLOGICAL TOOLS

This section provides an overview of the types of tools used in fluvial geomorphic analysis. Only a few of the more basic tools are discussed herein.

OBSERVATION

Observation has and continues to play an important role in the environmental sciences. Unlike chemistry or physics, laboratory experiments with controlled conditions and replication generally can not be conducted for complex natural systems. In the real world, the river environment is the experiment, and, as with any experiment, careful observation and measurements are required to evaluate experimental outcomes. As I noted above, the fluvial system operates over a wide range of spatial and temporal scales. To effectively evaluate a system, its forms and processes must be observed over the scales at which they occur (Bloschl and Sivapalan 1995). For river management and restoration analyses, this typically means observing at reach, channel segment, channel network and watershed spatial scales. Longer temporal processes are observed using historical analysis methods discussed later. The outcomes of observation are data, descriptions, and maps.

CLASSIFICATION AND COMPARISON

Geomorphology has a long history of condensing river diversity into a few succinct categories to provide a basis for comparing and unifying the wide range of river types. Melton (1936), Leopold and Wolman (1957), Kellerhals et al. (1976), Rosgen (1994) and many others have developed classification systems based upon morphological characteristics of rivers. Other investigators have created process-based river classification systems incorporating channel stability and mode of sediment transport (Schumm 1971); differential rates of channel and interchannel sediment accumulation (Woolfe and Balzary 1996); processes of specific environments such as mountainous environments (Whiting and Bradley 1993); or based upon energy or power parameters (Nanson and Croke 1992).

Classification is often an early component of a fluvial geomorphic analysis. Process-based classification schemes are perhaps the most useful types for river management and restoration purposes, for understanding sediment processes in a river is essential to river maintenance. Classifications are, however, of limited usefulness for they are merely arbitrary constructs devised to simplify the analysis of complex systems for some particular purpose. Also, useful information is lost when the many characteristics of a unique river are reduced to a class descriptor. As Richards (1996) notes, "rivers are diverse and spatially variable, but our appreciation of this appears to have diminished over the years" and the tendency "has been to emphasize, and even create, similarity among rivers." Classification is a useful tool for the toolbox, but like all tools, should be used judiciously.

QUANTITATIVE METHODS

A wide variety of methods that are more quantitative than observation and classification are available for analyzing a river's morphologic, hydraulic, and sedimentologic conditions. Many methods utilize equations that are partially or fully based upon empirical data, for geomorphic theory can not completely explain many river phenomena. Unfortunately, simple empirical relationships tell us nothing about *why* a certain situation occurs; the cause of the situation may only be inferred. Also, typical empirical geomorphic relationships often show order-of-magnitude ranges with regression lines traversing clouds of data points. Until more theoretically based methods are developed, empirical methods will be a necessity. Three specific quantitative methods are presented here.

Hydraulic geometry. Hydraulic geometry concerns the variation of channel cross section variables (width, depth, area) with discharge, and may be evaluated both at-a-station and in a downstream direction (Leopold and Maddock 1953). Evaluation of hydraulic geometry relations along a river may provide evidence of channel stability or instability (Williams 1987).

Channel pattern analysis. One parameter used for characterizing channel pattern is sinuosity, a dimensionless parameter defined as channel length divided by valley length. Several factors control sinuosity, including valley slope, character of the sediment load, and the nature of bank sediment and vegetation. Plotting channel sinuosity versus distance up the river valley can be useful in identifying non-equilibrium reaches. Sinuosity relationships, particularly with respect to channel stability, have been discussed by Williams (1986), Simon (1995), and van den Berg (1995).

Threshold analysis. Determining when a threshold condition resulting in significant river change will be reached is an essential, but difficult, geomorphic analysis. Valley reaches where the river may be subject to instability and frequent threshold crossings are often steeper or narrower than the average for the river. Schumm (1973) and Magilligan (1992) illustrate how river network spatial variability may lead to threshold producing conditions.

HISTORICAL ANALYSIS

Historical analysis of river channel changes may provide insight into the current state of the system. Aerial photography can frequently be used to track changes during the past 40 to 50 years. Prior to that time, historical maps may be used to derive earlier channel and riparian zone topography. Site photography can be sought from archival sources to provide photographic comparisons with existing conditions. Land survey records in the West can be used to establish pre-settlement riparian characteristics (Galatowitsch 1990). The historical flow record should be analyzed to see if trends, jumps, or extreme events may have influenced historical channel changes. If streamflow records are unavailable for a given location, they may be estimated from regional flow records, or flood descriptions can be sought from newspapers and other historic sources. Geologic methods (Miall 1996) can be used to examine and interpret valley floor deposits and to reconstruct the depositional and erosional history of the valley floor. Valley floor vegetation ages and distribution may also prove useful in reconstructing river history (Hupp and Osterkamp 1996).

GEOMORPHOLOGICAL MODELING

Models are generally used for their predictive ability, but they may also be used to provide a mechanism to test explanations regarding physical processes and forms (Beven 1989; Kirkby 1996). Models may be either quantitative or qualitative. Qualitative models are quite useful in geomorphology as they can incorporate complexities and multiple possible explanations of outcomes, which can not be incorporated into the mathematical descriptions (Beven 1996). Current models of geomorphological systems are quite limited in their capabilities for a variety of reasons, including limited theoretical knowledge of the processes of complex dynamical systems, time- and space-scale observation constraints, unknown or unknowable boundary conditions, and process behaviors that are chaotic or exhibit deterministic uncertainty (Church 1996; Beven 1996; Phillips 1996). However, models may provide a framework for better assessing and understanding fluvial processes, which in turn will provide a foundation for management and restoration success.

SUMMARY

This paper has presented a few fundamental concepts and tools that a geomorphologist might use when analyzing a river problem. Probably the most distinctive aspect of the geomorphologist's approach to investigating a river is to view it over a much wider range of spatial and temporal scales than do other scientific or engineering disciplines. Geomorphologists recognize rivers and streams as integral components or subsystems of watersheds, which are complex geomorphic, water- and sediment-generating systems composed of landforms and processes that encompass flows, stores, transformations, cycles, thresholds, feedbacks, and complex responses to external forcing and intra-watershed processes. Fluvial geomorphology is not a panacea for all river management problems, but it does offer the only currently viable approach for making predictions about human impacts to alluvial rivers and streams (Brookes 1995). Geomorphological approaches should therefore be considered when addressing the environmental and engineering problems of Wyoming's rivers and streams.

REFERENCES

Beven, K., 1989, Changing ideas in hydrology - the case of physically-based models. *Journal of Hydrology* 105:157-172.

Beven, K., 1996, Equifinality and uncertainty in geomorphological modeling. In: Rhoads, B.L., and Thorn, C.E., The Scientific Nature of Geomorphology, Wiley, Chichester, pp.289-313.

Bloschl, G. and Sivapalan, M., 1995, Scale issues in hydrological modeling: a review. In: Kalma, J.D., and Sivapalan, M. (editors), Scale Issues in Hydrological Modeling, Wiley, Chichester, pp. 311-330.

Brookes, A., 1995, Challenges and objectives for geomorphology in U.K. river management. *Earth Surface Processes and Landforms* 20:593-610.

Church, M., 1996, Space, time and the mountain - how do we order what we see? In: Rhoads, B.L., and Thorn, C.E., The Scientific Nature of Geomorphology, Wiley, Chichester, pp.148-170.

Hupp, C.R., and Osterkamp, W.R., 1996, Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14:277-295.

Galatowitsch, S.M., 1990, Using the original land survey notes to reconstruct presettlement landscapes in the American West. *Great Basin Naturalist* 50:181-191.

Kellerhals, R., Church, M., and Bray, D.I., 1976, Classification and analysis of river processes. *Journal of the Hydraulics Division, American Society of Civil Engineers* 102:813-829.

Kirkby, M.J., 1996, A role for theoretical models in geomorphology? In: Rhoads, B.L., and Thorn, C.E., The Scientific Nature of Geomorphology, Wiley, Chichester, pp. 257-272.

Leopold, L.B., and Maddock, T., 1953, The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey Professional Paper 252, 57 p.

Leopold, L.B., and Wolman, M. G., 1957, River channel patterns: braided, meandering and straight. U.S. Geological Survey Professional Paper 282-B, 85 p.

Magilligan, F.J., 1992, Thresholds and the spatial variability of flood power during extreme floods. *Geomorphology* 5:373-390.

Melton, F.A., 1936, An empirical classification of floodplain streams. *Geographical Review* 26:593-609.

Miall, A.D., 1996, The geology of fluvial deposits. Springer-Verlag, Berlin, 582 p.

Nanson, G.C., and Croke, J.C., 1992, A genetic classification of river floodplains. *Geomorphology* 4:459-486.

Phillips, J., 1996, Deterministic complexity, explanation, and predictability in geomorphic systems. In: Rhoads, B. L., and Thorn, C. E., The Scientific Nature of Geomorphology, John Wiley and Sons, Chichester, pp. 315-335.

Richards, K., 1996, Samples and cases: generalization and extrapolation in geomorphology. In: Rhoads, B.L., and Thorn, C.E., The Scientific Nature of Geomorphology, Wiley, Chichester, pp. 171-190.

Rosgen, D.L., 1994, A classification of natural rivers. *Catena* 22:169-199.

Schumm, S.A., 1971, Fluvial geomorphology: the historical perspective. In: Shen, H. W. (editor), River Mechanics, pp. 4-1 to 4-30.

Schumm, S.A., 1973, Geomorphic thresholds and complex response of drainage systems. In: Morisawa, M. (editor), Fluvial Geomorphology Symposium: Binghamton, State University of New York, Publications in Geomorphology, p. 299-310.

Simon, A., 1995, Adjustment and recovery of unstable alluvial channels: identification and approaches for engineering management. *Earth Surface Processes and Landforms* 20:611-628.

van den Berg, J.H., 1995, Prediction of alluvial channel pattern of perennial rivers. *Geomorphology* 12:257-279.

Whiting, P.J., and Bradley, J.B., 1993. A process-based classification system for headwater streams. Earth Surface *Processes and Landforms* 18:603-612.

Williams, G.P. 1986. River meanders and channel size. *Journal of Hydrology* 88:147-164.

Williams, G.P., 1987, Unit hydraulic geometry - an indicator of channel changes. U.S. Geological Survey Water Supply Paper 2330, pp. 77-89.

Woolfe, K.J., and Balzary, J.R., Fields in the spectrum of channel style. *Sedimentology* 43:797-805.

SESSION 2:

GIS APPLICATIONS IN WATER MANAGEMENT

USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO AID IMPLEMENTATION OF CONSERVATION STRATEGIES FOR NATIVE FISH

R. Nick Schmal, J.W. Newton and Thomas W. Kohley[1]

Land managers are seeking an integrated perspective that effectively deals with environmental problems related to aquatic ecosystems. Until recently, analytical tools were not readily available that suited the temporal or spatial scale necessary to address conservation of native fish. Geographic Information Systems (GIS) provide the electronic environment necessary to manipulate physical, chemical, and biological information about aquatic species at risk. Furthermore, a GIS can provide a useful tool for developing applications that support complex natural resource management decisions at the regional level. The objective of this paper is to demonstrate how a GIS can aid implementation of conservation strategies that address regional concerns related to viability of native fish populations. The native trout recovery efforts that exist in the interior west often contain different conservation goals. We will demonstrate how a GIS application can be used to assess extinction risks using information from a conservation status report (Young et al. 1996) for the Colorado River cutthroat trout (*Oncorhynchus clarki pleuriticus*). Finally, we will suggest that our procedures could be a framework for agencies and interested groups to use when developing new conservation strategies.

Imperilment of our freshwater biota is an important warning of how inadequately we are acting as stewards of river systems and the landscapes they drain (Allan and Flecker 1993). Langner and Flather (1994) suggest that changes occurring in the distribution and abundance of native diversity in the past 300 years are likely to continue declining due to human population growth and associated development. Consequently, state and federal natural resource management agencies must work together with external stakeholders and landowners to ensure the persistence of native inland trout. Recreational fishing contributes to losses but overall declines of native trout can largely be attributed to habitat loss and introduction of non-native species into aquatic systems (Williams et al. 1989; Behnke, 1992; Young 1995). In Wyoming, Baxter and Stone (1995) list 76 fish species believed to have viable populations, of which 49 are native and 27 introduced.

[1] Rocky Mountain Region Fish Habitat Relationships Unit, USDA Forest Service, Laramie, WY; Department of Rangeland Ecology and Watershed Management, UW; and Wyoming Water Resources Center, UW, Laramie, Wyoming 82071

Recovery plans for threatened or endangered trout species in the interior west contain a wide variety of goals and objectives. For example, a recovery plan for Lahontan cutthroat trout (*O. clarki henshawi*) recommends that three metapopulations be established in the native trout=s historic range. (Coffin and Cowan 1995). A metapopulation, according to Burgman et al. (1993), is a set of populations of the same species. A single population is a collection of individuals that are sufficiently close geographically that they can find each other and reproduce. Metapopulations are usually more or less isolated from one another in discrete patches of spatially separate habitat, that may exchange individuals through migration.

Alternatively, a draft recovery plan for greenback cutthroat trout (*O. clarki stomias*) suggests that recovery would be reached when 20 stable populations are developed in portions of the headwaters in the South Platte drainage, and another 20 in the Arkansas River drainage in Colorado. Range expansion efforts purposely avoid conflicts with water development projects and downstream private land entities in the greenback plan. But the Lahontan plan includes participation by stakeholders and private landowners. Greenback trout are often stocked in high elevation headwater streams and/or alpine lakes. Viability is questionable when target recovery populations are managed in isolated stream fragments and seepage lakes. Greenback recovery efforts do not use similar conservation biology principles that characterize the Lahontan plan. GIS might provide insight into viability questions for the greenback recovery efforts. A multi-agency effort is currently underway in Colorado to evaluate these kinds of issues using a GIS as the primary data clearinghouse. Combinations of site-specific stream habitat and watershed scale attributes are being incorporated into the system (Harig 1996).

Regardless of the differences in biological criteria contained in various recovery plans, or management plan priorities, a GIS can aid developing and monitoring consistent strategies for native trout conservation. We suggest that agencies use a GIS for evaluating broad-geographic scale (regional) characteristics of Colorado River cutthroat trout populations, such as replication and synchrony (Rieman et al. 1993). This is a change from traditional management since, local, or more site-specific projects, are usually developed prior to conducting broad-scale assessments. For example, regional synchrony relates to the proximity of remnant populations and how these populations can fluctuate together due to environmental variation. Recovery of threatened or endangered species would depend on creating a geographically well-distributed series of viable populations or metapopulations in a regional context. Asynchronous population patterns are desirable to

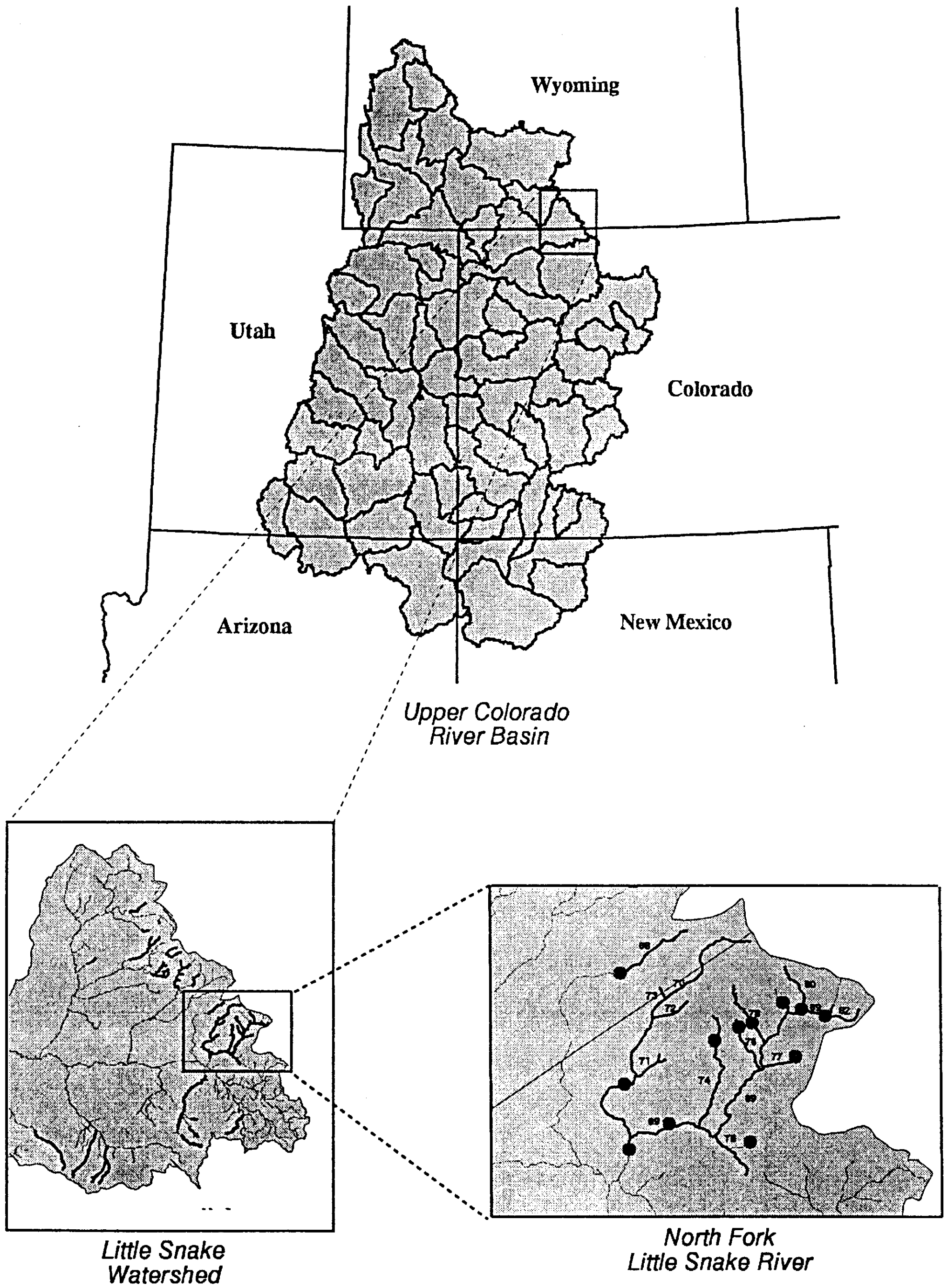


Figure 1. Hierarchy of watersheds that can be analyzed using GIS for Colorado River cutthroat trout range expansion priorities.

maintain viability. To achieve this goal, a GIS could perform a nearest neighbor or proximity analysis to spatially locate the remnant populations within watersheds. If we assume that a watershed such as the Little Snake River is the appropriate size to manage for a metapopulation, then outputs from a GIS analysis would be used at that scale to evaluate range expansion priorities against environmental events related to synchrony (Figure 1). Depending on the population locations within each subregion watershed, managers would evaluate viability risks based on flood and drought analysis, wildfire, and spread of disease (related to number and densities of road crossings) by human activities. Introduction of non-native trout by humans is another risk to be considered.

Each subregion watershed could have a viability analysis performed on remnant populations. And, each watershed (potential metapopulation) would have its own set of priorities and conservation opportunities based on ranking of current and anticipated landscape conditions, locations, size, and juxtaposition of remnant Colorado River cutthroat trout populations. The regional summary of these analyses would then be compared to various probabilities of extinction threats. Watersheds with lower risks to extinction from random environmental events would be managed as a higher priority across the three state geographic range. Participation by landowners and organizations would be critical for this type of management policy to be accepted, since not all potential opportunities for range expansion occur on public lands.

Before this type of broad-scale information is integrated into a strategy, there must be an acceptance of involvement of people from local to federal levels. The GIS provides a view of data and information in a way not currently used in management of native trout. In the case of recovery of bull trout (*Salvilinus confluentus*), an argument was made for a stronger state role in management of threatened or endangered species (Schilwachter 1996). If states do assume a greater role, then alternative planning processes that include diverse stakeholders (e.g., private individuals) will be a necessity. Regardless of how the human dimensions of native species management evolves, understanding the ecology of large spatial scales over longer time periods (IETF 1995) will be an integral component of sustaining Colorado River cutthroat trout for future generations. GIS can play an important technical role in the efforts.

REFERENCES

Allan, J.D. and A.S. Flecker. 1993. Biodiversity conservation in running waters. *BioScience* 43;32-43.

Baxter, G.T. and M.D. Stone. 1995. Fishes of Wyoming. Wyoming Game and Fish Department. Cheyenne, Wyoming. 290p.

Behnke, R.J. 1992. Native trout of western North America. American Fisheries Society. Monograph 6. Bethesda, Maryland.

Burgman, M.A., S.Ferson, and H.R. Akcakaya. 1993. Risk assessment in conservation biology. Chapman and Hall London, England.

Coffin, P.D. and W.F. Cowan. 1995. Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) recovery plan. U.S. Fish and Wildlife Service. Region 1. Portland, Oregon. 108p. +Appendices.

Harig, A.L. 1996. Characterizing cutthroat trout habitat with a geographic information system. Unpublished manuscript. Colorado State University, Department of Fishery and Wildlife Biology. 24p. + Appendices.

Interagency Ecosystem Management Task Force. 1995. The ecosystem approach: healthy ecosystems and sustainable economies. Volume II-Implementation Issues. NTIS. Springfield, Virginia. 137p.

Langner, L.L. and C.H. Flather. 1994. Biological diversity: status and trends in the United States. USDA-Forest Service. Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-244. Fort Collins, Colorado.

Rieman, B.D., D.C. Lee, J.D. McIntyre, K. Overton and R. Thurow. 1993. Consideration of extinction risks for salmonids. USDA-Forest Service. Fish HabitatRelationships Technical Bulletin 14. Eureka, California.

Schildwachter, G.T.M. 1996. State action to conserve endangered species: Bull trout restoration. *In* K.G. Wadsworth and R.E. McCabe, editors. Facing realities in Resource Management. Transactions 61st North American Wildlife and Natural Resources Conference. Wildlife Management Institute, Washington, D.C.

U.S. Fish and Wildlife Service. 1993. Draft greenback cutthroat trout (*Oncorhynchus clarki stomias*) recovery plan. Prepared by the Greenback cutthroat trout recovery team. U.S. Fish and Wildlife Service. Region 6. Denver, Colorado. 68p.

Williams, J.E., J.E. Johnson, D.A. Hendrickson, S. Contreras- Balderas, J.D. Williams, M. Navarro-Mendosa, D.E. McAllister, and J.E. Deacon. 1989. Fishes of North America endangered, threatened, or species of special concern: 1989. Fisheries 14(6):2-20.

Young, M.A. 1995. Conservation assessment for inland cutthroat trout. General Technical Report RM-GTR-256. USDA-Forest Service. Rocky Mountain Forest and Range Experiment Station.Fort Collins, Colorado.

Young, M.K., R.N. Schmal, T.W. Kohley and V.G. Leonard. 1996. Conservation status of the Colorado River cutthroat trout. General Technical Report RM-GTR-282. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station,Fort Collins, Colorado.

INTEGRATING GEOGRAPHIC INFORMATION SYTEMS (GIS) TECHNOLOGY INTO GROUNDWATER AND SURFACE-WATER MODELING ASSOCIATED WITH WYOMING'S CUMULATIVE HYDROLOGIC IMPACT ASSESSMENT

James R. Oakleaf and Jeffrey D. Hamerlinck[1]

ABSTRACT

The coal-permitting process places heavy demands on both permit applicants and regulatory authorities with respect to the management and analysis of hydrologic data. Currently, this correlation is being addressed for the Powder River Basin, Wyoming by the ongoing Cumulative Hydrologic Impact Assessment (CHIA) efforts at the University of Wyoming. One critical component of the CHIA is the use of a Geographic Information System (GIS) for support, management, manipulation, pre-analysis, and display of data associated with the chosen groundwater and surface water models. This paper will discuss the methodology in using of GIS technology as an integrated tool with the MODFLOW and HEC-1 hydrologic models. Pre-existing GIS links associated with these two models served as a foundation for this effort. However, due to established standards and site specific factors, substantial modifications were performed on existing tools to obtain adequate results. The groundwater-modeling effort required the use of a refined grid in which cell sizes varied based on the relative locations of ongoing mining activities. Surface water modeling was performed in a semi-arid region with very limited topographic relief and predominantly ephemeral stream channels. These were substantial issues that presented challenges for effective GIS/model integration.

INTRODUCTION

The coal-permitting process places heavy demands on both permit applicants and regulatory authorities with respect to the management and analysis of hydrologic data. Currently, this correlation is being addressed for the Powder River Basin, Wyoming by the ongoing efforts to develop a Cumulative Hydrologic Impact Assessment (CHIA) at the University of Wyoming. One critical component of the CHIA is the use of a Geographic Information System (GIS) for support, management, manipulation, pre-analysis, and display of data associated with the chosen groundwater and surface-water models. This paper will discuss the methodology in using of GIS technology in the CHIA modeling process.

BACKGROUND

CUMULATIVE HYDROLOGIC IMPACT ASSESSMENT

Surface coal-mining activities result in modifications to the natural landscape that have or will potentially impact surface and groundwater resources. Through employment of proper reclamation techniques, the hydrologic impacts of individual surface coal-mining operations can be significantly minimized. However, postmining or residual impacts, though individually insignificant, may, with development of additional mines, accumulate to magnitudes that are potentially damaging to the hydrologic balance of the area (OSM, 1985).

The requirements for obtaining a permit to conduct coal mining under the federal Surface Mining Control and Reclamation Act of 1977 (SMCRA) contain provisions for mitigating adverse cumulative impacts, focusing on the collection, analysis, interpretation and application of "baseline" hydrologic information. Specifically, permitting requirements call for the development of hydrologic predictions by both the applicant and the regulatory authority, in order to provide a means by which: 1) water resources are characterized; 2) potential impacts are identified; 3) appropriate mitigation or prevention of those impacts is achieved; and 4) verification of results is obtained, thus ensuring that mine sites are reclaimed as productive postmining areas (OSM, 1991).

In conjunction with the permit applicant's Probable Hydrologic Consequences (PHC) determination, regulatory authorities are required, before issuing a permit to conduct surface coal mining and reclamation, to complete a CHIA of all anticipated mining in the area to assure that the proposed operation has been designed to prevent material damage to the hydrologic balance outside the permit area (OSM, 1985).

The CHIA process involves completion of six major steps: 1) define the area to be studied, known as the cumulative impact area or CIA; 2) describe the hydrologic system and determine baseline hydrologic-resource values; 3) identify hydrologic resources likely to be affected; 4) develop standards for determining impacts; 5) estimate the impacts of mining on the hydrologic resources; and 6) make a material damage determination and prepare a statement of findings (OSM, 1985). In Wyoming, SMCRA provisions for a surface-mining permit and associated CHIA requirements are promulgated under the Wyoming Environmental Quality Act. As a primacy state, this regulatory authority is administered by the Department of Environmental Quality, Land Quality Division (DEQ/LQD).

[1] Wyoming Water Resources Center, UW, Laramie, WY 82071

THE WYOMING INITIATIVE[2]

> The hydrology provision for permitting has been among the least understood requirements under SMCRA... Because the hydrologic issues which arise are tied to the environment in which the operation is to be permitted, and because there are differing types of operations and differing environments each with its own set of potential impacts, it is impossible to develop a standard methodology which would satisfy all possible situations, (OSM, 1991, p. 1).

A comprehensive understanding of regulatory requirements specific to CHIA has been hampered in part by difficulties encountered in transferring and adapting successful methodologies between permit environments (OSM, 1991). The results of the last basin-wide CHIA carried out for Wyoming's Powder River Coal Region identified a need to establish coordinated and efficient methods for collecting, storing, accessing, manipulating and analyzing data required for carrying out future hydrologic impact assessments (Martin, et al., 1988).

In 1992, in partial response to the data management needs identified above, the Office of Surface Mining (OSM) launched the Wyoming Initiative, a program focusing on three major arenas within the coal-mine permitting and reclamation process. These arenas include: 1) development of a revised, dynamic CHIA process; 2) electronic permitting facilitation; and 3) transfer of OSM's Technical Information Processing System capabilities to regulatory authorities and permitees through a comprehensive training program. Critical to each of these efforts is the need for establishing a framework for hydrologic data exchange, access and sharing, and associated scientific applications related to Wyoming's surface and groundwater resources in the context of surface mining activities across the state.

GIS, HYDROLOGY AND MINE LAND RECLAMATION

GIS and Hydrologic Modeling. The use of computers in hydrologic analysis has become increasingly widespread among hydrologists and modelers alike. Because hydrology is linked in so many ways to processes at the earth's surface, the connection to such sophisticated computer-based technologies as geographic information systems (GIS) is a predictable step in the evolution of hydrologic analysis (De Vantier, et al., 1993).

[2] The Wyoming Initiative was established through a state/federal interagency cooperative agreement involving the USDI Office of Surface Mining and Bureau of Land Management, the Wyoming Department of Environmental Quality, the Wyoming State Engineer's Office, the Wyoming State Geological Survey, and the University of Wyoming (Cooperative Agreement No. DOI-OSM-BLM; WY DEQ; WY SEO; UW-93-1, 1993).

Simply defined GIS is a computer-based information technology which stores, analyzes, and displays both spatial and non-spatial data (Parker, 1988; Maguire, 1991). In the last 20 years, GIS technology has been increasingly applied to a wide range of water-resource-related studies (Males and Grayman, 1992). Specifically, "..hydrologic applications of GIS have ranged from synthesis and characterization of hydrologic tendencies to prediction of response to hydrologic events, " (DeVantier, et al., pg. 247).

Maidment (1993) provides the following interpretation of the relationship between GIS technology and hydrologic modeling:

> GIS provides representations of the spatial features of the Earth, while hydrologic modeling is concerned with the flow of water and its constituents over the land surface and in the subsurface environment... Hydrologic modeling has been successful in dealing with time variation, ...but spatial disaggregation of ...study area[s] has [traditionally] been relatively simple. In many cases, hydrologic models assume uniform spatial properties or allow for small numbers of spatial subunits within which properties are uniform. GIS offers the potential to increase the degree of definition of spatial subunits, in number and in descriptive detail... (Maidment, 1993, page 147).

GIS-hydrologic-model integration may be grouped into four major categories: 1) hydrologic assessment; 2) hydrologic parameter determination; 3) hydrologic modeling inside GIS and linking GIS; and 4) hydrologic models. Of these categories, hydrologic parameter determination and GIS-hydrologic model linking are currently the primary focus of ongoing research nationwide (Maidment, 1993). Relative to GIS-modeling linking, numerous example may be identified in the current literature which illustrate the development of applications linking GIS to both surface-water (Yoon, et.al., 1993; Sasowsky, et al., 1991) and groundwater hydrology models (Hinaman, 1993; El-Kadi, et.al., 1994).

The advantage of integrating GIS into the hydrologic modeling process, is in its ability to relate different data sets through the common denominator of location. GIS links data sets and analyzes them as a unit within one integrated system, making it an excellent tool for managing the modeling process, analyzing the results, and updating and archiving spatially-referenced data sets (Richards, et al., 1993).

GIS and Mine Reclamation. The use of GIS in the management of mining activities and mine reclamation is a new and growing application of the technology. Specific examples of recent work related to coal mine reclamation include development of GIS-based statistical methods for conducting coal availability studies (Watson and Bryant, 1993), spatial predictive modeling of mine subsidence risk (Hao and Chugh, 1993), and restoration of polluted streams and watersheds stemming from acid mine drainage associated with abandoned coal mines (USEPA and OSM, 1996). GIS has also been incorporated into the Office of Surface Mining's Technical Information Processing System (OSM, 1991), which is utilized in many state Regulatory Authority offices for tracking permit compliance, etc.

GIS and Wyoming's CHIA Modeling Process. A logical merging of technologic applications can be realized when incorporating GIS into the cumulative hydrologic impact assessment process. This paper outlines the utilization of GIS in the modeling process developed for conducting CHIAs in the Powder River Basin of northeastern Wyoming. The following sections focus on the methods applied in the use of GIS to develop, manipulate, and display model inputs and outputs.

METHODS

The GIS utilized in this study was ARC/INFO® GIS, a relational, arc-node vector/raster-based system running in a UNIX® operating system environment. Application development was carried out using ARC/INFO's Arc Macro Language (AML). This language is an interpreted language modeled after Prime Computer, Inc.'s Command Procedure Language (CPL) and provides programming capabilities and a set of tools for tailoring the user interface of ARC/INFO applications. These specific products were selected based on compatibility with other cooperating parties and pre-existing expertise with the software.[3]

Surface water modeling was performed using HEC-1 and generally required data layer overlays and querying of the GIS database. HEC-1 is a lumped parameter, rainfall-runoff and flood-prediction model developed by the United Sates Army Corps of Engineers (Peacock, et al., 1996). Groundwater modeling employed the United States Geological Survey's Modular Three Dimensional Finite Difference Groundwater Flow Model (MODFLOW; McDonald and Harbaugh, 1988) and directly used manipulated GIS data layers as inputs in the modeling process.

STUDY AREA AND NEEDS ASSESSMENT

All hydrologic models require the input of data, and, regardless of what is being modeled, there are certain factors that must be considered before gathering these data. First, the study area must be defined; subsequently needs specific to the models are assessed. Once these items have been addressed, development of the data can begin.

Study Area. Due to modeling efforts being directed towards both groundwater and surface water, two separate CIA study areas were developed for the Little Thunder Creek CHIA. The study area boundaries related to the hydrologic regimes for surface water (defined by Little Thunder Creek watershed), and groundwater (defined by geological lineaments, faults, and folds). Three coal mines (Jacob's Ranch, Black Thunder, and North Rochelle) located within the study area were the focus of modeling efforts.

For the surface-water modeling, the 250 mi^2 watershed of Little Thunder Creek established the study area in question. This watershed is located in Southeast corner of Campbell County and is a tributary of the Cheyenne River Drainage Basin (Figure 1). On the groundwater modeling side, a grid centered over the three mines (angled north-northwest) constituted the two-dimensional spatial extent of the study area (Figure 1). This grid covered 790 mi^2 and encompasses not only the three mines, but also a portion of the coalbed methane wells found in the region and four additional coal mines (Peacock et al., 1996).

Needs Assessment. Once the study areas had been defined, it was necessary to determine what spatially- referenced data were required. Through careful collaboration among modelers and GIS analysts involved with the pilot CHIA process, 18 GIS data layers were initially identified for development. These layers could be classified by feature type (point, line, or polygon), spatial application (groundwater aquifer system or surface hydrology watershed, or both), and functionality (modeling or cartographic reference). Table 1 provides a brief outline of the type of data layers developed, the feature type, the spatial extent, and the use of each.

GIS DEVELOPMENT

Once the study areas had been defined and the initial data requirements established, the next objective was to develop the GIS layers. Five steps were identified for the development and manipulation of each GIS data layer required in the modeling process: 1) data acquisition; 2) data automation; 3) database design and construction; 4) quality control; and 5) metadata. For the CHIA pilot study, data acquisition required the most time, followed closely by database design and construction (Figure 2).

[3] The remainder of the text will make reference to ARC/INFO GIS specific commands and functions in *ITALIC CAPS*

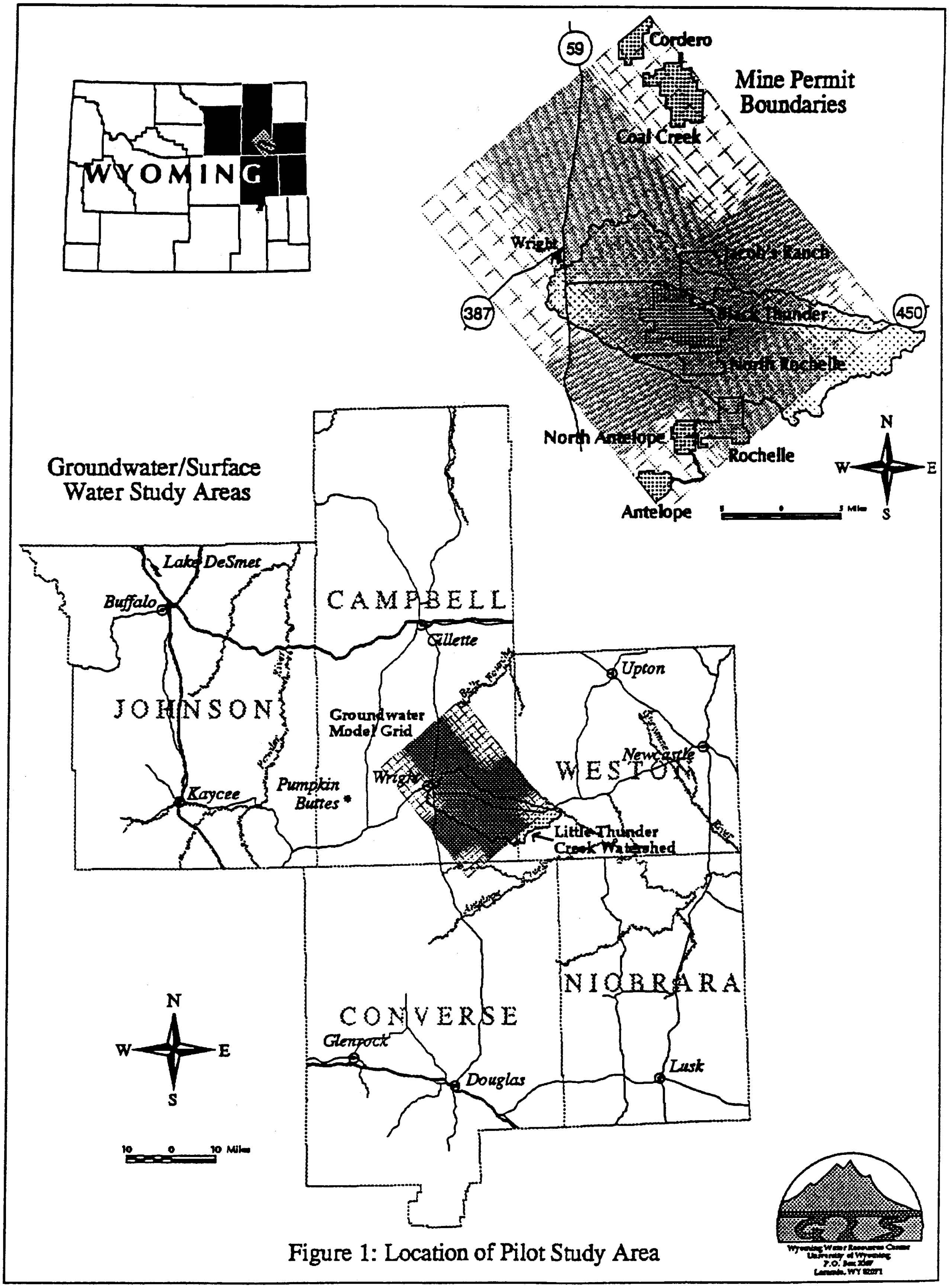


Figure 1: Location of Pilot Study Area

Table 1: GIS data layers for pilot CHIA.

Data Layer	Feature Type	Spatial Extent	Use
Surface Water Flow Stations	point	surface water	modeling
Climate Stations	point	surface water	modeling
Surficial Hydrography	line/polygon	surface water	modeling
Vegetation	polygon	surface water	modeling
Soils	polygon	surface water	modeling
Surficial Geology	polygon	surface water	modeling
Bedrock Geology	polygon	both	modeling
Coal Faults and Folds	line	groundwater	modeling
Coal Isopach	point/polygon	groundwater	modeling
Coal Burnline	line	groundwater	modeling
Clinker	polygon	both	modeling
Monitoring Wells	point	groundwater	modeling
Mining Sequence	polygon	both	modeling
Surface Water Rights	polygon/point	surface water	modeling
Ground Water Rights	point	groundwater	modeling
Digital Elevation Models	point/polygon	both	modeling
Public Land Survey System	polygon	both	cartographic
Transportation	line	both	cartographic

Data Acquisition. Data for the CHIA could be classified as digital or analog and was provided by an assortment of state and federal agencies in a variety of scales and formats. Some of the more common forms, other than Arc/Info, were paper and mylar maps, AutoCad data exchange files, and database and ASCII files. Additionally, some mining operations provided large scale, mine-specific data that were also incorporated into the modeling process.

Data Layer Automation and Management. This is the process of converting data from its existing source format to a digital, spatially-referenced GIS layer while maintaining each data layer in the same projection and units. Different techniques were employed to create the 18 GIS data layers and depended directly on the original format of the data. Hardcopy maps were either digitized or scanned. AutoCad files and dBase tables were directly converted into ARC/INFO through the *DXFARC* and *DBASEINFO* commands respectively. ASCII text files were manipulated and formatted by AWK (UNIX based pattern scanning and processing language) scripts allowing for the *GENERATE* command to be applied. These techniques were the most common methods of data automation throughout the pilot study. Many additional steps accompany these commands and by no means were these the only methods applied; however, such a detailed discussion of data automation is beyond the scope of this paper. Table 2 list these data layers displaying the scale, the source, and briefly explains the conversion technique employed for each layer.

Once data are converted into their respective GIS data layers, the layers must be projected into a common coordinate system allowing for data

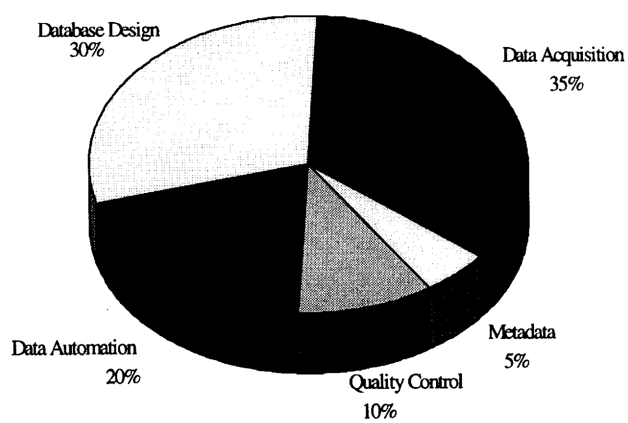


Figure 2. GIS data layer development, percentage of time required per step.

compatibility in the modeling process. For the CHIA pilot study, all the data layers were projected to a state plane coordinate system in reference to the Wyoming, East Zone. This coordinate system uses a Lambert projection and measures units in feet, consistent with the units employed in the surface and groundwater models (inches, feet, cfs, acre-feet, etc.).

Database Design and Construction. Creating a sound structure in which modelers can access and use the data layers becomes essential even with only 18 layers. First, the layers were divided by application-dependent areal extent for groundwater and surface water. Then each layer was placed under a thematic directory. For example, both monitoring and agricultural/stock wells were placed under a wells subdirectory of the groundwater directory. This allows for a logical and systematic approach to organizing the data.

In addition to the overall data structure, each individual data layer could have numerous attribute fields associated with each depicted feature. These attributes could be either directly tied to the data layer or indirectly accessed through relational files. For ease of use by modelers, most data layers, with a few exceptions, did not have an associated relational database structure.

Quality Control. With any modeling, a degree of data quality assurance is necessary to provide defensible results. For the GIS data layers, both spatial feature completeness and location were examined, as well as the accuracy of associated attributes. This was accomplished, in many cases, by producing a map of the data layer and comparing it to the original. This allowed for missing and/or mislabeled features to be identified and corrected. In cases where comparable maps were not available, the source data were directly compared with its GIS counterpart. Spatial accuracy of all the data layers followed the US National Map Accuracy Standards (U.S. Bureau of the Budget, 1941).

Table 2: GIS data layers' scale, source, & automation method

Data Layer	Scale	Source	Conversion Technique.
Surface Water Flow Stations	n/a	WWRC	DBASEINFO
Climate Stations	n/a	WWRC	DBASEINFO
Surficial Hydrography	1:24,000	7.5 minute USGS quadrangles	digitizing
Vegetation	1:100,000	Wyoming GAP Analysis Project	pre-existing
Soils	1:250,000	NRCS	pre-existing
Surficial Geology	1:100,000	WWRC	pre-existing
Bedrock Geology	1:500,000	WWRC	pre-existing
Coal Faults and Folds	1:62,500	USGS (Denson, 1980)	digitizing
Coal Isopach	n/a	Wyoming DEQ/LQD Coal Permit and Reclamation Database	ASCII to Arc/Info with GENERATE
Coal Burnline	1:24,000	BLM (Heffern, 1996)	digitizing
Clinker	1:24,000	BLM (Heffern, 1996)	digitizing
Monitoring Wells	n/a	Wyoming DEQ/LQD Coal Permit and Reclamation Database	ASCII to Arc/Info with GENERATE
Mining Sequence	1:2,000	DEQ/LQD Mining Permits	digitizing
Surface Water Rights	1:24,000	Wyoming State Engineer's Office	digitizing
Ground Water Rights	n/a	Wyoming State Engineer's Office	DBASEINFO
Digital Elevation Models	30 meter resolution	USGS	DEMLATTICE
Public Land Survey System	1:100,000	WWRC	pre-existing
Transportation	1:100,000	U.S. Bureau of Census	pre-existing

Metadata. Metadata describe the content, quality, condition, and other characteristics of data (Federal Geographic Data Committee, 1995). For each GIS data layer that had not been previously developed, metadata were completed. This allows for people, other than the creator, to understand and have reference to all the different aspects related to the data layer (i.e. data quality, type of features, spatial reference, attribute-naming conventions, etc.). This is an essential complement to any GIS data layer deliverable and accompanies the data during distribution.

MODEL INTEGRATION

For the pilot CHIA, GIS model integration involved modifying and querying data layers for model input and aid in spatially displaying model outputs. Future work will be directed at producing a seamless GIS connection for each model used in the assessment.

Model Input. The main focus surrounding the use of GIS data in the surface-water modeling effort was limited to developing hydrological response units (HRUs) and then querying data with reference to these units. Hydrography, slope, aspect, land cover, soils, surficial geology, and clinker (baked and fused geologic material generated during the combustion of a coal seam) data layers were all used in determining the boundaries of the HRUs. The goal during creation was to maximize homogeneity with respect to these data layers while maintaining a catchment identity. This required a multitude of overlays and several modifications before a final layer could be produced.

The HRU data layer provided the framework in which parameter estimation and/or calculations were structured. For example, each HRU had an associated attribute relating to the total channel length and drainage density for that particular unit. Additionally, a percentage breakdown of land cover, soils, surface geology, and clinker could be found within the attributes of this layer. All of these attributes were determined by overlaying the HRU layer with the necessary data layer, and applying specific calculations.

GIS played a significant role in the pilot CHIA groundwater modeling. A refined, non-equal area, cell-based grid set the data structure into which all other data layers had to be transformed before modeling could occur. This grid was developed by MODELGRID (Winkless and Kernodle, 1993), an Arc Macro Language (AML) program was designed to produce a vector-based grid with both polygon (cells) and point (cell centroids) attribute data.

The most common data manipulation involved placing vector data layers and the associated attributes into this pre-defined, irregularly-shaped grid. For example, it was necessary to determine which grid cells have 50% or more of their total area designated as clinker and differentiate those cells from the others. Other data layers such as burn line, coal faults and folds, mining sequence, and monitoring wells, all had to be incorporated into the grid with each layer having its own set of standards. These processes required extensive Arc Macro Language (AML) programming for testing and attributing each of the 5,994 grid cells based on specific criteria. Once all model input data layers had been placed within the grid, the MODARRAY (Winkless and Kenoodle, 1994) AML was used to export the data from an ARC/INFO coverage to an ASCII array format specific to MODFLOW.

Additional data manipulation was required in converting spot groundwater elevations into contours. This first involved kriging (process that interpolates a surface from a set of variably-spaced points) the data points in order to interpolate the values throughout the region. Due to ARC/INFO's limited kriging models, all kriging was performed using an external statistical package that produced a surface which could be imported back into ARC/INFO to create a contour coverage. These contours were then transformed back into the refined grid through an AML that used a weighted average method to determine each cell's approximate groundwater elevation.

Model Output. In addition to parameter estimation, GIS played a significant role in displaying MODFLOW modeling outputs. Through the use of spatial contour mapping, visual comparisons could be made between years and aquifers in relation to coal mining effects on groundwater.

Groundwater drawdown outputs produced by MODFLOW were placed back into the previously-discussed refined grid. This was accomplished through the use of AWK scripts for ASCII array manipulation, and subsequent importation of the data into INFO (the Arc/Info database system) with the cell identifier and accompanying drawdown output. Once within INFO, the table was joined to the refined grid data layer. The centroids for each cell then provided spot elevations from which a Triangular Irregular Network (TIN) was created. With an elevation TIN, the command *TINCONTOUR* was applied to produce drawdown contours for the specific MODFLOW modeled year. This process was repeated for five different years and two different aquifers.

DISCUSSION

GIS proved to be a critical tool for completing the CHIA modeling process in an accurate and efficient manner. Building on initial methodologies, it is anticipated that the role of GIS will continue to expand in future CHIA efforts, given the enormous data-management tasks associated with each of the three remaining cumulative impact areas delineated in the Powder River Basin.

BUILDING A SPATIAL DECISION SUPPORT SYSTEM

While certain specific data-management and analysis issues are currently being addressed by the ongoing CHIA development effort at the University of Wyoming, a broader need still exists for the development of computer-application tools capable of: 1) managing large quantities of spatial and non-spatial digital hydrologic data; and 2) providing an efficient means for utilizing such information in an integrated hydrologic impact analysis/modeling environment. The utilization of GIS can greatly enhance complex spatial problem solving. However, such systems often do not adequately support decision making because they are lacking in analytical modeling capabilities when not linked to existing models. One response to this shortcoming is the development of a spatial decision support system (SDSS) specifically designed to support a decision research process for addressing complex spatial problems. An SDSS provides a framework for integrating database management systems with analytical models, graphical and tabular display, and reporting capabilities, in combination with the knowledge of decision makers (Densham, 1991).

Supported by funding from the Wyoming Abandoned Coal Mine Land Research Program, research is currently underway at the University of Wyoming to develop an integrated, modular spatial decision support system (SDSS) for assessing the hydrologic impacts of coal mining and land reclamation activities in the Powder River Coal Basin of northeastern Wyoming. Components of the System will include existing surface-water and groundwater models (HEC-1; MODFLOW), a geographic information system (ARC/INFO GIS) and a relational database management system (ORACLE RDBMS). The overall goal in developing the System will be to provide resource managers with a dynamic evaluation and decision making tool. Applications will include model input generation/manipulation, model execution, and transfer of model-generated results into a spatially referenced format.

By integrating the surface- and groundwater models chosen for the CHIA, the SDSS will provide regulatory authorities with: 1) a user-friendly, integrated modeling software application, providing hydrologists and resource managers with the ability to pose "what if..." type questions concerning hydrological conditions without having to be GIS experts or database managers; and 2) an adaptable methodology for conducting dynamic CHIAs in any foreseeable application area of Wyoming. In addition, the SDSS will also provide a set of application tools for use by mine permit applicants in completing PHC determinations, as well as contributing to the advancement of electronic permitting methods (format compatibility, data transfer, etc.), thus making the permitting process more efficient and cost-effective for all parties involved.

REFERENCES

Densham, P.J. 1991. "Spatial Decision Support Systems", In Geographical Information Systems, Volume 1: Principles, edited by D.J. Maguier, M.E. Goodchild, and D.W. Rhind. John Wiley & Sons, Inc, New York, NY.

Denson, N.M. and C.T. Pierson, 1991. Geologic Map showing the Thickness and Structure of the Anderson-Wyodak Coal Bed in the South half of the Powder River Basin, northeastern Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-2094-B.

DeVantier, B. A. and A. D. Feldman. 1993. Review of GIS applications in hydrologic modeling. *Journal of Water Resources Planning and Management*, 119(2):246-247.

El-Kadi, A.I., A. A. Oloufa, A. A. Eltahan, and H. U. Malik. 1994. Use of a geographic information system in site-specific ground-water modeling. *Ground Water*, 32(4):617-625.

Federal Geographic Data Committee. 1995. Content Standards for Digital Geospatial Metadata Workbook. Federal Geographic Data Committee, Washington, D.C.

Heffern, E.L., and J.R. Oakleaf. 1996. Digital Clinker Map of the Powder River Basin, Wyoming (work in progress).

Hinaman, K. C. 1993. Use of a geographic information system to assemble input-data sets for a finite-difference model of ground-water flow. *Wat. Res. Bul.* 29(3):401-405.

Hoa, Q. and Y.P. Chugh. 1993. Spatial predictive modeling of mine subsidence risk with GIS. *In:* GIS/LIS '93: Proceedings of the conference in Minneapolis, MN, November, 1993, by ACSM, ASPRS, AM/FM International, AAG and URISA. Bethesda, MD: ACSM, ASPRS, AM/FM International, AAG and URISA, 270-281.

Maguire, D. J. 1991. An overview and definition of GIS. *In:* Maguire, D. J., M. F. Goodchild, and D. W. Rhind (Eds.). Geographic Information Systems: principles and applications. Longman, London, Vol. 1, pp. 9-20.

Maidment, D. R. 1993. GIS and hydrological modeling. *In:* Goodchild, M. F., B. O. Parks, and L. T. Steyaert (Eds.). Environmental modeling with GIS. Oxford University Press, New York, pp. 147-167.

Males, R. M. and W. M. Grayman. 1992. Past, present and future of geographic information systems in water resources. *Water Resources Update* 87:5-11.

Martin, L.J., D.L. Naftz, H.W. Lowham, and J.G. Rankl. 1988. Cumulative hydrologic impacts of surface coal mining in the eastern Powder River structural basin, northeastern Wyoming, U.S. Geological Survey Water-Resources Investigations report 88-4046. U.S. Department of the Interior, Cheyenne, WY.

McDonald, M.G., and A.W. Harbaugh. 1988. A modular three-dimensional finite-difference ground-water flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 6. U.S. Geological Survey, Reston, VA.

Office of Surface Mining Reclamation and Enforcement (OSM). 1985. Guidelines for preparation of a cumulative hydrologic impact assessment, draft. U.S. Department of the Interior, Washington, D.C.

Office of Surface Mining Reclamation and Enforcement (OSM). 1991. Managing hydrologic information in the coal mine permitting process - guidance for PHC and CHIA, draft. U.S. Department of Interior, Washington, D.C.

Parker, H. D. 1988. The unique qualities of a geographic information system: a commentary. *Photogrammetric Engineering and Remote Sensing*, 54(11):1547-1549.

Peacock, K., A.J. Anderson, J.R. Oakleaf, E.L. Heffern, and S.P. Gloss. 1996. Pilot CHIA

Study, Little Thunder Creek Drainage, Wyoming Wyoming Water Resources Center, Laramie, Wyoming (in review).

Richards, C. J., H. Roaza, and R. M. Roaza. 1993. Integrating geographic information systems and MODFLOW for ground water resource assessments. *Water Resources Bulletin*, 29(5):847-853.

Sasowsky, K. C. and T. W. Gardner. 1991. Watershed configuration and Geographic Information System parameterization for SPUR model hydrologic simulations. *Water Resources Bulletin* 27(1):7-18.

U.S. Bureau of the Budget. 1941. National Map Accuracy Standards. U. S. Bureau of the Budget, Washington, D.C.

U.S. Environmental Protection Agency and the USDI Office of Surface Mining. 1995. 1995 Progress Report: Statement of mutual intent strategic plan for restoration and protection of streams and watersheds polluted by acid mine drainage from abandoned coal mines. USEPA, Philadelphia, PA.

Watson, W. and K. Bryant. 1993. Assessing U.S. coal resources: an integration of GIS and statistical methods. *In:* GIS/LIS '93: Proceedings of the conference in Minneapolis, MN, November, 1993, by ACSM, ASPRS, AM/FM International, AAG and URISA. Bethesda, MD: ACSM, ASPRS, AM/FM International, AAG and URISA, 738-752.

Winkless, D. and Kernodel. 1993. MODELGRID. An Arc Macro Language/FORTRAN program to develop an Arc/Info point, line, and polygon coverages from user inputs.

Winkless, D. and Kernodel. 1994. MODARRAY. An Arc Macro Language/FORTRAN program to develop MODFLOW arrays from Arc/Info point, line, and polygon coverages.

Yoon, J., G. Padmanabhan, and L. H. Woodbury. 1993. Linking agricultural nonpoint source pollution model (AGNPS) to a geographic information system (GIS). GIS & WR:79-87.

WYOMING/UTAH INTERSTATE COOPERATIVE WATER RIGHTS PROJECT: WYOMING STATE ENGINEER'S OFFICE AND UTAH STATE ENGINEER'S OFFICE

Nancy McCann[1]

An interstate cooperative GIS project was developed between the Wyoming State Engineer's Office and the Utah State Engineer's Office based on the Upper Colorado River Basin Interstate Compact. The Compact deals with the waters of Henry's Fork and tributaries which originate in the State of Utah and flow into the State of Wyoming. Due to the Compact, waters diverted from Henry's Fork, Beaver Creek, Burnt Fork, Birch Creek and their tributaries shall be administered without regard to the stateline on the basis of an interstate priority schedule to be prepared by Wyoming and Utah.

The purpose of this project is to identify and resolve the differences between Utah and Wyoming for adjudication and administration of the water rights lying in both states. In order to resolve the differences, it was determined that all the lands and water rights involved should be mapped using Geographic Information System (GIS). Water rights in Wyoming are tied to physical locations that are owned by the possessor of the water right, therefore, if one owns the land then one owns the water right. Since a water right is defined by a geographical location then a GIS provides a more efficient system of water rights administration. Once mapped, the acreages, sources, ditches, and conflicts can be identified and a delivery (priority) schedule can be prepared and delivered to the Colorado River Commission for approval and use by both state's water administration officials.

This project has several interrelated problems that GIS can address. Over time, many permits were issued without regard to the existence of other permitted water rights which resulted in some lands having more than one primary water right. The effect is an overappropriation of water. Since no composite map of all water rights within a drainage existed, the Wyoming State Engineer's Office used GIS to provide the functionality in determining overlapping water right permits. Once the overlapping area is known, then field investigations can be made and administrative resolution implemented. To further complicate the issue, the state of Utah also issued water right permits for diversions from Utah streams for irrigation of lands in Wyoming which may overlap Wyoming water rights. In addition to the coexistence of Wyoming/Utah water rights, each state has different water laws and policies on administration of water.

Through cooperation between the states, Wyoming will administer the water rights (both Wyoming and Utah) within these specific river basins regardless of stateline.

The project area is located in southwestern Wyoming in Sweetwater and Uinta counties. There are 510 water rights mapped using GIS technology, 250 Wyoming water rights and 260 Utah water rights. These maps will be used to conduct on-the-ground inspections in the future. By matching the paper water rights to the actual field situation, the actual use of water will be clarified. GIS coverages that are completed for the Burntfork area are U.S.G.S. quadrangle boundaries, township and range, section lines, resurvey tracts, hydrology, Wyoming water rights and ditches, Utah water rights and ditches. In addition to the GIS coverages, there are related databases that give additional permit information, water right status, acreage locations and priority information for Wyoming.

If you would like additional information or have questions about the water rights project please contact either Nancy McCann or Shari Feltner.

Nancy McCann
Special Projects Administrator
Wyoming State Engineer's Office
Herschler Building, 4E
Cheyenne, WY 82002
Phone: (307) 777-5958
Fax: (307) 777-5451
Email: nmccan@missc.state.wy.us

Shari Feltner
Water Rights Specialist
Wyoming State Engineer's Office
Herschler Building, 4E
Cheyenne, WY 82002
Phone: (307) 777-6149
Fax: (307) 777-5451
Email: sfeltn@missc.state.wy.us

[1] Wyoming State Engineer's Office, Herschler Building, 4E, Cheyenne, WY 82002

GIS-BASED SURFACE WATER RIGHTS MAPPING IN THE TONGUE RIVER BASIN

Robert Niedenzu[1]

INTRODUCTION

The incorporation of surface water right data into a Geographic Information System (GIS) allows for a comprehensive and efficient way to store both the spatial and tabular data associated with water rights. The process by which these water right data are converted to a GIS format has to be flexible, because, over time, the data have been stored in several different formats. This paper explains the basics of the Wyoming water right system, GIS, and their integration.

Streams, lakes, and springs were declared property of the State by the Wyoming Constitution and can not be used without permission from the State. Those who wish to use water from these sources must apply for a surface water right permit. Surface water right permits are issued by the Wyoming State Engineer after examination and approval of the application. This permit must be secured before any work can begin on the water diversion structure. After completion of the construction and the application of water to beneficial use as described in the permit, the State Board of Control will issue a certificate of appropriation, which means the water right is adjudicated. There are 4 types of surface water right facilities:

- Ditch
- Enlargement of Ditch
- Reservoir
- Stock Reservoir

A lot of water rights are established for irrigation purposes. A diversion of 1 cubic foot per second per 70 acres of land is provided for these permits

These permit records are currently kept in the State Engineer's Office (SEO) surface water division database. This relational database (Advanced Revelation or AREV) keeps a record for each permit. Under each record are fields for owner, location, purpose, amount of water used, priority date, and other relevant information (Table 1). For each record in this digital database, a copy of the permit map is kept on file. In addition to some of the same information as the database record, this document contains a rough map with surveyors notes describing and depicting the actual location of the diversion and the area of use. Water rights dating back to the 1800's are stored this way with some of the early water rights recorded on linen and paper, while most newer water rights are recorded on mylar. The link between these documents and the records in the database is the permit number. In order to retrieve both spatial and tabular data, both sources must be consulted. The current system causes problems; over time, some lands have been issued more than one permit while others have been mapped in the wrong location. Confirmation of beneficial use is only possible through an expensive and time consuming field check, and finally, paper maps degrade over time and need to be replaced and updated periodically.

By using a Geographic Information System (GIS) to store both spatial and attribute data for these water rights in a comprehensive database, problems as described earlier can be addressed more effectively.

WHAT IS A GEOGRAPHIC INFORMATION SYSTEM ?

As the title suggests, the general purpose of this project was the development of a Geographic Information System as a water right permit management tool for the Tongue River basin. A GIS combines two software technologies: database management and digital mapping. It allows for the capture, storage, manipulation, analysis, and display of spatial and non spatial data. Rather than maintaining tabular and spatial data on separate media, a GIS links the two digitally. In a vector based GIS like the one used in this study, spatial data consists of layers of line, point, and polygon elements representing real world features. Layers can represent roads, rivers, cities, forest, etc.. These layers can be combined for visualization or manipulated for spatial analysis. Associated non-spatial data may include type of road, height of forest, peakflow of rivers, etc.. This tabular data in the database is automatically linked with the line, point, and polygon elements on the digital map. Manipulation of spatial data will result in automatic updating of the tabular database, while changes made in the tabular database will affect the digital map right away. The need for time consumptive manual cartography is no longer present as spatial data can easily be added or deleted digitally, while tabular data is stored in the same system. Although the cost of the initial implementation of a GIS is usually high due to time consuming data input, the advantages of automation will nearly always be cost effective in the long run. The same can be expected for this system.

THE TONGUE RIVER BASIN STUDY AREA

Located in north central Wyoming (Figure 1), the Wyoming side of the Tongue River basin is bordered on the western side by the Bighorn Mountains, has green pastures in the center, and plains on the eastern end. With the Tongue River, Goose Creek, and Dutch Creek as the major streams of the basin, there is plenty of water for irrigation and other uses available in those regions

[1] Riverside Technologies, Inc., Fort Collins, CO 80525

Table 1. Partial Database Record Water Rights Background

FIELD	CONTENT
Permit_No	CR/225A
Orig_Perimit	P6224S
Permit_Sta	ADJ
Proof_No	31806
Facility_N	GROSHART #2 STOCK RES
Priority_D	09/03/1968
Use_Codes	STO
Adj_Cfs_To	.000
Adj_Acre_F	7.33
Adj_Gpm_To	.00
Adj_Acres_	.00
Point_Loca	57 86 14 SWNE
Source_Nam	MILL DR
Trib_Nam	FIVE MILE CREEK TONGUE RIVER

Source: Wyoming State Engineer's Office.

surrounding these waters. Many water right permits have been issued for irrigation, industrial, and domestic uses.

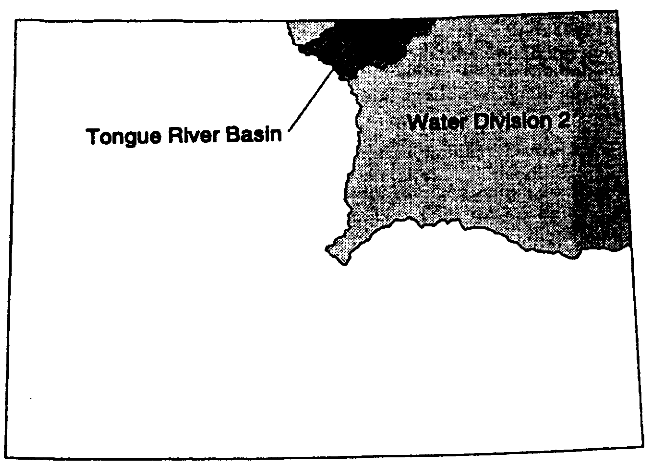


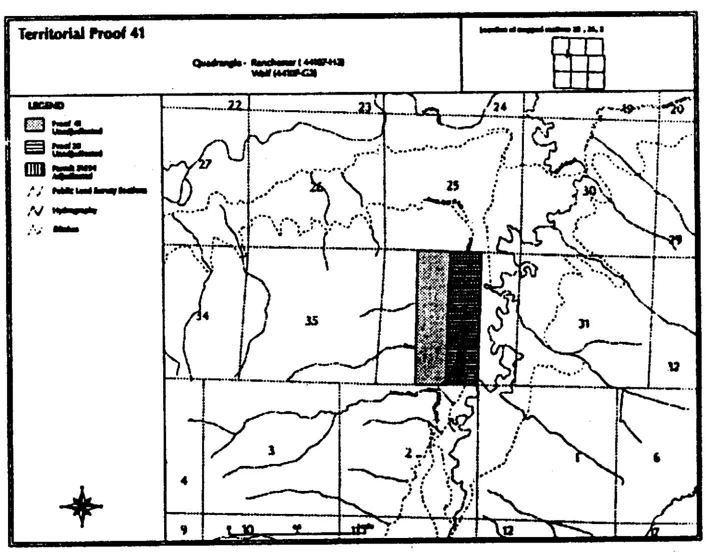
Figure 1. Wyoming and the Tongue River Basin

GIS DESIGN

The database was setup in ARC/INFO 7.04. As with any GIS, several layers of spatial data combined with tabular information form the backbone of the system. These are the layers for this project:

- Water Rights
- Streams
- Lakes
- Roads
- Township and Range
- Township and Range Sections
- USGS 1:24,000 Quadrangle
- Basin Boundary

All layers except for the water rights layer were created from United States Geological Survey (USGS) source data to function as a basemap. For the water right layer, the mylar, paper, and linen maps mentioned earlier had to be digitized and combined. Since the source maps had no projection information recorded on them and were therefore impossible to geographically reference exactly, most water rights were located and digitized by interpreting the stream, road, and Public Land Survey System (PLSS) information on the maps. The tabular data associated with each permit was linked to the digitized spatial data by using the permit number as a unique identifier. Finally, by organizing the data in ARCVIEW software, the data



Water Right Map

is easily accessible and can be displayed, manipulated, and queried in an easy-to-use point and click environment. Tables showing the appropriate clicking on the water right on the screen permit information can be displayed simply by

MAPPING

With all data incorporated into the system, maps can be produced for each permit showing the unadjudicated and adjudicated lands, streams, roads, PLSS, and other permits in the area. The process of mapping was automated to accommodate reproduction of the map after any possible changes to the permit or other permits in the area. The maps also show any existing overlaps. The maps can be printed as needed, eliminating the need to keep them all on file.

CONCLUSION

The use of a GIS to store water right information seems to be a logical choice. The combination of database management and automated mapping is very well suited to keep track of water rights in an efficient manner. Due to the large number of permits issued by the State, the process of converting all water right data in Wyoming to this format will be a long one.

WATER DIV-II GIS: PROTOTYPE TOOLBOX FOR DYNAMIC WATER PLANNING IN WYOMING

Jeffrey D. Hamerlinck[1]

ABSTRACT

While many studies have addressed various water resource issues in Wyoming's basins over the last 20 years, a comprehensive update of basin water availability and use has not been undertaken since the Wyoming Water Planning Program basin reports of the early 1970s. As a means of evaluating water supply and demand in each basin individually and in relation to the overall water resource needs of the State, an update is needed to understand how surface and ground water resources are currently being utilized. Maintaining up-to-date water resource documentation requires powerful and flexible planning tools which can manage and utilize basin inventory data in a timely and efficient manner. The primary objective of this project was to construct a geographic information system (GIS) for the purpose of developing a water resources inventory for Wyoming Water Division II in northeastern Wyoming. The project has resulted in development of a spatial digital database and associated text- and tabular-based descriptive information providing a detailed inventory of water and related land resources within the region. A second objective of the project addressed development of a customized, interactive graphical user interface for query and display of mapped and tabular information. The interface provides an infrastructure for development of tools for analyzing and modeling existing and potential water supply and demand. Finally, the project will result in an evaluation of the overall utility of GIS as a decision support tool for basin planning and the feasibility of expanding this GIS-based inventory methodology to a statewide water planning effort.

INTRODUCTION

In the early 1970s, a series of reports were produced by the Wyoming Water Planning Program inventorying water availability, water use, and water-related land resources for each of the major river basins in Wyoming. As part of the 1973 Wyoming Water Framework Plan, the basin reports provided a means of evaluating the water needs and resources in each basin individually and in relation to the overall water resource needs of the State. While many studies have addressed various water resource issues in Wyoming's basins over the last twenty years, a comprehensive update of basin water availability and use is needed for a present day understanding of how surface and groundwater resources are being utilized.

Historically, basin water planning documents have not often been revised due to the large volume of data involved and the traditional, manual cartographic and data tabulation methods used to revise reports. Today, up-to-date water resource documentation requires more powerful and flexible planning tools which can manage and utilize basin inventory data in a timely and efficient manner. To address this need, the Wyoming Water Resources Center at the University of Wyoming, in 1994, began development of a water resources geographic information system (GIS) database to demonstrate how such technology might be used for efficiently inventorying, updating, and managing the water resources within Wyoming's major river basins.

OBJECTIVES

Two major objectives were identified within the scope of the project:

1) Development of a water resource inventory geographic information system for one of Wyoming's major river basins as a case study with the purpose of demonstrating: (a) the flexible data management capabilities of a GIS, and (b) the adaptability of a GIS for use in other basins where similar information is available;

2) Construction within the GIS of an interactive, graphical user interface for displaying, querying and analyzing both spatial and non-spatial water resource information.

The goal in the project's first objective was to demonstrate the use of GIS technology as a powerful tool for inventorying and managing a basin-wide water resource inventory database. Expanding upon the mission of the original Water Planning Program basin reports, the GIS developed in this case study was designed to demonstrate a *more dynamic* means for inventorying and evaluating basin water resources for planning and decision making.

Objective Two - construction of a graphical user-interface - was undertaken to demonstrate the utility of such a tool as a means for displaying and querying spatial and non-spatial data sets contained within a GIS database. Comprised of a collection of "point-and-click" menus in a multi-windowing PC environment, the interactive system was designed to ultimately provide planners and managers at both state and local levels with real time access to information for decision support and basic spatial analysis involving the state's water resources.

A final objective of the project which is currently being addressed involves conducting an evaluation of the results of the case study in terms of the overall utility and effectiveness of GIS technology for compiling and managing water resource inventory data for basin planning activities. This evaluation will address the feasibility of expanding

---

[1] Wyoming Water Resources Center, UW, Laramie, WY 82071-3067

on existing methods in order to *digitally and spatially* compile water and related land resource data on a statewide basis.

BACKGROUND

BASIN WATER PLANNING IN WYOMING

The Wyoming Water Planning Program was established by the 1967 Wyoming Legislature to study the availability and use of the State's water, as well as future needs for water in the State. A primary objective of the Program was to provide a framework plan for water and related land resources development (Wyoming Water Planning Program 1969). Issued in 1973, the Wyoming Framework Water Plan provided, "an inventory of the State's water and related land resources, a summary of the State's present water uses, a projection of future water needs, and an identification of alternative decisions to meet or not to meet the indicated future water needs, " (Wyoming Water Planning Program 1973b, [2] 1).

The information incorporated into the Wyoming Framework Water Plan was originally compiled in a series of Water Planning Program reports for each of the major basins in the State, including the Bighorn, Green, Platte and Snake Rivers, along with the basins of northeastern Wyoming. These reports, published between 1970 and 1973, inventoried by basin, water availability and use along with related land resources. Prior to the publication of these documents, the State Engineer's Office had produced water resources inventories for each of the four water divisions in the State (e.g. Streeter 1965). However, the Water Planning Program reports not only provided a means of evaluating water needs and resources in each basin individually, but also in relation to the overall water needs and resources of the State.

In the last thirty years, none of the basin water inventory reports have been updated. While many studies have addressed various aspects of water resources in the State's basins during this time period, only a small number have followed a similar, comprehensive inventory approach (Lowry, et al. 1986; HDR Engineering,Inc. 1988; Ostresh, et al. 1990; Division of Water Resources 1992).

GIS AND WATER RESOURCES

In the last 20 years, geographic information systems (GIS) technology has been increasingly applied to a wide range of water resource-related studies (Males and Grayman 1992). Simply defined, GIS is a computer-based information technology with the capability to capture, store, manage, manipulate, analyze and display *both spatial and non-spatial data*. The ability of a GIS to integrate diverse types of data makes it a powerful tool for inventorying river basin resources for water planning purposes. Further, once an initial database has been built, flexible GIS data management capabilities allow for efficient data storage, retrieval and revision.

GIS research associated with river basin planning grew from initial efforts carried out primarily by government agencies. For example, one of the first major USGS water-resources projects to apply GIS techniques to the examination of river basin water data was a study by Moody, et al. (1983) of the Fox and Wolf River basins in Wisconsin (Lanfear 1992). Initially, applications within the states focused on sub-basin watershed management (Etzel and Ellis 1990; Smith, et al. 1990). Examples of GIS database development for water resource inventories include Brown, et al. (1987), Gersmehl (1987), and more recently, Juracek and Kenny (1993).

In Wyoming, projects involving basin-related GIS applications include the USGS NAWQA study on the upper Snake River (Leahy, Risenshein and Knopman 1990), and several projects recently completed by the Wyoming State Engineer's Office, involving water rights mapping (McCann 1997; Division of Water Resources 1992).

METHODOLOGY

OBJECTIVE 1: DATABASE DEVELOPMENT

Water Division II, in northeastern Wyoming, was the area selected as the project's case study. This region was chosen after a cursory review of recent Wyoming river basin planning documents indicated that a need existed for an up-to-date inventory of water availability and use in the area - an observation confirmed through inquiries at the Wyoming State Engineer and Water Development offices. In particular, an assessment of water allocation and use in tributaries to the Yellowstone River was identified as a high priority need relative to current interstate stream agreements. A final factor in the selection of this region was the large number of existing, available digital data sets, including a wide coverage of 1:24,000-scale U.S. Geological Survey Digital Line Graph and Digital Elevation Model data.

The GIS database was constructed utilizing ESRI, Inc.'s ARC/INFO[1] GIS software. A wide range of data layers were incorporated into the database, either through digital automation or conversion techniques. These digital coverages were compiled from a variety of sources, including existing digital data sets available from government sources (USGS, BLM, etc.), as well as through the digital conversion of available paper and mylar base maps, and through geographic referencing of existing non-spatial, tabular databases.

[2] ARC/INFO is a registered trademark of Environmental Systems Research Institute, Inc., Redlands, CA USA.

Data layers were developed at one of two different scales; as intermediate, basin-wide coverages at a scale of 1:250,000, or as more detailed, sub-basin coverages at a scale of 1:24,000. Compiling data layers at two different scales provided an excellent opportunity for comparing and evaluating differences in spatial detail in terms of utility for water use inventories, etc. This approach has since provided an opportunity to assess the feasibility of inventorying water and related land resources for all of Wyoming's major basins at one or both of these scales, relative to available data and associated time, personnel and equipment requirements.

Intermediate Scale Mapping. Data layers developed at a basin-wide scale were chosen to reflect information originally presented in the Water Planning Program's Water and Related Land Resources of Northeastern Wyoming (1972). Examples included hydrography, watersheds, soils, geology and land status. A more comprehensive listing and description of the database's contents may be found in Hamerlinck (in preparation).

Large-Scale Mapping. The Tongue River watershed was selected as the focus of more detailed, 1:24,000-scale mapping within the study area after it was determined that available resources would not allow for detailed, basin-wide data layer development. While its size makes for relatively manageable digital data input, it was also selected in part for interstate compact -related needs to quantify water use within the Yellowstone River Basin of Wyoming and Montana.

Two 1:24,000-scale digital data layers were identified for development for the Tongue River watershed: surface water rights and irrigated agricultural lands. The initial goal in mapping these layers was to quantify and compare water allocations with actual water use both at the time the Yellowstone River Compact was established in 1950 and in the present day. The post-1950 water rights were the rights of primary concern in regard to interstate stream allocation issues involving the Tongue River, since the Yellowstone River Compact honors all appropriated rights in existence as of January 1, 1950 (State Engineer's Office 1982).

After distinguishing between pre- and post-1950 surface water rights, a decision was made to limit mapping to the Wolf Creek tributary of the main stem Tongue River. In total, 80-100 ditches, enlargements, reservoirs were digitally automated within the GIS from permit application maps available from the Wyoming State Engineer's Office. These spatial features were then attributed through links to information retrieved from the Wyoming State Engineer's Office existing water right databases.

Irrigated agricultural lands in the Tongue River basin were inventoried and mapped using a variety of techniques. Initially, a set of 1953 Soil Conservation Service air photos were used to delineate and compile a mapped approximation of the amount and location of irrigated agricultural lands in the basin at the time that the Yellowstone Compact was established (Driessen, et al. 1992). Current-day irrigated agricultural lands were then mapped from available NHAP and NAPP aerial photography. These delineations were verified through field surveys carried out by area hydrographers from the State Engineer's Office, and through comparison with the statewide land cover map recently completed by the Department of Botany at the University of Wyoming.

OBJECTIVE TWO: GRAPHICAL USER-INTERFACE

ArcView GIS[2] software was utilized in designing and developing a customized user-interface for the GIS, complete with a set of tailored display, query and analysis tools. ArcView was originally developed to allow end-users of GIS to access, manipulate and display data without requiring them to learn a complex and dynamic technology. Since its release in 1991, ArcView's analysis capabilities have been greatly expanded. A wide range of natural resource ArcView applications have been developed, including a number of water resource system management tools (Perisho, et al. 1993; Yada, et al. 1993).

Interactive in nature, the interface consists of a collection of mouse-activated, "point-and-click" menus. In addition to water right permit administration and cropland/permit acreage overlays, examples of analysis applications currently being developed include consumptive water use and depletion estimation calculations.

RESULTS

The content of the digital water resources inventory database developed for Water Division II is similar in many ways to the original 1972 Water Planning Program basin report for northeastern Wyoming. However, in addition to summary tables and statistics, the automated nature of WaterDiv-II GIS will provide great potential for applications beyond the utility of a static publication, not only in water planning efforts, but for comprehensive resource management initiatives as well.

In evaluating the feasibility of applying case study methods at a statewide-scale, particular consideration must be given to data needs and associated spatial resolution requirements. While detail is compromised with an intermediate scale (e.g. 1:250,000), it does allow for a general

[2] ArcView is a trademark of Environmental Systems Research Institute, Inc., Redlands, CA USA.

overview of water and related land resources for a relatively large planning area. Conversely, while more detail can be achieved with associated analysis possibilities when an inventory is done at a large scale of 1:24,000 or better, it will also cost more money, require more time and personnel, and most likely will be limited to a much smaller area.

CONCLUSION

In considering new statewide water planning initiatives, it is important to recognize that objectives and priorities have shifted toward the need for a dynamic and flexible planning process which will focus on efficient water management, while accounting for both consumptive and non-consumptive demands. Maximizing use of existing, state-of-the-art technology will play a major role in meeting this challenge. The WaterDiv-II GIS provides a model for the type of "information database" which can successfully facilitate informed decision-making in a statewide water planning effort.

ACKNOWLEDGEMENTS

Funding for this project was provided by a grant from the Wyoming Water Resources Center State Grants-In-Aid Program. The author wishes to acknowledge Ross Staugh, James R. Oakleaf, Robert J. Niedenzu, and Joshua H. Johnson for their assistance as graduate student technicians on the project. Thanks is also extended to Sue Lowry, Nancy McCann and Shari Feltner of the Wyoming State Engineer's Office for their contributions made toward completion of the study.

REFERENCES

Brown, D. A., K.L. Anderson and P.J. Gersmehl. 1987. "Hydrographic Data for a Water Resources GIS," in File Structure Design and Data Specifications for Water Resources Geographic Information Systems, D.A. Brown and P.J. Gersmehl, eds. St. Paul, MN: Minnesota Water Resources Research Center, 12.1-12.16.

Division of Water Resources. 1992. Utah State Water Plan: Bear River Basin. Salt Lake City, UT: Utah Department of Natural Resources.

Driessen, R., et al. 1992. "From Aerial Photographs to ARC/INFO, " in Proceedings of the Twelfth Annual ESRI User Conference, Vol. 1. Redlands, CA: Environmental Systems Research Institute, Inc.: 83-92.

Etzel, R. A. and G. K. Ellis. 1990. "Comprehensive Watershed Management Planning: A Case Study - The Magothy River," in Watershed Planning and Analysis in Action, Riggins, Robert E., et al., eds. New York, NY: American Society of Civil Engineers: 495-503.

Gersmehl, C.A. 1987. "Land Cover Data for Water Resources GIS," in File Structure Design and Data Specifications for Water Resources Geographic Information Systems, D.A. Brown and P.J. Gersmehl, eds. St. Paul, MN: Minnesota Water Resources Research Center, 7.1-7.39.

Hamerlinck, J.D. (in preparation). Development of a water Resources Inventory GIS for River Basin Planning in Wyoming. Laramie, WY: Wyoming Water Resources Center.

Juracek, K.C. and J.F. Kenny. 1993. "Management and Analysis of Water-Use Data using a Geographic Information System," in Proceedings of the Symposium on Geographic Information Systems and Water Resources, J.M. Harlan and K.J. Lanfear. Eds. Bethesda, MD: American Water Resources Association: 483-490.

Lanfear, K. J. 1992. "Water-Resource Applications of Geographic Information Systems by the U.S. Geological Survey," *Water Resources Update* (87): 12-16.

Leahy, P.P., J.S. Risenshein, and D.S. Knopman. 1990. Implementation Plan for the National Water-Quality Assessment Program, Open-File Report 90-174. Reston, VA: U.S. Geological Survey.

Lowry, M. E., J. F. Wilson, Jr., and Others. 1986. Hydrology of Area 50, Northern Great Plains and Rocky Mountain Coal Province, Wyoming and Montana, Water Resources Investigations Open-File Report 83-545. Cheyenne, WY: U.S. Geological Survey.

Males, R. M. and W. M. Grayman. 1992. "Past, Present and Future of Geographic Information Systems in Water Resources," *Water Resources Update* (87): 5-11.

McCann, N. 1997. "Wyoming/Utah Interstate Cooperative Water Rights Project," in Proceedings, Wyoming Water '97, Laramie, WY: Wyoming Water Resources Center.

Moody, D.W., et al. 1983. "Use of a Geographic Information System for the Analysis of Water Resources, Conditions and Issues," in Seminar for Multipurpose Land Information Systems: Applications of Information Technology for Natural Resource Planning, Management, and Monitoring, Wisconsin Land Information Report No. 3, Institute for Environmental Studies Report 132. Madison, WI: University of Wisconsin: 59-70.

Niedenzu, R. 1997. "GIS-Based Water Rights Mapping in the Tongue River Basin, Northeastern Wyoming," in Proceedings, Wyoming Water '97, Laramie, WY: Wyoming Water Resources Center.

Ostresh, L. M., Jr., R. A. Marston and W. M. Hudson. 1990. Wyoming Water Atlas.

Cheyenne, WY: Wyoming Water Development Commission.

Perisho, Ron, et al. 1993. "Using ArcView to Improve Public Involvement Opportunities in Natural Resource Decision-making," in Proceedings of the Thirteenth Annual ESRI User Conference, Vol 1. Redlands, CA: Environmental Systems Research Institute, Inc.: 331-340.

Smith, John W., et al. 1990. "Utility of a GIS in Watershed Management: A Case Study," in Watershed Planning and Analysis in Action, Riggins, Robert E., et al., eds. New York, NY: American Society of Civil Engineers: 201-210.

State Engineer's Office. 1982. Compacts, Treaties and Court Decrees. Cheyenne, WY: State of Wyoming.

Streeter, Robert L.1965. Water Resources Inventory for Division Number 2, State of Wyoming. Cheyenne, WY: Wyoming State Engineer's Office.

Wyoming Water Planning Program. 1972. Water and Related Land Resources of Northeastern Wyoming, Wyoming Water Planning Program Report No. 10. Cheyenne, WY: Wyoming State Engineer's Office.

Wyoming Water Planning Program. 1973. The Wyoming Water Planning Program: A Summary. Cheyenne, WY: Wyoming State Engineer's Office.

Wyoming Water Planning Program. 1973b. The Wyoming Framework Water Plan. Cheyenne, WY: Wyoming State Engineer's Office.

Wyoming Water Planning Program. 1969. Objectives and Policies of the Wyoming Water Planning Program, Wyoming Water Planning Program Report No. 2. Cheyenne, WY: Wyoming State Engineer's Office.

Yada, Frank, et al. 1993. "GIS Applications: Automated Theme Generation for Monitoring Water Resources Systems using Relational Databases and ArcView," in Proceedings of the Thirteenth Annual ESRI User Conference, Vol 1. Redlands, CA: Environmental Systems Research Institute, Inc.: 537-540.

SESSION 3:

WELLHEAD PROTECTION

WELLHEAD PROTECTION IN WYOMING: AN OVERVIEW

Kevin Frederick and Phillip Stump[1]

ABSTRACT

In 1986, Amendments to the Safe Drinking Water Act (SDWA) established the Wellhead Protection (WHP) Program. Under these Amendments, each state was called upon to develop, and submit to EPA for approval, a plan that would protect ground water which supplies wells, well fields, springs, and tunnels that provide drinking water to the general public. The basic, minimum 'elements' that states must address and include in their WHP plans are also specified in the SDWA. To date, 45 states have developed and submitted state WHP plans to EPA for approval; 40 states have received EPA's approval of their plans. Of the EPA Region VIII states, (WY, CO, MT, UT, ND & SD) Wyoming is the remaining state to submit and receive approval of its WHP plan. Wyoming's Wellhead Protection Program's Guidance Document represents Wyoming's Wellhead Protection (WHP) plan, and is intended to serve as a guideline to communities, Public Water Systems (PWSs), and others wishing to develop local WHP plans that will meet the minimum criteria for approval by EPA as set forth in the 1986 Amendments to the SDWA.

Prior to developing its WHP plan, in 1991 the Wyoming Department of Environmental Quality (WDEQ) sponsored public meetings throughout the state to measure the degree of public interest and support for wellhead protection, and to gather public input on the issues and options that Wyoming should consider when developing its own plan. Questionnaires completed by attendees at these meetings revealed that ***100% of those who responded indicated that "...communities should protect their public drinking water supply wells...from contamination," and 90% indicated that "A Wellhead Protection (WHP) Program should be established in their community."***

The principal objective of a WHP plan is to *prevent* the contamination of groundwater resources that supply PWSs. As stated in §35-11-102 (*'Policy & Purpose'*) of *Wyoming's Environmental Quality Act* (Title 35 ["Public Health & Safety"]; Chapter 11 [Environmental Quality]), the policy and purpose of the Act is *".... to enable the state to prevent, reduce and eliminate pollution ...."* and *".... to plan the development, use, reclamation, preservation and enhancement of the .... water resources of the state"*. In recognition of this purpose, WDEQ has identified the importance of providing assistance to local governments to protect drinking water supplies as an important objective in its Strategic Plan. WDEQ has identified the development of a state Wellhead Protection Plan as its primary means to meet this objective; this document is intended to provide such assistance. Responsibility for the development and administration of the state's Wellhead Protection Plan will reside within the jurisdiction of the Department of Environmental Quality, Water Quality Division's (WDEQ/WQD) Groundwater Pollution Control (GPC) Program.

Wyoming's WHP plan adopts the systematic and logical *proactive* approach to protecting drinking water supplies that has been established under the Safe Drinking Water Act Amendments of 1986. Communities and PWSs *may* follow this plan to develop and implement efforts that are designed to protect drinking water supplies from contamination. *Potentially significant financial benefits and cost avoidances may be realized through the development and implementation of local WHP plans in accordance with the* criteria set *forth in the Guidance Document.* Implementation of Wellhead Protection Plans at the local level may benefit both the *Farm Loan Program* and the *Wyoming Water Development Commission* from the reduced need for emergency funding to *replace contaminated wells* or *provide for water treatment facilities.* As presented in the state's plan, *there are no requirements, rules or regulations that impose the development or implementation of WHP plans on any PWS, either publicly or privately owned.* Communities and their PWSs should weigh the benefits of developing and implementing WHP plans and proceed accordingly.

NEED FOR LOCAL WELLHEAD PROTECTION (WHP) PROGRAMS:

Development and implementation of local WHP plans is important in Wyoming because a major portion of the state's PWSs depend upon groundwater. As illustrated in Table 1, approximately 75% of Wyoming residents rely on groundwater supplied by PWSs for all, or part, of their drinking water supplies.

The value of a clean, high quality groundwater supply cannot be overestimated. The enormous cost of aquifer remediation and developing alternative water supplies are only two of the many reasons why the protection of all groundwater resources developed by a PWS should be a priority. Aquifer remediation efforts described in technical literature and the news media over the past two decades have shown how difficult, if not impossible, it is to restore a contaminated drinking water supply. Clean drinking water is protective of human health and, from national media surveys, has been found to be an important factor in evaluating one's 'quality of life'.

[1] Wyoming Department of Environmental Quality; Water Quality Division, Cheyenne, WY 82002

Table 1
Wyoming (Groundwater) Public Water Systems (PWSs):
Number of Systems by System Class[2]

Class of System	*Number in Class*	*Number of Sources (Wells)*	*Population Served*
'Community' PWSs	218	527	355,906
'Transient Non-Community' PWSs	336	420	49,680
'Non-Transient Non-Community' PWSs	86	129	13,215
Total PWSs	**638**	**1,076**	**418,801**

Source: Preliminary data from Wyoming Water Resource Center query of EPA PWS database (Personal Comm., Jim Oakleaf, 12-15-95).

Potential scenarios of contaminant introduction to drinking water sources are common to most PWSs, and can result from accidental spills and leaks, leaking underground storage tanks, septic systems, mining, agricultural and industrial operations, and other events and activities. The development of WHP plans includes management strategies designed to help ensure that existing groundwater resources used for public drinking water supplies will remain viable.

In the past several years, WDEQ/WQD has provided technical assistance and public information and education to many Wyoming communities which are active or interested in developing WHP plans. As depicted in Figure 1, WHP plan development and implementation is currently in progress in many communities throughout the state, including Cheyenne and Casper. Laramie and Torrington have both received EPA grants (Wellhead Protection Demonstration Projects) to develop WHP plans. These, and other on-going projects represent a variety of aquifer conditions, land use activities, community sizes and socio-economic conditions in Wyoming. The techniques and procedures developed for each project can, and have been, used to assist other communities and PWSs in the development of their WHP plans.

COST/BENEFIT OF LOCAL WELLHEAD PROTECTION:

As illustrated in Table 2, the majority of groundwater-supplied PWSs in Wyoming serve fewer than 500 people, and all but 8 serve fewer than 3300 people.

Fact: ***92% of all Wyoming Public Water Systems (groundwater-based) serve fewer than 3300 people.***

Fact: ***All but 18 of Wyoming's communities have populations less than 3300 people.***

Actual and projected costs for development of Wellhead Protection Plans are provided in Table 3 for two small towns (Elk Mountain, WY and Gilbert, LA) and for three small PWSs (State of Washington Department of Health). Since most Public Water Systems in Wyoming serve communities similar in size to those illustrated in Table 3 (i.e., < 2500), the costs to the majority of Wyoming Communities (or PWSs) to develop a Wellhead Protection Plan should approximate the costs depicted in Table 2, or roughly:

- for Wyoming's 366 PWSs serving fewer than 100 people
- for PWSs serving between 100 and 175 people
- for PWSs serving between 175 and 2500 people

As mentioned earlier, 92% of all Wyoming Public Water Systems serve fewer than 3300 people and all but 22 of Wyoming's communities have populations of less than 2500 people. The cost estimates above would therefore reasonably apply to the majority of communities (and PWSs) within the state.Unlike

[2] As classified by EPA , a **'community'** water system serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents. A **'non-community'** water system may be classified as either (1) **'transient non-community'** (regularly serving fewer than 25 of the same persons over six months per year), such as a park, campground, gas station, or restaurant; or (2) **'non-transient non-community'** (regularly serving at least 25 of the same persons over six months per year), such as a rural schools, business offices, mines, or power plants, with their own water supply systems.

Table 2

Wyoming (Groundwater) Public Water Systems (PWSs) by Class and Size

Class of System	*Number of PWSs*	*Number of PWSs per Population Served*					
		<100	>100 <500	>500 <1000	>1000 <3300	>3300 <10000	>10000
Community PWSs	186	81	81	6	12	4	2
Transient, Non-Community PWSs	319	232	72	8	5	2	0
Non-Transient, Non-Community PWSs	82	53	26	2	1	0	0
TOTAL	**587**	**366**	**179**	**16**	**18**	**6**	**2**

Source: Data collected from the EPA Safe Drinking Water Program Database; Non-purchase PWSs only; (1/23/96).

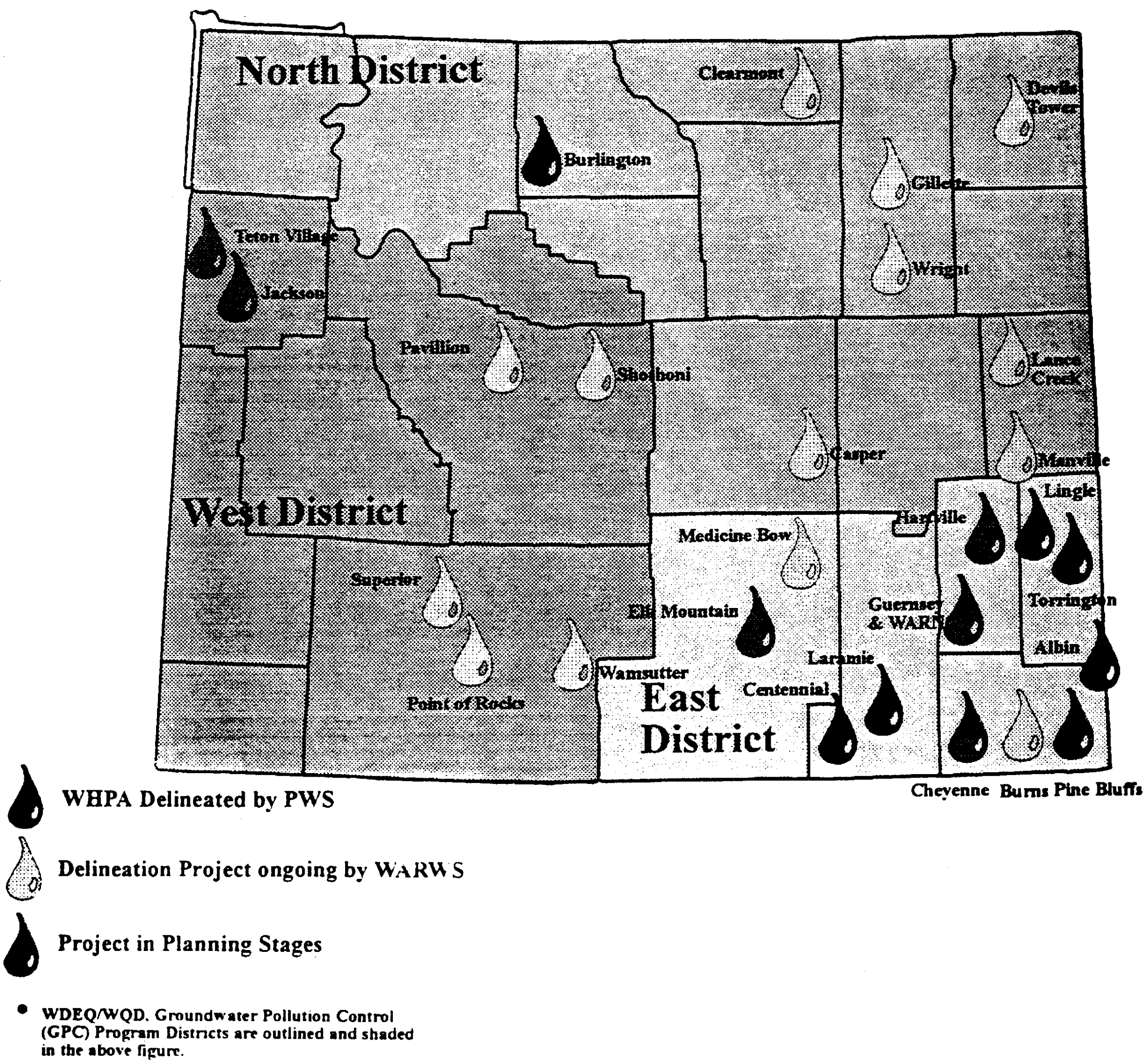


Figure 1. Progress of Wyoming's PWSs' Wellhead Protection Programs

Table 3

Costs to Develop Wellhead Protection Plans			
	Population Served	Number of Wells	WHP Costs (5 year)
Gilbert, LA (1994)	700	2	$5041
Elk Mountain, WY 1996	186	2	$5790
3 Small PWs; Washington DOH (1995)	>25 <100	1-2	$500
DOH (1995) (USEPA, Benefits and Costs of Prevention. Volume 1)	>100 <175	1-2	$2000
	>175 <2500	2-3	$5000

many other States, Wyoming has been extremely fortunate in that very few PWS wells have been impacted or 'lost' due to contamination. Table 4 illustrates potential financial savings which a typical Wyoming community might accrue in the event that implementation of a local Wellhead Protection plan: 1) assists a PWS in obtaining a *susceptibility monitoring waiver* from EPA, allowing it to reduce the degree of monitoring required by the Safe Drinking Water Act; 2) reduces the possibility of the need for costly treatment of a contaminated drinking water supply; and, 3) precludes the need to replace a drinking water supply well that has been lost due to contamination.

The cost/benefit ratios illustrated in Table 4 demonstrate that from ***$7 to $130 might be saved (or avoided) for every $1 spent*** by a community (or PWS) to develop a Wellhead Protection Plan. ***In most cases it is the smaller communities that stand to gain the most by developing Wellhead Protection Plans.*** Very small PWSs (<100 people served) could possibly save (or avoid) as much as $1300 for every $1 spent if development and

Table 4

Benefit/Cost Accruing From Implementation of Local WHP Plans				
	Benefit (Savings)	**Period**	**WHP Costs**	**Ratio (Benefit/Cost)**
Monitoring Costs 5 years (SVOCs and VOCs)	$33K	5 years	$5K	7:1
Treatment Costs (Reverse Osmosis at Wellhead)	$506K	Once	$5K	100:1
Replacement Costs of New Wall (300 ft. deep and 2.5 miles from the system intake)	$650K	Once	$5K	130:1
Note: Estimated WHP Costs for PWSs Serving between 175 to 2500 people.				

implementation of a Wellhead Protection plan prevented the contamination of one drinking water supply well. For all sizes of PWSs (or communities), the cost savings that might be achieved by obtaining monitoring waivers *alone* can justify the cost involved in developing the Wellhead Protection Plans.

PUBLIC INPUT AND PARTICIPATION IN DEVELOPMENT OF WYOMING'S WELLHEAD PROTECTION PLAN:

The development of Wyoming's Wellhead Protection (WHP) plan stemmed from the establishment (July, 1995) and voluntary participation of a 20-member, multi-interest advisory committee. Members of the advisory committee were selected from federal and state agencies, local (city/county) governments and associations, industry, citizen interest groups and environmental interest organizations. Major tasks of the committee involved the identification and establishment of goals, guidelines, minimum criteria, examples and reference materials deemed pertinent by the committee for inclusion in the draft plan. Results of public surveys (1991) to measure the degree of public interest and support for wellhead protection, and public input on the issues and options that Wyoming should consider when developing its own plan where provided to committee members for consideration during development of the plan.

Public participation in the development of this plan also was solicited through press releases distributed to local and statewide newspapers, informing the public of the establishment of the Wellhead Protection Advisory Committee and its role(s), and encouraging interested parties to respond with comments, ideas and suggestions to the draft elements of the state's proposed plan. The opportunity for public participation in development of the state's plan will again be provided when the proposed final draft plan is released for public review and comment before the Wyoming's Water Quality Advisory Board. The final plan will then be presented to the Governor for signature and submittal to EPA for approval; formal adoption of the plan by WDEQ/WQD will occur upon receipt of EPA's approval.

PREVIEW OF WYOMING'S WELLHEAD PROTECTION PLAN

The basic premise behind the state's WHP plan is that it should allow *voluntary*, as opposed to mandatory, participation and provide reasonable flexibility in development and implementation at the local level. The development of WHP plans by communities or PWS owner/operators is often dependent upon whether the benefits derived, or potentially derived, from the development and implementation of the plan will meet community goals and objectives, and can be justified from an economic standpoint.

As detailed in this document, Wyoming's WHP plan addresses each of the 'elements' (of WHP plans) required under the SDWA Amendments, and establishes minimum criteria for WDEQ/WQD acceptance and approval of WHP plans.

Special consideration has been given to assisting WHP plan development for the smaller 'Non-Community' PWSs[3] which, although constituting the majority of public drinking water systems in the state, service only approximately 14% of the total population served by Wyoming's PWSs. To facilitate the development of WHP plans for these types of systems, a condensed model 'plan' has been developed for these systems to complete and use in the belief that a simplified, streamlined approach will better suit the needs of not only these types of PWSs, but their users as well. The University of Wyoming (with funding from EPA), the Wyoming Water Resource Center, and WDEQ/WQD have all been involved in an effort to assist some of these smaller systems by delineating wellhead protection areas (WHPAs) for their systems, and providing a map of the delineated WHPA to them for inclusion into their WHP plans.

PWSs wishing to use WHP plans, or parts thereof, to participate in federal incentive programs (e.g. SDWA Monitoring Waivers) must meet the minimum criteria as set forth in this document and be approved by WDEQ/WQD. Although some communities (and their respective PWSs) may have no desire to use WHP plans to enjoy such benefits, they are encouraged to develop their plans toinclude all elements of the guideline, meet the minimum criteria for approval, and obtain WDEQ/WQD's approval of the plan. WHP plans which are approved by WDEQ/WQD are also considered acceptable by EPA.

Just as WHP plans developed by other states are dynamic and evolving to make them more useful to their communities, Wyoming's plan will also be subject to periodic change in hopes of improving the success of wellhead protection in Wyoming.

REFERENCES

U.S. Environmental Protection Agency, Office of Water. Benefits and Costs of Prevention: Case Studies of Community Wellhead Protection - Volume 2, (EPA 813-B-95-006), March 1996.

U.S. Environmental Protection Agency, Office of Water. Benefits and Costs of Prevention: Case Studies of Community Wellhead Protection - Volume 1, (EPA 813-B-95-005), October 1995.

[3] Common examples of these types of systems include: state parks, rural schools, rest areas and those mine sites, trailer courts and subdivisions that meet the definition of 'Non-Community' PWSs.

GROUNDWATER & WELLHEAD PROTECTION FOR RURAL DRINKING WATER SUPPLIES

Floyd Field[1]

As Groundwater Technician (G/W) for Wyoming Association of Rural Water Systems (WARWS), I am charged with the responsibility to inform, educate and involve water systems in the protection of their water source, be it a well, spring, stream or tunnel.

WARWS is a non-profit association consisting of members from across the state. Funding for the G/W program is from EPA channeled through our national office with headquarters in Duncan, OK.

During the past few years, WARWS has helped in the education process by training 2,375 individuals and 1411 systems in all aspects of water system operation. Our conference, held annually in Casper, is widely attended with this year's registrations totaling over 200.

Why is this important?

Money Magazine - Readers' Poll Results

You rate a clean environment over low crime. When it comes to choosing a place to live, you put clean water and air slightly ahead of a low crime rate. That's a shift from previous years, when a low crime rate topped the list of our readers' concerns. Mean scores were: Clean Water - 8.9, Clean Air - 8.7, Low crime rate - 8.7.

WHY IS THIS IMPORTANT IN WYOMING?

Over 75% of the population in Wyoming relies on groundwater for part or all of their drinking water supply.

Protection from contamination is a key to maintaining good quality groundwater. One way to protect groundwater supplies is to protect the area surrounding a water supply source.

Contaminated ground water means costly treatment facilities or alternative sources which may or may not be available.

The program utilizes local land use control with unanimous local government and citizen support. It is Voluntary.

Wyoming Department of Environmental Quality, Water Quality Division has initiated a framework to develop a program designed to protect wellhead areas within the state.

If local governments do not initiate WHPP, the federal government will continually intervene.

Wyoming communities can suffer a profound financial impact when their water supplies become contaminated.

The only true way of ensuring a safe water supply for the future is to protect the source.

WHAT IS THE PROGRAM?

The Ground Water/Wellhead Protection program assists small water systems and rural communities in designing and implementing individual ground water (wellhead) protection plans at the local level. Since the program began Nationally in March 1991, more than 2,050 local communities, with populations totaling almost 4 million, took ownership and responsibility for protecting their drinking water. In Wyoming the program began in April of 1994 and has grown to include over 50 communities.

There is probably no other environmental area where the adage of "An Ounce of Prevention is Worth a Pound of Cure" has as much meaning as that of Groundwater/Wellhead protection for rural drinking water supplies.

HOW DO WE GET THERE? WITH ASSISTANCE FROM THE FOLLOWING:

- Department of Environmental Quality - Water Quality Division
- Department of Civil Engineering, University of Wyoming
- Geological Survey, State of Wyoming
- Wyoming Water Resources Center, University of Wyoming
- Geological Survey, United States
- National Rural Water
- Environmental Protection Agency, Region 8
- Environmental Protection Agency, Headquarters
- Conservation Districts of Wyoming
- State Engineer's Office
- Local Boards and Councils
- Local Water System Professionals

[1] Wyoming Association of Rural Water Systems, 213 W. Birch, Glenrock, WY 82637

WE TAKE A PROACTIVE APPROACH TO:

- Prevent contamination
- Promote compliance with the Safe Drinking Water Act (SDWA)
- Decrease financial burdens on consumers and funding agencies
- Protect drinking water sources for future generations

A FIVE STEP PLAN TO PROTECT YOUR WATER SOURCE:

- Select a Planning Team
- Delineate the Protection Area
- Identify Contamination Sources
- Manage the Protection Area
- Develop a Contingency Plan

PEOPLE IN WYOMING WHO ARE MAKING A DIFFERENCE!

Albin

Burlington

Burns Brothers TS

Burns Utilities

Camp Guernsey

Centennial W&SD

Chugwater

Country Meadows

Devil's Tower Mon

Dubois

Elk Mountain

Fort Laramie

Guernsey

Hartville

Hulett

La Grange

Lake Water Co

Lingle

Lyman Reg Wtr

Manville

Maverick Motel

Medicine Bow

Newcastle

Opal

Pavillion

Pine Bluffs

Pine Haven

Point of Rocks

Riverton

Sapp Brothers TS

Shoshoni

Shoshoni Utility

Smoot

Sundance

Superior

Ten Sleep

Torrington

Vista West Water

Wamsutter

Wheatland

Winchester Hills

Wright

Our goal is to save money and resources for each system.

Wyoming has been granted two monitoring waivers:

- Asbestos - if system has no asbestos pipe
- Dioxin - waived state wide - not used in the state

Remember: "We do not inherit our world from the previous generation...we borrow it from the next".

"DO IT YOURSELF" EXPERIMENT IN WELLHEAD PROTECTION, ELK MOUNTAIN, WYOMING

W. Todd Jarvis and Benjamin Jordan[1]

ABSTRACT

In Wyoming, the development and administration of the Wellhead Protection (WHP) program is the responsibility of the Department of Environmental Quality, Water Quality Division (DEQ-WQD). While the WHP program guidance document is currently under final review prior to public release, the basic premise behind the state's program is to promote voluntary participation, and provide guidance on how to "do-it-yourself" at the local level. In response to this challenge, the Town of Elk Mountain petitioned the Nonpoint Source Pollution Task Force for funding to test whether or not a small public water system can complete the various tasks associated with a local WHP Plan at a reasonable cost.

The project is generating a WHP Plan for the Town's two wells, which develop water from the Cloverly Group (Lakota and Dakota Sandstones), an important oil and gas reservoir in Wyoming, and the sole source of drinking water for the Town of Elk Mountain. As with many small Wyoming communities, the role of oil and gas wells located near the municipal water wells as a potential source of contamination is a primary concern.

The results of the project will be useful to Wyoming communities developing WHP Plans in areas where oil and gas exploration and development occurs near deep water wells serving as a public drinking water supply. This project demonstrates that small public water systems can economically develop high quality, workable WHP Plans using the "do-it-yourself" approach outlined in the state's WHP program.

PROJECT LOCATION AND WATER SYSTEM DESCRIPTION

The Town of Elk Mountain is located in Carbon County in southeastern Wyoming. The Town is a rural, residential community composed of approximately 186 residents situated along the Medicine Bow River at an elevation of 7,268 feet. It is located three miles south of the Interstate-80 corridor, approximately 55 miles west of Laramie and 41 miles east of Rawlins.

Figure 1 depicts the location of the existing water supply wells, transmission pipelines, and storage system. Water service is provided to homes, businesses and state government facilities from two wells which derive water from the Dakota and Lakota Sandstones of the Cloverly Group encountered at depths ranging from 2,500 to 3,000 feet beneath the Town of Elk Mountain. Transmission pipelines connect the wells to an aerator which removes dissolved hydrogen sulfide (H_2S) gas from the water prior to storage in two 100,000 gallon capacity storage tanks. The stored water is then transmitted to the distribution system.

NEED FOR A LOCAL WHP PLAN

While the Environmental Protection Agency (EPA) has not formally designated the Cloverly Group as a sole-source aquifer, the Town of Elk Mountain is extremely concerned about protecting this aquifer from degradation because no other aquifers can be developed which yield the same quantity and quality of water. Developing and implementing a WHP Plan is currently one of the Town's top priorities. Two potential threats to the aquifer have been identified: (1) oil wells and petroleum test holes that may serve as conduits for low quality waters from other formations to commingle with the Cloverly Group aquifer; and (2) land use in the recharge area.

For example, the recently plugged Elk Mountain No. 1 was drilled as an oil well with the deeper Sundance Formation as the target oil reservoir. While the well produced uneconomic quantities of oil from the Sundance Formation, it flowed 63 gallons per minute (gpm) of fresh water from the Lakota Sandstone. The oil company plugged the lower oil producing part of the well and sold it to the Town for use as a water supply. Thirty years later, water produced from the well contains 11.1 mg/L oil and grease, due to apparent leakage of oil derived from the Sundance Formation either around the bridge plug that was designed to isolate the lower part of the well, or from the shallower Niobrara Formation through possible perforations corroded in the well casing in places where little cement was used to seal the casing. This well and others like it, may contribute oil and high salinity waters to the Cloverly Group in the vicinity of the Town's wellfield.

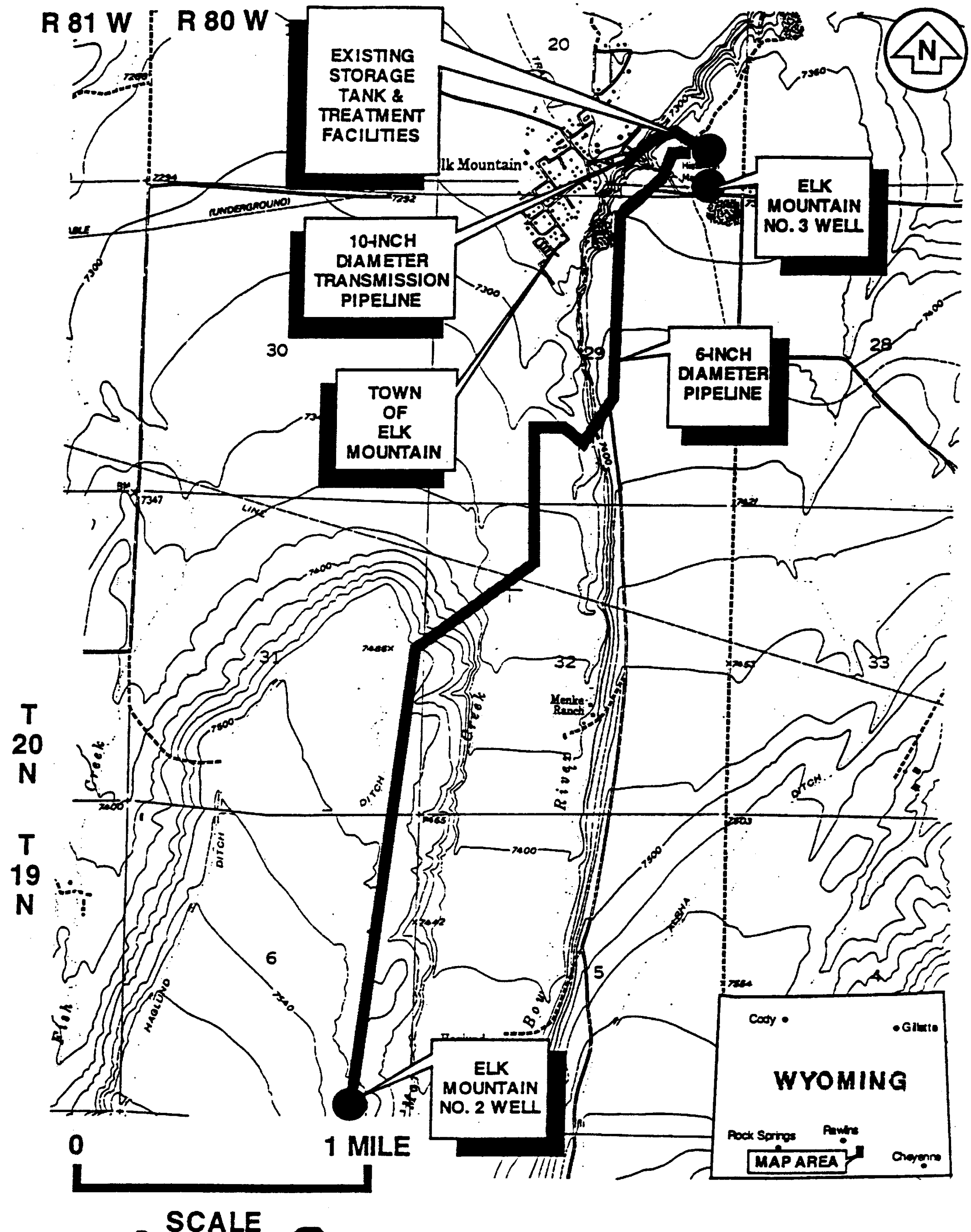
WELLHEAD PROTECTION PLAN ELEMENTS

The following five elements will comprise the majority of local WHP Plans in Wyoming.

- Formation of a Local Wellhead Protection Committee
- Delineation of WHP Areas
- Identification of Existing and Potential Contaminant Sources
- Management Approaches
- Contingency Plan

Local wellhead protection programs completed within Wyoming to-date have determined that

[1] Weston Engineering, Inc., P.O. Box 3166, Laramie, WY 82070



WESTON
GROUNDWATER • ENGINEERING

Figure 1: Elk Mountain WHP Plan --Water System Location Map

implementation of a public participation program must be initiated early to guarantee public acceptance of any WHP Plan.

The following sections provide an overview of the Town's approach to meeting the requirements of each WHP Plan element.

LOCAL WELLHEAD PROTECTION COMMITTEE

Formation of the Town of Elk Mountain WHP Planning Committee was completed at one Town Council meeting and includes the Mayor, two Council members, the water system operator, and two interested citizens (stakeholders) who participated when their schedule permitted. The groundwater technician from the Wyoming Association of Rural Water Systems (WARWS) participated at most meetings. A representative from the DEQ-WQD and a technical consultant attended select meetings when a technical or political milestone was reached.

DELINEATION OF WHP AREAS

The first task of the Elk Mountain WHP Committee was to identify and map the area that supplies water to their wellfield. The Wyoming-adopted criteria for the delineation of local wellhead protection areas (WHPAs) are based on the type of aquifer from which a particular well or wellfield produces groundwater. In general, the recommended criteria include a fixed radius, coupled with the groundwater time-of-travel (TOT) and flow system boundaries determined from hydrogeologic mapping or analytical models. The adopted delineation criteria are based on the use of three WHPAs described in later sections of this paper.

Because of the wealth of hydrogeologic data collected during the course of completing a water supply master plan and drilling a replacement well for the Town of Elk Mountain under the auspices of the Wyoming Water Development Commission (WWDC), the Elk Mountain WHP Committee retained a technical consultant to complete the WHPA delineations for the two wells. An overview of the local hydrogeologic setting is presented in the following sections to justify the technical approach to WHPA delineation.

Hydrogeologic Setting. The Town of Elk Mountain is located in the Pass Creek Basin. Strata along the basin margin have been folded inward into a north plunging, asymmetrical syncline bordered on the east and west by asymmetrical anticlines. The anticline cored by the Arlington Fault separates Pass Creek Basin from the Laramie Basin to the east; the Elk Mountain uplift marks the western boundary. Localized deformation in the area is typified by north-south trending anticlines and synclines superimposed on the basin margins (Saulnier, 1968).

As shown on Figure 2, drilling depths to and groundwater circulation within the various bedrock aquifers are controlled by the structural geology of the area. The typical fault-cored fold in the Pass Creek Basin is an asymmetric anticline less than one mile in breadth. The geometric form of the fault is based on seismic profiles across other anticlines in Wyoming (see Stone, 1985) and local well control.

Groundwater Circulation in the Cloverly Group Aquifer. The principle sources of recharge to the Cloverly Group are snow melt and infiltration from streams flowing over the outcrop located east and south of Elk Mountain. Based on the shut-in pressures and wellhead elevations of the three wells tapping the Cloverly Group in the Elk Mountain area, groundwater circulates northwesterly from the recharge area. Local large displacement thrust faults sever the hydraulic continuity of the aquifer along the eastern margin of the Elk Mountain uplift, and the northeastern margin of the Pass Creek Basin along the Arlington Fault.

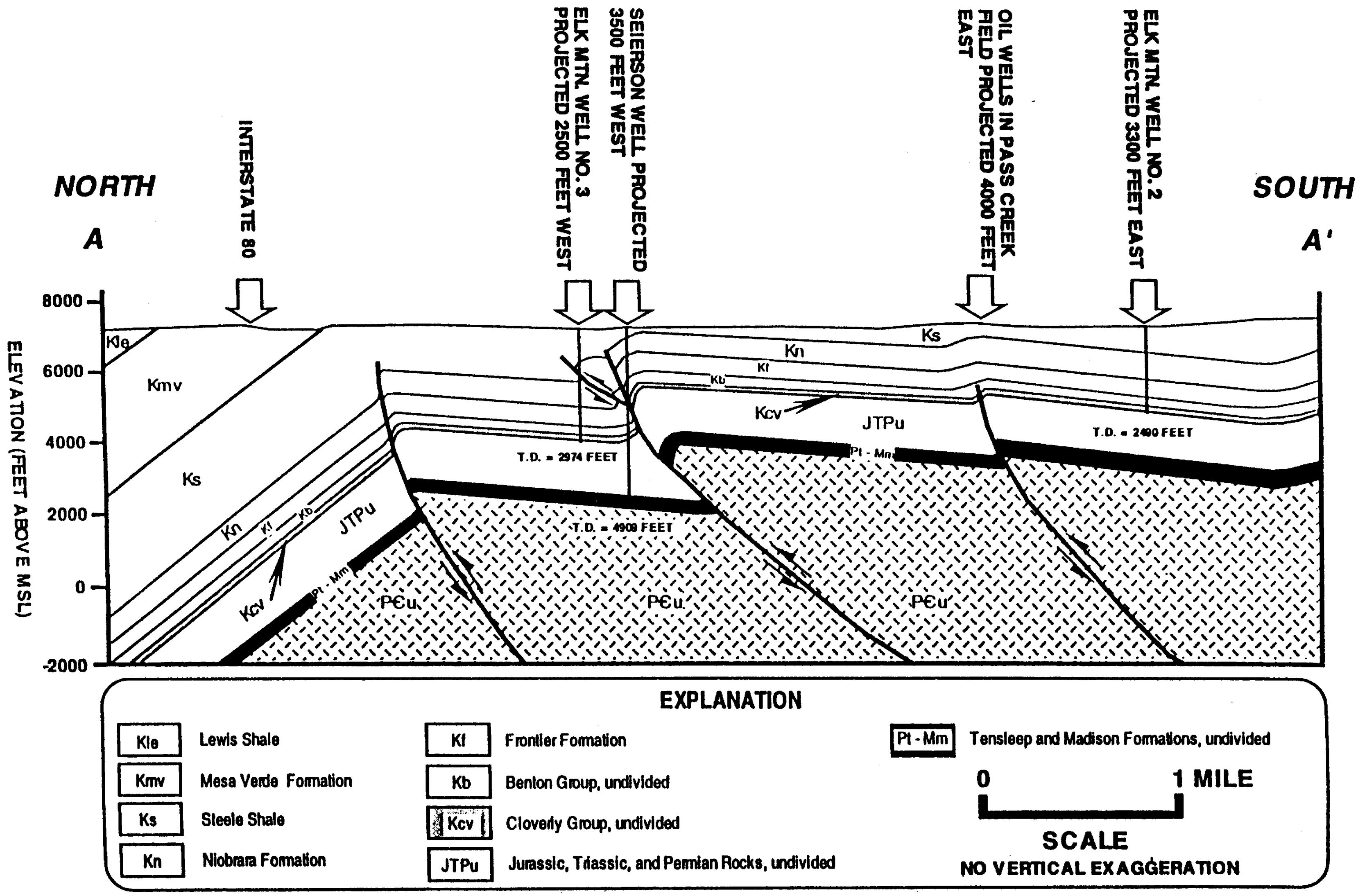
Sampling of the natural flow from Elk Mountain Well No. 3 for tritium determined that the groundwater TOT from the recharge area to the deep wells serving the Town is greater than 44 years.

Well Construction Data. The water supply wells are between 2,500 and 3,000 feet deep. As shown on Figure 3, the Town's wells are open only to the Cloverly Group; shallower formations have been sealed by steel casing and cement. Both Elk Mountain Well Nos. 2 and 3 tap a confined aquifer with shut-in pressures ranging from 50 to 60 psi. Evaluation of the cement seal on Elk Mountain Well Nos. 2 and 3 using cement bond logging methods verified that the surface seals are within 200 to 600 feet of the ground surface.

Aquifer Testing Data. Hydraulic parameters for the aquifer were determined using data and calculations from flow and pump tests of the Town's wells as outlined in the WWDC-sanctioned Level I and Level II Water Supply Project reports (see WESTON, 1995a,b). Table I summarizes the various aquifer parameters determined from these aquifer testing programs.

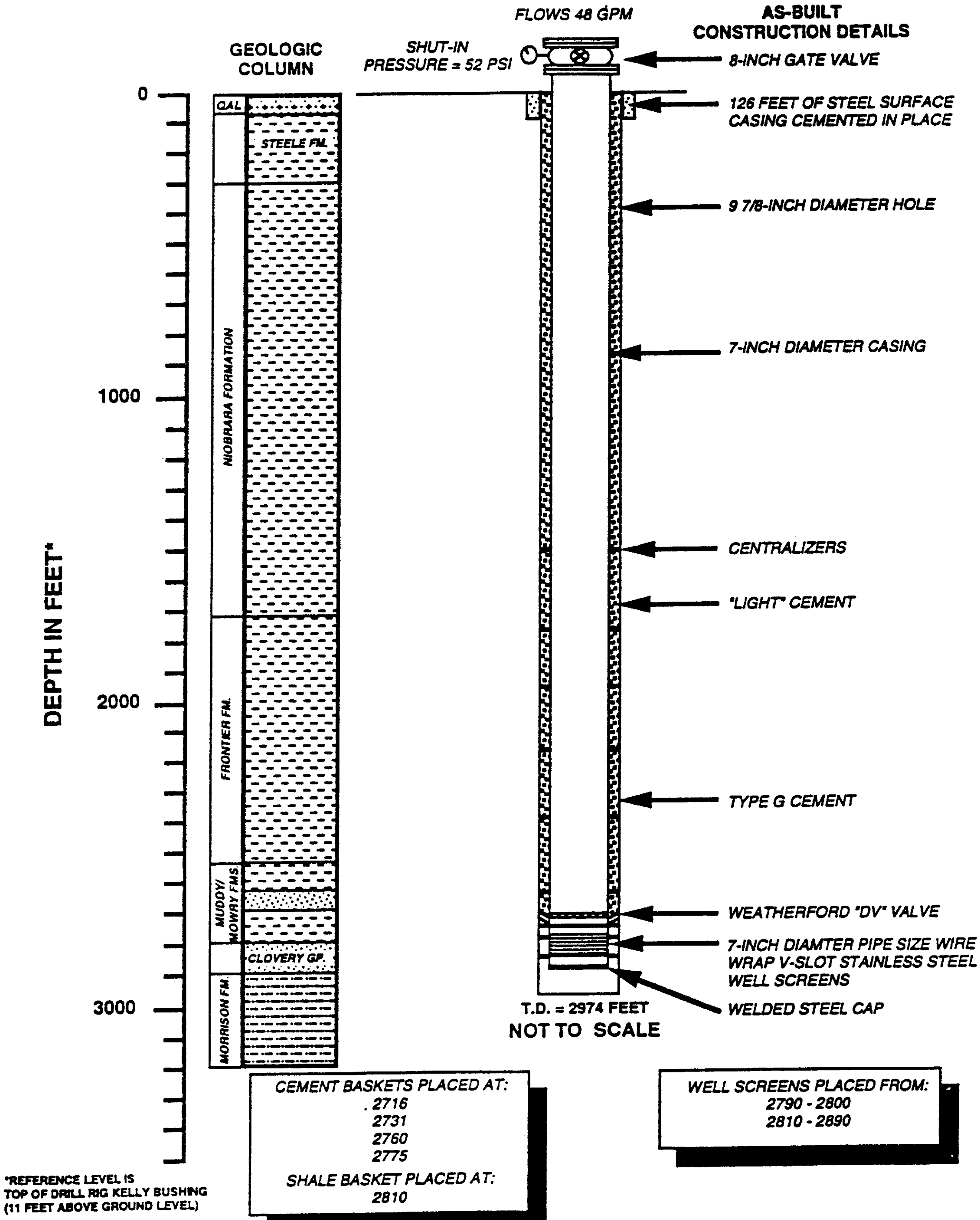
WHPA Zone One (Accident Prevention Zone). The boundary of Zone One is set at an "arbitrary" fixed radius of 50 feet or 100 feet from the well or spring, and is dependent on factors such as the depth of the well, the type and depth of the surface and annular seal, and the type, number and proximity of potential contaminant sources.

Because both wells were (1) constructed according to DEQ-WQD rules and regulations, (2) completed in a confined aquifer with diffuse flow, and (3) were determined to have low or moderate



WESTON
GROUNDWATER • ENGINEERING

Figure 2: Elk Mountain WHP Plan—Schematic Geologic Cross Section



WESTON
GROUNDWATER • ENGINEERING

Figure 3: Elk Mountain WHP Plan -- As-Built Diagram of Town Well

susceptibility based on the cement bond logging program, the wells qualify for a 50-foot radius for Zone One.

Methods Used to Delineate WHPA Zones Two and Three. The proposed criteria for Zone Two called the attenuation zone are based on a TOT of 180 days or a minimum of a 400-foot radius (whichever is greater) for wells with porous or diffuse flow characteristics. Zone Two is established to protect the well from pathogenic microorganisms from a source located close to the well and to protect the well from the direct introduction of contaminants into the aquifer from nearby spills, surface runoff, or leakage from storage facilities or containers.

Zone Three is defined as the remedial action zone which uses a 5-year TOT with appropriate flow boundaries for the porous aquifers. Zone Three is designed to protect the wellhead from chemical contaminants that may migrate to the wellhead within a 5-year time period for porous aquifers.

Given the aquifer parameters determined from various aquifer tests during the course of the WWDC-sponsored projects, the WHPAs were delineated using a semi-analytical model tempered with hydrogeologic mapping. WHPA, version 2.2, developed by Blandford and Hyakorn (1993) is a semi-analytical groundwater flow model that consists of four computational modules designed to delineate WHPAs. Two protection zones based on the 180-day and 5-year TOTs were defined for the Elk Mountain wells using the GPTRAC module of the WHPA model. The GPTRAC module was used for WHPA delineation because (1) time-related capture zones for pumping wells are delineated, (2) confined aquifers can be simulated, (3) well interference can be simulated, and (4) various hydrogeologic boundaries can be incorporated into the numerical analysis.

Recalling the Elk Mountain wells develop water from the confined Cloverly Group aquifer, the WHPAs were determined based on the assumption that the hydraulic properties of the aquifer remain consistent over the study area - a fact borne out by the numerous aquifer tests of the Town's wells spread over a three mile area (see Table I). The 180-day and 5-year TOT protection areas were estimated for the Town's two wells using the input values listed in Table II. Plots of the 180-day and 5-year TOTs for both wells are depicted on Figure 4.

Sensitivity Analysis. No other wells in the Elk Mountain area were found to be producing from the Cloverly Group. Wells producing from other geologic units have no impact on the Town's wells because of the hydraulic isolation of the Cloverly Formation from other water-bearing units by low permeability shales found stratigraphically above and below this aquifer.

Because of the variable spacing between the three wells tapping the Cloverly Group in the Elk Mountain area, the input parameter with the greatest uncertainty in this study was the hydraulic gradient. However, varying the hydraulic gradient by an order of magnitude in the GPTRAC module did not make a significant difference in the size or shape of the WHPAs for the Elk Mountain wells.

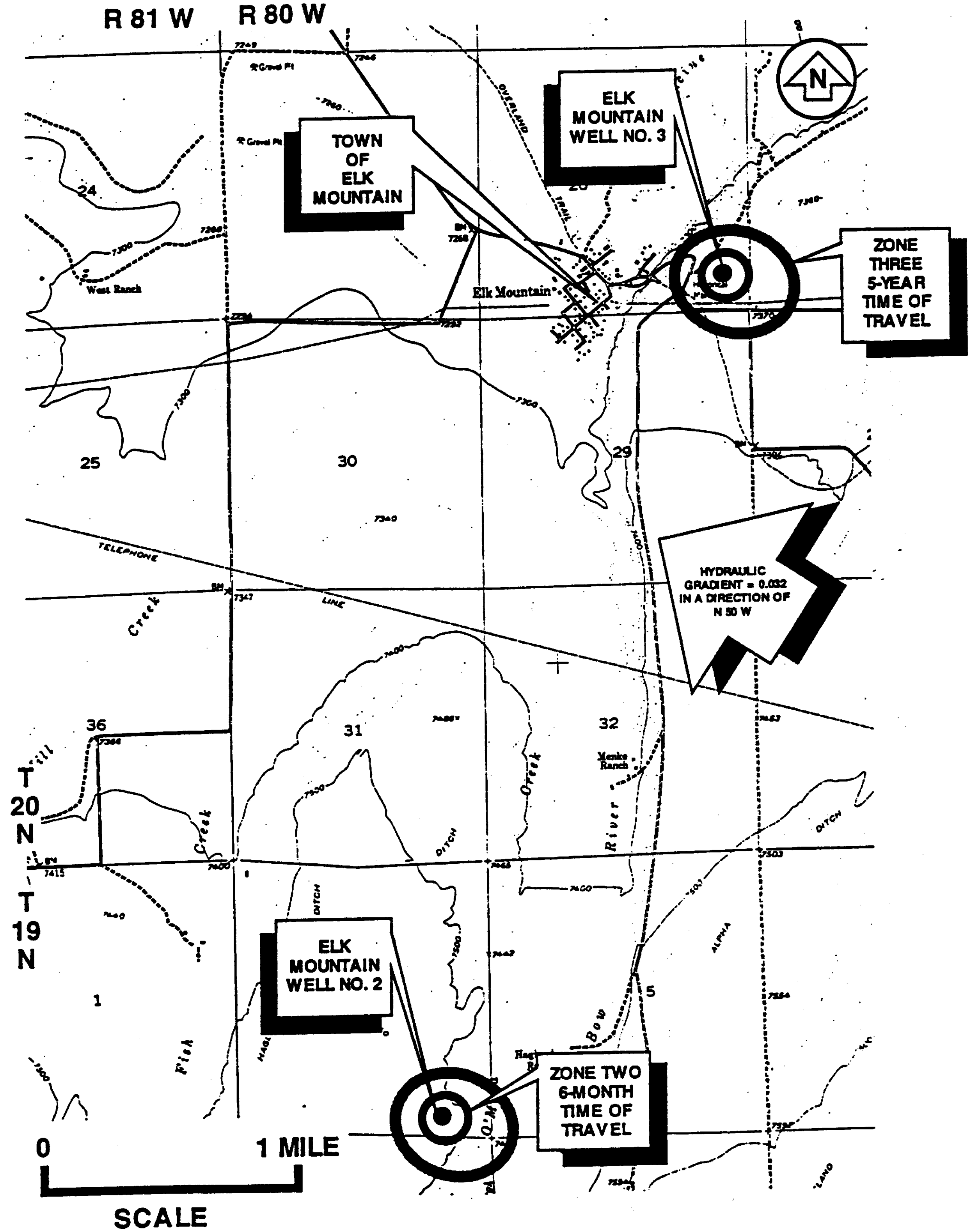
The hydraulic influence of the inferred fault located south of Well No. 3 remains problematic (see Figure 2). To conservatively estimate the WHPAs for the Elk Mountain wells, the fault was simulated as a low permeability boundary located 1,600 feet south of Well No. 3. There were no perceptible differences in the sizes or shapes of the WHPAs with or without the fault based the WHPA model output.

Table 1
Aquifer parameters determined from WWDC Elm Mountain Water Supply Projects

Location and Date of Tests	Aquifer Thickness (feet)	Trans-missivity (gal/day/ft)	Hydraulic Conductivity (ft/day) *	Porosity (percent) **	Discharge Rate (gpm)	Hydraulic Gradient and Direction
Well No. 2 Aug. 1994	90	1040	11.55	18	150	0.032 Northwest
Well No. 3 Oct. 1995	90	1130	12.55	18	140	0.032 Northwest

*Calculated based on transmissivity and saturated thickness.

**Determined from porosity log in Well No. 3.



WESTON GROUNDWATER • ENGINEERING

Figure 4: Elk Mountain WHP Plan -- WHPA Map

Table 2
Input values for WYPA zone two and three delineations

Well Name	Pumping Rate (ft^3/day)	Well Radius (feet)	Trans-missivity (ft^2/day)	Aquifer Thickness (feet)	Porosity	Hydraulic Gradient and Direction
No. 2	28,877	0.66	133.7	90	18	.032 Northwest
No. 3	26,952	0.54	151.1	90	18	.032 Northwest

IDENTIFICATION OF EXISTING AND POTENTIAL CONTAMINANT SOURCES

The potential sources of groundwater contamination were inventoried by the Town's WHP Planning Committee using a site reconnaissance and windshield surveys to identify and confirm the locations of potential sources, as well as review of the readily available State of Wyoming and EPA databases. Based on this inventory, the Town's WHP Planning Committee determined that active and historic oil exploration and production from the Pass Creek Basin pose the major threat to the integrity of the Town's water supply. While reviewing the plugging and abandonment records of old wells using files maintained by the Wyoming Oil and Gas Commission, the Town discovered the University of Wyoming Department of Electrical Engineering was conducting research to determine the risk posed by old petroleum test holes potentially serving as conduits for commingling of formation waters through improperly placed plugs. The University of Wyoming consented to assisting the Town by conducting a pilot study of their technical approaches on local abandoned oil exploration wells (the preliminary results of the University of Wyoming's work are the subject of another paper presented at this conference).

MANAGEMENT APPROACHES

Implementation of a management plan for existing and future potential contaminant sources can rely on regulatory and non-regulatory approaches. Considering that (1) surface activities within the delineated WHPAs would probably have little to no impact on the Cloverly Group aquifer due to the nearly 2,000 to 3,000 feet of low-permeability shale and siltstones between the land surface and the developed aquifer, and (2) the apparent long groundwater TOT for recharge to circulate to the existing water supply wells based on the tritium data, the Elk Mountain WHP Planning Committee will rely primarily on a non-regulatory approach to managing potential contaminant sources within the WHPAs and a regulatory approach for portions of the recharge area.

Education And Information. The WHP Planning Committee is using a education and information brochure to alert local industrial concerns of their efforts at implementing a WHP Plan. A letter writing campaign was initiated targeting potential users of the Cloverly Group aquifer. Likewise, the brochure will be circulated to area residents to promote protection of the recharge area.

The brochure and WHP Plan will also be submitted to the Wyoming Oil and Gas Conservation Commission (WOGCC) to alert potential operators of the "sensitive" areas near the Town's wells to promote voluntary cooperation in developing drilling programs and well completions designed to protect the Town's drinking water supply.

Sole Source Aquifer Petition. The stratigraphic section in the Pass Creek Basin is composed of sedimentary rocks up to 6,200 feet in thickness (Gries, 1964; Richter, 1981). WESTON (1995a) determined that development of water from aquifers other than the Cloverly Group is not economically feasible in the vicinity of the Town of Elk Mountain.

Given the unique quality of water (less than 200 mg/L TDS) developed from the Town's wells tapping the Cloverly Group, coupled with a large part of the recharge area lying within federally-owned land, the Town's WHP Planning Committee elected to apply for special protection for the Cloverly Group aquifer using the Sole Source Aquifer program. The Sole Source Aquifer program was established under Section 1424(e) of the Safe Drinking Water Act (SDWA) of 1974 (see EPA, 1987). This section authorizes the regional EPA Administrator to determine that an aquifer is the "sole or principal" source of drinking water for an area. The program also provides for EPA review of Federal financially-assisted projects planned for the area to determine their potential for contaminating the aquifer.

CONTINGENCY PLAN

The State-wide WHP Guidance Document recommends each public water system (PWS) prepare a contingency plan to provide potable water to the public during emergencies. Potential emergencies such as well or, wellfield contamination, water shortages due to droughts, and interruption of water supply comprise items to be addressed in a contingency plan.

The immediate threats to Elk Mountain's water system include a landslide that regularly breaks the transmission pipeline from Well No. 2 and deep petroleum test wells. Given the water system operator usually is the first person to identify and respond to water supply emergencies, the Town of Elk Mountain's water system operator prepared the local contingency plan. The water system operator prepared a roster of the Emergency Response Team, and inventoried equipment and contractors to be mobilized in the event of an emergency or contamination incident. Part of the Emergency Response Plan included simply contacting all of the Town's residents by telephone.

New well locations were identified in the Town's water supply master plan prepared by WESTON (1995a) as part of a WWDC-sponsored Level I project.

PUBLIC PARTICIPATION

As the completion of the Town of Elk Mountain's WHP Plan nears in the coming months, the Town has developed an Information and Education Brochure which has been distributed to the local water consumers. Brochures have been provided to the WARWS so that the lessons learned during this project can be passed on to other small water systems and to other communities whose wellfields are located in close proximity to areas undergoing active and inactive oil exploration and production. Likewise, the Town is using the program to educate the school children of the value of their unique water supplies.

CONCLUSIONS

Although a few other Wyoming communities have delineated WHPAs, those communities are all significantly larger than Elk Mountain and face very different threats to their water supply. The Town of Elk Mountain relies entirely on the Cloverly Group (Lakota and Dakota Sandstones) for its municipal drinking water. Protection of water quality in this aquifer is vital to the Town because extensive studies have shown that the Town has no reasonable alternatives for its drinking water supply.

By dedicating the time of Town staff and utilizing the volunteer efforts of residents to complete most of the requisite tasks, Elk Mountain has demonstrated that community residents can work together to develop a quality WHP Plan for a minimal investment. Elk Mountain's WHP project has provided a field check of the utility and practicality of the "do-it-yourself" process emphasized by the State's program, and will be useful to help similar-sized Wyoming communities develop WHP Plans in areas where oil and gas exploration and development occurs near deep water wells serving as a community drinking water supply.

REFERENCES

Blandford, T.N., Huyakorn, P.S., and Wu, Yu-Shu, 1991, WHPA - Wellhead Protection Area Delineation Code, Version 2.2: Modular Semi-Analytical Model Computer Code and User Manual available from the International Ground Water Modeling Center, Institute for Ground-Water Research and Education, Colorado School of Mines, Golden, CO.

Environmental Protection Agency (EPA), 1987, Sole Source Aquifer Designation Petitioner Guidance: Office of Ground-Water Protection, EPA 440/6-87-003, 30 pp.

Gries, J.C., 1964, The structure and Cenozoic stratigraphy of the Pass Creek Basin Area, Carbon County, Wyoming. M.S. thesis, University of Wyoming.

Richter, H.R., 1981, Occurrence and characteristics of ground water in the Laramie, Shirley, and Hanna Basins, Wyoming. *Water Resources Research Institute of the University of Wyoming: Report to U.S. Environmental Protection Agency*. Volumes III-A and B.

Saulnier, G.J., 1968, Ground water resources and geomorphology of the Pass Creek Basin Area, Albany and Carbon Counties, Wyoming. M.S. thesis, University of Wyoming.

Stone, D.S., 1985, Geologic interpretation of seismic profiles, Bighorn Basin, Wyoming, Part 1: in *Seismic Exploration of the Rocky Mountains, Rocky Mountain Association of* Geologists and the Denver Geophysical Society publication, Denver, Colorado.

Weston Engineering, Inc., (WESTON), 1995a, Elk Mountain Water Supply Master Plan, Level I. Consultant's report prepared for the Wyoming Water Development Commission and the Town of Elk Mountain.

WESTON, 1995b, Elk Mountain Water Supply Project, Level II. Consultant's report prepared for the Wyoming Water Development Commission and the Town of Elk Mountain.

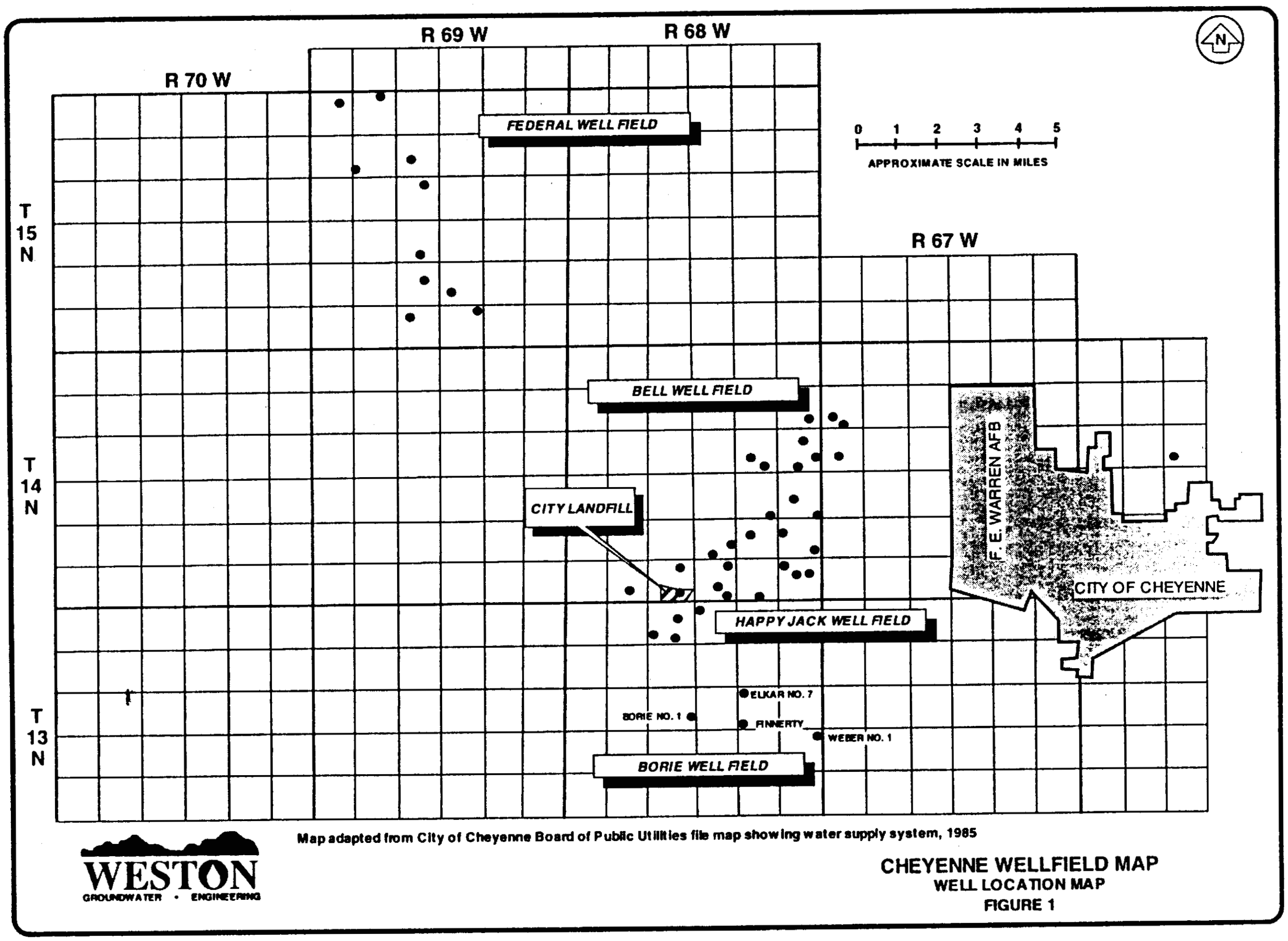
UTILIZING WATERSHED MANAGEMENT IN CONJUNCTION WITH WELLHEAD PROTECTION IN THE CHEYENNE BOARD OF PUBLIC UTILITIES BORIE WELLFIELD, LARAMIE COUNTY, WYOMING

Benjamin J. Jordan, W. Todd Jarvis, and Dr. Peter Huntoon[1]

ABSTRACT

The City of Cheyenne has utilized groundwater from the Borie wellfield since 1945. The wellfield is located approximately 6 miles southwest of Cheyenne and contains 4 municipal water wells (See Figure 1). The wells include Borie 1, Weber 1, Elkar 7 and Finnerty 2. The wells all produce from the Ogallala and/or White River Formations and range in depth from 210 feet to 395 feet. The Borie 1 and Elkar 7 wells were rehabilitated in 1995 and Weber 1 was rehabilitatied in 1994; Finnerty 2 is approximately 50 years old. In 1996 the City of Cheyenne decided to participate in the Wyoming Wellhead Protection Plan to protect its wells from contamination.

Lone Tree Creek is an ephemeral stream that flows east out of the Laramie Range and passes less than a mile to the south of the Borie wellfield. The stream is hydraulically upgradient from and recharges the



CHEYENNE WELLFIELD MAP
WELL LOCATION MAP
FIGURE 1

[1] Weston Engineering, Inc., P.O. Box 6037, Laramie, WY 82070 and Professor, Dept. of Geology & Geophysics, UW, Laramie, WY 82071, respectively.

Cheyenne municipal wells. It is estimated that it takes less than a week for water to flow 23 miles, from the headwaters of the creek to the Borie wellfield. Water from the stream takes approximately 6 years to reach the Borie 1 well, based on time of travel calculations. It is highly probable that any conservative contaminants in the creek will contaminate the Borie wellfield. To better protect the Borie wellfield, Cheyenne has begun to implement a Watershed Management Program for Lone Tree Creek, in concert with the Borie Wellhead Protection Plan.

WELLHEAD PROTECTION

SUMMARY OF GEOLOGIC DATA

The City of Cheyenne and its wellfields are located along the northwestern margin of the Denver-Julesburg structural basin. The Tertiary Ogallala and White River Formations compose the principal aquifers for the municipal wells. The discussion below is a very brief overview of the Tertiary rocks which supply water to the Cheyenne municipal wells.

WHITE RIVER FORMATION

The White River Formation consists predominantly of pale, fine-grained rocks with a high proportion of volcanic ash, and of minor sandstone and conglomerate. Thickness estimates range from a few hundred to over 1,000 feet (Lowry and Crist, 1967). In most areas, the White River Formation has been divided into a lower unit, the Chadron Formation, and an upper unit, the Brule Formation. The Chadron Formation contains siltstone, mudstone, claystone, minor fine- to coarse-grained sandstone, and rare conglomerate, generally at the base. The distribution of calcite cement is variable and some sandstones and conglomerates are tightly cemented by silica.The Brule Formation is mostly siltstone but also contains minor mudstone, claystone, sandstone, and rare limestone, volcanic ash, and conglomerate. Many authors have mentioned the blocky appearance and the fractures and "fissures" in Brule outcrops (Lowry and Crist, 1967). Extensive clastic dikes, usually sub-vertical, have also been reported.

ARIKAREE FORMATION

The Arikaree Formation is absent in the area of the Borie Wellfield. The Arikaree Formation is exposed below the Ogallala Formation along the northern escarpment of the Gangplank and in small areas to the east and southeast of Cheyenne (Bart, 1975), but apparently not to the west or southwest of Cheyenne. The regional cross sections of Cooley and Crist (1981) show the southernmost extent of the Arikaree being near the boundary of Townships 14 and 15 North, which is approximately 6 miles to the north of the Borie wellfield.

OGALLALA FORMATION

The Ogallala Formation is exposed at the land surface throughout the Borie Wellfield. The general lithologic character of the Ogallala Formation is distinctly different from the Arikaree and White River Formations. It is more heterogeneous, has a greater proportion of coarse-grained detritus, has

Table 1
Aquifer Parameters Used in Wellhead Protection Delineations

Well Name	Pumping rate (gpm)	Well radius (feet)	Transmissivity (gpd/ft)	Aquifer Thickness (feet)	Hydraulic gradient (no units)	Direction (degrees)
Borie 1	1000	.83	75,000	50	.0087	35
Elkar 7	375	.83	37,000	100	.0069	23
Finnerty 2	350	.67	13,200	100	.0120	26
Weber 1	350	.83	5,800	150	.0110	351

only a minor component of volcanic ash, and is almost entirely of alluvial origin. The total depositional thickness of the Ogallala Formation in the wellfield area is on the order of 300-600 feet.

The Ogallala Formation is composed of well-sorted to poorly sorted, fine- to coarse-grained sandstone, granule to pebble conglomerate, siltstone and minor beds of claystone, volcanic ash, and limestone. The Ogallala Formation southwest of Cheyenne differs from the Ogallala Formation found elsewhere. Outcrops observed in the Cheyenne wellfields are dominantly very clay-rich, variably calcite-cemented, very fine- to medium-grained sandstones with variable proportions of coarse sand, granules, and cobbles as disseminated grains or concentrated in streaks and lenses.

DELINEATION OF WELLHEAD PROTECTION AREAS

Three Time of Travel (TOT) protection zones based on 180 days, 1 year, and 5 years were defined using the RESSQC module of the EPA Wellhead Protection Area (WHPA) Model, Version 2.2, dated September 1993 (Blandford and Huyakorn, 1993). The RESSQC module was selected for use with Elkar 7, Finnerty 2, and Weber 1 because it: (1) delineates time-related capture zones for pumping wells; (2) allows the aquifer to be confined; and (3) accounts for the effects of well interference. The GPTRAC model was used to delineate the protection areas for Borie 1 because it: (1) delineates time-related capture zones for pumping wells; (2) allows the aquifer to be semi-confined; and (3) accounts for the effects of well interference.

All of the wells in the Borie field derive water from the Ogallala and Brule Formations. Although it is known that the Ogallala Formation is not laterally continuous in hydrologic properties, no significant boundary effects were noted in pump tests completed in the Borie Wellfield by Weston (1996). The model was run following the assumption that the aquifer is relatively homogeneous in each, individual WHPA.

The hydrogeologic values utilized in the WHPA model for the municipal wells are displayed in Table 1.

The pumping rates for Borie 1, Elkar 7, and Weber 1 are based on their safe yield, as determined from pump tests. The safe yield is defined as the amount of groundwater one can withdraw "without getting into trouble" (Lohman, 1972). In the Borie Wellfield trouble occurs when the water level drops below the pump setting. The pumping rate for Finnerty 2 is based on its adjudication. The transmissivities are the results of pump tests performed on the wells by Weston Engineering (1995) during the 10 Well Rehabilitation Project and by pump tests performed by Wester-Wetstien (1994) during the rehabilitation of Weber 1. The aquifer thicknesses were determined from Lowry and Crist (1967), Plate 2, and from lithologic and geophysical logs (Weston, 1996). Horizontal hydraulic gradients were determined from Water Supply Paper 1367, Plate 2 (Lowry and Crist, 1967). Porosity logs are not available for the wells in the Borie wellfield. According to the textbook, Groundwater, by Freeze and Cherry (1979) unconsolidated sands and gravels have porosities of 20 to 50 per cent, while sandstones have porosities of 5 to 30 per cent. A porosity of 15 per cent was used in this study, which is a conservative estimate.

Private water wells were not included in the delineations for Borie 1, Elkar 7, and Finnerty 2. A survey of wells in these areas shows that pumping rates of the private wells are low enough to preclude large drawdowns near the municipal wells. The WHPA model of Weber 1 did include nearby industrial wells which have large enough pumping rates to affect the shape of the WHPAs.

The 180 day TOT, 365 day TOT, and 5 year TOT Protection areas for the Borie wells are depicted in Figure 2.

IDENTIFICATION OF EXISTING AND POTENTIAL CONTAMINANT SOURCES

Once WHPAs were delineated for the Borie wells, potential contaminant sources within the protection areas were identified. The potential contaminant source inventory was completed by a review of EPA and Wyoming DEQ databases and by site visitation to identify and confirm the locations of potential sources. The databases revealed no potential contaminant sources. However, numerous sources were identified during the site visits. These contaminant sources include abandoned vehicles, the Union Pacific Railroad, private water wells, residential septic systems, vehicle maintenance shops, above ground storage tanks, oil wells, a refuse pit, and agricultural land use.

WATERSHED MANAGEMENT

FLOWS IN LONE TREE CREEK

Lone Tree Creek flows most of the year in its upper reaches over the relatively impermeable Sherman granite. Flows are diminished where it crosses onto the Casper Formation. Lone Tree Creek is ephemeral as it passes over the White River and Ogallala Formations. The creek becomes a losing stream in this area, which indicates that it is recharging the Tertiary aquifers. In October, 1996 flow in the stream was estimated to be 235 gpm before reaching the Tertiary aquifers, and flow ceased before the stream reached the Borie wellfield. It can be concluded that at least 235 gpm is recharged to the Tertiary aquifers. Downstream of the Borie Wellfield stream flow becomes perennial once again.

DETERMINATION OF MANAGEMENT AREA

The boundaries of the watershed management area were determined by the likelihood of a contaminant reaching the recharge area of the Borie Wellfield. It is estimated that water entering the creek at its headwaters would take 4 to 6 days to reach the recharge area directly upgradient from the Borie Wellfield. A period of less than a week would not allow for the decomposition or immobilization of most contaminants. The short travel time of water in Lone Tree Creek would seem to necessitate including the entire watershed, down to the Borie Wellfield. However, it is unrealistic to manage such a large area, therefore it was decided to create a watershed management area that encompasses the watershed a distance 10 miles upstream from Borie Wellfield (Figure 3). This management area covers the most populated and most heavily used section of the watershed, down to the wellfield.

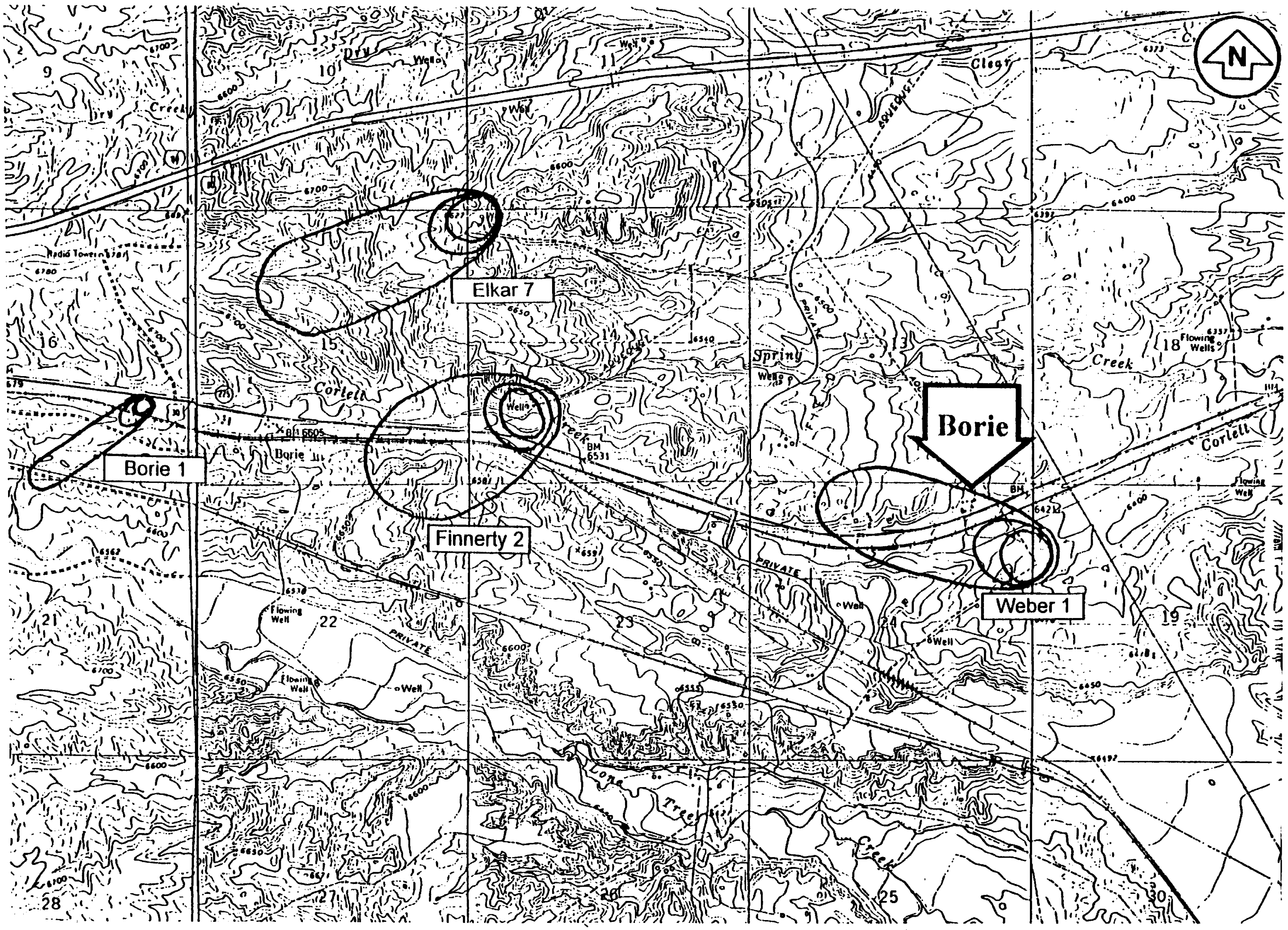


Figure 2. Wellhead Protection Areas

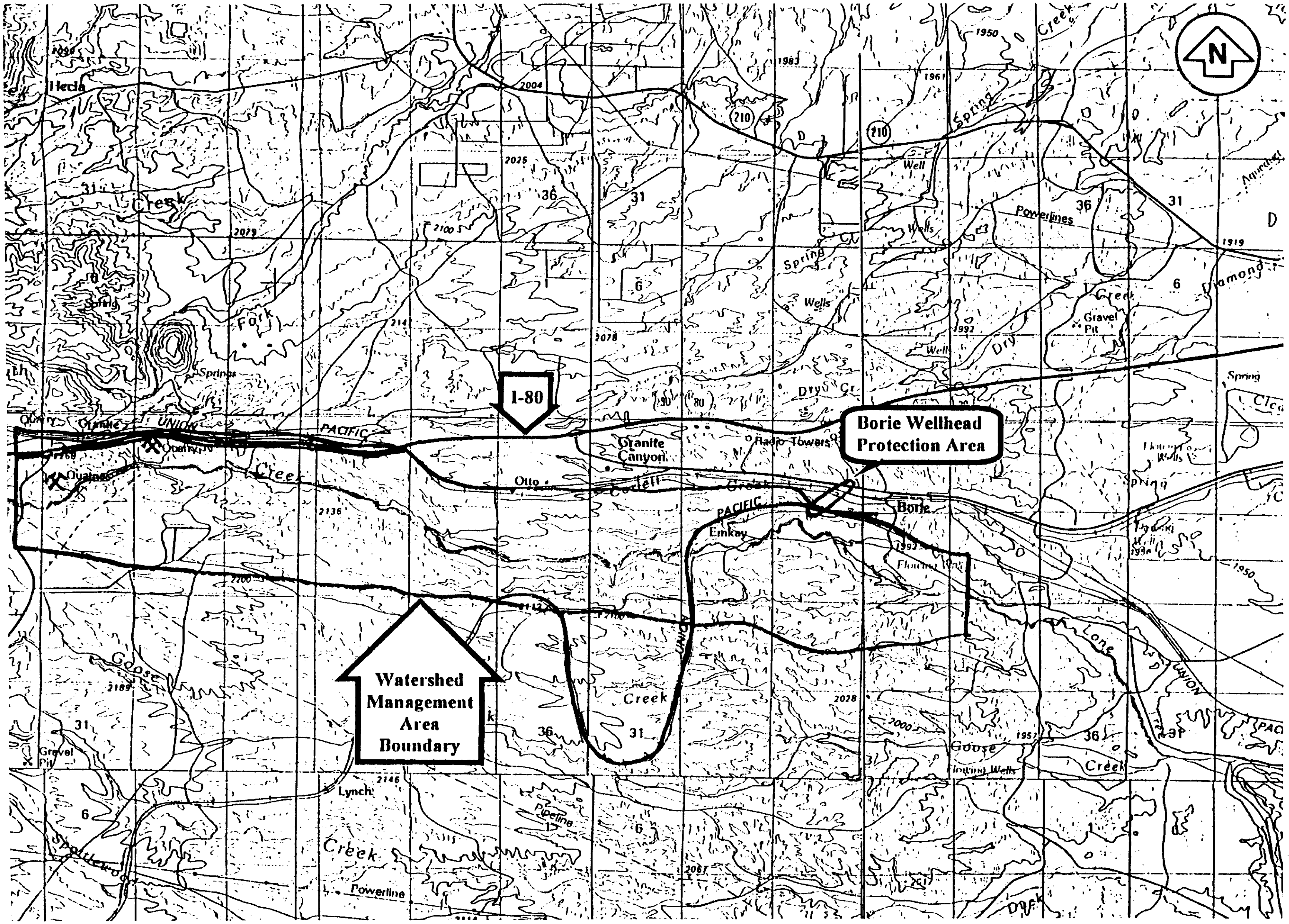
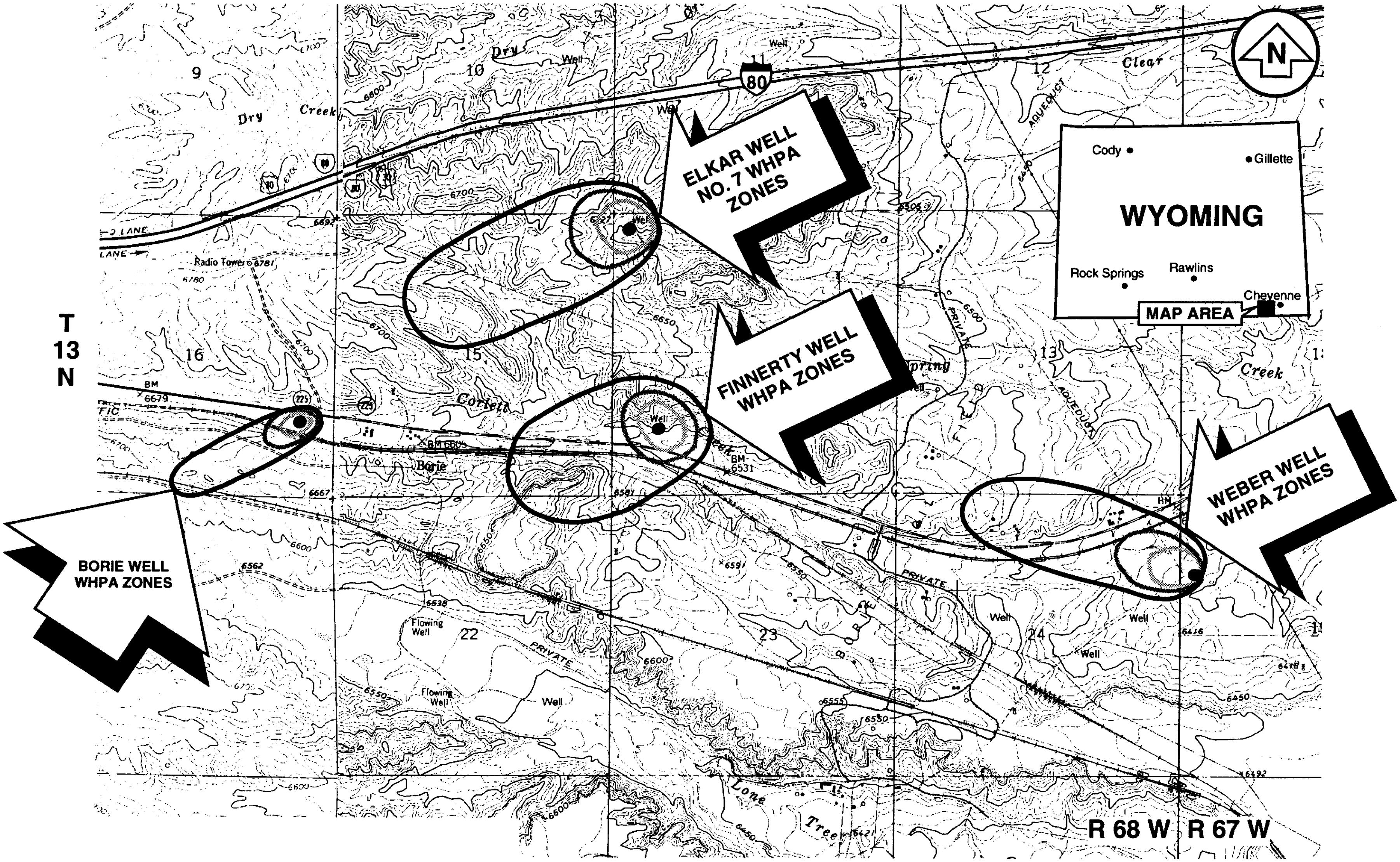


Figure 3. Lone Tree Creek Watershed Management Area

0 2
SCALE (Miles)

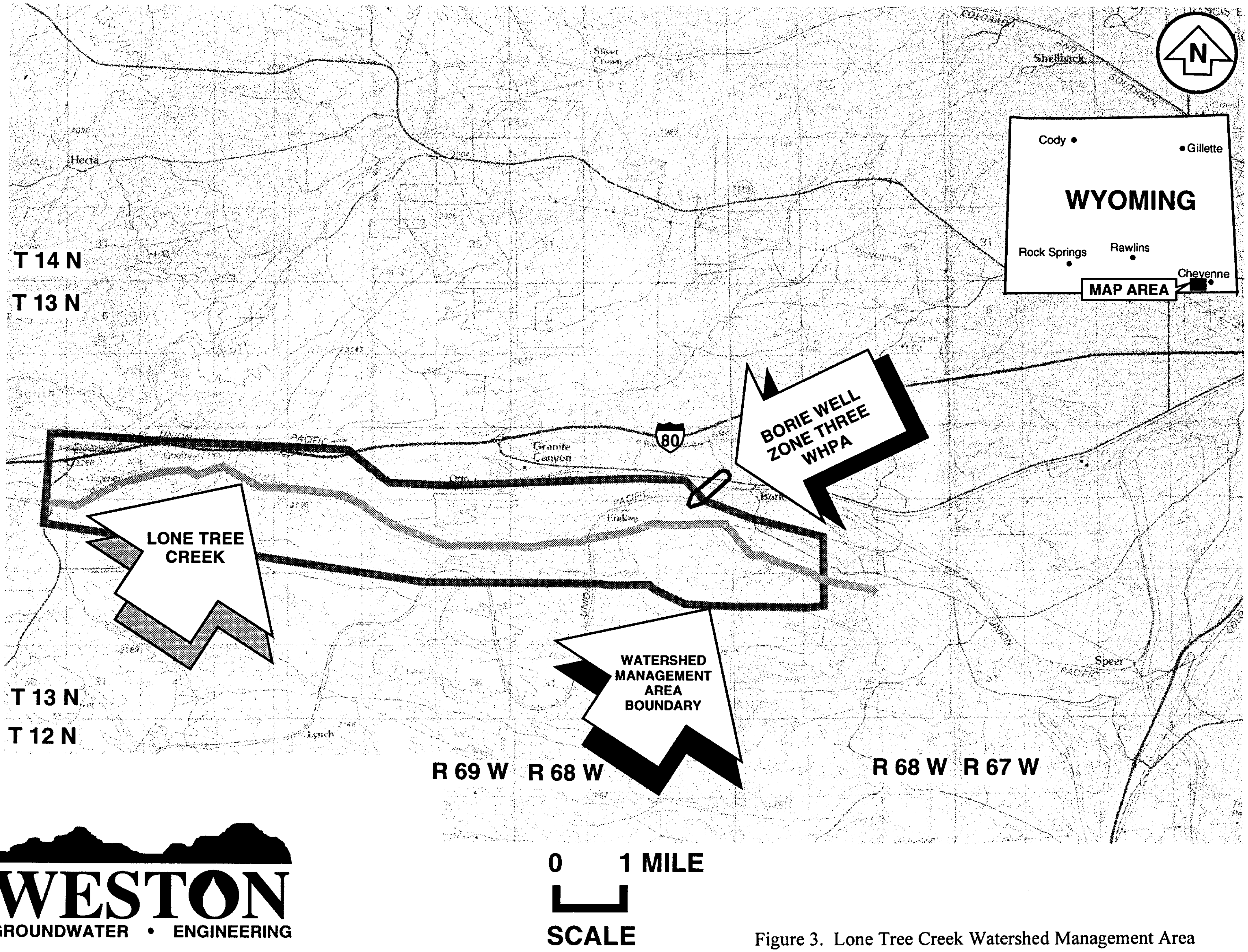


0 1 MILE

SCALE

WESTON
GROUNDWATER • ENGINEERING

Figure 2. Wellhead Protection Areas - Borie Wellfield



WESTON
GROUNDWATER • ENGINEERING

Figure 3. Lone Tree Creek Watershed Management Area

IDENTIFICATION OF EXISTING AND POTENTIAL CONTAMINANT SOURCES

After designating the boundaries of the Watershed Management Area, potential contaminant sources within the protection area were identified. The potential contaminant source inventory was completed by a review of EPA and Wyoming DEQ databases and by site visitation to identify and confirm the locations of potential sources. The databases revealed no potential contaminant sources within the management area. Four potential contaminant sources were identified during field inspections and aerial fly-overs of the management area. These sources are agricultural land use, the Union Pacific Railroad, Interstate 80, and gravel quarries.

MANAGEMENT OF POTENTIAL CONTAMINANT SOURCES

Following the identification of potential contaminant sources in the wellhead protection areas and the watershed management area, the sources must be managed to prevent contamination of the aquifer supplying water to the municipal wells. A variety of management techniques are available for use, however, it is the goal of the Wyoming Wellhead Protection Program to be as non-regulatory as possible to achieve the protection of the municipal wells. Educational programs will be aimed at those individuals whose activities might jeopardize the quality of the of the aquifer. Brochures explaining the importance of Wellhead Protection will be one phase of public education. Other programs will encourage the proper disposal of common household contaminants such as paints, used motor oil, and cleaning agents. Memoranda of Agreement or Understanding can be used to ensure that land owners will not allow activities to occur on their property which might contaminate the aquifer. The Memoranda of Agreement can also be used to guarantee that land owners will remove potential contaminant sources from their property, such as abandoned vehicles. Active Laramie County and State of Wyoming ordinances can be used to make certain that private water wells and septic systems are properly constructed, and thus reduce the threat of contamination to the aquifer. The City of Cheyenne can also consider purchasing property that is deemed very sensitive to contamination, or if a land owner refuses to participate in a Memoranda of Agreement. Signs posted along the boundaries of the Wellhead Protection Areas and the Watershed Management Area will increase public awareness of the sensitivity of the land they are crossing.

CONCLUSIONS

The Cheyenne Board of Public Utility Borie Wellfield is vulnerable to contamination from a variety of sources. Developing a Wellhead Protection Program for the wellfield and managing the contaminant sources will help to protect the investment Cheyenne has in the water wells. Because Lone Tree Creek recharges the aquifer used by the Borie wells and the stream is vulnerable to contamination, integrating watershed management with wellhead protection affords an even greater degree of protection to the wellfield.

Currently, there are no state or federal guidelines for utilizing watershed management in conjunction with wellhead protection. Despite this lack of guidance, it is believed that it is necessary to use both management techniques in the Borie wellfield to protect the aquifer. In the future it is expected that Wyoming and the EPA will adopt this practice to better protect wells that are close to a recharging stream.

REFERENCES

Black and Veatch, 1994, WWDC/Cheyenne BPU Water Supply Master Plan, Preliminary Draft.

Blandford, T.N. and Huyakorn, P.S., 1993, WHPA, Wellhead Protection Area Delineation Code, version 2.2.

Bearlodge LTD., Inc. 1990, Cheyenne Well Rehabilitation, 1990: Well construction and testing data for the Merritt No. 5 and King No. 2 wells; Consultant's report to the City of Cheyenne Board of Public Utilities.

CENTRAC Associates, Inc., 1985, Report of Investigations: Water well testing and evaluations; Consultant's report to the City of Cheyenne Board of Public Utilities.

Cooley, M.E. and Crist, M.A., 1981, Generalized fence diagram showing stratigraphy and potentiometric surface of the Tertiary formations in southeastern Wyoming and an adjacent part of Colorado; U.S. Geological Survey, Miscellaneous Investigations Series, Map I-1308.

ERTEC, 1984, Ground-water system modeling and optimization of pumpage patterns, Cheyenne municipal well fields; Report to the U.S. Department of the Air Force, Ballistic Missile Office, 147 pp., 1 plate.

Freeze, R.A. and Cherry, J.A., 1979, Groundwater; Prentice Hall, Inc. Englewood Cliffs, NJ, 604 pp.

Lohman, S.W., ed., 1972, Definitions of selected groundwater terms—revisions and conceptual refinements; U.S. Geological Survey, Water Supply Paper 1988, 21 pp.

Lowry, M.E., Crist, M.A., and Tilstra, J.R., 1967, Geology and ground-water resources of Laramie County, Wyoming; U.S. Geological Survey, Water Supply Paper 1834, 71 pp., 2 plates.

Wester-Wetstein, 1994, Construction and testing of the Weber No. 1 well; Consultant's report submitted to the City of Cheyenne, 83 pp.

Weston Engineering, 1996, Cheyenne 10 well rehabilitation report; Consultant's report submitted to the City of Cheyenne.

IDENTIFYING GROUND-WATER THREATS FROM IMPROPERLY ABANDONED BOREHOLES

Robert Kubichek, Jerry Cupal, William Iverson, Sangsung Choi, Michael Morris[1]

ABSTRACT

The University of Wyoming has been investigating techniques to determine the status of plugged and abandoned wells. Proper abandonment procedures require that cement plugs be carefully positioned within the borehole to prevent contamination of aquifers by toxic fluids from adjacent rock formations. The plugs seal off aquifer layers and prevent transmission of fluids through the borehole between formations. Many abandoned wells, especially wells closed before more stringent environmental rules were established, may have been abandoned without proper plugging. If successful, the techniques could be used by well head protection programs to determine which abandoned wells require mitigation, as well as by agencies responsible for enforcing well abandonment regulations.

In this approach, a down-going acoustic pulse generated at the surface produces reflections at each plug boundary. The up-going reflection energy is detected by acoustic sensors at the surface and used to estimate plug size and location. Initial experiments used an artificial borehole constructed horizontally on the ground using actual well casing. Computer modeling has been used to help interpret reflection signals. Field experiments were conducted during the summer of 1996 on a variety of plugged and unplugged wells. Initial results have been mixed. In some cases, possible reflections are seen from the bottom of the surface plug and the top of the next deeper plug. However, determining whether acoustic events are actual plug reflections or due to other acoustic sources is difficult.

INTRODUCTION

Each year many wells are plugged and abandoned throughout the United States. These include water wells, mineral exploration wells, and oil and gas production wells. Many wells penetrate one or more aquifers, i.e., layers of sand, gravel, or permeable rock containing potable subsurface water. The wells also pierce formations containing oil and gas reservoirs, mineral deposits such as uranium and lead, and water contaminated with concentrations of salts and other dissolved solids.

The borehole provides a mechanism for communication of fluids and gasses between formations, and therefore poses a threat to fresh water aquifers. For example, if the borehole passes through both an aquifer and a brine-bearing formation, the brine can invade the aquifer and compromise the quality and purity of the water. Aquifers are typically isolated by non-permeable formations above and below the water-bearing material, which confines the water and protects it from contamination. Improperly plugged wells compromise the integrity of the aquifer by destroying its natural isolation, and allowing water to be exposed to potentially toxic materials from nearby formations.

PREFERRED OR MANDATED ABANDONMENT PROCEDURES

Well abandonment procedures have been developed to prevent communication of fluids between formations via the abandoned borehole to avoid damage to fresh-water aquifers. These usually require that wells be plugged with concrete, bentonite, or other dense material. One-hundred foot long cement plugs are used in oil and gas wells at 1000 to 2000 foot intervals. Aquifer formations are either sealed off by continuous cement plugs, or by plugs placed above and below the formation. Dense fluids such as drilling mud are used to fill the spaces between borehole plugs. A smaller plug, 30 to 100 feet in length, seals the borehole at the surface. Costs of following proper abandonment procedures vary widely, but can range from a few tens of thousands to well over one hundred thousand dollars.

OVERSIGHT RESPONSIBILITY

Responsibility for proper plugging and abandonment of wells usually belongs to the well operator or owner. Depending on the type of well, oversight of abandonment procedures falls under several jurisdictions. For example, in Wyoming, the State Engineer's Office is responsible for water wells. The Wyoming Department of Environmental Quality (DEQ) has responsibility for stratigraphic test and exploration wells, while the state Oil and Gas Conservation Commission monitors oil and gas wells. The U. S. Bureau of Land Management (BLM) oversees wells on Federal Lands. Each agency may have a different set of abandonment procedures.

Enforcement of proper abandonment procedures is problematic due to the number of agencies involved and their sometimes-overlapping jurisdiction. Limited resources mean that it is seldom possible for an inspector to be present to ensure proper plugging practices are followed, and the majority of abandoned wells are plugged without any oversight.

Unfortunately, considering the high cost, limited inspection, complicated jurisdiction, and conflicting abandonment procedures, there is temptation to abandon the well with nothing more than a surface plug. Wells abandoned 20 or more years ago are even more likely candidates for improper abandonment due to fewer requirements and less sensitivity to environmental concerns.

[1] Electrical Engineering Department, UW; E.E. Dept., UW; Subsurface Engineering, 14802 167th PL SE, Renton, WA 98059; E.E. Dept., UW; E.E. Dept., UW, Laramie, WY 82071, respectively.

IDENTIFICATION OF IMPROPERLY ABANDONED BOREHOLES

In order to develop effective well head protection programs, it would be very useful to know whether regional plugged wells have been properly abandoned, or if mitigation is needed to protect local aquifers. The only known way to confirm whether a well has been properly plugged is to re-drill it. This is an expensive procedure with costs ranging anywhere from $20,000 to over $50,000. Clearly, a remote sensing system able to identify and characterize the size and location of borehole plugs would be of great interest.

Since fall of 1995, the University of Wyoming has been studying the feasibility of remotely detecting borehole plugs using acoustic sensors. The project has investigated the production of guided or casing waves in the borehole, and detection of reflections from subsurface plugs via acoustical sensors at the surface. So far, a great deal has been learned about the problem, but results have been mixed. No previous investigations in this area have been reported in the literature, and it is the authors' hope that other researchers will begin to focus on this important problem.

This paper describes the theory, techniques, and results of the research project to date, including computer simulation results and field experiments conducted over the past year. Section 2 provides background on the proposed technique; Section 3 describes the experimental approach along with example results, and Section 4 summarizes the status of the project.

THEORETICAL CONSIDERATIONS

WAVE PROPAGATION

Traditional seismic exploration uses low-frequency acoustic waves to probe subsurface geology. Unfortunately, these techniques would probably not resolve small reflecting surfaces on the borehole plugs due to frequency limitations, high attenuation from spherical divergence, and interference from larger subsurface reflectors. Acoustic energy is also carried by guided wave modes which remain confined to the borehole. These modes are subject only to leakage and frictional losses in the medium and do not suffer the geometric attenuation afflicting plane waves. Examples include casing waves and tube waves which exist at the boundaries between the fluid interior and the borehole wall. Another guided wave, called a fluid wave, is a high frequency compressional wave traveling within the fluid interior.

These types of guided waves are well known in Vertical Seismic Profiling (VSP) and acoustic logging work as strong sources of unwanted noise which obscure weaker desirable reflections from surrounding strata. However, the very attributes that make them a nuisance in VSP and acoustic logging (e.g., high amplitude and confinement to the borehole) make them well suited for this application. Such guided waves represent our best hope of learning the size and location of down-hole plugs using surface-based tests.

MODELING

The structure of the received geophone signal is very complex, being made up of both primary reflections from each plug surface, and secondary reverberations that occur when energy reflects back and forth between the plugs. To help determine the origin of each reflection event, two computer programs were written to model the flow of sound energy within the borehole. The first model generates a synthetic geophone signal, as well as showing the location of sonic pulses as they travel through the borehole. The casing is treated as a simple layered media which somewhat over-simplifies the physics of an actual borehole [1]. Thus, some wave modes present in an abandoned well are not represented by this program.

To help understand propagation in an actual borehole, we also developed a finite-difference modeling program that provides a discrete solution of the elastic wave equation, and accurately computes all wave modes including guided waves [2]. This program is being used to address questions about how much of the sonic pulse passes through cement plugs, and how to process the reflection signals for best detection results.

EXPERIMENTAL APPROACH

ARTIFICIAL BOREHOLE

During the early stages of the project, a simulated borehole was developed for evaluating acoustic sensors, data acquisition techniques, and signal processing methods. The test bed allows experiments to be performed in an environment where the plug dimensions and locations are known exactly. The borehole was constructed on University of Wyoming Animal Science Farm outside of Laramie using approximately 200 feet of 5.25 inch well casing. The casing includes cement plugs at each end, and a single cement plug near the center. Acoustic sensors have been installed in each plug to measure vibrations traveling along the casing. Spigots have been installed so that the unplugged sections can be flooded with water to simulate fluid-filled sections of actual boreholes. Tests using the artificial borehole have the following objectives: (1) assess the effectiveness of

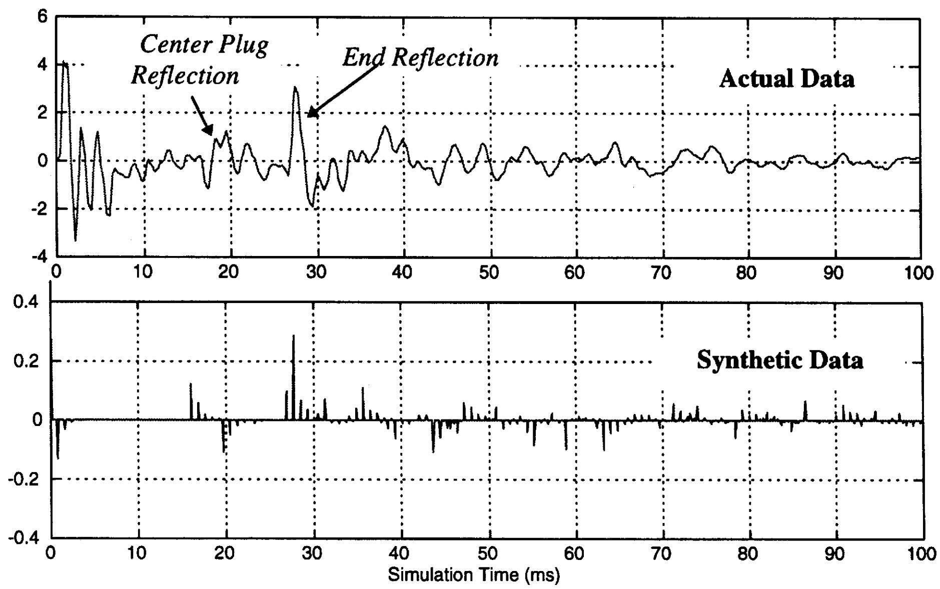


Figure 1. Acoustic record from artificial borehole (top) and synthetic model (below). Good correspondence is observed between data sets. Note complex multiple reflection structure.

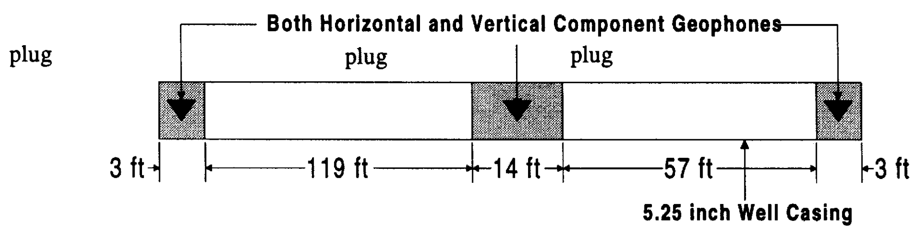


Figure 2. Diagram of artificial borehole

the acoustic sensors (geophones) and determine the best geophone orientation, i.e., transverse or longitudinal, (2) determine the spectrum of the sonic pulses, (3) measure signal and noise levels, and (4) determine whether plug reflections can be detected in the measured data. A diagram of the setup is shown in Fig. 1. An example acoustic recording from the test bed, along with a synthetic model prediction are given in Fig. 2.

RECORDING SETUP AND PROCESSING

Acoustic reflections are recorded using a geophone device chained to the steel surface casing. The device consists of two series-connected geophones embedded in a concrete container. The container provides mass damping to help suppress ringing when the casing is struck. Three geophone sensor pairs are included in the package and aligned to measure vertical, transverse, and radial vibration components. To further reduce ringing effects, sandbags are strapped to the steel marker post.

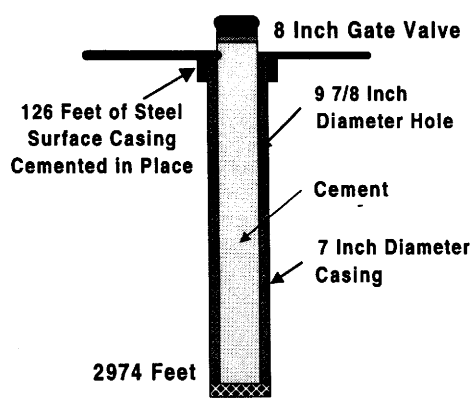


Figure 3. Simplified diagram of Elk Mountain Water Well #3

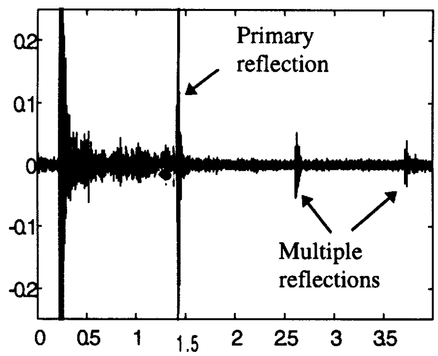


Figure 4. Transverse geophone output showing primary and 2 multiple reflections from well bottom.

The three sensor channels are sampled using a PC - based analog-to-digital converter running at 10000 samples per second per channel, and the data is stored for later processing. Between 5 and 15 records are made for each experimental condition. Acoustic impulses are generated using a large hammer applied either to the top of the marker post or the steel plate welded to the top of the surface casing. Generated waveforms are remarkably consistent from one hammer blow to the next. Typical post-processing steps include averaging of multiple records to reduce noise, low-pass and band-pass filtering, and deconvolution to further alleviate ringing.

FIELD TESTS

A variety of plugged and unplugged wells was tested during the summer of 1996. The goal was to understand sound propagation in these real world environments, and determine the feasibility of an acoustic approach. Selected examples are presented and discussed in the following sections.

UNPLUGGED WATER WELL

The citizens of Elk Mountain have kindly allowed us to test several plugged and unplugged wells located near their town. Figure 3 shows a diagram of their newly-drilled water well. This 3000-foot deep cased well represents an advantageous test site because of its simple structure and detailed available documentation. Figure 4 displays the transverse component acoustic data, and clearly shows the primary well bottom reflection at 1.5 seconds, along with 2 multiple path reflections. These strong reflections are convincing evidence that guided waves are being generated and recorded in the borehole.

MEDICINE BOW #1 WELL

Two wells were tested near the town of Medicine Bow, Wyoming. These are presented here as examples of the broad range of configurations commonly encountered with oil and gas wells. The first represents a complicated structure involving multiple casing layers, and is shown in Fig. 5. In

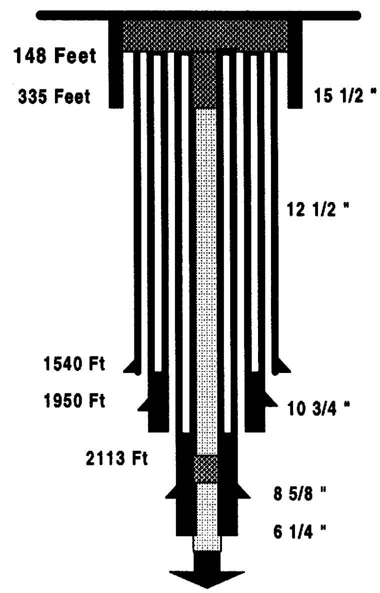


Figure 5. Complicated structure of abandoned well south of Medicine Bow, WY. Numbers indicate casing diameters and depths. Plugs are shown at surface down to 335', and at 2113'.

this well, some (but not all) of the casings have been cemented to the hole or to adjacent casings; this makes it very difficult to accurately predict the nature of acoustic propagation in this borehole.

Figure 6 shows a set of data records where each data trace corresponds to a single hammer blow. Using an approximate velocity of 10000 fps, reflections would be expected from surface plug discontinuities at 30 and 67 ms. As seen in the data, coherent reflections are seen at about 35 ms and may be related to a plug surface reflection. The event could

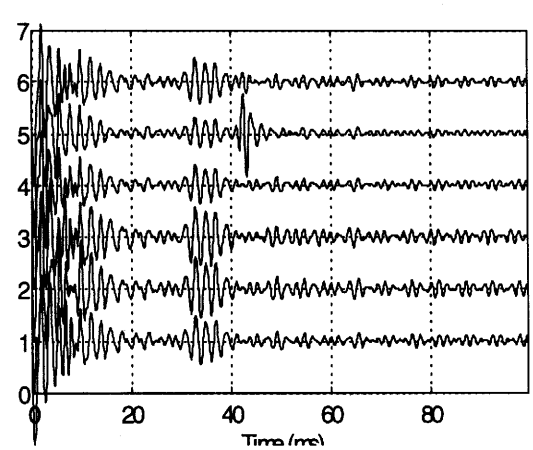


Figure 6. Vertical component seismic data from Medicine Bow #1 well. Events at 35 to 40 ms may be possible plug reflections. A fifth-order deconvolution operator was used to reduce ringing.

also be a reflection from an interface between two different rock types, such as sand and shale, at approximately the same depth as the plug. Identifying the origin of such reflections is a major challenge of this research.

MEDICINE BOW #2 WELL

A second well south of Medicine Bow was also investigated. As seen in Fig. 7, this well's structure is significantly simpler than the previous well, suggesting that the resulting data may be easier to interpret. However, the example results shown in Fig. 8 are quite puzzling. Here, several coherent events are seen that could be associated with plug surfaces. Closer inspection shows a 6 ms reverberation that persists throughout the data set. To learn more about the nature of this problem, we drilled a hole through the steel surface plate, and found that the cement apparently subsided after the surface plug was poured, resulting in a 3 foot air gap above a 12 foot water column. Multiple reflections in these sections could produce the unwanted 6 ms reverberation.

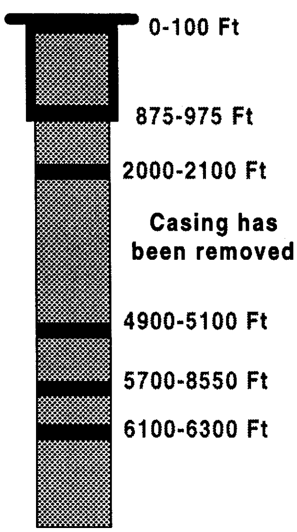


Figure 7. Medicine Bow Well #2 configuration. Depths indicate plug locations.

CONCLUSIONS

Results indicate that the plug reflections are weaker than predicted by computer modeling. This is possibly because the wave guide effect of the borehole is not as strong as the models have indicated. Furthermore, unwanted acoustic energy such as ringing of the casing, and multiple reflections from near-surface boundaries make it difficult to identify reflections in the raw signal. Simple band-pass filtering and smooth software gain have shown promising results, but plug reflections still cannot be determined with certainty.

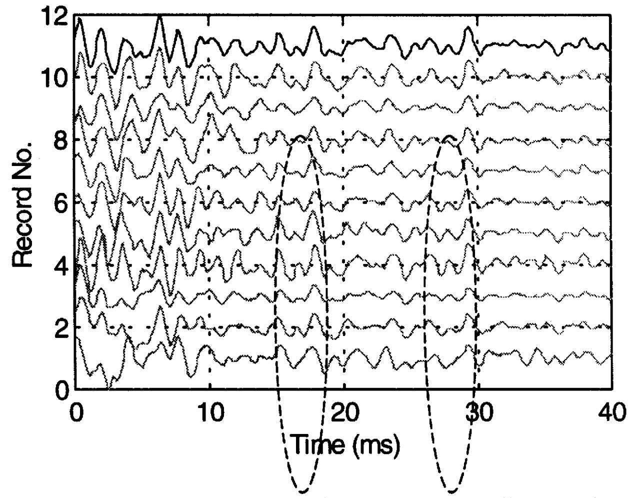


Figure 8. Data from Medicine Bow #2 well. Note 6 ms reverberation, and apparent event at 30 ms. Possible events are circled. (The first 20 ms of data has been deleted; thus, t=0 occurs 20 ms after the hammer struck the casing).

Overall, findings based on the raw data have been mixed. The best results were seen on tests of an unplugged water well, where strong reflections were seen from the 3000 foot-deep well bottom. Acoustic records from the plugged wells have been more challenging to interpret. In some cases, possible reflections are seen from the bottom of the surface plug and the top of the next deeper plug. However, it is difficult to determine whether a particular acoustic event is an actual plug reflection, or whether it is due to other sound sources such as ringing from the casing or reflections from subsurface strata.

For the last year of the project, we plan to test the effectiveness of a high frequency (5 - 20 kHz) piezo-electric transducer as the acoustic source. The main advantage will be generation of a repeatable source signal with significant high-frequency content. Such a source should not excite the low-frequency vibrational modes associated with ringing, and we believe will result in much cleaner, higher resolution records. Additionally, it is known that guided tube waves are most efficiently generated using high frequency sources, so the new source may better excite these wave modes. The source will be pre-tested using the artificial borehole, and field tested on actual plugged wells.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to all the individuals and organizations who have provided assistance. In particular, thanks are due to Kip Purinton and the U. S. Bureau of Land Management, the citizens of Elk Mountain, Todd Jarvis of Weston Engineering, and the University of

Wyoming Animal Science Farm. The research is supported under a grant from the Hazardous Substance Research Center, Kansas State University, Project 94-24.

REFERENCES

Wyatt, K. D., "Synthetic vertical-seismic-profile," *Geophysics,* 46, no. 6, 880-891, 1981

Cheng, N, C. H. Cheng, and M. N. Toksoz, "Borehole wave propagation in three dimensions," *J. Acoust. Soc. Am.* 97 (6), pp. 3483-3493, June 1995

SESSION 4:

WATER QUALITY

NONPOINT SOURCE WATER POLLUTION CONTROL: THE ROLE OF CONSERVATION DISTRICTS

Earl DeGroot[1]

The 34 conservation districts in Wyoming (Figure 1) have a large degree of authority and responsibility for managing nonpoint source water pollution. State statutes (W.S. 11-16-101 et. al.) give conservation districts authority to levy taxes and 21 districts have chosen to do so.

In recent years, conservation districts have intensified their water management activities. At the 1995 annual convention, district representatives overwhelmingly passed a resolution to take a leadership role in coordinating watershed management efforts at the local level. Since then, a strategic plan has been developed that will help the districts build leadership capacity.

Conservation districts are currently involved with, or have recently completed, numerous watershed implementation projects. These include the Ocean Lake project in the Lower Wind River Conservation District, the Squaw Creek-Baldwin Creek project in the Popo Agie Conservation District, the Muddy Creek project in the Little Snake River Conservation District, the Reardon Draw project in the Sublette Conservation District, and the Crazy Women project in the Lake DeSmet Conservation District, the Willow Creek project in the Uinta County Conservation District and the Sage Creek project in the Saratoga-Encampment-Rawlins Conservation District.

In addition to implementation projects, numerous assessment projects are taking place. Assessment projects, which are an important precursor to implementation projects, are underway on the Bighorn River in the Washakie County Conservation District, the North Platte River in the Converse County Conservation District, the lower Wind River in the Lower Wind River Conservation District, Flat Creek in the Teton County Natural Resource District, the Laramie River in the Laramie Rivers Conservation District and the Tongue River in the Sheridan Conservation District. In addition, several conservation districts have initiated an assessment and planning project in the Belle Fourche Watershed. Also as a joint effort, three Goshen County districts have united to participate in a ground water assessment project.

Recently, the Wyoming Association of Conservation Districts (WACD) received a grant from the Wyoming Department of Environmental Quality (DEQ). This 319 Program grant, provides funds for several important initiatives. First, statewide water quality planning assistance, which has been provided for the past three years, will continue. Second, a group of conservation districts will be provided financial assistance for two years to hire a water resource planner. Third, a geographical information system (GIS) demonstration project will be developed. A GIS focus area will be selected and project managers will work closely with the Wyoming Water Resources Center to assemble various map layers. After the layers have been developed, the information will be loaded into a district computer and used to make planning and management decisions at the local level.

In addition to these exciting initiatives, WACD has recently signed a contract with DEQ to provide financial and technical assistance to operators of small confined feeding operations. Currently, operations with less than 1000 animals units are not required to have a permit. Depending on their location, these small operations have the potential to impact water quality. The DEQ contract provides cost-share funds to establish five demonstration sites in the state. Best management practices will be applied and then tours will be conducted to demonstrate their effectiveness. In addition, the contract provides for numerous educational activities such as brochures, public service announcements and workshops.

Finally, WACD and the 34 conservation districts in the state would like to encourage everyone to participate in watershed planning and watershed management. Open lines of communication are important to achieving natural resources goals while preserving personal freedoms.

For more information about WACD's water resource activities contact:

Bobbie Frank, Executive Director
Wyoming Assoc. of Cons. Districts
2505 E. Fox Farm Road
Cheyenne, WY 82007
(307) 632-5716
waocd@trib.com

Earl DeGroot, Water Qual. Consultant
Western Management Services
P.O. Box 1415
Cheyenne, WY 82003
(307) 634-0286
earl@tcd.net
http://www.tcd.net/~earl

For more information about specific conservation district activities contact the district at the locations provided on the following page.

[1] Wyoming Association of Conservation Districts, 2505 East Fox Farm Rd., Cheyenne, WY 82007

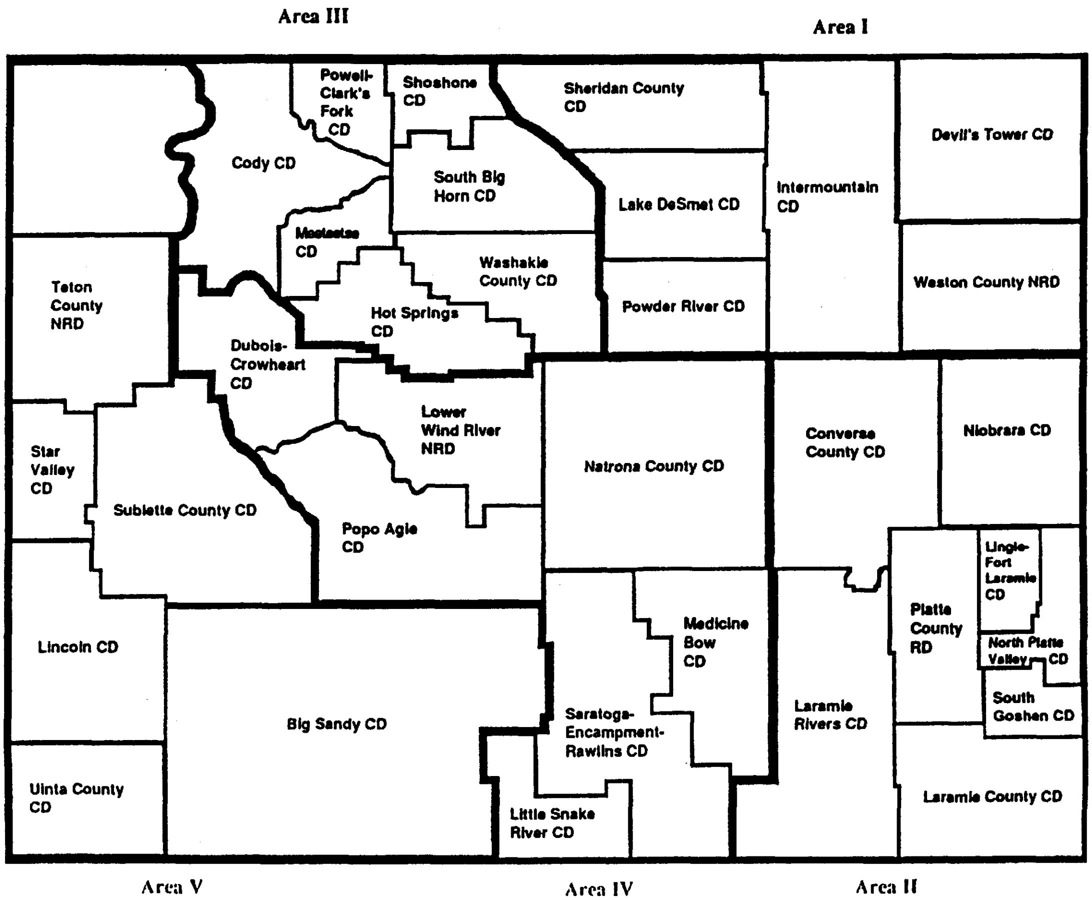


Figure 1. Wyoming Association of Conservation Districts Map of Districts and Areas

Big Sandy Conservation District, 273-5531
Cody Conservation District, 587-1212
Converse County Conservation Dist., 358-9825
Devil's Tower Conservation Dist., 283-2501
Dubois-Crowheart Cons. Dist., 455-2388
Hot Springs Conservation Dist., 864-3488
Intermountain Conservation Dist., 682-1824
Lake DeSmet Conservation Dist., 684-2527
Laramie County Cons. Dist., 772-2316
Laramie Rivers Cons. Dist., 745-7129
Lincoln Conservation Dist., 279-3256
Lingle-Ft. Laramie Cons. Dist., 532-4290
Little Snake River Cons. Dist., 383-7860
Lower Wind River Cons. Dist., 856-7524
Medicine Bow Cons. Dist., 379-2224
Meeteetse Conservation Dist., 868-2484
Natrona County Cons. Dist., 261-5404
Niobrara Conservation Dist., 334-2953
North Platte Valley Cons. Dist., 532-4290
Platte County Resource Dist., 322-9061
Popo Agie Conservation Dist., 332-3114
Powder River Cons. Dist., 738-2321
Powell-Clarks Fork Cons. Dist., 754-9301
Sara.-Encamp.-Rawlins Cons. Dist., 326-8626
Sheridan Conservation Dist., 672-5820
Shoshone Conservation Dist., 548-7422
South Big Horn Conservation Dist., 765-2483
S. Goshen Conservation Dist., 532-4290
Star Valley Conservation Dist., 886-3018
Sublette County Conservation Dist., 367-2257
Teton County Nat. Resource Dist., 733-8179
Uinta County Conservation Dist., 787-3810
Washakie County Cons. Dist., 347-2212
Weston County Nat. Resource Dist., 746-3264

TEAM APPROACH FOR PROTECTING GROUNDWATER QUALITY FROM NON-POINT SOURCE POLLUTION IN GOSHEN COUNTY, WYOMING

Katta J. Reddy[1]

INTRODUCTION

Groundwater has played a significant role in the development of Wyoming. A large number of public water supplies in the state of Wyoming utilize groundwater resources. Wells provide drinking water for approximately 75% of the state's population and are a principal source of water for livestock (U.S. Geological Survey, 1985). It is in the public and state interest to protect these groundwater resources from contamination by various pollutants which can be harmful to the health and welfare of humans and livestock.

The impacts of intensive agricultural practices (non-point source pollution) on the quality of groundwater are well documented throughout the United States. Nitrate (NO_3^-) and pesticides are most frequently detected in groundwater associated with the intensive agricultural areas. High nitrate concentration in drinking water can cause blue baby syndrome (oxygen deficiency) in infants (Fletcher, 1991). Therefore, the Environmental Protection Agency (EPA) drinking water standard for NO_3^- is 10 milligrams per liter (nitrate as nitrogen).

During the mid 1980's, the EPA reported 17 pesticides in groundwaters of 27 states at concentrations ranging from a trace to several milligrams per liter (Sun, 1986). A later survey conducted by Parsons and Witt in 1988 on "Pesticides in Groundwater in the United States of America" indicated 67 pesticides in 33 states. Seventeen of these pesticides from this latter study were detected at levels greater than the U.S. EPA's Health Advisory limit (HAL).

Two pesticides most frequently detected in groundwaters are atrazine and aldicarb. Atrazine has been reported to be the second most widely used pesticide in the U.S at 79 million pounds of active ingredient applied yearly as a pre- or post-emergent treatment to control weeds. An estimated 12,000 acres, or 13% of Wyoming's corn acreage is treated with atrazine (Legg et al., 1992). Because of its possible carcinogen (cancer causing agent) nature, the EPA has set the HAL for atrazine at 3 micrograms per liter in drinking water (U.S. EPA, 1989).

Aldicarb is extensively used to control mites, nematodes, and aphids by direct application to soils and plants. In Wyoming, aldicarb is applied to approximately 22,000 acres, or 30% of the total acreage of sugarbeets (Legg et al., 1992). Aldicarb has been detected in groundwaters of several states with 175 wells exceeding the HAL of 10 micrograms per liter (Parsons and Witt, 1988). Although Wyoming has a lower application rate of fertilizers and pesticides than many high production areas in the United States (i.e., Corn Belt, Atlantic Seaboard, Southwestern and Pacific Regions), their extensive use in several Wyoming counties (e.g., Goshen, Park) may present a potential problem. For example, the Torrington area of the North Platte River valley located in Goshen County is one of four major irrigated agricultural areas in Wyoming. High levels of nitrate (> 10 milligrams per liter nitrate as nitrogen) have been detected in several wells throughout the Torrington area (Parks, 1991). The presence of high nitrates in Torrington area groundwaters may be an indication of a potential for leaching of other pollutants such as pesticides. In another case, leaching of aldicarb from the soils of the Powell area was reported (Barkan and Nelson, 1991).

Since the detection of isolated groundwater quality problems in Goshen County, different Wyoming state agencies, in cooperation with the EPA, are developing strategies to help citizens and landowners protect groundwater quality. These agencies include: the Wyoming Department of Environmental Quality (WDEQ), Wyoming Department of Agriculture (WDA), U.S. Geological Survey (USGS), and Wyoming Water Resources Center (WWRC). Additionally, other groups such as the Wyoming Association for Rural Water Users (WARWU), the Midwest Assistance Program (MAP), and various consulting firms are also offering assistance to citizens and landowners throughout the state to develop wellhead protection methods to improve groundwater quality.

The protection of groundwater quality from non-point source pollution is a complex issue and requires an interdisciplinary team approach. Thus, the purpose of this report is to review the efforts of WWRC in Goshen County, Wyoming in protecting groundwater resources from non-point source pollution. The WWRC with the cooperation of the WDEQ, EPA, Torrington Research and Extension Center, and Wyoming Cooperative Extension Service is working with local citizens and landowners for protecting groundwater resources from non-point source pollution.

ON-GOING WWRC PROJECTS IN GOSHEN COUNTY

As shown in figure 1, the Wyoming Water Resources Center is involved in three projects at Torrington, Goshen County, Wyoming. The overall goal of these efforts is to enhance environmental awareness in citizens and landowners through an educational process by informing them about water quality issues and availability of various groundwater

[1] Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071

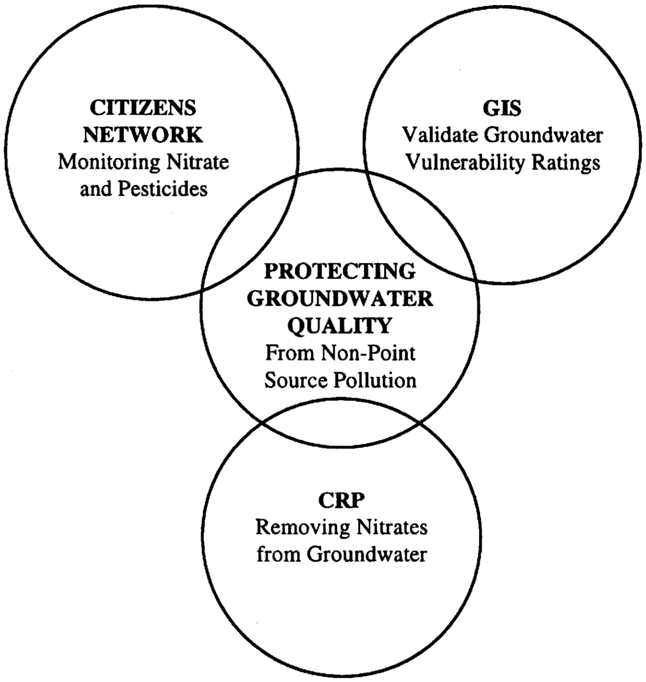


Figure 1. Various research projects in Goshen County, Wyoming to protect groundwater resources from non-source pollution.

management tools and appropriate groundwater remediation approaches.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

In recognition of the need for effective and efficient methods for protecting natural resources (e.g., surface water, groundwater) from future contamination, scientists and resource managers have sought to develop techniques for predicting which areas are more likely than others to become contaminated as a result of activities at or near the land surface. Today this concept has been widely termed "groundwater vulnerability to contamination," referring to contamination resulting from non-point sources or already distributed point sources of pollution. The U.S. EPA has collectively identified groundwater vulnerability determination methods as one of four primary approaches to assessing groundwater resources for statewide groundwater protection and management (NRC, 1993; U.S. EPA, 1993). The best solution to prevent the degradation of groundwater quality from non-point source pollution is to identify the most susceptible aquifers for contamination from agricultural activity at the surface using GIS. Such information will help citizens and landowners to identify best management practices (BMPs) to prevent the future pollution of groundwater resources.

CITIZENS NETWORK

The successful use of BMPs to sustain groundwater quality in agricultural areas will depend on citizens and landowners. The citizens and landowners use different management practices (e.g., pesticide and fertilizer application rates and irrigation systems) to increase agricultural production. Some of these practices may or may not affect the quality of groundwater. Involving citizens and landowners in groundwater monitoring program for nitrate and pesticides could enhance environmental awareness. Enhanced environmental awareness will lead to the identification of BMPs, by citizens and landowners, which have little impact on the quality of groundwater. With time, use of BMPs by the citizens and landowners may help sustain the quality of groundwater in intensively agricultural areas of Wyoming.

To increase the environmental awareness and education of local citizens and landowners on the importance of groundwater quality, citizens monitoring networks for nitrate and pesticides in groundwaters of Goshen County, Wyoming were established (Goertler et al., 1996). Thirteen landowner cooperators, within intensively agricultural areas, were selected based on the GIS groundwater vulnerability ratings with the assistance of Wyoming Cooperative Extension personnel. Wells chosen for sample collection were located along the North Platte River Valley upstream and downstream of the town of Torrington, Wyoming.

Thirteen wells were sampled before planting, during the crop growth, and after harvest and were analyzed for nitrate and pesticides (atrazine and aldicarb) with ion chromatography (IC) and immunoassay, respectively. As groundwater quality data for nitrate and pesticides became available, landowner cooperators were informed of results. From nitrate and pesticides data, GIS vulnerability ratings for groundwater were validated (Reddy et al., 1997).

REMOVAL OF NITRATE FROM GROUNDWATER WITH A CATALYTIC REDUCTION PROCESS (CRP)

The best solution to nitrate pollution would be to prevent nitrate input into groundwater through the BMPs. This approach will help in protecting groundwater from future nitrate contamination. However, to meet the current EPA drinking water standard, removal of nitrate from already contaminated groundwater is required. Application of treatment technologies to remove nitrate from contaminated groundwater is becoming increasingly important, particularly where alternate water supplies are not available (Bouwer, 1989).

At present, nitrate can be removed from the groundwater with ion exchange, biological denitrification, reverse osmosis, and electrodialysis. Among these techniques, ion exchange and biological denitrification are widely used. The ion exchange process is more selective for sulfate than nitrate and groundwater in the Torrington area consists of higher concentrations of sulfate than nitrate, which will affect nitrate removal efficiency. The biological denitrification is slow and very difficult to handle (Green and Shelef, 1994). Thus, the groundwater remediation projects in the Torrington area may require an effective and economical nitrate removal process which is suitable for small communities.

Initially, thirteen groundwater samples from the citizens network were investigated. From these, three were further investigated for the NO_3^- reduction with the CRP. Three catalysts were tested in this study: Palladium (Pd) 5% on carbon, Platinum (Pt) 10% on carbon, and Rhodium (Rh) 5% on carbon. A liter of each groundwater sample was amended with 0.5 grams of catalyst and reacted at different Eh values (340 to -400 mV). At each Eh value samples were reacted from 1 to 6 hours. At a given Eh and reaction time, samples were analyzed for NO_3^- and nitrite (NO_2^-) with ion chromatography (IC).

Among the three catalysts, the Rh was most effective in removing NO_3^- from groundwater samples. Additionally, groundwater chemical composition did not affect the efficacy of the CRP with Rh. Platinum could remove NO_3^- from groundwater but the reduction process was very slow. The efficiency of Rh to remove NO_3^- from groundwater samples is much higher than Pt. The Pd showed no reduction of NO_3^- during the reaction time of 1 to 6 hours. Results also suggest that the Rh was effective at lower Eh values such as -250 and -400 mV (Wyman et al., 1996).

CONCLUSIONS

Assessment of groundwater vulnerability ratings with GIS is useful in identifying the most susceptible aquifers for contamination from surface activities. Such information will help identify BMPs to prevent the future pollution of groundwater resources. Most groundwater samples tested were found positive for both atrazine and aldicarb, however, concentrations were far below the EPA drinking water standards. For nitrate, few groundwater wells exceeded the EPA drinking water standard during the crop growth, but reduced significantly after the harvest. We are in the process of organizing an informal meeting at the Torrington Research and Extension Center to present the results of CRP to the citizens and landowners. Several cooperators around the Torrington and Lingle area expressed interest in this project. As the project progressed, more citizens and landowners became interested in participating in the project possibly because of the availability of rapid test results for their wells and information on the importance of good water quality. The team approach was found to be an effective tool to enhance environmental awareness in citizens and landowners to protect groundwater resources from non-point source pollution. For example, one of the study area cooperators, a farmer and landowner, decided on his own to change the type of management practice he routinely used after participating in the project.

REFERENCES CITED

Barkan, D.N. and D.A. Nelson. 1991. Transport, detection and degradation of aldicarb in droughty irrigated soils of the Big Horn Basin of Wyoming. Progress Report to WWRC, University of Wyoming.

Bouwer, H. 1989. Agricultural contamination: Problems and solutions. Water Environment and Technology. October Issue:292-297.

Fletcher, D.A. 1991. A national perspective. In R.F. Follett et al. (ed.) Managing nitrogen for groundwater quality and farm profitability. Soil Sci. Soc. Am. J. Madison, WI.

Goertler, C.M., K.J. Reddy, J.G. Hiller, J.T. Cecil, and C. Stephenson. 1996. Citizens monitoring network for nitrate and pesticides in groundwaters of Goshen County, Wyoming. Agronomy Abstracts, 1996 Annual Meetings, Indianapolis, Indiana. p22.

Green, M. and Shelef, G. 1994. Treatment of nitrate contaminated ground water. In U. Zoller (ed.) Ground water contamination and control. Marcel Dekker, Inc. New York.

Legg et al. 1992. Pesticide use in Wyoming: 1990, Extension Report RJ-211, Univ. of Wyoming. p.20.

National Research Council. 1993. Groundwater vulnerability assessment: Contamination potential under conditions of uncertainty. National Academy Press, Washington, D.C.

Parks, G.D. 1991. Numerical simulation of groundwater flow and contaminant transport in an alluvial aquifer. M.S. Thesis, University of Wyoming.

Parsons, D.W and J.W. Witt. 1988. Pesticides in groundwater in the United States of America. Oregon State Univ. Extension Service.

Reddy, K.J., C.S. Arneson, and J.D. Hamerlinck. 1997. Assessment of groundwater vulnerability ratings for nitrate and pesticides in intensive agricultural areas. In: Fourth International Conference on the Biogeochemistry of Trace Elements. University of California, Berkeley, California. (in press).

Sun, M. 1986. Groundwater ills: Many diagnoses, few remedies. *Science*. 232:1490-1493.

U.S. Environmental Protection Agency. 1989. Health advisory summaries. U.S. EPA, Office of Water, Washington, DC 20460.

U.S. Environmental Protection Agency. 1993. A review of methods for assessing aquifer sensitivity and groundwater vulnerability to pesticide contamination. U.S. EPA, Office of Water, Washington, D.C.

U.S. Geological Survey. 1985. Hydrologic events, selected water quality trends and groundwater resources: USGS water supply paper 2275, p.467.

Wyman, V., J.P. Lin, and K.J. Reddy. 1996. Catalytic reduction process to remove nitrate from groundwater: Effects of reaction time, pH, and redox potential. Agronomy Abstracts, 1996 Annual Meetings, Indianapolis, Indiana. p343.

OCEAN LAKE HYDROLOGIC UNIT AREA- DESIGN AND ACCOMPLISHMENTS

Kirk Faught[1]

Since 1989 a partnership made up of NRCS, CES, FSA, and local interest groups (primarily the Save Ocean Lake Committee) have worked to restore the Ocean Lake fishery to a level achieved during the 1950s' and 60s'. Drains from irrigated croplands had been actively eroding with the silts being deposited in the lake. As the drains cut into volcanic ash derived soils, the silts tended to remain suspended in the lake thus reflecting solar energy.

A number of best management practices were incorporated to stabilize the drains. These included inlet pipes, energy dissipation structures, fencing, and bank sloping. On farm practices were incorporated to reduce excess water. Surge valves, gated pipe, sprinkler systems, and water scheduling are all accepted methods of water conservation.

Presentation will include slides of the area and a discussion of the effects.

[1] University Extension Educator, Box 158, Pavillion, WY 82523

EFFECTS OF COPPER ON SULFIDOGENIC ACTIVITY IN FRESHWATER SEDIMENTS

Song Jin and Patricia J.S. Colberg[1]

ABSTRACT

The effects of copper on sulfidogenic activity in freshwater sediments have been examined. Sulfate-reducing consortia were enriched from metal-free and metal-contaminated sediments. Copper ion was added at three different concentrations. At 0.8 ppm Cu^{2+}, no inhibitory effects were observed on sulfate reduction in either consortia; Cu^{2+} was quickly precipitated from the media. At 8 ppm Cu^{2+}, activity in the metal-free consortium was significantly inhibited, as illustrated by an extended lag and slower rate of sulfate reduction; sulfidogenesis in the metal-contaminated consortium was unaffected. When Cu^{2+} concentration was increased to 30 ppm, the sulfate reducing activity in the metal-free consortium was completely inhibited. The rate of sulfate reduction was also decreased in metal-contaminated enrichments but recovered after a lag. The results suggest that the increase in metal tolerance of the sulfate reducing consortia may be attributed to the pre-exposure of the microbial population to metals.

INTRODUCTION

Organic contaminants and heavy metals always coexist. As metals are usually toxic to microorganisms, the observed biodegradation of organic compounds in laboratory experiments may not reflect the actual situation in nature. Most heavy metals exert toxic effects on entire food chains, including microorganisms (1, 5). Metals occur as either soluble ions or in combination with metal oxides or other organic compounds. They are tightly associated with microbial metabolism in the environment. So far, most studies addressing tolerance to heavy metals have been carried out with aerobic microorganisms. Environments with a high heavy metal content probably foster highly metal-resistant bacteria strains (20). Studies on interactions between metal and anaerobic microbes have been confined to methanogenic mixed cultures (e.g., 9, 4). Only a few reports demonstrate a relationship between heavy metals and sulfate-reducing bacteria by pure cultures or short period batch experiments (8, 16). As sulfidogenesis has a major role in the biogeochemistry of organic contaminants in the subsurface, and natural deposits of heavy metals typically occur as sulfide minerals which are extremely insoluble under anaerobic conditions, understanding metal/sulfate-reducing bacteria interactions is critical. In addition, under low redox conditions, most Mn and Fe-oxyhydroxides are reduced through microbially mediated processes (12, 19), thereby releasing adsorbed metals into solution. This results in increased aqueous concentrations of heavy metals and creates a potentially abundant metal environment for sulfate-reducing bacteria.

Sulfate reduction is a microbial process occurring at lower redox states (<-100 mv) than iron reduction and other redox reactions (14). The sulfides resulting from sulfate reduction are known to precipitate heavy metals, immobilizing them as sulfide minerals (e.g., CuS, ZnS) or as trace constituents of other major metal sulfides like pyrite and FeS. Despite recent work documenting the microbial transformation of various environmental contaminants under sulfidogenic conditions (see, e.g., 3, 6, 7, 10), very little work has been performed on the immobilization of heavy metals through sulfate reduction (2, 15, 17). Heavy metals have been assumed to be passively 'detoxified' by precipitation with sulfides released during sulfidogenesis. This process may imply a unique detoxification of metals by sulfate-reducing bacteria; however, studies on metal resistance in sulfate-reducing bacteria are lacking (18). In this study, I considered whether previous exposure of microbial communities to heavy metals confers tolerance to their toxic effects. The immobilization of Cu^{2+} by sulfidogenic activity was also evaluated.

MATERIALS AND METHODS

Sediments were sampled from a metal-free pond (Laramie, WY) and a metal-contaminated stream (Milltown, MT, with Cu at 26 ppm). Sediment-free sulfate-reducing consortia were enriched by transferring into fresh sulfate-reducing(SR) media sequentially. The SR medium (in g/l) consisted of : NaCl, 1.17; $MgCl_2.6H_2O$, 0.87; KCl, 0.30; $CaCl_2.2H_2O$, 0.14; KH_2PO_4, 1.2; K_2HPO_4, 3.15; cysteine-HCl, 0.35. The trace metal solution includes (in mg/l): H_3BO_4, 0. 62; $MnCl_2.4H_2O$, 0. 98; $FeCl_2.4H_2O$, 1.49; $CoCl_2.6H_2O$, 1.19; $NiCl_2.6H_2O$, 2.37; $CuCl_2$, 1.34; $ZnCl_2$, 0.68. Vitamins were added after boiling and cooling of the medium. BESA was added at 10 mM to inhibit methanogenic activity (13) and resazurin (1.0 mg/l) served as a redox indicator. Strict anaerobic techniques were followed throughout the experiment. Sulfate and lactate were added for a final concentration of 20 mM. The microbial population density was determined spectrophoto-metrically at 600 nm. Cu^{2+} (as $CuCl_2$) was added for final concentrations of 0.8, 8, and 30 ppm. Molybdate at 20 mM was added to controls to inhibit sulfate reduction. Media without Cu^{2+} acted as positive controls.

Samples were taken for periodic analysis with a sterile syringe which was degassed with N_2-CO_2 (80:20). Sulfate and lactate were monitored by an ion chromatography with an AS-4A column (Dionex Corp., Sunnyvale, CA). The concentration of dissolved metal ions was determined on filtered (0.45-μm pore size) culture samples. A Varian

[1] Environmental Microbiology and Biogeochemistry Laboratory, Department of Zoology and Physiology, University of Wyoming, Laramie, WY 82071-3166

spectra AA atomic absorption spectrophotometer equipped with lamps specific for copper was used.

RESULTS

Sulfidogenic activities in both types of consortia were not affected by Cu^{2+} at 0.8 mM, as shown in Fig. 1a. Sulfate-reducing rates were also similar between the two consortia, and no lag in activity was observed. In controls where molybdate was added, sulfate reduction was inhibited, and Cu^{2+} concentration remained constant. In the two active consortia, Cu^{2+} was quickly precipitated, corresponding with the reduction of sulfate (Fig. 1b). Brown colored macroscopic precipitates were observed.

When Cu^{2+} was at 8 ppm, a significant inhibition of sulfate reduction was observed in consortia from the metal-free sediments. The lag time was about 15 days before the sulfate reduction started (Fig 2a). Accordingly, Cu^{2+} remained stable during this period and precipitated when sulfate started to be reduced (Fig. 2b). No inhibitory effect was observed in the consortia from the metal-contaminated sediments (Fig 2a). The rate of sulfate reduction and the precipitation of Cu^{2+} concentration were indistinguishable from the positive controls where Cu^{2+} was absent.

When Cu^{2+} was increased to 30 ppm, a marked effect was observed in terms of sulfidogenic activities. The sulfate-reducing activity of the metal-free enrichments was completely inhibited, as evidenced by the stable sulfate and Cu^{2+} concentration profiles which resembled the molybdate controls (Fig 3a). No recovery of sulfidogenic activity was observed during the 35 days of incubation. Sulfate reduction in the consortia from the metal-contaminated sediments had a lag time of about 7 days, and the rate of sulfate depletion was slower than that at lower Cu^{2+} concentration. The complete precipitation of Cu^{2+} took 15 days.

DISCUSSION

The sulfate-reducing enrichments were repeatedly transferred and treated with BESA (10 mM), so that methanogenic activity may be ignored. No methane production was ever detected during the experiments. The emission of H_2S gas and the formation of precipitates suggested that sulfate reduction was the dominant process. At low Cu^{2+} concentration (0.8 ppm), no inhibition was observed in either type of consortia, even though this copper concentration was at a highly toxic range for other microorganisms, such as methanogens (11). The sulfidogenic bacteria reduce sulfate to sulfide, which removes all Cu^{2+} ions from solution. The reaction proceeds so quickly that the metal-sensitive proteins and enzymes may not be exposed to ionic copper. This detoxifying mechanism probably attributes to a generally higher metal tolerance in sulfate-reducing bacteria.

When Cu^{2+} was increased to 8 ppm, an extended lag time was shown in metal-free consortia, but no effects were observed in metal-contaminated consortia (Fig. 2). Elevated levels of heavy metals can affect the qualitative as well as the quantitative structure of microbial communities. Such levels may act as selection factors in the biochemical activities of microorganisms. Microorganisms exposed to heavy metals may evolve resistance mechanisms to deal with metal toxicity, which include precipitation, volatilization and cell surface binding. Plasmid-encoded resistance may be also be involved (20).

When exposed to metal concentrations of 30 ppm, which is higher than the local Cu^{2+} concentration in the metal-contaminated sediment, an inhibitory effect was observed in the metal-contaminated consortia (Fig. 3). This may reflect the limit of copper resistance for the consortia. The lag time was relatively short (7 days) and sulfate reduction resumed after the initial delay. In the consortia from metal-contaminated sediments, the exposure of the microbial population to heavy metals may have caused the evolution of some metal-resistant enzymes that are involved in sulfate reduction. Even 30 ppm of copper decreased the general rate of metabolism, and the surviving sulfate reducers could quickly remove the Cu^{2+}. In comparison, the sulfate-reducing activity in the consortia from metal-free sediments was terminated at Cu^{2+} of 30 ppm.

In summary, sulfate-reducing bacteria exhibited a higher metal tolerance than other anaerobic microbes. This could be attributed to the sulfide-metal precipitation during sulfate reduction. The results suggest that sulfate-reducing bacteria from metal-contaminated sediments possess a significantly higher metal resistance than bacteria from uncontaminated sediments. The mechanisms to explain these results in this study require further study. Until we fully understand the correlation between heavy metal resistance and population function within a community, the potential for the use of such organisms in remediation of contaminated system is limited.

ACKNOWLEDGMENT

We acknowledge the grant support from the US Environmental Protection Agency. We also thank Linda Mickley for her help in methane analysis, and Connie Boese for her assistance in spectrocopic analysis of metals.

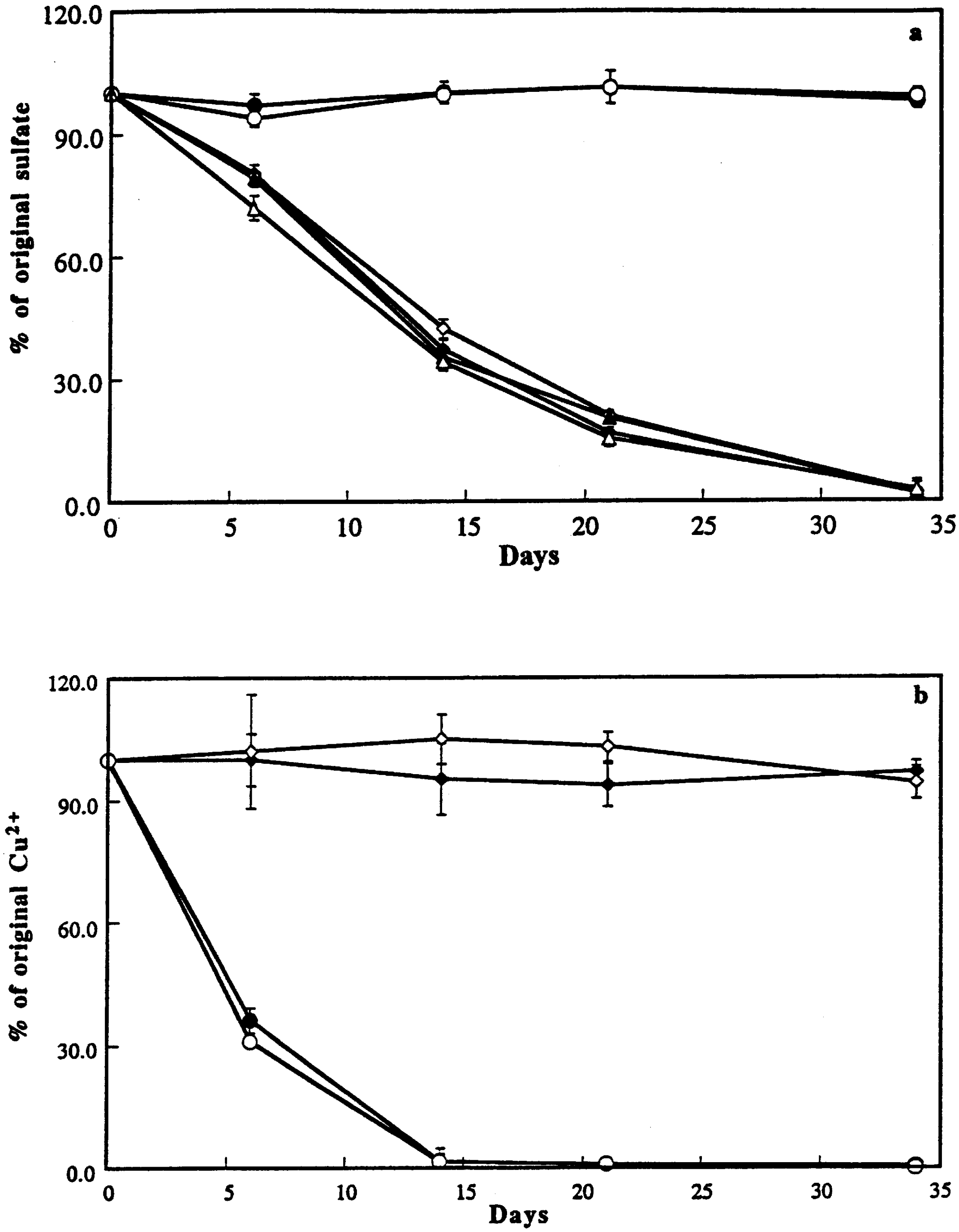


Fig. 1. (a). Sulfate concentrations in consortia from metal-free and metal-contaminated sediments, when Cu^{2+} is at 0.8 ppm. (b). Cu^{2+} concentrations in the two consortia. Symbols: (●) metal-contaminated consortia with 20 mM molybdate; (○) metal-free control with 20 mM molybdate; (◆) metal-contaminated consortia without Cu^{2+}; (◇) metal-free consortia without Cu^{2+}; (▲) metal-contaminated consortia with 0.8 ppm Cu^{2+}; (△) metal-free consortia with 0.8 ppm Cu^{2+}.

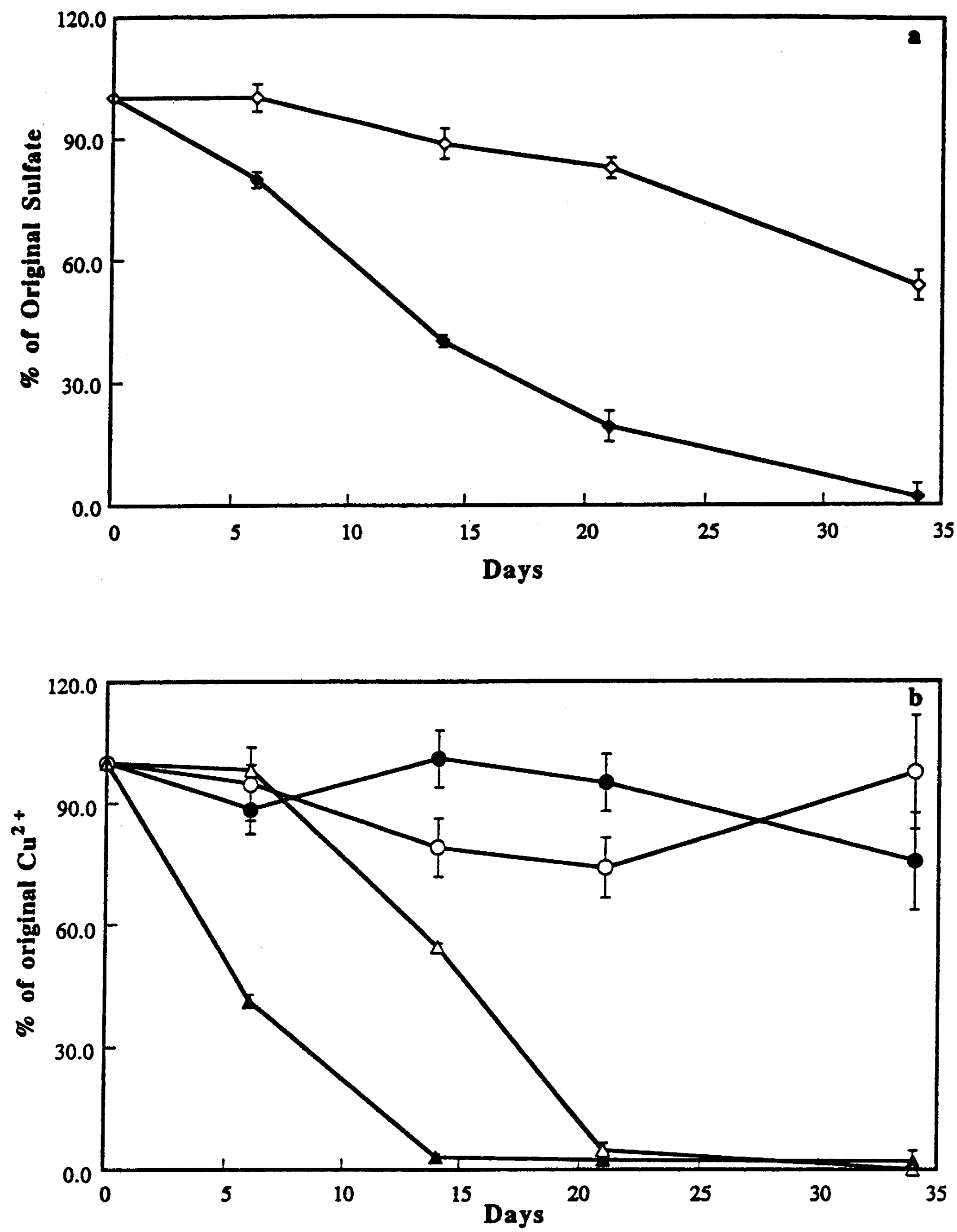
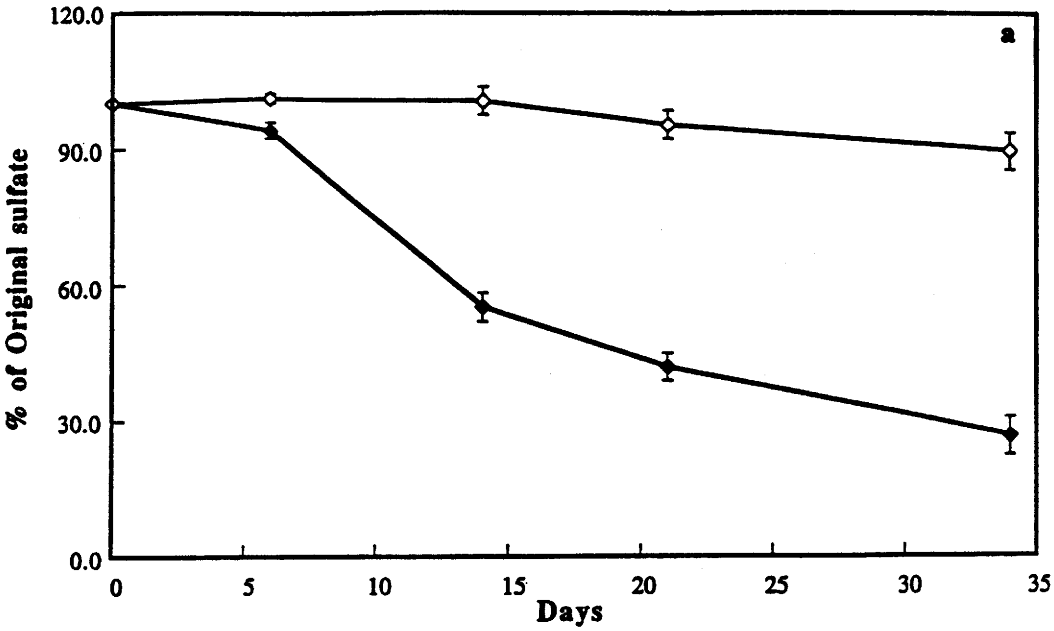


Fig. 2. (a). Sulfate concentrations in consortia from metal-free and metal-contaminated sediments, when Cu^{2+} is at 8.0 ppm. (b). Cu^{2+} concentrations in the two consortia. Symbols: (●) metal-contaminated consortia with 20 mM molybdate; (○) metal-free control with 20 mM molybdate; (◆) metal-contaminated consortia without Cu^{2+}; (◇) metal-free consortia without Cu^{2+}; (▲) metal-contaminated consortia with 8.0 ppm Cu^{2+}; (Δ) metal-free consortia with 8.0 ppm Cu^{2+}.



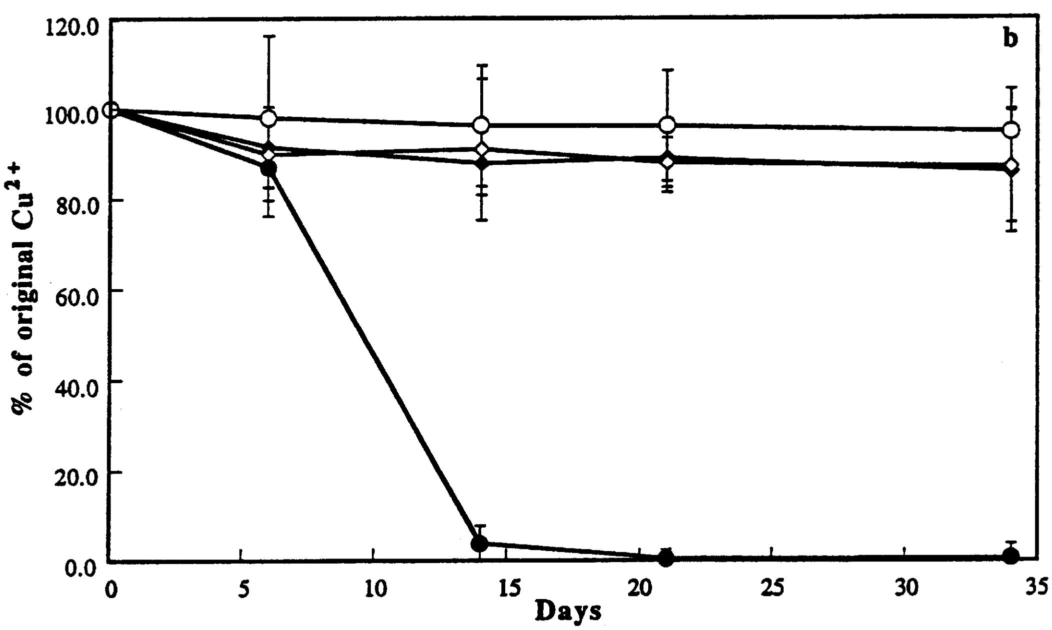


Fig.3. (a). Sulfate concentrations in consortia from metal-free and metal-contaminated sediments, when Cu^{2+} is at 30 ppm. (b). Cu^{2+} concentrations in the two consortia. Symbols: (●) metal-contaminated consortia with 20 mM molybdate; (O) metal-free control with 20 mM molybdate; (◆) metal-contaminated consortia without Cu^{2+}; (◇) metal-free consortia without Cu^{2+}; (▲) metal-contaminated consortia with 30 ppm Cu^{2+}; (Δ) metal-free consortia with 30 ppm Cu^{2+}.

REFERENCES

Bååth, E. 1989. Effects of heavy metals in soil on microbial processes and populations. *Wat. Air Soil Poll.* 47:335-379.

Barnes, L.J., P.J.M. Scheeren, and C.J.N. Buisman. 1994. "Microbial removal of heavy metals and sulfate from contaminated groundwaters", pp. 39-49. *In* J. L. Means and R.E. Hinchee (eds.), *Emerging Technology for Bioremediation of Metals.* Lewis Publishers, Boca Raton, FL.

Colberg, P. J. S. 1990. The role of sulfate in microbial transformations of environmental contaminants: Chlorinated aromatic compounds. *Geomicrobiol. J.* 8:147-165.

Fang, H.P., and H.H. Hui. 1994. Effect of heavy metals on the methanogenic activity of starch-degrading granules. *Biotechnology Letters,* 16: 1091-1096

Gadd, G.M., and A.J. Griffiths. 1978. Microorganisms and heavy metal toxicity. *Microb. Ecol.* 4:303-317.

Genthner, B.R.S., W.A. Price II and P.H. Pritchard. 1989. Characterization of anaerobic dechlorinating consortia derived from aquatic sediments. *Appl. Environ. Microbiol..* 55:1472-1476.

Häggblom, M.M., and L.Y. Young. 1990. Chlorophenol degradation coupled to sulfate reduction. *Appl. Environ. Microbiol.* 56:3255-3260.

Hao, O.J., L. Huang, J.M. Chen., and R.L. Buglass. 1994. Effects of metal additions on sulfate reduction activity in wastewaters. *Toxicol. Environ. Chem.* 46: 197-212

Kim, B-K., E. C. DE Macario, J. Nölling, and L. Daniels. 1996. Isolation and characterization of a copper-resistant methanogen from a copper-mining soil sample. *Appl. Environ. Microbiol..* 62: 2629-2635

Kohring, G.-W., W. Zhang, and J. Wiegel. 1989. Anaerobic dechlorination of 2,4-dichlorophenol in freshwater sediments in the presence of sulfate. *Appl. Environ. Microbiol.* 55:2735-2737.

Kuo, C-W., and B.R.S. Genthner. 1996. Effect of added heavy metal ions on biotransformation and biodegradation of 2-chlorophenol and 3-chlorobenzoate in anaerobic bacterial consortia. *Appl. Environ. Microbiol.* 62: 2317-2323

Lovley, D. R. 1991. Dissimilatory Fe(III) and Mn(IV) reduction. *Microbiol. Rev.* 55:259-287.

Oremland, R.S., J.W. Blum, C.W. Culbertson, P.T. Visscher, L.G. Miller, P. Dowdle, and F.E. Strohmaier. 1994. Isolation, growth, and metabolism of an obligately anaerobic selenate-respiring bacterium, strain SES-3. *Appl. Environ. Microbiol..* 60:3011-3019.

Oremland, R.S., and Capone, D.S. 1988. Use of "specific" inhibitors in biogeochemistry and microbial ecology. *Adv. Microb. Ecol.* 10: 285-383.

Patterson, J.W. 1977. *Waste Water Treatment,* pp. 23-67. Sci. Publishers Inc., New York, NY.

Poulson, S.R., P.J.S. Colberg, and J.I. Drever. 1996. The toxicity of heavy metals (Ni, Zn) to sulfate-reducing bacteria. *Geomicrobiol.* 14: 41-49.

Rittle, K.A., J.I. Drever., And P.J.S. Colberg. 1995. Precipitation of arsenic during bacterial sulfate reduction. *Geomicrobiology J.* 13:1-11.

Smith, L.A., B.C. Alleman, and L. Copley-Graves. 1994. Biological treatment options. *In* J. L. Means and R.E. Hinchee (eds.), *Emerging Technology for Bioremediation of Metals.* CRC Press, Boca Raton, FL.

Stumm, W., and Morgan, J. J. 1982. *Aquatic Chemistry* (2nd Ed.), John Wiley and Sons, New York, NY.

Trevors, J.T., K.M. Oddie and B.H. Belliveau. 1985. Metal resistance in bacteria. *FEMS Microbiol. Rev.* 32: 39-54

FATE OF NITRATE AND ALDICARB UNDER IRRIGATION MANAGEMENT

Shankar Sharmasarkar, Florence Cassel-Sharmasarkar, Renduo Zhang, and George F. Vance[1]

ABSTRACT

Environmental contamination by agrochemicals (fertilizers and pesticides) due to overuse of irrigation water is a national concern, particularly where flood irrigation has been the conventional water application method. Therefore, there is a need to assess other management approaches that can potentially reduce leaching of agrochemicals; the use of drip irrigation may offer such an alternative. The objective of this study was to evaluate nitrate (fertilizer) and aldicarb (pesticide) movement through soils under flood and drip irrigation practices. A transport and irrigation model, CHAIN_IR, was utilized to assess the leaching potential of these two solutes. With flood irrigation, higher concentrations of both nitrate and aldicarb were found deeper in the soil profile as compared to drip treatment, thus, suggesting a greater leaching of chemicals under flooding. In addition to the downward flow, a lateral movement of both nitrate and aldicarb was observed and the results suggested that under drip, fertilizers and pesticides would be available for a greater extent around the point of application, whereas under flood irrigation, there would be run-off loss of the agrochemicals. Nitrate concentration at an internal point ($x = 0$, $z = 35$) inside the soil profile increased curvilinearly with time from 0 to 17 g/cm^3 within 7.5 d, thus, indicating leaching of the added nitrate from the surface ($x = 0$, $z = 0$). Concentrations of aldicarb decreased exponentially following first order kinetics with a specific rate constant (K) of 0.25/d and half-life period ($t_{0.5}$) 2.8 d. Two daughter compounds, aldicarb sulfoxide and sulfone, were also predicted to be formed following a logarithmically increasing function and a zero order linear reaction (K of 0.008g/cm^3/d), respectively. Correlations for all these equations were significant at the 1% probability level. The contour maps for soil water pressure head (h) distribution at 0.5 d post-irrigation period, indicated a greater percolation of the water-front under flood irrigation as compared to the drip irrigation, which would lead to less leaching of the contaminants with drip practices. The overall results of this study suggest that application of drip irrigation is a better alternative for developing best irrigation management practices that can diminish leaching of agrochemicals and control overuse of water.

INTRODUCTION

Environmental contamination due to nitrate (NO_3^- from nitrogenous fertilizers) and aldicarb (2-methyl-2-(methylthio) propionaldehyde-O-(methylcarbamoyl)oxime; pesticide; EPA #264-330) is a national concern as both of these chemicals have been identified as major pollutants (Environmental Protection Agency, 1990). In Torrington, Wyoming (Goshen County), high nitrate levels in groundwater were first observed in 1986 that surpassed the critical EPA level of 10 ppm NO_3-N in 1988 in several municipal wells. In a recent study, several residential wells in the Torrington area, had "predictably high nitrate levels" (Wyoming Hydrogram, December, 1995). Aldicarb, a "Restricted Use Pesticide", is a highly water soluble contaminant that has been detected in waters of several states including Wyoming (Environmental Protection Agency, 1994; Jones and Estes, 1995; Crop Protection Reference, 1995). The contamination problems have been attributed to excessive water application by conventional flood irrigation practice. This practice has several disadvantages, such as: low water use efficiency, less uniform distribution of water, and high labor cost (Finkel, 1982; Lau and Mink, 1987). Hence, it is necessary to develop an alternative irrigation management practice (for example, drip irrigation) that will utilize low-volume water while sustaining crop productivity and controlling agrochemical leaching. Therefore, the objective of this study was to assess and compare the fate of nitrate and aldicarb under flood and drip irrigation practices.

METHODOLOGY

A transport and irrigation model CHAIN_IR (Zhang, 1996), which includes irrigation scheduling and use of water content sensors for interpreting both temporal and spatial changes, was used to simulate flood and drip conditions. This model can simulate flow geometry in 2-D or plane symmetry for a line-source system, and 3-D or axicylindrical symmetry for an isolated point source by utilizing Galerkin-type linear finite element schemes. The water flow for plane symmetry is determined by the equation:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}[K(h)\frac{\partial h}{\partial x}] + \frac{\partial}{\partial z}[K(h)\frac{\partial h}{\partial z} - K(h)] \qquad (1)$$

with $(x,z) \in S = [0, x_{max}] \times [0, z_{max}]$, where x and z are horizontal and vertical coordinates, respectively, within the domain S, 2 = volumetric water content, K(h) = unsaturated hydraulic conductivity at a pressure head h. The water flow equation for axicylindrical symmetry with $(r,z) \in S = [0, r_{max}] \times [0, z_{max}]$, where r = the radial distance, is:

[1] Soil and Environmental Sciences Group, Dept. of Plant, Soil & Insect Sciences, UW, Laramie, WY 82071.

$$\frac{\partial\theta}{\partial t} = \left(\frac{1}{r}\right)\frac{\partial}{\partial r}\left[rK(h)\frac{\partial h}{\partial r}\right] + \frac{\partial}{\partial z}\left[K(h)\frac{\partial h}{\partial z}\right]\frac{\partial K(h)}{\partial z} \qquad (2)$$

The model can simulate chemical transformations as well as transport of both nitrate and aldicarb when subjected to different irrigation scheduling. Irrigation practices can be controlled automatically by a predetermined pressure head (h) at a specific location or by a schedule table indicating irrigation periods. With automatic control, the pressure head can be measured in-situ or can be obtained by a sensor generally located at the driest point within the root zone. When the pressure head at the node representing the sensor location is smaller (dryer) than h, the irrigation system is activated automatically. For the schedule-table control, irrigation practices follow the prescribed time and flow rates.

In this study, the fate of nitrate and aldicarb was evaluated over time (0.5 to 7.5 d) in a sandy loam soil using a uniform-layer domain S having 25 cm radial distance from a point source placed on the surface of a 150 cm soil profile. Flood irrigation was simulated by applying water on the soil surface. For flood, ponding infiltration was simulated using a zero suction (h) by defining 6 and 39 nodes in the x- and z-direction, respectively, with a total of 234 nodes and 190 elements. Drip irrigation was simulated by including 351 nodes and 304 elements with 9 and 39 nodes in the x- and z-direction, respectively. The source (drip-emitter) was defined by a plane surface of 1 cm located at the origin (0,0,0) of the soil profile. Both types of irrigation were scheduled for 0.5 d with nitrate and aldicarb concentrations of 22 and 0.76 g/cm^3, respectively. These simulation conditions were used on the basis of general soil texture, plant row spacing, maximum rooting depth, and fertilizer and pesticide application practices observed for sugarbeet production areas of Wyoming. The initial and boundary conditions for nitrate and aldicarb transport were:

$$h(x, z, 0) = -400 \text{ cm} \qquad (3a)$$

$$Q(x, z, t) = 0 \text{ and } h(x, z, t) = 0 \text{ at } (x, z) \in \text{'}_i \qquad (3b)$$

$$C_s(x, z, 0) = 0 \text{ g/cm}^3 \qquad (3c)$$

$$C_s(x, z, t) = 22 \text{ g/cm}^3 \text{ (nitrate) and } 0.75 \text{ g/cm}^3 \text{ (aldicarb) for } 0<t\leq 0.5 \text{ d at } (x, z) \in \text{'}_I \qquad (3d)$$

$$C_s(x, z, t) = 0 \text{ g/cm}^3 \text{ for } t>0.5 \text{ d at } (x, z) \in \text{'}_i \qquad (3e)$$

where h = soil water pressure head, Q = water flux, C_s = concentrations of added solute as nitrate and aldicarb, and $'_i$ = irrigation boundary of the flow domain S. Selected soil parameters used as input in the simulations are listed in Table 1.

Table 1. Selected soil parameters used as simulation input.*

Parameters	Values
Residual water content (2_r cm^3/cm^3)	0.065
Saturated water content (2_s cm^3/cm^3)	0.410
Coefficient in retention function (" cm^{-1})	0.075
Exponent in retention function (n)	1.89
Saturated hydraulic conductivity (K_s cm/d)	106

*After Leij et al. (1996).

RESULTS AND DISCUSSION

Within 0.5 d of flood irrigation and application of the agrochemicals, higher concentrations of both nitrate and aldicarb were found deeper in the soil profile as compared to drip treatment, thus, suggesting a greater leaching of these solutes under flood irrigation (Fig. 1). During this period, nitrate under drip irrigation remained within the top 25 cm of the profile; in contrast, a percolation beyond 110 cm depth was predicted under flood irrigation. After 7.5 d, leaching was observed under both irrigation practices; however, with drip irrigation, detection of

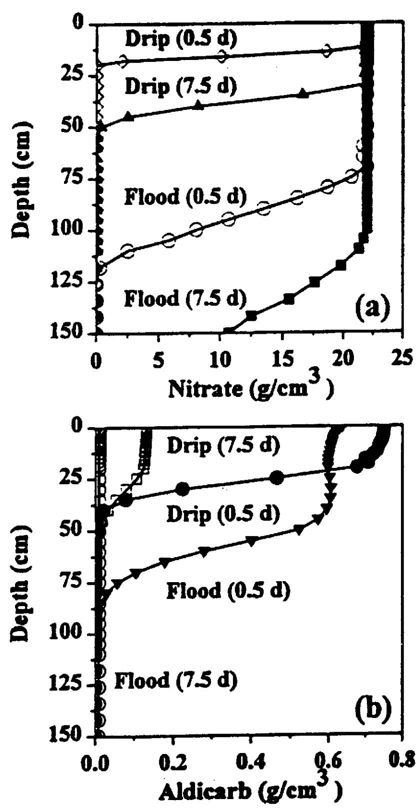


Fig. 1. Change in solute concentrations with depth at different post-irrigation periods: (a) nitrate and (b) aldicarb.

nitrate at much lower depth (within top 50 cm) than with flood indicated a greater efficacy of drip application for leaching control. Thus, for example, 7.5 d after flooding, a nitrate concentration of 10 g/cm^3 was observed around 150 cm depth (bottom of the profile), in contrast to much lower depth (less than 50 cm) with drip irrigation.

Similar to nitrate, less aldicarb leached with drip irrigation as compared with flood (Fig. 1). Compared to 0.5 d, a sharp concentration drop after 7.5 d suggested a possibility of aldicarb transformations, in addition to leaching. This could also be the reason for the difference in the aldicarb and nitrate curve patterns. The concentration drop was more pronounced under flood irrigation, reaching a level near zero after 7.5 d. Besides controlling agrochemical percolation, less leaching with drip irrigation would suggest a greater utilization of the agrochemicals.

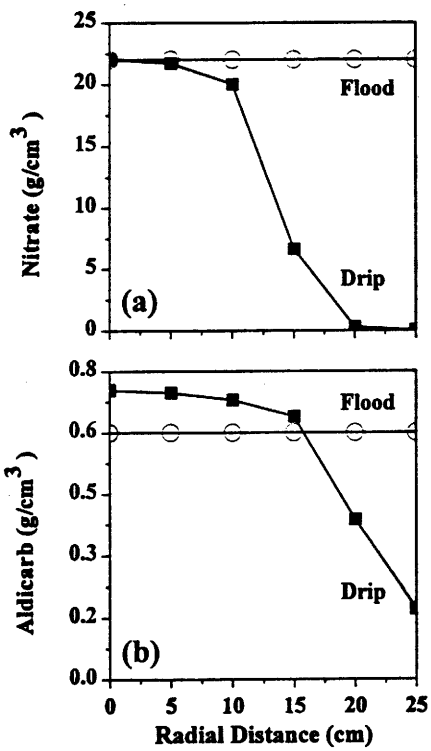


Fig. 2. Surfacial radial distributions of (a) nitrate and (b) aldicarb at a 0.5 d post-irrigation period.

In addition to the downward flow, a lateral flow of both nitrate and aldicarb was indicated by the model as shown by the radial distribution of the solutes (Fig. 2). Under drip irrigation, the concentrations of both chemicals decreased with the increase in radial distance from the point of application. In contrast, with flood irrigation, the radial concentrations remained constant. This suggests that under drip irrigation, fertilizers and pesticides would be available for a longer period of time around the point of application, whereas under flood irrigation, there would be a greater chance of leaching and run-off loss of the agrochemicals.

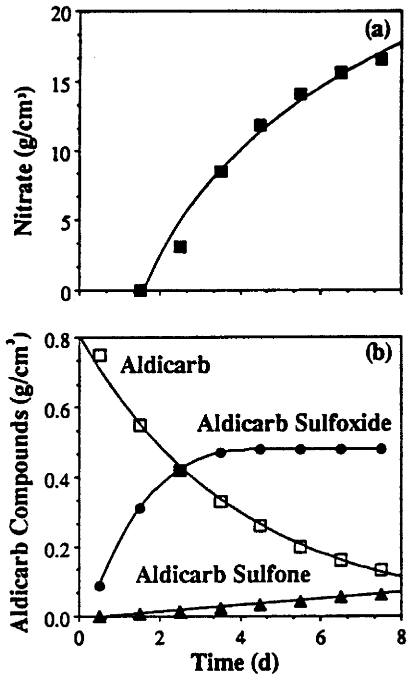


Fig. 3. Change in agrochemical concentrations with time: (a) nitrate at 35 cm and (b) aldicarb compounds at surface.

The fate of nitrate and aldicarb under drip irrigation is shown in plots of concentration against time (Fig. 3). Nitrate concentrations (shown at 35 cm depth) increased curvilinearly with time from 0 to 17 g/cm^3 within 7.5 d, thus, indicating leaching of the added nitrate from the surface ($x = 0$, $z = 0$). The analytical solution of the curve followed a logarithmic function (Table 2). Based on this equation, the leaching time (t_l) of the added nitrate (22 g/cm^3) was calculated to be 11.3 d. The purpose of conducting these analyses at 35 cm was to evaluate nitrate percolation behavior at an internal point ($x = 0$, $z = 35$) inside the soil profile. Similar assessments can be conducted at any point within the profile.

Table 2. Analyses of concentration-time plots for nitrate and aldicarb compounds.*

Species	Equations	r^2	Description
Nitrate	$C=-5.4+26\log t$	0.98	Logarithmic function $t_l=11.3d$
Aldicarb	$C=0.81e^{-0.25t}$	0.99	First order reaction $K=0.25/d$, $t_{0.5}=2.8d$
Aldicarb Sulfoxide	$C=0.23+0.34\log t$	0.92	Logarithmic function
Aldicarb Sulfone	$C=-0.008+0.009t$	0.99	Zero order reaction $K=0.008g/cm^3/d$

*C= concentration, t= time, r^2= square of correlation coefficient (significant at 1% level). Specific rate constant (K) for the zero order reaction was calculated by regressing the equation at zero intercept ($C=Kt$ with $r^2=0.97$).

The concentration of aldicarb decreased exponentially following first order kinetics with a specific rate constant (K) of 0.25/d and half-life period ($t_{0.5}$) 2.8 d (Fig. 3 and Table 2). Two daughter compounds, aldicarb sulfoxide and sulfone, were predicted to be formed following a logarithmically increasing function and a zero order linear reaction (K of $0.008g/cm^3/d$), respectively. Thus, in addition to leaching, the fate of aldicarb also includes oxidative transformation products. These oxidative daughter products are important because of their potential to act as insecticides and groundwater contaminants as well (Jones and Estes, 1995). The correlations for all of the above mentioned equations were significant at the 1% probability level. The purpose of conducting these analyses at the profile surface was to evaluate transformations of aldicarb at the place of pesticide and drip applications.

Finally, the contour maps for soil water pressure head (h, cm) distribution, at a 0.5 d post-irrigation period, indicated greater percolation of the water-front under flood irrigation as compared to the drip irrigation. Thus, for drip irrigation the water-front moved to nearly 25 cm in depth in the form of concentric circles. For flood irrigation, a piston-flow horizontal distribution was observed to nearly 87 cm in depth. Below these depths the profile was relatively dryer, as indicated by the -380 cm h value. Values of isolines with lower magnitude correspond to the wetter zone. For example, under drip irrigation, a wet-zone with -30 cm of h was observed at the 12.5 cm depth and 12.5 cm radial distance. For flood irrigation, the same h value was found at a 70 cm depth and 25 cm radial distance. Thus, the difference in the patterns for water movement under flood and drip irrigation can result in low leaching of the agrochemicals with drip practices.

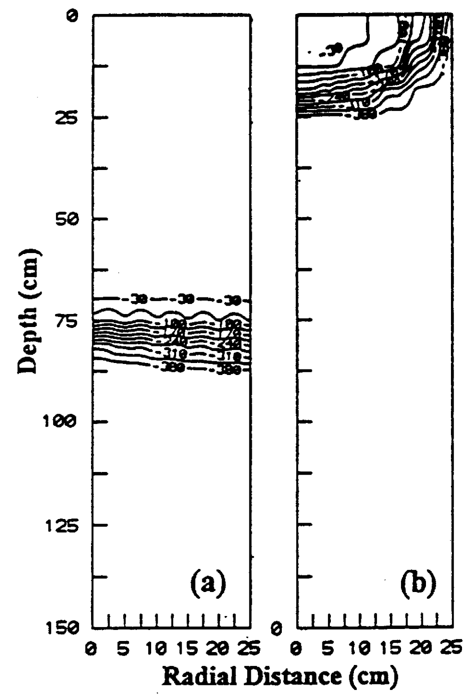


Fig. 4. Contour maps for soil water pressure head distributions in the profile at a 0.5 d post-irrigation period: (a) flood and (b) drip.

CONCLUSIONS

The overall results of this study suggest that the use of drip irrigation is a better alternative for developing best irrigation management practices that can reduce the leaching of nitrate and aldicarb and minimize the overuse of irrigation water. Such a simulation study is important in evaluating the primary management process prior to field implementation. Research is being conducted in an ongoing effort to evaluate *in situ* implementation of this irrigation practice to enhance water quality while sustaining cost-effective crop production.

ACKNOWLEDGMENT

This research was funded by the Wyoming Water Resources Center (WWRC) - U.S. Geological Survey (USGS). We also acknowledge the support of the College of Agriculture Experimental Station.

REFERENCES

Crop Protection Reference. 1995. 11th edition, C&P Press, Inc., New York, NY. 2242p.

Environmental Protection Agency. 1990. National groundwater quality survey. Office of Drinking Water.

Environmental Protection Agency. 1994. Status of Pesticides in Registration and Special Review (Rainbow Report).

Finkel, H.J. 1982. CRC handbook of irrigation technology, vol 2. CRC Press, Inc., Boca Raton, Florida.

Jones, R.L., and T.L. Estes. 1995. Summary of aldicarb monitoring and research programs in the U.S.A. *J. Contm. Hydrol.* 18:107-140.

Lau, L., and J.F. Mink. 1987. Organic contamination of groundwater: a learning experience. *J. Am. Water Works Assoc.* 79:37-42.

Leij, F.J., W.L. Alves, M.Th. van Genuchten, and J.R. Williams. 1996. The UNSODA unsaturated soil hydraulic database user's manual version 1.0. U.S. Environmental Protection Agency, Cincinnati, OH. 103p.

Wyoming Hydrogram. December, 1995. Wyoming Water Resources Center, Volume 7, Number 2, University of Wyoming, Laramie, WY. 8p.

Zhang, R. 1996. Modeling flood and drip irrigation. *ICID Journal: Irrigation, Drainage and Flood Control.* 45:81-92.

PRESENT AND FUTURE IMPACTS OF THE BIG SANDY RIVER SALINITY CONTROL PROGRAM ON AN AGRICULTURAL COMMUNITY

Tom Heald and Kelly Crane[1]

OVERVIEW

The Big Sandy River of South West Wyoming is a tributary of the Green and Colorado River systems. The Big Sandy River and the associated irrigation district located in Farson had been identified as one of seven major sources of salt entering the Colorado river system. In 1988, in order to mitigate the impact salt had on the river the Federal Government created the Big Sandy Salinity Control Program. The goal of the salinity control program was to improve irrigation practices on agricultural lands by conserving water and thus reduce salt loading onto the river system.

To accomplish this goal on the Big Sandy River, the federal government implemented a cost share program with agricultural water users (70%-30% split) for sprinkler irrigation systems. From 1988 to 1996, one hundred irrigation systems were installed representing 8,620 acres and amounting to a cash outlay of over five million dollars by the government. It is estimated that a total of 30,000 tons of salt is saved annually.

Now as the Salinity control program winds down, what effect has this program had on the economy, the culture, and structure of the community of Farson? Further, is the Salinity Control Program sustainable?

THE ECONOMY

Farson, including the surrounding irrigation district has a population of approximately 500 people. An infusion of over five million dollars by the government into the local economy created a boom. Four independent sprinkler distributors went into business. Along with the distributors, jobs were created for installers, concrete layers, electricians and other affiliated industries. A General Store opened. Eleven professional jobs were created including eight Natural Resource and Conservation Service personnel, two Farm Service Agency personnel and one full time Water Quality Extension Agent. Today, theses jobs, including those of the Federal Government have dwindled to about the levels before the Control Program went into effect. Land values have risen from \$250.00 / acre in 1987 to over \$1,000.00 per acre in 1997 at least in part to the enhancement of the irrigation systems.

THE CULTURE

No longer is Farson considered an agricultural community but rather a community in transition. As a result of the improved irrigation systems, opportunities were created for persons with jobs elsewhere to farm and still maintain their existing jobs. Approximately 25 families have moved into the area that fit this profile. Of the 118 irrigated units on the project (an irrigated unit consists of land acreage from 1 to 1,000 acres) approximately 40 families derive the majority of their income through agriculture. This data suggests that as traditional agriculturalists moved on, people from other areas filled these vacancies but with different priorities other than profiting from agriculture.

THE STRUCTURE

The Structure of Agriculture in the Farson area has changed significantly since the addition of sprinkler systems. Traditionally, crops raised included native hay, with an occasional crop of alfalfa or oats. Average production for the area before the sprinkler systems was 1.25 tons / acre of native hay. Today, alfalfa hay is the dominant crop with average production of 3.5 tons / acre. Costs of production have nearly doubled from \$25.00 - \$30.00 / ton in 1987 to \$45.00 - \$60.00 / ton in 1996. The average farm is now producing more forage than their on farm needs demand. This increase in forage has been good and bad. It has allowed for opportunities to market forage elsewhere. The problem has been identifying markets with in the region that is in need of forages on a consistent basis. Average sale prices for alfalfa hay in the Farson area from 1990 - 1996 was \$75.00 / ton. Therefore, profits range from\$105.00 / acre for the least cost producer to \$52.50 for others (assuming all hay produced was sold). On a hundred acres of alfalfa profits range from \$10,500.00 to \$5,250.00. This represents near subsistence farming.

THE FUTURE

As noted earlier, Farson is in a time of transition. The sprinkler systems have saved salt, allowed for flexibility in farming, increased production and has been a contributing factor in the increase in land values. They have also been a significant boom to the local economy. However, the ability to make adequate profits to maintain agricultural operations is questionable. We have increased production but so too has the cost of production. Marketing of surpluses is not consistent. As these irrigation systems age, the cost of operating them becomes more expensive. At what point will it become impractical to operate these systems when agronomically it costs more to produce a product than what it can be sold for? What then will become of the sprinklers? Will farmers abandon them and return to flood irrigation?

The simple answer is to improve markets. However, the types of crops raised in this environment is limited. At this time there is no crop that can substitute for alfalfa. Although the Federal

[1] Wyoming Cooperative Extension Service, Rock Springs, WY 82902; and Sublette County Cooperative Extension Office, Box 579, Pinedale, WY 82941.

Government took significant measures to mitigate salt, they failed to address the long term sustainability of agriculture in the Big Sandy Salinity Control Program. It is now up to the area residents to make the systems work with no guarantee of being successful.

SESSION 5:

WATER RESOURCE EDUCATION

WYOMING'S APPROACH TO MULTI-DISCIPLINARY GRADUATE EDUCATION IN WATER RESOURCES

Thomas A. Wesche, Chris M. Goertler and Travis A. Bray[1]

INTRODUCTION

The Wyoming Water Resources Center (WWRC) at the University of Wyoming (UW) cooperates with the Graduate School and ten academic departments across campus to provide a master's degree program with multi-disciplinary education in water resources. UW awards this degree as a specialty option within each of the sponsoring department's graduate programs. The emphasis on water resources is acknowledged on the student's diploma and transcript to certify that the graduate has completed a multi-disciplinary program specializing in water resources.

The Master's Degree Water Resources Option (MDWRO) has been designated as a high quality program by the Wyoming Legislature through its 1982 authorizations providing for the WWRC. The purpose of the program is to emphasize the multi-disciplinary aspects of the water resources field and to impart such a perspective to the students consistent with the rigorous demands that graduates will face in their professional careers. The degree program is also designed to be flexible in order to meet the professional objectives of individual students.

The objective of this paper is to describe the program requirements of the MDWRO and to summarize student participation in the program since its inception.

PROGRAM REQUIREMENTS

The MDWRO requires a combination of approved course work, seminar participation and thesis research related to water resources. The general program includes nine semester hours of course work in addition to the departmental study requirements, with three credit hours in each of three areas; hydrology, law and natural resource economics, and water quality. An inter-departmental Academic Standards Committee approves courses from these three content areas for inclusion within the MDWRO. At least six of these nine hours must be outside of the student's major academic department. In addition, students must participate in a special one-semester seminar on water issues, giving at least one formal presentation. The master's thesis research must be related to an area in water resources, with only Plan A programs (requiring a written thesis) eligible for this option.

Ten departments in four colleges at UW have approved curricula and offer graduate programs with the MDWRO. These include the Departments of Agricultural Economics (AGEC), Molecular Biology (MB), Plant, Soil and Insect Sciences (PSIS), and Rangeland Ecology and Watershed Management (REWM) within the College of Agriculture; the Departments of Botany (BOT), Geography and Recreation (GEOG), Geology and Geophysics (GEOL), and Zoology and Physiology (ZOOL) within the College of Arts and Sciences; the Department of Civil Engineering (CIENG) within the College of Engineering; and, the Department of Economics and Finance (ECON) within the College of Business.

STUDENT PARTICIPATION

Since 1987, eighty-seven UW students have either graduated from or are currently enrolled in the MDWRO (Figure 1). Interest in the program has grown steadily since the late 1980's, with the largest increase occurring in 1993. Over the 1993-96 period, we have averaged 13 graduates per year, while at present, we have 17 students enrolled.

The majority of students participating in the MDWRO have been from the College of Agriculture (47%) and the College of Arts and Sciences (45%), with the remaining 8% from Engineering and Business (Figure 2). Within the College of Agriculture, the programs in the REWM, PSIS and AGEC Departments have been quite active, while within the College of Arts and Sciences, participating students have been almost equally distributed between the GEOG, ZOOL, and GEOL Departments.

Almost all students graduating from the MDWRO have been able to find professional employment in the water resource field. The largest employer of our graduates has been the private sector (35%), closely followed by state government/universities (32%) (Figure 3). Within the private sector, students have found opportunities with water resource, environmental, and engineering consulting firms, mining companies, and public power producers, among others. State agencies who have hired our graduates include the Wyoming State Engineer's Office, the Wyoming Department of Environmental Quality, the Wyoming Game and Fish Department, and the University of Wyoming. Similar agencies in other western states have also provided employment opportunities. Just under 20% of our graduates have entered federal and tribal service, including agencies such as the Bureau of Reclamation, the Forest Service, the Bureau of Land Management, the U.S. Fish and Wildlife Service, and the Yakima Indian Nation. The remaining 14% of our graduates have either found employment with such local entities as school, irrigation, and conservation districts or have chosen to further pursue their education.

[1] Department of Rangeland Ecology & Watershed Management and Wyoming Water Resources Center, WWRC; WWRC, P.O. Box 3067, University Station, UW, Laramie, WY 82071

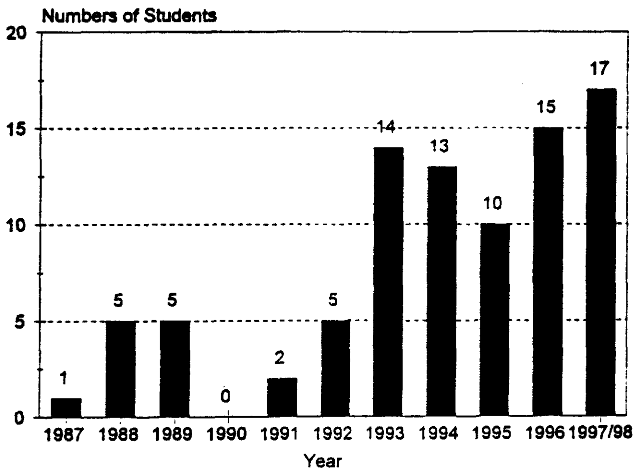


Figure 1. Number of University of Wyoming Students Graduated in the Master's Degree in Water Resources Option form 1987 to 1996. The 1997/1998 Data are for Students Currently Enrolled.

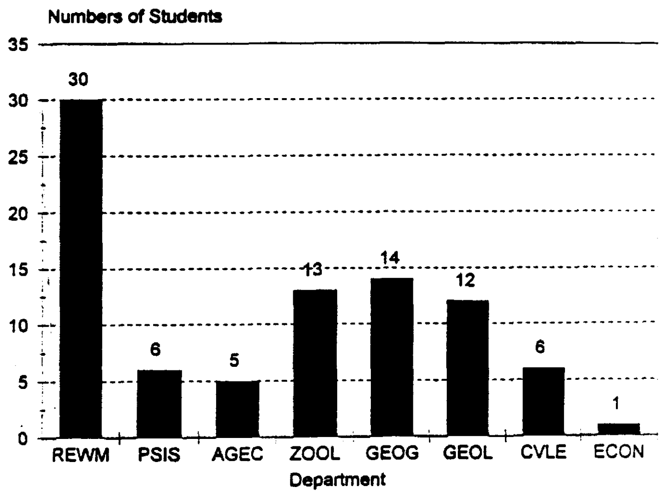


Figure 2. Distribution of University of Wyoming Students in the Master's Degree in Water Resources Option Among Academic Departments.

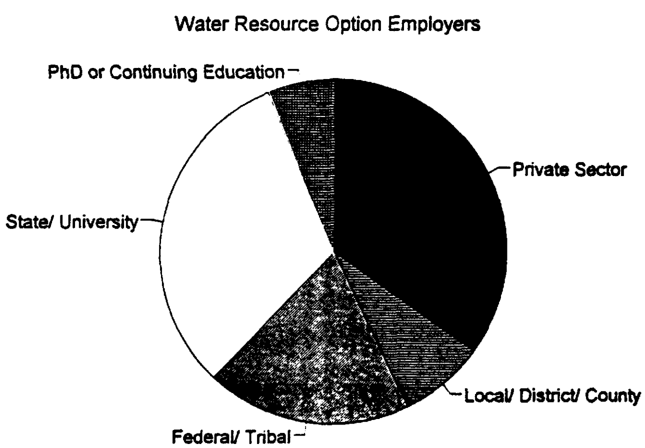


Figure 3. Employment of Graduates from the University of Wyoming's Masters Degree in Water Resources Option.

THE CONSERVE WYOMING PROGRAM

Donn Kesselheim and Thomas Whitney[1]

ABSTRACT

The Wyoming Riparian Association (WRA) was created to join natural resource agencies, agricultural producer groups, environmental groups and professional natural resource societies into one organization to promote sound management of riparian areas in Wyoming. It works toward this goal through education, networking, support for research, and technical assistance efforts.

One WRA initiative is an educational program called ConServe Wyoming. The purpose of the ConServe Wyoming program is to initiate (or continue) school-based, service-learning programs within Wyoming communities. Such programs are based upon involvement of students in a holistic approach to stream rehabilitation, that is designed to provide a "hands-on" component to school district efforts to implement student performance standards, and that is thoroughly integrated into the existing district curriculum.

An example of the kind of program ConServe Wyoming advocates is to be found at Kelly Walsh High School in Casper, where for several years Elizabeth Horsch, a gifted chemistry teacher, has chosen to involve her students in research related to water. The project compares one heavily impacted stream, Garden Creek, with a second, lightly impacted stream, Squaw Creek. One of Ms. Horsch's former students will share responsibility for the presentation.

ORGANIZATION DESCRIPTION

ConServe Wyoming is a project which seeks to involve students outdoors in watershed rehabilitation activities, as a form of community service integrated with the school curriculum. Responsibility for administering the Project is carried by the Wyoming Riparian Association (WRA). The WRA was created in 1989 at the request of then-Governor Mike Sullivan to join together state and federal natural resource agencies, agricultural producer groups, environmental groups and professional natural resource societies into one organization, for the purpose of promoting improved management of Wyoming's riparian habitat. At the outset, Governor Sullivan proposed that the new association ought to build upon existing areas of *agreement* between disparate points of view, while spending little time trying to sort through areas of *disagreement.* Utilizing a consensus mode for decision-making, the WRA works toward this goal by means of education, communication and coordination, support of research and development, and technical assistance and review. The association is a 501(c)(3) not-for-profit organization.

This program is based upon extensive experience in environmental education. An earlier program of educational outreach is listed in Renew America's Environmental Success Index. These outreach endeavors consisted of:

* the Conservation Biology Project, a six-year drive to provide training in field study skills and curriculum materials about the basic concepts of biological diversity and climate change for teachers and administrators in Wyoming public schools, along with natural resource agency personnel; and

* a series of weekly radio programs, entitled "Wyoming Outdoors," which were broadcast statewide on Wyoming Public Radio, and subsequently picked up for dissemination on two E-mail networks. About 300 programs were produced.

The Conservation Biology Project – from which ConServe Wyoming evolved – received a "Take Pride in America" award in 1989 from the U. S. Fish and Wildlife Service. Donn Kesselheim, the coordinator of both these projects, played a central role in founding the Wyoming Association for Environmental Education in 1992.

PROBLEM STATEMENT

One of the problems we confront is that young people growing up in Wyoming – including Native American youth – tend to have a very superficial investment in the land that nurtures them. Nearly all of them live under circumstances that afford them only infrequent contact with the abundance of natural resources which surround them. Neither do they have much awareness of the threads that tie their particular community together, the network of ecological relationships and personal commitments that make it function as an integrated unit.

At the same time, there is intense concern in many quarters about the continuing degradation of a number of Wyoming's streams and the associated riparian areas. People connected to agriculture generally agree that, in managing natural resources, the deterioration of our watersheds is an enormous problem.

Consequently, the problems addressed by the project are three-fold:

1. How to give Wyoming youth a "sweat equity" in the natural resources of the area in which they grow up?

2. How to provide insight for young people into the network of relationships – both human and ecological – that make their community function as an integrated unit?

[1] Wyoming Riparian Association, 22 Pheasant Run Dr., Lander, WY 82520; and 525 White Hall, UW, Laramie, WY 82070.

3. How to accomplish the rehabilitation of selected stream drainages on a holistic basis?

There is a need here in Wyoming to test the hypothesis that engaging public school students in community service related to a meaningful conservation project, like watershed rehabilitation, will cause them to sink deeper roots into the soil of their home state. As they experience community service, leading to a gradual improvement in the condition of nearby streams, students will be able to assess the value of being involved in purposes larger than their individual goals. In this way, we hope that they will develop:

(a) a clearer sense of their own identity; and

(b) a better understanding of the individual's role in their respective communities – along with a commitment to making these communities function more effectively.

GOALS AND OBJECTIVES

A. To engage public school students in community service related to natural resource management, at the level of *doing*

1. To improve ecological literacy, related to riparian management, among students in grades K-12 involved with the Project

2. To develop students' leadership potential, and to provide them with opportunities to exercise this potential

3. To develop and disseminate usable curriculum materials within cooperating school districts

4. To promote integration of community service and in-classroom activities by teachers and students involved with the Project

5. To involve students in a coherent community service project, and to help them internalize that experience, thereby:

   a. enhancing their sense of *connection* to, and appreciation for, their local environment;

   b. giving them an experience of authentic accomplishment; and

   c. stimulating interest in natural resource management that may have future career implications.

6. To increase the capacity for critical thinking about public policy issues related to riparian management among teachers and students involved with the Project

7. To promote constructive interaction between personnel from school districts and natural resource agencies

B. To bring about positive changes in watershed management practices, with an emphasis upon innovative techniques of riparian management and reduction of non-point source pollution *(Objectives for this goal will be site-specific.)*

PROJECT DESCRIPTION

ConServe Wyoming, in its effort to promote service-learning in Wyoming, first carried responsibility for introducing a national initiative into this state. The Project seeks to establish a school-based, service-learning program in public school districts. The central idea is to engage students in a form of community service that is also integrated into the school curriculum. In this case, the vehicle is stream rehabilitation. Students participate in field work related to watershed restoration, while at the same time they are learning about natural resource management in the classroom. The Project benefits from the experience that the Project Director has gained through his involvement in the rehabilitation of two connected drainages near the town of Lander, an undertaking in which students have played an important role. Its program builds around identification of a high-profile, demonstration area on a short reach of stream easily accessible to local schools – an approach to involving young people in stream rehabilitation that has been successful in Lander.

During Year 5, the project will create school-based, service-learning programs in more Wyoming public school districts. To provide start-up motivation for students, ConServe Wyoming will work with schools to organize "Youth Service Days," a one-day event that gets kids working outdoors under the supervision of natural resource agencies on local conservation projects. We shall use a combination of curriculum materials. Some which focus on the cognitive, technical aspects of watershed rehabilitation are pre-existing packets; some which focus on the affective side of service learning – reflective writing, poetry or painting, for example – were created in the Year 1 planning phase of ConServe Wyoming. The curriculum materials will be enriched by the use of a groundwater flow model and watershed management simulation software.* High school tutors and elementary-age tutees will be brought into contact with each other through the conscious use of a cross-age teaching strategy. Teachers and school children will assist in designing and carrying out baseline studies, erosion analysis, resource management, monitoring of range conditions, environmental mitigation, and water quality monitoring. Then these activities will be creatively integrated into classroom learning by means of a series of modules that help students to internalize the significance of what they

* It is anticipated that this software will be customized for use in Wyoming by the addition of data from watersheds from within this state, in several versions. One will be for use in schools, while others will address the concerns of agricultural producers, community planners and such natural resource agencies as the Wyoming Water Development Commission.

are doing. These latter modules emphasize empowerment of students through the strengthening of self-esteem and the development of social skills.

EXAMPLE OF A LOCAL PROJECT

In Casper, a comparative study of two short streams, Garden Creek and Squaw Creek, was conducted by high school and elementary students. Both drainages originate on nearby Casper Mountain. Garden Creek flows through the city, and is quite heavily impacted, while Squaw Creek is as yet relatively pristine because it flows through areas where development has been light to non-existent. The original intent was to draw lessons from the unplanned development of Garden Creek, to be applied to the future development of Squaw Creek.

After an initial period of data collection from both streams, the focus of the study during the past two years has concentrated upon Garden Creek. An indicator study of the overall water quality of Garden Creek has been conducted by several groups of students at Kelly Walsh High School. One of these students is Thomas Whitney, who is a co-presenter at the WYOMING WATER 1997 Conference.

The purpose of this study was to measure chemical and physical factors concerning the stream's ability to support aquatic life and its safety for casual use. Tests were performed at several sites along the stream to show the effects of urbanization. These sites included Garden Creek Falls, the Leotta property, a site near Sunrise Shopping Center, Nancy English Park, and a site where Garden Creek empties into the North Platte River. The tests were done between September 1994 and October 1995, primarily in the fall and spring.

The tests concerning physical factors were temperature, volume, and velocity. The chemical tests involved pH, dissolved oxygen, nitrates, phosphates, biological oxygen demand (BOD), and total solids (TS). Benthic macroinvertebrates were collected at each site, and tests were performed for fecal coliforms. Data collected will be summarized in the conference presentation.

The water quality indices* at the different data collection sites indicate that overall stream health declines when Garden Creek first flows through the developed areas around the stream, and then slowly recovers as it nears the Platte River. The main reasons for this decline are the nitrate concentrations and fecal coliforms measured at the sites, which both jump to abnormally high levels when the stream first flows through a developed area. Both nitrates and fecal coliforms are indicators of sewage or fecal material entering the stream. One possible cause for this would be livestock along the stream. Another possible cause lies with the individual septic systems that belong to all of the houses along the section of stream where these readings were highest. The leach fields for these septic systems could be saturated, and the organisms in the soil may not be breaking down the sewage fast enough. The sewage then moves down in the soil until it reaches an impermeable layer of shale or bentonite, along which the sewage travels until it reaches Garden Creek. The groundwater in this area may also be polluted in the same way.

WHO BENEFITS?

A. The primary target audience is students in grades K-12 in the school districts selected for involvement in the Project.

B. Also targeted are the public land managers and private landowners in the watersheds selected for attention.

C. Secondarily, teachers and administrators working with the students in the primary target audience will also become more aware of good riparian management practices.

PERSONNEL

The Project Director is Donn Kesselheim, who brings to this initiative a doctoral degree from Harvard in educational administration, and over 40 years of experience as a teacher and school administrator.

At each Project site, individuals to assume the following roles will be identified:

1. The Site Coordinator, an individual from the staff of a local agency office with interest (and experience, perhaps) in public education

2. Two lead teachers, one from an elementary school, one from a high school

For further information, contact:

DONN KESSELHEIM
WYOMING RIPARIAN ASSOCIATION
22 PHEASANT RUN DRIVE
LANDER, WYOMING 82520
PH: 307/332-6518 FAX: 307/332-6899

THOMAS WHITNEY
525 WHITE HALL
LARAMIE, WYOMING 82070

* A quality index is a measurement based on the data, weighted to reflect the importance of the factor to the overall health of the stream.

THE STATEWIDE INTEGRATED CONSERVATION EDUCATION PROGRAM

Duane Keown and David Rizor[1]

One of the most pressing needs in today's world is wise decision making on issues concerning the environment. The best insurance for good decision making is good education about the environment. This needs to be done not in a piecemeal or fragmented approach, but rather in a comprehensive program which exposes students to the inter-relatedness of all parts of the environment: biotic, abiotic, human and non-human. Issues related to the environment and natural resources dominate both the electronic and print media in Wyoming and the West, with special interest groups constantly lobbying for their point of view. This makes it imperative for our decision makers as well as the general public to be well prepared to make decisions which will have long term implications on the environment and our quality of life. In fact, when the Wyoming Game & Fish Department held a series of community meetings throughout the state (Wildlife 2010) in 1993, asking for public input on what action that department should take as they look ahead toward the year 2010, the overwhelming response was a call for more environmental education.

There are many fine programs available today in environmental education for teachers to use, but most address only limited pieces of the environment such as wildlife, water, energy, or forests. They do not present a comprehensive view of the environment, and most are not being disseminated in a way that produces the largest impact in reaching our future decision makers. In Wyoming for example, most school districts have outcomes of accomplishment for students regarding conservation/environmental education, but they do not have a prescribed curriculum and teachers are not required to prepare to teach about natural resources, their use and conservation. In 1997 there are only three states: Delaware, Arizona, and Wisconsin, that even require teachers to study about natural resources conservation in becoming certified to teach in the public schools. Yet, what is more basic to the future of our quality of life and the quality of the environment than understanding our natural resources?

Some of the fine programs presently available are Project Wild, which focuses primarily on wildlife, Project Learning Tree, which focuses primarily on forests, Project WET, which focuses primarily on water, and others. The need exists for a holistic program which ties together these individual programs which center around specific pieces of the environment because, after all, the parts of the environment are inextricably inter-related and must be considered in the context of the larger whole. This is where the Statewide Integrated Conservation Program, and its curriculum, *Wild, Wonderful, Wyoming: Choices for the Future*, fits in.

THE STATEWIDE INTEGRATED CONSERVATION EDUCATION PROGRAM

The Wyoming Conservation Connection, a unique unit of the Natural Science Program at the University of Wyoming, began in 1987 by offering Project Learning Tree Workshops for teachers. By 1994 workshops for several specific areas of natural resource conservation education were, and still are, being offered. Project Learning Tree continues to be popular along with the Energy & Recycling Curricula Workshops and Water Conservation Curricula Workshops (both curricula were developed at the Conservation Connection), as well as Population Education and others. In the summers, the Conservation Connection's three day Natural Science Workshops for teachers provide a means to witness the powerful learning opportunity provided by a more comprehensive program. These workshops include many individual pieces with limited focus which are joined together in the more complete context of conservation/environmental education, stewardship of natural resources and their sustainability, and a long range vision for quality of life. The Statewide Integrated Conservation Education Program (SICEP) is the natural outgrowth of these workshops.

With a continuing grant from Eisenhower Math and Science Improvement Funds, the curriculum materials of the SICEP program integrate conservation concepts into all subjects of our schools in grades K-12. *Wild Wonderful Wyoming* is not another class being added to an already bulging school curriculum. The design of the *Wild Wonderful Wyoming* materials is intended to incorporate concepts about sustaining the environment and our high quality of life into the school curriculums that are already in place.

As the name implies, *Wild Wonderful Wyoming: Choices for the Future* is designed to give K-12 students the background needed to make important decisions about the future. Wyoming is included in the title because, unlike many curriculum materials that are generic and produced for the nation or even the globe, Wyoming is the focus of *Wild Wonderful Wyoming*. The philosophy of the curriculum follows the popular bumper sticker adage, "Think Globally, Act Locally." Wherever people live on the planet, it is the environment of the place where they live that should most concern them. Stewardship of earth begins with taking care of home. Earth stewardship is not somewhere else. Although "Wyoming" is included in the name because the program focuses on

[1] Natural Science Program, Box 3992, University Station, Laramie, Wyoming 82071; and Walden Middle School, Box 798, Walden, CO 80480

Wyoming resources, the model is for the West, and the model is going beyond Wyoming.

The SICEP was put together not by a company hoping to make money or by a group pushing a slanted agenda, but by outstanding professional educators who have taken this opportunity to compile and modify activities from various sources such as those mentioned above to make one outstanding comprehensive program. The elementary manual has 77 activities drawn from 27 sources which have been modified to reflect the most effective pedagogical methods by people who understand how children learn. This allows the best ideas and activities from many outstanding sources to be put together and modified into one logical, comprehensive program.

One of the less visible features of this program that sets it apart from others is the dissemination method. Most current programs are offered to teachers as weekend workshops or after school workshops. This generally attracts those already teaching the subject because they are interested and want new ideas and materials. The SICEP program has used a different approach by "networking" with school districts. School districts have "bought in" to the program by choosing the teachers who have helped put the program together. Thirty-nine of the forty-nine Wyoming school district superintendents chose teachers who came to the University over three summers to compile and write the curriculum. Each of these teachers not only has an interest in environmental education, they are also among the very best educators in the state. As a result, whole-school workshops are offered as in service in these districts on a program one or more of their teachers has helped develop. By approaching the workshops in this way they don't have to be offered at inconvenient times but include all teachers in the school. We avoid preaching to the choir. Most teachers who would not have otherwise attended are pleasantly surprised and eager to try the activities. Also, each workshop is attended by representatives from state and federal resource management agencies, conservation districts, industry and community leaders. Teachers find these people make up a community support group and the SICEP is not a school project in isolation, but a cooperative community program.

Wild, Wonderful Wyoming: Choices for the Future is not designed to be an added-on class to a school curriculum which is probably already full. Rather, the lessons are designed to integrate with the current curriculum framework. Though conservation/environmental education is rooted in science, it is a large umbrella containing virtually all subject areas from science to history, political science to art, and from language arts to music.

SICEP Teacher-Representatives are master teachers. They wanted the manual to get used and they had good ideas about what it would take. It needed page layouts, charts, pictures, titles, graphics, and other information that would enhance "teacher friendliness" in the finished product. Early into the SICEP project the Bureau of Land Management, a long-time partner in the Wyoming Conservation Connection, became interested in the project. The professional services provided BLM artists, computer technicians, and nearly a hundred color photographs from the Wyoming Game & Fish Department (Wyoming Wildlife Magazine) and others, have produced a manual of a professional quality hardly imagined at the program's beginning. And who will be better qualified to teach teachers how to use the manuals than the teachers who helped produce them?

CURRICULUM STRUCTURE

The framework for the curriculum was built using several environmental education reference documents and materials, as well as materials developed in the SICEP. The basic wording of the goals was drawn from *Learner Outcomes for Environmental Literacy* (Wyoming Environmental Education Task Force, 1991), and the *Comprehensive Plan for Environmental Education* (Governor's Task Force on Environmental Education 1992):

Goals of the SICEP are to realize a Wyoming High School Graduate who:

Goal A: Has a working knowledge of those cross-disciplinary concepts pertaining to the sustainable use of an environment hospitable to the diversity of Earth's species, including man.

Goal B: Seeks to expand direct human experience with the natural world to satisfy curiosity about "how things work."

Goal C: Understands and values natural systems; comprehends that all life is connected and that before any part of an ecosystem is changed, the impact of the change on the ecosystem and the biosphere must be considered.

Goal D: Thinks critically about environmental issues, communicates effectively about them, and is motivated to help resolve them.

Goal E: Is committed to the continuing development and application of a sustainable land ethic.

Goal F: Will understand what natural resources management is, how and why humans manage natural resources and how this management affects humans. Students will further understand that management decisions are based on human-defined goals, values and needs.

To complete the framework, appropriate concepts were either written or chosen from references such as *Essential Learnings in Environmental Education* (Ballard & Pandya 1990), and listed under each of the goal statements.

Working within this framework, the teacher-facilitators have developed activities during a series of three two week summer workshops. Then, during the school year, they have used the activities in their classrooms to evaluate them. Many of the activities are being borrowed from other excellent programs such as *Project Wild, Project Learning Tree*, and *OBIS*, but the finished product will be much more comprehensive than any of these programs are individually. In fact, nearly 27 sources are used in the elementary manual alone. Rather than focusing on wildlife, trees, nature awareness or any other single perspective, *Wild Wonderful Wyoming* takes a complete environmental education approach utilizing the best of other programs as well as including new activities. If not already written to incorporate current pedagogical techniques, these activities are modified into formats that center around discovery learning, the learning cycle, and cooperative learning when appropriate.

Wild Wonderful Wyoming is never completed. At both the elementary and secondary level, the activities go in attractive two and one-half inch, three ring binder. The organization of SICEP Teacher Representatives remains to continually produce activities for the manuals and lead in conservation/environmental education in their districts. They will continue to meet at the University of Wyoming in summers to add needed components to the statewide manuals. In the summer of 1997 the theme of the summer conference at the University is Global Change. The workshop now includes all interested in conservation/environmental education and all surrounding states have been invited. Noted global change scientists are scheduled to attend and speak to the SICEP educators and others who attend.

The six topic areas, or chapters, in Wild, Wonderful Wyoming are:

Earth Systems - Looks at the dynamic cycles and systems on earth.

Water Resources - Water is vital to all living things, and is especially precious in the arid west.

Energy & Recycling - We depend on an abundant energy supply and Wyoming is a major energy supplier. Recycling is vital to conserve energy, raw materials, and landfill space.

Wildlife Resources - Wildlife is an important economic, biological, and quality of life resource.

Forest Resources - Forests are also an important resource for our economy, biological health, and quality of life.

Agriculture Resources - Agriculture depends on a healthy environment and society depends on agriculture.

Five common themes tie these topic areas together. Within each chapter these five strands: Earth Time, Geology-Geophysical, Ecosystem Function, Evolution-Adaptation, and Population — help maintain the continuity and interconnected structure of the activities . The strands center scientific concepts that are essential for citizens to understand if they are to live in harmony with the systems that sustain life on earth. Education, especially that which examines long-term effects of important public policy and personal lifestyle choices is not the proper forum for emotionally charged material. Therefore, all of the activities, whether they are primarily science activities or in another area such as history, language arts, or art, are based on fact and sound scientific reasoning.

NOT JUST SCIENCE

One of the exciting aspects of environmental education that allows it to be easily integrated into an existing curriculum is its diverse nature. Virtually every subject area is included under the umbrella of environmental education: science, to understand the relationships between and among living things and the physical earth; economics and health, for we will always depend on the resources of the earth for food and raw materials; language arts to communicate our ideas in language; art, music, dance, and theater to communicate ideas in other ways; history, to examine what has and hasn't worked in the past; sociology; political science; and so on are all important in helping students develop into wise decision makers.

NOT JUST FOR KIDS

The *Wild Wonderful Wyoming: Choices for the Future* manuals are not just a collection of outstanding activities for teachers to do with their students. The books are designed to help the teacher become better educated about environmental concepts as well. Each chapter begins with an essay which describes the importance of the concept and some of the issues involved with that resource area, as well as orienting the teacher to where the activities fit into the topic area. Also, each activity has a background piece to help further acquaint teachers with how the lesson fits into the larger picture of the environment.

THE ADVISORY BOARD

To insure the integrity of the material for content, educational appropriateness, and objective analysis of issues, the project is being overseen by an 18 member Advisory Board composed of members of industry, school board members, scientists, resource managers, and educators. The entire curriculum goes to the members and members solicit comments from the groups they represent. Together, the Advisory Board collaborates about the product. Wyoming opinion about natural resources and their use and conservation is very polarized and agreement is not always reached about the issues represented by the curriculum. But the need for the curriculum is understood and a curriculum the board can live with and support is the product.

A COOPERATIVE EFFORT

The Wyoming Conservation Connection is a cooperative effort between the University of Wyoming, state and federal natural resource management agencies and others to see that conservation/environmental education reaches the students in the schools of Wyoming. The SICEP project has even enlarged upon the WCC cooperative history. The implementation workshop, which offer University of Wyoming graduate credit are funded mainly by the school districts. Other agencies who have either purchased manuals for teachers, purchased the workshops or helped to publish the manuals are:

- University of Wyoming
- U.S. Bureau of Land Management
- Wyoming Game and Fish Department
- U.S. Forest Service
- Local Conservation Districts
- Wyoming Department of Environmental Quality
- Wyoming Department of Agriculture
- Wyoming Riparian Association
- The Nature Conservancy
- Montana Game and Fish Department
- Educational Services Unit Number 13, Scottsbluff, Nebraska

STATUS

Forty-six of Wyoming's forty-nine school districts have now contributed in building the *Wild Wonderful Wyoming: Choices for the Future* curriculum or are using it. In the 18 months since the elementary curriculum came from the press (January 1996), 750 Wyoming elementary teachers have received the curriculum through 27 workshops in 23 school districts in 15 counties. Montana Game and Fish Department purchased 20 copies of the elementary curriculum to use in association with the Montana State Department of Education as a model for that state. The largest single sale of the elementary manual, 150 copies, was to fifteen school districts of western Nebraska where the manual will be used as they build a model for Nebraska from the Wyoming manual.

Wild Wonderful Wyoming: Choices for the Future is also being produced for secondary teachers. The secondary manual is behind schedule in being completed. Hopefully, the secondary manual will be ready for the beginning of school in the fall of 1997.

REFERENCES

Ballard, Melissa & Pandya, Mamata, compilers 1990. *Essential Learnings in Environmental Education..* Troy, OH: North American Association for Environmental Education.

Governor's Task Force on Environmental Education, 1992. *Comprehensive Plan for Environmental Education.* Phoenix, AZ: Arizona Department of Education.

Lawrence Hall of Science, developers 1979. *Outdoor Biology Instructional Strategies.* Nashua, NH: Delta Education

W.R.E.E.C. 1975. *Project Learning Tree.* Washington, D.C.: The American Forest Council.

W.R.E.E.C. 1986. *Project WILD.* Bethesda, MD: Western Regional Environmental Education Council

W.R.E.E.C. 1987. *Aquatic Project Wild.* Bethesda, MD: Western Regional Environmental Education Council.

Wyoming Conservation Connection 1992. *Water, Youth, and Optimism.* Laramie, WY: Wyoming Conservation Connection.

Wyoming Department of Agriculture 1992. *Wyoming Agriculture in the Classroom.* Cheyenne, WY: Wyoming Department of Agriculture

Wyoming Environmental Education Task Force 1991. *Learner Outcomes for Environmental Literacy.* Cheyenne, WY: State of Wyoming Department of Education.

NORTH PLATTE VALLEY WATER COALITION

Jim Merrigan[1]

Thank you for inviting the North Platte Valley Water Coalition to *Wyoming Water 1997*. I am proud to represent the coalition here this afternoon.

I. OUR MISSION

To promote sound water policy, economic growth and wildlife/environmental protection in the North Platte Valley.

The North Platte Valley Water Coalition is a grassroots endeavor by local citizens in eastern Wyoming and western Nebraska to provide information and education about water issues relating to the North Platte River system.

This two-state effort is comprised of volunteers. We represent agriculture and irrigation, business, industry, education, wildlife, conservationists and governmental entities. A 15-member board is a cross-section of volunteers from communities and rural regions affected by the North Platte River.

The coalition was founded in 1990 by a group of individuals who had a vision for long-term water monitoring, management, education and action by the residents of this Valley, primarily from Guernsey, Wyo., to Oshkosh, Nebraska.

II. SEVERAL PRINCIPALS GUIDE OUR ACTIONS:

A. Need to work together.

Wyoming and Nebraska share more than just water. Our irrigators and businesses have common economies, interests, community and social relationships, and see no "state line."

B. Need to minimize differences.

We might agree 95 percent of the time, most agree 3 percent of the time, and disagree 2 percent of the time, yet, where do we spend our time and energy?

C. Need to communicate with a scientific basis.

Therefore, the NPVWC is collecting research and data.

III. NORTH PLATTE RIVER IRRIGATION SYSTEMS STUDY:

A. Overview

1. Purpose

- Develop a computerized water model which simulates the North Platte River basin as a whole from Whalen Dam to Lewellen.
- Quantify surface and ground water flow in the North Platte Valley.
- Provide data to water conservation plans and measures.
- Define wildlife habitat and wetlands created by river/irrigation.

2. Methods

- Employed water engineers Bishop-Brogden Associates, Inc., of Englewood, Colo., to conduct research, develop model.
- Raised money locally to fund first half of study costs. ($100,000).
- Seeking grants, contributions for Phase II.
- Established 15-member Technical Advisory Committee to oversee study on quarterly basis. (Wyoming representatives from Bureau of Reclamation, University of Wyoming and Goshen Irrigation District.

3. Anticipated outcomes

- Computer-based water management tool for all uses, not just irrigation management.
- Water policy input (a voice, place at the table) based on science.
- Improved, increased data for local irrigation districts.
- Identification, preservation of wildlife habitat and wetlands.
- Opportunities to improve water efficiency.
- Ability to define economic impacts of irrigation, wildlife in Valley.

B. How are we doing?

- Study started in June, 1996 and is now entering its fourth quarter.
- Phase I research centered on data collection, irrigation district interviews, on-farm irrigation efficiency studies, return flow research, ground water usage and model configuration.
- Bishop-Brogden has RIBSIM (River Basin Simulation Model) running.
- Calibration and validation are next.
- Coalition is short on fundraising for Phase II. A constant struggle but we continue and remain hopeful. Irrigation districts are key contributors.
- Phase II begins in June, 1997. Will repeat on-farm field irrigation studies. Wetlands and wildlife habitat assessment begins.

C. What are future needs for study improvement, support?

[1] North Platte Valley Water Coalition, 1721 Broadway, Suite 309, Scottsbluff, NE 69361-2465

- Policy or guidelines for computer modeling.
- Distribution of information, data.
- Organization which coordinates, directs it.
- Funding.

IV. CRITICAL ISSUES

A. Rural communities doing for themselves, seizing the initiative, accepting responsibility and being proactive.

"Poor us" mentality won't work. Hard work creates results. Intelligent hard work can help us achieve a balanced future.

- America's natural resources are in good hands with rural Americans.
- Rural America can be a prosperous and fulfilling way to live.
- We can achieve balance – and harmony – But only by forcefully advocating our need to be heard. Take and use the voice.
- This is our challenge/our opportunity.
- This is our right to educate.
- The winners can be rural Americans, whooping cranes and America–- as a whole.

IT'S UP TO US.

Thank you to the University of Wyoming for allowing the North Platte Valley Water Coalition an opportunity to share "what's new" in its toolbox.

SHOSHONE PROJECT CULTURAL RESOURCES MITIGATION

A PILOT PROJECT FOR IRRIGATION EDUCATION

Beryl Churchill[1]

In 1993 the four irrigation districts comprising the Shoshone Reclamation Project entered into a $15 million Rehabilitation and Betterment Program to repair aging irrigation facilities and use water more efficiently. Because some of the facilities of the project are nearly 90 years old, the irrigation districts were required, under the National Historic Preservation Act, to mitigate the adverse effects on the qualities which made these facilities eligible for the National Register of Historic Places.

In March 1993, the four districts' Joint Powers Board entered into an agreement with the U.S. Bureau of Reclamation and the State Historic Preservation Office to prepare a traveling educational display emphasizing the history and contributions of the Shoshone Irrigation Project and create ten wayside exhibits which highlighted the engineering achievements and contributions of irrigation to the settlement and development of the Shoshone River Valley. The final task was to prepare a brochure which would serve as both a guide book for the wayside exhibits and a history of the Shoshone Project which is one of the oldest reclamation projects in the nation.

The mitigation project, the first of its kind in the nation, was completed in December 1996.

[1] Shoshone Joint Powers Board, 848 Road 10, Powell, WY 82435

SESSION 6:

WATER MODELING AND RELATED DATABASES

ASSESSING THE CUMULATIVE IMPACTS OF SURFACE MINING AND COAL BED METHANE DEVELOPMENT ON SHALLOW AQUIFERS IN THE POWDER RIVER BASIN, WYOMING

Kenneth Peacock[1]

ABSTRACT

Large scale surface coal mining has been active along the cropline of the Wyodak-Anderson coal seam since approximately 1977. Groundwater impacts due to surface mining of coal and other energy related development is a primary regulatory concern and an identified deficiency in the Wyoming coal program. The modeled aquifers are the upper unit (coal) of the Paleocene Fort Union Formation and the overlying Eocene Wasatch Formation. A regional groundwater model using MODFLOW covering 790 square miles was constructed to simulate the impacts from three surface coal mines and coal bed methane development occurring downdip. Assessing anisotropy of the coal aquifer, quality checking of *in situ* aquifer tests and database maintenance and integrity were precursors to modeling. Data was kriged to develop the structural model of the aquifers. A GIS was utilized to facilitate storage, analysis, display, development of input modeling arrays and assessment of hydrologic boundaries. Model output presents the predicted impacts of likely development scenarios including impacts from coal bed methane development and surface coal mining through anticipated life of mining and surface mining impacts independent of gas development.

[1] United States Department of Interior, Bureau of Land Management, 1701 East "E" Street, Casper WY. 82062

CUMULATIVE HYDROLOGIC IMPACT ASSESSMENTS ON SURFACE WATER IN NORTHEASTERN WYOMING USING HEC-1: A PILOT STUDY

A. J. Anderson, M. E. Anderson, D. C. Eastwood[1]

ABSTRACT

The purpose of this study was to perform an assessment of the affect of mining on the total discharge of an impacted watershed in Northeastern Wyoming. The surface water model HEC-1 was used to model four separate rainfall-runoff events that occurred in the study basin over three years (1978-1980). Although these storms were used to represent pre-mining conditions, they occurred during the early stages of mining and the models were adjusted accordingly. The events were selected for completeness of record and antecedent moisture conditions (AMC). Models were calibrated to the study events and model inputs were altered to reflect post mining conditions. The same events were then analyzed with the new model inputs. Peak flow, total discharge and timing of flows were compared for pre-mining and post-mining models.

INTRODUCTION

LITTLE THUNDER CREEK STUDY

The Little Thunder Creek Drainage is approximately 250 square miles in size and is being affected by three surface coal mines. The purpose of this study was to assess the best methods of modeling the impacts of surface mining on the quantity of surface water in the post-mining environment. The surface water modeling for the study area was conducted using HEC-1 with a "front end" developed by BOSS International called the Watershed Modeling System (WMS) (BOSS Int. 1996). HEC-1 is a rainfall-runoff and flood prediction model developed by the United States Army Corps of Engineers (ACOE).

HEC-1 is a lumped parameter model, combining a wide range of related variables into a single parameter. The input parameters represent a wide range of possible conditions and are subject to interpretation. The primary output from HEC-1 is a set of hydrographs that represent the discharge at the base of each individual component of the system. These hydrographs were then compared to observed data to determine the accuracy of the model.

METHODS

DATA ACQUISITION

The ephemeral nature of stream flow in the Little Thunder Creek watershed necessitated the acquisition of hourly precipitation and discharge data for the area. The hourly precipitation data of 12 mine company and National Weather Service stations were analyzed and those stations with consistent records were used to determine the total precipitation and the hyetograph for a given storm.

One United States Geological Survey (USGS) continuous gage was located on the main channel of Little Thunder Creek approximately 12 miles east of the mine permits and approximately 24 river miles downstream. The hourly stage measurements for the station were converted to discharge readings using the stage-discharge rating tables for the station.

MODEL DEVELOPMENT

The pilot study area was divided into 33 catchments or hydrologic response units (HRU), based upon analysis of surficial geology, soils, vegetation, mine permit locations, gaging stations and hydrography. Areas of uniform vegetative and soil cover were grouped within an HRU whenever possible.

The Natural Resource Conservation Service Runoff (NRCS) Curve Number method was used to estimate runoff from each HRU. These numbers express the rainfall-runoff relationship for an area. Lower numbers represent less runoff while larger numbers indicate increased runoff. An area's curve number is subject to change depending upon variable antecedent moisture conditions (AMC). The unit hydrograph method associated with the NRCS runoff curve numbers assigns a lag-time that approximates the time that will elapse between precipitation and runoff to each HRU.

The Muskingum-Cunge Routing method was chosen to represent the channel components of the pilot study area. The Muskingum-Cunge method was considered to be more robust with regard to irregular channel shapes and textures (ACOE 1990). The kinematic wave method is more stable at low flows and was used when numerical instability in the Muskingum-Cunge method became too great (ACOE 1990).

MODEL PARAMETERS

Mining in the basin started around 1977. The data from 1978-1981 were used to represent pre-mining conditions. Five of the twenty-seven contributing basins were impacted by mining activities during the time period of the calibrated storms. Contributing areas for these mined HRUs were reduced 90 percent to account for the presence of sediment retention ponds. The diversions around the mines were not accounted for and stream flow was modeled as it would have been without the diversions. The contributing areas of all the HRUs were returned to their actual values, reservoir storage reductions excluded, when generating the "pre-mining" model.

Four storms were chosen to represent a variety of antecedent moisture conditions (Chow 1964). Antecedent moisture conditions were estimated for

[1] Wyoming Water Resources Center, UW; Department of Geology & Geophysics, UW; and Department of Statistics, UW, Laramie, WY 82071, respectively.

each storm by analyzing the daily precipitation and temperature values at a nearby climate station for the thirty days prior to the first hourly precipitation of each storm. Antecedent conditions were then used to determine curve numbers for each HRU.

Antecedent moisture condition, in conjunction with contributing area, was used to simulate reservoir storage in each HRU. It was decided that contributing area would be adjusted to reflect the impact of reservoir storage on an HRU. The locations of water rights were plotted and analyzed to generate approximations of how much of the contributing area was impacted by reservoir storage. The percentage of the HRU that was impacted was estimated and the impacted area reduced 20, 50, or 80 percent for dry, intermediate and wet antecedant conditions, respectively. Contributing area was thus reduced more for dry conditions than for wet.

The convective nature of most of the storms that impact the study area results in spatially and temporally inconsistent distributions of rainfall. Precipitation depth and temporal distribution were recorded at 5-7 stations for each storm. A contour map of total precipitation was developed for each storm. The contoured map output provided an estimation of total precipitation in HRUs where data was insufficient or unknown and allowed for a range of acceptable values to be developed.

Analysis of tables in Chow (1964) indicated that the land type in the Little Thunder Creek drainage would have curve numbers between 55 and 80. Best professional judgment and the tables and graphs in Chow (1964) were used to develop specific curve numbers for each HRU. The relationship of each HRU to adjacent or similar HRUs was considered and the curve numbers assigned with these relationships in mind.

Additional input parameters for each HRU include a recession point, a recession constant, and a lag-time. The recession point is the point of inflection in the hydrograph and occurs at the amount of discharge at which the HRU's runoff hydrograph begins an exponential decay. The recession constant is the exponential slope value that controls the rate of the decay. Lag-times were initially estimated from knowledge of the shape and size of each HRU.

CALIBRATION

Calibration is an iterative process by which the initial estimates of model parameters are changed to better fit the observed data. The greater the uncertainty and or sensitivity associated with a parameter the more likely it was to serve as a valuable calibration tool. The initial estimates of each parameter were entered into the model and the output was compared to the observed data. Peaks that appear in the model output can be traced to their point of origin. Altering the basin parameters for the HRU of origin allowed the peaks and valleys of the predicted data to be matched to the peaks and valleys of the observed data. NRCS curve numbers and total precipitation were usually the first parameters to be changed.

The drainage areas of each HRU remained constant throughout the calibration process associated with each storm. Increasing or decreasing the lag time allowed storm peaks to be moved up or back in time to better fit the observed data. Most Muskingum-Cunge parameters were held constant for a given storm. NRCS curve numbers for the driest and wettest storms, as determined by AMC, were established by calibration. The remaining two storms were then calibrated by keeping the curve numbers between the two extreme values.

Other parameters, such as the recession point and the recession constant were used to shape the hydrograph once the total volume was approximately correct. The adjustments to the model were then used to generate new hydrographs. Each series of new hydrographs was compared to the previous set and additional adjustments were made to generate a better fit between the predicted and observed values.

The goal of the calibration process was to generate a model that matched, as closely as possible, the rainfall-runoff relationships within the basin without entering parameter values that were outside the range of feasibility. During the calibration process, each parameter that was altered was bracketed by values believed by the authors to represent the minimum and maximum acceptable values for that parameter. There were times however, when calibration was impossible without exceeding the maximum or dropping below the minimum. Values of plus or minus 5-10 percent of the observed for peak flow and total volume were preferred

POST-MINING MODELS

NRCS curve numbers were changed to reflect the post-mining environment. The types of changes in the post-mining environment were, at times, contradictory with regard to the direction of change in NRCS curve numbers. The authors decided that based upon expected changes in infiltration, the overall changes in NRCS curve numbers would be small and positive.

Uncertainty exists however, as to the direction or extent of the changes and led to additional runs of the models. The first model represents our prediction regarding the most likely post mining condition and has an increase of one curve number in the impacted HRUs. The second model predicts a decrease of one curve number in the affected areas. Changes of two, three, and four curve numbers in each direction were also modeled. Other parameters were also changed between the pre- and post-mining models. The post-mining channel lengths and slopes were incorporated into the post-mining models.

RESULTS

MODEL DEVELOPMENT

Twenty-seven HRUs were identified that actively contributed to runoff. Six of the 33 HRUs identified for the Little Thunder Creek watershed represent enclosed playas or dry lakes and were removed from the model. The model developed for Little Thunder Creek includes only two reservoirs. They are large reservoirs on the main channel that were deemed to be large enough to model explicitly. These reservoirs are both present in the post-mining models. It was felt that the reservoir removed by mining (Reno Reservoir) would adequately represent the terrain features that are to replace it. The observed hydrographs and the hydrographs developed during calibration for all four storms are presented in Figure 1.

STORM 1_78

Storm 1_78 started on July 6th at 11:00 AM. It is a small flow event during one of the wettest years on record. After a large event in May, the month of June was relatively dry. The dry weather and relatively high temperatures of June, 1978 indicated to the authors that 1_78 would be a good representative of dry conditions and contributing areas were adjusted accordingly. The peak flow and total volume values used to determine the accuracy of calibration and the magnitude of expected change in the post-mining environment for all four storms are given in Tables 1 and 2. Hydrographs representing the pre-mining conditions and the post-mining conditions with an increase and decrease of one NRCS curve number are presented in Figure 2.

Storm 1_78 shows an unexpected increase in total volume in the model using a decrease of 1 curve number. The total volume figures become repetitive with further decreases in the curve numbers. The low flows of the receding limb apparently developed instability and, as a result, produced an unexpectedly large peak in the receding limb of the hydrograph. This result was unexpected but not entirely surprising. The instability of HEC-1 at low flows was a limitation of the model that the authors were unable to avoid and were willing to accept.

STORM 2_78

Storm 2_78 started on July 21st at midnight. It is a large flow event that follows storm 1_78 by 15 days. The small reservoirs were treated as they would for intermediate conditions and contributing areas were adjusted accordingly. During the calibration process, it became evident that water was flowing out of the reservoirs on the main channel. The starting conditions for the reservoirs therefore, became part of the calibration process and were altered accordingly. The available storage of the larger reservoirs was adjusted downward from those expected of the other storms to reflect the storage from the 100 year event in May and the storm of 15 days earlier. The NRCS curve numbers are just slightly higher than those used for storm 1_78.

STORM 3-79

Storm 3_79 started on June 25th, 1979 at midnight. It is a medium sized event of longer duration. The nature of the hydrograph is unlike the other three storms. Flows exhibit the flashy tendencies of ephemeral systems. They peak sharply but remain unusually consistent for nearly two days. A second storm occurred in the study area approximately 2 days after the initial precipitation. The last two peaks in the observed hydrograph could coincide with the runoff from that event. The storm was calibrated using only the earlier peaks. The comparison of the total volumes for the calibrated and observed hydrographs was cut off after 51 hours when the two hydrographs begin to permanently diverge

The one month period prior to Storm 3_79 was fairly wet. A storm two or three days prior to the event deposited substantial amounts of rain in the area. The calibration indicated that wet condition contributing areas and wet intermediate curve numbers were appropriate.

Storm total values also changed substantially from our initial estimates. It was decided that the low storm totals in the lower basin would prevent any calibration and that the low values at the Rochelle station were having too great an effect. The storm totals were increased to be more consistent with the other recording stations in the study area.

STORM 2_80

The storm labeled 2_80 started on June 24, 1980 at 10:00 AM. It is a large flow event that exhibits the large peaks associated with ephemeral systems. Water year 1980 was intermediate with regard to precipitation. The storm labeled 2_80 was just the second major flow event recorded by the USGS in that water year. 2_80 is an earlier storm than the other three storms used in the study. The one month period prior to the storm was fairly wet and cold. A storm shortly prior to the event deposited substantial amounts of rain in the area. The calibration procedures later indicated that this was a valid analysis. The wet and cold month prior to the storm also suggested that most of the smaller reservoirs would be full and would have experienced little evaporative depletion.

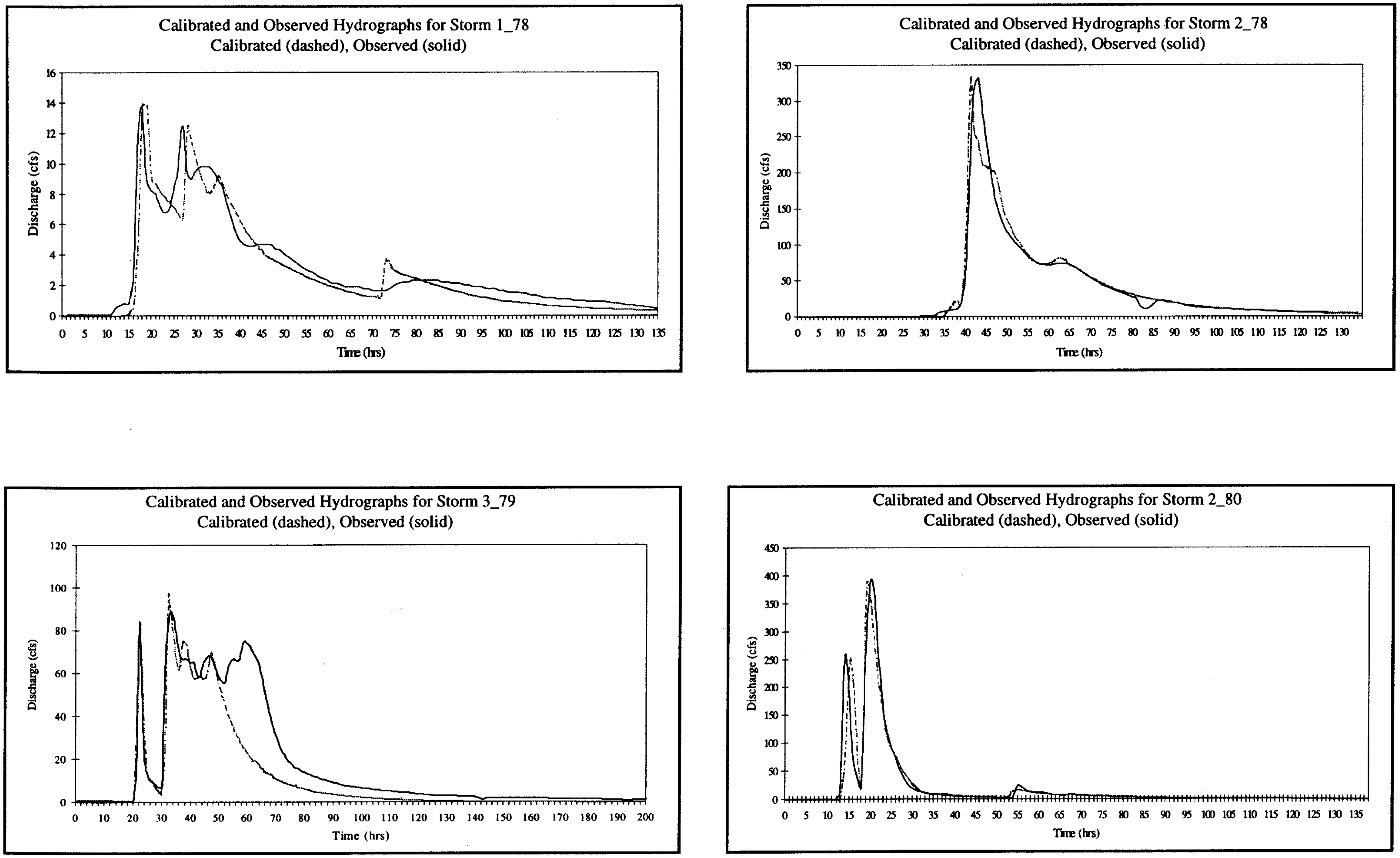


Figure 1. Calibrated and observed hydrographs for each of the four storms selected in the Little Thunder Creek, Wyoming study. Calibrated hydrographs were generated by the HEC-1 models. The observed data was obtained from USGS primary sheet records. Only the first 51 hours of storm 3_79 were calibrated due to the occurrence of a second rainfall event.

Table 1. Comparison of peak flow rates in cubic feet per second (cfs) from the observed, calibrated (Predicted), premining and post-mining models. Percentages indicated change between observed and calibrated and between the pre-mining and post-mining models.

Storms	1_78	2_78	3_79	2_80
Predicted	13.9	327.5	95.7	387.2
Observed	13.8	332.6	88.5	392.8
% Difference	0.7%	1.5	8.1%	1.4%
Pre-mining	13.9	376.9	93.2	372.4
+1	13.9	414.3	90.1	372.4
% Difference	0.0%	9.9%	3.2%	0%
-1	13.9	331.7	93.2	372.4
% Difference	0.0%	12.0%	0%	0%
+2	13.9	426.9	111.3	372.4
% Difference	0.0%	13.3%	19.4%	0%
-2	13.9	321.6	93.2	372.4
% Difference	0.0%	14.7%	0%	0%
+3	13.9	465.6	127.0	372.4
% Difference	0.0%	23.5%	36.3%	0%
-3	13.9	276.3	93.2	372.4
% Difference	0.0%	26.7%	0%	0%
+4	13.9	470.3	155.5	372.4
% Difference	0.0%	24.8%	66.8%	0%
_4	13.9	305.5	93.2	372.4
% Difference	0.0%	18.9%	0%	0%

Table 2. Comparison of total flow volumes in acre-feet (ac-ft) from the observed, calibrated (Predicted), pre-mining, and post-mining models. Percentages indicated change between observed and calibrated and between the premining and post-mining models. Starred (*) total volumes for storm for the observed and calibrated storm 3_79 are presented for the first 51 hours of the event to eliminate the impact of a second rainfall-runoff event.

Storms	1_78	2_78	3_79	2_80
Predicted	30.99	407.95	129.9*	242.70
Observed	33.62	392.41	135.7*	240.66
% Difference	8.49%	3.81%	4.3%*	0.84
Pre-mining	30.48	453.84	189.43	242.65
+1	32.64	480.37	193.27	247.57
% Difference	7.09%	5.85%	2.03%	2.03%
-1	30.54	429.42	176.81	239.25
% Difference	0.20%	5.38%	6.66%	1.40%
+2	33.06	506.26	203.63	252.13
% Difference	8.46%	11.55%	7.5%	3.91%
-2	31.20	407.63	170.29	233.44
% Difference	2.36%	10.18%	10.10%	3.80%
+3	34.82	538.33	214.32	258.54
% Difference	14.24%	18.61%	13.14%	6.55%
-3	31.20	382.90	165.89	229.39
% Difference	2.36%	15.63%	12.43%	5.46%
+4	39.52	562.80	229.47	269.31
% Difference	29.66%	24.0%	21.14%	10.99%
-4	31.20	367.21	162.17	227.33
% Difference	2.36%	19.09%	14.39%	6.31%

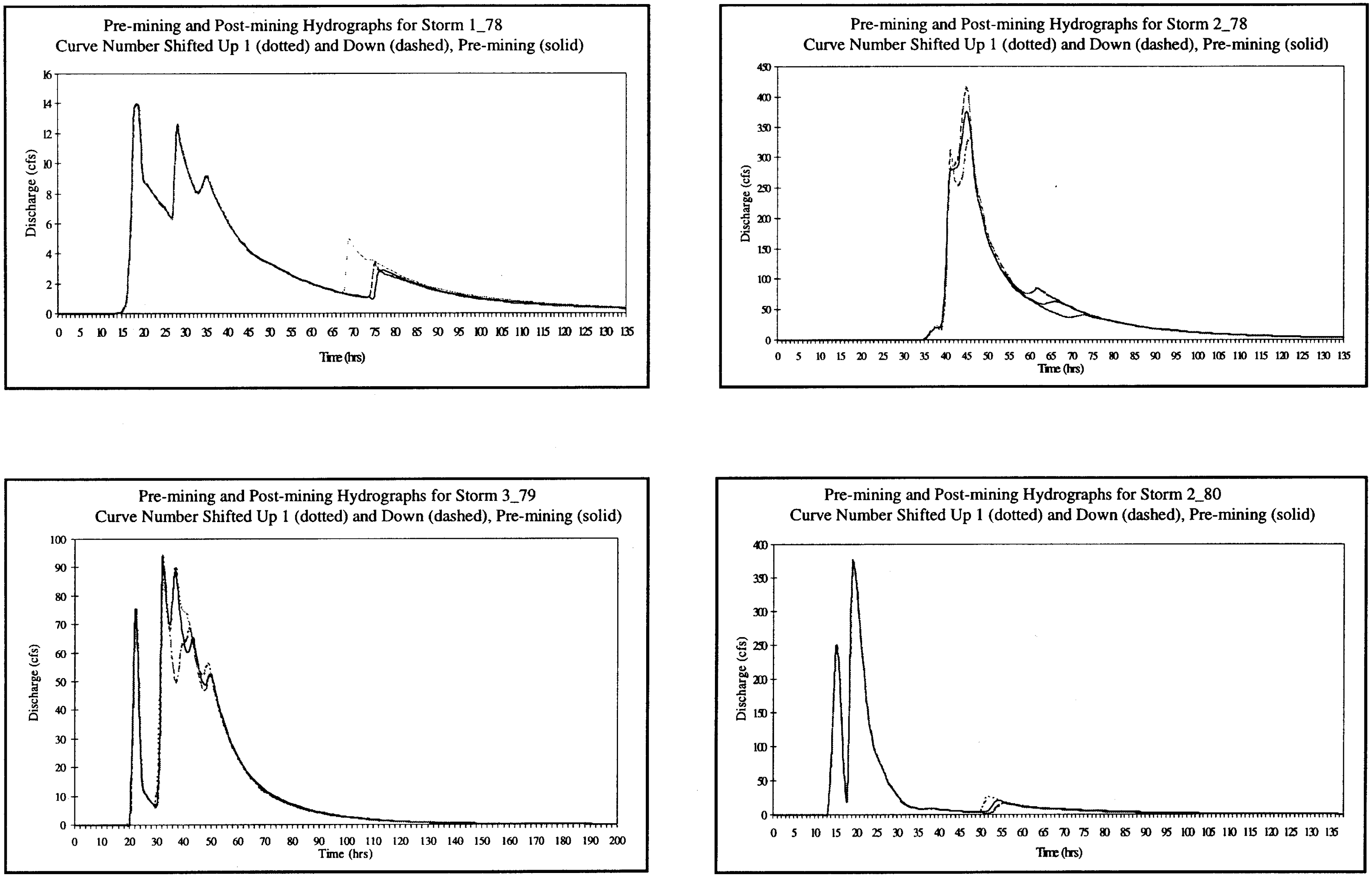


Figure 2. Pre-mining and post-mining hydrographs for each of the four storms selected in the Little Thunder Creek, Wyoming study. The post-mining hydrographs represent possible post-mining conditions with an increase and decrease of one NRCS curve number. The hydrographs are all predicted for the location of the USGS gaging station near the mouth of the stream.

DISCUSSION

The current implementation of HEC-1 for this modeling project is somewhat unique in its approach. In most modeling situations, the model is developed with known or closely estimated parameters and data applied to the model. Predictions regarding real or hypothetical events are based upon that model. These calibrated models were developed, not to predict an unknown, but to reflect observed data. Using the NRCS curve numbers and the total precipitation of an HRU, the total volume of output and the peak flows were approximated. Finer adjustments usually reflected changes in timing, hydrograph shape, or, to a smaller extent, the peak flow. Lag time, recession point, recession constant, and others were the parameters used to match the hydrograph shapes.

The modeling process documented above was an inherently intuitive process. Alterations in NRCS curve number and precipitation storm totals, as well as, lag time and conveyance loss were made based upon interpretation of the WMS output from each model run. They represent the best professional analysis of the authors with regard to calibration of 4 storms in the Little Thunder Creek drainage. Models developed by others may be substantially different from those developed here. It is anticipated that the process of calibrating four storms and analyzing them relative to one another allowed the authors to identify any conceptual errors within the algorithms or assumptions used to calibrate and eventually model the basin. The underlying concepts used in the driest and wettest models were confirmed during the calibration process of the intermediate storms. By recreating 4 different hydrographs, the models have, in a sense, been validated relative to one another.

Post-mining impacts can be added to the pre-mining models by determining the areas to be impacted, ascertaining post-mining terrain features such as topography or channel lengths, and then altering those values in the model. Curve number changes are largely a function of best professional judgment with regard to the direction and amount of change. Nothing about the model is dependent upon a standardized change in NRCS curve numbers. To the contrary, the authors have provided a wide range of changes based upon the simplest possible assertions. The uniform change in curve numbers for the entire impacted area is the simplest model that could be developed. The flexibility of the model is such that a large number of scenarios can be put into place if future conditions warrant.

REFERENCES

ACOE (United States Army Corps of Engineers). 1990. HEC-1; Flood Hydrograph Package User's Manual. Hydrologic Engineering Center, U.S. Army Corps of Engineers. Davis, California

BOSS International and Brigham Young University. 1996. BOSS WMS User's Manual. Boss International. Madison, WI.

Chow, V. T. 1964. Handbook of Hydrology . McGraw - Hill Book Company. New York, New York.

A NETWORK MODEL FOR BIOFILM GROWTH AND ITS EFFECTS IN POROUS MEDIA

Brian J. Suchomel, Benito M. Chen, Myron B. Allen III[1]

ABSTRACT

A new technique for controlling pollution in groundwater is the use of biofilms. Biofilms are bacteria that link themselves with extracellular polymeric substances. The bacteria, already present in the porous or injected into the porous medium, are used to either destroy the contaminant or to plug the medium by forming biobarriers, and, thus limiting the spread of the pollutant.

We present a network model for the SCALE-UP of flow, transport and biofilm growth in porous media. We will start with calculations in straight tubes of different diameters and will link them into rectangular arrays. These arrays of tubes with random diameters simulate the porous medium in two dimensions. Cubic arrays are used in three dimensions. The tubes are subdivided into cells and a new scheme based on upwinded finite differences is used to control numerical diffusion. As the pollutant is transported the bacteria will consume it and grow. This bacterial growth changes the diameter of the tubes and therefore the flow and transport properties of the whole network. Relations between amount of bacteria present and macroscopic properties of the medium, such as permeability and porosity, are derived.

INTRODUCTION

In this paper we describe how a network model may be used to predict the way in which the permeability of a porous medium changes as the geometry of the pore spaces changes. In particular, we consider what happens as a biofilm grows in the medium. A biofilm forms when certain bacteria bond to a surface, reproduce, and create extracellular polymeric substances (EPS), which help fix the bacteria in space (Characklis and Marshall, 1990).

A porous medium consists of a solid matrix and a number of pore spaces, through which a fluid may flow (Scheidegger, 1957). A network model uses a set of interconnected conduits to represent the pore spaces. The diameters of the conduits determine the permeability of the medium. We propose a natural method for simulating changes in the diameters of the conduits, and for calculating the resulting changes in permeability. This scale-up of microscopic flow, transport and biofilm growth to macroscopic properties such as porosity and permeability is very important in the determination of whether biofilms will form biobarriers or not.

NETWORK MODELS

In a network model the pore spaces in a porous medium are represented by a series of interconnected pipes or conduits. It is assumed that all flow through the medium takes place inside the conduits. In some models the junctions are assumed to have no volume (Simon and Kelsey, 1971), while in other models the majority of the pore space exists at the junctions (Koplik, 1982). The conduits may be arranged in a regular configuration or may be randomly placed. The lengths and diameters of the conduits may be given by some random distribution or may be constant. In our model we use regularly shaped grids, where the conduits have constant length and varying radii given by a lognormal probability distribution function. The junctions have negligible volume. Two typical two dimensional grids are shown in figure 1. Our model can be used on two or three dimensional grids. Averages must be taken with networks with different probability distributions in order to better simulate the randomness of the porous medium.

To compute flow rates through the network, We

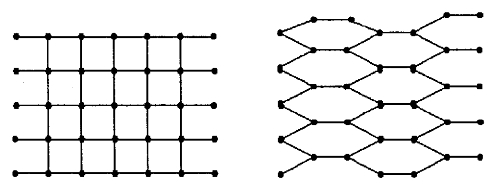


Figure 1. Square and hexagonal grids used to model pore spaces in 2-D. Both have size 7 by 5. Overall flow direction is from left to right.

impose a pressure gradient across the grid by fixing pressure head values at the inlet and outlet sides of the grid. We assume Poiseuille flow through each of the pipes so that the volumetric flow rate through a pipe is given by

$$q_{i,j} = k_{j,i}\left(h_i - h_j\right) , \qquad (1)$$

where $q_{i,j}$ is the flow into junction j from junction i through the pipe, h_j and h_i are the values of head at junctions j and i, respectively, and $k_{j,i}$ is proportional to the fourth power of the radius. We assume that the sum of the flow rates into any of the interior nodes is 0. This leads to a sparse, symmetric, positive definite system of equations that we solve iteratively to get head values at the interior nodes. When head values are known at all of the nodes, we can compute the volumetric flow rates through each of the pipes.

We calculate the total flow through the grid as the sum of the flow rates out of the nodes on the inlet side of the grid. This will be the same as the sum of the flow rates into the nodes on the outlet side of the grid since we impose the no accumulation condition

[1] Institute for Mathematics and its Applications, UM, Minneapolis, MN; Dept. of Mathematics, UW; Dept. of Mathematics, UW, Laramie, WY 82071, respectively.

at all of the interior nodes. For a fixed pressure drop across a grid the permeability is proportional to the volumetric flow rate through the grid. We can also divide the grid up into layers and compute permeabilities at what would correspond to different depths in a medium.

TRANSPORT IN A NETWORK MODEL

A solute moves through a porous medium via the physical processes of advection and dispersion. Dispersion in a porous medium occurs because of diffusion on a molecular level, and is also the result of varying velocities within the different pores in the medium. We consider transport to be a one dimensional process in each of the individual pipes in our grid, governed by the partial differential equation

$$\frac{\partial c}{\partial t}+\bar{v}\frac{\partial c}{\partial x}-D\frac{\partial^2 c}{\partial x^2}=0. \quad (2)$$

The mean velocity in a pipe is $\bar{v}=\frac{q}{\pi a^2}$ where a is the radius of the pipe and q is computed using equation (1) after solving the flow equation to get head values at the interior nodes. We integrate (2) using an upwinded, explicit finite difference scheme in each pipe. This method is numerically diffusive, so we drop the second order partial derivative term in (2) and adjust the numerical diffusion to represent the physical one. Boundary concentrations at the inlet side of a pipe are given by a weighted average of the concentrations at the outlet sides of pipes flowing into the node that serves as the boundary. In this method of modeling transport, we represent two physical processes that lead to dispersion in porous media. We represent diffusion on a molecular level with the numerical diffusion in the upwinded integration scheme. We represent the varying velocities in the individual pores by the different velocities in the pipes. The flows through the individual pipes merge and diverge to create dispersion in the medium.

Transport is integrated on a finer grid than the one on which we solve the flow equation. Each pipe in the grid is divided into a number of cells with mesh points at the centers of the cells. Transport is considered one dimensional in each individual pipe, but either two or three dimensional globally, depending on the geometry of the grid. We plot concentration profiles on the coarser grid used for solving the flow equation. Concentrations at the nodes are weighted averages of values at neighboring mesh points in the neighboring pipes. Figure 2 shows concentration profiles at three different times for one realization of a simulation of flow of a solute into a two-dimensional grid with initial concentration 0. One-dimensional concentration profiles are shown in the lower right. The phenomenon of fingering is evident in the 2-D profiles. Results from a number of realizations should be averaged to smooth out irregularities due to specific lognormal distributions. Also, a smoothing in the 1-D profiles is usually seen as the grid size is increased.

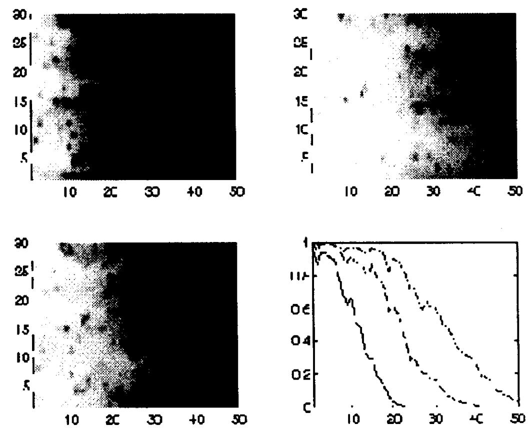


Figure 2. Transport on a 50 by 30, 2-D rectangular grid. Flow is in from left. Black corresponds to a concentration of 0 and white to a concentration of 1.

BIOFILM EFFECTS

Many physical and chemical processes occur as a biofilm develops in a porous medium. We concentrate on two of each. We introduce a model that includes five different species. Three concentrations are in solution: nutrients, bacteria, and EPS. Two concentrations are adsorbed: bacteria and EPS. Both chemical processes involve depletion of nutrients in the system. Bacteria consume the nutrients, and the carbon is converted to either EPS or more bacteria. We assume Monod reaction kinetics govern the rate (Characklis and Marshall, 1990). The physical processes involve transfer between the adsorbed and solution phases. Adsorption is a transfer from the bulk solution to the wall of a pipe. We assume that the rate of transfer is proportional to the concentration of bacteria and EPS in solution. Erosion is a transfer from the pipe wall to the bulk solution. We assume that the rate is proportional to the thickness of the biofilm squared (Wanner and Gujer, 1986).

The three species in solution are mobile, or free to move by advection and diffusion, and the two adsorbed species are fixed in space and may only move if they become dislodged due to erosion. Let the vector u contain the concentrations of the mobile species: $u=(c_n, c_b, c_e)'$ and the vector w contain the concentrations of the biofilm species: $w=(B,E)'$. Then u obeys a transport-reaction equation of the form:

$$\frac{\partial u}{\partial t}=D\frac{\partial^2 u}{\partial x^2}-\bar{v}\frac{\partial u}{\partial x}+f_1(u,w), \quad (3)$$

where $f_1(u,w)$ contains reaction, adsorption and erosion terms. The two species in the biofilm are not mobile, so w is governed by an ordinary differential equation of the form

$$\frac{dw}{dt} = f_2(u, w) \qquad (4)$$

where $f_2(u,w)$ also contains reaction, adsorption and erosion terms. The functions f_1 and f_2 are coupled and nonlinear. A physical constraint on the system is that all concentrations must remain non-negative.

Two biofilm effects that we are interested in are decreases in porosity and permeability of the medium. Adsorbed concentrations of bacteria and EPS decrease the effective radii of the pipes. We assume that all of the adsorbed species are distributed evenly around the walls of the cell. The effective volume of the cell is reduced by an amount equal to the volume of the biofilm. There is a corresponding reduction in the effective radius of the cell. Let B_{TOT} be the total biofilm concentration in a pipe at a given time and ρ_B. Then the new effective radius of the pipe at that time is

$$a_{new} = a\sqrt{1 - \frac{B_{TOT}}{\rho_B}}.$$

The thickness of the biofilm, d_b, is the difference in between the original and new radii,

$$d_b = a - a_{new} = a\left(1 - \sqrt{1 - \frac{B_{TOT}}{\rho_B}}\right).$$

We calculate changes in permeability and porosity of the grid as time progresses. The porosity of the grid is proportional to the sum of the squares of the effective radii of the pipes. The permeability is proportional to the volumetric flow rate through the grid for a given pressure drop across the grid. We can also calculate changes in porosity and permeability in certain regions of the grid. Some researchers have done physical experiments in the lab investigating biofilm effects in soil columns. Some were able to show that permeability reduction varies with depth in a column (Taylor and Jaffé, 1990). In our model a depth "layer" consists of a column of nodes and the pipes connected to them, all at the same distance from the inlet side of the grid. We can track changes in porosity in the layer by comparing the sums of the squares of the radii of the pipes. We can compute the permeability of a layer by imposing a pressure gradient across only the layer, solving the flow equation, and determining the flow rate through the layer.

We present results of a series of simulations designed to model physical experiments that have been performed in soil columns in a lab. At time 0 all pipes in the grid have 0 concentration of all species except for a small concentration of adsorbed bacteria. For time $t \geq 0$ the fluid flowing into the left side of the grid has unit nutrient concentration. Figure 3 shows relationships between biofilm (adsorbed species) concentration and permeability. The plots on the left show concentrations and permeabilities at t=100, 200...500. The biofilm grows and progresses downstream as nutrients are fed in from the left. The plot in the upper right shows permeability of the whole grid as a function of time. The plot in the lower right shows the relationship between biofilm concentration and permeability. The open circles show global concentrations and permeability of the entire grid. The dots show permeability of a layer as a function of concentration in the layer.

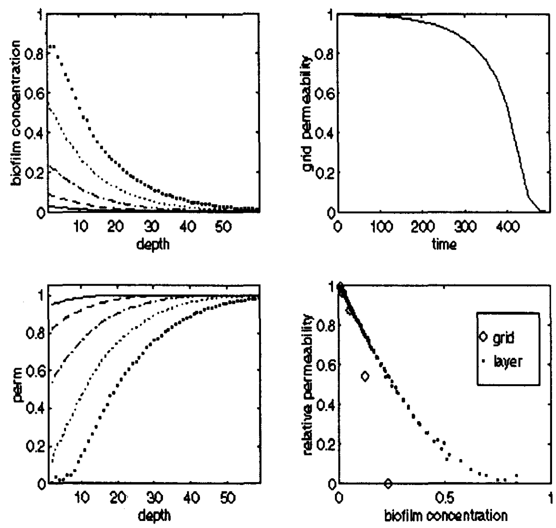


Figure 3. Permeability reduction as a function of biofilm concentration.

CONCLUSIONS

A network model is shown to be a physically meaningful method for modeling the changes in the flow properties of porous media due to the growth of biofilms. The permeability is shown to decrease as a biofilm grows in the pore spaces. This method also allows one to model permeability changes as a function of time and space.

REFERENCES

Characklis, W. G. and Marshall, K. C., editors, 1990, Biofilms, John Wiley & Sons, New York.

Koplik, J., 1982, Creeping Flow in Two-dimensional Networks, *Journal of Fluid Mechanics*, 119, 219-247.Scheidegger, A. E., 1957, The Physics of Flow Through Porous Media, University of Toronto Press.

Simon, R., and Kelsey, F. J., 1971, The Use of Capillary Tube Networks in Reservoir Performance Studies: I. Equal-Viscosity Miscible Displacements, *Society of Petroleum Engineers Journal*, 11, 99-112.

Taylor, S. W., and Jaffé, P. R., 1990, Biofilm Growth and the Related Changes in the Physical Properties of a Porous Medium 1. Experimental Investigation, *Water Resources Research,* 26,(9), 2153-2159.

Wanner, O. and Gujer, W., 1986, A Multispecies Biofilm Model, *Biotechnology and Bioengineering,* 28, 314-328.

THE WATER RESOURCES DATA SYSTEM (WRDS)

Barry B. Lawrence[1]

ABSTRACT

The Water Resources Data System (WRDS) is a clearinghouse of hydrological and climatological data for the State of Wyoming. WRDS offers a wide variety of products and services to its users, including retrievals for water resources information from in-house databases, CD-ROM products, and alternate data systems from across the region and/or country via the Internet. WRDS is actively migrating its databases to the World Wide Web (WWW) environment for online access by its users. Currently, both *The Wyoming Water Bibliography* and Water Quality databases are accessible in this manner. Cooperative data posting efforts with federal and state agencies in Wyoming have led to additional water resources information being disseminated through the site. Online data may be accessed at the following Uniform Resource Locator (URL): **http://www-wwrc.uwyo.edu/wrds/wrds.html**

Funded by an allocation from the Wyoming Water Development Commission, the system strives to provide the most comprehensive compilation of water resource information available to its requesters. Operating in such a one-stop shopping environment mandates not only linkages to other databases, but also the keen awareness of who the end users are and how the data will be utilized, which can be as varied as the number of sources of information. During the 1996 calendar year, more than 580 requests for data and analyses were received and processed by the WRDS office, while thousands more visited the WRDS web site for online information.

INTRODUCTION

During the late 1960's, the need for Wyoming streamflow records in computerized format was recognized by the Water Planning Program of the Wyoming State Engineer's Office. The Water Resources Research Institute (WRRI) received a grant to begin manual loading of US Geological Survey (USGS) surface water records for the state. As part of the project, both listing and analysis programs were written to display and summarize the data. This was later followed in subsequent years with additional funding from the State Engineer's Office for data loading of other climatological and hydrological datasets. Through the years the system underwent numerous hardware and software upgrades as computer technology advanced. Additional analyses and graphics capabilities were added as the system grew into a clearinghouse for such information in the state. Ties with other state and regional data warehouses were established to provide increased capabilities and services to the end users of the system. WRDS is currently operated through an allocation from the Wyoming Water Development Commission to the Wyoming Water Resources Center.

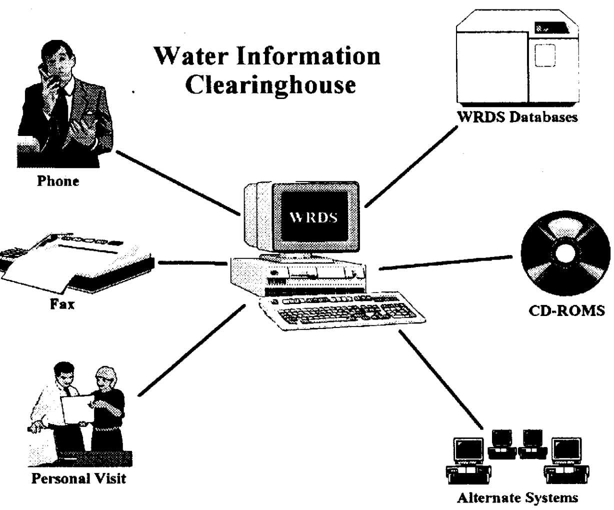


Figure 1. WRDS Products and Services

WRDS offers a variety of products and services to its users as depicted in Figure 1. In-house databases exist which offer requesters long-term hydrological and climatological data for hundreds of locations throughout the state. These databases are in the process of being migrated to the World Wide Web (WWW) environment for online access by requesters. A library of CD-ROM data products supplements the request process and expands the geographical area of data coverage. Similarly, access through cooperative agreements to numerous additional databases maintained by federal and state agencies further augments the amount of data available to requesters. Finally, cooperative data posting efforts on the web with federal and state agencies in Wyoming have led to additional water resources information being disseminated by the system.

Operating in such a clearinghouse environment has led to tremendous growth in the Water Resources Data System, not only in the capabilities provided, but in the numbers of requests received on an annual basis. Inquiries by traditional methods (phone, fax, personal visit) are continuing to increase, as are the ever growing numbers of individuals contacting WRDS via email or performing their own retrievals via the WRDS web site.

WRDS DATABASES

Six unique databases comprise the Water Resources Data System: surface water, climate, water quality, well water levels, snow course and *The Wyoming Water Bibliography*. Each of the databases contains

[1] Coordinator, Water Resources Data System, Wyoming Water Resources Center, UW, Laramie, WY 82071.

specific unique data elements, collecting agencies, periods of record, and frequencies of collection.

SURFACE WATER

Data from 13 different source agencies, representing more than 1500 locations are resident in this database. The major source for the information is the US Geological Survey; however, data exist for agencies such as the US Bureau of Reclamation, Wyoming State Engineer's Office, Wyoming Water Resource Center, etc. Typical data elements include: average daily streamflows and instantaneous peak flows in cubic feet per second (cfs), and reservoir storage contents in acre-feet.

CLIMATE

Information for more than 600 locations may be found in this database and constitutes the single-largest collection of Wyoming climatological information worldwide. The primary source for the data is the National Oceanic & Atmospheric Administration (NOAA) and includes such data elements as: maximum, minimum and average temperatures, precipitation, snowfall, snow depth, relative humidity, atmospheric pressure, wet and dry bulb temperatures, dewpoint temperatures, evaporation, wind speed, wind direction, and maximum, minimum and mean evaporation pan temperatures. The frequency of data collection (hourly, 3-hourly, 6-hourly, daily) and the availability of each of the parameters varies by station location and collecting agency. Manual data loading efforts have captured many of the earliest records (1890's-1920's) in digital format, lengthening the corresponding periods of record.

Supplemental to the digital information are National Weather Service (NWS) monthly cooperator forms which detail daily climatological observations at each of the observing sites during the month. These "hard copy" forms exist for many of the stations back to the early 1900's and contain numerous remarks and observations not available in any database, thus adding fullness and providing context to the observed values. Working with the five National Weather Service offices with jurisdiction in Wyoming (Cheyenne and Riverton, Wyoming; Salt Lake City, Utah; Billings, Montana; and Rapid City, South Dakota), WRDS is continuing to receive these forms on a monthly basis, thus "bridging the gap" until such information is available in a digital format.

WATER QUALITY

Data for more than 16,000 locations are resident in this database and include both daily and grab water quality samples from surface water and groundwater sites throughout the state. While the primary source for the information is the US Geological Survey, data for more than 80 different collecting agencies may be found in the database. Parameters available include: biological, chemical and physical attributes. More than 800 different parameters are available for retrieval.

A recently funded project to assess available water quality datasets throughout the state and acquisition of the corresponding data through ongoing cooperative arrangements has led to many new additional datasets being incorporated into the database. Data have been received in numerous formats and on a variety of media types. Procedures dictate that each of the datasets be scrutinized prior to inclusion into the database (QA/QC, standardization, methodologies employed, etc.). With the assistance of water quality experts in the state, many of these questions were answered. Also, the database was restructured to handle the newly acquired information as well as the historical data set. Paramount to the project was the development of an online interface for ready access of the database to the end users. This was accomplished through an interfacing of the Oracle relational database management system already in use, with World Wide Web technology. The resulting product represented the first WRDS database to be migrated to the web environment.

WELL WATER LEVELS

Data for more than 6,000 locations are present in the database and comprise information collected from numerous source agencies. The primary source for the information is the US Geological Survey. Typical data elements include: daily and grab samples of static water level and yield. Driller's log information is also available for some of the wells.

SNOW COURSE

Data for approximately 240 locations are resident in the database, representing manual snow survey information as collected by the Natural Resources Conservation Service (NRCS) throughout the state. Typical data elements include: monthly samples (January - June) of snow depth, water equivalent, and density. Daily data from automated snow survey sites are available through alternate database system access.

THE WYOMING WATER BIBLIOGRAPHY

This bibliographic citation database is available online through the WRDS web site and contains more than 13,000 entries dealing with the development, management, and use of Wyoming's water resources. Retrievals may be conducted by geographic area, descriptive keywords or combination of the two, as well as by author or title. Created in the early 1980's, the system has continued to grow as new acquisitions become available and are loaded into the database. A current agreement between the State Engineer's Office, Water Development Commission, State Lands Office, State Library, University of Wyoming Libraries, and the Water Resources Center will ensure that documents from the state's Water Library (State Engineer's Office, Herschler Building, 4th Floor East, Cheyenne, Wyoming) will be added to the database and made available through the WRDS web site.

CD-ROM LIBRARY

WRDS maintains a library of CD-ROM products from which to supplement the request process. Typical data include USGS daily and peak streamflow records, NOAA daily, hourly, and 15-minute climatological data, USGS and Environmental Protection Agency (EPA) water quality data, and USGS Selected Water Resources Abstracts. Numerous additional titles are available covering a range of specific climatological and hydrological datasets. Many of the products are regional or national in scope.

ALTERNATE DATA SYSTEMS

During the request process, information may be needed which is available through other water information systems. WRDS possesses computer access agreements with numerous state and federal water resource agencies for the purpose of retrieving data from their specific databases from which to further augment the request process. It should be noted that this access requires an actual login account and password with each of the agencies and utilizes a telnet session as compared to visiting their web sites with a browser. Many of the agencies have made only a small fraction of their holdings available on the web, which mandates access at a increased capability level in order to obtain complete records and possess full database functionalities.

Cooperative agreements are in place with the following agencies (offices) and provide access to the following **databases** and information: 1) U.S. Geological Survey (Denver, Colorado; Boise, Idaho; Billings, Montana; Rapid City, South Dakota; Salt Lake City, Utah; Reston, Virginia, and Cheyenne, Wyoming) - **ADAPS, QWDATA, GWSI, WATSTORE** - daily and real-time streamflow, water quality, and groundwater site inventories; 2) U.S. Bureau of Reclamation (Billings, Montana; Boise, Idaho) - **HYDROMET, AGRIMET** - climate, streamflow, reservoir contents, and North Platte River accounting; 3) Natural Resources Conservation Service (Portland, Oregon) - **CFS** - climate, streamflow, snow telemetry data, and basin outlook reports; 4) U.S. Environmental Protection Agency (Research Triangle Park, North Carolina) - **STORET, SDWIS** - water quality and public water supply system records; 5) Western Regional Climate Center (Reno, Nevada) - **WESCLIM** - climatological data from the National Weather Service (**AFOS, ASOS, COOP**), Bureau of Land Management (**RAWS**), US Forest Service (**WIMS**) and others. WRDS also serves as a user assistance center for the National Water Data Exchange (NAWDEX) of the U.S. Geological Survey.

WWW COOPERATIVE DATA POSTINGS

A World Wide Web (WWW) site has been established by WRDS on the Internet for online access to WRDS databases as they are migrated (currently available: water quality and *The Wyoming Water Bibliography*); and for cooperative data postings by federal and state agencies having valuable Wyoming water resource information to disseminate, but lacking the mechanism to do so. WRDS received numerous inquiries for these latter products and was regularly contacting the various agencies involved in order to provide the information to its requesters. Through cooperative efforts, the information is made available to WRDS from each of the agencies for posting on the web. Both WRDS requesters and agency personnel may then regularly "pull down" the desired information from the site, thus eliminating numerous phone calls and duplication of efforts by all parties involved.

Currently WRDS is working with the following agencies (offices) to provide the following information on the 'net': 1) National Weather Service (Cheyenne, Wyoming) - water year precipitation data, 30-year precipitation normals, monthly precipitation summaries, water year precipitation summaries, NWS office climatic reports, coordinated NWS/NRCS water supply forecasts, and snow accumulation, snowmelt and streamflow analyses; 2) Natural Resources Conservation Service (Casper, Wyoming) - snow precipitation updates, Wyoming Monday Morning Snow Reports, and Wyoming Basin Outlook Reports; 3) Wyoming State Engineer's Office (Cheyenne, Wyoming) - agency information and directory, Water Forum Meeting minutes; 4) Wyoming Water Development Commission (Cheyenne, Wyoming) - agency information and directory, legislative report, water projects information, and applications materials; 5) Wyoming State Geological Survey (Laramie, Wyoming) - agency information and directory, publications database, *Selected Bibliography on Selenium*, and earthquake information; 6) Wyoming State Climatologist (Laramie, Wyoming) - agency information and climate information resources; and the 7) Board of Registration for Professional Engineers and Professional Land Surveyors (Cheyenne, Wyoming) - agency information, directory, and applications materials/requirements. The WRDS online data pages may be found at: **http://www-wwrc.uwyo.edu/wrds/wrds.html**

DATA REQUESTS

Requests for information are received from a broad range of sectors, including federal and state agencies, counties, municipalities, educational institutions, private firms, industry, and private citizens. Reasons for requests are as diverse as the requesting population and include concerns such as: research, construction, event planning, litigation, industrial siting, agriculture, commerce, environmental assessments, etc.

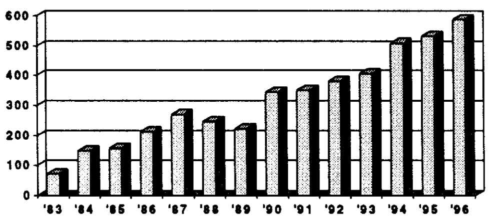


Figure 2. Water Resources Data System: Yearly Requests Totals

Over the last decade WRDS has seen an overall increase in the number of requests received and processed annually. See Figure 2. During the 1996 calendar year alone, more than 580 requests for data and analyses were handled by the WRDS office. These numbers do not include the thousands of individuals visiting the WRDS data pages on the World Wide Web for online water resources information. Such visits have grown in numbers exponentially since the site went online more than two years ago.

MAKING A DATA REQUEST

Individuals desiring further information about WRDS, its capabilities, or wishing to place a request for water resource data for the state or region are encouraged to contact a WRDS Data Specialist at the Wyoming Water Resources Center, University of Wyoming, 13th & Lewis Streets, Vocational Annex Building, Room 161, P.O. Box 3067, Laramie, Wyoming 82071.

Phone: (307) 766-6651 Fax: (307) 766-3785

Email: wrds@uwyo.edu

WWW: http://www-wwrc.uwyo.edu/wrds/wrds.html

ACKNOWLEDGMENTS

The author wishes to acknowledge the cooperation of the Wyoming State Engineer's Office, Wyoming Water Development Commission, Wyoming State Geological Survey, Wyoming Board of Registration for Professional Engineers and Professional Land Surveyors, Wyoming State Climatologist, U.S. Geological Survey, US Bureau of Reclamation, U.S. Environmental Protection Agency, Natural Resources Conservation Service, National Weather Service, and the Western Regional Climate Center in the conduct of data access and/or dissemination. Special appreciation is extended to Mr. Tom Dietrich, Hydrologist with the National Weather Service in Cheyenne, Wyoming for outstanding cooperation and support of WRDS' data clearinghouse activities.

Funding for the operation of the WRDS system is provided by an allocation from the Wyoming Water Development Commission to the Wyoming Water Resources Center, University of Wyoming.

SESSION 7:

RIPARIAN AREA MANAGEMENT

USE OF BEAVER TO IMPROVE RIPARIAN AREAS IN WYOMING

Mark McKinstry and Stanley Anderson[1]

ABSTRACT

Beaver (Castor canadensis), through their dam building activities, store water, trap sediment, subirrigate vegetation, and subsequently improve habitat for fish, wildlife, and livestock. Many landowners realize the benefits that beaver can bring to a riparian area and are interested in using them to improve riparian habitat. Beginning in 1993 we introduced beaver to eight areas throughout Wyoming. Our goal was to use beaver to improve riparian habitat. We trapped and relocated over 110 beaver during two and one-half years. Predation and emigration accounted for the loss of 36% and 48% of telemetered beaver throughout the three year study, respectively. Our results show that 1) trapping and moving beaver needs to be done within a short period of time, generally 5 days, 2) beaver need to be introduced in large numbers (i.e. > 5 animals for each introduction site) to compensate for high predation and emigration losses, 3) follow-up introductions need to be done once beaver become established, 4) spring and fall releases tend to be equally successful although animals released in the fall remain nearer to the release sites when starting to build dams, 5) beaver introductions can be successful in a wide variety of habitats including some that are not considered primary beaver habitat (i.e. scrub oak habitat in the Black Hills), and 6) a large amount of interest was generated from the project especially from private landowners.

INTRODUCTION

Beavers (Castor canadensis) alter riparian-stream ecosystems through their woodcutting and dam-building activities. The construction of dams, canals, and drainage networks broadly influence hydrological regimes and results in community impacts that far surpass their initial activities. The resultant habitats are rich mosaics of diversity that are beneficial hydrologically, biologically, and socially (Naiman et al. 1988). The construction of beaver dams creates a lentic habitat in an otherwise lotic system. These ponds retain sediment and organic matter in the channel, create and maintain wetlands, modify nutrient cycling and decomposition dynamics, modify the structure and dynamics of the riparian zone, alter hydrologic regimes (Butler 1991), and influence the character of water and materials transported downstream (Naiman et al. 1988). The elimination of beaver from portions of its historic range has been cited as a major influence on the structure and patterns of vegetation in these systems (Barnes and Dibble 1986, Naiman et al. 1986, Nolet et al. 1994, Nummi 1989).

Beaver-influenced habitats can be beneficial to some forms of wildlife and detrimental to others (reviewed in Hill 1982; Jenkins and Busher 1979; Olson and Hubert 1994). Since beaver create wetlands, the majority of investigations have focused on the impacts of beaver on waterfowl (reviewed in Brown 1994), fish (Hanson and Cambell 1963, Johnson et al. 1992, Rabe 1970), invertebrates (Legeyda 1987, McDowell and Naiman 1986, Naiman et al. 1984) and non-game birds (Medin and Clary 1990). Livestock are also attracted to beaver-influenced areas for water, shade, and vegetation that remains green after upland forage has dried out. Forage production near these wetlands is often two to three times higher than comparable upland ranges and can be a great socio/economic benefit to landowners (Apple et al. 1985).

Beaver can also cause problems for land managers that outweigh their usefulness (Butler 1991, Enck et al. 1992, Woodward et al. 1985). Important damage concerns among Wyoming landowners include tree cutting, blockage of irrigation and drainage ditches, and flooding of roads (McKinstry and Anderson unpublished data). Beaver damage problems in Wyoming, where beaver are considered a furbearer, currently fall under the jurisdiction of the Wyoming Game and Fish Department (WG&FD). The WG&FD presently handles beaver problems by allowing the land manager to trap or kill any beavers that are causing damage. Additionally, WG&FD personnel often assist landowners by trapping problem animals and either killing them, or transplanting them to other more suitable areas.

Throughout the intermountain west great interest has been expressed in improving riparian areas for wildlife, livestock, and humans (Apple et al. 1985). Beaver can be used to realize these benefits and many states have undertaken beaver transplant programs to improve riparian areas (Butler 1991, Hill 1987). Wyoming, like many western states, has been very interested in using natural methods to improve riparian areas (Collins 1993).

In 1994 we initiated a study to 1) document the effects of beaver on riparian areas in Wyoming, 2) identify suitable methods of trapping and transplanting beaver, and 3) determine beaver movements, survival, and habitat changes after beaver were transplanted. This paper will address trapping, mortality, and emigration of beaver introduced for the purposes of riparian enhancement and wetland creation.

STUDY AREA

Beaver were transplanted into various habitats throughout Wyoming. All habitats had sufficient vegetation to support beaver and had perennial water sources. Release sites are shown in Figure 1 and

1 Wyoming Cooperative Fish and Wildlife Research Unit, UW, Laramie, WY 82071

vegetation types and elevation, listed by release site, are given in Table 1.

METHODS

Beaver were trapped from areas where they were causing damage to landowners (primarily irrigation conflicts). All beaver were trapped from colonies that were dam and lodge builders (creek dwelling beaver) as opposed to bank denning non-dam builders (river beaver). We felt that these animals would be more likely to create the desired habitat and would be more successful at avoiding predation.

Snares and Hancock live-traps were used to trap all animals (Krause, no date). Animals >55 kg were implanted with Advanced Telemetry Systems (Isanti, MN) model 17 internal telemetry transmitters using techniques described by Davis et al. (1984). All transmitters were equipped with 24 hour mortality sensors. Implanted beaver were monitored for a minimum of 24 hours post surgery prior to release (Davis et al. 1984). All animals were released after 1500 hours in an attempt to decrease predation during daylight hours.

Table 1. Habitat type and elevation (m) for beaver introduction sites.

Release Site	Vegetation Type	Elevation
Breteche Crk	aspen/cottonwood	2000
(Cody	(Populus tremuloides/Populus spp.)	
Red Crk.	spruce/cottonwood	2350
(Rock Springs)	(Picea/Populus spp.)	
Lake Crk	narrowleaf cottonwood/willow	2250
(Saratoga)	(Populus angustifolia/Salix spp.)	
S. Pine Crk.	scrub oak/common chokecherry	1150
(Sundance)	(Quercus gambelii/Prunus virginiana)	
Deep Crk.	scrub oak/aspen	1250
(Sundance)	(Quercus gambelii/Populus tremuloides)	
Trabing Crk	aspen/western hawthorn	1700
(Big Horn)	(Populus tremuloides/Crataegus succulenta)	
Prairie Dog Crk.	aspen/cottonwood	1650
(Big Horn)	(Populus tremuloides/Populus spp.)	
Bear Gulch	aspen/cottonwood	1540
(Story)	(Populus tremuloides/Populus spp.	

Table 2. Comparison of trapping results between snares and Hancock traps.

Category	Hancocks	Snares
Number captured	10	113
Trap nights	140	1269
Mortality	10% (1)	6.2% (7)
Live-trapping success	6.43%	8.35%
Total success	7.14%	8.90%
Average Weight (kg)	9.4	17.9

Beaver were monitored for movements and mortality for 2 days after release and approximately every 2 weeks thereafter. Streams were walked a minimum of 2.0 km in both directions to determine if beaver were established. By examining the stream for evidence of tree cuttings or dam construction we also determined if non-telemetered beaver were present.

Cause of mortality was determined through examination of hair and scat samples found at the kill site, bite marks on beaver carcasses, and track marks (O'Gara 1978). Lab work and necropsies were performed by Dr. Elizabeth Williams, Pathologist at the Wyoming State Veterinary Lab. Hair samples were examined by Tom Moore, Forensic Supervisor for the Wyoming Game and Fish Department Lab.

RESULTS

Snares and Hancock traps were used to capture 123 beaver (Castor canadensis) at 15 locations throughout Wyoming. Trapping mortality was 7.7% and 10% for snares and Hancock traps, respectively

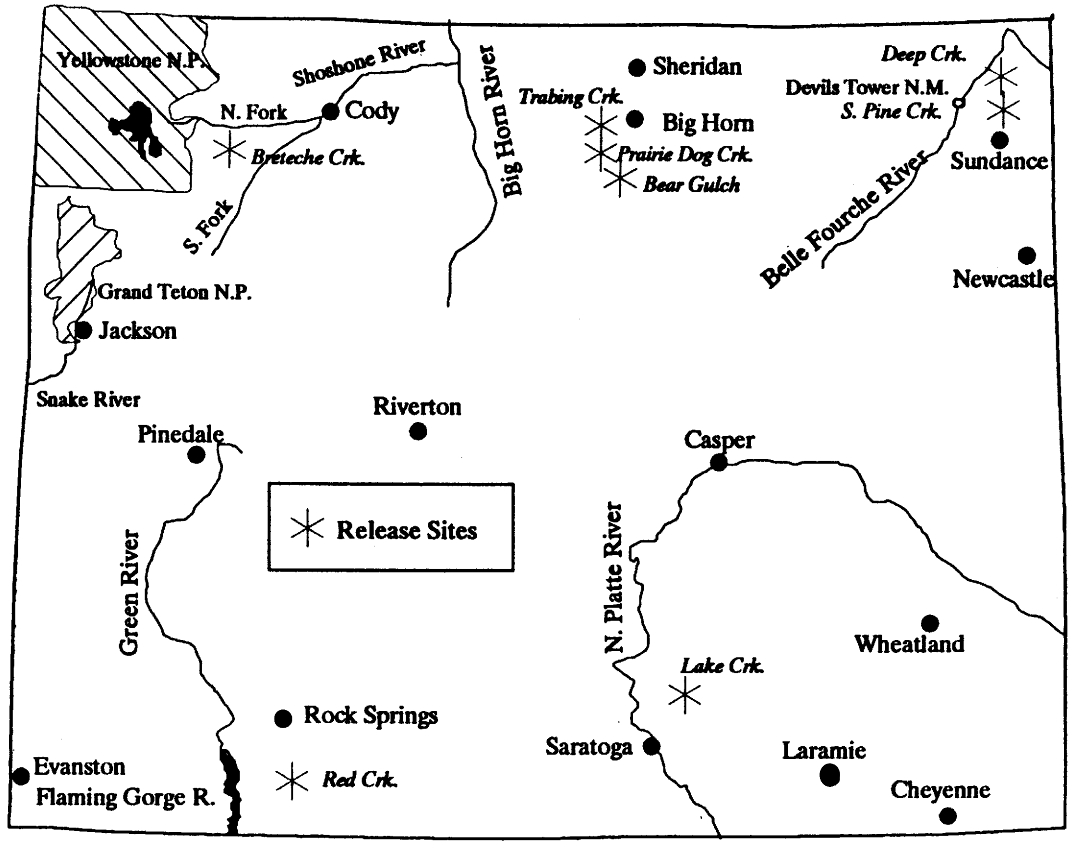


Figure 1. Beaver relocation sites in Wyoming

Table 3. Fates of introduced beaver by release location.

	Fate						
	Emmigration[1]	Coyote	B. Bear [2]	G. Bear[3]	Unknown[4]	Remaining	TOTAL:
Bear Gulch						1	1
Breteche Cr,.	2	3		4	2	1	12
Deep Drk.	3						3
Lake Crk.	3	1				5	9
Prairie Dog Cr.	2						2
Red Crk.	7	1	5		1		14
S. Pine Crk.	3					3	
Trabing Creek	3					1	4
TOTAL	23	5	5	4	3	8	48

1. Animals traveled >2 km from release site.
2. Black bear predation.
3. Grizzly bear predation.
4. Predation from unknown source.

and was not significantly different ($P = 0.84$), however the average weight of beaver caught in snares was significantly greater ($P < 0.001$) than those captured in Hancock traps (Table 1).

Of 48 beaver trapped, implanted with a transmitter, and relocated 17 (36%) died as a direct result of predation (Table 2). Coyotes, black bears, and grizzly bears killed five (10%), five (10%), and four (8%) beaver, respectively. Three (6%) other beaver were killed by undetermined predator(s). Ten (21%) beaver are still alive and appear healthy. And an additional 23 (48%) beaver traveled > 2 km from the release site and have not been relocated.

Beaver killed by predation lived for an average of 17 days until killed, however 6 of 17 died within 6 days of release. With the exception of one, all beaver were killed within 0.25 km of the release site (the exception was found 0.75 km upstream of release site).

DISCUSSION

Snares allowed us to saturate an area with traps and to quickly capture a large number of animals.

Hancock traps were effective at capturing kits and yearling animals but not adults. Snares can be placed in a variety of areas that beaver use and we found them to be very effective. We recommend a combination of snares and Hancock traps for live-trapping beaver.

Limited range of transmitters may have affected the number of animals located. Advertised range from the manufacturer was 0.5 km but we found that the range was usually limited to 200 m. Animals located within dens were often not located until we were within 50 m of the transmitter. Walking the streams up and downstream of the release site allowed us to be within 20 m of the creek bed and was undoubtedly necessary to determine movements and mortality.

Animals not relocated may have had higher survival rates but we feel this is improbable. More likely, we feel that they may have been killed and cached in holes and dens, or dragged out of range of receivers. Animals moving out of the vicinity of the release area may also have experienced higher predation rates due to higher exposure time and less time spent hiding in dense vegetation or constructing dens. Smith et al. (1994) found that beavers, sympatric with black bears on islands in Lake Superior, traveled less distances from water than those found on islands where bears were not present and suggested that this was a direct attempt to avoid predation.

Stanley-Price (1989) reported that relocated animals will undoubtedly have a higher susceptibility to predation. Beaver have many natural predators and do not have the capability to avoid predation through fighting or evasion, preferring instead to use water as an escape medium (as reviewed in Smith et al. 1994). Without ponds and dens to use for escape, beaver are vulnerable to predation. Naturally dispersing beaver have been seen in upland areas >1 km from water sources and have even been observed crossing mountain passes (Smith 1980). These animals would be extremely vulnerable to predation as are newly introduced beaver. While it is not known how natural dispersal occurs in beaver, we hypothesize that they move primarily in a linear fashion up or down established waterways. Movements across upland areas are undoubtedly successful but we question the frequency of this success in areas where predators occur sympatrically.

The value of riparian areas for wildlife has been emphasized by many authors (as reviewed by Naiman et al. 1988), but predator-prey relationships and how they relate to habitat quality and availability are not well understood (Smith et al. 1994). During dry years animals may concentrate in riparian areas along with their respective predators. These predators, while normally dependent upon another prey species, may find beaver to be easy prey items.

We found that by releasing a large number of animals (generally a family unit) we could get a few to establish. We then released more animals once the initial animals had constructed dams and ponds. By releasing more animals we reduced the probability that animals would not stay because a mate was lacking or had been killed. It was only through these additional releases that we were able to establish populations at our release sites.

ACKNOWLEDGEMENTS

This research was supported by grants from the Wyoming Game and Fish Department, U.S. Fish and Wildlife Service, Rocky Mountain Elk Foundation, Ducks Unlimited, National Rifle Association, National Fish and Wildlife Foundation, Jack's Plastic Welding, George E. Menkins Memorial Fellowship, and the University of Wyoming. Field assistance, provided by Rory Karhu, was much appreciated. Our thanks are also extended to the Breteche Creek Foundation, Tony Malmberg, Major Miller, U.S. Forest Service, Bureau of Land Management, and State of Wyoming for allowing us access to release sites.

REFERENCES

Apple, L. L., B. H. Smith, J. D. Dunder, and B. W. Baker. 1985. The use of beavers for riparian/aquatic habitat restoration of cold desert, gully cut stream systems in southwestern Wyoming. pp. 123-130 in Investigations on Beavers, G. Pilleri (ed.), V.VI Berne: Brain Anatomy Institute.

Barnes, W. J., and E. Dibble. The effects of beaver in riverbank forest succession. *Can. J. Bot.* 66:40-44.

Brown, D. J. 1994. Waterfowl and waterbird use of beaver-created wetlands in southeastern Wyoming. Unpublished M.S. Thesis. University of Wyoming, Laramie. 72 pp.

Butler, D. R. 1991. The changing south: the reintroduction of the beaver into the South. Southeast. *Geogra.* 31(1):39-43.

Collins, T. 1993. The role of beaver in riparian habitat management. Habitat Extension Bull. No. 38. Wyoming Game and Fish Department, Cheyenne. 6pp.

Davis, J. R., A. F. von Recum, D. D. Smith, and D. C. Guynn, Jr. 1984. Implantable telemetry in beaver. *Wildl. Soc. Bull.* 12(3):322-324.

Enck, J. W., P. G. Bishop, T. L. Brown, and J. E. Lamendola. 1992. Beaver-related attitudes, experiences, and knowledge of key stakeholders in wildlife management unit 21. HDRU Series No. 92-7. Human Dimensions Research Unit, Department of Natural Resources, Cornell University, Ithaca, New York. 74 pp.

Hanson, W. D., and R. S. Cambell. 1963. The effects of pool size and beaver activity on distribution and abundance of warm-water fishes in a north Missouri stream. *The Am. Midl. Nat.* 69:136-149.

Hill, E. P. 1982. Beaver. pp. 256- 281 in Chapman, J. A., and G. A. Feldhamer (eds.). Wild mammals of North America: biology, management, and economics. Johns Hopkins Univ. Press, Baltimore, MD.

Hill, E. P. 1987. Beaver restoration. pp. 281-286 in H. Kallman, C. P. Agee, W. R. Goforth, J. P. Linduska, and N. Rollison (eds.) Restoring America's wildlife 1937-1987: The first 50 years of the Federal Aid in Wildlife Restoration (Pittman-Robertson) Act. U.S.D.I., Fish and Wildl. Serv. U.S. Govt. Printing Office, Washington, D.C.

Jenkins, S. H., and P. E. Busher. 1979. *Castor canadensis*. Mammalian Species No. 120. American Society of Mammalogists, Shippensburg, PA. 8 p.

Johnson, S. L., F. J. Rahel, and W. A. Hubert. 1992. Factors influencing the size structure of brook trout populations in beaver ponds in Wyoming. *North Am. J. of Fish. Manage.* 12:118-124.

Krause, T. (no date). Dynamite snares and snaring. Spearman Publishing and Printing, Sutton, NE. 80 pp.

Legeyda, I. S., V. L. Dolinskiy, and T. D. Rogozyanskaya. 1987. Effect of beaver on aquatic fauna. *J. Hydrobiologia* 23:98-100.

Medin, D. E., and W. P. Clary. 1990. Bird populations in and adjacent to a beaver pond ecosystem in Idaho. USDA Forest Service, Intermountain Research Station, Research Paper INT-432. 6 pp.

McDowell, D. M., and R. J. Naiman. 1986. Structure and function of a benthic invertebrate stream community as influenced by beaver (Castor canadensis). *Oecologia* 68:481-489.

Naiman, R. J., C. A. Johnston, and J. C. Kelly. 1988. Alteration of North American streams by beaver. *Bioscience* 38(11):753-762.

Naiman, R. J., J. M. Melillo, and J. E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (Castor canadensis). *Ecology* 67(5):1254-1269.

Naiman, R. J., D. M. McDowell, and B. S. Farr. 1984. The influence of beaver (Castor canadensis) on the production dynamics of aquatic insects. *Verh. Internat. Verein. Limnol.* 22:1801-1810.

Nolet, B. A., A. Hoekstra, and M. M. Ottenheim. 1994. Selective foraging on woody species by the beaver Castor canadensis, and its impact on a riparian willow forest. *Biological Conservation* 70:117-128.

Nummi, P. 1989. Simulated effects of the beaver on vegetation, invertebrates and ducks. Ann. *Zool. Fennici* 26:43-52.

O'Gara, B. 1978. Differential characteristics of predator kills. pp. 380-393 in Proc. of the 8th bienn. pronghorn antelope workshop, Jasper, Alberta, May 2-4, 1978. Alberta Dep. of Recreation, Parks and Wildl., Edmonton.

Olson, R., and W. A. Hubert. 1994. Beaver: water resources and riparian habitat manager. University of Wyoming Press, Laramie. 48 pp.

Rabe, F. W. 1970. Brook trout populations in Colorado beaver ponds. *Hydrobiologia.* 35:431-448.

Smith, B. H. 1980. Not all beaver are bad; or, an ecosystem approach to stream habitat management, with possible software applications. Proc. 15th Annu. Colorado-Wyoming Chap. *Am. Fish. Soc.* Feb 27-28, Fort Collins, Colo.

Smith, D. W., D. R. Trauba, R. K. Anderson, and R. O. Peterson. 1994. Black bear predation on beavers on an island in Lake Superior. *Am. Midl. Nat.* 132:248-255.

Stanley-Price, M. R. 1989. Animal reintroductions, the Arabian Oryx in Oman. Cambridge Univ. Press. Cambridge, England. 29 1pp.

Woodward, D. K., R. B. Hazel, and P. B. Gaffney. 1985. Economic and environmental impacts of beavers in North Carolina. pp. 89-96 in P. T. Bromley (ed.). Proc. Second Eastern Wildl. Damage Control Conf., Raleigh, North Carolina.

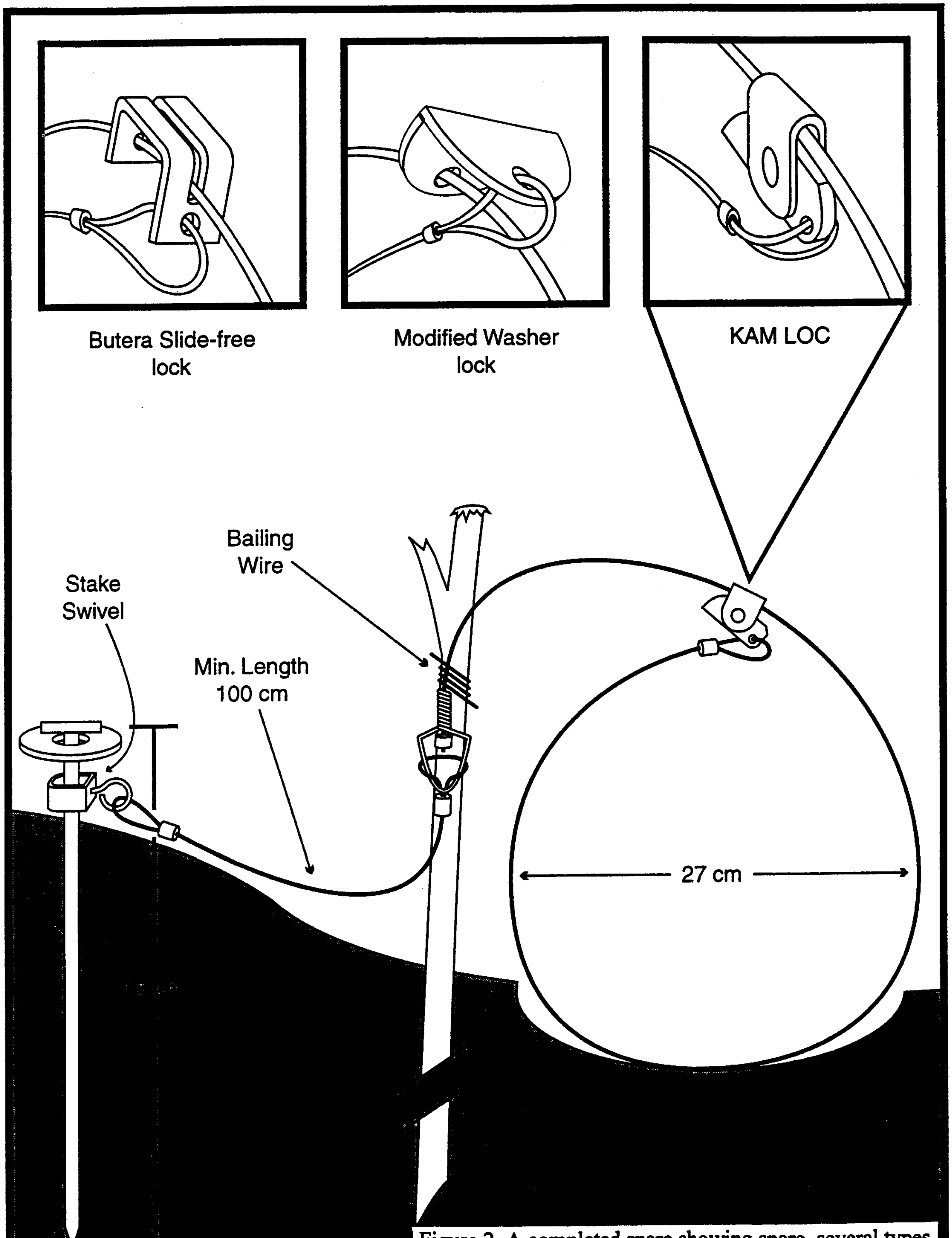


Figure 2. A completed snare showing snare, several types of locking mechanisms, swivels, lead, and stake.

THE EFFECTS OF THREE RESIDUAL-VEGETATION HEIGHTS ON STREAMBANK SEDIMENT DEPOSITION AND VEGETATION PRODUCTION

Carrie L. Gray, Quentin D. Skinner and Robert J. Henszey[1]

ABSTRACT

This is a continuation of a study initiated by Rumsey in 1994. The study is designed to test the validity of the 15.2 cm residual vegetation height standard currently used by land managers. The study is being conducted along Spring Creek, in the city of Laramie, Wyoming. The objectives are to measure and compare above-ground vegetative production, below-ground biomass, stem density, and sediment deposition on stream banks when residual vegetation is maintained at 2.5, 7.6, 15.2 cm, and unclipped vegetation heights, and to measure suspended sediment during high flow events. Sample plots located with a 1 m^2 grid were maintained at the designated treatment levels. Each treatment level (2.5, 7.6 and 15.2 cm and unclipped control) was replicated four times per reach on five reaches. Vegetation from the plots was collected, dried and weighed. Buffer zones 3 m upstream and downstream were maintained at the designated treatment levels to ensure consistent flow across sample plots. Sediment deposition was measured immediately following a high flow event using nine uniformly spaced 2.5 cm^2 stakes set flush with the ground. Stem density counts were taken inside and outside of the sample plots and will be used to compare Spring Creek with other streams in the area and to see how density affects sediment deposition. Base flow measurements and suspended sediment load were determined. Preliminary results suggest significant differences in vegetation production between the 2.5 cm and the unclipped with the other treatments. The 2.5 cm showed more cumulative production than the other clipped treatments, but not more than the unclipped. No significant differences were found between the 7.6 and 15.2 cm treatments. No significant differences were found for sediment deposition between treatment levels. Stem density inside the plots was not significantly different from outside the plots. The relationship between stem density and the amount of sediment deposited was minimal.

INTRODUCTION

Riparian zones constitute the narrow, green, vegetation communities that exist in a close proximity to water (Elmore and Beschta 1987, Kauffman and Krueger 1984, Lowrance et al. 1985) and form the interactive link between xeric upland sites and aquatic ecosystems (Gregory et al. 1991). These highly productive areas contain a large diversity of plant and animal life, both aquatic and terrestrial (Kauffman and Krueger 1984, Lowrance et al. 1985), are important fisheries and recreation areas (Abt et al. 1994), and are crucial to wildlife in providing cover along migration routes (Gregory et al. 1991, Kauffman and Krueger 1984).

As parts of dynamic systems, riparian zones differ in size and stability according to such factors as soil morphology, topography, hydrologic regime, geology and location. Despite these differences, however, they all perform the same ecological function which is to maintain the overall quality of the stream system as well as the adjacent upland areas. In addition to providing forage for wildlife and domestic animals (Elmore and Beschta 1987), vegetative cover and root biomass are crucial in the stabilization of stream banks (Bohn 1986, Lowrance et al. 1985, Swanson and Kamyab 1996, Zonge et al. 1996), sediment retention, regulation of water temperature and decreasing the water velocity through increased resistance (Swanson and Myers 1994). In 1987, Elmore and Beschta demonstrated the importance of riparian vegetation as a source of forage and showed that riparian areas provide habitat for approximately four-fifths of the wildlife species in Oregon. The dissipation of stream energy by riparian vegetation (Lowrance et al. 1985) prevents erosion by slowing the velocity of run-off or stream overflow in the case of high flow events. By slowing flood waters, more water is available to be absorbed into the underground water storage system. This not only helps to prolong flow in the stream system but also reduces flood levels downstream (Elmore and Beschta 1987). The deposition of sediment acts as building material for the restoration of stream banks (Abt et al. 1994).

Riparian vegetation acts as a filter, trapping and utilizing sediment and nutrients before they enter and contaminate the stream system (Abt et al. 1994, Gregory et al. 1991). Larger woody vegetation such as trees and shrubs provide shade, providing animals and fish with areas to escape extreme summer temperatures. Debris from these woody plants controls sediment and water routes (Kauffman and Krueger 1984), provides habitat areas on the bank, and creates pools and substrates for microorganisms within the stream system. (Elmore and Beschta 1987).

Using simulated stream systems, Abt et al. in 1994 showed that the presence of vegetation enhances sediment deposition along stream channels. They found that short and mid-lengths enhance deposition at a greater rate than longer lengths. While short and mid-lengths have similar entrapment potential, longer blades tend to bend under the flow, protecting sediment already present, although not promoting further entrapment. In a similar study in 1996, Clary et al. show similar results. However, Zonge and

[1] Department of Rangeland Ecology and Watershed Management, UW, Laramie, WY 82071 and Platte River Whooping Crane Maintenance Trust Inc., Grand Island, NE 68803-1214, respectively.

Swanson (1996) suggest that the presence of vegetation alone may not be enough to stabilize stream banks because of the dynamic complexity of stream systems.

In a study by Rumsey (1996), along Spring Creek in Laramie, Wyoming, vegetation height was found to be an insignificant factor in sediment deposition along stream banks. Results suggest sample plot elevation above streamflow was more significant.

Currently, federal and state land managers use a 15.2 cm (6") residual vegetation height as a criteria to determine when to remove livestock from public lands. This study tests the validity of this standard and examines the effects of vegetation height on the amount of sediment that is deposited after high flow events. Based on results from Rumsey's study, it is expected that the vegetation height will not be a significant factor in the amount of sediment that is deposited. The primary objectives are:

1) Measure and compare the above-ground vegetative production when residual vegetation is maintained at 2.5, 7.6, 15.2 cm, and unclipped vegetation heights.

2) Measure and compare sediment deposited on stream banks when residual vegetation is maintained at 2.5, 7.6, 15.2 cm, and unclipped vegetation heights.

3) Measure and compare stem density effects on sediment deposition.

4) Measure suspended sediment during flood events.

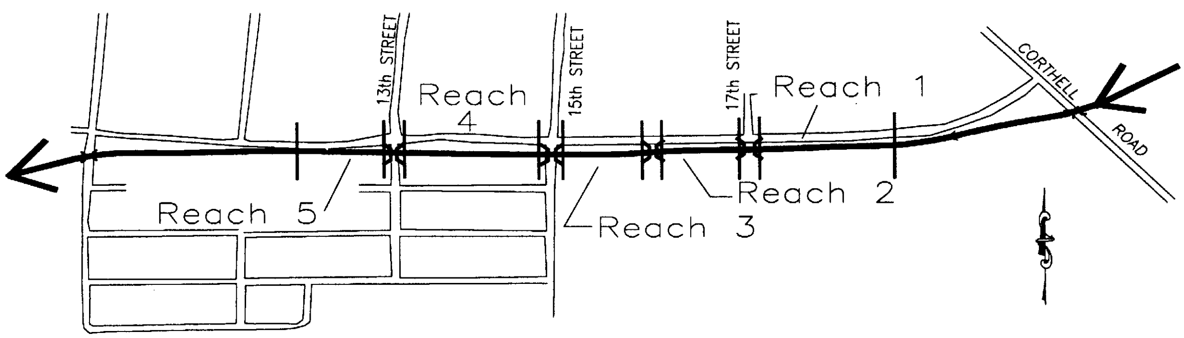


Figure 1. Stream Reaches Along Spring Creek, Laramie, WY

MATERIALS AND METHODS

Reach and Treatment Design. The study was conducted along Spring Creek in the city of Laramie, Wyoming. Spring Creek is an urban, perennial stream fed by natural springs and the Laramie Range watershed. It shows quick response to high flow events and receives a steady supply of sediment from city culverts and run-off from the Laramie Range (Rumsey 1996). Five stream reaches measuring 762, 1041, 658, 1670 and 731 meters in length within a straight channel section along Spring Creek (Figure 1) contain sample plots and buffer zones established by Rumsey (1996).

Sixteen sample plots within the reaches were selected based on ground elevation and bank disturbance (Figure 2). Buffer zones include 3 meters upstream and downstream from each 1 m^2 sample plot and ensure consistent flow across the plots. Each plot was randomly assigned one of four treatment levels: 2.5 cm, 7.6 cm, 15.2 cm, and unclipped controls. There were two replicates of each treatment on each bank of each reach for a total of four replicates/treatment/reach (Rumsey, 1996). Sample plots were located using wooden stakes placed at opposite corners of a 1 m^2 portable grid divided into 16 sections. The plots were maintained weekly during the growing season at the four treatment levels with hand clippers while the buffer zones were maintained with a gas trimmer.

Vegetation Production. During each clipping treatment the vegetation within the center 0.25 m^2 of the plot was placed in labeled bags and oven dried for 48 hours at 60° C. The vegetation was weighed and the amount of production measured.

Sediment Deposition. Nine evenly spaced sediment stakes were placed flush with the ground at each cross hair location of the portable grid at the start of the initial study (Rumsey, 1996). Following each high flow event, a rod was inserted through the sediment to the top of the stakes and sediment accumulation was measured using a ruler.

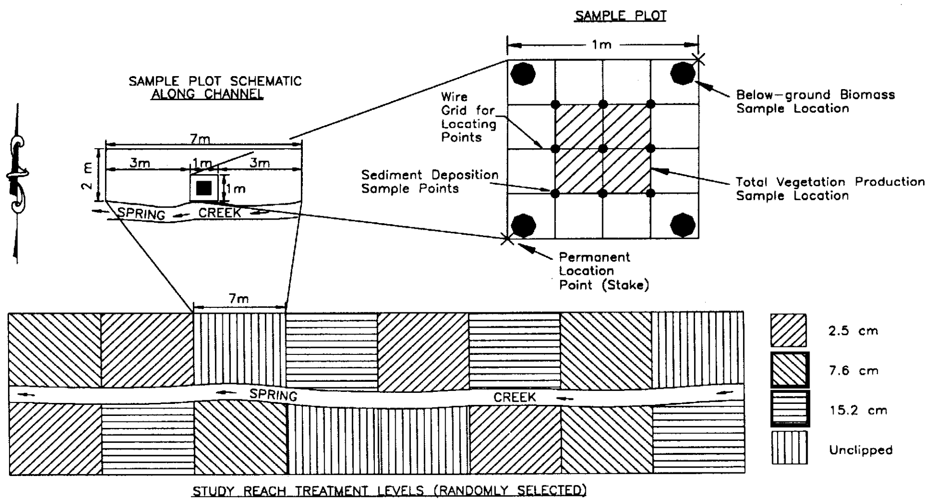


Figure 2. Sample plots and treatment levels with buffer zones.

Stem Density. Stem density counts were taken from 5 cm^2 sampling sections. There were 16 of these sections inside and outside of the sample plot. Stem density counts from the inside of the plots will be used to determine the effects of stem density on sediment deposition and to compare Spring Creek with other streams in the area.

Hydrology. During high flow events, flow rates were measured using a Marsh-McBirney Model 201 portable velocity meter. Measurements were taken at the upper crest gages of reaches 1 and 5 (Rumsey 1996). A tape measure was placed across the stream, the meter was calibrated and inserted into the water at 15.2 cm intervals. Suspended sediment was measured at the same locations using a USDH-48 hand-held, depth integrated sampler (Interagency Committe on Water Resources 1963). The samples will be analyzed to measure suspended sediment load in the water.

Analyses. A one-way Analysis of Variance (ANOVA) was used to measure differences in above-ground biomass and in sediment deposition. A one-way ANOVA was also used to compare stem density inside and outside the plots. A regression analysis was used to determine the relationship between the number of stems and sediment deposition. Further analysis will be done using multiple-regression analysis for vegetation height, elevation of plot above base streamflow, distance and number of inputs, and stem density. A three-way ANOVA with production and treatment level as variables and years as repeated measures will also be conducted. Results from this two-year study will be compiled with those of Rumsey for a total of four years data.

RESULTS

Vegetation Production. The cumulative amount of production was different between the 2.5 cm and 7.6 cm and the 2.5 cm and 15.2 cm, with the 2.5 cm showing the largest amount of production in the clipped treatments. There was no significant difference between the 7.6 cm and the 15.2 cm vegetation heights (Figure 3).

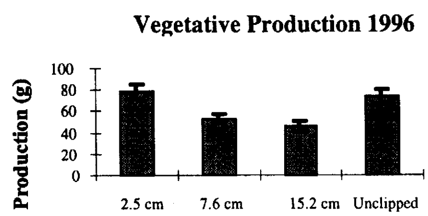


Figure 3. Vegetation

Sediment Deposition. Due to the lack of flood events over the summer, four sediment readings were taken, only two of which followed flood events. An initial reading on the first clipping date and one on the last clipping date were also measured. No significant differences were found between any of the treatments (Figure 4).

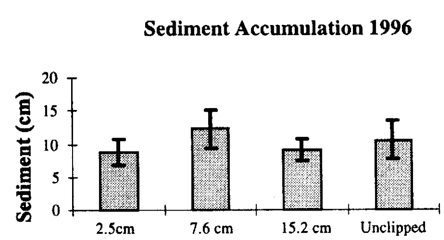


Figure 4. Vegetation Height

Stem Density. There was no significant difference between the number of stems inside the plot and outside the plot. Also, there was no significant difference in the number of stems among treatment levels (Figure 5).

There is a weak inverse relationship between the number of stems and the amount of sediment deposited. The R^2 value is only .021, showing very little, if any, relationship between the two (Figure 6).

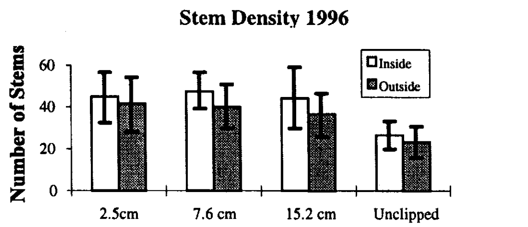


Figure 5. Vegetation Height

Hydrology. Base readings were taken at the start of the summer and at the end of the field season, however no measurements were taken because the two flood events occurred at night.

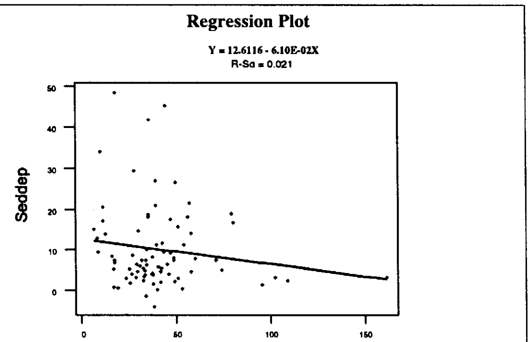


Figure 6. StemIn

DISCUSSION AND CONCLUSIONS

Using a simulated stream system, Clary et al. (1996) counted approximately 1500 stems of *Poa pratensis* and approximately 900 stems of *Carex praegracilis.* We found approximately 1300 stems in a mixture of *Phleum pratense*, *Poa spp.* and *Eleocharis spp.* We will continue stem density counts on other streams in the area in the following field season for additional comparison.

Similar to results found by Abt et al. (1994) and Clary et al. (1996), we found that shorter vegetation heights are as effective in trapping sediment as longer lengths.

Results are only preliminary and are subject to change as the study continues. However, our results correspond to those of Rumsey (1996) at the same site. Rumsey found that vegetation height was not a significant factor in sediment deposition. When this study is completed, results will be compiled with those of Rumsey (1996) for a total of four years data that will be used for final analysis.

The actual control plots were used only for the sediment deposition measurements but not for the cumulative above-ground production. Instead, a representative sample taken from within each reach but outside the control plots was used. This is because the treatments will continue through to the end of the two-year study. At that time all plots will be fully harvested and excavated, regardless of treatment level and the total above-ground production and below-ground biomass of each plot will be determined.

REFERENCES

Abt, S.R., W.P. Clary, and C.I. Thornton. 1994. Sediment deposition and entrapment in vegetated streambeds. *J. Of Irrig. and Drain. Eng.* 120(6):1098-1111.

Bohn, C. 1986. Biological importance of streambank stability. *Rangelands* 8:55-56.

Clary, W.P., C.I. Thornton, and S.R. Abt. 1996. Riparian stubble height and recovery of degraded streambanks. *Rangelands* 18:137-140.

Elmore, W., and R.L. Beschta. 1987. Riparian areas: perceptions in management. *Rangelands* 9:260-265.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience.* 41:540-551.

Interagency Committee on Water Resources. 1963. A study of methods used in measurement and analysis of sediment loads in streams. Rept. No. 14, Minneapolis, MN.

Kauffman, J.B., and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications. A review. J. Range Manage. 37:430-438.

Lowrance, R.R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control non-point source pollution. *J. Soil and Water Conserv.* 40:87-91.

Rumsey, C.J. 1996. The Effect of Three Residual Vegetation Heights on Streambank Sediment Deposition and Vegetative Production. M.S. Thesis, Range Management, Univ. Wyo., Laramie.

Swanson, S. and T. Myers. 1994. Streams, geomorphology, riparian vegetation, livestock and feedback loops: Thoughts for riparian grazing management by objectives. Effects of Human-Induced changes on hydrologic systems-AWRA. June, 1994.

Swanson, S. and Kamyab, I. 1996. Simulated stream bank erosion of surface and subsurface samples from three meadow plant communities. In: Sixth Federal Interagency Sedimentation Conference.

Zonge, K.L., and S. Swanson. 1996. Changes on streambanks in the Sierra Nevada Mountains: Perspectives from a wet and dry year. *Restoration Ecology 4*:192-199.

Zonge, K.L., S. Swanson, T. Meyers. 1996. Drought year changes in streambank profiles on incised streams in the Seirra Nevada mountains. *Geomorpholgy* 15:47-56.

STUBBLE HEIGHT AND FUNCTION OF RIPARIAN COMMUNITIES: CHANNEL AND PLANT SUCCESSION

Quentin D. Skinner[1]

ABSTRACT

Stubble height, a measurement of remaining vegetation at a time the measurement occurs will be discussed as it influences sediment deposition. Because sediment deposition may occur, succession from one stream channel configuration to another should take place. Therefore, groundwater relationships to plants growing along these changing banks may be altered and plant succession may also occur. Evidence will be presented to show that plants which require high water tables most of the growing season may be at a disadvantage to compete with plants which can withstand a rapid decline in the water table and therefore, these may become dominate along a mature channel system. Furthermore, stubble height required to maintain plant health may also decrease when plant succession occurs. Therefore, managers should consider using flexible stubble height standards to manage sediment deposition and grazing of riparian zones.

INTRODUCTION

Livestock and wildlife grazing of Western rangeland is essential to maintain the economic and social values now realized by the livestock industry and general public. However, livestock grazing impacts of riparian zones is most often singled out and cited as reason to change how public lands are managed as a natural resource (U.S. GAO 1988). Kauffman and Krueger (1984) review and illustrate the importance of riparian zones and how livestock grazing may impact this wetland resource. Because livestock utilize vegetation as forage, measuring utilization to evaluate how livestock grazing alters attributes of riparian zones is common practice. There appear to be two general thoughts about how to measure utilization. One can attempt to estimate the amount of vegetation that has disappeared through consumption or, one can measure the amount of vegetation that remains after herbivores have used an area. Clary and Webster (1989) address the latter method of evaluating utilization and support use of this methodology as a valid way to determine when to remove grazing from riparian habitat and pasture land. In part, this paper addresses Clary and Webster's school of thought because stubble height is one measure of remaining vegetation when the height is read. This paper also addresses how stubble height may be related to function of riparian zones.

Function of riparian zones has generally been addressed by Chaney et al. (1990) which indirectly suggests that stream channels may go through a successional sequence from unincised to incised. These authors suggest that unincised is functioning well as a riparian zone and the incised is not. This school of thought has been extended by the Bureau of Land Management (BLM) to the point that function of riparian zones is being used as a way to evaluate condition of riparian zones within lands they manage (USDI 1993).

The BLM's manual "***Riparian Area Management: Process for Assessing Proper Functioning Condition***" suggests that stream channels may move through a successional sequence from bare ground to late seral (USDI 1993). This manual also suggests that as stream channels move through succession, associated plant community composition may change and that before or when the late seral stage in channel succession has formed, expected potential or natural type communities should exist. To the BLM, the late seral channel condition and expected associated potential and natural plant community represents their definition of properly functioning riparian zones. This definition does not recognize the basic function of a stream, which is to remove water and sediment from its drainage basin, but appears to only promote one half of the natural and cyclic process of erosion. This paper in contrast assumes that in the cycle of erosion sediment that is deposited in one point in time will be eventually removed in a down stream direction. Also, different stages in this cyclic process may occur along the course of any one stream during any one point in space and time. Therefore, all recognized stages in channel succession may be functioning properly when each is considered separately. By following this thought process, stubble height and sediment deposition relationships can be used to evaluate how well management of vegetation and grazing meets an objective of moving from one stage in channel succession to another.

Because it appears, in part, that water and sediment transport may create the successional sequence used by the BLM (USDI 1993) to evaluate condition of riparian zones, this paper will address if and how stubble height alters sediment deposition. Then, sediment deposition will be discussed as it relates to channel and plant succession because this topic may relate to available water for growing riparian plants, plant species composition, and use of stubble height standards.

STUBBLE HEIGHT AND SEDIMENT DEPOSITION

In the past streambank vegetation has been shown to increase channel roughness (Beschta and Platts 1986, Gregory et al. 1991) which can modify Manning's n (Ree et al. 1977). Increased channel roughness and a higher Manning's n (Ree et al. 1977) may dissipate stream energy and cause sediment deposition

[1] Department of Rangeland Ecology and Watershed Management, UW, Laramie, WY 82071

(DeBano and Heede 1987, Debano and Schmidt 1989). Vegetation may sort sediment by size and retains it along riparian zones (Lowrance et al. 1985, Platts and Rinne 1985, Beschata and Platts 1986, Middleton 1993). Established vegetation roots appear to bind soil and stabilize stream channel banks (Gebhardt et al. 1989, Lowrance et al. 1985, Elmore and Beschta 1987, Chaney et al. 1990). Vegetation has also been shown to increase protection of water ways (Chow 1959) and tall grass causes flow resistance which may decrease when it lays over in the direction of flow when streamflow velocity and depth in a channel increases (Haan and Barfield 1978).

With recent concern about livestock grazing and maintaining riparian zone condition, monitoring of vegetation using stubble height standards is receiving focused attention. Consequently, studies have been conducted to evaluate how stubble height modifies sediment deposition. Clarey et al. (1996) conducted a flume study in which treatment controlled streamflow, sediment supply, and stubble height of flexible and rigid herbaceous vegetation. Figure 1 illustrates results of this study.

Flexible vegetation maintained at 0.5 inches high caused more sediment deposition than greater stubble heights tested. More sediment was deposited using rigided vegetation that was 3 inches high. With flooding trials and no sediment, the 0.5 inch flexible vegetation retained more sediment but the ability to do so decreased rather quickly when the treated plants were taller than 6 inches. With rigid vegetation, loss did not occur as fast at any one height but there was less net gain in sediment deposited than with the flexible plant treatments. No time allowed for regrowth of vegetation between the period of deposition and repeated flooding.

Rumsey's (1996) study of stubble height and sediment deposition increases the scale of study over

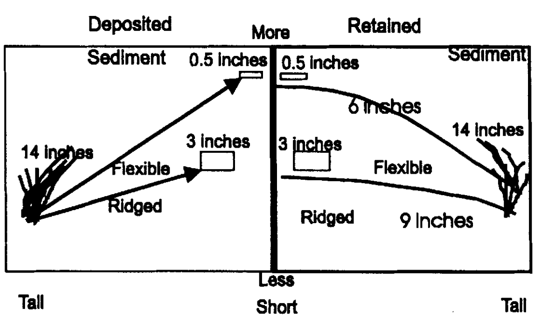


Figure 1. Stubble Height and Sediment Deposition after Clarey et al. 1996

Clarey et al's. (1996) flume experiments but lacked the control of streamflow and sediment supply. Rumsey was able to maintain control over direction of flow because the study was conducted in an urban stream that had been channelized in a straight flume like configuration and the low gradient channel bottom was maintained by permanent structures.Vegetation and floodplains had become established within the channelized reach before the study was initiated.

Rumsey found that there was no significant difference in sediment deposited over two years when stubble heights were maintained at 1 inch, 3 inch, 6 inch, and unclipped heights. Amount of sediment deposited decreased with elevation of the floodplain above the level of streamflow. The average sediment deposited was between 0.5 and 1.0 cm. Gray et al. (1997) reported the third year of this study and up to 12 cm of sediment was deposited during the summer of 1996. There are still no significant differences between stubble height treatments.

In a natural meandering and high sediment transport stream system (Muddy Creek, WY), Goertler (1992) found that in six years, the existing vegetation on banks and channel conditions did not cause a reduction in suspended sediment during years of high flow but did during years of low flow. Middleton 1993 found that particle size classes of sediment changed with distance away from Muddy Creek's active channel and related this sorting to decreased power of streamflow as flooding receded. Budd (1994) reported that at least 1 foot of sediment was deposited over six years in places like point bars during Muddy Creek flood events and that overall change in sediment deposited was not significant among vegetation types, stream study segments, or years.

In summarizing the examples provided, one may conclude that vegetation can filter sediment from streamflow. It appears that shorter stubble height may filter more sediment than taller or undisturbed vegetation. There may be a difference between plant species and their ability to filter sediment depending on their flexiblity. Amount of sediment deposited on flood plains appears to vary with stream channel configuration, amount of streamflow, and sediment supply. Amount of sediment deposited because of the condition of flood plain vegetation may not be significant compared to sediment deposition caused by the channel and streamflow attributes.

FUNCTION OF STUBBLE HEIGHT AND SEDIMENT DEPOSITION

Assuming that vegetation remaining on flood plains (stubble height) can filter and stabilize sediment, then channels can move through a successional sequence from incised to unincised (Chaney et al. 1990) or early seral to late seral (USDI 1993). The riparian zone function of stubble height trapping sediment must then be that channels can go from a degraded or empty state of sediment collection to a state of being full of sediment or, to a mature channel state which is assumed to be the state that is functioning properly as a riparian zone by Chaney et al. (1993) and the BLM (USDI 1993).

This paper accepts that channel succession occurs because vegetation causes streamflow sediment deposition and then stabilizes it, and that there are ways to remove it at some point in space and time. Stream channel meandering and slope adjustment are two natural ways of removing stored sediment from flood plains discussed by Leopold et al. (1964), Morisawa (1968), Schumm (1977), and Heede (1980). Now it is reasonable to assume that sediment deposited on flood plains can increase the height of channel banks year to year and the soil surface may move higher and farther away from the water table during low streamflow conditions. It can also be assumed that, during periods of flood plain saturation, the drainage of stored water will vary with the soil attributes of the sediment material stabilized in the channel bank building process. Differences in plant and water table relationships determine plant species composition and thus, potential for plant stubble to cause sediment deposition during flooding. Therefore, the significance of using stubble height to evaluate riparian zone management objectives is, that agreed upon standards may have to be altered as plant species composition changes in relationship to different stages in channel succession. Figure 2 is presented to illustrate channel and plant succession while accepting that erosion is cyclic.

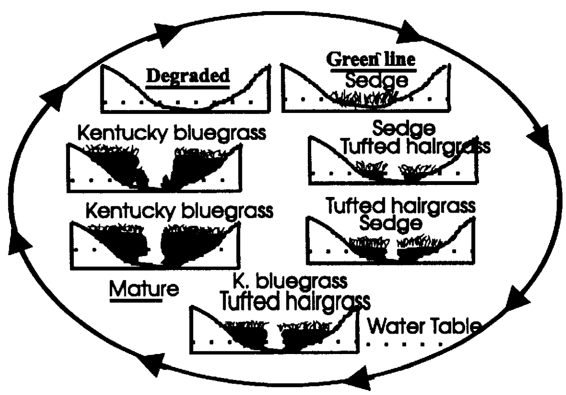


Figure 2. A hypothetical sequence illustrating channel and plant succession assuming erosion is a cyclic process.

Henszey (1993) explored the relationship of riparian plant communities to depth-to-groundwater levels over an eight year period. Figure 3 illustrates a summary of a part of his results. The study found that Wet Meadows supported mostly a tall sedge plant community and the Moist-Wet Meadow complex supported tall and short growing sedges and Tufted hairgrass.

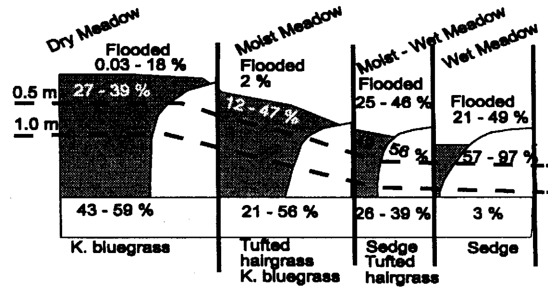


Figure 3. Water table and riparian zone plant community relationships after Henszey (1993).

Although both community types were flooded 21 to 49 % of the time, drainage to a water table deeper than 1 meter during the summer occurred only 3 % of the time in Wet Meadows and 26 to 39 % of the time in Moist-Wet Meadows. Drainage to a water table deeper than one meter increased in his Moist Meadow type to 21 to 56 % of the time and to 43 to 59 % of the time in Dry Meadows. His Moist Meadows supported mostly Tufted hairgrass and Kentucky bluegrass and his Dry Meadows Kentucky bluegrass. This study supports a hypothesis that depth to groundwater and rate of drainage or, drainage and soil water depletion by plants may cause a change in plant species composition along streams as they move through a successional sequence from degraded to mature.

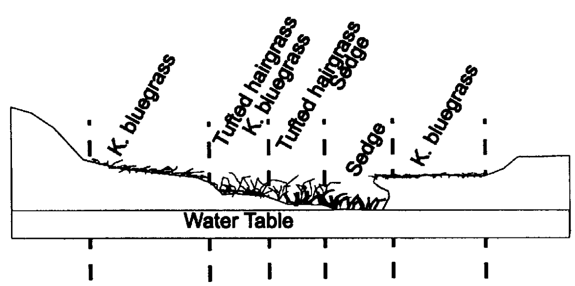


Figure 4. Hypothetical relationship between channel configuration and plant succession.

If one now uses Henszey's (1993) plant communities and places them on a degraded straight reach or a building point bar of a meandering stream as illustrated in Figure 4, tall sedges would occupy the area close to the low flow level of the stream. Based on the information presented in Figure 3, the other plant communities would fall into place as the depth of the bank material increased over the established water table away from the channel itself. Kentucky bluegrass would occupy the driest site of the riparian zone. As sediment is deposited and stabilized by vegetation on the lower portions of the bank, it is reasonable to assume that the degraded bank could eventually reach the channel profile shown in Figure

5 and, that the sedges and Tufted hairgrass would decrease and Kentucky bluegrass would increase.

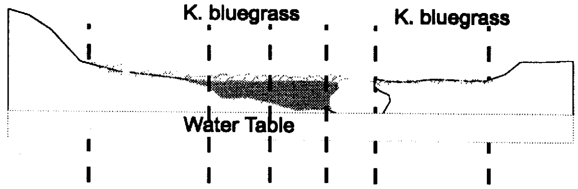


Figure 5. Hypothetical change in channel configuration and plant species composition caused by deposited sediment and bank building.

To further test the hypothesis that riparian plant species respond differently to water table levels, Henszey and Yeager used 10 foot tall by 4 inch wide and 1 inch deep columns filled with sand. Reverse column flow and outlet reservoir control was then used to test response of Nebraska sedge, Tufted hairgrass, and Kentucky bluegrass to 1,2, 4, and 6 cm per day watertable decline rates (Yeager 1996). Sand was used to minimize the capillary rise of water after plants were fully established while water levels were at the surface of the columns. Pertinent results are shown in Figures 6 and 7.

Depth (cm)	Kentucky bluegrass	Tufted hairgrass	Nebraska sedge
0 - 10	117	43	108
10 - 20	30	27	10
20 - 30	5	2	0
30 - 40	2	0	0

Note: Maximum root depth after 30 days (plants dead)

Figure 6. Recorded maximum visual root depth and length in cm at a watertable decline rate of 4 cm per day (Yeager 1996).

The visual length and depth recorded by Hensey and Yeager (Yeager 1996) on the clear plastic front of columns suggest that Kentucky bluegrass is more aggressive in growing roots to keep up with a declining water table. It is assumed that capillary rise in sand was not sufficient to supply required water for growth of each of the three plants tested for death occurred after 30 days in all decline rates tested. The ash free weights taken after the clear plastic column fronts were removed confirm visual data recorded and again suggest that Kentucky bluegrass may be more adapted than the other two species tested for growing in deeper soils over groundwater.

In summary, it appears that sediment deposition can cause channel succession and that this process may be used to predict change in plant succession. Also, as flood plains fill with sediment, soil water and plant relationships may be more like those found in adjoining upland areas. Land and water managers should recognize that this occurs when evaluating function of riparian plant communities when using stubble height as a monitoring protocol. Because the BLM USDI (1993) is now leading an effort to determine proper function of riparian zones, and uses the mature state in channel succession as one of their ultimate management goals, this paper suggests they consider using variable stubble height standards when managing the riparian landscape of a drainage basin. Doing so will help insure that the individual states in channel and plant succession recognized in this paper, and which appear to be functioning as they should be, are accounted for in the design of future monitoring and management programs (Figure 2).

REFERENCES

Beschta, R.L. and W.S. Platts. 1986. Morphological features of small streams: significance and function. *Water Resources Bull., Amer. Water Resource Assoc.* 22:369-379.

Budd, R.W. 1994. A Wyoming stream's riparian zone response to instream structures. M.S. Thesis, Range Management, Univ. Wyo., Laramie. 72 p.

Chaney, E., W. Elmore, and W.S. Platts. 1990. Livestock grazing on western riparian areas. Produced for US-EPA by Northwest Resource Information Center, Inc. Eagle, Ida.

Chow, Ven Te. 1959. Open-Channel Hydraulics. McGraw-Hill Book company, Inc., New York. 680 p.

Clary, W.P. and B.F. Webster. 1989. Managing grazing of riparian areas in the intermountain region. U.S.D.A. Forest Service. Intermountain Research Station. General Technical Report INT-263. 11p.

Clary, W.P., C.I. Thornton, and S.R. Abt. 1996. Riparian stubble height and recovery of degraded streambanks. *Rangelands* 18:137-140.

DeBano, L.F. and B.R. Heede. 1987. Enhancement of Riparian ecosystems with channel structures. *Water Resources Bull., Amer. Water Resource Assoc.* 23:463-470.

DeBano, L.F. and L.J. Schmidt. 1989. Interrelationship between watershed condition and health of riparian areas in southwestern United States. P.45-52. ***In***: Gresswell, R.E.: B.A. Barton; J.L. Kershner (eds.). Practical approaches to riparian resource management: an educational workshop; Billings, Mont. USDI BLM.

Elmore, W. And R.L. Beschta. 1987. Riparian areas: perceptions in management. *Rangelands* 9:260-265.

Gebhardt, K.A., C. Bohn, S. Jensen, and W.S. Platts. 1989. Use of hydrology in riparian classification. p. 53-59. ***In***: Gresswell, R.E.: B.A. Barton; J.L. Kershner (eds.). Practical approaches to riparian resource management: an educational workshop; Billings, Mont. USDI BLM.

Goertler, C.M. 1992. Sediment dynamics within channel and riparian zone types along a cold-desert Wyoming stream. M.S. Thesis, Range Management, Univ. Wyo., Laramie. 205 p.

Gray, C.L., Q.D. Skinner, and R.J. Henszey. 1997. The effect of three residual-vegetation heights on streambank sediment deposition and vegetation production, Abstracts, 50th Annual Meeting, Soc. for Range Manage., Rapid City, SD. p66.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience.* 41:540-551.

Haan, C.T. and B.J. Barfield. 1978. Hydrology and Sedimentology of Surfaced Mined Lands. Office of Continuing Education and Extension. University of Kentucky. 286 p.

Heede, B.H. 1980. Stream dynamics: an overview for land managers. U.S. Forest Service, GTR-RM-72, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. 26 p.

Henszey, R.J. 1993. Riparian zone changes caused by streamflow augmentation. P.H.D. Thesis, Range Management, Univ. Wyo., Laramie. 120 p.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications. A review. *J. Range Manage*. 37:430-438.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial Processes in Geomorphology.W.H. Freeman and Company, San Francisco, CA, 522 p.

Lowrance, R.R., R. Leonard, and J. Sheridan. 1985. Managing riparian ecosystems to control non-point source pollution. *J. Soil and Water Conserv.* 40:87-91.

Middleton, M.A. 1993. Chemistry and soil texture survey of sediments in a Wyoming riparian zone. M.S. Thesis, Range Management, Univ. Wyo., Laramie. 113 p.

Morisawa, M. 1968. Streams: their dynamics and morphology. Earth and Planetary Science Series, McGraw-Hill Book Company, New York, NY. 175 p.

Platts, W.S. and J.N. Rinne. 1985. Riparian and stream enhancement management and research in the Rocky Mountains. *N. Amer. J. Fish. Manage.* 5(2A):115-125.

Ree, W.O. and V.J. Palmer. 1949. Flow of water in channels protected by vegetative linings. Div. Of Drain. And Wat. Cont. Res. Soil Conservation Service Tech. Bull. 967. 115p.

Rumsey, C.J. 1996. The effect of three residual vegetation heights on streambank sediment deposition and vegetative production. M.S. Thesis, Rangeland Ecology and Watershed Management, Univ. Wyo., Laramie. 61p.

Schumm, S.A. 1977. The Fluvial System. John Wiley & Sons, New York, NY. 338 p.

U.S. Department of Interior. 1993. Riparian area management: process for assessing proper functioning condition. U.S. Depart. Of Interior, Bureau of Land Management, TR1739-9 1993. 51p.

U.S. General Accounting Office. 1988. Public rangelands: some riparian areas restored but widespread improvement will be slow. Report to Congr. Requestors, GAO/RCED-88-105. Washington D.

Yeager, T.D. 1996. Critical groundwater hydroperiods for maintaining riparian plant species. M.S. Thesis, Rangeland Ecology and Watershed Management, Univ. Wyo. Laramie 52 p.

EFFECTS OF HERBIVORY ON WILLOW (*SALIX SPP.*) CANOPY VOLUME ON MOUNTAIN RANGELANDS OF NORTHERN WYOMING.

Mark S. Thorne, Quentin D. Skinner, Mike A. Smith, William A. Laycock, and Jerry L. Dodd[1]

ABSTRACT

Grazing management of western riparian areas has become increasingly important. Willows, *(Salix spp.)* a common shrub species throughout the west are being used as an indicator of riparian condition. The structural diversity of a willow community provides important habitat for many species of wildlife. Willows are also a forage source for large ungulates. However, little is known about the effects of herbivory on willow and its structural diversity. Canopy volume can be used to quantify changes in community structure. This study investigated the relationship between willow canopy volume and utilization by large ungulates. Transects were randomly selected and established on two northern Wyoming grazing allotments to monitor canopy volume and utilization. Transects were evaluated seasonally, and before and after cattle use. Canopy volume was calculated using the height and diameter of each plant in an ellipsoid volume formula. Utilization measurements were calculated from the length of current years twig growth removed and the number of available twigs browsed. Regression analysis was used to define the relationship between changes in canopy volume and different levels of utilization at both the species and community level. New knowledge about canopy structure, and above ground responses to herbivory will provide valuable understanding of the ecological role of willow. These results will aid managers in determining proper use levels by large ungulates that will maintain willows as a wildlife habitat component.

INTRODUCTION

Most of the current methods used to quantify shrub community structure, production, utilization and composition are based on two dimensional, area measurements. While these biomass and canopy coverage methods estimate the lateral extent of shrub communities, they do not account for their vertical structure. However, it is the combination of the lateral spread and the vertical structure of a shrub community that provide important wildlife habitat components. Furthermore, it is the three-dimensional area, or volume, that is impacted by both wildlife and livestock.

Volume measurements have been used in the past on a variety of plant species for estimation of different parameters. Daubinmire (1968) felt that canopy volume, as a structural parameter, could be used to determine and compare dominance of plant species in a community. Until Zamora (1981), who used procedures first described by Daubinmire (1959; in Zamora 1981), canopy volume measurements had been reserved for estimating biomass or current year twig production of shrubs (Lyon 1968; Peek 1970; Rittenhouse and Sneva 1977; Uresk et al. 1977; Bryant and Kothmann 1979; Creamer 1991). More recently, Myers (1989) suggested that the addition of height measurements to canopy coverage data might be a more practical level of description for riparian communities. In Montana, Manoukian (1994) also recognized the importance of the vertical structure in riparian communities. Accordingly, he used canopy volume measurements to evaluate the response of willows to several ecological factors.

Riparian and wetland condition is frequently determined by the status of its shrubby vegetation. Departures from the pristine condition of these plants is usually attributed to livestock grazing and other current land management practices. Willows *(Salix)* are considered so important to riparian area condition that the U.S. Forest Service is emphasizing measurement of their status after livestock grazing (USDA-FS 1994). However, in these guidelines, there is no attempt to partition use by livestock from use by other large ungulates. This is despite the fact that willows provide an important source of forage for a wide variety of wildlife, as well as livestock.

Hobbs et al. (1980) found willow to be a major component of winter and summer elk diets in Colorado. These shrubs are even more important as dietary components for elk in severe winters when other sources of forage are not available (Gruell 1980). Willow communities and riparian habitat are also important for moose (Wilson 1971), deer (Loft et al. 1991), cattle (Kauffman and Krueger 1984), beaver (Thomas et al. 1978, Alksiuk 1970), and fisheries (Platts et al. 1983, Platts 1978). Because of this importance, and since both wildlife and livestock browse willow, utilization is the most often monitored parameter in evaluating communities. Furthermore, it is felt that by controlling utilization, willow height can be increased. Since the addition of height to canopy coverage data constitutes canopy volume, utilization may also influence the volumetric area of willow communities. However, little is known about the relationship between different levels of utilization and changes in willow canopy volume.

In recognition of this lack of knowledge, we initiated this study to accomplish two objectives: (1) To determine how the frequency and intensity of browsing affects canopy volume at the species and community type level across seasons; and (2) to determine the relationship between utilization and changes in canopy volume of willows by species.

[1] Department of Rangeland Ecology and Watershed Management, UW, Laramie, WY 82071 and Dept. of Animal and Range Sciences, NDS, Fargo, ND 58105, respectively.

METHODS AND MATERIALS

STUDY AREAS

The Paintrock allotment is located in the Bighorn Mountains of Washakie county, Wyoming. The allotment is managed by the U.S. Forest Service, Bighorn National Forest. The Hyatt ranch is the lessee and runs approximately 900-1000 head of livestock on the allotment during the summer. Elevation on the allotment ranges between 2500m and 3500m. Lodgepole pine *(Pinus contorta)* forests dominate the landscape with intermingled parks dominated by grasses and grass-like vegetation. At the higher elevations and north facing slopes the lodgepole pine gives way to spruce-fir forests. Aspen *(Populas tremuloides)* are also common on south and west facing slopes on the allotment. Precipitation is received mostly as snow and ranges from 40 cm in the lower elevations to 1000cm at the higher elevations. The allotment has three main streams running through it, which include the North Fork, Main Fork, and Middle Fork of Paintrock Creek. Additionally, two smaller streams, Sheep Creek and Long Park Creek flow into Paintrock Creek.

The Greybull allotment is located on the Shoshone National Forest in Park county, Wyoming and is administered by the U.S. Forest Service. The Pitchfork ranch is the lessee and runs approximately 1100 head of cow-calf pairs during the summer on the allotment. The landscape is dominantly open with patches of spruce *(Picea spp)*, lodgepole pine, or Douglas fir *(Pseudotsuga menziesii)* stands surrounded by open grassland. Elevations on the allotment range between 2000m and 3500m. Precipitation is primarily in the form of snow and ranges between 40 and 1000cm depending on elevation. The allotment is bound on the north and west by the Greybull river. The allotment is bisected by Jack Creek. Willow Creek, Hay Maker Creek, and several smaller streams provide additional water and willow habitat.

STUDY DESIGN

A total of six representative willow communities for each allotment were selected for the establishment of transects. Each site had four randomly selected transects. Every transect had a total of 25 randomly selected, marked twigs (100 total twigs per site) on 6-12 plants for the utilization survey. Canopy volume was measured from each plant along the transect lines in each community. Measurements were repeated in three different and consecutive seasons (winter/spring, summer, and summer/fall). Additionally, measurements were taken immediately before and after the cattle grazing period in communities were livestock were permitted.

At the time of marking, and in subsequent readings, the twig length and browsing status of each twig were recorded. Utilization was calculated as the percent of potentially available current year's twig length removed between sampling dates. Potentially available current year's growth was determined with a growth coefficient calculated as the percent increase in length between sampling dates from unbrowsed twigs. Growth coefficients were calculated for each site in each seasonal period, and applied to twigs which were browsed between corresponding sampling dates. Thus, utilization was estimated by the equation, utilization (%) = [(potentially available length for period - measured length at end of period) ÷ potentially available length for period] x 100. In addition, utilization was calculated as the percent browsed of available marked twigs in which the formula, utilization (%) = [(number of marked twigs - number of browsed twigs) ÷ number of marked twigs] x 100, estimated utilization.

Canopy volume was measured by first determining the height of each plant and subsequently, two diameter readings were taken at right angles at 50% of the plant height. The volume measurements were then applied to an ellipsoid volume formula:

CV= 2/3pi(Height)(Major axis/2 * Minor axis/2)

Where: the major and minor axis are the canopy diameters at 50% of the plant height.

We determined the ellipsoid model to be superior in estimating plant volume because of it's relative elasticity and ability to approximate a wider range of shapes than other formulas.

Percent and actual change in canopy volume was calculated at the plant, transect and site levels. A canopy volume growth coefficient was calculated (percent increase between seasons) from plants that remained unutilized between sampling dates. Potential canopy volume was calculated by applying the growth coefficient to utilized willows in the corresponding seasons. Since growth is a multiplicative function, the subsequent seasons growth coefficients were applied the previous seasons potential canopy volume. The actual and percent difference between potential and measured canopy volume was calculated at the site level for each sampling period.

STATISTICAL ANALYSES

Regression analysis was used to evaluate the relationship between utilization and several predictor variables including, percent change in measured canopy volume, percent difference between measured and potential canopy volume, and percent of available marked twigs browsed. Analysis of Variance procedures were used to determine the significance of seasonal differences in utilization and canopy volume.

RESULTS AND DISCUSSION

All of the results presented here are from Willow Swamp, a site on the Paintrock allotment. Willow Swamp is a community of mixed Bog birch *(Betula glandulosa* Michx*)* and Planeleaf willow *(Salix planifolia* Pursh*)*. This site is commonly used for livestock grazing and is also used primarily by elk and a few moose, for the majority of the year.

At willow swamp a significant interaction existed between the seasonal distributions of utilization and measured canopy volume (Figure 1). Specifically, mean canopy volume increased during the pre-cattle period (between June 24 and July 21, 1996) from an initial value of 0.168 ''' 0.14 m^3 to 0.207 ''' .129 m^3 when wildlife utilization was about 5 $\pm$ 10%. During the period of cattle use from July 21 through July 29, 1996, utilization increased to 20 ''' 13%, and continued to increase after cattle, through October 12 to 36 ''' 14%. Over this same period mean canopy volume decreased to 0.198 ''' 0.152 m^3 and 0.162 ''' 0.118 m^3 respectively. Both utilization and mean change in canopy volume were significantly ($p < 0.0009$) different between all seasons. However, the end canopy volume on October 12 was not significantly different from the initial canopy volume on June 24, 1996.

In the regression analysis between percent utilization and measured changes in canopy volume there was only a moderate, negative relationship ($R^2 = .496$). Although the p-value was less than 0.01, this relationship may not represent the true relationship because of an interaction with canopy volume growth.

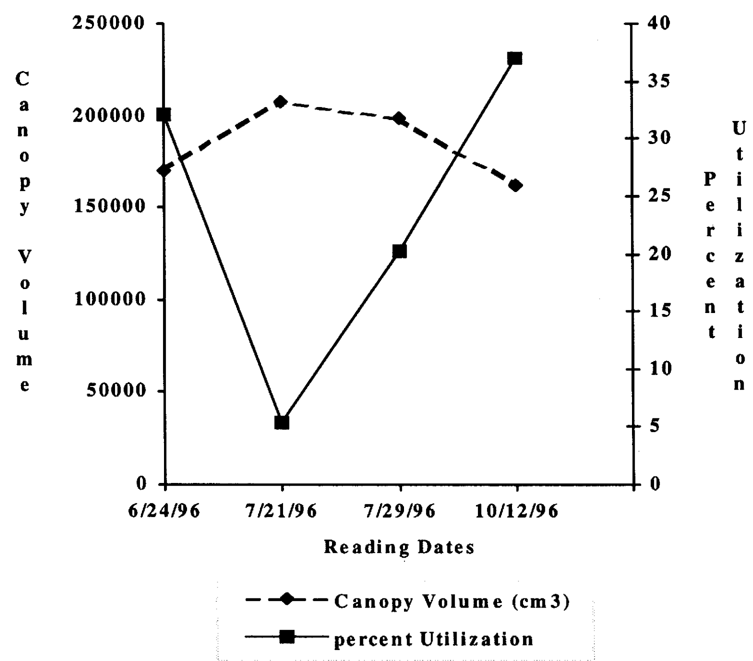


Figure 1. Seasonal distribution of percent utilization and canopy volume (cm^3) for willow swamp. The period from 6/24-7/21/96 was prior to cattle entering the site. Cattle were present on willow swamp from 7/21-7/28/96. The post-cow period is from 7/29-10/12/96.

Growth was adjusted for by using the volume growth coefficient to estimate potential canopy volume. Early in the growing season, when utilization was low, the measured and potential canopy volume were not significantly different (Figure 2). However, by July 29, after cattle, measured and potential canopy volume began to diverge. As utilization increased after 7/29, the departure of the measured canopy volume from the potential increased. It is important to note that growth is a multiplicative function while utilization is additive. Consequently, utilization may not be directly reflected in changes in the measured canopy volume because of the growth rate. Rather, utilization has more of a moderating effect on the rate of canopy volume increase. The measure of that effect is the difference or area between the potential and measured canopy volume curves. Thus, the true relationship between utilization and canopy volume may lie in the proportional amount that the measured canopy volume departs from the potential.

To determine if utilization was related to measured canopy volume departures from the potential we used a simple linear regression between the two variables (Figure 3). The results indicated that utilization was significantly related to the percent difference between the measured and potential canopy volume ($R^2 = 0.705$, $p < 0.0009$). This is further evidence to suggest that utilization depresses the rate of canopy volume

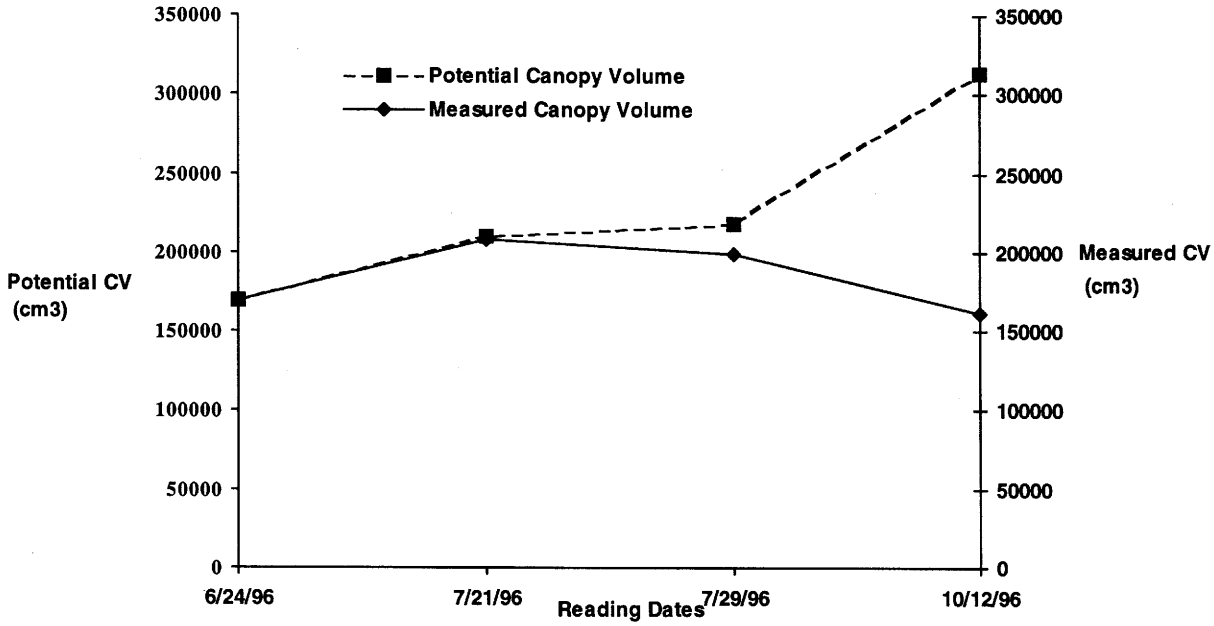


Figure 2. Plot of potential and measured canopy volume by sampling date for willow swamp. The difference between the measured and potential canopy volume could be considered a point estimate for utilization.

increase, rather than directly impacting it. Furthermore, at relatively high utilization rates there is the potential for positive increases in canopy volume, if the potential canopy volume for that period is large enough. This of course would be controlled by the environmental factors that influence growth in any given growing season.

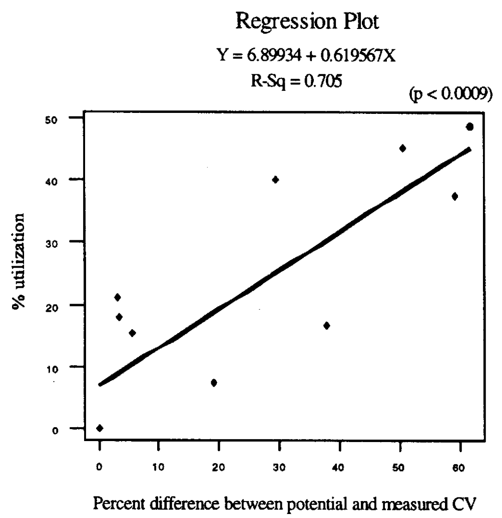


Figure 3. Fitted line plot between utilization calculated as the percent of potentially available current years growth removed and the percent difference between potential and measured canopy volume for willow swamp, Paintrock allotment, 1996.

The two indices of utilization, percent of current year's growth removed and percent of available twigs browsed, were strongly correlated ($r = 0.86$). However, the regression analysis (Figure 4) between the percent of available twigs browsed and the percent difference in potential and measured canopy

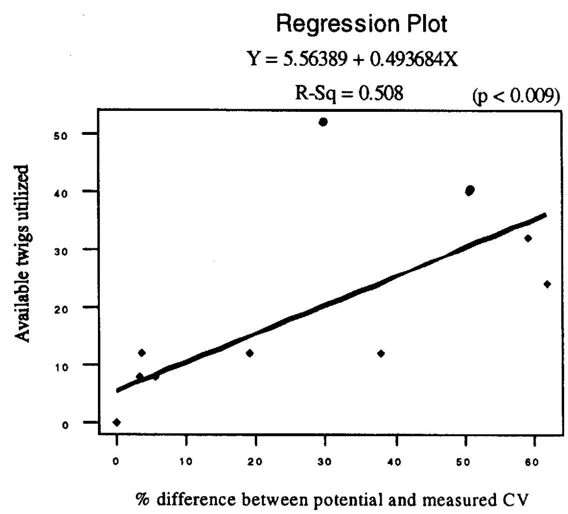


Figure 4. Fitted line plot of utilization as a percent of available twigs browsed and the percent between potential and measured canopy volume for willow swamp, Paintrock, allotment, 1996.

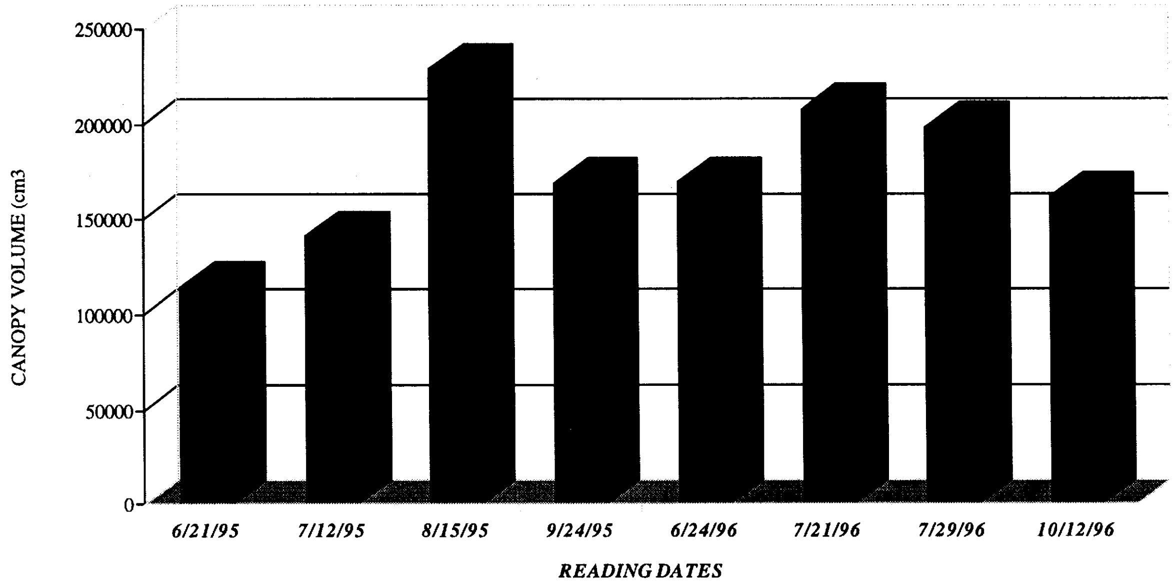


Figure 5. Two-year seasonal distribution of canopy volume for willow swamp, Paintrock allotment, 1995-1996.

volume was less significant than when percent of current year's growth was regressed with this same predictor variable (Figure 3). Although the correlation is only moderate ($R^2 = 0.508$), the p-value suggest that the relationship is still strong. One reason that our correlation between these two variables is not high, is in part because of the variability within our sample population. Another, slightly less obvious explanation is that canopy volume increase is a function of increasing twig length. Consequently, a simple count of browsed twigs does not reflect the loss of twig length and thus, does not accurately account for the departure of measured canopy volume from the potential.

Despite periods of high utilization, and subsequent losses in the potential canopy volume, the general two year trend at willow swamp has been an increase in willow canopy volume (Figure 5). Indeed, at the end of the 1996 growing season, the mean canopy volume (0.162 " 0.118 m3) was 67% greater than the initial mean canopy volume (0.114 "' 0.093 m^3) in June of 1995. It is important to note that the 1996 growing season was dry compared to the 1995 season. The fact that canopy volume was nearly the same at the end of 1996 growing season as it was at the beginning may in part be explained by these dry conditions. Additionally, some of the variability in our canopy volume estimates may be due to twig mortality from the dry conditions of 1996.

CONCLUSIONS

To summarize, we found that utilization and canopy volume were significantly different between all seasons. However, there was no significant difference in canopy volume between the initial volume on June 24 of 1996 and the ending volume on October 12. This suggests that wildlife utilization on willows is as much if not more of a factor controlling the rate of increase in willow size. Consequently, wildlife utilization should also be considered when determining a desired objective for willow communities.

We also concluded that utilization only depresses the rate of canopy volume increase. Because of this, the change in measured canopy volume does not accurately reflect utilization. Consequently, the degree to which the measured canopy volume departs from the potential canopy volume may be a better indicator of utilization. Thus, the measured canopy volume must be converted to a relative canopy volume decrease from the potential. This decrease in canopy volume may be more useful when assessing a willow community based on it's three dimensional characteristics.

Since Daubinmire (1959), canopy volume has been recommended as a useful, simple and efficient method to quantify shrub communities. Indeed, in range management, a technique that can be used to define shrub community composition, structure, species dominance, and estimate production and utilization both rapidly and accurately is clearly more desirable. Canopy volume techniques are capable of fulfilling these requirements.

REFERENCES

Aleksiuk, M. 1970. The seasonal food regime of Arctic beavers. *Ecology* 51:264-270.

Bryant, F.C. and M.M. Kothmann. 1979. Variability in predicting edible browse from crown volume. *J. Range Mange*. 32:144-146.

Creamer, W.H. IV. 1991. Prediction of available forage production of big sagebrush. Thesis, Montana State University, Bozeman, Montana. 73p.

Daubenmire, R. 1968. Plant communities- A textbook of synecology. Harper and Row Publications, N.Y. 300p.

Gruell, G.E. 1980. Wildlife habitat investigations and management implications on the Bridger-Teton National Forest. p. 63-74. In: Boyce, M.S. and L.D. Hayden-Wing (eds.). North American Elk: Ecology, Behavior and Management. University of Wyoming. Laramie, Wy.

Hobbs, N.T., D.L. Baker, J.E. Ellis and D.M. Swift. 1980. Composition and quality of elk diets during winter and summer: A preliminary analysis. p. 47-53. In: Boyce, M.S. and L.D. Hayden-Wing (eds.). North American Elk: Ecology, Behavior and Management. University of Wyoming. Laramie, Wy.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications..a review. *Journal of Range Management* 37:430-438.

Loft, E.R., J.W. Menke and J.G. Kie. 1991. Habitat shifts by mule deer: The influence of cattle grazing. *J. Wildl. Manage*. 55:16-26.

Lyon, L.J. 1968. Estimating twig production of serviceberry from crown volumes. *J. Wildl. Manage*.32:115-119.

Manoukian, M.E. 1994. Evaluation of tall willow *(Salix spp)* within a livestock grazing allotment in southwest Monatana. Thesis, Montana State University, Bozeman, Montana. 52p.

Myers, L.H. 1989. Riparian area management: Inventory and monitoring riparian areas. TR 1737-3, U.S. Dept. Int. Bureau of Land Management, Dillon Resource Area, Montana. 79p.

Peek, J.M. 1970. Relation of canopy area and volume to production of three woody species. *Ecology* 51:1098-1101.

Platts, W.S. 1978. Livestock grazing and riparian/stream ecosystems - an overview. p. 39-45. In: Forum - Grazing and Riparian/Stream Ecosystems. Nov. 3-4, 1978. Denver, CO.

Platts, W.S., W.F. Megahan and G.W. Minshall. 1983. Methods for evaluating stream, riparian and biotic conditions. USDA Forest Service General Technical Report INT-138.

Rittenhouse, L.R., and F.A. Sneva. 1977. A technique for estimating big sagebrush production. *J. Range Manage*. 30:68-70.

Thomas, J.W., C. Maser and J.E. Rodiek. 1978. Riparian zones in managed rangelands - their importance to wildlife. p. 21-31. In: Cope, O.B. (ed.). Forum - Grazing and Riparian/Stream Ecosystems. November 3-4, 1978. Denver, CO.

Uresk, D.W., R.O. Gilbert, and W.H. Rickard. 1977. Sampling big sagebrush for phytomass. *J. Range Manage*. 30:311-314.

Wilson, D.E. 1971. Carrying capacity of the key browse species for moose on the north slopes of the Uinta Mountains, Utah. Utah State Division of Wildlife Resources Publication No. 71-9.

Zamora, B.A. 1981. An approach to plot sampling for canopy volume in shrub communities. *J. Range Manage*. 34:155-156.

ESTABLISHMENT RATES AND BIOMASS PRODUCTION OF WILLOW AND GRASSES UNDER GREENHOUSE CONDITIONS OF VARIABLE SOIL SALINITY AND NUTRIENT CONCENTRATION.

Mark Rogaczewski, Jeff Powell, Joe Hiller and Michael Parker[1]

ABSTRACT

Nearly all of the research on vegetation filters has been conducted on acid to neutral wetland soils. However, many of the riparian soils in Wyoming cropland and rangeland areas are characterized as sodic or saline. The relative amount of nitrate removal from groundwater through denitrification and plant uptake may be quite different under semi-arid land conditions and should be determined in a more realistic setting for western riparian areas. Hybrid willow (*Salix matsudana X alba*), Jose tall wheatgrass (*Agropyron elongatum*), Alkar tall wheatgrass (*Agropyron elongatum*), Whitmar beardless wheatgrass (*Agropyron spicatum f. inerme*), Garrison creeping foxtail (*Alopecurus pratensis*), and Magnar basin wildrye (*Elymus cinereus*) were subjected to 3 levels of salinity and 5 different concentrations of phosphorus and nitrogen inputs. Establishment rates of willows and grasses, above- and below- ground biomass production, and uptake of phosphorus and nitrogen were measured. Preliminary results for willow and grass establishment and above- and below-ground biomass are presented.

INTRODUCTION

Riparian ecosystems link stream environments with their terrestrial catchment. Because of this physical proximity, riparian buffer strips have been adopted as a viable and useful tool for restoring and managing streams and rivers (Osborne and Kovacic, 1993). Several researchers have measured >90% reduction of nitrate concentrations and up to 50% retention of surface-water phosphorus entering them (Gilliam 1994), and as much as 80% of the phosphorus adsorbed to sediment particles can be filtered by riparian buffer zones (Welsch 1991).

Vegetative filter effectiveness studies conducted by Lowrance, Gilliam, O'Neill, Gordan and many other scientists, were in riparian areas with acidic to neutral wetland soils; however saline soils are commonly found in the semi-arid to arid west. Harmful effects of salts on vegetation is due not only to disturbances in water uptake, but also to the direct toxic action of ions penetrating the plant. The uptake and elimination of nonpoint source pollutants from groundwater is of major concern for domestic and recreational water supplies. Nutrient filtering capacity of streamside vegetation is important and the study of species selection for riparian plantings is encouraged (O'Neill and Gordon 1994).

The purpose of this study is to evaluate the establishment rates, and above- and below ground biomass production of Australian hybrid willow (*Salix matsudana X alba*), Jose tall wheatgrass (*Agropyron elongatum*), Alkar tall wheatgrass (*Agropyron elongatum*), Whitmar beardless wheatgrass (*Agropyron spicatum f. inerme*), Garrison creeping foxtail (*Alopecurus pratensis*), and Magnar basin wildrye (*Elymus cinereus*) were subjected to 3 levels of salinity and 5 different concentrations of phosphorus and nitrogen inputs. Hybrid willow was selected rather than native species because hybrid willow is generally faster growing and produces more annual biomass than native species (Kovalchik 1992). This particular hybrid grows rapidly when its roots reach the water table (Powell 1990) and is appropriate due to its high demands and utilization of large amounts of soil water. The 5 grasses used were recommended by the Natural Resources Conservation Service, Torrington, Wyoming for their salt tolerance, and palatability. It is our goal to predict potential suitability and production of these individual species as vegetation filters in saline soils similar to those in Eastern Wyoming.

MATERIALS AND METHODS

Research was conducted at the University of Wyoming Plant Soil and Insect Sciences greenhouse facilities, Laramie, Wyoming. Soil samples containing 3 different salinity levels were obtained from the Rottman Ranch, approximately 5 km north of Hawk Springs, Wyoming, to establish low, medium, and high salinity levels (Table 1). Salinity of samples was determined by obtaining conductivity readings (Singer and Munns, 1996), from 15 g samples of soil wetted with deionized water and mixed to a smooth paste. Samples were allowed to incubate at room temperature for one hour to allow sufficient wetting of soil and then filtered to extract water. Conductivity of the extracted solution was obtained with a Hanna Instruments Conductivity meter and converted to deciSiemens/m. Low salinity soil was primarily Ulysses loam, 1-3%, class IIe-2, irrigated (Stephans et al. 1971) and textured as loamy sand. Medium and high saline soils were obtained from deep, poorly drained alluvium riparian soils with alkali and/or saline inclusions. These soils were textured as sandy clay loams and loamy sands.

[1] Department of Rangeland Ecology and Watershed Management; Wyoming Cooperative Extension Service; and Department of Physiology and Zoology, UW, respectively, Laramie, WY 82071.

Table 1. Salinities, deciSiemens/m, of soils obtained from Rottman Ranch, Hawk Springs, Wyoming.

Salinity	Conductivity
Low	1.50
Medium	3.62
High	7.10

Hybrid willows and Jose Tall Wheatgrass were planted in 4" X 40" lined PVC tubes capped on one end between late May and early July, 1996. Each tube averaged 35 inches of soil. Alkar tall wheatgrass, Whitmar beardless wheatgrass, Garrison creeping foxtail, and Magnar basin wildrye were planted in early August. Two applications of 5 different concentrations of nitrogen and phosphorus fertilizer solutions were applied during the growing season of early June to early November. Concentrations were based on soil tests for total nitrogen and phosphorus performed on soil obtained from the Rottman Ranch. Rates included minimum, average, maximum, 1.5 X maximum, and 2.0 X maximum total nitrogen and total phosphorus of soil samples (Table 2). To ensure that neither nitrogen or phosphorus would limit growth, phosphorus was applied at a rate equal to the average phosphorus content of the soil where nitrogen was the major nutrient applied. Where phosphorus was the major nutrient applied, nitrogen was applied at a rate equal to the average nitrogen content of soil samples. Three replicates of 4 plants per treatment were grown for willow in low and medium saline soils, and Jose tall wheatgrass in low, medium, and high saline soils. Three plants of each nitrogen treatment were grown in 2 high saline soils for Alkar tall wheatgrass, Whitmar beardless wheatgrass, Garrison creeping foxtail, and Magnar basin wildrye.

Table 2. Nutrient application concentrations (mg/kg).

NO3-N/PO4-P	PO4-P/NO3-N
6.0 : 8.0	2.0 : 17.0
17.0 : 8.0	8.0 : 17.0
34.0 : 8.0	10.0 : 17.0
51.0 : 8.0	15.0 : 17.0
68.0 : 8.0	20.0 : 17.0
68.0 : 8.0	20.0 : 17.0

Upon establishment, Jose Tall Wheatgrass seedlings were thinned to ten plants per tube, similar to Curtin's (et al., 1993) research on vegetative response to salinity. Thinning was not required for tubes containing Alkar tall wheatgrass, Whitmar beardless wheatgrass, Garrison creeping foxtail, and Magnar basin wildrye.

Growing conditions consisted of temperatures of 65:85 F (night:day) with watering every 7-10 days or as needed with deionized water to ensure an adequate water supply existed within each tube. Disease and insects were controlled with the spraying of the fungicide Bentholate and Safer Insecticidal Soap as needed. Both are nitrogen- and phosphorus-free compounds. Growing season lengths averaged 167, 152 and 140 days.

Above-ground total biomass collections of willow and grasses were performed between early and mid-November with the onset of dormancy. Samples were dried at 165 F in a drying oven and weighed. Establishment rates were obtained by counting those tubes with visible growth at the time of the second nutrient application and dividing by the total number of tubes planted per species. Establishment rates are shown in Table 3.

Below-ground total biomass collections were performed from mid-January to mid-April. Root samples were divided into 5 equal soil horizons, 7 inches in length. Soil was washed from the roots according to procedures described by Lauenroth and Whitman (1970).

Table 3. Establishment rates(%) for willow and grass species per soil salinity level (mmhos/cm).

Species	Salinity Level				
	1.50	3.50	3.62	7.10	10.70
Salix	97.5	N/A	52.5	0.0	N/A
AGEL	100	N/A	96.6	97.5	N/A
ALTW	N/A	N/A	N/A	97.5	93.3
AGIN	N/A	N/A	N/A	0.0	0.0
ALPR	N/A	N/A	N/A	0.0	0.0
LECI	N/A	N/A	N/A	86.7	20.0

Large detritus particles were removed from samples. Ocular estimates of percent root biomass in each horizon were obtained during washing. Root samples were dried at 165° F in a drying oven and weighed. Final root weights were determined by subtracting an average percent of fine detritus material from the total weight.

Experimental units were arranged within the greenhouse in a randomized block design. A SAS general linear model (GLM) program was used for statistical analyses due to missing values where plant establishment failed. Dependent variables were leaf, stem, and root weight production per day of growing season for willows. Leaf and root production per day of growing season were dependent variables for grasses. Independent variables were salinity level, nutrient type, and nutrient application concentration. Additional analyses on interactions will be performed.

RESULTS AND DISCUSSION

All differences discussed are significant at the 5% level of probability unless otherwise stated. Using low salinity soil as a standard, medium and high salinity soils reduced biomass production by 23% and 100% for leaves, 76% and 100% for stems and 41 % and 100% for roots respectively (Figs. 1-3). Phosphorus additions produced 22% more leaf and stem biomass than nitrogen. The 152 day growing season produced 31% and 45% more leaf biomass

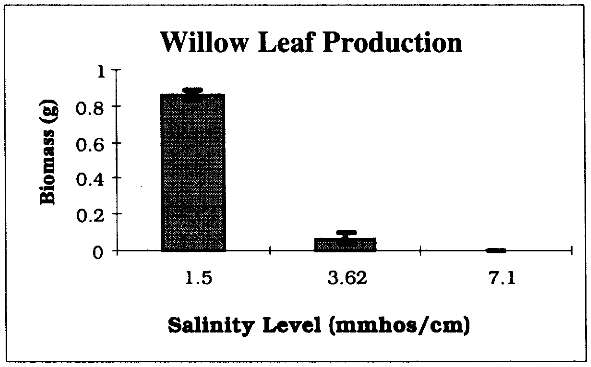


Figure1. Mean willow leaf production vs. salinity level

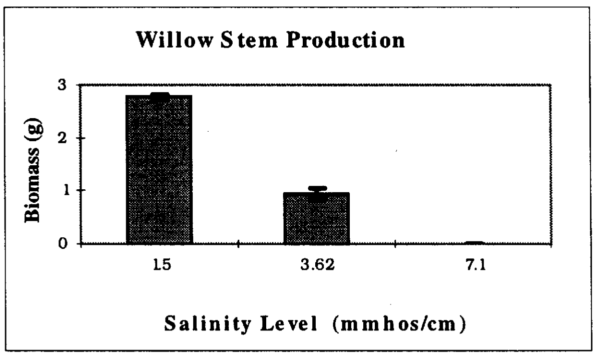


Figure 2. Mean willow stem production vs. salinity level

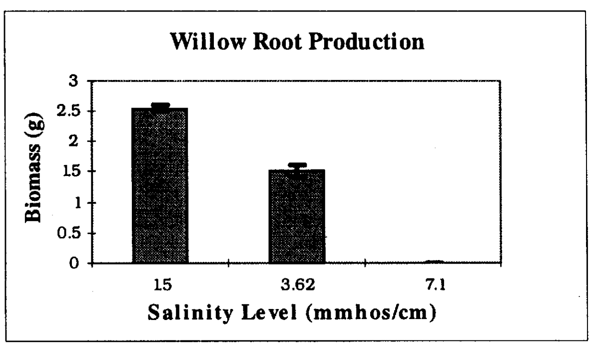


Figure 3. Mean willow root production vs. salinity level

than the 167- and 140-day growing season. The 167-day growing season produced 20% and 24% more stem biomass than the 152- and 140-day growing seasons.

Jose tall wheatgrass above-ground production declined as nutrient concentration declined (Fig. 4).

Above-ground biomass production increased as growing season decreased with the 140 day growing season producing the greatest amount (Fig. 5).

Salinity level had no effect on establishment rates for Jose tall wheatgrass; establishment rates were greater than 95% for all salinity levels. Salinity level did

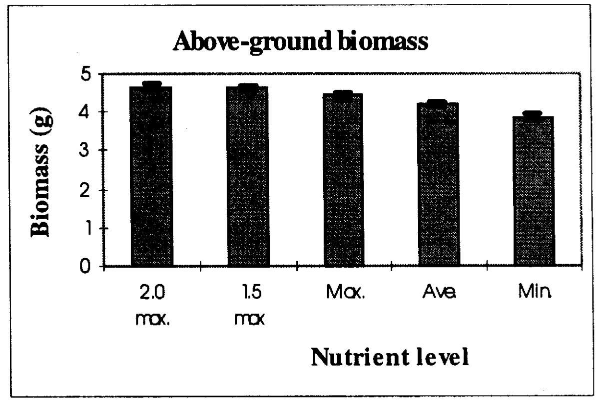


Figure 4. Mean Jose tall wheatgrass production vs. nutrient level

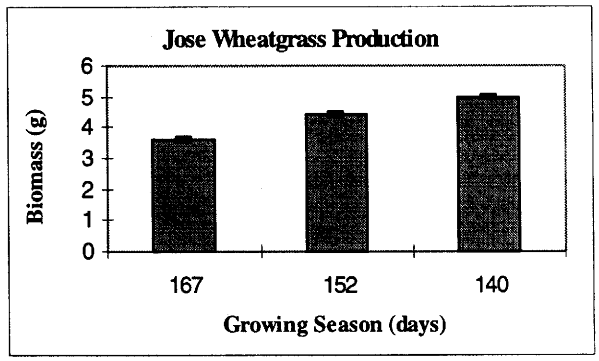


Figure 5. Mean above-ground biomass production for Jose tall wheatgrass vs. growing season

have an effect on willow establishment with 97.5 and 52.5% in low and medium saline soils and 0.0% for the high. Alkar tall wheatgrass, Whitmar beardless wheatgrass, Garrison creeping foxtail, and Magnar basin wildrye establishment rates were 93.3, 0.0, 0.0, 86.7% and 93.3, 0.0, 0.0, and 20.0% for the 2 high saline soils.

CONCLUSIONS

Biomass production of willows in response to increased salinity are similar to results reported by Ungar (1996), as salt stress occurred in saline levels near 4 deciSiemens (Singer and Munns, 1996). Similarly, established rates of willow, Whitmar beardless wheatgrass, Garrinson creeping foxtail, and Magnar basin wildrye were hampered as salinity of the soil increased. However, Jose tall wheatgrass production and establishment was not affected at salinity levels up to 7.1 deciSiemens with medium saline soil producing the greatest biomass.

Hopkins (1995), reports that leaf and shoot production should increase with excess nitrogen while root production should increase with excess phosphorus. As analyzed, our data currently does not support these findings. Shoot to root ratios will need to be analyzed.

According to our results and the greenhouse conditions described, Jose tall wheatgrass, Alkar tall wheatgrass and Magnar basin wildrye are capable of resisting saline soil levels beyond normal stress occurance. For greatest biomass production and elimination of direct return of nutrients to the system, harvesting of these grasses is recommended around 140 days of growth. Willow and the other 3 grasses tested seem unable to sustain growth beyond moderate saline soil levels.

REFERENCES

Curtin, D., H. Stepphun, and F. Selles. 1993. Plant responses to sulfate and chloride salinity: Growth and ionic relations. *Soil Sci. Soc. Am. J.* 57:1304-1310.

Gilliam, J. W. 1994. Riparian wetlands and water quality. *J. Environ. Qual.* 23:896-900.

Hopkins, W.G. 1995. Plants and inorganic nutrients. P. 65-80. *In* B. Cabot and S. Cheney (eds.) Introduction to plant physiology. John Wiley & Sons, Inc., New York, USA.

Kovalchik, B.L. 1992. Growth and yield of willows in Central Oregon compared to reports in world literature. p. 83-88. In: W.P. Clary, E.D. McArthur, D. Bedunah, and C.L. Wambolt (comp.). Proc. - symp. on ecology and management of riparian shrub communities.; 29-31 May 1991; Sun Valley, ID. USDA For. Serv. Gen. Tech. Report INT-289. 232 p.

Lauenroth, W.K. and W.C. Whittman. 1971. A rapid method of washing roots. *J. Range Manag.* 24: 308-309.

O'Neill, G. J., and A.M. Gordon. 1994. The nitrogen filtering capability of Carolina poplar in an artificial riparian zone. *J. Environ. Qual.* 23:1218-1223.

Osborne, L. L., and D.A. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biol.* 29:243-258.

Powell, J. 1990. Low maintenance windbreaks, erosion control, wildlife habitat with Australian hybrid willows (*Salix matsudana X alba*) in Goshen Country, Wyoming. Report submitted at Austree Field Day, 1 October 1990, Meridan, Wyoming. 4 p.

Singer M. J. and D. N. Munns. 1996. Soil: An introduction. Third edition. Prentice-Hall, Inc. New Jersey, USA.

Stephens, F., E. F. Brunkow, C.J. Fox, H.R. Ravenholt. 1971. Soil survey of Goshen Country, Wyoming, southern part. USDA Soil Conserv. Serv., US Govt. Printing Off., Washington, D.C. 100 p.

Welsch, D.J. 1991. Riparian forest buffers: function and design for protection and enhancement of water resources. NA-PR-07-91. USDA For. Serv., Radnor, PA.

Ungar, I.A. 1996. Effect of salinity on seed germination, growth, and ion accumulation of Atriplex patula (Chenopodiacea). *Amer. J. Bot.* 83:604-607.

SESSION 8:

STREAM AND WETLAND ECOLOGY

CHANGES IN CHANNEL MORPHOLOGY AND RIPARIAN MOSAICS ON THE BIG HORN RIVER, WYOMING

Travis J. Bray, Thomas A. Wesche and Wayne A. Hubert[1]

ABSTRACT

Three sets of aerial photographs (1954, 1975, and 1989) of the Big Horn River floodplain between Thermopolis and Worland, Wyoming, were analyzed and compared to determine temporal and spatial trends in channel characteristics and the riparian mosaic. Since flow regulation by Boysen Dam in 1952, the river morphology and riparian mosaic have changed. Channel width and area of active channel have decreased, but there has been no change in channel sinuosity. Changes in riparian mosaic included decreases in the riparian herbaceous plant community and non-vegetated bar areas, and increases in the amount of agricultural land and woody species canopy cover.

INTRODUCTION

Reservoir storage alters natural hydrographs. Flows are commonly augmented during natural low-flow periods and decreased during high-flow periods. Following dam closure, the base level of a river bed (downstream) may lower; thereby, altering the base level of tributaries flowing into the river and creating head cuts. This degradation will continue until a geologic control is reached (Simons and Senturk, 1977). By altering the hydrograph, transport capability may be decreased and sediment deposited by tributaries may not be removed from the system. Such changes in water and sediment regimes can lead to changes in channel morphology as the system attempts to reach a new equilibrium.

Flow regulation can affect the abundance and diversity of riparian vegetation (Mizell and Skinner, 1986). Auble et al. (1994) stated that riparian vegetation is sensitive to changes in minimum or maximum flow and it is possible to substantially change the riparian vegetation community without changing mean annual flow. Flow alteration may allow the establishment of exotic vegetative species and the reduction or disappearance of native plant species. An example of this is the invasion of russian olive (*Elaeagnus angustifolia*) and the decline in cottonwoods (*Populus* spp.) along the Arkansas and South Platte rivers (Snyder and Miller, 1991).

STUDY AREA

The Big Horn River is currently regulated by one main-stem dam in Wyoming, Boysen Dam, which was completed in 1952 and is located 22 km upstream of Thermopolis, Wyoming. The Wyoming Game and Fish Department (WGFD) has classified the tail waters as a Class 1 - blue ribbon fishery (fishery of national importance) from the northern boundary of the Wind River Indian Reservation to the confluence of Kirby Creek. In Wyoming, less than 2% of all stream miles are so classified. Due to the prominence of the Big Horn River fishery, management of the river is a priority for the WGFD (Wiley, 1995). The study area was divided into three reaches. Reach 1 began at Wedding of the Waters and ended at the Lucerne pumping station; reach 2 as from the Lucerne pumping station to Hanover Canal; and reach 3 extended from Hanover Canal to Worland (Figure 1).

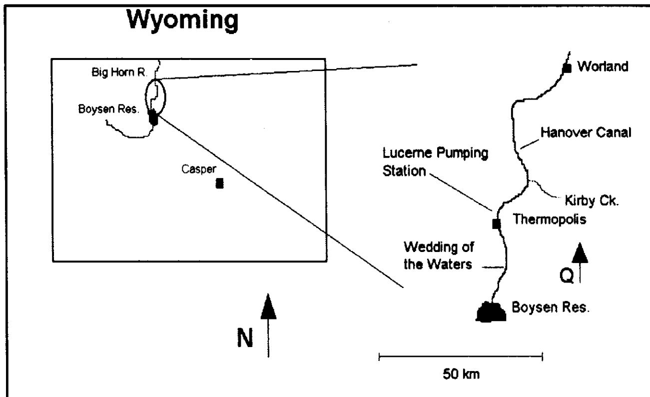


Figure 1. Map of Wyoming and the Big Horn River study area.

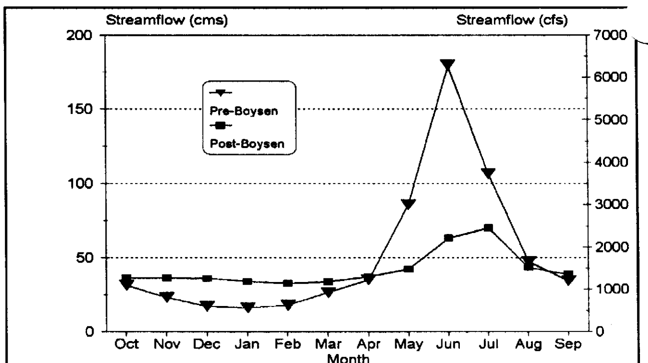


Figure 2. Pre (water years 1912 to 1952, USGS# 06259500) and post (water years 1953 to 1994, USGS# 0625900) Boysen Dam mean monthly hydrographs for the Big Horn River, Wyoming.

Boysen Dam altered the streamflow regime of the Big Horn River as recorded by U.S. Geological Survey (USGS) stream gaging stations at Boysen Dam and Thermopolis (Figure 2). Operating conditions have increased the average fall-winter flow (Sept. through April) by 11.5 cubic-meters per second (cms), decreased summer flow (May through Aug.) by 38 cms and decreased the peak flow by 110 cms. Also, peak flow has been delayed by one month due to river regulation.

[1] Wyoming Water Resources Center; Department of Rangeland Ecology and Watershed Management; and Wyoming Cooperative Fish/Wildlife Research Unit and Department of Zoology and Physiology, UW, Laramie, WY 82071, respectively.

METHODS

Spatial and temporal changes in channel morphology and riparian mosaics were determined by examining three sets of aerial photographs. The first set was taken by the U.S. Army in 1954, the second by the U.S. Bureau of Land Management in 1975, and the third set by the U.S. Geological Survey (USGS) in 1989. Possible sources of error were minimized by selecting aerial photographs with similar characteristics: time of year taken, flow conditions, antecedent hydrology (previous year's flow regime), and scale.

Quantitative assessment of temporal and spatial changes in channel morphology was accomplished by measuring the following characteristics: (1) width of bankfull channel; (2) sinuosity (channel thalweg length divided by valley length, where valley length is the straight line distance from upstream to downstream); and (3) area of active channel (AAC) (channel length multiplied by width of bankfull channel).

Riparian vegetation, within the 100-year flood plain as defined by the BOR (1983), of each study reach was classified to allow for spatial and temporal comparisons between years. Dominant riparian vegetation classes were: (1) riparian herbaceous plants; (2) non-vegetated areas (i.e. point and lateral sediment bars); (3) agriculture; and, (4) woody species canopy cover. The aerial photographs taken in 1975 and 1989 were of a high enough quality to distinguish cottonwoods and russian-olive communities. Thus, two additional classification categories were added.

The study area was visually surveyed on the ground during August, 1995. At that time, the 1989 aerial photographs were verified to assure proper classification of vegetation types. Also it was noted that no young cottonwood stands were present within the study area and head-cuts were present on tributaries.

RESULTS

CHANNEL MORPHOLOGY

Channel morphology appears to have responded to streamflow regulation. Channel width and area of active channel (AAC) of the Big Horn River decreased from 1954 to 1989 (Figure 3). The largest change occurred between 1954 and 1975 in reach 2 where a 28.3-m (1.4 m/yr) decrease in channel width and a 98.8-ha (29%, 4.7 ha/yr) reduction in AAC occurred. Reach 1 had the least change, between 1954 and 1975, with channel width decreasing by 11.2-m (0.5 m/yr) and AAC by 11.3-ha (9%, 0.5 ha/yr). Between the years of 1975 and 1989 the amount of change diminished. In reach 2 a decrease in channel width of 5.5-m (0.4 m/yr) and a 22.9-ha (9%, 1.6 ha/yr) reduction in AAC was noted. Reach 1 had a decreased in channel width of 2.7-m (0.2 m/yr) and a reduction in AAC of 5.8-ha (5%, 0.4 ha/yr). Between 1954 and 1989 channel width decreased in reaches 1, 2, and 3 by 0.4, 1.0, 0.7 meters per year respectively; and AAC decreased by 208.8-ha (6.0 ha/yr) within the study area. Channel length and sinuosity changed little between 1954 and 1989 (Figure 4).

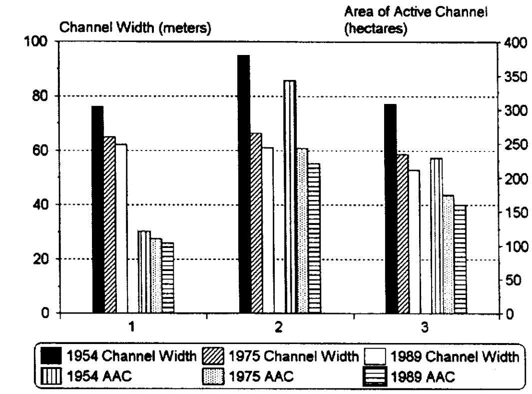


Figure 3. Channel width and area of active channel by study reach and sample year for the Big Horn River, Wyoming.

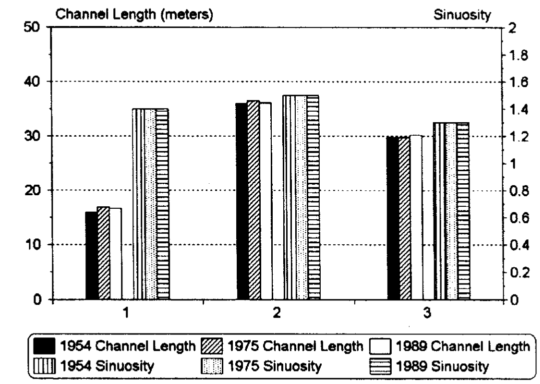


Figure 4. Channel length and sinuosity by study reach and sample year for the Big Horn River, Wyoming.

RIPARIAN MOSAIC

The riparian mosaic along the Big Horn River changed from 1954 to 1989. Riparian herbaceous vegetation and non-vegetated areas both decreased while agriculture and woody species increased (Figure 5). The majority of change occurred within the riparian herbaceous (decrease of 35%) and agricultural (increase of 27%). Non-vegetated areas decreased form 1.7% to 0.1% and woody species canopy cover increased by 7.5%. Cottonwood and russian olive communities increased between 1975 and 1989 by 10.4 and 15.4% respectively. Increases in agriculture are likely due to regulation of the Big Horn River. The construction of Boysen Dam provides a year long water supply and minimizes the chances of flooding. With a constant water supply and decreased threat of floods, agriculture was encouraged to cultivate areas previously occupied by riparian herbaceous communities.

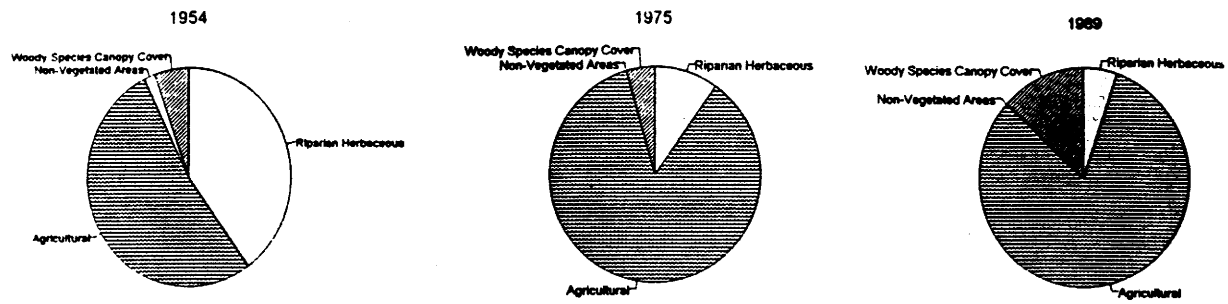


Figure 5. Riparian composition by classification category and sample year within the study area on the Big Horn River, Wyoming

DISCUSSION

CHANNEL MORPHOLOGY

Rivers are dynamic systems and are in a constant state of change or quasi-equilibrium. Each river is unique and can respond differently to various stimuli. The morphology of a river is characterized by channel width, depth, sediment size and load, velocity, discharge, slope, and roughness (Rosgen, 1996). Altering one factor may lead to a series of changes in all remaining factors until a new quasi-equilibrium is reached.

Low-gradient streams, such as the Big Horn River, may have greater responses to flow modifications than those of higher gradient. Wesche (1991) measured the effects of diversion structures on smaller streams by comparing channel morphology above and below diversions. He observed that streams with a channel slope greater than 1.5% had no statistically significant differences above and below diversion structures. However, streams with a slope less than 1.5% had significantly lower depths, areas, and capacities downstream from diversions; a response to the flow alterations. As the Big Horn River is a low gradient stream below Wedding of the Waters, the changes observed below Boysen Dam are not unexpected.

Since the completion of Boysen Dam in 1952, the Big Horn River has been adjusting its channel morphology in order to reach a new state of quasi-equilibrium. While channel sinuosity has remained almost constant, channel width and AAC have decreased substantially. Accompanying these changes, channel bed elevation has likely lowered in response to flow concentration in the narrowed channel. In turn, degradation of tributaries has likely occurred, increasing the net amount of suspended sediment in the river system. An indicator of this process is the presence of head-cuts on tributaries, encroachment of the channel, and the stabilization of streambanks by woody riparian species. Similar results were reported by Harris and Fox (1987) on nine streams in the Sierra Nevada region of California. All of these streams studied were 1200 to 3000 m above sea level, small to moderate in size, on alluvial fans, and had at least one hydroelectric diversion.

RIPARIAN MOSAIC

Changes in the riparian mosaics on the Big Horn River can likely be attributed to the operation of Boysen Dam, but other contributing factors are urban development and agricultural expansion. Decreases in the amount of riparian herbaceous vegetation can be linked to increases in agricultural lands and the encroachment of woody species. This is similar to the findings of Snyder and Miller (1991); they found encroachment by salt tamarisk and agriculture associated with a narrowing, deepening channel along the Arkansas River in Colorado.

Vegetation encroachment and the modified flow regime on the Big Horn River may also explain the decrease in non-vegetated areas on islands and the river bank. The reduction in peak flows reduces the river's capability to scour sediment bars and remove pioneering vegetation. Similar findings were observed by Miller et al. (1995) while investigating the effects of dams on the North Platte River in Wyoming.

Cottonwood is a pioneer species and requires recently disturbed areas with a high water table for regeneration (Akashi, 1988). This species produces a large number of seeds, which are viable for only a few weeks each year, corresponding with the natural spring runoff. This timing allows seeds to be transported and deposited on newly formed bars. Once deposited, the seeds develop roots rapidly trying to keep pace with the declining river stage and water table.

River regulation has likely affected cottonwood reproduction sucess along the Big Horn River. Large destructive floods have been eliminated, thus slowing the rate of channel migration and limiting the development of barren stream banks necessary for cottonwood regeneration. Other factors may also play a role. The seedlings must be located a sufficient distance from the active channel to avoid ice damage in the winter and flooding during runoff, but close enough so river regulation does not cause water levels to recede faster than the roots can grow (Rood and Mahoney, 1990). As cottonwoods become isolated from the active river channel, fewer seeds reach the river to be dispersed. Thus, cottonwood seedling establishment is reduced (Rood and Mahoney, 1990; Stromberg, 1993).

Russian olive and tamarisk appear to be invading along the Big Horn River. Akashi (1988) observed increases in five-stamen tamarisk and decreases in plains cottonwood immediately upstream from Yellowtail Reservoir, and my findings are similar. Currently, tamarisk and russian olive are the predominate stream-side vegetation. Both species are capable of out competing native plants (i.e., cottonwoods and willows (*Salix* spp.)) (Snyder and Miller, 1992; Shafroth et al., 1995) and do not follow the same establishment patterns as cottonwood. Increases in these two invader species are likely along the edges of the river and cultivated fields, within the riparian herbaceous community, and the understory of cottonwood stands. Similar findings have been observed by Stromberg (1993) in the southwestern United States and by Snyder and Miller (1991) along the Arkansas River in Colorado.

Russian olives propagate by releasing a seed that is transported by animals. Once the seed is deposited, it requires a ripening period before germination. This feature allows seeds to wait until optimum conditions are attained before beginning to grow. Thus, a cohort of seeds may germinate at different times of the growing season. Young seedlings are shade tolerant and thrive under a variety of soil and moisture conditions (Shafroth et al., 1995).

Tamarisk, once established, can rapidly become abundant. Seedlings use water in the amount it is provided and can withstand saline conditions. Tamarisk also release a large amount of salt through their leaves which produces saline soil conditions inhibiting growth of other species. Invasion potential is increased by physiological adaptations and wind dispersion (Griffin et al., 1989; Stromberg, 1993). Tamarisk does not appear to be advancing up the river past the town of Thermopolis. In fact, observations made in the summer of 1995 show that tamarisk is at its upper range of climatic tolerance. Immediately below the Thermopolis Hot Springs, which has warmer winter water temperatures, there was a stand of tamarisk, but the next stands were not observed again until further downstream at a lower elevation. Snyder and Miller (1991) found that tamarisk are not winter hardy and climate is the primary factor limiting their distribution. This appears to be the case along the Big Horn River.

CONCLUSION

Channel morphology of the Big Horn River appears to be moving toward a new quasi-equilibrium. Sinuosity has remained stable, and channel width and AAC have begun to stabilize. Therefore, future researchers will likely observe a similar channel pattern as found in 1989, provided operation of Boysen Dam remains constant. However, the future riparian mosaic will most likely be absent of cottonwood stands, with increases in russian olive and salt tamarisks. With limited bar areas, reduced channel migration and a regulated flow regime, it is doubtful that new cottonwood recruitment will occur to replace the mature stands now present.

ACKNOWLEDGMENTS

The authors thank the U.S. Bureau of Reclamation and the Wyoming Game and Fish Department for providing funding for this project.

REFERENCES

Akashi, Y. 1988. Riparian vegetation dynamics along the Big Horn River, Wyoming. M.S. thesis, University of Wyoming, Laramie. 245 pp.

Auble, G.T., Friedman, J.M., and Scott, M.L. 1994, 'Relating riparian vegetation to present and future streamflows', *Ecological Applications*, 4:544-554.

Griffin, G.F., Stafford Smith, D.M., Morton, S.R., Allan, G.E., Masters, K.A. 1989, 'Status and implications of the invasion of Tamarisk (*Tamarix aphylla*) on the Finke River, Northern Territory, Australia', *Journal of Environmental Management*, 29:297-315.

Harris R.R. and Fox, C.A. 1987, 'Impacts of hydroelectric development on riparian vegetation in the Sierra Nevada region, California, USA', *Environmental Management*, 11:519-527.

Miller, J.R., Schultz, T.T., Hobbs, N.T., Wilson, K.R., Schrupp, D.L., and Baker, W.L. 1995, 'Changes in the landscape structure of a southeastern Wyoming riparian zone following shifts in stream dynamics', *Biological Conservation*, 72, 371-379.

Mizell, S.A., and Skinner, Q.D. 1986. 'Hydrologic impacts in riparian zones' in *Proceedings, Wyoming Water 1986 and Streamside Zone Conference*. Casper, Wyoming. pp. 59-62.

Rood, S.B., and Mahoney, J.M. 1990, 'Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation', *Environmental Management*, 14:451-464.

Rosgen, D.L. 1996, 'Classification of natural rivers', *Partners Conservation Technology Information Center*, 14:10.

Shafroth, P.B., Auble, G.T., and Scott, M.L. 1995, 'Germination and establishment of the native plains cottonwood (*Populus deltoides* Marshall subsp. *monilifera*) and the exotic russian-olive (*Elaeagnus angustifolia* L.)', *Conservation Biology*, 9:1169-1175.

Simons, D.B. and F. Senturk. 1977. Sediment transport technology. Water Resources Publications, Ft. Collins, CO. pp: 24 - 29.

Snyder, W.D., and Miller, G.C. 1991, 'Changes in Plains cottonwoods along the Arkansas and South Platte Rivers - eastern Colorado', *Prairie Naturalist*, 23:165-176.

Snyder, W.D., and Miller, G.C. 1992, 'Changes in riparian vegetation along the Colorado River and Rio Grande, Colorado', *Great Basin Naturalist*, 52:357-363.

Stromberg, J.C. 1993, 'Fremont cottonwood-Goodding willow riparian forests: A review of their ecology, threats, and recovery potential', *Arizona-Nevada Academy of Science*, 26:97-110.

U.S. Department of the Interior Bureau of Reclamation. 1983. Boysen Dam inundation map, Casper, WY.

Wesche, T.A. 1991. Flushing flow requirements of mountain stream channels. Wyoming Water Resources Center, report number 91-18. 195 pp.

Wiley, D.E. 1995. Development and evaluation of flushing flow recommendations for the Big Horn River. M.S. thesis, University of Wyoming, Laramie. 103 pp.

USE OF RADIOTELEMETRY TO DEFINE WINTER HABITAT USE BY SMALL RAINBOW TROUT IN THE BIG HORN RIVER, WYOMING.

Darin G. Simpkins, Wayne A. Hubert, and Thomas A. Wesche[1]

INTRODUCTION

Coldwater rivers downstream from reservoirs in Wyoming provide sport fisheries of state-wide and national significance (Braaten and Annear 1994). These regulated rivers, often referred to as tailwaters, support year-around trout fisheries. Recently, it has become apparent that the overwinter survival of small (20- to 25-cm TL) rainbow trout (*Oncorhynchus mykiss*) in these tailwaters has declined. Such is the case with the Big Horn River, downstream from Boysen Dam (Yekel 1990; 1994). However, research on the overwinter survival, movement, and habitat use of rainbow trout in tailwaters is limited. Only two studies on the winter habitat of rainbow trout in tailwaters have been published, both were on the Henrys Fork of the Snake River below Palasides Dam in Idaho (i.e. Griffith and Smith 1995; Smith and Griffith 1994).

The goal of this study was to identify winter habitat features that may limit the overwinter survival of naturally spawned (wild) and recently stocked (hatchery) rainbow trout (20- to 25-cm TL) in the Big Horn River downstream from Boysen Dam. Our objectives were to: (1) describe physical habitat, including the magnitude and variation in flow, air and water temperature, and ice formation during the 1995-96 winter (November through March); (2) describe the distribution and movements of small rainbow trout relative to changing physical habitat characteristics during the winter; and (3) assess the influence of ice formation on the habitat use and movements of small rainbow trout.

STUDY AREA

The study section encompassed 12 km of the Big Horn River, from Wedding of the Waters (15 km downstream from Boysen Dam) to the Hot Springs State Park in Thermopolis, Wyoming. Discharge through the section comes from deep-water releases from Boysen Dam; consequently, winter water temperatures are warm enough to prevent surface ice formation throughout the section. Over the last decade, large fluctuations in wild rainbow trout and brown trout abundances have been documented by the Wyoming Game and Fish Department (Wiley 1995). Population studies have indicated poor survival of stocked trout with large fluctuations in abundance (Yekel 1990; 1994).

[1] U.S. Geological Survey; Wyoming Cooperative Fish and Wildlife Research Unit; and Wyoming Water Resources Center and Department of Rangeland Ecology and Watershed Management, UW, Laramie, WY 82071, respectively.

METHODS

CHANGES IN PHYSICAL HABITAT

Discharge was assessed during the 1995-96 winter to compare to previous winters. Discharge data were obtained from the U.S. Geological Survey gaging station just below Boysen Dam from the Wyoming Water Resource Center's Data Systems.

Air temperatures were recorded in Thermopolis by the Western Regional Climate Center and obtained from the Wyoming Water Resource Center's data base. Temperatures during the 1995-96 winter were compared to winters from 1980 to 1995.

Water temperatures were monitored near the stream bottom at six sites throughout the study reach using Optic Stowaway Temperature Loggers (Onset Computer Corporation model WTA32-39+75; range -39 to 75° C). Daily minimum and maximum temperatures were computed for each site. The occurrence of ice (frazil, anchor, and surface; Calkins 1993) was visually monitored on a daily basis, and the water and air temperatures associated with the occurrence of ice were determined.

HABITAT AVAILABILITY

Habitat availability was defined as the relative amount (percent) of several microhabitat features (habitat type, depth, mean column velocity, nose velocity, instream cover, dominant substrate, and instream cover; Bisson et al. 1981; Gordon et al. 1992; Helm et al. 1985) in the study area. Measurements were made across 30 randomly selected transects in October 1995 and February 1996. A cable with marked intervals was stretched across the river, perpendicular to streamflow, and sampling was conducted at 30 equally spaced points across each transect. Additionally, measurements were made where the water met the river bank. Water surface elevation (stage) was visually monitored using staff gauges (Gordon et al. 1992) at 2-week intervals.

HABITAT USE

The distribution, movement, and habitat use of 20- to 25-cm wild and hatchery rainbow trout were monitored utilizing radiotelemetry. This length range of fish was used because it was the smallest length fish that could be implanted with 180-day radio-transmitters (Advanced Telemetry Systems model 357; 48200-48.980 Mhz; pulse width 20-22 ms) and was the length of stocked fish at the beginning of winter. The locations of radio-tagged fish were determined at 2-3 day intervals during daylight hours using a scanning receiver (Advanced Telemetry Systems RSA2000) and a bi-directional loop antenna (Advanced Telemetry Systems). The locations were recorded in the field on U.S. Geological Survey 7½ minute topographic maps using landmarks to identify specific locations.

Habitat use at fish locations was determined by sampling several microhabitat characteristics within an area of probable occurrence (a circle with a 2-m radius) surrounding the identified location. Habitat type, substrate, cover, maximum depth, maximum water velocity, and minimum nose velocity were sampled within the area of probable occurrence. Maximum mean column velocity was the swiftest velocity that could be found at 0.6 of the water's depth within the area of probable occurrence. Minimum nose velocity was the slowest velocity found near the stream bed within the area of probable occurrence.

RESULTS AND DISCUSSION

CONDITIONS DURING THE 1995-96 WINTER

The flow conditions during the 1995-96 winter study period were lower than the previous 42-year average, but several of the last 15 winters have had average discharges less than the 1995-96 winter. Flows were relatively constant during the 1995-96 winter study period, only changing twice. Changes were ≤ 25% if the previous flow, and each change was spread over a 3-day interval. Similar changes have occurred in other years.

Daily air temperatures during the study were generally warmer than the average winter, but they were occasionally colder than the previous 15-year average. Frazil ice was observed on several occasions when night-time air temperatures were less than -24°C (-12°F). Frazil-ice occurrences are frequent winter events in the Big Horn River.

HABITAT AVAILABILITY

Habitat features changed during the winter due to the decomposition of rooted aquatic vegetation. As aquatic vegetation declined, water surface elevations decreased (Griffith and Smith 1995), water flows through side channels declined, and the total amount of stream-margin habitat was reduced (Holden 1979; Simons 1979; Helm et al. 1985). The loss of aquatic vegetation caused velocities near the stream bed surface to increase, thereby moving sand and gravel particles and increasing the amount of cobble substrates (Hynes 1976). The loss of aquatic vegetation, as well as side-channel and stream-margin habitat (Smith and Griffith 1994; Griffith and Smith 1995), in conjunction with changes in substrate composition, affected habitat use of small rainbow trout during the winter.

HABITAT USE

The distribution of small rainbow trout in the study section was probably influenced by the area in which they originated. Wild fish were predominately found in the upper portion of the study section near spawning habitat identified by Wiley (1995). Hatchery fish were found near the stocking site at the Hot Springs State Park. The only major movements of radio-tagged fish were observed during and several days after the occurrence of frazil ice, but most of the fish remained near the areas in which they originated.

Throughout the winter both wild and hatchery fish were generally found in main channel pools at sites with cover reducing current velocities near the stream bed, but with swifter water velocities in close proximity. These locations provided refuges from the current and delivery of drifting aquatic invertebrates. Fish were generally associated with cover formed by aquatic vegetation early in the winter, but shifted to cobble and boulder cover in deeper water as aquatic vegetation decomposed and winter progressed. Episodes of frazil ice formation were associated with fish movements from these feeding locations in channels to refuges at the bottom of pools or under shelf ice in shallow water near shore. Such movements probably enhanced stress and depletion of stored lipid reserves (see Cunjak and Power 1987; Riehle and Griffith 1993) which probably contributes to overwinter mortality (see Johnson and Evans 1996). Direct mortality of some fish was associated with the occurrence of frazil ice.

REFERENCES

Bisson, P. A., J. L. Nielson, R. A. Palmason, and L. E. Grove. 1981. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. Pages 62-73 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat: inventory information. Symposium of the Western Division of the American Fisheries Society, Portland, Oregon.

Braaten, P. J., and T. C. Annear. 1994. Green River instream flow investigations, Sweetwater County. Wyoming Game and Fish Department Administrative Report IF-4494-07-9301, Cheyenne.

Calkins, D. J. 1993. Physical effects of river ice. Pages 4-6 *in* T. D. Prowse and N. C.

Gridley, editors. Environmental aspects of river ice. National Hydrology Research Institute Science Report 5. Saskatoon, Saskatchewan, Canada.

Cunjak, R. A., and G. Power. 1987. The feeding and energetics of stream-resident trout in winter. *Journal of Fish Biology* 31:493-511.

Gordon, N. D., T. A. McMahon, and B. L. Finlayson. 1992. Stream hydrology, an introduction for ecologists. John Wiley and Sons, Chichester, England.

Griffith, J. S., and R. W. Smith. 1995. Failure of submersed macrophytes to provide cover for rainbow trout throughout their first winter in the Henrys Fork of the Snake River, Idaho. *North American Journal of Fisheries Management* 15:42-48.

Helm, W., T. P. Brouha, M. Aceituno, C. Armour, P. Bisson, J. Hall, G. Holton, and M. Shaw. 1985. Glossary of stream habitat terms. Pages 1-34 *in* W. T. Helm, editor. Aquatic habitat inventory, glossary and standard methods. Habitat Inventory Committee, Western Division of the American Fisheries Society.

Holden, P. B. 1979. Ecology of riverine fishes in regulated streams with emphasis on the Colorado River. Pages 57-74 *in* J. V. Ward and J. A. Stanford, editors. The ecology of regulated streams. Plenum Press, New York.

Hynes, H. B. 1976. The ecology of running waters. University of Toronto Press, Toronto, Ontario.

Johnson, T. B., and D. O. Evans. 1996. Temperature constraints on the overwinter survival of age-0 white perch. *Transactions of the American Fisheries Society* 125:466-471.

Riehle, M. D., and J. S. Griffith. 1993. Changes in the habitat utilization and feedingchronology of juvenile rainbow trout (*Oncorhynchus mykiss*) in fall and onset of winter in Silver Creek, Idaho. *Canadian Journal of Fisheries and Aquatic Sciences* 50:2119-2128.

Simons, D. B. 1979. Effects of stream regulation on channel morphology. Pages 95-111

in J. V. Ward and J. A. Stanford, editors. The ecology of regulated streams. Plenum Press, New York.

Smith, R. W., and J. S. Griffith. 1994. Survival of rainbow trout during their first winter in the Henrys Fork of the Snake River, Idaho. *Transactions of the American Fisheries Society* 123:747-756.

Wiley, D. 1995. Development and evaluation of flushing flow recommendations for the Big Horn River. Master's thesis. Department of Range Management and Wyoming Water Resources Center, University of Wyoming, Laramie, Wyoming.

Yekel, S. 1990. Upper Big Horn River creel census, a comparative analysis, 1982-1987. Wyoming Game and Fish Department Administrative Report 22-005-09, Cheyenne.

Yekel, S. 1994. Upper Big Horn River (22UB) sub-area management plan. Wyoming Game and Fish Department, Cheyenne.

COMPARISON OF BIRD USE OF ADJACENT WETLANDS IN SOUTHWESTERN WYOMING

Brian J. Heath and S. H. Anderson[1]

ABSTRACT

We investigated bird use of adjacent riparian habitats at the Bear River State Park and old ice ponds in southwestern Wyoming. We collected habitat data to show how common species utilize the two areas. Our results show that common species on both sites use various combinations of vegetative components and emphasizes the importance of maintaining woody vegetation on these sites. Because the vegetative composition on our study sites is similar to that along other major rivers in Wyoming, our results should be applicable to other riparian communities at similar elevations.

INTRODUCTION

Riparian ecosystems in the inter-mountain west have a wide variety of plant communities because of elevation, geomorphic, and climatic influences (Brinson et al. 1981, Johnson and Lowe 1985). Nongame birds constitute a major component of riparian wildlife communities (Brinson et al. 1981) and nationwide more than 250 species of birds use riparian habitats (Szaro 1980, Brinson et al. 1981). Factors that influence use of riparian habitat by passerine birds include quality of adjacent habitats, structural diversity, species composition of vegetation, and location of the habitat (Stevens et al. 1977). Stauffer and Best (1980) concluded that vertical stratification of vegetation, sapling or tree size, plant species richness, and the presence of special habitat features were the habitat features most frequently related to abundance of bird species in riparian habitat. Riparian communities along high-order, low-elevation, riverine cover types probably have the greatest values for wildlife in the inter-mountain and southwestern United States (Schroeder and Allen 1992).

The riparian habitat along the Bear River, a high order stream in southwestern Wyoming, is extremely important wildlife habitat because of the physical and vegetational diversity it provides to this arid environment. However, very little information exists on bird communities in this area. Therefore, we investigated passerine bird use of riparian habitats along the Bear River during 1991 and 1992. Our objectives were to 1) compare bird use of two adjacent riparian habitats, and 2) determine habitat variables that influenced bird use.

STUDY AREA

Bear River State Park (BRSP) is a 113-ha parcel of land adjacent to Evanston, Wyoming and was incorporated into the State Park System in 1982. The Bear River passes through the park and has created both riparian and palustrine wetland habitats within the park. Riparian habitats are dominated by a mixture of trees, shrubs, and herbaceous vegetation. Dominate woody species are narrow-leaf cottonwood (Populus angustifolia) and willows (Salix spp.) that occur in patches throughout the flood plain. Herbaceous vegetation consists primarily of native grasses and forbs. Small palustrine wetlands, created by beaver (Castor canadensis) dams, are found along river channels and irrigation canals. Emergent wetland vegetation primarily consists of cattails (Typha spp.), bulrushes (Scripus spp.), and rushes (Juncus spp.)

The ice pond (IP) site is located within the city of Evanston adjacent to BRSP. This site was historically used to produce ice for rail cars until the 1950's. However, the area has not been used or maintained since that time and woody vegetation has established within the ponds. The woody vegetation occurs in patches throughout the area and dominate species are narrow-leaf cottonwood and willows. A mixture of perennial grasses and annual forbs compose the herbaceous vegetation at this site.

METHODS

Line transects were established on each of the study sites and used for bird surveys and habitat sampling. After randomly selecting a starting point, transects were systematically placed throughout the study area. Transects were 250 m long and 9 and 8 transects were established at the BRSP and IP study sites, respectively.

Birds were surveyed along line transects (Hanowski et al. 1990) from early to mid-May through mid-July in 1990 and 1991. Surveys were conducted from 0.5 hr before sunrise to 3.5 hr after sunrise on days with little wind (<10 km/hr) and no precipitation. Transects were walked at a rate of 0.5 km/hr. Five-min stops were made at 50 m intervals to allow birds to call and emerge from concealment. Birds flying above the transect were not recorded.

At each bird sighting, flagging tape was tied to the vegetation and marked with information that identified the exact location for subsequent habitat sampling. Flushing of birds was avoided and, if flushed, their location noted so as not to duplicate counts. Each site had 5 surveys conducted in 1990 and 7 in 1991. Density, represented as number per hectare, was calculated for each species observed during surveys.

Habitat variables were measured or evaluated at each bird sighting and at random available points along each transect. The location of a random available point was determined by using a random numbers table to determine distance along (between 0-250), distance from (between 0-11.5), and side (either left or right) of the transect.

[1] Wyoming Cooperative Fish and Wildlife Research Unit, UW, Laramie, WY 82071

Habitat sampling followed the point-center quarter method (James and Shugart 1970) and incorporated the non-forest (< 25% cover by trees) modifications suggested by Noon (1981). This technique incorporates line-intercept and point-quarter methods to measure non-forested habitats in avian habitat studies. The methods were further modified by replacing line-intercept measurements with a visual assessment of life forms or habitat features in 10 x 25 m sections centered at the sampling point. The percent of each section covered by the life forms or habitat features (Table 1) was visually estimated. The number of life forms and habitat features per 10 x 25 m area was calculated to indicate life form richness. We measured herbaceous vegetation coverage at each sampling point from 4, $0.1m^2$ Daubenmire (1959) quadrat readings taken from the cardinal directions and a meter from the point.

Quantitative measurements at each sampling point included water depth, height of vegetative ground cover, and distance to nearest cover, open water, and disturbance. A modified cover board (Nudds 1977) replaced the graduated 1 cm rod to measure vertical vegetation density. The number of squares that were >50% visually obstructed by vegetation were counted for the 0-.3, .3-1, 1-2 m intervals above the ground and estimated for the 2-9 m interval from each cardinal direction. The height and distance from the sampling point to the nearest shrub, sapling, and tree in each quarter were measured. Averages were calculated from each quarter measurement for each of the 4 coverboard intervals; height and distance to shrub, sapling, and tree; and herbaceous vegetation coverage.

Discriminant function analysis was used to test the null hypotheses of no difference among bird species and between bird use and random sites for each study site (Klecka 1980). The number of sites measured for each bird or group of birds was often less than the number of random points measured. To compensate for these sample size differences during discriminant analyses, a sub-sample of the total random sites was selected and discriminated against use sites for each bird or bird group (Anderson and Shugart 1974). Pearson's correlation coefficients were obtained for all variables, and only 1 of a pair of highly correlated variables (r>.50) was included in discriminant analyses.

Classification results were used to estimate group separation and identify patterns of misclassification. Misclassification patterns aided in interpreting discriminant results. The variable Tau, the reduction in error of using discriminant analysis for classification rather than classifying by random chance alone, was calculated. All analyses were conducted using SPSS/PC+4.0 (Norusis/SPSS Inc., 1990).

RESULTS

We observed 199 and 290 individual birds representing 39 species during surveys in 1990 and 1991 at BRSP. The most common birds observed were yellow warblers, American robins, red-winged blackbirds, and northern orioles (Table 2). The difference in the number of individuals between the years can be attributed to the extra counts that occurred in 1991.

We detected 225 and 156 birds representing 21 species during surveys in 1990 and 1991 at IP. During both years the most common birds detected were house finches, American robins, yellow warblers, red-winged blackbirds, and American goldfinches. The decrease in the number of individuals detected in 1991 is a result of 2 less transects and the removal of shrubs by city personnel around the pond perimeter. This change is likely responsible for the decrease by approximately one-third of the house finches observed between 1990 and 1991.

BEAR RIVER STATE PARK

Discriminant analysis indicated that 3 functions were significant in discriminating bird species (function 1 x^2=256, df=68, p<0.0001; function 2 x^2=116, df=48, p<0.0001; function 3 x^2=55, df=30, p=0.003). The structure coefficients indicated that distance to the nearest sapling defined function 1, function 2 was interpreted as vertical cover less than 2 m in height, and function 3 as diversity and amount of herbaceous ground cover.

American robins used habitats that were close to saplings with low vertical cover and moderate diversity of ground cover at BRSP. Yellow warblers were found in areas that were close to saplings and had moderate vertical cover with highly diverse ground cover. Red-winged blackbirds used areas that were farther from saplings than areas used by other bird species, and had moderate vertical cover and plant diversity. Northern orioles used areas that were close to saplings with high vertical cover and very little diversity of ground cover.

Classification results indicated that 66% of the cases were correctly classified and reduction in error of using discriminant analysis for classification rather than by random chance alone (Tau) was calculated at 53%. The majority of misclassifications were for northern orioles, which in several cases were classified as yellow warblers.

There was discriminating ability between American robin, yellow warbler, northern oriole, and red-winged blackbird used and random sites (P<0.0001). American robin used areas that had more life forms (4 to 3) and percent tree cover in the 10 x 25 m area around the sampling point (5 to 1%) than what was available. They also used sites closer to saplings (22 vs. 76 m) and had higher amounts of vertical cover

Table 1. Life forms and habitat features visually estimated in 10 x 25 m transect sections centered at each sampling site.

LIFE FORM	HABITAT FEATURES
Grasses	Narrow -leafed herbaceous plants
Forbs	Broad-leafed herbaceous plants
Emergents	Cattail, bulrush, and rush spp.
Woody ground cover	Woody vegetation <1 m tall
Shrubs	Woody vegetation >1 m tall and <3 cm dbh
Saplings	Woody vegetation >1 m tall and 3 cm $\leq$ dbh $\geq$8 cm
Trees	Woody vegetation $\geq$ 8 cm dbh
Litter	Dead plant material excluding downed logs
Water	
Bare ground	
Rocks	
Downed logs	Woody vegetation $\geq$ 8 cm dbh and $\geq$ 1.5 m long

Table 2. List of common and scientific names of species observed during bird surveys. List includes species observed in both years on all study sites.

COMMON NAME	SCIENTIFIC NAME	BRSP #/HA	IP #/HA
Black-crowned Night Heron	Nycticorax nycticorax	.02	
Mallard	Anas platyrhynchos	.03	.03
Blue-winged Teal	Anas discors	.02	
Cinnamon Teal	Anas cyanoptera	.28	
Ring-neck Duck	Aythya collaris	.16	
American Wigeon	Anas americanus	.02	
Canvasback	Aythya valisineria	.02	
Lesser Scaup	Aythya affinis	.04	
Sora	Porzana carolina	.04	
American Coot	Fulica americana	.04	
Killdeer	Charadrius vociferus	.06	.28
Common Snipe	Gallinago gallinago	.07	.03
Spotted Sandpiper	Actitis macularia	.24	.12
Mourning Dove	Zenidia macroura	.10	
Broad-tailed Hummingbird	Selasphorus platycercus	.02	.16
Northern Flicker	Colaptes auratus	.03	
Hairy Woodpecker	Picoides villosus	.02	
N. Rough-winged Swallow	Stelgidopteryx serripennis	.12	
American Crow	Corvus brachyrhynchos	.04	
Black-capped Chickadee	Parus atricapillus	.09	.04
House Wren	Troglodytes aedon	.27	
American Robin	Turdus migratorius	1.3	.99

Table 2. Continued

COMMON NAME	SCIENTIFIC NAME		BRSP #/HA	IP #/HA
Cedar Waxwing	Bombycilla cedrorum		.06	.03
European Starling	Sturnus vulgaris		.02	.09
Yellow Warbler	Dendroica petechia		1.7	.95
Western Meadowlark	Sturnella neglecta	.07	.06	
Yellow-headed Blackbird	Xanthocephalus xanthocephalus		.04	
Red-winged Blackbird	Agelaius phoeniceus		.67	.73
Northern Oriole	Icterus galbula		.62	.13
Brewer's Blackbird	Euphagus cyanocephalus		.07	.02
Common Grackle	Quiscalus quiscalus		.36	.19
Brown-headed Cowbird	Molothrus ater		.03	
Black-headed Grosbeak	Pheucticus melanocephalus		.06	
House Finch	Carpodacus mexicanus		.15	1.2
American Goldfinch	Carduelis tristis		.15	.47
Chipping Sparrow	Spizella passerina	.03		
Song Sparrow	Melospiza melodia		.13	.07
Ruby-crowned Kinglet	Regulus calendula		.04	
White-crowned Sparrow	Zonotrichia leucophrys		.03	.02
Wilson's Warbler	Wilsonia pusilla		.04	
Eastern Kingbird	Tyrannus tyrannus		.03	

between 1-2 m high (11 vs 5). The discriminant function classified 74% of the cases correctly and Tau was calculated to be 49%. Habitat use by yellow warblers was determined by the amount of vertical cover between 1-2 m high (18-4) and the percent tree cover in the 10 x 25 m area around the sampling site (8 vs. 1%). The discriminant function classified 87% of the cases correctly and predicted yellow warbler habitat use 87% better than by random chance. Variables important in discriminating between northern oriole used and available sites were vertical cover between 1-2 m high, shrub height (17 vs. 4m), and forb (19 vs. 32%) and shrub cover (24 vs. 13%). The discriminant function correctly classified 86% of the cases as northern oriole used or random sites. The model predicted northern oriole habitat use 73% better than by random chance alone. Discriminant analysis indicated that red-winged blackbirds used sites with moderate amounts of vertical cover between 1-2 m high (10 vs. 3) that were located around water (39 vs. 11%). Forb cover at red-winged blackbird use-sites was less than available (20 vs. 32%). The discriminant function correctly classified 80% of the cases and Tau was calculated to be 61%.

ICE PONDS

Discrimination of habitat use by individual species indicated that three functions were significant in separating the five bird species (function 1 x^2=160, df=28, p<0.0001; function 2 x^2=61, df=18, p<0.0001; function 3 x^2=23, df=10, p=0.01). These 3 functions were defined through structure coefficients as (1) vertical cover between 1-2 m tall, (2) vertical cover between 2-9 m high and height of herbaceous ground cover, and (3) percent grass coverage.

American robins used areas that provided vertical cover over 2 m high with moderate grass cover and few shrubs. Yellow warblers used areas with trees and saplings that provided the highest amount of vertical cover at the IP site. The combination of trees and saplings with grass ground cover separated yellow warbler use sites. Red-winged blackbirds were found in shrub-dominated areas that provided the most vertical cover up to 2 m high and grass coverage was moderate. House finch habitat had very little vertical cover over 1 m high and high grass coverage. American goldfinch were found in areas characterized by trees with tall herbaceous ground cover other than grass. Classification results indicated that only 46% of the cases were correctly classified and Tau was calculated at 31%. The majority of misclassifica-tions were American goldfinches, which were misclassified as American robins.

There was discriminating ability between American robin, yellow warbler, red-winged blackbird, house finch, and American goldfinch used and random sites (*P*<0.0001). American robins used sites that had taller trees (8 vs. 7 m) and more vertical cover over 1 m high (12 vs. 6). The discriminant function correctly classified 74% of the cases and Tau was calculated to be 48%. Yellow warblers used sites with more vertical cover between 1-2 m and 2-9 m high (21 vs. 5) than was available in the general habitat at the IP site. The discriminant function correctly classified 86% of the cases and predicted habitat use 73% better than by random chance alone.

The discrimination of red-winged blackbird used sites from available locations was based on vertical cover between 1-2 m high (20 vs. 4) and height of herbaceous ground cover (3 vs. 0.6 m). The discriminant function correctly classified 94% of the cases as red-winged blackbird used or random sites and Tau was calculated to be 89%. House finches used sites that were characterized by taller herbaceous ground cover (1.4 vs. 0.5 m). Cover of woody vegetation (14 vs. 0.8%), distance to the nearest shrub (0.6 vs. 6 m), and forb cover (32 vs. 16%) contributed to distinguishing between house finch used sites and random locations. The discriminant function correctly classified 85% of the cases and predicted habitat use by house finch 71% better than random chance.

American goldfinch used sites could be distinguished from available locations based on the amount of vertical cover between 1-2 m high (12 vs. 5), rush cover (2 vs. 0.5%), and height of herbaceous ground cover (0.3 vs. 0.7 m). The discriminant function correctly classified 82% of the cases as American goldfinch use sites or random and Tau was calculated to be 63%.

DISCUSSION

The abundance of birds on the study areas indicate the importance of the Bear River to wildlife in southwestern Wyoming. Structural and vegetative diversity in riparian habitat along the river provide unique habitats for a variety of birds. Birds observed at BRSP and the IP study sites were similar and some species (e.g. American robin and red-winged blackbird) occurred in similar abundance. There were 19 species observed on both study sites and most of these species were found during each survey. More species were observed at BRSP than the IP, probably because of habitat diversity, study area size, and location.

BEAR RIVER STATE PARK

Riparian habitat features that influenced use among species were distance to saplings, the amount of vertical cover available less than 2 m high, and the diversity and height of the herbaceous understory. Although species were found together, each used different combinations of riparian habitat features. These differences indicate how birds partitioned the habitat and coexisted on the study area.

The amount of vertical cover between 1-2 m high was important in discriminating American robin, yellow warbler, northern oriole, and red-winged blackbird used sites from general riparian locations. Patches of shrubs > 3 m tall should be preserved to maintain available northern oriole habitat. Red-winged blackbirds used sites were separated from available locations by the presence of water in association with vertical cover. Development of water impoundment's in areas with shrubs would provide red-winged blackbirds with available habitat on the study site.

There were very few areas with narrow-leaf cottonwood trees along the west side of the park, however, the presence of trees was important in separating American robin and yellow warbler used sites from the general riparian habitat. Future development plans should not remove trees ($\geq$ 8 cm dbh) because it will reduce available habitat for American robins and yellow warblers.

ICE PONDS

American robins, yellow warblers, red-winged blackbirds, and American goldfinch used riparian sites with shrubs that provided more vertical cover between 1-2 m than was available in the general study area. The areas that contained saplings and trees in addition to shrubs provided American robin and yellow warbler habitat.

House finch used sites were described by high coverage of woody vegetation. They used areas around the pond perimeter where dead shrubs and forbs were located. American goldfinch used riparian sites with shrubs where the ground cover contained higher coverage of rush. The removal or alteration of areas with shrubs and saplings will adversely affect the abundance and habitat available to the common species at this site.

Although the BRSP and IP sites were adjacent to each other there are differences in bird species and habitat use. Our results provide important insight into the need for site specific data when placing any form of habitat alteration. Minor differences in habitat as well as the birds species composite can result in habitat use differences. Maintaining the current bird community is dependent on cottonwood germination, therefore without the annual deposition of soil, the diversity in vertical structure will be reduced and over time the bird community may be altered.

ACKNOWLEDGMENTS

This project was supported by the Wyoming Game and Fish Department and the Wyoming Cooperative Fish and Wildlife Research Unit. We appreciate the assistance of the many people in Evanston that assisted. Linda Ohler helped with the manuscript preparation.

REFERENCES

Anderson, S. H., and H. H. Shugart, Jr. 1974. Habitat selection of breeding birds in an east Tennessee deciduous forest. *Ecology* 55:828-837.

Brinson, M. M., B. L. Swift, R. C. Plantico, and J. S. Barclay. 1981. Riparian Ecosystems: their ecology and status. *U.S. Fish and Wildlife Serv. FWS/OBS-81/17.* 151pp.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. *Northwest Sci.* 33:43-64.

Hanowski, J. M., G. J. Niemi, and J. G. Blake. 1990. Statistical perspectives and experimental design when counting birds on line transects. *Condor* 92:326-335.

James, F. C., and H. H. Shugart. 1970. A quantitative method of habitat description. *Audubon Field Notes* 24: 727-736.

Johnson, R. R., and C. W. Lowe. 1985. On the development of riparian ecology. Pages 112-116 in R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Folliott, and R.H. Hamre, technical coordinators. Riparian ecosystems and their management: reconciling conflicting uses. First N. Am. Riparian Conf.: 1985 U.S. For. Ser. Gen. Tech. Rep. RM-120.

Klecka, W. R. 1980. Discriminant Analysis. Sage Publishers, London. 71 p.

Noon, B. R. 1981. Techniques for sampling avian habitats. Pages 45-52 in D. E. Capan, ed. The use of multivariate statistics in studies of wildlife habitat: Proc. of a workshop. USDA For. Ser. Gen. Tech. Rep. RM-87. Ft. Collins, Co.

Norusis, M. J. 1990. SPSS/PC+ Statistical data analysis. SPSS Inc., Chicago, Il.

Nudds, T. D., 1977. Quantifying the vegetative structure of wildlife cover. *Wildl. Soc. Bull.* 5(3):113-117.

Schroeder, R. L., and A. W. Allen. 1992. Assessment of habitat of wildlife communities on the Snake River, Jackson, Wyoming. *U.S. Dept. Int., Fish & Wildl. Ser., Res.Pub.190.*

Stauffer, D. F., and L. B. Best. 1980. Habitat selection by birds of riparian communities: evaluating effects of habitat alterations. *J. Wildl. Manage.* 44(1)1-15.

Stevens, L. E., B. T. Brown, J. M. Simpson, and R. R. Johnson. 1977. The importance of riparian habitat to migrating birds. Pages 156-164 in R. R. Johnson and D. A. Jones, technical coordinators. Importance, preservation, and management of riparian habitat. *U. S. For. Ser. Gen. Tech. Rep. RM-43.*

Szaro, R. C. 1980. Factors influencing bird populations in southwestern riparian forests. Pages 403-418 in Management of western forests and grasslands for nongame birds. *U. S. For. Ser. Gen. Tech. Rep. INT-86.*

WATERBIRD USE, PRODUCTIVITY AND WATER LEVEL FLUCTUATION

Christopher Mason and Stanley Anderson[1]

ABSTRACT

We conducted a two year study on the Table Mountain Wildlife Habitat Management Unit in Goshen County Wyoming. The purpose of the study was to relate waterbird use and productivity to changes in water levels in the 12 water impoundments. We observed 59 waterbird species on the Unit. Breeding pairs of waterfowl were dabbling ducks and geese. Our results indicated that there were significant correlations between waterbird use and water level. Shore birds and dabbling duck use was negatively correlated with mean water depth and positively correlated with water level coefficients of variation. Other bird groups and their young were positively correlated with mean water depth and negatively correlated with water level coefficients of variation.

INTRODUCTION

Wetlands are some of the most productive ecosystems in the world and serve as critical habitat for a vast array of flora and fauna. In addition to providing wildlife habitat, wetlands possess a variety of functional values including desynchronization and storage of flood waters, aquifer recharge, and water quality maintenance (Mitsch and Gosselink 1986). Wetland resources are relatively scarce in arid western states such as Wyoming and, therefore, are particularly important resources. It is estimated that only 3.2% of the land surface in Wyoming can be classified as wetland habitat (Dahl 1990).

In the arid high plains created wetlands often provide areas where wildlife populations, particularly, waterbirds and shorebird can flourish. Wetlands with impoundments of varying size and shapes may provide different habitats managing the diversity of wildlife. We conducted a two year study of such a complex in southeastern Wyoming. Our objective was to determine waterbird use and productivity on impoundments on the Table Mountain Wildlife Habitat Management Unit and relate use and productivity to changes in water level.

STUDY AREA

All research for this investigation was conducted on the Table Mountain Wildlife Habitat Management Unit located in Goshen County, southeastern Wyoming (Figure 1). The total area of the Unit is 695 ha. with an elevation of approximately 1300 meters. The climate is semi-arid averaging 33.5 cm of precipitation annually. December, January, and February are the driest months with snow fall rarely exceeding 30 cm and snow cover short in duration. May and June are the wettest months with precipitation exceeding 5 cm per month in most years (National Oceanographic and Atmospheric Administration 1982). July temperatures may reach 37° C while January temperatures may be less than -23° C (United States Department of Agriculture 1971). The average growing season is about 123 days. High evaporation rates exist.

The Unit presently has a complex of 12 distinct wetlands or ponds (Figure 1). The primary water source for the Unit is Dry Creek. Dry Creek begins about 6.4 km south of the Unit with approximately 4 km of the creek being contained within the Unit. Dry Creek is fed mainly by irrigation runoff, but does receive some natural runoff. Flows of 3-4 c.f.s. occur during irrigation season, but diminish to about 1 c.f.s. during other months.

METHODS

Waterbird use was determined by making counts from vantage points around the perimeter of each pond. The vantage points were established such that all areas of the wetland could be visually observed using a 15 to 60 power zoom spotting scope (Uresk and Severson 1988). Surveys were conducted for a period of two hours after sunrise and for a period of two hours before sunset. Surveys lasted from 15 to 90 min depending on pond size and waterbird activity. Three to four ponds could be sampled during a morning or evening survey period. Each pond was surveyed twice weekly with one morning survey and one evening survey from 1 May to 30 August 1991 and 1992. During this period at least 24 surveys were conducted on each pond.

During each survey the total number of individuals of each species was counted. Observed individuals were identified to species and sex for sexually dimorphic species. Waterbird use on ponds was defined as "use days per hectare," where each individual waterbird observation was considered to be one use day and the total number of observations for each taxa during a given survey was divided by pond size to determine use days per hectare.

Brood use on each pond was considered to be a measure of waterbird productivity. Brood use was defined as "brood use days per ha" as described for waterbird use above. Because of the high frequency of visits, it was felt that nearly all broods would be encountered during brood surveys without attempting to flush broods from shorelines or vegetation (Rumble and Flake 1983).

Water gauges were established near the water control structures of each pond to monitor water level fluctuations. Gauges used were standard metal water gauges that allowed water levels to be recorded to the nearest 0.01 ft. Gauges were read on a weekly basis from May through August and monthly through the fall and winter. The coefficient of variation for water level recordings on individual

[1] Wyoming Cooperative Fish and Wildlife Research Unit, UW, Laramie, WY 82071

Table 1. Designated Waterbird Groups

COOTS AND GREBES	GULLS AND TERNS	CORMORANTS AND PELICANS
Pied-billed Grebe *(Podilymbus podiceps)* American Coot *(Fulica americana)*	California Gull *(Larus californicus)* Ring-billed Gull *(Larus delawarensis)* Franklin's Gull *(Larus pipixcan)* Forster's Tern *(Sterna forsteri)* Black Tern *(Chlidonias niger)*	Double-crested Cormorant *(Palacrocorax auritus)* American White Pelican *(Pelecanus erythrorhynchos)*

DABBLING DUCKS	DIVING DUCKS	GEESE
Mallard *(Anas platyrynchos)* Gadwall *(Anas strepera)* American Widgeon *(Anas americanus)* Green-winged Teal *(Anas crecca)* Blue-winged Teal *(Anas discors)* Cinnamon Teal *(Anas Cyanoptera)* Northern Shoveler *(Anas clypeata)* Northern Pintail *(Anas acuta)* Wood Duck *(Aix sponsa)*	Redhead *(Aythya americana)* Canvasback *(Aaythya valisineria)* Lesser Scaup *(Aythya affinis)* Ringed-necked Duck *(Aythya collaris)* Common Golden Eye *(Bucephala clangula)* Buffelhead *(Bucephala albeola)* Ruddy Duck *(Oxyura jamaicnesis)*	Lesser Snow Goose *(Chen caerulenscens)* Canada Goose *(Branta canadensis)*

WADING BIRDS	SHOREBIRDS
American Bittern *(Botaurus lentiginosus)* Great Blue Heron *(Ardea herodias)* Great Egret *(Casmerodius albus)* Snowy Egret *(Egretta thula)* Cattle Egret *(Bubulcus ibis)* Green-backed Heron *(Butorides striatus)* Black-crowned Night Heron *(Nycticorax nicticorax)*	Wilson's Phalarope *(Phalaropus tricolor)* American Avocet *(Recurvirostra americana)* Black-necked Stilt *(Himantopus mexicanus)* Common Snipe *(Gallinago gallinago)* Short-billed Dowitcher *(Limnodromus griseus)* Long-billed Dowitcher *(Limnodromus scolopaceus)* White-rumped Sandpiper *(Calidris fuscicollis)* Least Sandpiper *(Calidris minutilla)* Semipalmated Sandpiper *(Calidris pusilla)* Western Sandpiper *(Ccalidris mauri)* Marbled Godwit *(Limosa fedoa)* Greater Yellowlegs *(Tringa melanoleuca)* Solitary Sandpiper *(Tringa solitaria)* Willet *(Catoptrophorus semipalmatus)* Spotted Sandpiper *(Actitis macularia)* Killdeer *(Charadris vociferus)*

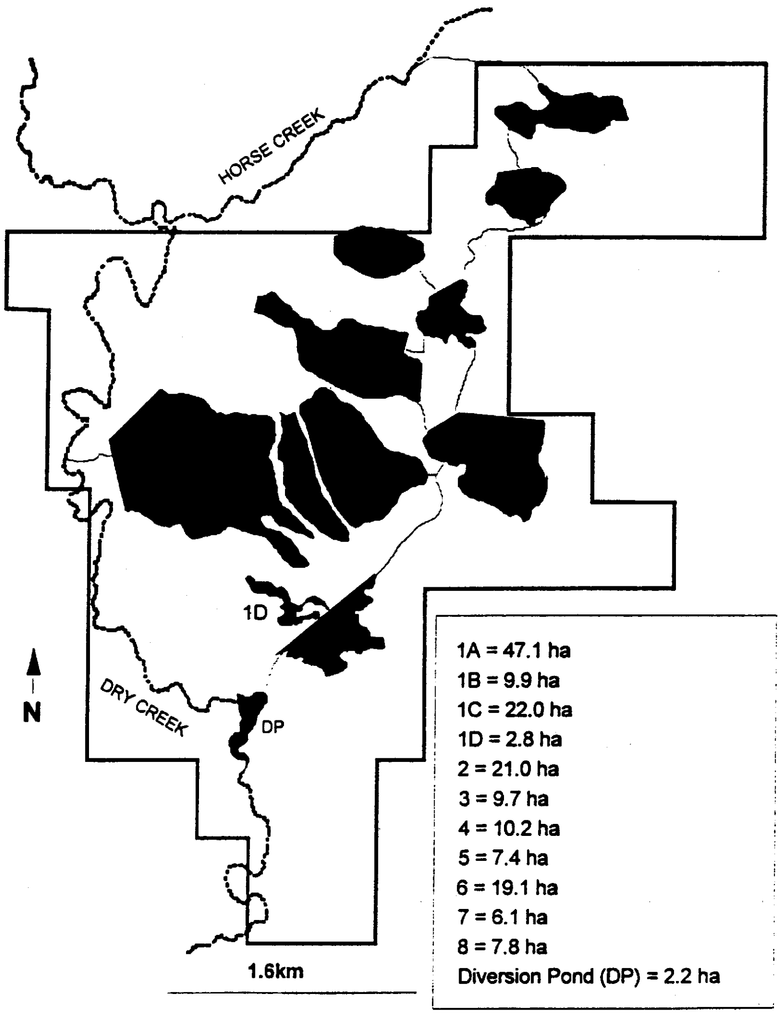


Figure 1. Study site in eastern Wyoming

ponds was used as a measure of water level stability. This coefficient was the average of weekly differences between readings.

RESULTS

A total of 60 waterbird surveys were conducted during 1991 and 1992. Fifty-nine waterbird species were encountered during surveys. The greatest number of waterbirds were seen during the spring and summer. Species richness varied among ponds. Differences in species richness occurred between 1991 and 1992 on ponds 1B, 7, and 8. However, paired *t*-tests identified no significant difference ($p > 0.64$) in species richness between 1991 and 1992 for the Unit as a whole.

To simplify analysis, 50 of the waterbird species were organized into eight groups based on habitat use (Table 1). Sandhill cranes (Grus canadensis), Common mergansers (Mergus merganser), and black-bellied plover (Pluvialis squatarola) were not present in summer surveys and not included in analysis. The western grebe (Aechmophorus occidentalis), eared grebe (Podiceps auritus), white-faced ibis (Plegadis chihi), and Virginia rail (Rallus limicola were rare, thus were not included in analysis. Although American coots and pied-billed grebes have considerably different diets they were grouped together because of very similar habitat use (Barnes and Nudds 1990).

Paired *t*-tests indicated that there were significant differences in of the Unit as a whole between 1991 and 1992 seasons. This suggests that waterbird use was higher during the 1992 season and not merely the same amount of waterbird use distributed differently among ponds. The general result for the Unit as a whole was that coot and grebe use was lower during the summer of 1992, while dabbling duck and shorebird use was higher during the summer of 1992.

BREEDING PAIRS

A total of 166 breeding pairs of waterfowl were observed on the Unit in 1991 and 286 pairs in 1992. Breeding pairs on the Unit were primarily dabbling ducks and geese. In 1991, dabbling ducks accounted for 45.7% of the Unit's breeding waterfowl population, geese 39.8%, and diving ducks 14.5%. In 1992, dabbling ducks accounted for 57.4% of the breeding population, geese 29.0%, and diving ducks 13.6%. Differences in pair use between 1991 and 1992 on individual ponds and the Unit as a whole were obvious for dabbling ducks, but not for geese or diving ducks. Paired *t*-tests indicated that pair use for the Unit as a whole was not significantly different between 1991 and 1992 for diving ducks or geese, but significantly higher in 1992 than in 1991 ($P < 0.005$) for dabbling ducks. Waterfowl pair use days per hectare were found to be significantly correlated ($P < 0.03$) with corresponding waterbird group use days per hectare and excluded from further analysis.

BROODS

Broods of 15 different species were observed during surveys in 1991 and 1992. Canada geese were the most productive species on the Unit, followed by coots and grebes, dabbling ducks, diving ducks, and shorebirds. Differential brood use of ponds was distinct for both 1991 and 1992. Although brood use was lower in 1992 than in 1991, with the exception of shorebirds, paired *t*-tests indicated that for the Unit as a whole there were no significant differences in brood use between years for coots and grebes, geese, diving ducks or shorebirds during May and June.

WATER LEVEL FLUCTUATIONS

Water level had a substantial influence on waterbird distribution and abundance during the summer months of each year and between years. Both 1991 and 1992 exhibited high water levels during the spring which dropped through the summer and rose again in early fall. As water levels dropped on individual ponds, dabbling duck and shorebird use increased, while use by other bird groups decreased.

To better examine the influence of water levels and waterbird use the 1991 season was compared to the 1992 season. Differences in waterbird use between seasons were obvious with shorebird and dabbling duck use being considerably higher in 1992 and other bird groups for the most part being somewhat lower in 1992. The 1991 season was a relatively wet year and the 1992 season a relatively dry year. The 1991 season had more spring rain in conjunction with earlier irrigation runoff that filled ponds beyond normal pool levels and ponds remained full until late in the season. The 1992 season did not receive substantial spring rains or early irrigation runoff resulting in low spring water levels which dropped considerably through the summer. Paired *t*-tests indicated that there were significant ($P < 0.002$) differences in mean water depth between the 1991 and 1992 seasons. The coefficient of variation for weekly water level recordings was used as a measure of water level fluctuation for each pond. Water level fluctuations were generally more pronounced in 1992 than in 1991, but paired *t*-tests indicated that these differences were not statistically significant.

Spearman rank correlations indicated that there were significant correlations between waterbird use and water levels. The general trends were that shorebird and dabbling duck use was negatively correlated with mean water depth and positively correlated with water level coefficients of variation, while other bird group broods were positively correlated with mean water depth and negatively correlated with water level coefficients of variation.

DISCUSSION

USE

Waterfowl composition and concentrations on the Table Mountain Unit resemble waterfowl use on grass-sage stock ponds in north central Wyoming (Svingen 1991) and other wetlands in the Great Plains (Uresk and Severson 1988, Rumble and Flake 1983, Ruwaldt et al. 1979, Lokemoen 1973, and Smith 1953). Uresk and Severson (1988) studied shorebird and waterfowl use on 37 ponds in Wyoming, North Dakota, and South Dakota. Species composition and concentrations were similar to that found at Table Mountain.

PRODUCTIVITY.

Dabbling duck breeding pair densities on the Unit were lower than densities reported for similar wetlands. Diving duck breeding pair densities were intermediate to densities found on similar wetlands. Breeding goose pair densities on the Unit were higher than densities found on Wyoming stock ponds, but are similar to densities found on other WGFD Management Units (Wyoming Game and Fish Department 1990).

WATER LEVEL FLUCTUATIONS

Water level fluctuations on the Table Mountain Unit had a definite influence on waterbird distribution and abundance. Shorebirds and blue-winged teal were associated with low water levels and mudflat conditions, while cormorants and pelicans, dabbling duck broods, diving duck broods, and Canada goose broods were associated with more stable water levels.

Dabbling ducks were associated with low water levels, but correlations were not consistent because use declined with persistent mudflat conditions. Increases in dabbling duck use associated with low water levels can be identified more readily by comparing the water level fluctuations on Ponds 3, 5, and 8 with dabbling duck densities on these ponds. High use of shallow wetlands by dabbing ducks has been well documented (Lagrange and Dinsmore 1989, Rumble and Flake 1983, and Ruwaldt and Flake 1979). Conversely, waterfowl brood use on Table Mountain was negatively associated with low and highly fluctuating water levels. Similar results were found for wetlands in South Dakota (Rumble and Flake 1983, and Mack and Flake 1980).

Low water levels in the 1992 season created drawdowns on much of the Unit. Ponds 1B, 3, 5, 8, and the Diversion Pond experienced complete drawdowns, while Ponds 1A, 4, and 7 experienced partial drawdowns. Ponds 1C, 1D, 2, and 6 although lower in 1992 remained relatively full. Drawdowns function in several ways to promote change in a wetland. The most notable changes are in vegetation structure. Exposure of bottom sediments may increase soil fertility as a result of aerobic nitrification (Kadlec 1962). Increases in plant nutrients may stimulate submergent vegetation growth leading to increased invertebrate populations and improved water clarity when higher water levels return (van der Valk and Davis 1981).

While drawdowns are an important factor in maintaining marsh productivity, drawdowns may be detrimental to wetland productivity in some instances. Continually low water levels and high evaporation rates can increase wetland salinity and limit the abundance and diversity of aquatic vegetation (Kadlec and Smith 1989). Stimulation of emergent vegetation growth associated with drawdowns may create undesirably dense stands on wetlands susceptible to becoming choked with emergent vegetation (Kadlec and Smith 1989). If drawdowns occur on ponds located within wetland complexes, where waterfowl broods have access to other water sources, the effects on waterfowl production will probably be negligible. However, if drawdowns occur on an isolated wetland, waterfowl production may be severely impacted and any site fidelity that has developed on the area set back or lost.

ACKNOWLEDGMENTS

We appreciate the funding support provided by the Wyoming Game and Fish Department. R. Straw, R. Beiswenger, W. Hubert and J. Lovvorn provided help in data analysis. B. Gurnsey and G. Thayer let us use the Table Mountain Facility and gave us access to historical records. Thanks to D. Brown and K. Stiener for the field assistance.

REFERENCES

Dahl, T. E. 1990. Wetlands losses in the United States 1780's to 1980's. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D. C. 21pp.

Kadlec, J. A., and L. M. Smith. 1989. The Great Basin marshes. Pages 451-474 in L. M. Smith, R. L. Pederson, and R. M. Kaminski, eds. *Habitat Management for Migrating and Wintering Waterfowl in North America.* Texas Tech Univ. Press.

Lagrange, T. G., and J. J. Dinsmore. Habitat use by mallards during spring migration through central Iowa. *J. Wildl. Manage.* 53:1076-1081.

Lokemoen, J. 1973. Waterfowl production on stock ponds in the Northern Great Plains. *J. Range. Manage.* 25:179-184.

Mack, G. D., and L. D. Flake. 1980. Habitat relationships of waterfowl broods on South Dakota stock ponds. *J. Wildl. Manage.* 44:695-700.

Merendino, M. T., L. M. Smith, H. R. Murkin, and R. L. Pederson. 1991. The response of prairie wetland vegetation to seasonality of drawdown. *Wildl. Soc. Bull.* 18:245-251.

Mitsch, J. W. and J. G. Gosselink. 1986. *Wetlands.* Nostrand Reinhold, New York. 539pp.

National Oceanographic and Atmospheric Administration. 1982. Monthly normal temperature, precipitation and heating and cooling degree days, 1951-1980, Wyoming. *U. S. Gov. NOAA. No. 81.*Rumble, M. and L. D. Flake. 1983.

Management considerations to enhance use of stock ponds by waterfowl broods. *J. Range Manage.* 36:691-694.

Ruwaldt, J., L. Flake and J. Gates. 1979. Waterfowl pair use of natural man-made wetlands in South Dakota. *J. Wildl. Manage.* 43:375-383.

Smith, R. 1953. A study of waterfowl production on artificial reservoirs in eastern Montana. *J. Wildl. Manage.* 17:276-291.

Svingen, D. N. 1991. Waterfowl production on grass-sage stock ponds in Wyoming. M. S Thesis Univ. Wyoming. 79pp.

United States Department of Agriculture. 1971. *Soil survey Goshen County, Wyoming. USDA*, SCS. 96pp.

Uresk, W. D. and Severson. 1988. Waterfowl and shorebird use of surface-mined and livestock water impoundments on the Northern Great Plains. *Great Basin Natur.* 48:353-357.

Wienhold, C. E., and A. G. van der Valk. 1989. The impact of duration of drainage on the seed banks of northern prairie wetlands. *Can. J. Bot.* 67:1878-1884.

Wyoming Game and Fish Department. 1990. Jack Sedman allotment grazing plan for the Table Mountain Unit 1990-1994. Unpub. *Grazing Plan for Table Mountain Unit.*

SESSION 9:

INSTREAM FLOWS

FLUSHING FLOW REQUIREMENTS OF LARGE REGULATED RIVERS IN WYOMING

Thomas A. Wesche, Travis J. Bray and Wayne A. Hubert[1]

INTRODUCTION

Trout require clean gravel in which to deposit their eggs during the spawning process (Reiser and Wesche 1977). Spawning gravels which remain downstream from dams may become imbedded with fine sediments recruited from bank erosion or downstream tributary inflow, thereby reducing survival of the emerging embryos (Hausle and Coble 1976 and Young et al. 1991). The removal of these fine sediments has become an objective of many flushing flow studies (Reiser et al. 1989).

River channel maintenance below regulatory structures can be accomplished with instream and flushing flows. A flushing flow is a controlled release of a high amount of water over a relatively short period of time whose purpose is to remove accumulations of fine sediment in the gravel by temporarily mobilizing the bed. Among the methods available to evaluate the effectiveness of flushing flows are measurements of bed material composition, bedload and suspended load transport, amount of intergravel fine sediment, and channel geometry (Reiser et al. 1985).

Flushing flows have been implemented and evaluated on two rivers in Wyoming, the North Platte River and the Big Horn River. This paper will present a portion of our findings.

STUDY AREAS

NORTH PLATTE RIVER

The river is controlled by eight main-stem dams whose reservoirs have a total storage capacity of approximately 2.8 million acre-feet (Wenzel 1993). Five of these dams are located upstream from Casper, Wyoming: Seminoe, Kortes, Pathfinder, Alcova, and Gray Reef. Gray Reef Dam is located approximately 2.5 miles below Alcova Dam and forms a small reservoir to re-regulated releases from Alcova Dam to provide flows acceptable to irrigation, municipal, industrial, and fish and wildlife interests downstream to Glendo dam (Wenzel et al. 1992) (Figure 1).

Mean monthly flows for the North Platte River at Gray Reef (USGS Gage #06642000) have been altered since the completion of Gray Reef Dam in

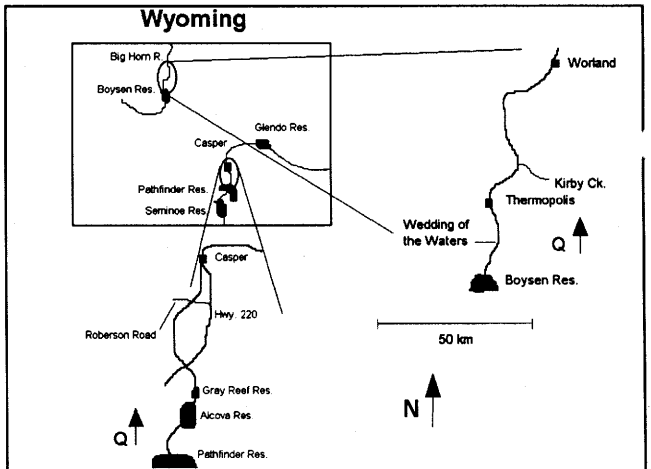


Figure 1. Map of Wyoming showing the North Platte and Big Horn river study areas.

1961 and are different from the unregulated North Platte River upstream from Seminoe (USGS Gage #06630000) (Figure 2). The flow regime upstream from Seminoe is largely a factor of snow-melt runoff while flows downstream of Gray Reef Dam are dominated by power and irrigation needs (Wenzel et al. 1992). The average annual flow (Q_{AA}) at Gray Reef is 1270 cubic feet per second (cfs), peak flow with a two year return interval (Q_{P2}) is 4000 cfs, and the seven day, two year return period low flow (Q_{7L2}) is 500 cfs. Above Seminoe the Q_{AA} is 1385 cfs, the Q_{P2} is 7000 cfs and the Q_{7L2} is 180 cfs (Wenzel 1993).

Wenzel (1993) determined that, as a result of river regulation, the North Platte River from Gray Reef to the Robertson Road Bridge has experienced a decrease in average channel width, length, surface area, and sinuosity. Average width decreased

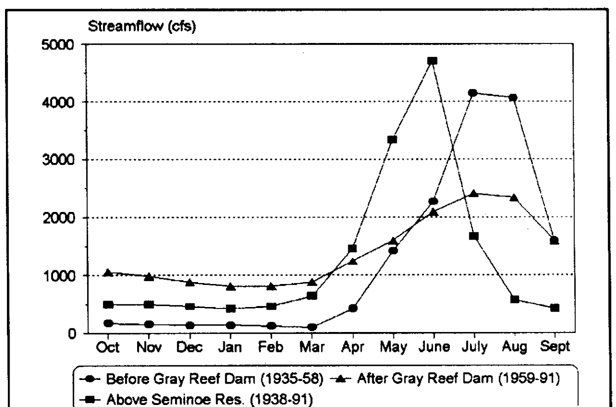


Figure 2. Mean monthly hydrograph for two different locations during three different time periods on the North Platte River, Wyoming.

approximately 43.3 feet while length and surface area were reduced approximately 2.7 miles and 309 acres, respectively (Wenzel 1993).

The North Platte River from Gray Reef Dam to Bessemer Road Bridge is classified by the Wyoming Game and Fish Department (WGFD) as Class One, a

[1] Department of Rangeland Ecology and Watershed Management; Wyoming Water Resources Center and Wyoming Cooperative Fish; and Wildlife Research Unit/Department of Zoology and Physiology, respectively, UW, Laramie, WY 82071

fishery of national importance. Department personnel have identified several areas in this section of river which have experienced a loss in spawning habitat due to fine sediment deposition. In addition, Department personnel feel that these fine sediment accumulations have caused a shift in aquatic insect communities towards species which can tolerate higher accumulations of sediment. In turn, this shift has impaired trout food production capabilities (Leonard 1995). Population estimates reflect a decrease in numbers and biomass for all species of trout since 1987 (Wenzel 1993).

BIG HORN RIVER

The river is currently regulated by Boysen Dam, which was completed in 1952 and has a storage capacity of 802,000 acre-feet. Boysen Dam has altered the stream flow regime of the Big Horn River. These changes were recorded by the USGS stream gaging stations at Boysen Dam (06259500) and Thermopolis (0625900) (Figure 3). Current operating conditions have increased the average fall-winter flow (Sept.-April) by 407 cfs, decreased summer flows (May-Aug.) by 1345 cfs and decreased the peak flow by 3900 cfs. Also, peak flow has been delayed by one month due to river regulation (Bray 1996).

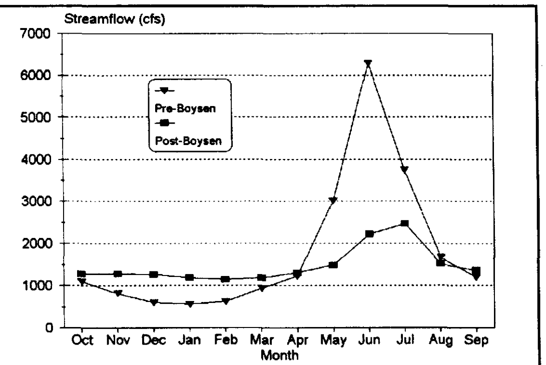


Figure 3. Pre (water years 1912 to 1952, USGS# 06259500) and post (water years 1953 to 1994, USGS# 0625900) Boysen Dam mean monthly hydrographs for the Big Horn River, Wyoming.

Average annual flow prior to Boysen Reservoir was equaled or exceeded 23% of the time compared to 35% after construction. The Q_{P2} prior to the dam was 9326 cfs and the Q_{7L5} was 325 cfs. Since completion of Boysen Dam the Q_{P2} has been reduced 76% to 2279 cfs and the Q_{7L5} has increased 48% to 482 cfs.

The Big Horn River is classified by the WGFD as a Class One -- Blue ribbon fishery from the northern boundary of the Wind River Indian Reservation to the confluence of Kirby Creek. In Wyoming less than two percent of all stream miles are so classified. Due to the prominence of the Big Horn River fishery, management of the river is a priority for the WGFD (Wiley 1995).

Bray (1996) determined that the Big Horn River below Boysen has decreased channel width (93 feet) and area of active channel (244 acres) between Wedding of the Waters and Worland, Wyoming. The riparian mosaic within the 100 year flood plain has also responded to flow regulation. Riparian herbaceous vegetation decreased by 47.3% while agricultural areas increased by 51.4% (Bray 1996).

METHODS

Study sites were selected on each river to monitor bed characteristic changes. Temporary instrument stations were set up to monitor hydrology and sediment transport changes. Cross-sections were established to evaluate channel profile, bed-load and suspended sediment transport. Potential spawning areas were identified and substrate samples were taken using McNeil core (McNeil and Ahnell 1964) and freeze-core samplers (Walkotten 1976). Core samples were analyzed using the fredle index, the median particle size (d50), percentage of fine sediment less than 0.08 inches, and percentage less than 0.03 inches. During the flushing flow on the North Platte River, painted gravel was placed in two riffles and travel distance of different substrate sizes as measured.

RESULTS

NORTH PLATTE RIVER

Three flushing flows have been monitored on the North Platte River: July 1993, Oct. 1993, and Oct. 1995. The first two were described by Leonard (1995) and the third by Wesche (1996).

Flushing flow one and two had a peak and duration of 4250 cfs and seven hours respectively. The third flow was a pulsed release. River discharge was increased from 750 to 2000 cfs and held steady for three hours; then increased to 4000 cfs for six additional hours and then returned to base flow. This process was repeated four more times over the next week.

Analysis of suspended sediment measurements revealed a sharp increase with flow (Figure 4); as discharge increased so did Qss and as discharge decreased Qss followed with a slight lag.

Substantial movement of painted rocks occurred as a result of test flow two. The flow transported 56% of the 0.5 inch size class, 75% of the 1.0 inch class, and 38% of the 2.0 inch class. Median particle movement was 7.0, 6.5, and 3.5 feet for the 0.5, 1.0, and 2.0 inch size classes respectively. The majority of particles that were found had been transported less than 6.6 feet.

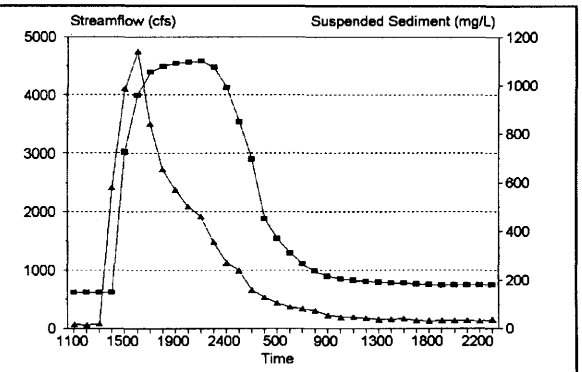


Figure 4. Hourly discharge and suspended sediment concentrations for the North Platte River below Gray Reef Dam. The time period is 10/13/93 through 10/14/93.

BIG HORN RIVER

The monitoring of flushing flows has occurred twice on the Big Horn River: March of 1994 and 1996. The first flow was monitored by Wiley (1995) and the second by Bray et al. (1997).

Flushing flow one had a peak of 7000 cfs and lasted for five hours. Peak sediment discharge occurred at most of the sites as flow was increased from 3000 to 4600 cfs (Figure 5). Flushing flow two had a peak of 5000 cfs and a duration of ten hours. At this time suspended sediment samples have not been analyzed.

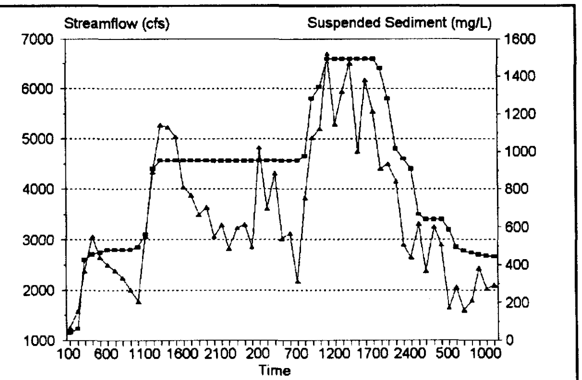


Figure 5. Hourly discharge and suspended sediment concentrations for the Big Horn River below Boysen Dam. The time period is 3/28/94 through 3/30/94.

DISCUSSION

The most productive tailwaters in Wyoming are the Big Horn River downstream from Boysen Reservoir, North Platte River downstream from Gray Reef Reservoir, Shoshone River downstream from Buffalo Bill Reservoir, Green River downstream of Fontenelle Reservoir, and the Snake River downstream from Jackson Lake. Flushing flows on the North Platte and Big Horn river can provide insight regarding flushing flows needed to maintain or enhance trout habitat in these tail waters. Our studies suggest that the magnitude of a flushing flow release should be equivalent to the flood having a recurrence interval of 3.5 to 4 years (post reservoir construction) to be effective. Flushing flows should be of a magnitude approaching bankfull conditions to transport peak bedload and suspended sediment. The duration of the event should be dependent on the quantity of material to be removed and the length of the stream reach involved. Regardless of the similarity of rivers, flushing flows should only occur if there is a specific identified need and should be tailored to the specific stream and drainage basin (Wiley 1995).

REFERENCES

Bray, T.J., T.A. Wesche, and W.A. Hubert. 1997. Evaluation of a recommended flushing flow on the Big Horn River, Wyoming. DRAFT report to WGFD.

Bray, T.J. 1996. Changes in channel morphology and riparian mosaics on the Big Horn River, Wyoming. M.S. thesis, University of Wyoming, Laramie, Wyoming.

Hausle, D.A., and D.W. Coble. 1976. Influence of sand in redds on survival and emergence of brook trout (Salvelinus fontinalis). *Transactions of the American Fishery Society* 104:57-63.

Leonard, D.S. 1995. An evaluation of North Platte River flushing flow releases. M.S. thesis University of Wyoming, Laramie, Wyoming.

McNeil, W.J., and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Special Scientific Report, Fish. No. 469.

Reiser, D.W., M.P. Ramey, T.A. Wesche. 1989. Flushing Flows. Chapter 4 pp. 91-135, In (J.A. Gore and G.E. Petts, editors), Alternatives in Regulated River Management. CRC Press Boca Raton, FL.

Reiser, D.W., and T.A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Water Resources Series No. 64. Water Resources Research Institute, University of Wyoming, Laramie, Wyoming.

Reiser, D.W., M.P. Ramey, and T.R. Lambert. 1985. Review of flushing flow requirements in regulated streams. Pacific Gas and Electric Company. Dept. of Engineering Research, San Ramon, CA. Contract No. Z19-5-120-84.

Walkotten, W.J. 1976. An improved technique for sampling streambed sediments. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. Research Note PNW-281.

Wenzel, C.R. 1993. Flushing flow requirements of a large, regulated, Wyoming river to maintain trout spawning habitat quality. M.S. thesis. University of Wyoming, Laramie, Wyoming.

Wenzel, C.R., T.A. Wesche, and W.A. Hubert. 1992. Flushing flow requirements of a large, regulated, Wyoming river to maintain trout spawning habitat quality. Annual Progress Report for WWRC Project No. 5-38976. July 1, 1991-June30,1992. Wyoming Water Resources Center, University of Wyoming. Laramie, Wyoming.

Wiley, D.E. 1995. Development and evaluation of flushing flow recommendations for the Big Horn River. M.S. thesis, University of Wyoming, Laramie, Wyoming.

Young, M.K., W.A. Hubert, and T.A. Wesche. 1991. Selection of measures of substrate composition to estimate survival to emergence of salmonids and to detect changes in stream substrates. *North American Journal of Fisheries Management* 11:339-346.

EVALUATION OF FLOW DURATION ANALYSIS TO ESTABLISH WINTER INSTREAM FLOW STANDARDS FOR WYOMING TROUT STREAMS

Wayne A. Hubert, Cindy A. Pru, Thomas A. Wesche and Travis J. Bray[1]

ABSTRACT

There are no widely accepted methods to define minimum instream flow needs for trout in ice- and snow-covered streams during winter, as there is during ice-free periods of the year (Annear and Conder 1984). Accumulation of ice on stream channels changes hydraulics and prevents sampling in standard ways. Therefore, methods for determination of instream flow needs during ice-free periods are often not applicable to many streams during winter.

There is a history of using hydrologic criteria to define minimum instream flow needs during ice-free periods. In Wyoming, Wesche (1973) recommended 25% of average daily flow during the summer (July-September) to support good trout populations. Burton and Wesche (1974) found that streams where this criterion for instream flow was met or exceeded 50% of the time between July and September 30 had good trout fisheries. The most widely applied technique using hydrologic criteria is the Tennant method (Tennant 1976). Tennant recommended use of a percentage of the historic mean annual flow to estimate minimum instream flow requirements.

The purpose of this project was to assess the use of hydrologic data in the establishment of winter instream flow standards for trout streams in Wyoming. We utilized analysis of flow duration curves in our assessment. Flow duration curves identify the percent of time that specified discharges (defined as a percentage of average daily flow) are equaled or exceeded. Our objectives were to: (1) describe physical conditions and trout habitat at various locations in watersheds during winter; (2) determine the extent to which spatial and temporal variation in stream flow affects physical conditions and trout habitat in streams during fall and winter; (3) describe stream flows from fall through winter in streams with and without irrigation and water development in the watershed; and (4) determine if criteria based on flow duration curves can provide standards for minimum instream flow determina-tions to maintain trout fisheries during winter.

METHODS

Objectives 1 and 2.--This portion of the study was conducted on the Laramie Range and Snowy Range of the Medicine Bow Mountains in southeastern Wyoming. Eight sites selected for study were proximal to active year-round water flow gaging stations. Relations among variables describing geomorphology of the watershed, winter flow duration values, winter habitat features and trout standing stocks were assessed.

Objectives 3 and 4.--The Water Resources Data System (WRDS) at the Wyoming Water Resources Center was searched to identify gaging stations with suitable hydrologic data on streams with trout fisheries. We selected stream gaging stations based on these criteria: (1) daily discharge data were available for a 10-year period beginning with Water Year 1985, (2) the streams were not downstream of a mainstem reservoir or highly regulated by small upstream reservoirs, (3) the streams were not substantially influenced by flows from springs or geothermal sources, (4) the gaging stations were on stream reaches known to support trout fisheries, and (6) the streams were in Wyoming.

Exceedence values representing the percent of time a specified discharge was equaled or exceeded were computed. Discharge values were normalized by dividing by mean annual discharge to allow comparisons among sites. Discharge data were stratified for the winter (January-March) period with exceedence values computed for that period. For each gaging station, the elevation of the stream gage, drainage area upstream from the stream gage, the area and proportion (percent) of upstream watershed that was irrigated land, and the existing upstream water storage capacity were identified. Multiple regression analysis was used to assess relations between normalized exceedence values and variables describing the watershed.

RESULTS

WINTER HABITAT

Wide ranges in geomorphic and discharge features occurred among the eight study sites in southeastern Wyoming. No significant relations were found between geomorphic features or measures of discharge and estimates of standing stocks of trout in the streams. Significant differences in habitat features were observed between the two years of the study. Among pools, mean water depth, mean water velocity, mean ice thickness, and mean snow depth differed between years with greater values in 1994-95 than in 1993-94. At riffles, significant differences in mean water depth were also observed between years, but significant differences in mean ice thickness or mean snow depth were not detected. Within transition areas between riffles and pools, mean water depth and mean water velocity were significantly greater in 1994-95 than in 1993-94, but significant differences in mean ice thickness or mean snow depth were not observed.

[1] Wyoming Cooperative Fish and Wildlife Research Unit, UW; Rangeland Ecology and Watershed Management, UW, respectively, Laramie, WY 82071.

FLOW DURATION ANALYSIS

A total of 31 gaging stations that met our criteria were identified from across Wyoming. Relations to watershed features were observed for normalized discharge values that were equalled or exceeded 50% (Q_{50}) of the time during winter (January-March).

During the winter, elevation of the gaging station, drainage area upstream from the gaging station, and the percent of the drainage area that was irrigated land were each significantly correlated with winter Q_{50}. However, the coefficients of determination were low and the standard error of the estimates were high, indicating poor predictive capabilities. The highest amount of variation ($R^2 = 0.55$) was accounted for from knowledge of elevation and the percent of irrigated land. A lesser amount of variation ($R^2 = 0.48$) was accounted for using elevation and the area of irrigated land as independent variables.

We divided the data set into three elevation classes: low (< 5,000 ft), middle (5,000-7,200 ft) and high (> 7,200 ft). Significant differences in Q_{50} and drainage area were found among the three classes. No drainages in the high-elevation class had irrigated land within them.

Flow duration frequencies among the three elevation classes were developed for the winter period. The normalized mean daily flow equaled or exceeded 50% of the time during the winter was 0.16 among the high-elevation streams (n = 9), 0.26 among the middle-elevation streams (n = 15), and 0.44 among the low-elevation streams (n = 7). We found the high-elevation sites to have substantially lower flow regimes during the winter period than the lower-elevation classes. Between the low- and middle-elevation classes, middle-elevation sites had lower flow regimes than low-elevation sites with the exception of extreme values at both ends of the flow duration spectrum (10 and 90% of time).

DISCUSSION

Variation in habitat features was observed between the two study years and was associated with variation in discharge. Variation in the availability of suitable habitat for incubating embryos and age-0 fish in transition areas between riffles and pools was observed between fall and winter, as well as between years. These changes were primarily a factor of variation in flow, not the accumulation of ice.

We observed substantial variability in winter flow regimes, but we were unable to account substantially for the variation using watershed features. Additionally, we were unable to identify any significant relationships between statistics describing winter flow frequencies and fish abundance or other factors related to habitat quality for fish in the eight study streams in southeastern Wyoming. This finding illustrates the high level of complexity of factors affecting trout populations, as well as the potential high risk of error when applying a simple hydrologic standard to identify a meaningful instream flow for trout.

Despite the inability of flow duration analysis to define winter instream flow needs for trout in Wyoming, flow duration analysis may be useful in the process of determining and negotiating winter instream flows for individual reaches of streams. When a minimum instream flow value or series of values are defined through habitat assessment techniques in the future, flow duration analysis may assist in determining the frequency of achieving particular values.

REFERENCES

Annear, C. T., and A. L. Conder. 1984. Relative bias of several fisheries instream flow methods. *North American Journal of Fisheries Management* 4: 531-539.

Burton, R. A., and T. A. Wesche. 1974. Relationship of duration of flows and selected watershed parameters to the standing crop estimates of trout populations. *Water Resources Series No. 52*, Water Resources Research Institute, University of Wyoming, Laramie.

Tennant, D. L. 1976. Instream flow regimes for fish, wildlife, recreation, and related evironmental resources. *Fisheries* 1(4): 6-10.

Wesche, T. A. 1973. Parametric determination of minimum stream flow for trout. *Water Resources Research Series No. 37*, Water Resources Research Institute, University of Wyoming, Laramie.

DEVELOPMENT OF AN INDIVIDUAL-BASED MODEL TO ASSESS THE INSTREAM FLOW REQUIREMENTS OF STREAM SALMONIDS.

Russell B. Rader[1]

Individual-based modeling is a recent technique that is fast becoming an established discipline separate from more classical population models. Individual-based models (IBM's) incorporate 3 distinguishing characteristics. First, they reflect real life cycle complexity including mortality, fecundity, and spawning migrations that depend upon the age or size of individuals. Second, resources are explicitly modeled. Physical habitat availability, food abundance, temperature, and water quality are modeled using actual measurements at high, intermediate, and low flows. Third, and most important, is accounting for differences among individuals within a population. Rather than assume that mortality, growth, reproduction, movement, spatial distribution, and the effects of interference competition is the same for an average trout, IBM's model differences between individuals (e.g. size) providing a realistic prediction of the stream flows required to maintain salmonid populations. The in-stream flow incremental methodology (IFIM), is a straightforward technique of estimating potential fish abundance from field observations. Although IFIM is widely used, it is increasingly viewed as an inadequate oversimplification. A new approach (IBM's) will incorporate increased biological realism by considering how environmental factors influence fish energetics and growth.

[1] Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, 222 South 22nd, Laramie, Wyoming 82070

WYOMING WATER DEVELOPMENT COMMISSION'S ROLE UNDER THE WYOMING INSTREAM FLOW LAW

Bruce R. Brinkman[1]

INSTREAM FLOW BACKGROUND

Just what is the Wyoming Instream Flow Process and where did it come from?

As early as 1899 laws have been enacted to protect flows in natural channels. The Rivers and Harbors act of 1899 was enacted to protect the navigable capacity of the nations waterways. This flow protection by the U.S. Army Corps of Engineers was expanded in the 1960s to include protection of water resources. The Corps regulatory authority was again expanded in 1972 with Section 404 of the Clean Water Act.

An early attempt at an instream flow water right in Wyoming was in 1969. An application was filed by the Wyoming Outdoor Coordinating Council for an in place flow right on the Green River Habitat. Due to several problems with a minimum instream flow right, including the lack of consumptive use of the water, the permit was rejected.

In 1972 the focus on preserving our nation and Wyoming's waters moved from the federal level to the state level in Wyoming. In April of 1972, the League of Woman Voters under the coordination of the Wyoming Recreation Commission held a Wild, Scenic and Recreational Rivers Seminar in Casper. They resolved that it was time that the legislature pass some sort of protection for free flowing rivers and streams in Wyoming.

The next year the House introduced a Stream Preservation Feasibility Study with a funding package of $25,000. This passed the House 39 to 20. The Senate reduced the amount to $7,500 and passed it 21 to 9. The House then passed the amended bill by 53 to 8. From this legislation, the Stream Preservation Feasibility Study Committee was formed. The Stream Preservation Feasibility Study Committee presented a final report to the Legislature in 1974 proposing two bills, a Protection of Stream Channels bill and a River Protection System bill. The Protection of Stream Channels bill basically required a review and permitting process before any stream channel alterations would be allowed in Wyoming. The Wyoming River Protection System bill provided for the management of primitive, scenic and recreational rivers by creating a Wyoming River Protection Council and four (water division) River Protection Advisory Committees.

These two bills were introduced in both the Senate and House in 1975. The Senate bills were both sent to Senate Committee No. 5. The Committee recommended "do not pass" and the bills both died on general file. The House bills were sent to House Committee No. 5 and died in committee.

In 1976 similar forms of both bills were introduced in the House. The Protection of Stream Channels bill came out of Committee No. 5 with a "do not pass" recommendation and died on general file. The Wyoming River Protection System bill died in Committee No. 5.

The Protection of Stream Channels bill was introduced in the Senate in 1979. After getting an "amend and do pass" recommendation out of Committee No. 6, the Senate approved it 17 to 13. House Committee No. 5 then recommended do not pass. The bill then died on general file. 1979 was also the year that the legislature formed the Water Development Commission.

The Protection of Stream Channels bill was a state bill that provided similar regulations as the federal 404 permitting process that was already in existence. This may have had some effect on the disappearance of the bill in 1980. The Wyoming River Protection System bill, however, did not have similar federal regulatory provisions and reappeared in a revised form in 1981.

In 1981, similar forms of an Instream Flow bill were introduced in both the Senate and the House. The Senate adopted its bill 24 to 6 and sent it to the House. House Committee No. 5 then recommended "do not pass." The bill died on general file. The House bill was sent to House Committee No. 5 and died in committee.

For the next four years, Instream Flow bills were presented and amended in several forms in both the Senate and House. In 1982, one Senate bill and two House bills died in committee. In 1983, a Senate bill died on general file and three House bills died in committee. In 1984, one Senate bill and two House bills all fail to be introduced. Around this same time, 1983 to 1984, a petition sponsored by several conservation groups was circulated with the intent to place an instream flow bill on the 1986 general election ballot. In 1985, a Senate bill died in committee and a House bill failed in conference committee.

Finally in 1986, House bill No. 209, after several amendments, made it all the way through both the Senate and the House and became Chapter 76 of the 1986 Session Laws of Wyoming. The House passed the first version of the bill by 48 to 16 on first reading and after several amendments and two more readings, it passed by a vote of 58 to 6. After additional amendments, committee reviews and three readings in the Senate it passed by 19 to 11. The final vote taken in the House passed the final form of the bill by a vote of 40 to 24. Chapter 76 of the 1986

[1] Wyoming Water Development Commission, Herschler Bldg., 4th Floor West, Cheyenne, WY 82002

Session Laws of Wyoming created Wyoming Statutes 41-3-1001 through 41-3-1014.

These statutes are the same as the ones used today with two changes. In 1987, Chapter 50 of the statutes transferred the authority given to the division of water development within the Economic Development and Stabilization Board to the Water Development Commission. It also placed the responsibility for fees and costs of the permitting and adjudication process of the instream flow water rights with the Game and Fish Commission.

One additional statute, Chapter 177, that was created in 1975, also pertains to instream flows. This statute states that "In the administration of water rights on any stream and in the consideration of any applications for permits, the State Engineer may require that water be provided to meet reasonable demands for instream stock use."

INSTREAM FLOW LAW STATUES PERTAINING TO THE WWDC

The major statutes dealing with instream flows in Wyoming are found in Wyoming Statutes 1977, Title 41- Water, Article 10 - Instream Flows, W.S. 41-3-1001 through W.S. 41-3-1014. These statutes have implications and requirements for the Wyoming Water Development Commission (WWDC), the Wyoming State Engineer's Office (SEO), the Wyoming Game and Fish Commission (WGFD), and the legislature itself.

The six major statutes affecting the WWDC are listed below broken down into five phases of the Instream Flow process affecting the WWDC.

Phase 1, WGFD Report and Flow Requests, 41-3-1003 and 1006, provides for the WGFD to provide the WWDC with a (Biologic) study of the instream flow segment area and the minimum instream flow amounts necessary to provide adequate instream flows.

Phase 2, Application Filing and Funding, 41-3-1003, requires the WWDC to file instream flow applications in the name of the State of Wyoming and requires the WGFD to provide the fees associated with the instream flow filings.

Phase 3, WWDC Report, 41-3-1004, requires the WWDC to conduct a (Hydrologic) study of the instream flow segment. This statute also requires the WWDC to provide a report of their findings and other pertinent information.

Phase 4, Public Hearing, 41-3-1003 and 1006, requires a public hearing on the instream flow request.

Phase 5, Regulation, 41-3-1008, requires the WWDC to submit regulation reports from the WGFD to the SEO.

WWDC INSTREAM FLOW STATUE PROCEDURES

The first phase of the ISF process affecting the WWDC is performed by the WGFD. This phase includes the selection of the ISF segment and a (biologic) analysis of the segment. From this analysis, the WGFD submits a biological report, filing fees and an application for the ISF filing including the requested flow amounts determined by the WGFD. As of January 1997, the WGFD had submitted 68 applications.

The second phase of the ISF process has the WWDC filing the ISF application and fees, received from the WGFD, with the State Engineer's Office in the name of the State of Wyoming.

The third phase of the ISF process affecting the WWDC is the most intensive for the WWDC. This phase consists of a WWDC review of the WGFD's applications and reports, a WWDC hydrologic analysis of each ISF segment and a WWDC report of the findings.

After the review of the WGFD's applications and reports, the first step of phase 3 is to determine the scope of the project. If reliable historic gage data is available in the segment drainage basin, then the boundaries of the hydrologic analysis should be the segment's drainage basin. If this is not the case the analysis may require data from several basins to assist in the determination of a historic flow record for the segment.

Once a historic flow record is established for the ISF segment, the total historic diversions coming from existing storage and direct flows are analyzed to determine the segment's virgin stream flows. The basic steps to do this involve placing the total historic diversion amounts back into the historic stream flows. This should come close to reestablishing the total virgin flows in the stream segment. Once the virgin flows are determined, the segment's appropriated water right consumptive uses and depletions are removed from the stream flows and the return flows are added back into the stream flows to determine the unappropriated flow amounts in the stream. This virgin flow process is needed due to the fact that historic diversions are not always the same as the permitted diversions.

From the unappropriated flow data set, a minimum of three flow analyzes are produced. These include the mean monthly flows, the dry year flows and the driest month flows. The dry year and driest month flow analyzes are the worst case scenarios for the segment. The mean monthly flow analysis looks at the mean flows to determine if there are any flows less than the requested amounts. If there are mean monthly unappropriated flows below the requested amounts, then the potential for storage is analyzed. The storage analysis determines the availability of any excess unappropriated flows in other months that could be stored to help mitigate the shortages in the low flow months.

In addition to the monthly flow analysis, the daily flows are also analyzed to determine the percentage of time individual flows are available in the ISF segment.

All of this data is then collected and placed in the WWDC's hydrologic report. Much of the data is placed in graphic figures and tables to condense data in a easier reading format. A summary is placed at the beginning of the report and a conclusion at the end of the report. The conclusion will contain a summary of the assumptions used in the report analysis.

As of January 1997, fifty-seven WWDC hydrologic reports have been completed and eleven are in different stages of completion. The WWDC hydrologic reports have undergone several transformations through the fifty-seven publications. The latest reports are broken down into several sections as follows:

WWDC INSTREAM FLOW HYDROLOGIC REPORT OUTLINE

1. Summary [approximately two (2) pages]
2. Maps
3. Water Rights
4. Flow Records
5. Hydrology
   A. Historic Flow Analysis
   B. **Appropriated** Flow Analysis
      1. Diversions and Diversion Rates
      2. Consumptive Use
      3. Depletions and Return Flows
      4. Virgin Stream Flow Determination
      5. Summary
   C. **Unappropriated** Flow Analysis
      1. Flow Analysis, Mean Monthly Flows
      2. Flow Analysis, Dry Year Flows
      3. Flow Analysis, Driest Month Flows
      6. Flow Shortage and Storage Analysis
      7. Daily Flow Exceedance Analysis
      8. Potential Water Development Analysis
      9. Conclusions (including statement of assumptions)
      10. Appendix
         A. Wyoming Game and Fish Report
         B. Other Information (as needed)

The forth phase requires the WWDC and the WGFD to present their findings to the State Engineer in a public hearing.

The final phase requires the WWDC to submit WGFD regulation reports to the State Engineer's Office. In the short history of the ISF laws in Wyoming, this phase has not occurred.

10 YEARS DOWN THE ROAD: A GAME AND FISH PERSPECTIVE ON THE STATE'S INSTREAM FLOW LAW

Tom Annear[1]

Beginning well before passage of the state's instream flow law in 1986, there have basically been two perspectives on the subject of instream flows. One perspective has opposed the very concept, fearing generally that recognition of instream flows would, among other things 1) diminish existing water rights, 2) negatively affect the state's ability to use all the water allotted under interstate compacts and supreme court decrees, 3) be impractical without storage specifically for this new water right and 4) limit traditional water development opportunities. The other perspective is generally supportive of instream flows. They thought instream flows would restore flows in dewatered stream segments, expand recreational opportunities and related economies, and put some legitimate controls on water development to name a few goals. Both felt very strongly about the rightness of their cause and both saw (and many still see) the state's instream flow law as validating their concerns.

Having worked with the instream flow process now for just over 10 years, some patterns and tendencies are becoming evident that in some cases support, but in other cases refute, many of the above misgivings and hopes. The following list of the Top Ten Problems With The State's Instream Flow Law is based on this history and shows one perspective of how the law really works.

10. The rivers around Wamsutter still don't flow.

Perhaps the most common questions we hear are "how is that water right going to change anything?" and "how are you going to guarantee that you get the requested amount all the time?". Both of these questions reflect the basic optimistic nature of people who think that an instream flow water right has powers greater than any other kind of water right and should or will be in the stream all the time. The fact is that filing for an instream flow does not create any new water or imply that the recommended amount necessarily needs to be in the stream all the time. Certainly the recommended amount of water needs to be present in the designated stream segment on some fairly regular frequency. But the frequency of availability of an instream flow varies for each stream depending on the unique hydrological, biological and geo-morphological characteristics of each segment. In most situations an instream flow won't change a thing - which is the very reason for the filing.

For this reason, we don't file on streams where fishery values are seriously limited or nonexistent because doing so won't change anything and the degraded values of those fisheries seldom warrant the significant investment of time and money required for a filing. We do file on streams with good fisheries and reasonable flow patterns where our goal is to maintain existing flow patterns up to the recommended amount. Again, the only change associated with an instream flow is the assurance that water will remain in the channel up to the specified amount when it is there in priority.

9. Spend half my time searching for critically important streams.

The law requires the Game and Fish Department to identify stream segments where instream flows are critically important. To guide our selection, the Game and Fish Commission approved a set of criteria that include a) Class 1, 2 and 3 streams, b) streams with sensitive native species, c) important recreational fisheries and d) streams with existing instream flow agreements that would benefit from regulation by the new state law.

These criteria lead us to some of the best trout streams in the state which isn't usually a problem. However we still get questions as to why (for example) it's necessary to file for streams where downstream senior water rights already have a call on the entire flow. Also, many of our filings have been in places that may be difficult to develop - at least with today's technology and water demands.

Filings upstream from senior irrigation rights usually aren't needed to protect fisheries today but they are an appropriate strategy for protecting fisheries for the future. One example of why we need instream flow rights in these places deals with small hydro-power projects. These projects often seek out the rugged country where we have made some of our filings. Those interests use the natural gradient of mountain streams to generate power by diverting water through a pipe and dropping it into a power generator at a lower elevation. This is a non-consumptive use, like instream flow, that would not harm senior irrigation rights but could dry up a stream channel. Though non-consumptive, those uses still need a water right. An instream flow operates on the same principle except that the instream flow "pipe" is the river channel and the use is fisheries instead of power generation.

Just like we see water uses today that were unthinkable 100 years ago, there will probably be uses in the next 100 years that we can't conceive of today that could result in serious stream fishery impacts. Growth demands in Colorado have resulted in massive projects to move West Slope waters to Denver's front range that were inconceivable to our forefathers. Future leaders and land managers will deal with the complex issues of resource development when the appropriate time arises; but, when those times come, the issue of fishery protection will have been addressed just like the

[1] Wyoming Game and Fish Department, 5400 Bishop Blvd., Cheyenne, WY 82009

ranchers of 100 years ago took care of their needs and provided for their heirs and successors. Instream flows are not intended to preclude other development and typically call for a small fraction of the flow.

8. Spend the other half of my time doing all that extra math.

The days of arm-chair fisheries management have long since passed. They've been replaced by high tech equipment, extensive data gathering and computer models. Instream flow legislation requires application of this new age fisheries science by requiring that each filing be based on the unique habitat, hydrology and fish species associated with each stream.

To address this requirement, we use one or more of several widely accepted, scientifically based hydraulic and habitat models. Running these models requires data collection over several months and many more weeks of model calibration, data analysis, report writing and application preparation. The result is a unique flow recommendation for each stream. The science of instream flows has evolved considerably in the past 20 years and is continuing to improve today. One of the most important developments in this expanding science is the fact that not only are the flow needs of each stream and fishery unique; but, the frequency of availability that recommended flows are needed varies from stream to stream too. Consequently, the methods used when instream flow determinations first began 20 years ago (like the Tenant Method, 7Q10, and the New England Method) are not acceptable because they are based on simple hydrologic statistics and lack the ability to quantitatively analyze the specific habitat needs of each fishery.

7. All those extra meetings to go to.

The instream flow law requires the State Engineer's Office to hold public hearings for each instream flow filing. In addition to those meetings, the Game and Fish Department typically holds public information meetings about one week in advance of the scheduled hearing. The primary purpose of the information meetings is to help people participate more effectively at the hearing. The actual hearings are intended to gather public input on how the proposed filing might affect existing and future users.

One of the trends we've observed is that after a series of these meetings have been held, attendance at subsequent meetings seems to diminish. Probably the main reason for this is that people really don't like to go to meetings if they don't have to. And once people see that instream flows are administered like any other right, are junior to existing rights, really are a legitimate use of Wyoming's water that benefits a large cross-section of its citizens and by law can't negatively affect existing water uses, their motivation for attending yet another meeting seems to diminish. These meetings are very important because they demystify the process and help dispel biases that may not have been based on accurate information.

6. If an instream flow is issued, no one else can use that water in the future.

This actually is a fairly common comment that seems only natural to some people and absolutely absurd to others. Of course the obvious fact is that this is exactly correct. An instream flow is a water right that will be administered just like any other according to the State's "first in time, first in right" principle. This is a very important point because it does mean any other future water development project must consider the instream flow right just as it would any other senior right. This doesn't mean that the instream flow right will necessarily preclude future development, but, it does mean this particular use must be recognized just like all the rights that have been filed ahead of fisheries during the past 100 years. Of course it's also true that when water protected by an instream flow right leaves the designated segment it's fully available for other uses. An instream flow water right is not a higher value right nor is it a lessor value right than other water rights; but, it is a legitimate use of water.

The instream flow use is a valuable one considering that Wyoming anglers spent over $261 million dollars in 1994. That figure doesn't include revenues associated with any other recreational water users. Another hidden benefit is the enhanced value of land that has a trout stream running through it. People don't just come here to fish and go home. Many of them come here to make Wyoming their home and many of these new residents find that a good trout stream on a piece of land can drive the purchase price to pretty high levels.

5. All those complicated words.

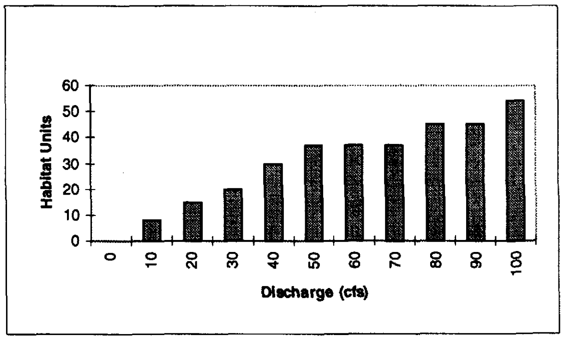
Section 41-3-1001(d) says that instream flows "shall be the minimum flow needed to maintain or improve the existing fishery". Although these words sound straight-forward enough, they can be a proverbial can of worms even to many fishery biologists.

To begin, a <u>fishery</u> is not just fish. Rather, a fishery includes all the biological, physical and chemical characteristics of a channel in addition to the people who use the stream. Our agency tries to manage all of these fishery elements by stocking fish, setting angling regulations and working with land management agencies to maximize fishery values. In this regard, instream flows are one more important tool we can use to manage fisheries by recommending flows that maintain the channel geo-morphology, clean sediments from spawning gravels, provide cool water temperatures and maintain adequate physical habitat for fish.

The existing fishery is another potentially confusing term. "Existing" fishery refers to some interval of time that may be instantaneous but may also apply to a longer interval. Fishery biologists know that the habitat, channel characteristics, water quality and fish populations of streams are all dynamic. That is, they exhibit both minimum and maximum levels over time. The table below shows an example of how trout populations in Sand Creek near Beulah varied over a 5 year period. If maintenance of this fishery were based on an instream flow that provided just the lowest trout density shown here, the present Class 1 status of this trout stream could not be maintained. Our perspective on "maintaining the existing fishery" is to file for flows that will maintain the existing dynamic characteristic of this and other streams. We don't expect stream flows to be high enough to maintain the highest number of fish every year and like any junior irrigator will accept whatever the flow is naturally even if it only supports a fraction of the maximum population. Our goal is to maintain natural stream flow patterns up to the specified amount on whatever frequency nature provides them because that will maintain the existing (dynamic) fishery.

Year	Number per Mile	Pounds per Acre
1977	646	48
1978	1,547	64
1979	4,060	143
1981	2,540	102

The minimum flow needed to maintain the existing fishery likewise has different meanings to different people. Too often, people think this means "the flow that maintains the minimum number of fish" or "the lowest flow that's ever been seen on a stream". Though fish can often survive for short periods at these low flows, this obviously is not the same as the minimum flow to maintain the existing (dynamic) fishery. The figure below shows one example of how this concept works for the Laramie River. In this situation, the normal late summer flow is about 60 cfs. According to the model used for this analysis, the minimum flow that will maintain this amount of habitat is 50 cfs.



4. Instream flows couldn't stop Tie Hack and couldn't build Deer Creek Dams.

In today's environment of public involvement, it is simply unrealistic to think that almost any water development project can be completed **without** including considerations for instream flows. In fact, the absence of instream flows for a project is an invitation for law suits and injunctions that can delay projects for years. Securing instream flows in advance of future water projects can actually facilitate development by letting potential developers know early in project planning exactly what the bypass requirements of their project will be and then design their project accordingly.

This is precisely the case with Tie Hack Dam where the City of Buffalo not only wanted to provide instream flows to maintain or improve the fishery on the Bighorn National Forest, they also wanted to improve flow levels through the city. Though they couldn't improve the flow situation in Buffalo, the project will maintain the existing fishery below the new dam and mitigate stream habitat losses caused by inundation by releasing specified quantities of water at different times of year. This project is one of the best examples in the history of the Water Development program where a project was developed to provide a wide range of multiple uses and still meet the primary needs of the project sponsor all because consideration for all those uses was included early in project planning.

In the case of Deer Creek, instream flow was and is an important issue, but, it was minor compared to others. If Deer Creek is ever built, the project must pass the daunting hurdle of securing the Supreme Court's blessing for developing the water. If built, the dam's water right will be senior to the instream flow right we filed for the stream below the dam. The instream flow right will simply ensure that once waters are released from the dam they will stay in the channel as long as they are in priority up to the amount requested. When releases from the dam are less than the recommended instream flow, there will not be a call placed on the reservoir because the instream flow is junior to the reservoir's right.

3. Haven't saved a single endangered species.

Wyoming only has one endangered fish species, the Kendall Warm Springs Dace and it lives in a spring along the Green River where instream flows aren't really an issue. However, Wyoming does have two native trout species, the Colorado River and Bear River cutthroat trout, that are teetering on the brink of listing because of significant habitat and population declines in the past 50 years. Keeping these species from being classified as T&E is in everyone's best interests because doing so keeps important decisions over issues like oil and gas development, timbering, grazing, road development and fisheries management at the state level instead of in Section VII consultation hearings. Certainly just having instream flows alone won't solve this problem, but recovery will be much more difficult without them.

In a broader sense, instream flows have been reasonably successful is maintaining some of the values that draw people to Wyoming. Though the changes aren't evident today, the protection provided by instream flows has been successful in protecting 327 miles of the best streams in the state. We've also used the law and the skills we've developed by working with instream flow water rights to resolve instream flow concerns on the Shoshone River in Cody and the Snake River in Jackson.

2. **Spend so much time hanging with SEO and WWDC I'm getting a reputation among the other biologists.**

Fifteen years ago this reputation might have been a bad one, at least among other biologists. In the "old" days, which really weren't that long ago, there was less trust and more unfamiliarity between the traditional water regulatory agencies and the Game and Fish Department. However, today's working environment necessitates that our agency work closely and regularly with the State Engineer's Office and Water Development Commission. Though our respective agency missions remain unchanged, the former "us versus them" mentality is being replaced with understanding and cooperation. As with almost any relationship, more communication improves the relationship by breaking down barriers and biases that have their roots in mistrust and incomplete knowledge. Whether it's submitting the application, reviewing the WWDC feasibility report or attending instream flow hearings, personnel from our respective agencies interact almost continuously.

An outgrowth of our these interactions has been the realization that we only have one constituency (the public) and in spite of the inherently different missions of our agencies, our overall goals are really quite similar. Water and related resources like fisheries all reside in a Public Trust which belong to all the citizens of the state and according to Public Trust Doctrine principles, it is our mutual responsibility to manage those resources for the well-being of everyone.

Though there are still some practical differences between our agencies, they're not so great that they generate the mistrust and suspicion of "hidden agendas" that we all looked for a short 10 years ago. The friendships and relationships that have developed improve the function of all our agencies by establishing lines of communication that are regularly used. The end result is improved function of our agencies, better resource management and a better-served public.

1. They're a taking!

Every year I receive calls from real estate developers and ranchers (old time and new ones alike) who are interested in converting some or all of an existing irrigation right to instream flow. Their reasons include everything from wanting to start up a dude ranch to just simply wanting to restore the stream to its natural character. I typically tell these people that such conversions are allowed by the law but if they are successful, they will have to give the instream flow right to the state. Not unexpectedly, most people don't pursue this idea any further at this point. About the only other comment I do hear is that because the water right is their property, the individual with whom I'm speaking thinks they should be able to do whatever they darned well please with it.

This provision of the law is a potentially serious problem because prohibition of private ownership of instream flow water rights limits what individuals can do with one of their most valuable property rights. In this regard, it has been suggested that this aspect of the law may be a legislated "taking". There is probably more interest in converting existing water rights to instream flow than most people might realize, especially considering that for every person who calls me, there are doubtless many more who don't call.

The issues associated with converting existing water rights to instream flow are very complicated; but, with ten years of instream flow experience, over 100 years of water law, a most capable State Engineer and his staff, an objective Water Development Commission and a willing Game and Fish department the problem is solvable. For the sake of those individuals who would exercise this option were it available, the legislature could consider dealing with this modification in the near future.

SUMMARY

Perhaps the greatest problems with Wyoming's instream flow law reside in the misinformation, biases, and suspicions that are harbored by people on both sides of this issue. Most people in Wyoming really aren't opposed to having fish in streams and many ranchers have always tried to sustain fisheries by letting a little water pass that they legally could divert to their crop lands. However while those individuals don't mind keeping a little water in the stream for fish on their own, they don't want a law that infringes in any way on their existing water rights. As this paper has tried to show, instream flows don't do that. Once most people realize that an instream flow is just another water right that doesn't impact existing water rights, their own "problems" with the instream flow law usually fall away.

Wyoming's instream flow law is basically a good one in spite of its many "problems". The law is an effective legal tool for helping the State more effectively exercise its Public Trust responsibilities to wisely manage the natural resources that belong to all of us. The law provides the State Engineer with another important tool to administer water and affords the citizens of Wyoming a reasonable opportunity to protect existing fisheries for future generations.

SESSION 10:

WATER MANAGEMENT

EFFECTIVENESS OF RESIDENTIAL WATER CONSERVATION PRICE AND NON-PRICE PROGRAMS IN URBAN AREAS IN THE WESTERN U.S.

Ari M. Michelsen, Thomas McGuckin, Donna Stumpf, Betty Olson, Luke Thelen, John Tschirhart, Steven Gloss, and Robert Ward[1]

INTRODUCTION

Municipal water conservation in the western U.S. is receiving increased attention by water managers, the public, professional organizations and the media as a means to balance water supplies and demand at reasonable costs. Both recurrent drought and projected long term demand-supply problems necessitate that municipal water suppliers plan for water conservation. However, the effects of conservation programs such as multi-part tariffs and uniform or inclining block rate structures upon residential water use in different regions is not well understood even though there is an extensive body of literature dealing with these questions. Further, the synergistic effects of price and non-price programs and persistence of program effects are not well studied and there is very little research literature that addresses these issues.

This report describes research conducted to evaluate the effectiveness of residential water conservation price and non-price programs in urban areas of the western U.S. The study encompasses seven cities in three states over a fifteen year period from 1980 through 1995. Additional information on the study areas and database documentation are provided in a separate report entitled ***Residential Water Consumption, Rate and Non-Price Conservation Program Database*** (1996) available through the AWWARF and The Powell Consortium (http://wrri.nmsu.edu/powell/).

BACKGROUND AND OBJECTIVE

Projected long term demand-supply problems and recurrent drought necessitate that municipal water suppliers plan and understand their options for water conservation programs and their effectiveness. Utility managers need to know how residential water demand changes or responds to changes in block prices and rate structures and to non-price conservation programs. This information is critical for selecting and incorporating demand-side management strategies that encourage conservation, manage cyclical drought induced supply shortages, make long-term demand forecasts, plan water supply and determine acquisition requirements, and formulate financial management decisions.

Most major utilities have already implemented programs to improve supply and delivery system efficiency and are not considering demand-side management measures. Demand-side management measures include both price and non-price conservation programs. Over the past decade an increasing number of utilities have changed from fixed price and declining block rate pricing to more conservation-oriented rate structures. Three examples are Los Angeles, Denver and Santa Fe. However, the effects of conservation price programs such as multi-part tariffs and uniform or inclining block rate structures upon residential water use in different regions, are not well understood. Further, the effects of non-price programs (such as public information, education, retrofit and regulations) and price and non-price program synergistic effects, if any, are not well known. The objective of this research is to provide a clearer understanding and regional assessment of price and non-price conservation program effects on residential water demand. The following four steps summarize the research procedure used for this study. The research and analytical methods applied are more fully described in the full report of the AWWWA-RF cited below.

Step 1. Conduct a literature review to identify the contributions and limitations of previous efforts in developing a core model of residential water demand and to evaluate regional price and non-price conservation program effects.

Step 2. Collect data required for the model for each of the seven selected study areas in three states in the western U. S. covering the period from 1980 through mid-1995. The seven study area cities are: Los Angeles and San Diego, California; Broomfield and Denver, Colorado; and Albuquerque, Las Cruces and Santa Fe, New Mexico. Data required for the model can be grouped into four major categories: 1)utility data; 2) climatological data; 3) socioeconomic data; and 4) non-price conservation program information.

Step 3. Develop, refine and document database of monthly observations for each variable consistent across all study areas. Reporting periods and units of measurement of use, price and other data varied both within and across cities over the period of study. Numerous computational adjustments were required to develop a consistent data series of monthly observations and to verify and correct anomalies in the collected data. The database developed for this research and data collection and adjustment procedures are described in detail in a separate report entitled ***Residential Water Demand, Price Structure and Non-Price Conservation Program Database*** (1996) available through the American Water Works Association and The Powell Consortium, Water Resource Research Institutes.

[1] Washington State University, Vancouver, WA; New Mexico State University, Las Cruces, NM; University of California, Irvine, CA; Wyoming Water Resources Center, UW, Laramie, WY; and Colorado State University, Fort Collins, CO, respectively.

Step 4. A statistical water demand model was tested and refined using the pooled time series cross-sectional data of the seven study areas developed in steps 2 and 3 above. The analysis proceeded in stages. In the first stage an ordinary least squares regression model is applied to the database. For the second stage, the cross sectional, time series model is tested and corrected as necessary for autocorrelation and heteroscedasticity. The third stage tests a city specific model against a more general regional formulation that does not have to be parameterized for individual cities. The fourth stage conducts standard t and F tests for variable significance. Significant coefficient values are analyzed for theoretical consistency and magnitude and price variables coefficients are analyzed for effect on use and for consumer recognition of conservation pricing programs. The model results are then examined for trends in regional water demand. Non-price conservation programs are evaluated for overall significance and effect of non-price conservation programs and for significance and effects of individual categories or types of non-price conservation programs. The model will also be used to examine and test for drought effects on residential use in southern California. The fifth stage compares the predicted results against actual quantities and trends in water demand for each study area.

PROJECT STUDY AREAS

This study encompasses seven cities in three western states - California, Colorado and New Mexico. The cities were selected because they are representative of other cities in the semi-arid western U.S.; several different rate structures and price levels have been implemented within individual cities and over time; the water utilities in these cities have implemented a variety of types and number of conservation programs, from many programs to none; the cities vary in size from small to large and in residential growth from slow to rapid; they vary in climate and precipitation seasons; and they include areas that have experienced drought as well as areas that have not. The cooperation and interest of the utility districts in these cities was also instrumental to their inclusion - this research could not have been accomplished without their enthusiastic participation and generous assistance. The study area cities and utility districts are:

CALIFORNIA

City of Los Angeles - Los Angeles Department of Water and Power

City of San Diego - San Diego Water Utilities Department

COLORADO

City and County of Denver - Denver Water

City of Broomfield - Broomfield Water Department

NEW MEXICO

City of Albuquerque - Albuquerque Water Utility Division

City of Santa Fe - Sangre de Cristo Water Company of Santa Fe

City of Las Cruces - Las Cruces Water Resources Department

RESIDENTIAL WATER USE, ACCOUNTS AND MONTHLY BILL

Total monthly and average account single family residential water use varies significantly among the study area cities. For example, over the two year period from April 1993 through April 1995, in Los Angeles, California total single family residential water use averaged 4.8 billion gallons per month or 12.4 thousand gallons per account per month. During the same period, total single family residential water use averaged 141 million gallons per month or just 7.1 thousand gallons per month per account in Santa Fe, New Mexico. The widest variation in monthly residential water use per account was observed in New Mexico, where annual average use ranged from 7,050 gallons per month in Santa Fe to 15,440 gallons per month in Las Cruces - more than double the monthly consumption. The total quantity of residential water consumed in a city is mostly a reflection of the size of the city and number of accounts. Variations in the quantity of water consumed per residence or account within and between cities are assumed to be related to several other factors such as price, rate structure, climate and socioeconomic conditions and various non-price conservation programs and these relationships are the focus of the water demand modeling and analysis.

Prior to the more detailed analysis it is helpful to have an understanding of the similarities and differences in water demand of the individual cities. The following table provides a summary of the total and monthly average, minimum and maximum residential water use, seasonal low and seasonal high water use and total and monthly average revenue per account of each study area over the period from April 1993 through April 1995.

Table 1. Water Use Statistics for Single-Family Residential Accounts by Study Area
April 1993 through April 1995 (1,000 gallons, G)

Statistic/ Study Area	Total Monthly Use (G)	Number of Accounts Per Month	Monthly Use Per SF Res. Acct (G)	Monthly Summer Use (G) per Acct.	Monthly Winter Use (G) per Acct.	Total Monthly Revenue $ (000)	Monthly Bill $ Per Account
LOS ANGELES							
Minimum	3,166,749	382,819	8.26	14.92	8.25	8,054.1	21.00
Maximum	6,526,893	394,331	16.71	16.7	11.03	17,298.4	44.28
Average	4,829,456	388,752	12.41	15.72	9.48	11,949.7	30.71
Avg. Drought			11.18	13.96	9.17		
SAN DIEGO							
Minimum	1,167,204	193,836	5.98	10.70	6.62	2,068.8	10.49
Maximum	2,875,050	197,307	14.79	14.79	8.82	5,443.9	28.00
Average	1,832,807	195,732	9.36	12.56	7.68	3,689.7	18.85
Avg. Drought			8.00	10.51	6.99		
DENVER							
Minimum	664,360	119,429	5.74	16.46	6.10	960.9	7.99
Maximum	3,147,242	121,085	27.37	27.37	6.51	3,912.9	32.45
Average	1,407,319	120,284	11.93	21.51	6.28	1,736.7	14.44
BROOMFIELD							
Minimum	44,161	7,338	5.23	12.77	5.23	130.1	16.07
Maximum	181,373	8,542	21.28	21.27	6.77	396.8	46.55
Average	91,367	8,033	11.42	17.97	6.18	220.7	27.55
ALBUQUERQUE							
Minimum	785,980	104,207	7.31	19.99	7.31	1,159.3	10.81
Maximum	3,064,545	107,928	27.58	28.60	8.70	2,939.5	26.63
Average	1,581,529	106,270	14.91	24.03	7.95	1,756.7	16.64
SANTA FE							
Minimum	82,162	19,463	4.11	7.56	4.77	392.8	19.67
Maximum	245,697	20,586	12.17	12.16	5.79	960.1	47.53
Average	141,003	20,037	7.05	10.01	5.26	596.7	29.82
LAS CRUCES							
Minimum	126,012	16,227	7.50	19.46	7.50	167.4	10.10
Maximum	495,477	17,260	29.07	29.07	9.25	552.8	32.44
Average	258,892	16,798	15.44	23.46	8.37	293.6	17.49

Source: Residential Water Use, Rate Structure and Non-price Conservation Program Database (1996).
Notes: Dollar values are in nominal terms. Period of drought defined as 1/91 though 3/93 (Water Providers).

Across the region, average monthly summer use is 1.5 to 3.4 times greater than the average monthly winter/minimum water use. For example, during the winter, average monthly use per single family residential account in Denver was 6,280 gallons; during the summer the average monthly use per account increased to 21,500 gallons. This cyclical seasonal demand pattern can be observed in each of the cities as illustrated by the graph of Denver's monthly average water use per single family residential account shown in the following figures.

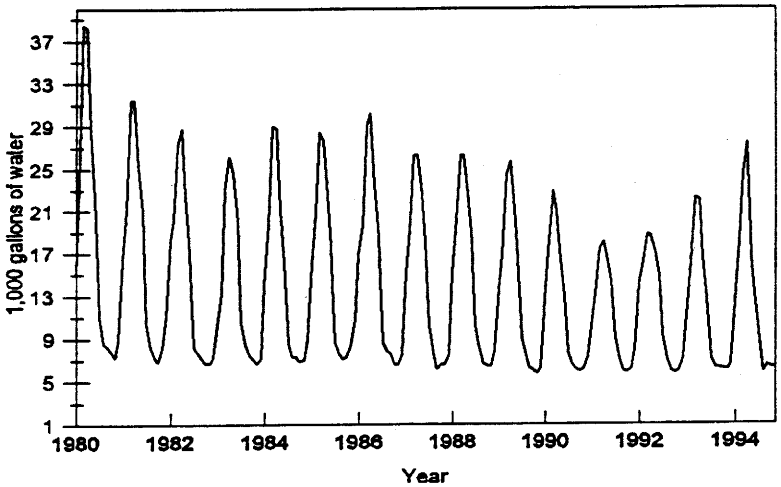


Figure 1. Denver Use per Account 1980-1995

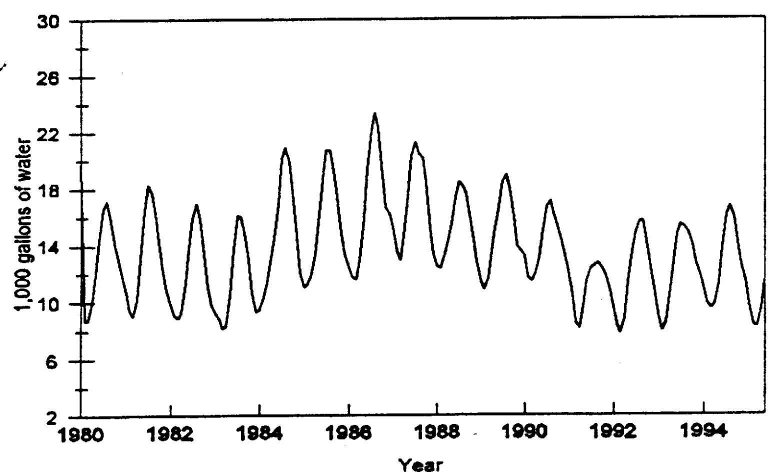


Figure 2. Los Angeles Use per Account 1980-95

The table also shows the average monthly residential water use for Los Angeles and San Diego during the most recent severe drought. Although the impact of the drought on water supplies in California lasted for several years, the impact on consumers was buffered by storage capacity. The period of the drought that directly affected water users was defined by the California water providers as January 1991 to March 1993. During this time, a number of price and non-price conservation programs, including temporary mandatory restrictions, were implemented by the California utilities to encourage immediate reductions in water consumption.

The quantity of water used and the different utility rates in each city resulted in a wide range in the amounts of average monthly bill or cost per account. Annual average monthly bills per single family account range from approximately $15.00 for residences in Denver consuming the recent average of 11.9 thousand gallons per month to almost $31.00 per residence in Los Angeles consuming 12.4 thousand gallons per month. For many of the areas, the average maximum monthly bill is more than three times the average minimum monthly bill.

NON-PRICE CONSERVATION PROGRAMS

A myriad of non-price conservation programs have been implemented by water utilities in the seven study area cities with the expectation that they will encourage either short-term and/or long term reductions in residential water use. Residential non-price conservation programs that have been implemented include television and radio announcements on the importance of conserving water, newspaper articles and advertisements, bill inserts, public distribution of conservation literature, school visits, speakers bureaus, school poster contests, educational video tapes, widespread distribution of retrofit devices, selected installation of retrofit devices, residential audits, water efficient appliance rebates, xeriscape demonstration gardens, metering programs, lawn watering guidelines and regulations, revised plumbing codes, and emergency ordinances and regulations. It cannot be overstated that the availability, level of detail, accuracy and consistency of information about non-price conservation programs maintained by water and other utilities is highly variable.

In order to evaluate, verify and quantify the effectiveness of individual non-price conservation programs, it is necessary to have accurate information about specific program activities, levels of effort, scope and coverage and the exact periods of program duration corresponding with activities and levels of effort. This information was often difficult or impossible to obtain from existing utility records.

For example, we found that similar or a number of different smaller programs were often aggregated and reported as one single or a joint set of programs without descriptions of individual programs or dates of implementation and measures of specific program efforts. For example, reports would simply state that several different education programs were implemented over a period of years (and without further documentation it was assumed they were effective). Aggregation was particularly common in the reports of education and public information programs. Among the non-price conservation programs, retrofit programs requiring significant utility expenditures for the distribution or installation of physical (easily countable) devices typically had the best documentation.

Programs targeted to influence a particular type of residential water demand are often conducted for periods of one month or less or for only a few months, however, the duration of these and other non-price conservation programs were usually reported on an annual rather than a monthly basis. Reporting these programs on an annual basis diminishes the ability to correlate individual programs with specific changes in water demand.

The non-price conservation program information that is available is often reported in different terms or measures over time within a utility (because of changes in reporting methods, focus or personnel) and almost always with different descriptions and measures than are used by other utilities. Because of the differences in definitions and measures and missing or unavailable information it was not possible to develop variables for this analysis that would accurately reflect the scope and level of effort of each of the individual non-price conservation programs or types of programs that would be comparable over time and/or between utilities.

Although it is recognized that utility resources are limited and non-price conservation program documentation can be a difficult and time consuming (costly) task, we strongly recommend that resources be dedicated to developing and maintaining detailed, consistent documentation of non-price conservation programs and efforts. This will enable water utility managers in the future to better monitor, evaluate and document the effectiveness of their non-price conservation programs and efforts, document the effectiveness of their non-price conservation programs and to implement the programs that will best suit their needs.

EFFECTIVENESS OF NON-PRICE CONSERVATION PROGRAMS

Among the five non-price conservation program categories, only the Ordinance (ORD) variable coefficient (city ordinances mandating water efficient household construction) was both significant and held the correct sign (negative or a reduction in water demand). The retrofit (RETRO) variable was significant, but held an incorrect sign (positive) and both the Public Information Program (public) and Temporary Restriction (Restrict) variables tested insignificant. Education programs (Educ) and public awareness programs had conservation effects (negative sign) but the coefficients were not statistically significant. Although temporary mandatory restrictions were not statistically significant, this result may be more a function of correlation of these programs with the period of drought in California. In addition, there is a systematic and significant long-term trend of declining residential use (per household). The variable (Time) is significant and negative. This trend may be attributable to the accumulative effect of conservation programs and drought.

CONCLUSIONS

Consumers respond to the average price of water. Due to a general lack of information regarding water pricing at the consumer level, inclining block-rate structures do not appear to influence single-family residential water use. Consumers are simply responding to the only piece of information they receive, the total bill. It can therefore be deduced that utilities employing inclining rate structures may be in effect assuming that such structures encourage consumers to reduce water use levels.

The importance of the marginal price depends on its weight in determining the overall average price and thus in determining single-family residential use. The consumer response to a price change depends on the relative combination or service charges and marginal price. The higher the service charge is to marginal price, the lower the response. For Los Angeles, with a zero service charge, the increase in marginal price has the highest reduction in use (an elasticity at -0.43). For other cities, the service charge dilutes the impact of an increase in the marginal price, and the elasticity estimates are lower. General elasticity is -0.30 to -0.40 depending on the size of the service charge.

Though utilities can raise the average price by increasing the service charge, the reduction in use is small. For a $1.00 increase in service charge, the change in use is less than one percent.

Conservation programs are less reliable in achieving reductions in use. Statistical analysis of conservation programs, as a whole, indicate that they do not significantly reduce single-family residential water use. Specific programs may be more successful. Of the broad categories of conservation programs, ordinances that mandate the installation of low-flow devices and education programs for public schools appear to be the most effective. In addition, there is a systematic and significant long-term trend of declining single-family residential use (per household). This trend may be attributable to the accumulative effect of conservation programs and drought.

The January 1991 through March 1993 drought in California resulted in a temporary 23% reduction in water use. It is not clear whether this effect has resulted in a permanent shift in use patterns. As a result of the drought, both Los Angeles and San Diego have implemented significant real price increases. A lasting reduction in water use may be attributable to these policies rather than the drought effect.

A straightforward demand model of water use (incorporating average price, marginal price, income, temperature, precipitation and time as explanatory variables) is very effective in predicting short term seasonal variations, long-term trends, and differential water price levels between cities.

RECOMMENDATIONS

The importance of detailed conservation program information cannot be stressed enough. Utilities need to record every detail surrounding the implementation of conservation programs. Pertinent information includes: 1) a thorough description of the scope of the program, 2) precise date of implementation, 3) the period of coverage (i.e. annually, summer months, school year), 4) the number of customers contacted/reached on a monthly basis, 5) the intensity of the program (i.e., number of classroom presentations, number of students attending, etc.), 6) the level of expenditures on a monthly basis and 7) estimated effectiveness.

A necessary program to be included in any utilities conservation plan is one that focuses on conveying detailed rate structure information to consumers. Because the results of this analysis indicate that single-family residential water users are responding to average price it can be concluded that consumers are completely unaware of the rate structure they face. If consumers are made knowledgeable of such information, they will be better equipped to make informed decisions regarding their seasonal use levels.

The pricing structure with the most potential for decreasing water use is the simplest – a uniform rate.

REFERENCES

Agthe, D. E., R. B. Billings, J. Dobra and K. Raffiee,. 1986. "A Simultaneous Equation Demand Model for Block Rates," *Water Resources* 22(1): 1-4.

Agthe, Donald E. and Bruce R. Billings. 1980. "Dynamic Models of Residential Water Demand," *Water Resources Research* 16: 476-480.

Billings, R. V. and D. E. Agthe. 1987. "Equity, Price Elasticity and Household Income Under Increasing Block-Rates for Water," *American Journal of Economics and Sociology*, 43(3): 273-286.

Billings, R. B. and D. E. Agther. 1980 "Price Elasticities for Water: A Case of Increasing Block Rates," *Land Economics* 56(1): 73-84.

Billings, R. B. and W. M. Day. 1983. "Elasticity of Water: Policy Implications for Southern Arizona," *Arizona Rev.* 31(2): 1-11.

Brown and Caldwell (1986).

Cameron T. A. and M. B. Wright. 1990. "Determinants of Household Water Conservation Retrofit Activity: A Discrete Choice Model Using Survey Data," *Water Resources Research* 26(2): 179-188.

Chicoine, D. L., S. D. Delles and G. Ramamurthy, G. 1986. "Water Demand Estimation Under Block Rate Pricing: A Simultaneous Equation Approach," *Water Resources Research* 22 (1): 859-863.

Foster, H. S. and B. R. Beattie. 1979. "Urban Residential Demand for Water in the United States," *Land Economics* 55(1): 43-58.

Green, William H. 1993. Econometric Analysis, 2nd ed. New York: Macmillan Publishing Company.

Judge, George G., William E. Griffiths, R. Carter Hill and Tsoung-Chao Lee. 1980. The Theory and Practice of Econometrics, New York: John Wiley and Sons.

Maddaus, William O. 1987. *Water Conservation*, American Water Works Association, ISBN 0-89867-387-9.

Martin, William E., H. M. Ingram, N.K. Laney and A. H. Griffin. 1984. "Saving Water in a Desert City" in *Resources for the Future*. Washington, D. C.

Martin, William E. and Susan Kulakowski. 1991. "Water Price as a Policy Variable in Managing Urban Water Use: Tucson, Arizona," *Water Resources Research*, 27(2): 157-166.

Nieswiadomy, Michael L. and David J. Molina. 1991. "A Note on Price Perception in Water Demand Models," *Land Economics* 67(3): 352-359.

Shin, J. S. 1985. "Perception of Price When Information is Costly: Evidence From Residential Electricity Demand," *Review of Economic Statistics* 76(4): 591-598.

Stevens, T. H., Jonathan Miller and Cleve Willis. 1992. "Effect of Price Structure on Residential Water Demand," *Water Resources Bulletin* 28(4): 681-685.

Tschirhart, John T. 199. Personal conversation.

WATER MANAGEMENT IN AN UNREGULATED RIVER SYSTEM: THE LITTLE SNAKE RIVER OF SOUTH CENTRAL WYOMING

John Boyer[1]

I wanted to be a part of this conference and went to the trouble of gathering data for this paper because my opinions, views, and feelings about water development are clearly in the minority. There is a relationship between the work we do at the Retreat Center and my views of how water development should or shouldn't take place. My times fasting in the desert or mountains of Wyoming or South Dakota have given me insights, understanding, and courage. It is not easy being here saying the things I am going to say, to ask the questions that I will ask. I hope you will all be open minded. And if am not correct in some of my judgments or views, especially in parts of the Valley that I don't know as intimately as the Savery Creek, I ask your understanding.

My interest in how water is managed in the Little Snake River Valley has only recently evolved since my return to the Valley in 1986 to create a retreat center on the ranch where I grew up. The way that I think now is very different than the way I thought when I was growing up on the ranch. I spent my childhood working with and for my father in his sheep operation. We rushed about our business, we used the land, we "cruised over it"--- we were not in it.

I am reminded of a wetland complex on our property, which consists of several acres of bog, willow, and shrubs, which abut both the barnyard area and the lower hay fields. As a child, we always talked about obliterating these wetlands to create a few more acres of hay field. Well, I must say that I am grateful that we never did anything to these wetlands--they are thriving as we speak. And I marvel at how my attitude towards them has evolved over the last 35 years.

How is it that we think about things? What are our primary needs, our secondary or supplemental needs? How do we justify them or evaluate them to know that they are critical to our survival? And how do our thoughts and beliefs about these needs influence our consideration of such things as habitat/ecosystem health, upstream-downstream, headwaters-end waters. ***What we think about them usually directly reflects how we feel about them, or vice versa.***

But now to the nuts and bolts of how the valley water system operates: for convenience I have broken the valley into segments or areas in order to describe flows , water rights, agricultural use and then correlate these aspects to the data from gauging stations. The Upper Little Snake River is all the lands and tributaries east and north of the confluence of Savery Creek and the Little Snake River. The Savery Creek includes all the tributaries and lands along the Savery Creek. The Lower Little Snake includes the lands and tributaries from below where Savery Creek comes in and down to the section of the river where the last ranches in Colorado or Wyoming draw water out for irrigation. [Detailed Map will be Available at Conference]

The flows in the valley vary enormously from year to year, depending on snow pack, melting rates and rainfall. The 73 year average flow through the gauge near Lily Colorado, which is near the confluence of the Yampa and the Little Snake, is 415,200 acre feet. It has been as high as 1,000,000 and as low as 200,000. The Upper Snake River as measured by the gauge near the Focus Ranch in Colorado, has provided 164,500 acre feet averaged over 51 years or about 40% of the volume year to year. Most of the water in this part of the basin comes from the Roaring Fork , the West Fork, the North Fork, the Middle Fork and the South Fork (and their smaller tributaries) of the Little Snake River. The lower portion of the Upper Snake River is fed mainly by Battle Creek and some smaller tributaries. About 30% of the annual flow through the system enters in this area of the river. The Savery Creek and its tributaries provide about 20% of the flow to the system annually or about 75,000 acre feet per year. The remainder of the input to the system (about 10 %) comes from a number of small tributaries between Savery and the Lily gauge-- these tributaries provide input to the system primarily in May and June during spring runoff or heavy rain episodes. For most of the year the tributaries in this part of the system are dry. [2]

The adjudicated water rights for irrigation in the Little Snake system far exceed the actual lands irrigated. The Upper Snake River (as defined above) has rights to irrigate 7705 acres, which represents about 25% of the total adjudicated acreage in the system. It is interesting to note that this same area provides about 70% of the annual flow to the system. The Savery Creek has adjudicated rights to irrigate 5737 acres or about 20% of the total adjudicated acreage in the system. The actual irrigated acreage is about 2200 acres along the lower reaches of the Savery Creek. The Lower Snake (as defined above} has 53% of the adjudicated acreage or 15,504 acres. Again it is interesting to note that only 10% of the supply enters the system where 53% of the irrigating could take place if all these lands were irrigated. The actual irrigated acreage in the whole system is presently estimated to be between 12000 and 14000 acres compared to a total of 28,946 adjudicated acres. The estimated irrigated acreage outside the Savery Creek is between 9800 and 11,800 acres. About 25% of these acres are in the Upper Snake (Savery and above) and 75% are in the Lower Snake

[1] PO Box 156, Savery, Wyoming, 82332

[2] USGS Gauging Data, Wyoming Water Resources Center, UW.

(Savery and below). There are also more than 200cfs of rights for the city of Cheyenne and numerous stock reservoir rights in the system. [3,4]

Actual consumption in the system is hard to estimate. Withdrawals during high runoff in May and June certainly exceed 1000 cfs which is six times the adjudicated right--everybody in the system is happy during high runoff, flumes [where they exist] are often submerged and the irrigators wear tall boots and irrigate in a frenzy. The problems and pressure in the system begin to develop as the supply and demand curves meet in late June early July. Management of the system is mysterious. A full time water commissioner has worked in the valley only during the last four years, partly driven by the fact that a supplemental supply reservoir may be built in the system, partly because we live in the 20th century and some regulation might be in order. But there is no regulation. The height of the river and where ones diversion structure is in the system determines ones level of consumption in July, August, and September. The major canals and the headgates close to rivers or tributaries with water in them get the water. It is not uncommon for the Little Snake to have 100 -200 cfs of water in it above the two major canals (First Mesa and West Side) and be essentially dry at the Dixon gauge. And even in this scenerio, only the irrigators in the upper parts of these canals get any water. Late season irrigation water for fall pasture is only presently available for a few irrigators in the upper part of the Savery Creek and the Upper Snake River (above Savery) and a few people along the large canals. And it is not clear that even with a new supplemental storage reservoir for late season irrigation, that distribution and availability to a significantly larger group of irrigators would evolve.[5]

Given that this is an agricultural community and the water available in the system is used almost exclusively for irrigation, some discussion is in order about how this priority relates to other aspects of the Little Snake River system, such as ecosystem health, fisheries conditions, riparian habitat conditions, and a variety of other upstream and down stream alterations to the overall environment. What has been created by 150 years of irrigating in this valley? How have the environmental conditions in the valley changed over time? Can we still reconstruct how it might have been 150 years ago, or 50 years ago, or 25 years ago? Is it important to reconstruct. It depends on ones views.

In general, and these are my views, the environmental condition of the land and river habitat in the areas, where crop production and livestock operations have dominated, are badly deteriorated. The fisheries in the lower reaches of the Savery Creek and almost all of the Lower Snake River (Savery and below) are very marginal or non existent. The existent and best fisheries are in the headwaters of the Savery Creek system and the tributaries of the Upper Snake. Fishing on the mainstem of the Upper Snake is fair to good in certain reaches depending on flows, whether or not stocking takes place, and how the riparian habitat is managed in conduction with livestock operations. Good self sustaining fisheries exist only in the headwaters of the Savery and the Upper Snake. Old timers in the valley reminisce about the quality of the fisheries, especially in the middle reaches of the Little Snake-- and they feel that it has deteriorated significantly over the last 50 years.

The condition of such things as wetlands, willow and cottonwood habitat, riparian habitat along the stream banks, is badly deteriorated in all of the river bottoms of the Savery and Little Snake where hay production and livestock operations exist. Over the years, the river channel has been significantly altered mainly by bulldozing large volumes of gravel and boulders out of the stream channel and up along the banks to reduce flooding during high flows. The result it that the wetlands, willow communities, and cottonwood forests have no natural way of rejuvenating themselves. The cottonwood forests are severely deteriorated and consist primarily of older trees, except in areas where natural flooding can still occur and young cottonwoods can take root. I have personally walked many miles of the Savery creek, and there are very few areas where significant numbers of young cottonwoods are coming along. The condition of the cottonwood forest in the area of the proposed Sandstone dam was recently assessed as a part of the EIS and the picture painted by the "experts" was not a pretty one. It was described as "severely deteriorated." There is no hay production on this part of the Savery, so this deterioration is driven entirely by how the livestock operations are managed. This area of the river has been severely abused by cattle and horse grazing.

And now to the larger issue at hand. What form of water management should be put in place in a system like the Little Snake? Should it be different than it is now? If a supplemental storage reservoir is built, should management practices be different? Clearly these are difficult questions, especially for the ranchers who have lived in the valley for a long time and are use to having little to no regulation. If more water is available from storage during low flow, should all of it go to irrigators? Clearly the environmental conditions in the valley as a whole need to be addressed and the management practices for crop production and livestock operations need to become more holistic. Some of these practices are already underway in terms of how riparian areas are grazed and managed in the Muddy Creek and Loco Creek areas and on a few ranches in the valley. But change on a large scale will be slow in coming. Is it possible to begin restoring the fisheries in the lower

[3] Water Rights Tabulation Book, Board of Control, Saratoga, WY
[4] Personal communication, Soil Conservation Office, Baggs, WY
[5] Measurement Data in LRRV, Board of Control, Saratoga, WY

reaches of the Savery Creek and the middle portions of the Snake River ? Can we begin to encourage the regeneration of the cottonwood forests in the whole Little Snake system? Can minimum stream flows in the whole system be a condition, if supplemental storage becomes a reality? Clearly the answer to a lot of these questions is yes, if you are in the minority or a part of the conservation groups of the state. But to many it is anathema, invasive, and unfair even to consider many of these things. This is what we are in the midst of now. We need to sit in the fire, however we think, whatever the position we have.

When I came back to Wyoming in 1986, after a 20 year absence, my desire was to create a place where people could slow down and learn about their connection to the land, to the earth, to the real mother. It is not an accident that I would return to Wyoming to begin a new "sort of spiritual phase" of my life and almost instantly have the whole prospect of the Sandstone Dam and all of its related issues thrust in my face. It was not a coincidence. It has been a test for me--to see if the values that I have about the earth are real. I really believe the prophesies that some of the Native Americans have about man's survival on the earth. I have held these beliefs in the back of my mind as we at the Retreat Center and members of my extended family have faced the hurdles of the 404 permitting process for a water development project in the valley. We have felt very alone and isolated--but we have persevered. Any large scale reservoir will not seem right to me, will not be appropriate for whatever piece of habitat that will be impacted by it. I am pleased that there are small scale projects like the Muddy Creek and Loco Creek projects. These are small scale, non destructive, and very effective in terms of improving very local habitat conditions for local industries. I have always wondered why the local politicians, members of the Water Development Commission, and the staff of the Commission didn't push for $15-20 million of funds for riparian habitat improvement and grazing system projects. They have really worked. They allow the natural system to operate in a way that allows us humans to use it and improve it at the same time. Wow!

I have always been very intrigued by the way the permitting process for a supplemental supply reservoir has worked. In all of the meetings from the beginning of the process, there has been a huge resentment by a majority of the players about having to follow the 404 guidelines. To our relief and the dismay of many, these guidelines have provided our only safety net. Without them, not much about the Sandstone and other sites would have been assessed. Wetlands, cottonwoods, hydrology, and many other particulars would not have been assessed. The alternative site analysis process and the requirement of choosing the Least Environmentally Damaging Alternative [LEDA], really did result in "due consideration." Why shouldn't the site that is ultimately chosen be the one that causes the least environmental damage? Otherwise it would be sort of like a cancer patient arbitrarily choosing the treatment with the most bad side effects, when other equally effective but less damaging treatments are available.

And somehow our perspective about water development is never quite large enough from my point of view. How do we keep expanding picture that we look at? How do we glean the essential truths of the larger picture and then apply them to the little pieces of the picture? How is water management/development in the Little Snake River Valley related to conditions up and down the whole system? What should we [be forced to] consider? I want to close with some data and a quote I came across recently in a World Watch Paper.[6]

A low altitude flight over the Colorado River Delta, not far from where the Cocopa traditionally harvested their nipa, reveals the dry channel of the Colorado, which still traces the river's meandering path to the sea. This is the place where, for millennia, the river deposited its rich load of silt and supported a diverse ecosystem before delivering its treasure of nutrients to the Upper Sea of Cortez. It is the place where American naturalist Aldo Leopold journeyed by canoe in 1922 and reported seeing deer, quail, raccoon, bobcat, and vast fleets of waterfowl. The winding river, slowing as it spread out through countless green lagoons, later led Leopold to muse, "for the last word in procrastination, go travel with a river reluctant to lose his freedom in the sea."

Leopold never returned to the delta for fear of finding this "milk and honey wilderness" badly altered--and his fears were justified. Today, the Colorado's freedom has been lost to a degree even the prescient Leopold could scarcely have imagined. Only in years of extremely high precipitation in its watershed does the Colorado run all the way to the sea. In most years, what remains of its flow after ten major dams and several large diversions is a trickle that literally disappears into the desert of northern Mexico, [See figure 1.] Much of the delta's once abundant wildlife is gone, Fisheries in the Sea of Cortez have declined dramatically. And the native Cocopa way of life is threatened with extinction.

---

[6] World Watch Paper 132, Dividing the Waters: Food Security, Ecosystem Health, and the Politics of Scarcity, Sandra Postel, Sept., 1996.

The condition of the Colorado River syetem at its mouth has obviously been altered to an extent that is incomprehensible. And we as humans all along the system are responsible. Are we really capable of managing this water system differently? What do we all have to do so that the orginal conditions, as Aldo Leopold saw them in 1922, might be restored. Are we even willing to think about it? I hope so!

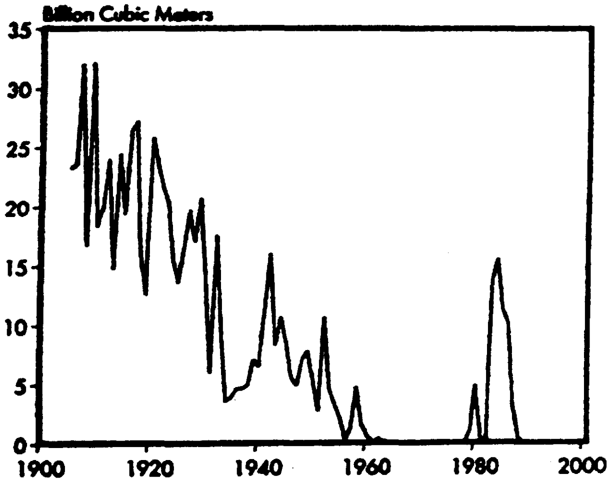


Figure 1 Flow of the Colorado River below All Dams and Diversions, 1905-1992

WYOMING WATER 1997
POSTER DISPLAYS

Note: Write-ups for Beryl Churchill's and Barry Lawrence's poster presentations are presented in sessions 5 and 6, respectively.

CITIZEN'S NETWORK FOR MONITORING GROUNDWATER QUALITY IN GOSHEN COUNTY, WYOMING: AN EDUCATIONAL AND OUTREACH PROJECT

Chris M. Goertler, Katta J. Reddy, Jack T. Cecil, Charlene Stephenson, and Joe G. Hiller[1]

INTRODUCTION

Approximately 75% percent of Wyoming's population uses groundwater as their primary drinking water source. This water resource is also frequently used for livestock watering throughout Wyoming and the semi-arid West. Groundwater, however, can become quickly contaminated through the application of fertilizers and pesticides. Therefore, a cooperative study involving local citizens, the Wyoming Cooperative Extension Service, and the Wyoming Water Resources Center was begun in 1993 to assess the concentrations of nitrate, atrazine, and aldicarb in the groundwaters of Goshen County, Wyoming; one of the more concentrated agricultural areas in the state.

RESEARCH OBJECTIVES

1) Establish citizen's monitoring networks forpesticides in groundwaters of Goshen County, Wyoming
2) Monitor the concentrations of atrazine and aldicarb in the groundwaters of Goshen County, Wyoming
3) Increase the environmental awareness and education of local citizens on the importance of water quality

METHODS

Wells chosen for sample collection were located throughout the study area along the North Platte River Valley upstream and downstream of the town of Torrington, Wyoming (Figure 1). Wells were selected with the assistance of local Wyoming Cooperative Extension Service personnel and thirteen landowners were chosen as cooperators.

The rapid enzyme immunoassay technique was utilized to determine the concentrations of atrazine and aldicarb in groundwater samples collected during March, May, and July before, during, and after the growing season. Sample analysis was conducted within 24-hours of collection at the Torrington Research and Extension Center. Nitrate samples were collected concurrently and analysis was performed at the Wyoming Water Resources Center's Environmental and Water Quality Lab located on the University of Wyoming campus using the ion chromatography technique. All samples were maintained at a cooler temperature (approximately 2°C) prior to analysis.

RESULTS

Project results are presented in Table 1. The pH of all groundwater samples was recorded within the Environmental Protection Agency (EPA) suggested ranges of 6.5 - 8.5. Atrazine was detected in 85% of the groundwater wells sampled, but in only 31% of the wells during all three sampling periods. Aldicarb was recorded in all groundwater wells during the May and July sampling periods, but was recorded in only one well, at 0.01 parts per billion (ppb), during March prior to planting.

Nitrate-N concentrations ranged from non-detectable levels to a high of 53.6 parts per million (ppm), above the EPA's recognized safe drinking water limit of 10 ppm. However, nitrate concentrations did decline after the growing season.

DISCUSSION

Both atrazine and aldicarb have been used as pesticides in Goshen County, Wyoming though atrazine has been classified by the EPA as a restricted-use pesticide, meaning all applicators must be licensed. This research suggests that pesticide levels are well below the EPA's recognized safe drinking water limits although concentrations of both pesticides tended to increase as the crop growing season progressed.

Nitrate, however, continues to be a problem in the Goshen County, Wyoming area. Groundwater wells located outside of the North Platte River floodplain had the highest nitrate concentrations reaching approximately five times the EPA recommended limit during the crop growing season. Wells located within the North Platte River floodplain appear to have reduced concentrations of nitrate as groundwater moves through the aquifer diluting and moving nitrate further downstream.

Landowner cooperators were informed of the research results and at least one has since altered the type and application of fertilizer to his fields in an effort to reduce nitrate levels in the area. Landowners making changes on their own, without coercion from outside sources, is an indication that this educational and outreach effort was successful.

ACKNOWLEDGMENTS

We wish to acknowledge the Environmental Protection Agency Region VIII for their financial contribution to this study. We also want to recognize the cooperation of the thirteen landowners, for without their kindness in allowing us access to their wells, this study would not have been possible.

[1] Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, WY 82071; WWRC; Torrington Research and Extension Center, Rt. 1, Box 374, Torrington, WY 82240; R&E Center, Torrington; and Wyoming Cooperative Extension Service, Box 3354, University Station, Laramie, WY 82071, respectively.

Table 1. Groundwater data for pH, nitrate, and pesticides; A= before planting, B = during crop growth, C = after the harvest, † = not detected and below 0.01µ L^{-1}, ‡ = not detected and below 1mg L^{-1} of nitrate. Wells are numbered 1-13 and their relative locations are identified on Figure 1.

	pH			Atrazine			Aldicarb			Nitrate as Nitrogen		
EPA Limit	6.5-8.5			3 (µ L^{-1})			10 (µ L^{-1})			10 (mg L^{-1})		
	A	B	C	A	B	C	A	B	C	A	B	C
Well # 1	7.0	7.0	6.9	ND†	ND	ND	ND	0.03	0.07	1.08	ND‡	ND
2	7.1	7.2	7.1	0.27	0.29	0.45	ND	0.04	0.14	11.5	12.8	6.6
3	7.0	7.1	6.7	ND	ND	0.03	ND	0.04	.07	1.8	3.8	11.1
4	7.1	7.1	6.9	ND	ND	ND	ND	0.04	0.07	17.4	27.4	4.4
5	7.1	7.1	7.0	0.51	0.78	0.73	ND	0.04	0.10	13.3	15.1	9.2
6	7.2	7.3	7.0	0.07	ND	0.02	ND	0.02	0.12	21.8	49.1	13.6
7	7.1	7.1	7.0	0.23	0.15	0.03	ND	0.04	0.19	6.0	3.5	3.1
8	7.3	7.3	7.0	ND	ND	0.08	ND	0.05	0.09	3.6	1.9	1.7
9	7.2	7.2	7.0	0.31	0.31	0.23	ND	0.03	0.15	20.3	53.6	11.9
10	7.1	7.2	7.0	0.01	ND	ND	0.01	0.03	0.15	4.35	3.0	3.34
11	7.1	7.0	6.8	0.04	ND	ND	ND	0.04	0.10	0.6	ND	ND
12	7.3	7.0	7.1	0.04	ND	ND	ND	0.04	0.10	5.88	1.9	3.56
13	---	7.1	6.8	---	0.08	ND	---	0.02	0.15	---	3.75	4.35

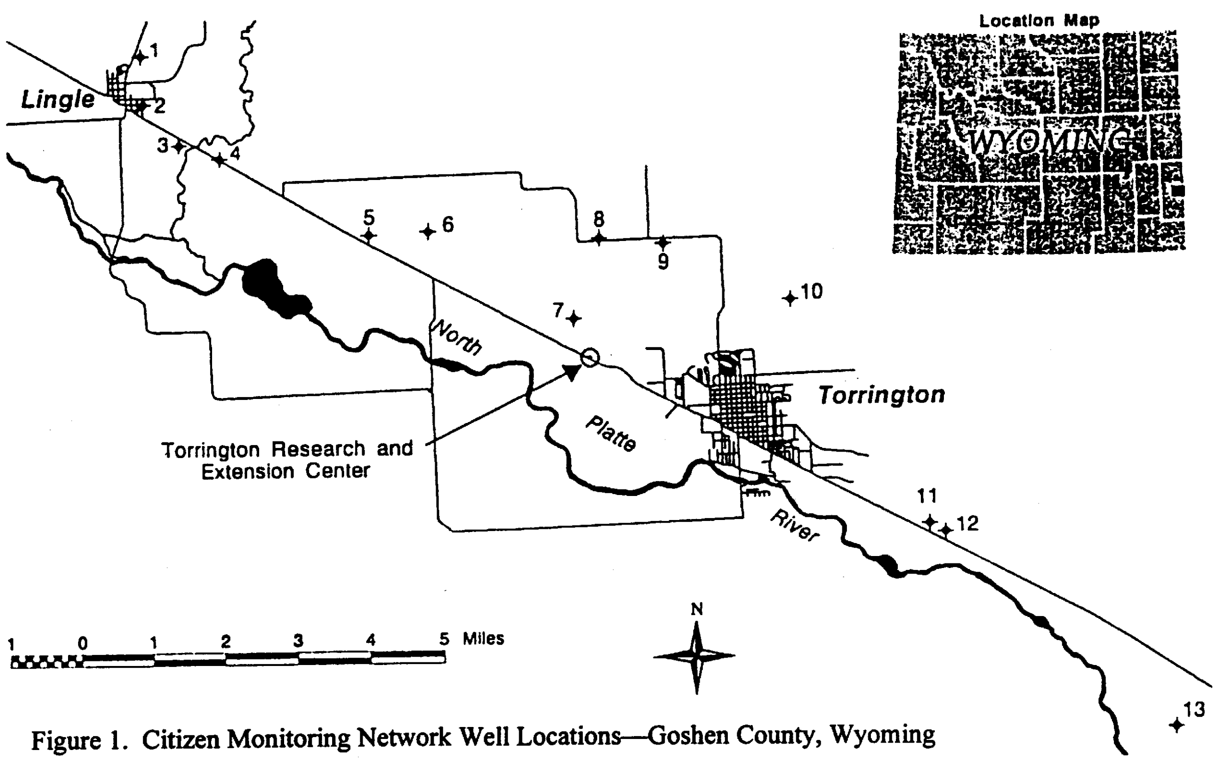


Figure 1. Citizen Monitoring Network Well Locations—Goshen County, Wyoming

A PEBBLE COUNT PROCEDURE FOR ASSESSING WATERSHED CUMULATIVE EFFECTS

Gregory S. Bevenger and Rudy M. King[1]

Land management activities can result in the delivery of fine sediment to streams. Over time, such delivery can lead to cumulative impacts to the aquatic ecosystem. Because many laws require Federal land managers to analyze watershed cumulative effects, field personnel need simple monitoring procedures that can be used directly and consistently. We have developed such a procedure. Our procedure was published in 1995 by the Rocky Mountain Forest and Range Experiment Station as RM-RP-319. It is titled *A Pebble Count Procedure for Assessing Watershed Cumulative Effects.* This research paper describes a simple monitoring procedure for sampling a longitudinal reach of a stream channel several hundred feet long using a zig-zag pebble count that crosses all habitat features within a stream channel. The technique is particularly useful for comparing fine sediment levels between study (impacted) and reference (unimpacted) reaches. The publication thoroughly describes validation of the procedure, how to develop a study plan and an appropriate statistical framework for data analysis. Case studies are offered as well.

[1] Shoshone National Forest, 808 Meadow Lane, Cody, Wyoming 82414; and Rocky Mountain Forest and Range Experiment Station, 240 West Prospect Road, Fort Collins, Colorado 80526, respectively.

INSTREAM FLOW WATER RIGHTS: THE PROCESS OF APPROPRIATION

Carla J. Rumsey[1]

Wyoming passed its first instream flow water law in 1986, yet today many individuals throughout the state are still uncertain what an instream flow water right is or how it affects existing water rights. Instream flows pertain to a quantity of water that flows through a stream channel and may or may not be adequate to support a fishery, while an instream flow water right is a legal instrument to protect an amount of water necessary to maintain or enhance a new or existing fishery (Merritt 1992).

The history of instream flow water law in Wyoming dates back to the early 1970's, when the first instream flow legislation was considered and defeated in the state legislature, with subsequent bills meeting the same fate. In 1986, supporters began collecting signatures on petitions with the intent of having an instream flow bill on the general election ballot through the initiative process. But before that could happen, the Legislature passed a bill identical to the bill on the petition (Merritt 1992).

In 1986, the Wyoming State Legislature declared that "instream flows to establish or maintain new or existing fisheries is a beneficial use of water subject to normal stream loss" (W.S. 41-3-1001(a)). The primary articles of instream flow water law encompass the following, as taken from the Wyoming Water Statutes: 1) that unappropriated water flowing in any stream or drainage may be appropriated for instream flows; 2) that those instream flows shall be the minimum flow necessary to establish or maintain fisheries; 3) an instream flow water right does not affect any existing water right and does not result in the loss of water for any water user in Wyoming; 4) all water used for the purpose of instream flows shall be applied only to that segment of the stream for which they are granted and that all rights to those instream flow waters are relinquished after passing through the specified stream segment; 5) the water development commission is responsible for conducting an instream flow feasibility study based on Wyoming Game and Fish Department requested flows; 6) an instream flow water right does not guarantee public ingress and egress through or upon private property to reach streams where instream flows are maintained; 7) Wyoming's instream flow law prohibits the Wyoming Game and Fish Department, the ability to condemn any existing water rights to obtain an instream flow and prohibits the State of Wyoming to file for the abandonment of an existing prior water right to obtain an instream flow; 8) an instream flow cannot be granted on the basis of providing benefits for anything other than fisheries resource - i.e. a flow cannot be requested for recreation, wildlife, floating, scenic values, etc.; 9) all compact and decree waters are protected by law; 10) instream flow water rights can only be held by the state of Wyoming.

Instream flow water rights are attained through the collaborative effort of several state agencies, the Wyoming Game and Fish Department (WGFD), Wyoming Water Development Commission (WWDC), and the Wyoming State Engineer's Office (SEO). This process begins with a study conducted by the WGFD. The following narrative presents this process through an example using a recent filing by the WGFD for instream flow rights along a 3.4 mile segment of Deep Creek located within the Little Snake River Basin in Southern Wyoming.

In 1994 a study was conducted as part of an ongoing monitoring and enhancement program for Colorado River cutthroat trout. The goal of the study was to determine instream flows necessary for maintaining or improving Colorado River cutthroat trout habitat in Deep Creek. The objectives were 1) to examine relationships between discharge and physical habitat quantity and quality available to Colorado River cutthroat trout in Deep Creek and 2) to determine instream flow amounts for Deep Creek to maintain or improve Colorado River cutthroat trout populations (Braaten et al. 1995).

Simulations for physical habitat were conducted for spawning, fry, juvenile and adult life stages of Colorado River cutthroat trout. Based upon these simulations, recommendations of 0.5 cubic feet per second (cfs) were requested from October 1 to April 30, 4.6 cfs from May 1 to June 30 and 0.5 cfs from July 1 to September 30. To achieve the requested flow amounts, data was gathered regarding general watershed characteristics, hydrology based on stream gaging stations and water rights near the segment area. A study site was then established comprised of ten transects encompassing riffles, runs and pools to represent habitat found throughout the middle reaches of Deep Creek. Information gathered from these transects was then applied to the remainder of the segment (Braaten et al. 1995).

The data was then entered into the physical habitat simulation model or PHABSIM. From this model the requested flow amounts are established based on the life stages of the Colorado River cutthroat trout. These flow amounts would nearly maximize physical habitat for all life stages and maintain or improve existing physical habitat suitability (Braaten et al. 1995). Following this analysis, a report is generated and submitted along with a standard water rights application to the WWDC. This process usually take around 13 months.

[1] Western Water Consultants, 611 Skyline Road, Laramie, Wyoming 82070

The next step in the adjudication process requires the WWDC to submit the application to the SEO. The WWDC also conducts a hydrologic study to determine whether the requested instream flows can be provided from the natural flow of the stream or whether storage water from an existing or new reservoir will be needed for part or all of the instream use. This part of the process usually takes around 10 months.

The WWDC solicits proposals from consulting firms to conduct the feasibility studies. Western Water Consultants, Inc. (WWC) from Laramie, Wyoming was awarded a contract to conduct the study for the Deep Creek instream flow segment, along with six other segments in the Savery area.

The feasibility study consists of many different tasks, one being a water right search for any rights above the downstream end of the instream flow segment. Flow records are also searched for stream gaging stations in the immediate and surrounding area for any information that may be used to analyze the streamflow of the individual instream flow segment. Often times, streams within a particular instream flow segment do not contain gaging stations near the segment and therefore require streamflow generation using other gages in the area and then generating streamflow for a particular segment based on characteristics such as drainage basin area and mean basin elevation versus yield calculations. The HEC4 streamflow simulation model was also used to aid in the extension of streamflow data for streamflow gages having different periods of record (WWC 1996).

To derive unappropriated flow estimates for the instream flow segment, the previously derived monthly flows needed to be adjusted to account for senior water rights. These flows were then compared to the requested amounts of instream flow to determine whether or not the requested flows could be met in a month of average flow, during each month of the driest year on record and in each of the twelve driest months for the period of record (WWC 1996).

The mean monthly, dry year monthly and twelve driest monthly flows all indicated that at various times of the year shortages will exist, resulting in insufficient unappropriated direct flows available to provide the requested instream flows. A reservoir storage analysis was then conducted using a simple reservoir mass balance to determine the reservoir storage required to provide the requested instream flow amounts for the instream flow segment (WWC 1996).

Lastly, a daily flow exceedance analysis was conducted to determine the percent of time flow rates are equal to or exceed a specific flow rate, measured at set intervals. The requests are then deemed feasible if the exceedance reaches an established percentage (WWC 1996). The WWDC "exceedance criteria deems an instream flow filing hydrologically feasible if the requested, unappropriated flow is equaled or exceeded at least 50% of the time during each filing period" (Brinkman 1996).

Upon completion of the final draft, the feasibility report is submitted by the consultant to the WWDC for review. Once the review is completed and meets the satisfaction of the WWDC, it is then submitted to the SEO for their consideration of the permit.

The final step in the appropriation process rests with the SEO and usually takes around 19 months. After receiving reports from the WGFD and WWDC, the state engineer may conduct his own evaluation. Before granting or denying a permit for instream flow in the specified stream segment, the State Engineer must conduct a public hearing in the vicinity of the instream flow segment and consider all available reports and information. Additional comments are usually accepted for 30 days after the hearing, and finally, a decision is made and a water right is issued. If granted, an instream flow permit can contain a condition for review of continuation of the permit at a future time (Jacobs 1990).

The instream flow appropriation goes into effect the date the State Engineer approves the permit. The water right cannot be adjudicated by the Board of Control for three years thereafter. An instream water right has a date of priority as of the date that the application was received and recorded by the State Engineer, and all senior priority water rights must be recognized in administration of the stream. The state engineer cannot issue an instream flow permit if it would result in loss of a portion of Wyoming's consumptive share of water allocated by interstate compact of U.S. Supreme Court decree, or if it would result in more water leaving Wyoming than allocated for uses downstream of Wyoming (Jacobs 1990).

In summary, instream flow water rights are legal instruments to protect an amount of water necessary to maintain or enhance new or existing fisheries throughout Wyoming. Since the inception of the law in 1986, a total of 68 filings have been made, 44 filings have gone to hearing, and 8 have reached permit status. However at this time, no instream flow water rights have been adjudicated due to questions by the Board of Control pertaining to prior irrigation rights and those of abandonment (Barnes 1997). Once these questions are answered, adjudication of instream flow water rights will begin.

REFERENCES

Barnes, John. 1997. Personal Communication. Wyoming State Engineer's Office. Surface Water Division.

Braaten, Patrick J. and Thomas C. Annear. 1995. Instream Flow Studies on Deep Creek, Carbon County. Project IF-4494-07-9401. Wyoming Game and Fish Department Fish Division Administrative Report.

Brinkman, Bruce. 1996. Personal Communication. Wyoming Water DevelopmentCommission.

Jacobs, Jim J., Gordon Fassett, Donald J. Brosz. 1990. Wyoming Water Law: A Summary. Cooperative Extension Service and the Wyoming Water Research Center. Bulletin B-849R.

Merritt, Steve. 1992. Understanding Instream Flow. Wyoming Wildlife News. Wyoming Game and Fish Department.

Western Water Consultants, Inc. 1996. Final Report of the Savery Area Instream Flow Study

Wyoming Water Statutes. Article 10 Instream Flows. § 41-3-1001 - 41-3-1014.

DETERMINATION OF PRECIPITATION SPATIAL DISTRIBUTIONS FOR STUDYING GROUNDWATER POLLUTION

Alexandra Kravchenko, Renduo Zhang, Steven P. Gloss, and Yeou-Koung Tung[1]

ABSTRACT

Groundwater pollution has become a great concern. Precipitation is a driving force for chemical pollutants movement from soil to groundwater systems. Therefore, the amount and spatial distributions of precipitation are important information to estimate and predict groundwater pollution. However, in most cases, the network of precipitation measuring stations is sparse and available rainfall data are insufficient to characterize high variability of precipitation spatial distributions. As a useful tool, geostatistics can be applied to estimate precipitation in unmeasured areas. In this study we used geostatistics to estimate precipitation spatial distributions in Wyoming. Coupling with numerical models, we utilized the precipitation distributions as input to study the rainfall impact on the groundwater pollution of the state.

INTRODUCTION

Leaching of pesticides, petroleum products, nitrates and other chemicals and subsequent contamination of groundwater is a significant public concern. Recent surveys detected pesticides and other contaminants in the groundwater systems of 38 states (Ratter, 1990; Parsons and Witt, 1988). Development of maps describing groundwater sensitivity and vulnerability to contamination is an important step in prediction and estimation of possible groundwater pollution (Zhang et al., 1996). All the components influencing the solute transport have to be considered to produce reliable sensitivity and vulnerability maps. Widely recognized factors affecting groundwater contamination are the depth to groundwater table, net recharge, aquifer geology, hydraulic and physical properties of the soils and aquifer (Aller et al., 1987). Since water flow is the major driving force in the pollutant movement through soil into the groundwater system, the total amount and spatial distribution of precipitation are also regarded as important factors of possible groundwater contamination. The objective of this study is to evaluate the sensitivity of the soil water flow and solute transport to the precipitation spatial distribution. Numerical simulations were conducted to model water flow and solute transport in soils. Mean annual precipitation values were used as inputs of the total amount of water applied on the soil surface.

MATERIAL AND METHODS

One-dimensional vertical water flow and solute transport in soils was simulated using the numerical model HYDRUS (Vogel et al., 1995). The governing equation for one-dimensional vertical water flow in soils is (Zhang et al., 1996):

$$C\frac{\partial h}{\partial z} = \frac{\partial}{\partial z}(K\frac{\partial h}{\partial z} - K)$$

where h is the pressure head, K is the hydraulic conductivity, z is soil depth, and $C=\partial\theta/\partial h$, where θ is volumetric water content. Mean annual precipitation data were used to characterize the amount of water applied on the soil surface (z=0) during the year. The mean annual precipitation value was divided into separate precipitation events. The simulations were carried out from the surface of the soil profile to the depth of 8 ft.

To solve the flow equation we need the relationship between the water content θ and pressure head h, and the relationship between the unsaturated hydraulic conductivity and water content. These relationships were described by the functions of van Genuchten (1980):

$$\theta(h) = \theta_r + \frac{\theta_s - \theta_r}{(1+|\alpha h|^n)^m}$$

$$K(S_e) = K_s S_e^{1/2}[1-(1-S_e^{1/m})^m]^2$$

where K_S is the saturated hydraulic conductivity, θ_r is the residual water content, θ_S is the saturated water content, α, n and m are empirical constants with m=1-1/n, and S_e is relative saturation defined as $S_e = (\theta-\theta_r)/(\theta_S-\theta_r)$.

A convection-dispersion equation is used to describe the one-dimensional vertical solute transport (Zhang et al, 1996):

$$\frac{\partial\theta c}{\partial t} = \frac{\partial}{\partial z}(\theta D\frac{\partial c}{\partial z}) - \frac{\partial(qc)}{\partial z}$$

where c is the solute concentration in the solution, D is the dispersion coefficient and q is the flow rate. Zero initial solute concentration was assumed in the

[1] Department of Plant, Soil and Insect Sciences, and Wyoming Water Resources Center, UW, respectively, Laramie, WY 82071

soil profile. Solute concentration of the infiltrating water was set to be equal to 10 mg/L. Total simulation period was set up for five years. The cumulative water flux reaching the lower boundary of the soil profile and the total amount of solute leached through the lower soil boundary were recorded during the simulation period.

Simulating water movement and solute transport in soils requires information about soil physical and hydraulic properties. Data on soil physical properties at 28 locations were obtained from the USDA national soil geographic database (NATSGO). The data points were located in the southwestern part of Wyoming from longitude of -111.0W to -110.2W and from latitude 41.9N to 43.5N. Soil properties included depths and thickness of the soil horizons and soil texture and bulk density at the horizons. The soils ranged in texture from fine sand to clay. Bulk density of the studied soils varied from 0.90 to 1.66 g/cm^3. Soil hydraulic properties, such as saturated hydraulic conductivity and parameters of the soil water retention function, were estimated based on the soil texture. Summary of hydraulic properties for soils with different textures are available from literature (Carsel and Parrish, 1988). In this study we used the information on θ_r, θ_S, α, n and K_S presented by Carsel and Parrish (1988).

Mean annual precipitation values were obtained based on the precipitation data collected over 50 years at 148 weather stations in Wyoming. The record length used for estimating the mean annual precipitation varied from 13 to 75 years for different stations. We applied geostatistical methods to estimate mean annual precipitation in the areas where precipitation has not been measured (Kravchenko et al., 1996). Additional geographical information, such as elevation, slope, exposure, and geographical coordinates, was utilized in the geostatistical procedure to improve the precipitation estimation. The resulting map of the mean annual precipitation on an 8.6x6.8 mile grid was used as the input for the numerical simulations.

RESULTS AND DISCUSSION

A five-year simulation was performed at each of the studied locations. To define the influence of both soil properties and precipitation on the solute transport in soils, three cases of simulations were carried out. In the first case, the mean annual precipitation was assumed to be the same through the studied area and equal to 12.2 in. This value corresponds to the average value of the mean annual precipitation for the studied area. In the second case, soil physical and hydraulic properties were assumed to be uniform and equal to those of the loam soil. In the third case, the precipitation spatial distributions and soil data were used in the simulation procedure. Minimum and maximum values of the cumulative water flux through the lower soil boundary at the end of the simulation period (TDRAIN) and the minimum and maximum of the cumulative amount of solute leached out of the soil profile by the end of the simulation (SLTOUT) are shown in Table 1.

Table 1. Extreme values of TDRAIN and SLTOUT in the western and eastern parts of the studied area.

Simulation case*	TDRAIN (cm)		SLTOUT (mg)	
	minimum	maximum	minimum	maximum
a	52.4	215.6	0.000	4.534
b	67.1	199.8	0.074	2.793
c	147.0	293.7	0.511	5.010

* a - simulation with both soil and precipitation data.; b - simulation with only soil data; c - simulation with only precipitation data;

Figure 1 presents the map of TDRAIN obtained from the three simulation cases for the studied area. Close resemblance is observed between the TDRAIN maps obtained with soil data only and with both soil and precipitation data. Such resemblance implies that soil properties have significantly larger influence on the water flow through the soil than the total amount of the precipitation. However, precipitation also produces noticeable effect on the water flow. In case of the simulation with both soil and precipitation data the minimum TDRAIN equals to 52.4 cm, while the maximum is equal to 215.6 cm. If precipitation influence is eliminated, it affects the TDRAIN values. TDRAIN obtained from the simulations with constant precipitation data has significantly higher minimum and lower maximum values.

Figure 2 shows the SLTOUT distributions in the studied area. The amount of precipitation has a strong influence on the solute transport in soils. For example, the peak of solute leaching (SLTOUT = 4.5 mg) located in the upper left corner of the studied area is a result of the precipitation influence only. In case of the simulation with the uniform precipitation

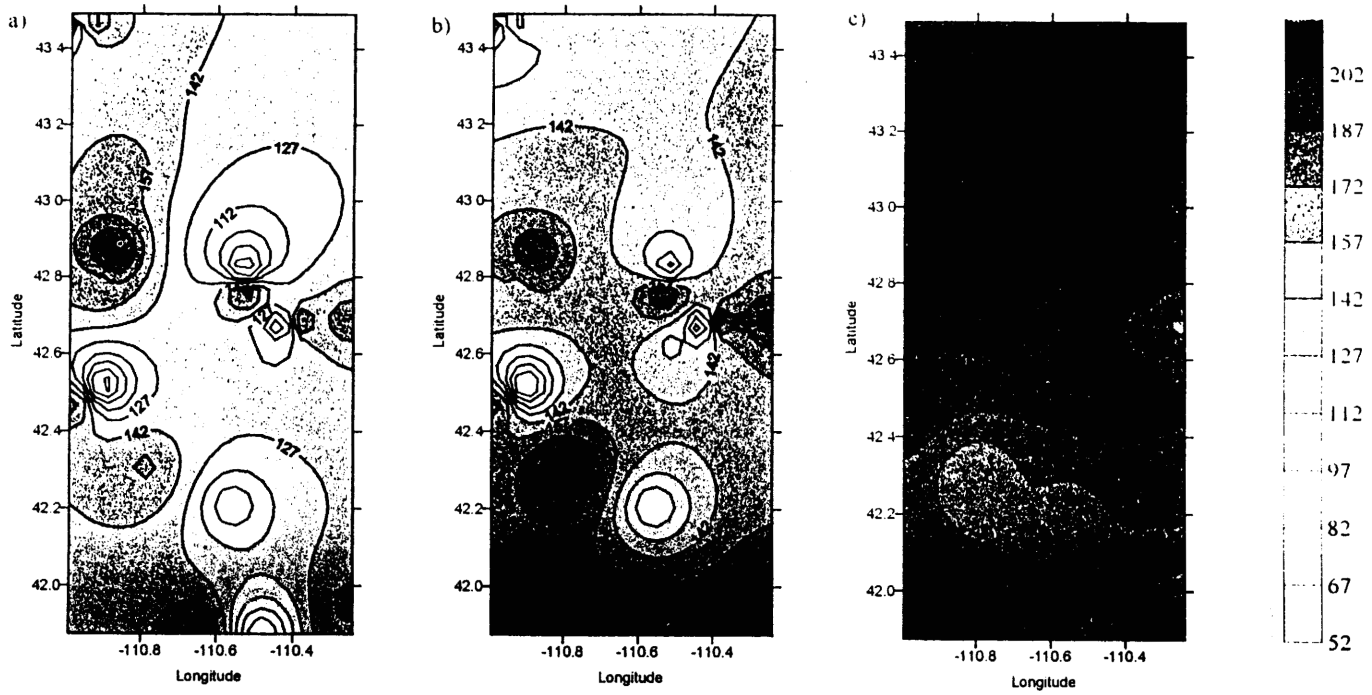


Figure 1. Water drainage through the 2.5 m soil profile during 5 year simulation period: a) both precipitation and soil information is used into simulation; b) only soil information is used with constant precipitation; c) only precipitation data are used with constant soil information.

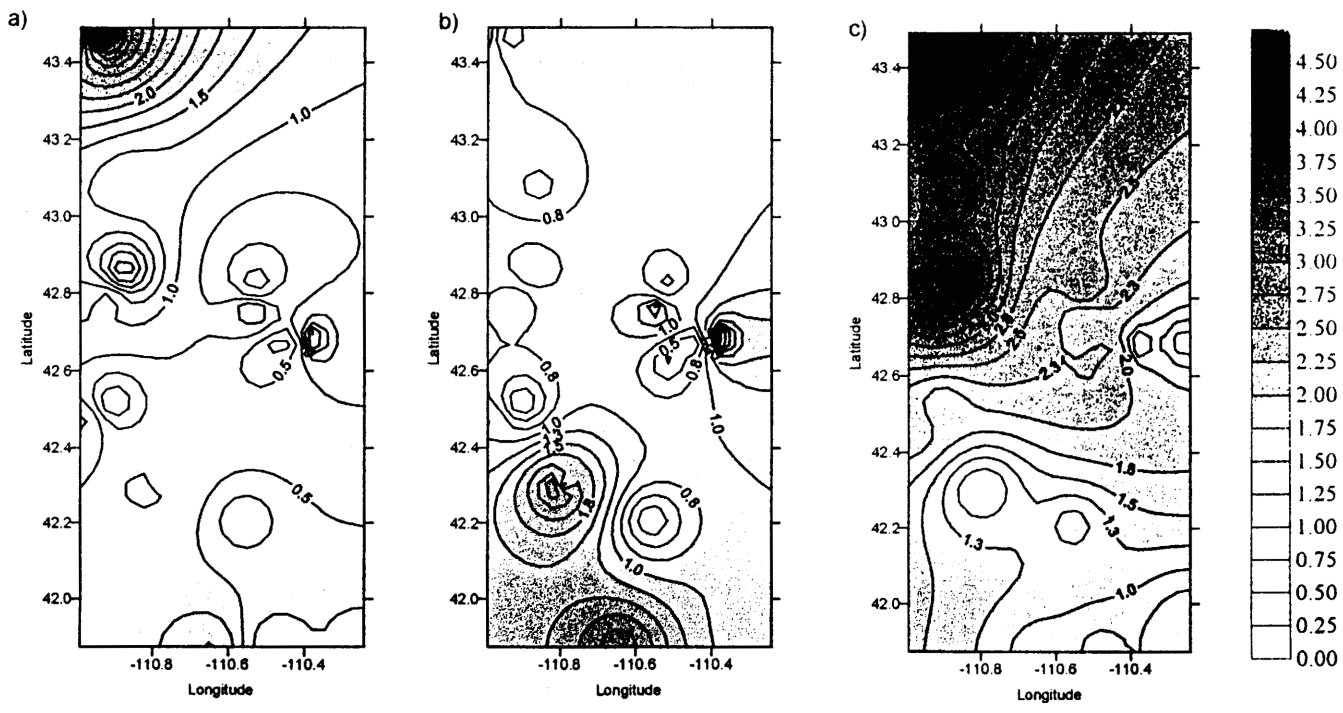


Figure 2. Solute leaching through the 2.5 m soil profile during 5 year simulation period: a) both precipitation and soil information is used into simulation; b) only soil information is used with constant precipitation; c) only precipitation data are used with constant soil information.

For example, the peak of solute leaching (SLTOUT = 4.5 mg) located in the upper left corner of the studied area is a result of the precipitation influence only. In case of the simulation with the uniform precipitation distribution, SLTOUT is less than 1.0 at that location. In the bottom part, where mean annual precipitation values are small, simulation with uniform precipitation overestimates the solute leaching. The maximum value of SLTOUT in that area reaches 2.6 mg for the simulation with uniform precipitation value, while including precipitation data results in the maximum of only 0.8 mg. The maximum SLTOUT value obtained from simulations with both soil and precipitation data is significantly larger than the maximum obtained from simulations with soil data only (Table 1).

SUMMARY

Precipitation data collected at an area of 139,000 mi^2 during more than 50 years in Wyoming were used to study the influence of the precipitation spatial distribution on the water flow and solute transport in soils which is related to groundwater pollution. Information about soil physical and hydraulic properties was obtained based on the USDA national soil geographic database. Simultaneous water flow and solute transport were simulated at 28 locations in the southwestern part of Wyoming. Three simulation scenarios were considered. In the first scenario, soil data and precipitation spatial distribution data were used in the simulation. In the second one, only soil data were used with an average precipitation uniformly distributed through the studied area. In the third one, only precipitation data were used in the simulation with uniformly distributed soil properties. The simulation results showed that the mean annual precipitation has significant effect on the water flow and solute transport in soils. Precipitation values influenced the total amounts of solute leached through the soil profiles as well as the distributions of zones with high and low amounts of leached solute. The results suggest that the spatial distribution of precipitation is an important input in hydrological modeling, and predicting and estimating ground-water pollution and ground-water vulnerability to contamination.

REFERENCES

Aller, L., T. Bennett, J.H. Lehr, R. Petty, and G. Hackett. 1987. DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeologic settings. USEPA Rep. 600/S287/035. USEPA, Cincinnati, OH.

Carsel, R.F., and R.S. Parrish. 1988. Developing joint probability distributions of soil water retention characteristics. *Water Resour. Res.* 24:755-769.

Kravchenko, A., Zhang, R. and Y. Tung, 1996. Estimation of mean annual precipitation in Wyoming using geostatistical analysis. Proceeding of Sixteenth Annual American Geophysical Union, *Hydrology Days*. pp. 271-282. Fort Collins, Colorado.

Parsons, D.W., and J.M. Witt. 1988. Pesticides in ground water in the United States of America. p. 18. Oregon State Univ. Ext. Serv., Corvallis.

Ratter, W.F. 1990. Pesticide contamination of ground water in the United States - A review. *J. Environ. Sci. Health* B25(1):1-29.

van Genuchten, M. The. 1980. A close-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.* 44:892-898.

Vogel, T., R. Zhang, M.Th. van Genuchten, and K. Huang. 1995. HYDRUS, one-dimensional variably saturated flow and transport model, including hysteresis and root water uptake, Version 3.4. Research Report. U.S. Salinity Lab., USDA-ARS, Riverside, CA.

Zhang, R., J.D. Hamerlinck, S.P. Gloss, and L. Munn. Determination of nonpoint-source pollution using GIS and numerical models. 1996. *J. Environ. Qual.* 25:411-418.

GENETIC IMPROVEMENT OF ALFALFA TO CONSERVE WATER

D. Claypool, R. Delaney, R. Ditterline and R. Lockerman[1]

ABSTRACT

Irrigated alfalfa (*Medicago sativa* L.) is a high user of water and has received limited research to improve its water-use efficiency (WUE). Alfalfa is grown on approximately one-half of the cultivated land and has the highest consumptive use of all crops in Wyoming. Alfalfa lines were developed which expressed lighter colored and larger leaves. The water relations and productivity of these lines were evaluated under a series of soil water levels in a controlled environment and under field environments in Wyoming and Montana. In the controlled environment the WUE of the pale and dark leaf genetic lines were 1.47 and 1.22 g dry forage kg^{-1} water, respectively, when averaged across seven soil moisture levels. Large-leaved alfalfa plants produced 1.43 and small-leaved 1.29 g dry forage kg^{-1} water. Leaf transpiration per unit leaf area of pale leaves in irrigated field studies ranged from 12 to 17% lower than dark (normal) leaves. Transpiration of large leaves was 10 to 16% lower than small (normal) leaves. In field studies, the forage yield of pale leaves was 25 to 29% higher than dark leaves. The yield of large-leaved plants was 17 to 22% higher than small-leaved. These studies indicate the WUE of alfalfa can be improved through plant breeding.

INTRODUCTION

Irrigated alfalfa (*Medicago sativa* L.) is a high user of water and has received limited research to improve its water-use efficiency (WUE). Alfalfa is grown on approximately one-half of the cultivated land and has the highest consumptive irrigation requirement of all crops in Wyoming. A comparison of some Wyoming irrigated crops is shown in Table 1. There is significant evidence some crop plants may contain excess chlorophyll (Chl) for optimum growth. A genetic reduction of the Chl concentration in alfalfa would result in lighter colored leaves which may reduce transpiration demand and improve the WUE. Ferguson (1974) studied pale-leaved barley (*Hordeum vulgare* L.) and found a reduction of Chl reduced leaf temperature. He concluded transpiration rates would also be significantly reduced. Photosynthetic rates of some of the barley lines with a 50% reduction in Chl were actually higher than normal-green lines. A similar photosynthetic response to reduced Chl concentration was reported by Pettigrew et al. (1989) in soybean [*Glycine max* (L.) Merr.] and by Kirchhoff et al. (1989) in cowpea [*Vigna unguiculata* (L.) Walp.].

Alfalfa leaf size could affect WUE as genotypes with superior yield demonstrate superior WUE under non-moisture-stressed conditions (Cole et al., 1970). Delaney and Dobrenz (1973) reported large-leaved alfalfa plants exhibit higher yields than small-leaved plants under irrigated conditions. Large leaves, for plants in general, typically have higher leaf temperatures because of greater boundary layer resistance and reduced convective heat loss, thus a higher transpiration demand (Smith and Geller, 1979). However, large-leaved alfalfa genotypes have thinner leaves than small-leaved plants (Delaney and Dobrenz 1974) which may reduce the transpiration demand. Smaller alfalfa leaves have smaller cells (Delaney and Dobrenz, 1981) which is typical of drought-resistant plants. Because of the transpiration demand and growth rate responses of plants with large or small leaves, the small-leaved alfalfa may have superior WUE under moisture stress conditions and the large-leaved may be superior under irrigated conditions.

A 15% reduction in consumptive water use of irrigated alfalfa in the 11 western states would reduce the agricultural water demand for this crop by 24,700 ha-m yr^{-1} (2 million ac-ft yr^{-1}). Water consumption for alfalfa is also very important in Wyoming as the 178,000 ha of irrigated alfalfa represents greater hectarage than all other irrigated cash crops combined. A 15% reduction appears to be a realistic goal for an approach using physiological and morphological criteria in a plant breeding program.

The objectives of these studies were to evaluate the transpiration and yield response of alfalfa breeding lines selected for reduced Chl (lighter-colored leaves) and larger leaves.

METHODS

Populations divergently selected for dark- and pale-leaf and large- and small-leaf characteristics were developed from 'Ladak 65' alfalfa according to methods described by Estill et al. (1991 and 1993). For controlled environment and field studies at Laramie, WY, twelve hundred plants of each population were established from Cycle-2 seed in the greenhouse. Plants were selected which expressed the desired traits for transplanting to complete the studies.

[1] Department of Plant, Soil, and Insect Sciences, UW, Laramie, WY 82071 and Department of Plant, Soil; and Environmental Sciences, Montana State University, Bozeman, MT, respectively.

Table 1. Consumptive irrigation requirements (CIR) for selected crops at Wheatland, WY.

Crop	Growing season	CIR
		mm
Alfalfa	Apr.-Oct.	658
Lawn grass	Apr.-Oct.	574
Corn	May-Oct.	472
Dry beans	June-Sept.	343
Sugarbeets	Apr.-Sept.	511

(Pochop et al., 1992)

CONTROLLED-ENVIRONMENT STUDIES

A commercial root medium (Metro-mix 220, W.R. Grace, Inc., Cambridge, MA) was used for plant culture. Plants were inoculated with commercial *Rhizobium meliloti* Danegard (Nitragin Co., Milwaukee, WI). Controlled-environment chamber conditions were 21°C day (16h) and 18°C night (8h) at 40% relative humidity. Light intensity at the top of the plant canopy was 640 μmol m^{-2} s^{-1} for the dark/pale leaf study and 840 μmol m^{-2} s^{-1} for the large/small leaf study.

Nine, 60-day-old plants of a specific leaf type were transplanted into 0.31 x 0.31 x 0.65 m deep containers. Water-use efficiency of large- and small-leaves genotypes were determined at four soil water levels. Pale- and dark-leaved genotypes were subjected to seven water levels. Containers were weighed daily to maintain soil water at desired levels. All containers received 0.5 L Hoagland's nitrogen-free nutrient solution once per week. The containers used for instantaneous transpiration measurements were composed of mixed stands (large and small or pale and dark) of alfalfa genotypes.

Water-use efficiency (WUE = grams of dry matter per kilogram of water transpired) was calculated from four replications of pure stands of each leaf type. A steady-state porometer was used to measure instantaneous transpiration and leaf size was determined with a video area meter for each leaf sampled for transpiration. Chlorophyll concentration was determined from random samples of all leaves on individual dark- and pale-leaved plants. Plants were harvested at the early bloom stage and dried (80°C for 48h) to determine dry matter yield.

FIELD STUDIES

Field studies were conducted at Laramie, WY and Bozeman, MT. The Bozeman site included large-, small-, pale-, and dark-leaved treatments. Four replications of each leaf type were established under each water level. Plots were 3.0 by 3.6 m and contained 120 plants transplanted on 0.3 m centers. Plants and soil water gradients were established the first year and data collected the following two years. A line-source sprinkler system was used to provide a decreasing soil water gradient at right angles to the source (Hanks et al., 1976). For each growth cycle (2 harvests per year) precipitation plus irrigation averaged 284, 249, 178, 109, and 72 mm for soil water levels 1 through 5, respectively. Irrigation occurred when approximately 50% of available soil water was depleted in water level 2. A neutron probe was used to monitor soil water in the center of each plot. Instantaneous transpiration of plants near the center of plots was measured 12 times across the four forage growth cycles. All measurements were taken under full sun between 1000 and 1400 h. Forage dry matter yield was determined at the 5% bloom stage on the twenty-four plants near the center of each plot.

At the Laramie site the water treatments were irrigated and nonirrigated. The Laramie irrigated study received 0.32 m of water per alfalfa growth cycle plus 0.20 m annual precipitation. Twelve plants (replicates) of each leaf type were transplanted on 0.3 m centers with the immediate neighbors to the sampled plants being the same leaf type. Yield and transpiration were collected on four growth cycles over a three-year period.

RESULTS AND DISCUSSION

PALE VS DARK LEAVES

Total chlorophyll concentration for pale and dark leaves was 2.17 and 2.48 mg g^{-1}, respectively, for irrigated alfalfa and 2.43 and 3.04 mg g^{-1} respectively for nonirrigated alfalfa grown at Laramie. The 13 to 20% reduction in total Chl of pale-leaved genotypes in this study was consistent with that observed in the

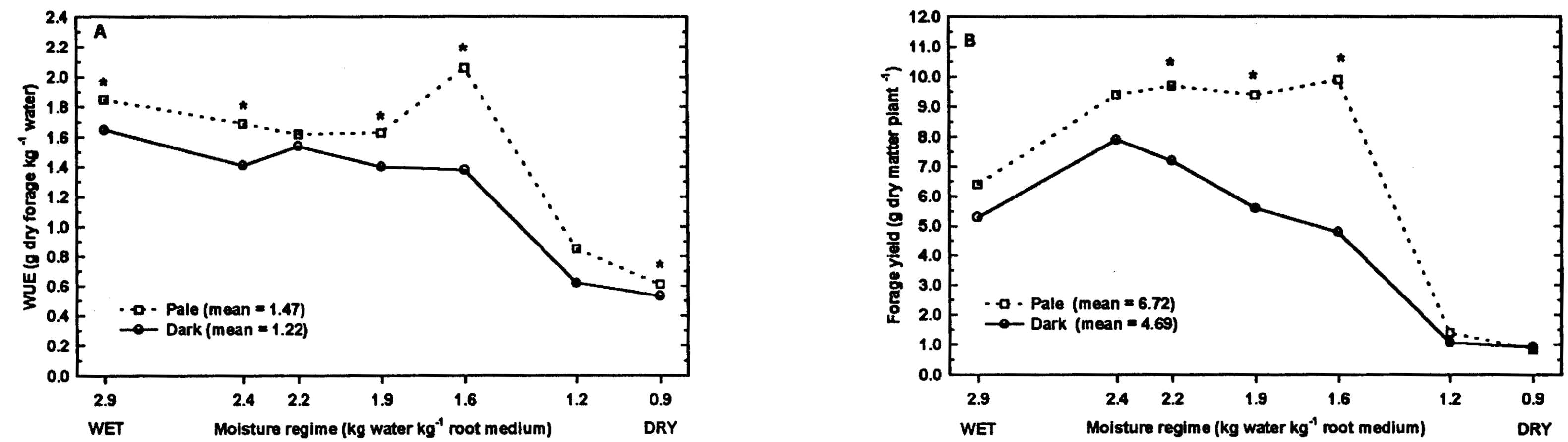


Fig. 1. Water-use efficiency (WUE) and forage yields of pale- and dark-leaf alfalfa variants grown under seven moisture regimes in a controlled environment. * Asterisk indicates leaf type within a moisture regime is significantly different at $P \leq 0.05$.

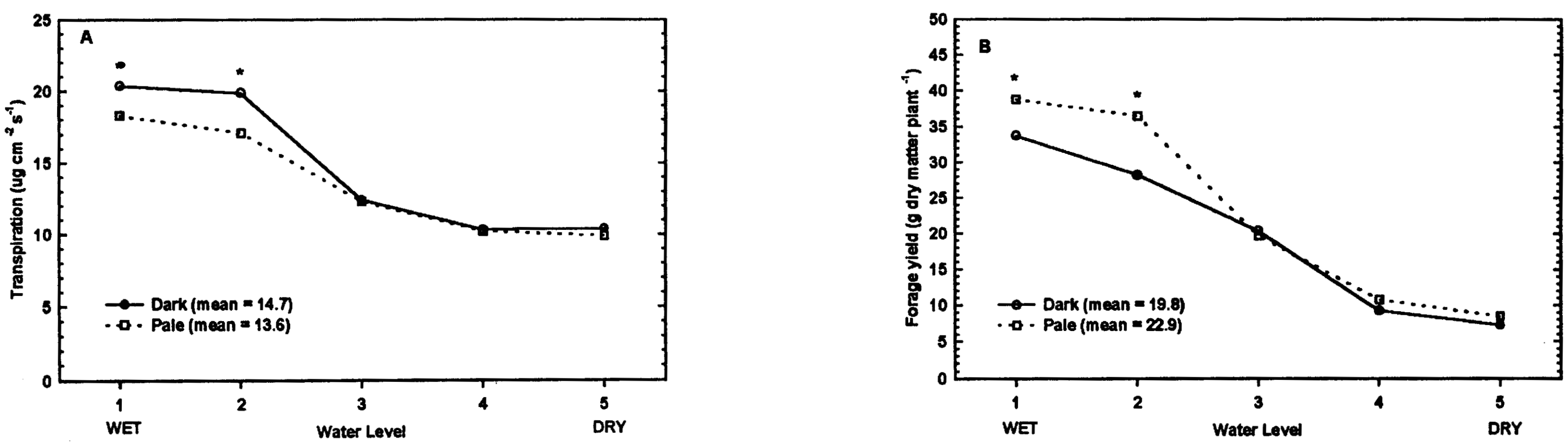


Fig. 2. Instantaneous transpiration rates and forage yields of pale- and dark-leaf alfalfa variants grown under five soil water levels in the field at Bozeman, MT. * Asterisk indicates leaf type within a water level is significantly different at $P \leq 0.05$.

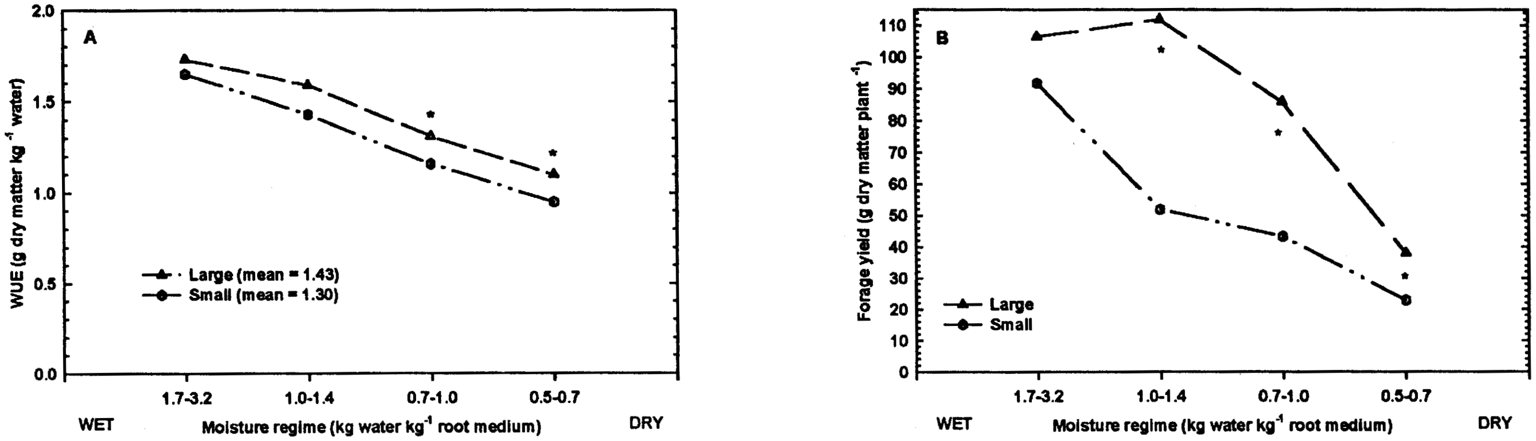


Fig. 3. Water-use efficiency (WUE) and forage yields of large- and small-leaf alfalfa variants grown under four moisture regimes in a controlled environment. A water content of 3.2 kg water kg^{-1} root medium represented 98% water-holding capacity and 0.5 to 0.7 kg water kg^{-1} root medium treatment exhibited midday wilting of some plants. * Asterisk indicates leaf type within a moisture regime is significantly different at $P \leq 0.05$.

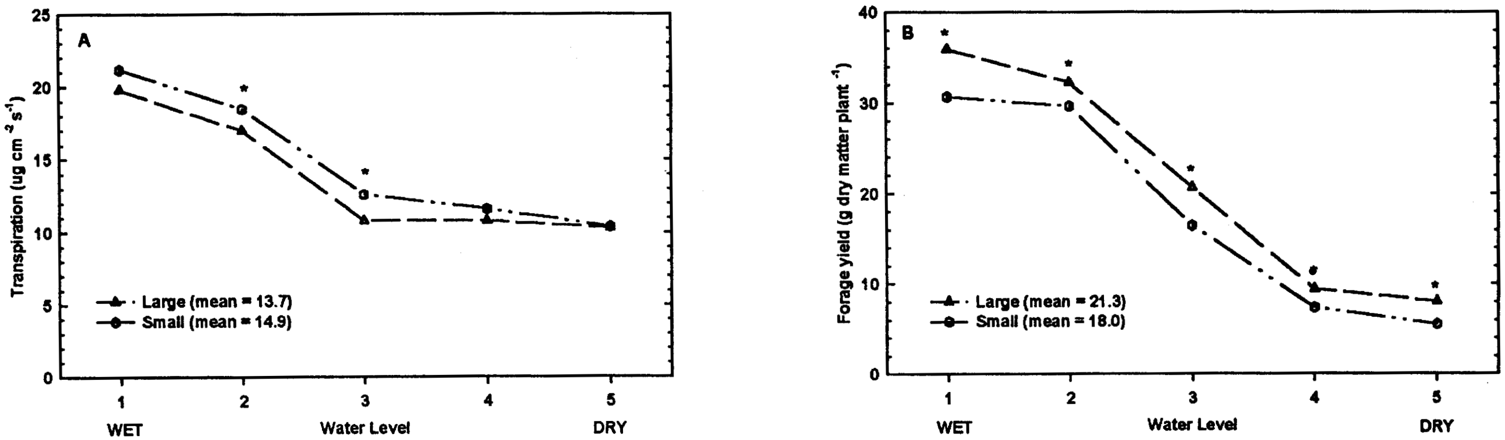


Fig. 4. Instaneous transpiration rates and forage yields of large- and small-leaf alfalfa variants grown under five soil water levels in the field at Bozeman, MT. * Asterisk indicates leaf type within a water level is significantly different at $P \leq 0.05$.

other studies. Pale-leaf Chl b was consistently reduced more than Chl a in all three of the study environments.

Water-use efficiency of the pale-leaved population was superior to the dark-leaved population for five of seven moisture regimes in the controlled environment (Fig. 1A). Averaged across the seven moisture regimes, pale leaf types produced 20% more dry matter per unit of water use. The greater WUE observed for the pale types was primarily due to their superior forage yield, which averaged 43% more than the dark types across moisture regimes (Fig. 1B). The observed relationship between alfalfa yield and WUE is in agreement with previous studies by Dobrenz et al. (1971). Reduced forage yield observed for both leaf types at the highest moisture regime did not adversely affect WUE. The reduced forage yield at moisture levels near field capacity is frequently observed in alfalfa (Peterschmidt et al., 1979). Chlorophyll concentration did not affect this response, although the pale plants maintained superior WUE. Reduced forage yield at the two lowest moisture regimes did reduce WUE for both leaf types. Carter and Sheaffer (1983) reported a similar WUE response to water stress in alfalfa. However, the pale variants maintained a small superior WUE at the lowest moisture level.

In Montana field studies, transpiration rate evaluated on a leaf-area basis for the dark-leaved population was significantly higher than pale-leaved populations at the two highest water levels (Fig. 2A). The pale-leaved population expressed 11 and 16% lower transpiration than the dark-leaved population for the two highest water levels, respectively. Transpiration did not differ among populations at the three lowest water levels. The pale population yielded 15 and 29% more than the dark population for water levels 1 and 2, respectively (Fig. 2B). Therefore, under normal soil water (irrigation) levels, both reduced transpiration and increased yield of pale leaves contribute to improved WUE.

Similar transpiration and yield responses to leaf color were observed from irrigated and nonirrigated field studies in Wyoming (data not shown). Under irrigated conditions the transpiration of pale leaves was reduced 17% and yield increased 25%, compared to dark leaves. For the nonirrigated study, transpiration of pale leaves was reduced 18% while forage yields were equal for pale- and dark-leaved populations.

LARGE VS SMALL LEAVES

Leaf sizes varied with environment. Depending on the study and leaf node sampled, leaves of the large-leaved population were 35 to 75% larger than the small-leaved population. In all studies leaf size decreased for both populations as moisture stress increased.

Water-use efficiency of both leaf size populations decreased as moisture stress increased in the controlled environment study (Fig. 3A). The large-leaved population had significantly superior WUE compared to the small-leaved population at the two driest moisture regimes. Across the four moisture regimes the large-leaved population averaged about 11% more forage production per unit of water. This higher efficiency resulted from the large-leaved population use of 51% more water but a 63% higher yield (Fig. 3B) than the small-leaved population. Cole et al. (1970) observed that WUE was positively correlated with leaf size and forage yield in seedling plants grown under non-stressed moisture conditions. The higher WUE of the large-leaved population can partially be explained by the higher forage yield of this population. Instantaneous transpiration per unit leaf area was also lower for large leaves (data not shown).

Transpiration rate for small-leaved population in the field at the Montana location was also significantly higher at the medium-high and intermediate water levels (Fig. 4A). Forage yields of the large-leaved population were greater than small-leaved population at all five water levels (Fig. 4B). For the Laramie field studies the small-leaved population averaged 20% higher transpiration than the large-leaved under irrigated conditions. Transpiration was not affected by leaf size under nonirrigated conditions.

In summary, there is ample evidence that reducing the Chl concentration in alfalfa can save water. This response occurs because pale leaves have lower transpiration rates. Pale plants also have improved growth rates which has been attributed to superior light penetration into the canopy and increased leaf area index. Large leaves also demonstrate reduced transpiration rates as well as superior leaf area index and yield potential.

CONCLUSIONS

LEAF COLOR

- Chlorophyll concentration can be genetically changed in alfalfa.
- Chlorophyll concentration appears to be excessive in alfalfa.
- Reducing chlorophyll decreases transpiration.
- Reducing chlorophyll increases forage yield.
- Reducing chlorophyll improves water-use efficiency.

LEAF SIZE

- Leaf size can be genetically changed in alfalfa.
- Larger leaves decrease transpiration.

- Larger leaves increase forage yield.
- Larger leaves improve water-use efficiency.

THEREFORE

24,700 ha-m^{-1} yr (2 million acre-ft^{-1} yr) of irrigation water applied to alfalfa in the 11 western states could be saved through plant breeding without reducing forage yield.

REFERENCES

Carlson, J.R. 1981. Ph.D. Diss. Abstr. 81-24728.

Carter, P.R., and C.C. Sheaffer. 1983. *Crop Sci.* 23:676-680.

Christian, K.R. 1977. *Adv. Agron.* 29:183-227.

Cole, D.F., A.K. Dobrenz, M.A. Massengale, and L.N. Wright. 1970. *Crop Sci.*, 10:237-240.

Delaney, R.H. and A.K. Dobrenz. 1973. *Crop Sci.* 14:444-447.

Delaney, R.H. and A.K. Dobrenz. 1973. *Prog. Agric. Ariz.* 15:11-12.

Delaney, R.H. and A.K. Dobrenz. 1981. *Wyo. Agric. Exp. Stn. Res. J.* 164:15-26.

Dobrenz, A.K., D.F. Cole, and M.A. Massengale. 1971. *Crop Sci.* 11:124-125.

Estill, K., R.H. Delaney, W.K. Smith, and R.L. Ditterline. 1991. 31:1229-1233.

Estill, K., R.H. Delaney, W.K. Smith, and R.L. Ditterline. 1993. *Field Crops Research* 33:423-434.

Ferguson, H. 1974. *Agric. Meteorol.* 14:25-30.

Hanks, R.J., J. Keller, V.P. Rasmussen, and G.D. Wilson. 1976. *Soil Sci. Soc. Am. J.* 40:426-429.

Kirchhoff, W.R., A.E. Hall, and W.W. Thomson. 1989. Crop Sci. 29:109-115.

Peterschmidt, N.A., R.H. Delaney, and M.C. Greene. 1979. *Agron. J.* 71:752-754.

Pettigrew, W.T., J.D. Hesketh, D.B. Peters, and J.T. Woolley. 1989. *Crop Sci.* 29:1025-1029.

Pochop, L., T. Teegarden, G. Kerr, R. Delaney, and V. Hasfurther. 1992. *Wyoming Cooperative Extension Ser. and Wyoming Water Res. Ctr. Bull.* MP-87.

Smith, W.K. and G.. Geller. 1979. *Oecologia* 41:109-122.

ASSESSMENT OF COPPER MOBILIZATION RESULTING FROM MICROBIAL REDUCTION OF IRON OXIDE

James T. Markwiese, J.S. Meyer and Patricia J.S. Colberg[1]

ABSTRACT

Microorganisms can greatly influence heavy metal mobility by reductively dissolving iron oxides and liberating adsorbed heavy metals; however, the toxicity of remobilized heavy metals to iron-reducing bacteria is unknown. We hypothesize that resistance to metals like copper enables bacteria to reduce more copper-complexed iron oxide than bacteria lacking resistance; the effect of which is increased remobilization of heavy metals in relation to increased resistance.

Resistance should be a function of exposure history to heavy metals with the more metal-resistant bacteria having been previously exposed to heavy metals. We have cultured iron-reducing bacteria from the Rio Calveras in the Jemez Mountains of New Mexico for use as a pristine enrichment. We also cultured iron reducers from the heavy metal-contaminated Milltown reservoir in southwestern Montana. Both pristine and heavy metal-contaminated enrichments were used to assess how previous exposure to metals influences the release of a toxic metal adsorbed to iron oxide.

Using iron oxide without adsorbed copper, iron reducing enrichments from both environments were relatively similar with regard to extent of total iron reduced. In the presence of copper, however, bacteria previously exposed to copper exhibited resistance with regard to total iron reduced relative to bacteria having no previous history with copper. A general linear model describing over 98% of the variation in total iron reduced is described for bacteria that differ in their copper exposure history and the presence or absence of copper. We will present the results of further copper mobilization studies using these major controlling variables.

[1] Environmental Microbiology and Biogeochemistry Laboratory, Department of Zoology and Physiology, UW, Laramie, WY 82071.

MASS BALANCE CHANGES ON TETON GLACIER USING HISTORICAL AND CONTEMPORARY DATA

Kelly Elder, Melinda Laituri, Kathy Tonnessen, Rich Greenwood[1]

ABSTRACT

Glaciers of Grand Teton National Park appear to be in a state of continued negative mass balance. Recent work on glaciers in the Wind River Range of Wyoming indicates that significant portions of the August through October flow in the Wind River basin is derived directly from glacier melt (Charles Love, personal communication, 1994; Marston et al., 1989). If glacial melt continues at the present rate, some of the major ice bodies responsible for this late season contribution may disappear entirely by the turn of the century. It is useful to know if the glaciers of Grand Teton National Park are under a similar ice-wastage regime. Loss of glaciers and perennial ice masses will have an effect on the hydrology, biogeochemistry and biology of the streams draining the regions containing ice. The results of this study provide an important database for hydrologists interested in regional conditions.

Reed (1963) completed detailed studies on Teton Glacier and published the first map of the glacier with a 1954 surface taken from aerial photographs and a 1963 surface derived from a plane table survey. Preliminary analysis of Reed's 1954 and 1963 map shows a loss of about 600,000 m^3 of ice during that period. Detailed contemporary studies of the glacier began in 1994 when we used electronic surveying equipment to map ground control points on Teton Glacier for reference to Reed's previous glacier surveys and to map surface topography for a high-resolution (1040 points) ground survey. A contour map with a 2 m contour interval was constructed from the 1994 ground survey. Aerial photography was acquired in August 1996 and a comprehensive high-resolution surface of the glacier will also be converted to a digital database and co-registered to previous maps using ARC/INFO software. A contour map with 0.5 m contour interval will be generated from our aerial photographs and improved ground truth. A quantitative description, using the digital data, will be made of the total volume and spatial distribution of ice mass changes in the glacier between periods of record. The 1954, 1963, 1994 and 1996 surfaces will be compared to quantify absolute changes in ice mass over the approximate 10, 30, and 40 year periods. An estimation of future health of the glacier will be made based on estimated ice mass, present climate and trends in ice wastage.

REFERENCES

Love, C., (1994) Personal communication, Department of Anthropology and Geology, Western Wyoming College, Rock Springs, WY

Marston, R., L. Pochop, G. Kerr, M. Varuska, (1989) Recent trends in glaciers and glacier runoff, Wind River Range, Wyoming, Proceedings, Symposium on Headwaters Hydrology, American Water Resources Association, p. 159-169.

Reed, J. C., Jr. (1963) Map of the lower portion of the Teton Glacier, Grand Teton National Park, Wyoming, U.S. Geological Survey Open-file Report.

[1] Department of Earth Sciences, Colorado State University, Ft. Collins, Co. 80523; Department of Earth Resources, Colorado State University, Colorado State University, Fort Collins, Co. 80523; Air Quality Division, National Park Service, Denver, CO. 80255; Box 461, Wilson, WY 83014, respectively.

THE WYOMING ANNUAL MEDIC BREEDING PROGRAM -- IMPROVING WATER USE EFFICIENCY AND WATER QUALITY IN THE WINTER WHEAT AGROECOSYSTEM

R.W. Groose, M.J. Walsh, D.A. Claypool, R.H. Delaney, and J.M. Krall[1]

SUMMER FALLOW WASTES WATER IN WYOMING

Summer fallow is a dominant practice in the Wyoming winter wheat agroecosystem. Fallow has stabilized wheat yields on the U.S. Great Plains but jeopardizes long-term economic and ecological sustainability in many ways, including: low water use efficiency as only 20-40% of precipitation during the 14 month fallow period is stored for the subsequent wheat crop; soil erosion by both water and wind resulting in soil loss and pollution of water and air; loss of soil organic C and N; leaching of fertilizers and pesticides into ground water; generation of saline seeps; and only one harvest every two years. Recent research shows that more intensive farming is more profitable for producers at the same time that it solves problems of ecological sustainability (Peterson et al., 1993).

In other words, Wyoming wastes water growing winter wheat in the summer fallow system. Wyoming harvests 200,000 acres of winter wheat per year, and thus, more than 300,000 acre-feet of precipitation falls on a similar acreage of fallowed ground each year (Wyoming Agricultural Statistics Service, 1996). At best, only 40% of this precipitation is stored in the soil for the subsequent wheat crop (Peterson et al., 1996). The remaining 60% of precipitation, approximately 200,000 acre-feet of water per year, is lost to evaporation, runoff, and leaching.

It may be argued that runoff and leaching do not waste water because they recharge streams, rivers and groundwater. At the same time, it must be acknowledged that fallow frequently pollutes these waters. Moreover, any precipitation that evaporates directly from the soil surface, rather than is transpired by economic plants, is wasted by Wyoming agriculture.

THE AUSTRALIAN LEY FARMING SYSTEM

In Australia, legume pastures integrate dryland crop and livestock production (Cocks et al., 1980; Crawford et al., 1989; Squires and Tow, 1991). Literally, "ley" means "meadow," and "ley farming" is to grow crops in rotation with self-regenerating annual legume pastures. In the ley farming system, medic pasture (annual species of the genus *Medicago*) alternates with wheat in a two year cycle in southern Australia (Figure 1).

Annual medics regenerate yearly from a soil seed bank, and in the pasture phase of the cycle provide forage for sheep and cattle. In the cereal phase of the cycle, regenerating medics may briefly furnish forage before being eliminated by seedbed preparation and wheat planting. In Australia, medics have largely replaced the fallow phase in the wheat production system. Today, annual medics are the principal legume component on more than 100,000,000 acres in the "wheat-sheep" zone of southern Australia.

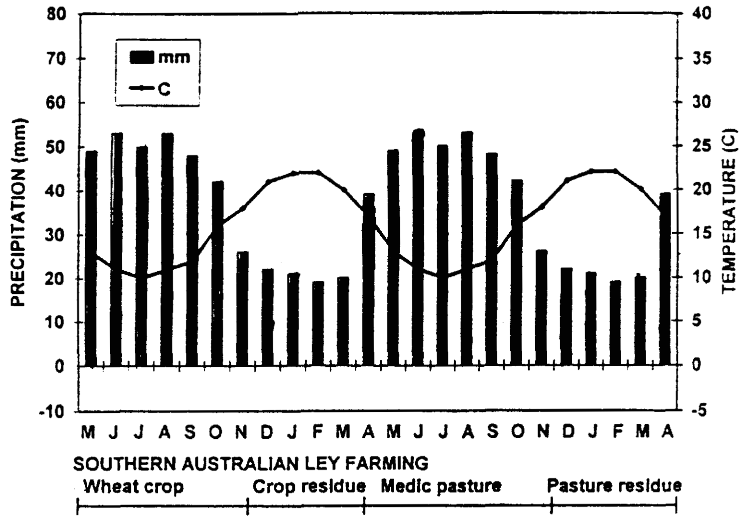


Figure 1. Climate and ley farming system at Roseworthy, South Australia.

Crops and pastures grow during the cool, wet winter in southern Australia's hot, semiarid Mediterranean climate. A graphical plot (Figure 1) that compares 2 mm of precipitation per 1 degree C over time provides a good first approximation of "effective rainfall" sufficient to support the growth of many crop plants (Altieri, 1995; Squires and Tow, 1991). The growing season is where the precipitation bars exceed the temperature curve.

TEN BENEFITS OF ANNUAL MEDICS IN THE LEY FARMING SYSTEM

Annual medics provide myriad benefits to Australian agriculture (Cocks et al., 1980; Squires and Tow, 1991), and might similarly sustain agriculture on the U.S. Great Plains:

(1) Water Use Efficiency. Growing a crop or pasture every year results in higher field water use efficiency than cereal-fallow systems. More intensive farming means that more precipitation is transpired by crop and pasture plants, rather than evaporating from the soil surface, running off, or leaching away. Furthermore, water use efficiency of cereal crops following pasture is higher in terms of biomass of grain produced per unit of precipitation.

[1] Plant, Soil & Insect Sciences, University of Wyoming, Laramie WY 82071

Water consumption by medics during the pasture phase is more than offset by better penetration of precipitation into improved soils with a higher water holding capacity. Vegetative cover and root fabric provided by medics also reduce runoff and direct evaporation from the soil surface.

(2) Water Quality. Reduction of runoff renders precipitation less erosive. Less sediment is carried into streams and rivers. Moreover, transpiration of water by medic pasture prevents leaching of nutrients and pesticides into groundwater. In sum, both watersheds and aquifers benefit from more intensive dryland farming with annual medic pastures.

(3) Air Quality. Medic vegetative cover and root fabric reduce wind erosion and airborne soil particulates.

(4) Soil Conservation. Both agricultural productivity and environmental quality benefit from soil conservation. In Australia, erosion is minimized as soil is exposed only briefly at cereal planting; otherwise, the soil is protected by crops, pasture, or plant residues. Minimum tillage and careful residue management further reduce exposure of soil to erosion.

(5) Soil Quality. Beyond conserving soil, legume pastures build soil by adding organic matter and atmospheric N. Soil physical characteristics such as aggregate stability, water penetration, and water holding capacity also improve. The cereal-legume rotation enhances both macro- and microbiological activity in the soil. And the ability of soil to store and recycle crop nutrients is increased.

(6) The End of Strip Farming. Ley farming renders strip farming unnecessary as soils are protected by growing vegetation, dry residues, and a stronger root fabric. Thus, producers with modern large farm machinery realize a tremendous advantage.

(7) Self-Regenerating Pastures. Once established, and when properly maintained, medic pastures regenerate annually from a soil seed bank, obviating the need for reseeding. Thus, additional benefits are that seed need not be purchased for every pasture phase and soil need not be disturbed by pasture reseeding.

(8) Reduced Fertilizer Inputs. Off-farm inputs are reduced as legume pastures provide N, the most limiting element in agriculture, for subsequent cereal crops. Many Australian ley farmers have not used chemical N fertilizer for decades.

(9) Integrated Pest Management. Pesticide inputs are reduced as the cereal-pasture rotation forms the foundation for a comprehensive and long-term integrated pest management system. Perhaps the greatest contribution of the pasture legume phase to the subsequent cereal crop is that it provides a much more effective break in the life cycles of cereal pathogens and insect pests than is afforded by fallow. Furthermore, in well-managed ley systems, medic seeds have largely replaced weed seeds; and where weeds do occur, they may be smothered by competitive, prostrate medics.

(10) Quality Livestock Forage. Annual medic (*Medicago* spp.) forage is comparable in nutritional quality to that of the related perennial species, alfalfa (*M. sativa*). In fact, annual medics may be considered superior to alfalfa in pastures. Grazing alfalfa can cause bloat in ruminant livestock but bloat is not a problem in Australian medic pastures.

In summary, annual medics form a foundation for economic sustainability in the Australian ley farming system. Operations are diversified. Producer income is increased as soil improvement and rotational effects boost cereal crop yields, fertilizer and pesticide costs are reduced, and high-quality forage provides a basis for meat and wool production.

SIX ESSENTIAL TRAITS FOR WINTER ANNUAL MEDICS IN WYOMING

In Wyoming, inclusion of an annual legume as a partial replacement for fallow could substantially enhance both the economic and ecological sustainability of the winter wheat agroecosystem. But, obviously, the Wyoming wheat-growing environment (Figure 2) differs substantially from that of southern Australia (Figure 1).

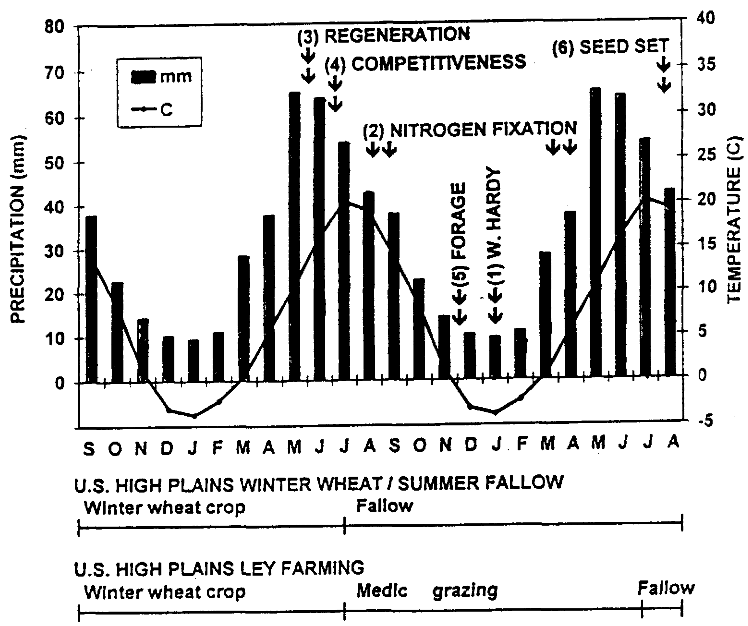


Figure 2. Climate at Archer,WY illustrating current summer fallow system and proposed ley farming system involving annual medics bred for six important traits as discussed in text.

The most conspicuous difference is that in Wyoming the average temperature is below freezing for three months of the year. Although the precipitation bars exceed the temperature curve from December through February in Figure 2, the concept of effective rainfall has no meaning in winter. Another difference is that although total precipitation is similar in these two semiarid climates, precipitation in southeastern Wyoming largely coincides with temperature (and sunlight). Also, there is much more effective rainfall in the spring and early summer than in late summer and autumn.

For medics to be successfully grown as self-regenerating winter annual pastures in rotation with winter wheat in our environment will require levels of cold tolerance unavailable in current Australian cultivars. We are now engaged in the development of winter-hardy, N-fixing, vigorously self-regenerating, strongly competitive, high quality and quantity forage-producing, early and prolific seed-setting annual medics. We summarize progress toward this goal as follows (and with reference to the timing of the expression of these traits in the proposed U.S. High Plains Ley Farming system illustrated in Figure 2):

(1) Winterhardiness. Based on geographical origin in cold climates in Eurasia, 66 potentially winter-hardy experimental lines representing 11 annual *Medicago* spp. were selected for testing in experiments conducted at three locations in southeastern Wyoming (Krall et al., 1996a&b). Most seed was kindly provided by the Annual Medic Genetic Resources Collection, South Australian Research and Development Institute in Adelaide SA. In one test, experimental lines were tested along with 7 commercial Australian annual medic cultivars, 2 winter-hardy alfalfa cultivars, and 1 black medic cultivar in trials seeded in August 1995. *M. rigidula* and *M. rigiduloides* proved to be the most winter-hardy annual medic species with 74% (14 of 19) and 56% (5 of 9) of lines, respectively, surviving at one or more locations. Limited survival of *M. orbicularis* (20%; 2 of 10 lines) was observed. No experimental lines or cultivars of other annual *Medicago* ssp. survived. Our program is now focused on winter-hardy lines of *M. rigidula* and *M. rigiduloides* and on progenies of intra- and interspecific hybrids of lines of these species. Preliminary observations in mid March 1997 of a test of these materials established at Archer and Laramie in July 1996 indicate excellent survival over the 1996-97 winter.

(2) Nitrogen Fixation. Efficient N fixation by *M. rigidula* and *M. rigiduloides* will require effective *Rhizobium* symbionts that are persistent in Wyoming soils. We have determined that these species differ markedly in *Rhizobium* specificity, although distinct within-species differences are also evident (Groose et al., 1996). *M. rigiduloides* lines function best with exotic *Rhizobium* strains from West Asia, whereas *M. rigidula* lines are more compatible with strains from Europe. Strains of *Rhizobium* that are effective on alfalfa in Wyoming have proven to be especially effective with *M. rigidula*. These include rhizobia that are known to be persistent in our soils. We have established our medic breeding nurseries with seed inoculated with appropriate strains of rhizobia in order to include the symbiont as part of our selective environment.

(3) Regeneration. High levels of hardseededness are a prerequisite to annual legume persistence through crop rotations. Gradual breakdown of dormancy in the soil seed bank ensures successful regeneration for each pasture phase in a ley farming system. Our experience with *M. rigidula* and *M. rigiduloides* confirms findings of other researchers (see Cocks, 1995 and references therein) that these species have high levels of hardseededness. In autumn 1996 we initiated a pod burial experiment at Archer, WY to evaluate patterns of hard seed breakdown in our environment.

(4) Competitiveness. We anticipate that in our environment the pasture phase of a ley system would begin with medics regenerating in spring or early summer under wheat. We would not anticipate that regenerating medics would affect the maturing wheat crop, but the medics would subsequently need to be competitive with any germinating weeds. Improved adaptation to our environment should improve competitiveness, but this trait may prove to be more a function of wheat, residue, weed and grazing management.

(5) Forage Production. In winterhardiness trials at Laramie and Archer, foliage of *M. rigidula* and *M. rigiduloides* lines has remained green until early February indicating that these species could provide high quality late fall and early winter forage for livestock grazing. Grazing at this time is in great demand by Wyoming livestock producers. And grazing at this time may, in fact, promote winter survival of medics as removal of foliage may reduce the desiccating effects of winter. Quantity of forage production may be considered a relatively "easy" trait insofar as in a successful ley system medic pasture replaces fallow which provides little grazing except for wheat residue.

(6) Early and Prolific Seed-Set. In the winterhardiness trial at the Archer location on 13 July 1996 mean mature seed production ranged from 0.0 - 79.8g per 1m linear microplot for surviving *M. rigidula* lines. Six lines produced at least 10g mature seed per 1m linear microplot at Archer. This compares favorably to a soil seed bank of 10g m^{-2} which is considered an adequate reserve for medic pasture regeneration by Australian standards (Branson, 1995). Seed set by early July is important to provide two full months of true fallow prior to seeding wheat in mid-September to establish the subsequent cereal phase.

REFERENCES

Alteiri MA. 1995. Agroecology. Westview, Boulder CO. 433pp.

Branson M. 1995. Watering rings and potential emergence. *In* C. DeKonig (ed.) Pasture decisions for the cereal-livestock zone. Aust. Soc. Anim. Prod. - S.A. Branch, Occas. Publ. No.5.

Cocks PS. 1995. Genotype X site interaction in seed production, hard seed breakdown and regeneration of annual medics (*Medicago* spp.) in West Asia. *J. Agric. Sci. Camb.* 25:199-209.

Cocks PS, Mathison MJ, Crawford EJ. 1980. From wild plants to pasture cultivars: Annual medics and subterranean clover in southern Australia. *In* Summerfield RJ, Bunting AH (eds) Advances in legume science. Royal Botanic Gardens, Kew.

Crawford EJ, Lake AWH, Boyce KG. 1989. Breeding annual *Medicago* species for semiarid conditions in southern Australia. *Adv. Agron.* 42:399-437.

Groose RW, Ballard RA, Charman N, Lake AWH. 1996. Cold-tolerant annual medics: *Medicago rigidula* and *M. rigiduloides*. Report of the 35th North American Alfalfa Improvement Conference, p.6.

Krall JM, Delaney RH, Claypool DA, Groose RW. 1996a. Evaluation of cold tolerance in annual medics with potential for use in rotation with winter wheat on the U.S. High Plains. Report of the 35th North American Alfalfa Improvement Conference, p.51.

Krall JM, Groose RW, Sobels J. 1996b. Assessment for winter survival of selected Austrian winter pea and annual medic cultivar/lines on the Western High Plains (USA) *In* Janick J (ed) New crops: New opportunities, new technologies: Proceedings of the 3rd national symposium. ASHS Press, Alexandria VA, in press.

Peterson GA, Schlegel AJ, Tanake DL, Jones OR. 1996. Precipitation use efficiency as affected by crop and tillage systems. *J. Prod. Agric.* 9:180-186.

Peterson GA, Westfall DG, Cole CV. 1993. Agroecosystem approach to soil and crop management research. *Soil Sci. Am. J.* 57:1354-1360.

Squires V, Tow PG (eds). 1991. Dryland farming: A systems approach. Sydney Univ Press. 306pp.

Wyoming Agricultural Statistics Service. 1996. Wyoming agricultural statistics 1996. Wyoming Department of Agriculture, Cheyenne WY.

WYOMING RIPARIAN ASSOCIATION

Tina Willis[1]

A riparian area is considered the pulse and heart beat of a watershed and it's communities. Each community is only as strong and healthy as its riparian systems. If one part is threatened, the vitality of the entire watershed, and all living things within it, is diminished.

Working together, the Wyoming Riparian Association, in a spirit of cooperative effort, promotes proper multiple use management of riparian areas and wetlands throughout Wyoming's watersheds. Through education, communication, research and development support, technical assistance and review, the Wyoming Riparian Association uses working relationships to achieve these goals.

The Wyoming Riparian Association was created to unite our state and federal natural resource management agencies, our agriculture and livestock producer groups, environmental groups, and professional natural resource organizations.

The independent nature of the diverse groups represented in the WRA, has brought strength, rather than division to the organization. Work-oriented, and project driven, members work in a consensus building atmosphere.

This brochure illustrates several projects initiated by the Wyoming Riparian Association. The tremendous success of these demonstration projects reflects the commitment from the WRA and the local communities, as they faced various natural resource challenges within Wyoming's watersheds.

By working together, Wyoming's riparian areas, the heart beat of her communities, WILL be healthy, tomorrow, because of their proper use, today.

The most recent project areas include:

The Washakie Outdoor Classroom which was initiated by the Washakie County Conservation District . This wetland area will provide students, teachers, organizations and others an outstanding educational opportunity to learn more about our environment, while providing aesthetic features and recreation. It offers a first hand opportunity to understand aquatic habitat functions. This project was also assisted by the Chief Washakie FFA Chapter, which provided the labor portion of the project, while the Nature Conservancy and local school districts developed the curriculum.

The Oil Creek Watershed in Weston County was a project targeting one mile of the watershed as a demonstration project. The project area supports a large wildlife population and species variety including beaver, whitetail deer, mule deer, wild turkey and other non-game animals. A number of years ago the beaver were trapped out of this region. The beaver dams washed out creating muddy flats, which in turn became infested with Canada thistle. Chemical control of the noxious weeds proved unsuccessful, as it also destroyed much of the project area's woody vegetation. This demonstration area was established developed with an emphasis on the following management practices:

- Monitoring through photo points and vegetative transects.
- Soil sampling which revealed residual chemical.
- Plantings of 200 native willow cuttings, cottonwood, river birch, and dogwood. Buffalo berries were also planted.
- Cross fencing creating a riparian pasture, and an upland pasture.
- A new grazing plan utilizing a modified intensive grazing system.
- Biological control of the Canada Thistle by introduction of the stem mining weevil.

The Star Lab Riparian Project is located in the Big Horn Basin. It was established to provide a life long learning environment, fostering an attitude of harmony of agriculture and civilization in a natural setting in Big Horn County. The goals of the project were to restore the Shell Creek bank with tree, grass and shrub plantings. Streambank stabilization, decreased siltation, and improved wildlife and fishery habitat were also targeted. These goals are currently being met through the development of a bentonite-lined pond; pipe irrigation, establishment of permanent water monitoring sites, vegetation transplants, brush control, and distribution of bird houses and feeders.

The South Fork Hay Creek Demonstration Area is located five miles east of Aladdin. The project area encompasses approximately 150 acres along a four mile stretch of Hay Creek. The purpose of this project was to establish a managed riparian zone, while promoting diversity and increasing wildlife numbers. Other project goals were to increase water flow and storage to reestablish the fishery. In June 1995, it was discovered that the area held extensive archaeological interest, and the landowner made the decision to halt further development. The landowner has completed a 246 rod fence, some instream structures outside of the culturally sensitive area, and an information sign will designate the project area with continued monitoring as a permanent project task.

Sportsman's Lake in Converse County became a very interesting project. It is located west of

[1] Wyoming Riparian Association, P.O. Box 1904, Cheyenne, , WY 82003

Douglas Wyoming, and held multiple use possibilities for the lake. This project focused on the wildlife habitat potential of the area. Tree plantings, waterfowl nesting structures, and improved fisheries were the original goals of the project. Although the landowner kept his commitment to provide food plots, divert fresh water to lower the lake's temperature, and increase water levels, only portions of the project were able to be completed. The overall instability of the lake, and possible expense to repair the overflow pipes made parts of this project no longer feasible. It will still provide excellent water monitoring possibilities, photo points have been established, and the waterfowl nesting sights have been completed. This has been accomplished while continuing to provide irrigation and livestock water for the landowner. The rapport and cooperation of the groups involved in this project, while making difficult decisions made this an excellent demonstration.

The George Dew/State land Wetlands project is located on Muddy Creek north of Baggs, Wyoming. It is part of the Muddy Creek CRM national demonstration project for 'Seeking Common Ground—Livestock and Wildlife on western range lands.' The wetlands component of this project consisted of protecting and enhancing 1100 acres of existing wetlands, and creating 125 acres of new wetlands. This project focused on:

Improved water quality by silt and sedimentation filtering.

Slow release of stored ground water to lower spring run-off and improve stream base flows.

Creation of additional wildlife habitat.

Establishment of brood rearing waterfowl habitat.

Ponds for livestock and wildlife use during drought.

Establishment of 1100 acres of late fall and winter livestock grazing vs. purchasing hay for livestock consumption.

In summary, the focus of the Wyoming Riparian Association has been very goal oriented. At no time, has this group allowed their diversity, or positions to supersede their commitment to getting the projects on the ground. Each meeting includes a tour. The Association's bylaws dictate the board will utilize a consensus building process, ideally the Coordinated Resource Management process, to assist them in reaching decisions. By example, this association has established that a small, hard working group of people can set aside their collective differences. They have further demonstrated that once this is accomplished, the group can focus on the projects, utilizing their various areas of experience and expertise. The projects have proven hugely successful, providing excellent demonstrations of improved riparian areas. Meanwhile the Wyoming Riparian Association, itself, is now regarded as a standard for other organizations.

A PRELIMINARY ESTIMATE OF THE INFLUENCE OF NORTH PARK, CO IRRIGATION PRACTICES ON THE COMMERCIAL RIVER SEASON IN NORTHGATE CANYON, MEDICINE BOW NATIONAL FOREST, WY.

Harry Osborn[1]

The North Platte River forms within the North Park valley in Jackson County, Colorado. The river and tributaries are precipitation-driven which in turn is provided primarily by annual snowpack in the surrounding mountains. North Park supports 111,000 to 113,000 irrigated acres used largely for native hay production. The North Platte River system provides the irrigation water. As the river leaves North Park and enters the Medicine Bow National Forest in Wyoming, its waters are put to a new use. The river flows through Northgate Canyon which enjoys a certain popularity for recreational whitewater use within a wilderness setting. The U.S. Forest Service currently licenses eleven businesses to offer river guide and outfitting services on this stretch of the North Platte River. Commercial river activity usually begins on June 1 or later and lasts as long as the river flow measured at the Northgate gage falls within a 900-2900 cubic feet per second window which is usually early to mid July.

Given the premise that water withdrawn for irrigation in North Park would impact recreational use of the river in Northgate Canyon, it is useful to try to quantify the nature and extent of the impact as an aid to planning resource use. Although the constant acreage, single crop, and precipitation-driven annual river flows suggest a relatively simple scenario, it is anything but simple. Weather drives the system. Daily flow data in cfs is available from a single river gage between North Park and Northgate Canyon. No North Park-specific lysimeter data is known to be available so consumptive use by agriculture is based on estimates.

Minimum-maximum consumptive use and total diversion estimates based on the expertise of individuals employed by the Colorado Division of Water Resources are used to construct a template that attempts to mimic the Northgate river gage as if there were no irrigation in North Park. The number of days that fall within the 900-2900 cfs window during June and July of 1961 to 1993 is compared between the recorded flows with irrigation and estimates based on the no-irrigation template. Results of the SPSS query show that the river was within the flow window 45% of the June-July days from 1961-1993 for the unaltered Northgate gage data and estimated 55-58% for the same time period using the no-irrigation template.

INTRODUCTION

Conflicting use of a single resource is a problem that will continue to plague and employ planners involved with natural resource decisions. Solutions, mitigation, and the civility of the dialogue about a problem can be improved if the user groups can at least agree about the nature of the problem. Quantification can help this part of the process. Planners also have to evaluate situations and recommend options based on the expertise of others. Called the Delphi Method [Patton and Sawicki 1993] and likely more cynical names as well, a loose variation of this approach is used to try to estimate the impact that North Park, CO irrigation is having on the duration of the commercial rafting season on the North Platte River in the Northgate Canyon, Medicine Bow National Forest, WY.

STUDY AREA

The irrigation side of the study area contains what is likely the least-disputed stretch of the North Platte River. The North Park area in north-central Colorado is a +\- 1500 square mile valley that encompasses much of Jackson County. [Bureau of Reclamation 1957] The North Platte River originates in this valley at the confluence of the Grizzly and Little Grizzly Creeks and is primarily fed by snowmelt from the surrounding mountains. [Bureau of Reclamation 1957] A consequence of this is that while the system isn't influenced by flows altered by hydroelectric dams or such, the river flow from one year to the next is modified by a myriad of long term, short term, and microclimate weather variables that all influence the rate and timing at which precipitation is delivered and the rate at which it is consumed on the fields. There are three reservoirs in North Park that can influence water available for irrigation and thus the North Platte River as well [Holt (a) 1997] but these aren't directly addressed in this paper. Municipal, industrial, and transbasin diversion influences aren't addressed either since they are outside the focus of this paper and generally small when compared to the consumptive use of agriculture. [Colorado Division of Water Resources 1997]

Irrigation for agriculture is primarily aimed at native hay production and pasturage. [Bureau of Reclamation 1957] Little else was recorded in Jackson County as an agricultural crop in 1957 and currently there is even less crop diversity. [Wagner (a) 1997] The irrigated acreage in North Park peaked through the 1940-early 1950's in the high 120,000's to low 130,000's acreage [Doherty 1943] and has generally declined to spend most of the past twenty-five years fluctuating around 113,000-114,000 acres. [Wagner (a) 1997]

[1] 2815 Iron Mountain Rd., Cheyenne, WY 82009

The recreational whitewater side of the study area begins in Northgate Canyon, MBNF soon after the North Platte River leaves North Park and enters Wyoming. Northgate Canyon's attraction is primarily for the runs of whitewater and for the relative solitude it offers. There is a river gage between Northgate Canyon and North Park that influences outfitting activity on the river. The guide/outfitting services, until 1993, generally operated in Northgate Canyon within a flow window of 900 cfs to 2900 cfs from June 1 to whenever the river ran below 900 cfs. The lower flow limit marks the point where float trips through the canyon become hard on equipment and involve a lot of dragging. The upper limit is a matter of safety. [The upper limit was previously believed to be 2400 cfs by the author based on a 10/05/1994 lecture at the University of Wyoming by USFS Routt-Medicine Bow NF Recreation Managers Michelle Pearson and Mary Sanderson.] If the river was running at greater than 2900 cfs up to 1993, the USFS kept its personnel off the river and recommended that the guide/outfitting businesses did the same. [Leisy 1997] Standards were altered slightly after 1993 but that's outside the scope of this paper's data.

The first permit for commercial river outfitting in the study area was issued around 1974 by the U. S. Forest Service and an upper limit on the number of permits was established in 1979. There are currently eleven businesses licensed to offer river guide/outfitting services in Northgate Canyon. [Leisy 1997]

Table 1. No-Irrigation Template Data Source

Question	Answer	Source
Ave irrigation season?	May 10 to July 10*	Wagner (b) 1997
Ave time needed to establish return flow ?	+\- 2 weeks	Wagner (b) 1997
Ave spread in total diversion?	2200-2700 cfs, ave 2250 cfs	Wagner (b) 1997
Estimate of return flow under full water supply?	1500 cfs	Wagner (b) 1997
Time needed after diversion is stopped for most of return flow to cease?	7-10 days to 2 weeks at most	Holt (b) 1997
Ave spread in consumptive use?	500-1000 cfs/day	Holt (b) 1997

* Based on examination of CDWR consumptive use reports of the various ditches and tributaries broken down by month and accompanied by specific irrigation season estimates per tributary for the years 1984 through 1993 [less 1991], the season was shortened by five days. This may have been a mistake by the author.

METHODS

Daily flow data from 1961 to 1993 at the Northgate gage and consumptive use data for North Park agriculture was provided by Water Commissioner Eric Wagner and Hydrographer Kent Holt of the Colorado Division of Water Resources from agency records. They also clarified the complexity of the problem to be addressed, the lack of site-specific lysimeter data to calibrate the Blaney-Criddle formula used to arrive at a consumptive use figure, and provided their best opinions of the average spread of total diversions, consumptive use by agriculture, and return flow. CDWR Hydrologist Dewayne R. Schroeder provided several glimpses into the chasm that exists between this estimate and hydrological modeling, but I proceeded anyway. With the reservation that what follows is only a best-guess based on informed opinion and partial data, a no-irrigation template was assembled from the information in Table 1.

The template itself, based on the estimate of the timing of the average irrigation season held against the average starting date for commercial river operation of June 1, doesn't look at the irrigation season until return flow is estimated to be established. The idea is to look at the gage readings and add or subtract a factor to represent the river flow if irrigation wasn't present. The first template interval thus equaled adding a minimum and maximum consumptive use estimate to the gage data from June 1 to July 6. The second interval addressed by the template ran from July 7 to July 20 and is derived by subtracting a crude exponential reduction rate fitted between the two July 6 no-irrigation estimates based on minimum and maximum consumptive use estimates and the actual gage reading on July 20. It estimates the reduction of return flow after diversions are stopped for the season. The gage reading of July 20 is held for both minimum and maximum no-irrigation estimates. The last interval of the template attempts to compensate for the absence of water returning to the river from the irrigated fields from deep percolation. Since readings of the Northgate gage frequently show 100-300 cfs flows through the winter and since the difference between Wagner's estimate of return flow and that obtained by subtracting consumptive use from total diversion amounted to 200 cfs, this factor is sequentially subtracted from daily gage readings from July 21 to July 31 by 25 cfs, then 50 cfs, then 100 cfs, and finally 200 cfs which is held until July 31.

The template applied to the SPSS files of daily gage readings at Northgate for June and July of the years 1961-1993 produces two no-irrigation estimates based on minimum and maximum consumptive use rates which are compared with the unaltered gage readings. The minimum and maximum estimates are used in place of an average figure. The closeness of the minimum-maximum estimates seem more appropriate for the data given the highly variable nature of the gage readings. For example, exploratory statistics run on the gage readings describes water years like 1983 where the majority of the May-July flow falls outside of three standard deviations of the thirty-three year mean.

RESULTS

A query of the database to count the number of days containing values from 900 to 2900 cfs from June 1 to July 31 for 1961 to 1993 estimates the differences between the three options. The no-irrigation template using the maximum estimate of consumptive use reports that 46% of the 2013 days addressed fell within the flow window for commercial river use. The minimum consumptive use figure reports 55% of the 2013 days as suitable for commercial operation while the maximum consumptive use figure yields an estimate of 58% as commercially suitable.

DISCUSSION

It is difficult to know whether to be reassured or made wary by the closeness of the no-irrigation minimum and maximum consumptive use estimates. The small magnitude of the gain - a worst-case 275 days out of 2013 over thirty-three years - between the template and the gage data makes sense considering that without irrigation there would be less water returning to the river late in the season. It also makes sense that there are intervals when water diverted for irrigation reduces the flow of the North Platte to the extent that days otherwise unsuitable for commercial operation then fall within the upper limit of 2900 cfs. Both of these factors would contribute to the small 10-13% increase under the no-irrigation template.

The template itself embodies all the problems associated with applying a simplified average description to measure a complex highly variable reality. One day of flow at 4000 cfs and the next at 400 cfs would be commercially useless in reality yet average to a viable 2200 cfs in the numerical world. The North Platte River in the Northgate Canyon/North Park area exhibits such variability that entire June-July seasons may pass with daily flows generally above or below the 900-2900 cfs window. The template doesn't consider the time delay between irrigation diversion points and arrival of the modified flow at the river gage at the downstream limit of North Park much less the time lags functioning in the ditch systems and fields. Thinking of ways in which to model the combined influence of daily weather in its various scales on evapotranspiration and the various ways in which return flow functions in a site-specific aquifer leads to despair.

Yet few decisions are made with complete information. Until North Park lysimeter data can be gathered to refine consumptive use estimates, the opinions of agency personnel administering the irrigation system in North Park applied to basic data are arguably the best way to estimate the influence of irrigation on the duration of the commercial rafting season. As long as one considers the warts on this toad of an estimate and recognizes its limitations, it is a method that can contribute a useful best-guess for future refinement.

I would like to thank the cited individuals and others in the Colorado Division of Water Resources, the Walden office of the United States Forest Service, the Wyoming State Engineer's Office, and the Wyoming Attorney General's Office for trying to raise my grasp of the situation from ground zero. May this not cause them to despair.

REFERENCES

Colorado Division of Water Resources. Photocopies and ASCII files of Division 6 District 47 water budget, consumptive use estimates by ditch system, and daily North Platte River flow at the Northgate gage. Provided from 1994 to 1997 by Holt and Wagner.

Dougherty, M. J. Report of Special Master in Nebraska v. Wyoming and Colorado, 7 Orig. (US) 45 (1943).

Holt (a), Kent. Hydrographer, Colorado Division of Water Resources. Steamboat Springs, CO. Telephone Interview. 21 Feb 1997.

Holt (b), Kent. Hydrographer, Colorado Division of Water Resources. Personal interview. 2 Feb 1997.

Leisy, Jeff. River Manager, North Platte River, USFS, Walden, CO. Telephone Interview. 4 March 1997.

Patton C. V. & Sawicki, D. S. (1993) Basic Methods of Policy Analysis and Planning. (2nd ed) Englewood Cliffs: Prentice Hall.

United States Department of the Interior. Bureau of Reclamation Region 7 Report on the North Platte River Basin: Colorado - Wyoming - Nebraska: An Inventory of Physical Potentialities for Resource Development. Denver:1957.

Wagner (a), Eric. Water Commissioner, Colorado Division of Water Resources, Walden, CO. Letter to author. 10 Jan 1997.

Wagner (b), Eric. Water Commissioner, Colorado Division of Water Resources. Telephone Interview. 6 March 1997.

GIS AND THE WYOMING WATER RESOURCES CENTER

Jeffrey D. Hamerlinck, Thomas W. Kohley, Christopher S. Arneson, James R. Oakleaf and Kevin R. Toohill[1]

ABSTRACT

The Geographic Information Systems (GIS) Lab at the Wyoming Water Resources was established in 1992. The mission of the Lab is similar to that of the overall mission of the WWRC, involving four major components: (1) Applied Research; (2) University and State GIS Support; (3 Information Transfer; and (4) Education and Training.

Funded primarily through state and federal grant monies, the WWRC GIS Lab's primary focus is on conducting applied GIS research associated with all aspects of natural resource management, from groundwater vulnerability assessment and wellhead protection, to basin water use inventories, cutthroat trout habitat mapping, and wetlands management. In 1994, the WWRC GIS Lab become a participant in the Wyoming Initiative, a state/federal, multi-agency partnership established to address coal mining and reclamation issues in Wyoming's Powder River Basin (e.g., hydrologic modeling, electronic permitting, and technology transfer). Last year, the Lab broadening the scope of its work by partnering with the University of Wyoming's Institute for Energy Research to establish the Spatial Data and Visualization Center (SDVC). The SDVC's goal is conduct both basic and applied research in the geographic information sciences, with an emphasis on decision support tools for natural resource management in Wyoming.

In addition to its cooperative efforts with the WWRC's Water Resource Data System, the Wyoming Initiative and SDVC, the WWRC GIS Lab provides both technical GIS assistance and digital cartography support to University departments affiliated with the WWRC and a wide range of state and local entities, including the State Engineer's Office, the Department of Environmental Quality, and the interagency Snake River Corridor Project. In addition, the WWRC GIS Coordinator also currently serves as the University of Wyoming representative to the Wyoming Geographic Information Advisory Council.

In 1993, the WWRC GIS Lab initiated publication of Wyoming HydroMaps. Widely distributed throughout the state, this digitally generated map series is designed to provide a spatially-based overview of the many facets of Wyoming's water and related land resources. Wyoming HydroMaps is just one vehicle for realizing the WWRC GIS Lab's goal of serving as a spatial data clearinghouse for natural resource data for Wyoming and the Rocky Mountain Region. The Lab's education function also extends to provision of training and practical, "on-the-job" experience to a number of undergraduate and graduate students in a wide range of natural resource related disciplines. Finally, the Lab also provides, in cooperation with the Wyoming Initiative, GIS application short course training for land and water resource managers throughout the region.

[1] GIS Lab, Wyoming Water Resources Center, P.O. Box 3067, UW, Laramie, WY 82071-3067

WATER RESOURCE MANAGEMENT SIMULATOR

Sue Lowry[1]

The Water Resources Management Simulator is an interactive computer simulator developed for youth and adult water resources education programs by Montana State University. Initially developed with funding from the Bureau of Reclamation and other agencies in the early 1980's as a large computer-based interactive graphic display, the simulator has evolved as technology advanced to a software system that runs on 386/486/pentium computers. The goal for the simulation is to place participants in a decision making role, dealing with real problems and compromises involved in watershed management in a "real time", interactive simulation. The simulator may be operated by a mouse or, preferably, by audience control units that spread the decision making over several participant groups who individually control aspects of the watershed - reservoir, agricultural water supply, and municipal water supply, and who find that they must work together to effectively mange the watershed. Participants devise and evaluate water management strategies, and test these via the simulator's actual water supply and demands data.

ACTIVITIES IN WYOMING

Dr. John Amend has been the principal developer of the watershed simulator at Montana State University. In October, 1996, Dr. Amend contacted the Wyoming Riparian Association to see if there would be interest in Wyoming to adapt the decision criteria programming with the simulator to more accurately reflect the conditions in Wyoming. The WRA reviewed the simulator and felt it could have wide applicability from a water education standpoint. The WRA invited other state and federal agencies with an interest in water resources to a demonstration in January, 1997 in Cheyenne where Dr. Amend demonstrated the program and its flexibility. A set of the audience control boxes have been loaned to the WRA for use throughout Wyoming to demonstrate the simulators applicability for water education in the state.

The simulator can be calibrated for any basin for which data from an unregulated stream gaging station is available. Data have been entered for two Wyoming gaging stations, one on the Laramie River and the other on the Green River. Some additional programming may be necessary to include criteria specific to Wyoming on issues such as aquifer depths and recharge rates, water quality components and actual precipitation and snowpack data.

[1] Wyoming Riparian Association, P.O. Box 1904, Cheyenne, Wyoming 82003

WYOMING'S COORDINATED RESOURCE MANAGEMENT PROCESS (WYCRM): A TOOL FOR SOUND RESOURCE MANAGEMENT

George Cleek[1]

ABSTRACT

Livestock can be managed to help heal riparian areas and rangelands damaged by excessive use from livestock, wildlife, recreation, mining, natural elements such as drought or flood, or weed and pest infestations. Livestock activity can also be used to enhance the productivity of naturally less-productive rangelands for the benefit of both wildlife and livestock.

Properly-managed grazing on riparian areas can facilitate re-establishment of streamside vegetation, while inhibiting noxious weeds or undesirable woody species that discourage use by wildlife and/or recreationists. Time-intensive rangeland grazing can help break up matted sods and reduce undesirable vegetation types, allowing more productive forage species to revegetate. Hoof action breaks up capped soils to create water-permeable seed beds, so native grasses can flourish and out-compete undesirable or less-productive vegetation. Livestock grazing is also important in maintaining open mountain meadows for elk and/or deer critical habitat by preventing or impeding encroachment of woody species.

The improvement and preservation of riparian/rangeland health and biodiversity through proper livestock management on public and private lands is not a new concept to the western livestock industry. Many of these livestock management techniques have been researched and reported in agricultural and natural resources journals during the last 20 years. In the past, however, such strategies were rarely implemented on public lands because of widespread public misunderstanding and misperceptions about livestock grazing, and increased pressure from anti-livestock groups to curtail livestock grazing altogether.

Wyoming's Coordinated Resource Management (WyCRM) process has been an effective agent for disseminating understanding and use of livestock grazing management strategies to producers and the public. WyCRM teams are collaborative problem-solving, stakeholder/ consensus groups comprised of federal and state land management personnel, agricultural producers, recreationists, planners, and other environmentally concerned citizens. Social change occurs as participants become more knowledgeable of total resource relationships and interactions, voluntarily amending their initial viewpoints. The result is often a comprehensive resource management plan for an area, based on multiple use and ecosystem management goals, rather than on the goals for a single resource or interest group. WyCRM teams provide the relief of shared responsibility for decision-making and risk, as well as group support for trying innovative strategies and techniques such as using livestock to heal or enhance the environment for wildlife, recreation, and livestock.

Accompanying photographs show damaged and healthy resources, including trend photos (before and after) of a riparian zone healed with livestock grazing; rare plant species preserved by livestock grazing; domestic goats controlling leafy spurge at Devil's Tower National Monument; and wildlife habitat enhanced by livestock grazing. Thought-provoking quotes from WyCRM team members highlight the text.

COORDINATED RESOURCE MANAGEMENT GUIDELINES

1. CRM is strictly a **VOLUNTARY** program.

2. It should be **LANDOWNER** initiated. It is imperative that local landowners accept and support natural resource management strategies, goals and objectives, and if possible, landowners take the leadership. If this doesn't happen, CRM will not be successful.

3. All interested or concerned agencies, organizations, and interest groups must be **INVOLVED**. They must have ownership and be part of the CRM committee. If these entities are not involved, they will create roadblocks and shoot at your plan.

4. **FACILITATION**. The CRM committee should be facilitated by a neutral party that is knowledgeable about natural resource management and facilitation. The facilitator must constantly focus on common goals and neutralize "big mouths, aggression, and arguments."

5. **GROUND RULES** need to be established, by group consensus, before the team starts working together and can be modified or revised at any time to help establish a safe environment and allow for a fair process. **GROUND RULES** establish guidelines of behavior for the group and can be considered as "rules of conduct" for participants.

6. **COMMON GOALS** must be developed at the very beginning of the CRM process. Focus on goals before tools. Talk about what you want from the area (i.e. clean water, healthy vegetation, wildlife, etc.) before you talk about how to obtain them (i.e. fences, roads, livestock, etc.). This allows you to open the lines of communication and create middle ground.

7. All agency and organization representatives must have the **AUTHORITY** to speak and make decisions for their respective entities. If not, a lot of time is

[1] Wyoming Department of Agriculture, 2219 Carey Avenue, Cheyenne, WY 82002

wasted getting approval and much confusion is created due to misunderstanding.

8. **MANAGEMENT BY CONSENSUS**. All CRM committee members must agree on management decisions. This prevents "stacking the deck" such as an interest group constantly voting against an individual or other interest groups to get their way. Every resource manager deserves respect regardless of differences of opinion, goals, or objectives. We must focus on our common goals and work to achieve them.

9. **NEEDS VERSUS POSITION**. Focus on what management practices are currently needed to improve the natural resource and not the agency policies or positions that have been implemented in the past. Laws and regulations are always flexible enough to implement practices that are needed or will provide the biggest benefit to the resource.

10. Create a **TEAM**. Develop an understanding among committee members and build trust. This is probably the hardest goal to achieve and usually requires teambuilding training.

11. **COMMITMENT**. All CRM committee members must be committed to the process. They must feel needed and have something to contribute. There must be a sense of accomplishment and progress.

12. **MANAGEMENT OBJECTIVES** must be developed and prioritized. Objectives should be measurable, attainable, and strive towards accomplishing common goals. An **ACTION PLAN** should then be prepared to identify who, when, where, and what will be accomplished. Assignments should be given to individual committee members and subcommittees should be formed to accomplish separate tasks.

13. **MONITORING** is very important to provide baseline data and to provide direction in accomplishing goals and objectives. If monitoring indicates downward trends, then replanning can take place to get back on track.

14. **FLEXIBILITY** must be in the CRM plan to allow for drought, floods, ownership changes, declining range conditions, etc.

REFERENCES

Alt, Kurt L., Michael R. Frisina, Frederick J. King. 1992. Coordinated management of elk and cattle, a perspective--Wall Creek Wildlife Management Area. *Rangelands*. 14(1):12-15.

Anderson, E. William. 1993. Prescription grazing to enhance rangeland watersheds. *Rangelands*. 15(1):31-35.

Anderson, E. William, David L. Franzen, and Jack E. Melland. 1990. R_xGrazing to benefit watershed-wildlife-livestock. *Rangelands*. 12(2):105-111.

Anderson, E. William, and R.J. Scherzinger. 1975. Improving quality of winter forage for elk by cattle grazing. *J. Range Manage*. 28:120-125.

Armour, Carl, Don Duff, and Wayne Elmore. 1994. AFS Position Statement: The effects of livestock grazing on western riparian and stream ecosystem. *Fisheries*. 19(9):9-12.

Budd, Bob. 1995. A look at the impact of grazing on plants. The Nature Conservancy/Wyoming Chapter. Spring/Summer:8.

Budd, Bob and Mark Diebert. 1995. Is grazing good? The Nature Conservancy/Wyoming Chapter. Spring/Summer:9.

Chaney, Ed, Wayne Elmore, and William S. Platts. 1990. Livestock grazing on western riparian areas. Northwest Resource Information Center, Inc., for U.S. EPA. 45pp.

Clary, Warren P. 1995. Vegetation and soil responses to grazing simulation on riparian meadows. *J. Range Manage*. 48(1):18-25.

Clary, Warren P. and Bert F. Webster. 1990. Riparian grazing guidelines for the Intermountain region. *Rangelands*. 12(4):209-212.

Cotton, Scott E., and Ann C. Cotton. 1994. Wyoming CRM: enhancing our environment. Wyoming Dept. of Agriculture. 20pp.

Deboodt, Timothy L. 1984. Vegetation composition and production dynamics in grazed versus non-grazed areas of central Wyoming. Masters Thesis, University of Wyoming.

Eckert, Richard E. Jr., and John S. Spencer. 1986. Vegetation response on allotments grazed under rest-rotation management. *J. Range Manage*. 39(1986):166-174.

Glimp, Hudson A. and Sherman R. Swanson. 1994. Sheep grazing and riparian and watershed management. *Sheep Research Journal, Special Issue*. 1994:65-71.

Havstad, K.M. 1994. Sheep grazing as a range improvement tool. *Sheep Research Journal*. 10(1):72-78.

Manley, J.T., G.E. Schuman, J.D. Reeder, and R.H. Hart. 1995. Rangeland soil carbon and nitrogen responses to grazing. *J. Soil and Water Cons*. 50(3):294-298.

Mosley, Jeffrey C. 1994. Prescribed sheep grazing to enhance wildlife habitat on North American *rangelands. Sheep Research Journal, Special Issue*. 1994:79-91.

Olson, B.E. and J.R. Lacey. 1994. Sheep: a method for controlling rangeland weeds. *Sheep Research Journal, Special Issue*. 1994:105-112.

Owsley, Cynthia. 1992. The healing of the waterways. *Colorado Rancher & Farmer*. August(1992):18-20.

Popolizio, Carlo A., Harold Goetz, and Phillip L. Chapman. 1994. Short-term response of riparian vegetation to 4 grazing treatments. *J. Range Manage.* 47(1):48-53.

Rodgers, David E. 1981. Ecological effects of grazing management systems on sagebrush-grassland vegetation of Wyoming. Masters Thesis, University of Wyoming.

Speck, John E. 1981. A comparative study of the effects of continuous season-long and deferred-rotation grazing on mountain riparian vegetation and water quality. Masters Thesis, University of Wyoming.

Stelljes, Kathryn B. 1994. Science at home on the range. *Agricultural Research.* ARS/USDA. November (1994):4-8.

Stelljes, Kathryn B. 1995. Sheep at home on the wild summer range. *Agricultural Research.* ARS/USDA. June (1995):4-8.

Stoddard, L.A., A.D. Smith and T.W. Box. 1975. *Range Management.* McGraw-Hill Book Company. New York

Thomas, Heather S. 1989. Do game and livestock duel for public lands? *Wyoming Wool Grower.* June(1989):12-22.

Uhlich, Jeffrey W. 1982. Vegetation dynamics of non-grazed and grazed sagebrush grassland communities in the Big Horn Basin of Wyoming. Masters Thesis, University of Wyoming.

Wester, William P. 1990. Prescribed grazing. *Rangelands*. 12(2):103-104.

SURFACE WATER ALLOCATION MODELS: BESTSM - BOYLE ENGINEERING STREAM SIMULATION MODEL.

Erin M. Wilson, and Jerry F. Kenny[1]

As water resource systems grow in complexity, water planners need a comprehensive tool for efficiently meeting growing demands with declining sources of supply and stringent regulatory requirements.

Boyle Engineering's staff of water resource engineers has developed a powerful tool to help meet the goals of today's water supply managers. BESTSM (**B**oyle **E**ngineering **St**ream **S**imulation **M**odel) is a general-purpose, data-driven water accounting and allocation simulation model. Application of the model to a particular river system requires only supplying the input data and information which defines the physical and operational characteristics of the basin. BESTSM starts with hydrology as streamflow input to the system, including simplified representations of stream-ground water interactions if appropriate. Using a linked node representation, physical features of the system, such as dams, reservoirs, diversions, canals, pipelines, and wells, are then added to the hydrology. Water quality in the form of conservative elements such as Total Dissolved Solids (TDS) can be represented and tracked using a mass balance approach. Finally, institutional/legal constraints are imposed in the form of water right priorities, operating rules, and compact requirements.

BESTSM's user-friendly data input structure, accompanied by complete documentation and report-writer capabilities, make application of the model simple and efficient. Boyle Engineers have used or are using BESTSM in the following successful applications:

SAN DIEGO RESERVOIR MANAGEMENT STUDY

The City of San Diego operates nine raw water reservoirs ranging in capacity from 5,000 to 113,000 acre-feet. The reservoirs provide a reliable emergency water supply and reduce the City's need to purchase expensive imported water by capturing local runoff. Population growth and changing water supply conditions have required the need to examine many long-standing operating policies, benefits associated with new storage and conveyance facilities, and potential conjunctive use opportunities. This study was undertaken to provide a comprehensive investigation of the City's raw water storage and delivery system and of current and future needs.

To analyze these issues BESTSM was used to simulate operations of the water supply system under a wide range of operating and facility configuration alternatives. Results from analyses allow the City to compare the costs of new facilities and revised, and to make rational decisions on project feasibility and facility sizing.

One specific example of the analyses performed in this project is the Lake Hodges investigation. Located downstream of the San Pasqual Ground Water Basin, Lake Hodges impounds local runoff from approximately 200 square miles of the San Dieguito River watershed. Surface water in the San Dieguito River enters the upper end of the ground water basin and is either intercepted by the basin or flows into Lake Hodges. The reservoir provides approximately 30,000 acre-feet of storage, but was disconnected from the City water system in 1960.

The City was interested in how inflows into the reservoir would be affected by proposed plans to manage the ground water basin, including recharging the basin with reclaimed water. The City was also interested in analyzing new facilities to reconnect Lake Hodges to the water system under a range of management scenarios. Application of BESTSM provided the magnitude and frequency of water supply and storage availability under a wide range of alternative facility and operating alternatives.

DENVER WATER SYSTEM MODEL

Boyle Engineering was selected by Denver Water to evaluate Denver's extensive water rights and supplies in the Colorado and South Platte River Basins and to develop a comprehensive computer model for analyzing and managing its raw water supply system.

The BESTSM model represents the Colorado River and its operations from the headwaters to the stateline and the South Platte River Basin from the headwaters to downstream of Denver. It includes 20 major reservoirs, six significant transmountain diversion facilities, over 200 key waters rights, numerous complex exchange and augmentation arrangements, and the ability to simulate conjunctive surface and ground water operations. A daily time step was used in the simulation over the entire 50-year study period.

The model provides Denver Water with a flexible tool to analyze alternative management and operational scenarios. Through these analyses, options for better use of existing supplies and potential new supplies can be easily evaluated.

WASHINGTON COUNTY PURPOSE AND NEEDS STUDY

Washington County is located in the southwest corner of Utah near Zion National Park. Agriculture, tourism, and retirement communities form the basis of the local economy. St. George is the major population center of the region and has experienced

[1] Boyle Engineering Corportation, Suite 200, 165 South Union, Lakewood, CO 80228

significant population growth over the past decade. A mild climate, scenic natural surroundings, and general desirability as a retirement destination have fueled the population growth. To assist in meeting the growing demands for water in the area, the Washington County Water Conservancy District retained Boyle Engineering.

Future water demands were compared to supplies physically and legally available through use of Boyle's hydrologic system operations model, BESTSM. A wide range of alternatives were formulated and evaluated using the model to determine yields available under the hydrologic, operational, and environmental constraints of the Virgin River system. Costs and environmental considerations associated with each alternative were also developed. Alternatives evaluated include additional reservoir storage at several sites, pipelines, water exchanges, and desalination of brackish springs.

SWEETWATER SUPPLY MANAGEMENT STUDY

The Sweetwater Water Authority in San Diego County, California, has multiple sources of water, each with a unique unit cost. Boyle assisted the Sweetwater Authority in developing a supply management model that allowed them to maximize the benefits and minimize the costs of their local supply operations, and to accurately predict the costs and benefits of operational changes and facility improvements.

In the Sweetwater study, Boyle's BESTSM model was applied on a monthly time-step. It was modified to include water supply cost accounting functions and a new front-end interface geared toward 12-month water supply and budget projections. The model incorporated two reservoirs, three ground water basins, an existing water filtration plant, and various types of imported water. It allowed the use of different rate structure categories. The model is an in-house decision support tool for ongoing use by Sweetwater staff to optimally manage their local surface and ground water resources.

SANTA FE WATER SUPPLY PROJECT

The City and County of Santa Fe depend on a combination of surface and ground water sources for water supply. Existing developed water supply sources don't always meet system consumer demands, and periodic water rationing has occurred in the recent past. Boyle Engineering Corporation is studying alternative surface water and ground water supplies to obtain a safe, adequate, and sustainable water supply to meet current and future demands.

For this study, BESTSM was applied to represent the Rio Grande from the Colorado-New Mexico stateline to Albuquerque, and the San Juan-Chama system from the outlet of the Azotea Tunnel to the confluence of the Rio Chama with the Rio Grande. The model, which operates on a monthly time step, has over 40 nodes and includes seven reservoirs. It simulates the San Juan-Chama transmountain diversions and the effects that pumping at the Buckman well field have on streamflow in the Rio Grande. It incorporates the legal constraints on the system due to the Rio Grande Compact and pre-compact Indian water rights. The model provides the platform for conducting a comprehensive study of water supply options. Boyle's task is to make conclusive recommendations for meeting current and future water supply needs.

AMERICAN WATER RESOURCES ASSOCIATION WYOMING SECTION

Bern Hinckley[1]

The American Water Resources Association (AWRA) was founded in 1964 with a mission "to promote understanding of water resources and related issues by providing a multidisciplinary forum for information exchange, professional development, and education." Membership in AWRA is individual, corporate, or institutional. Current AWRA membership stands at over 3,000, from throughout the United States and other countries.

AWRA pursues its multidisciplinary educational mission through organization of conferences and symposia on such diverse topics as the role of Man-Induced Changes in Hydrologic Systems (Jackson, WY; June, 1994) and Conjunctive Use - Aquifer Storage and Recovery (Long Beach, CA; October, 1997). The summer, 1997 AWRA Symposium will be held June 29-July 3 in Keystone, CO under the general topic of "Crossing the Stream to the 21st Century".

AWRA publications include the bi-monthly newsletter HyData - News and Views, a timely compendium of upcoming water resource meetings and educational offerings, employment opportunities, and news summaries. The primary AWRA outlet for scholarly research is the bi-monthly Journal of the American Water Resources Association (formerly the Water Resources Bulletin), which publishes approximately 115 refereed papers each year.

The AWRA has recently established an Internet web site which provides both general organization information and on-line proceedings from recent conferences. Those potentially interested in AWRA activities are encouraged to review the information available at http://www.awra.org/~awra.

The WYOMING SECTION of AWRA was organized in 1987. Membership is drawn from state and federal water resource agencies, the water resources consulting industry, and the University of Wyoming. Affiliated with the state section is a student section organized at the University of Wyoming. The state section provides the water resource professionals and students of Wyoming an opportunity to keep abreast of ongoing research developments throughout the state, to exchange ideas on topics of current interest, and to promote an awareness and appreciation of water resource management and research.

Primary Wyoming section activities consist of a spring meeting usually featuring a single water resources topic, publication of a chapter newsletter, and organization of a fall water resources conference. The fall conference is typically a two-day event, featuring current research by the university, agency, and consulting community. Prizes for the best undergraduate and graduate student papers are provided to encourage public exposure for the water resource professionals of tomorrow.

In addition to presentation of individual research papers, the annual fall conference typically presents an in-depth panel discussion or debate on a topic of special interest to those involved with Wyoming's water resources. Recent examples of this forum include mining and environmental hydrologists on the New World Mine near Cooke City, Montana; historical, regulatory, and scientific professionals on the stream pollution associated with the historic Ferris- Haggerty Mine west of Encampment, Wyoming; and public officials and regulatory agency representatives on the permitting and construction of the Tie Hack municipal supply reservoir west of Buffalo, Wyoming.

The Wyoming Section supports the educational activities of the Wyoming Water Resources Center through such projects as the Wyoming Water Calendar and has played a major supporting role in the organization of the Wyoming Water '97 conference.

Membership in the Wyoming Section of AWRA is open to all interested individuals. Current dues are $12 per year. 1997 officers are Bern Hinckley of Hinckley Consulting - President, Chris Arneson of the Wyoming Water Resources Center - Vice President, Mark Conrad of the Wyoming Dept. of Environmental Quality - Secretary, Carla Rumsey of Western Water Consultants - Treasurer, and Ken Peacock of the U.S. Bureau of Land Management - Past President.

Anyone wishing to join the Wyoming Section, to be placed on the mailing list for the newsletter and announcements of activities and events, or to receive further information is encouraged to contact Bern Hinckley at P.O. Box 452, Laramie, WY 82070; (307) 745-0066; e-mail at bhinckley@aol.com.

[1] P.O. Box 452, Laramie, WY 82070

THE TOTAL MAXIMUM DAILY LOAD (TMDL) ISSUE IN WYOMING

Mark Conrad, Beth Pratt, and Todd Parfitt[1]

In December 1996, the Sierra Club Legal Defense Fund (SCLDF), representing several environmental groups, filed suit against the United States Environmental Protection Agency (EPA), alleging that the EPA has done an inadequate job of overseeing the duties Wyoming is required to perform under section 303(d) of the Clean Water Act (CWA). Under section 303(d), states are required to assess their lakes and streams, and schedule those waters which have water quality impairments for Total Maximum Daily Load (TMDL) development. If a state does not adequately do this, the EPA must step in and assess the waters and develop TMDLs for the state. The lawsuit alleges that Wyoming has not addressed its 303(d) requirements to the satisfaction of the environmental groups. Currently, law suits have been filed alleging 303(d) discrepancies in water quality programs, or notices of intent to sue have been filed in over 20 states.

To respond to this lawsuit and maintain state control over water quality programs and regulation in Wyoming, the Department of Environmental Quality (DEQ) is restructuring its Water Quality Division to specifically address the 303(d), or TMDL, issue. The point source and non-point source programs are combining into a watershed protection and management program to better enable existing programs to incorporate TMDL concerns. Existing resources and additional positions are also being added to the program to address the TMDL concerns.

The TMDL process relies on quality controlled monitoring and assessment of individual water bodies or watersheds, so quantifiable water quality goals, or endpoints can be established to allow water bodies to meet their designated uses. Only then can TMDLs be developed for each pollutant that may be adversely affecting beneficial uses of a stream. TMDLs can be either the amount that a specific pollutant needs to be reduced, or the maximum loading of that pollutant, which will allow the TMDL endpoints to be met. A TMDL consists of Waste Load Allocations (WLAs) for point source dischargers and Load Allocations (LAs) for nonpoint sources (NPS) of pollution, along with a margin of safety.

Waste Load Allocations are developed based on models and water quality standards. They are regulated through discharge permits, and are usually in the form of effluent flow and concentration limits such as pounds per day or mg/L. LAs must incorporate natural, background loading of a pollutant as well as human induced sources. Since it is usually very expensive and time consuming to quantify NPS pollution in terms of concentration in water, such as mg/L, LAs are often based on other quantifiable parameters such as habitat or stream condition (i.e. 50% reduction in cobble embeddedness, 75% reduction in average annual bank erosion, etc.). When LAs are determined, Best Management Practices (BMPs) are also suggested so the LAs and TMDLs can be met. BMPs can be land management changes such as changing grazing strategies, using different timber harvesting methods or reducing miles of roads in a watershed. Implementing BMPs for NPS pollutants is strictly voluntary, and neither DEQ nor EPA has regulatory authority to require land management changes.

Since the majority of stream impairments in Wyoming are due to NPS pollution, which does not begin nor stop at property lines, all land owners and land managers in a watershed must be involved and work cooperatively to improve water quality. Local support and input from citizens, land owners, Conservation Districts and County Extension Agents is critical because these groups have demonstrated strong commitment to reduce NPS pollution at the local level through proactive voluntary management changes implemented in 319 water quality improvement projects. Public comment will be solicited and utilized throughout the TMDL process.

Wyoming's TMDL Work Plan has three primary goals: to accurately assess the streams and lakes of the state for water quality impairments; to confirm stream designation for beneficial uses; and to develop TMDLs for those water bodies which need them. Both of these goals rely on accurate water quality assessment, but although many water studies have been conducted in Wyoming, the use of different methodology between studies often does not allow direct comparisons of data collected in different water bodies, or provide the necessary data to develop TMDLs. In several cases, differing methodology has led to the improper listing, or not listing, of streams on the 303(d) list of streams scheduled for TMDL development. Therefore, stream assessment and TMDL development will require the use of consistent methodology throughout the state.

Fortunately, DEQ began the statewide Reference Stream Project (RSP) in 1992 to assess the water quality of streams throughout the state, using the same methodology so comparisons could be made between streams. RSP monitoring will be conducted on over 200 streams by the end of 1997, so DEQ will have a complete database to make comparisons with. RSP is based on analysis of benthic macroinvertebrate community structure (bioassessments) as the primary indicator of water quality and ecological integrity of streams. Benthic macroinvertebrates are exposed to all water quality changes in a stream, both short and long term, and

[1] Wyoming Department of Environmental Quality, Water Quality Division, Herschler Building, 4th Floor West, Cheyenne, Wyoming 82002

since certain species are more tolerant of certain pollutants than others, community structure is highly dependent on year-round water quality. Therefore, bioassessments have been used throughout the U.S. to quantitatively evaluate water quality changes related to a wide variety of point source and NPS pollutants, as well as land use changes. Standard RSP monitoring includes bioassessments incorporated with sampling for 12 water quality parameters, flow measurements, stream channel classification, 13 qualitative habitat parameters and 6 quantitative habitat parameters.

A major problem when assessing NPS pollution is distinguishing between pollution caused human activities and materials, such as sediment or nutrients, which occur naturally in a stream due to background sources. The RSP identifies impaired and least impaired streams, and stratifies them by ecoregion and by Rosgen stream classification. This allows formulation of realistic goals, objectives and end points for TMDL development by accounting for natural water quality and biological variability due to regional differences in soils, climate, hydrology, and geochemical and geomorphological processes.

The Department of Environmental Quality proposes a two phase monitoring approach for TMDL development and implementation, based on the prioritized 303(d) list. The first monitoring phase will be the Beneficial Use Reconnaissance Project (BURP). BURP monitoring will be conducted at each impaired stream segment on the 303(d) list, following RSP protocols. Additional monitoring parameters may be included, based on site-specific pollutants suspected during reconnaissance, in order to enhance detection of pollutants and increase sensitivity of the assessment. For example, metals may be sampled at streams affected by mining activity, or oil & grease and Total Radium 226 may be sampled at streams affected by oil and gas production.

The BURP is intended to differentiate between impaired and non-impaired streams, based on attainment of beneficial uses. It is not intended to identify every source of NPS pollution, but it may be possible to suggest causative agents through an evaluation of all existing data and other supporting evidence. Data generated from BURP monitoring will also supplement existing data for use in models to set, or modify, WLAs for streams which receive point source discharges. BURP monitoring should be sufficient to analyze streams which are not impaired by NPS pollutants. BURP monitoring will provide baseline data for more intensive sampling and TMDL development in Phase II, or to change the classification of streams which do not have the natural water quality to support their designated beneficial uses.

Streams meeting beneficial uses will go to public comment for delisting from the 303(d) list, while streams which are only impaired due to point source discharges will continue in the BURP process to determine effectiveness of WLAs. However, streams impacted by NPS pollutants, will progress to the second monitoring phase, the TMDL Sampling and Analysis Plan (SAP), due to the complexity of quantifying NPS pollutants and sources. The SAP is the site-specific monitoring and analysis plan designed to establish LAs, identify appropriate BMPs, and determine effectiveness of TMDLs toward restoration of beneficial uses.

No single set of monitoring parameters and no single monitoring design can be applied to all Impaired streams because of the wide variety of NPS pollutants, NPS pollutant sources, land uses and their varying effect on beneficial uses. Moreover, no single set of BMPs that implement the TMDL will be effective for restoration of water quality, habitat and biological integrity at all NPS impaired streams. Therefore individual SAPs, LAs, BMPs and TMDL endpoints will need to be developed for each stream segment or watershed impaired by NPS pollutants, with extensive public involvement throughout the process.

Each SAP design will incorporate water quality, biological and habitat monitoring to assess site-specific pollution sources, type of pollutants and TMDL endpoints defined for restoration of beneficial uses. Watershed size, access to sampling sites, size of stream segment, location of flow diversions, tributaries, change in land use, stream classification, geomorphology and other features also factor into the SAP design. Site-specific reference streams will be incorporated into the SAP design when possible. Reference streams are identified either within the same, or a nearby, drainage as the impaired segment and are sampled during the same time period as the study site. This design accounts for variability affecting water quality such as temperature, precipitation, stream flow, local geology, wildlife activity and other natural variables. The advantage of the reference stream design is that it provides information for establishing measurable objectives and endpoints on a site-specific or watershed basis, based on achieving conditions similar to the reference site.

Data from SAP monitoring will be assessed and TMDL endpoints established to address the pollutants of concern. Then, TMDLs will be established for each pollutant, and LAs will be calculated for different sources and/or stream reaches in order for the stream to meet its TMDLs. Unlike WLAs, which are usually concentration based standards, LAs and TMDLs are often measures which quantify habitat or stream condition. In order to meet LAs and TMDL endpoints, BMPs will be suggested to reduce NPS pollution. Because compliance with nonpoint TMDLs is voluntary, implementation of BMPs will be left up to individual land owners or managers. However, there may be incentive programs that can assist land managers with the implementation of BMPs. Through public participation and cooperation in the TMDL process, it is the hope of the DEQ that land managers will see the value of implementing BMPs and modifying land management practices in order to protect and restore waters of the state, while maintaining productivity of the land.

Following TMDL development and BMP implementation, monitoring intensity may be reduced for a period of time to allow the BMPs to take effect and give the stream time to recover. After the "recovery period", BURP or SAP level sampling, as decided on a case by case basis, will resume to determine if the stream is meeting its beneficial uses.

However, if beneficial use has not been attained, the BMPs and TMDLs for the stream will be investigated, with public comment, to determine what changes are needed for stream rehabilitation.

Quality Assurance / Quality Control (QA/QC) functions ensure that all data generated during monitoring is consistent, valid and of known quality by following approved and specific field, laboratory and data handling methods. BURP monitoring and SAP monitoring will follow QA/QC guidelines established for Wyoming point source and NPS water quality monitoring. The QA/QC guidelines ensure consistency for field and laboratory functions to guarantee quality data and thus, sound TMDL development and implementation.

INDEX OF AUTHORS

Allen, Myron B.	Department Head/Professor, Mathematics Department, P.O. Box 3036, University Station, Laramie, Wyoming 82071
	A Network Model for Biofilm Growth and Its Effects in Porous Media ... 118
Anderson, Anthony J.	Associate Research Scientist , Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071-3067
	Cumulative Hydrologic Impact Assessments on Surface Water in Northeastern Wyoming using HEC-1: A Pilot Study ... 111
Anderson, Mike E.	Masters Student, Department of Geology and Geophysics, P.O. Box 3006, University Station, Laramie, Wyoming 82071
	Cumulative Hydrologic Impact Assessments on Surface Water in Northeastern Wyoming using HEC-1: A Pilot Study ... 111
Anderson, Stanley	Unit Leader, Wyoming Cooperative Fish and Wildlife Research Unit, P.O. Box 3166, University Station, Laramie, Wyoming 82071
	Use of Beaver to Improve Riparian Areas in Wyoming ... 128
	Comparison of Bird Use of Adjacent Wetlands in Southwestern Wyoming. ... 164
	Waterbird Use, Productivity, and Water Level Fluctuation ... 170
Annear, Tom	Instream Flow Supervisor, Wyoming Game and Fish Department, 5400 Bishop Boulevard, Cheyenne, Wyoming 82009
	Ten Years Down the Road: A Wyoming Game and Fish Department Perspective on the State's Instream Flow Law ... 186
Arneson, Christopher S.	Research Associate, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071
	GIS and the Wyoming Water Resources Center ... 232
Bevenger, Gregory S.	Hydrologist, Shoshone National Forest, 808 Meadow Lane, Cody, Wyoming 82414
	A Pebble Count Procedure for Assessing Watershed Cumulative Effects ... 206
Boyer, John	P.O. Box 156, Savery, Wyoming 82332
	Water Management in an Unregulated River System: The Little Snake River of South Central Wyoming ... 198

Bray, Travis — Research Associate , Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071-3067

Wyoming's Approach to Multi-Disciplinary Graduate Education in Water Resources 96

Changes in Channel Morphology and Riparian Mosaics on the Big Horn River, Wyoming 156

Flushing Flow Requirements of Large Regulated Rivers in Wyoming 176

Evaluation of Flow Duration Analysis to Establish Winter Instream Flow Standards for Wyoming Trout Streams 180

Brinkman, Bruce R. — Hydrologic Engineer, Wyoming Water Development Office, Herschler Building, 4th Floor West, Cheyenne, Wyoming 82002

Wyoming Water Development Commission's Role Under the Wyoming Instream Flow Law 183

Cassel-Sharmasarkar, Florence — Doctoral Student, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Fate of Nitrate and Aldicarb Under Irrigation Management 87

Cecil, Jack T. — Superintendent, Torrington Research and Extension Center, Route 1, Box 374, Torrington, Wyoming 82240

Citizens Network for Monitoring Groundwater Quality in Goshen County, Wyoming: An Educational and Outreach Project 204

Chen, Benito M. — Professor, Mathematics Department, P.O. Box 3036, University Station, Laramie, Wyoming 82071

A Network Model for Biofilm Growth and Its Effects in Porous Media 118

Choi, Sangsung — Doctoral Student, Electrical Engineering, P.O. Box 3295, Laramie, Wyoming 82071

Identifying Ground-Water Threats from Improperly Abandoned Boreholes 67

Churchill, Beryl — Shoshone Joint Powers Board, 848 Road 10, Powell, Wyoming 82435

Shoshone Project Cultural Resources Mitigation: A Pilot Project for Irrigation Education 107

Claypool, David A. — Research Associate, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Genetic Improvement of Alfalfa to Conserve Water 214

The Wyoming Annual Medic Breeding Program: Improving Water Use Efficiency and Water Quality in the Winter Wheat Agroecosystem 222

Cleek, George — Natural Resource Program Coordinator, Wyoming Department of Agriculture, 2219 Carey Avenue, Cheyenne, Wyoming 82002

Wyoming Coordinated Resource Management Process (WYCRM): A Tool for Sound Resource Management 234

Colberg, Patricia — Assistant Professor, Environmental Microbiology and Biogeochemistry Laboratory, Department of Zoology and Physiology, Box 3166, University Station, Laramie, Wyoming 82071

Effects of Copper on Sulfidogenic Activity in Freshwater Sediments 81

Assessment of Copper Mobilization Resulting From Microbial Reduction of Iron Oxide 220

Conrad, Mark — Senior Environmental Analyst, Wyoming Department of Environmental Quality, Water Quality Division, Herschler Building, 4th Floor West, Cheyenne, Wyoming 82002

The Total Maximum Daily Load (TMDL) Issue in Wyoming 240

Crane, Kelly — Extension Range Specialist, Sublette County Cooperative Extension Service, Box 579, Pinedale, Wyoming 82941

Present and Future Impacts of the Big Sandy River Salinity Control Program on an Agricultural Community 92

Cupal, Jerry — Associate Professor, Electrical Engineering, P.O. Box 3295, Laramie, Wyoming 82071

Identifying Ground-Water Threats from Improperly Abandoned Boreholes 67

Degroot, Earl — Western Management Services, P. O. Box 1415, Cheyenne, Wyoming 82003

Nonpoint Source Water Pollution Control: The Role of Conservation Districts 74

DeLaney, Ronald H. — Professor, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Genetic Improvement of Alfalfa to Conserve Water 214

The Wyoming Annual Medic Breeding Program: Improving Water Use Efficiency and Water Quality in the Winter Wheat Agroecosystem 222

Ditterline, Ray

Professor, Department of Plant, Soil, and Environmental Sciences, Montana State University, P.O. Box 173120, Bozeman, Montana 59717

Genetic Improvement of Alfalfa to Conserve Water 214

Dodd, Jerry L.

Department Chair, Department of Animal and Range Sciences, Hultz Hall, North Dakota State University, Fargo, North Dakota 58105

Effects of Herbivory on Willow (Salix spp.) Canopy Volume on Mountain Rangelands of Northern Wyoming 144

Eastwood, Dan C.

Doctoral Student, Department of Statistics, Box 3332, University Station, Laramie, Wyoming 82071

Cumulative Hydrologic Impact Assessments on Surface Water in Northeastern Wyoming using HEC-1: A Pilot Study 111

Elder, Kelly

Assistant Professor, Department of Earth Sciences, Colorado State University, Fort Collins, Colorado 80523

Mass Balance Changes on Teton Glacier Using Historical and Contemporary Data 221

Faught, Kirk

University Extension Educator, Wyoming Cooperative Extension Service, P.O. Box 158, Pavillion, Wyoming 82523

Ocean Lake Hydrologic Unit Area -Design and Accomplishments 80

Felbeck, Eric E.

Masters Student, Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Assessment of Collaborative Watershed Management Approaches Used in the United States with Evaluation for Applicability in Wyoming 2

The North Tongue River: A Collaborative Approach to Watershed Management 7

Field, Floyd

Groundwater Technician, Wyoming Association of Rural Water Systems, 213 W. Birch, Glenrock, Wyoming 82637

Groundwater and Wellhead Protection for Rural Drinking Water Supplies. 49

Frederick, Kevin

Supervisor, Groundwater Pollution Control Program, Wyoming Department of Environmental Quality, Water Quality Division, Herschler Building, 4th Floor West, Cheyenne, Wyoming 82002

Wellhead Protection in Wyoming: An Overview 44

Gloss, Steven P. — Director, Wyoming Water Resources Center, P. O. Box 3067, University Station, Laramie, Wyoming 82071-3067

Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S. 192

Determination of Precipitation Spatial Distributions for Studying Groundwater Pollution 210

Goertler, Chris M. — Information and Education Coordinator, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071-3067

Wyoming's Approach to Multi-Disciplinary Graduate Education in Water Resources 96

Citizens Network for Monitoring Groundwater Quality in Goshen County, Wyoming: An Educational and Outreach Project .... .204

Goodwin, Craig — C. N. Goodwin Fluvial System Consulting, 1610 East 1185 North, Logan, Utah 84341-3036

The Geomorphologist's Toolbox: Analysis Tools for River Management and Restoration 15

Gray, Carrie L. — Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071

The Effect of Three Residual-Vegetation Heights on Streambank Sediment Deposition and Vegetation Production. 134

Greenwood, Rich — Box 461, Wilson, Wyoming 83014

Mass Balance Changes on Teton Glacier Using Historical and Contemporary Data 221

Groose, Robin W. — Associate Professor, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071

The Wyoming Annual Medic Breeding Program: Improving Water Use Efficiency and Water Quality in the Winter Wheat Agroecosystem 222

Hamerlinck, Jeffrey D. — GIS Coordinator, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071

Integrating Geographic Information Systems (GIS) Technology into Groundwater and Surface-Water Modeling Associated with Wyoming's Cumulative Hydrologic Impact Assessment 25

Water Div. II GIS: Prototype Toolbox for Dynamic Water Planning in Wyoming 38

GIS and the Wyoming Water Resources Center 232

Heald, Tom	University Extension Educator, Western Wyoming Community College, Box 428, Rock Springs, Wyoming 82902
	Present and Future Impacts of the Big Sandy River Salinity Control Program on an Agricultural Community 92
Heath, Brian J.	Biologist, Wyoming Game and Fish Department, P.O. Box 3166, University Station, Laramie, Wyoming 82071
	Comparison of Bird Use of Adjacent Wetlands in Southwestern Wyoming 164
Henszey, Robert J.	Plant and Wetland Ecologist, Platte River Whooping Crane Maintenance Trust, Inc., 2550 Diers Ave., Suite H, Grand Island, Nebraska 68803-1214
	The Effect of Three Residual-Vegetation Heights on Streambank Sediment Deposition and Vegetation Production 134
Hicks, Larry	Resource Coordinator, Little Snake River Conservation District, P.O. Box 355, Baggs, Wyoming 82321
	Loco Creek Small Wateshed Project 9
	Muddy Creek Seeking Common Ground Project 12
Hiller, Joe	Assistant Director, Agriculture and Natural Resources, Wyoming Cooperative Extension Service, P.O. Box 3354, University Station, Laramie, Wyoming 82071
	Establishment Rates and Biomass Production of Willow and Grasses under Greenhouse Conditions of Variable Soil Salinity and Nutrient Concentration 150
	Citizens Network for Monitoring Groundwater Quality in Goshen County, Wyoming: An Educational and Outreach Project 204
Hinckley, Bern	Hinckley Consulting, 165 North 5th, Laramie, Wyoming 82070
	American Water Resources Association - Wyoming Section 239
Hubert, Wayne A.	Professor and Assistant Unit Leader , Department of Zoology and Physiology, Wyoming Cooperative Fish and Wildlife Research Unit, Box 3166, University Station, Laramie, Wyoming 82071
	Assessment of Collaborative Watershed Management Approaches Used in the United States with Evaluation for Applicability in Wyoming 2
	The North Tongue River: A Collaborative Approach to Watershed Management 7
	Changes in Channel Morphology and Riparian Mosaics on the Big Horn River, Wyoming. 156

Use of Radiotelemetry to Define Winter Habitat Use by Small Rainbow Trout in the Big Horn River, Wyoming *161*

Flushing Flow Requirements of Large Regulated Rivers in Wyoming *176*

Evaluation of Flow Duration Analysis to Establish Winter Instream Flow Standards for Wyoming Trout Streams *180*

Huntoon, Peter — Professor, Department of Geology and Geophysics, P.O. Box 3006, University Station, Laramie, Wyoming 82071

Utilizing Watershed Management in Conjunction With Wellhead Protection in the Cheyenne Board of Public Utilities Borie Wellfield, Laramie County, Wyoming. *60*

Iverson, William — Subsurface Engineering, 14802 167th PL SE, Renton, Washington 98107

Identifying Ground-Water Threats from Improperly Abandoned Boreholes *67*

Jarvis, W. Todd — Weston Engineering, Inc., P.O. Box 6037, Laramie, Wyoming 82070

"Do it Yourself" Experiment in Wellhead Protection, Elk Mountain, Wyoming *51*

Utilizing Watershed Management in Conjunction With Wellhead Protection in the Cheyenne Board of Public Utilities Borie Wellfield, Laramie County, Wyoming *60*

Jin, Song — Doctoral Student , Environmental Microbiology and Biogeochemistry Laboratory, Department of Zoology and Physiology, Box 3166, University Station, Laramie, Wyoming 82071

Effects of Copper on Sulfidogenic Activity in Freshwater Sediments *81*

Jordan, Benjamin J. — Weston Engineering, Inc., P.O. Box 6037, Laramie, Wyoming 82070

"Do it Yourself" Experiment in Wellhead Protection, Elk Mountain, Wyoming. *51*

Utilizing Watershed Management in Conjunction With Wellhead Protection in the Cheyenne Board of Public Utilities Borie Wellfield, Laramie County, Wyoming *60*

Kenny, Jerry — Boyle Engineering Corporation, 165 South Union Boulevard, Suite 200, Lakewood, Colorado 80228

Surface Water Allocation Models: BESTSM - Boyle Engineering Stream Simulation Model *237*

Keown, Duane	Associate Professor, Wyoming Conservation Connection, P. O. Box 3992, University Station, Laramie, Wyoming 82071 *The Statewide Integrated Conservation Education Program (SICEP)* *101*
Kesselheim, Donn	Wyoming Riparian Association, ConServe Wyoming Program, 22 Pheasant Run Drive, Lander, Wyoming 82520 *The Conserve Wyoming Program* *98*
King, Rudy M.	Biometrician, Rocky Mountain Forest and Range Experiment Station, 240 West Prospect Road, Fort Collins, Colorado 80526 *A Pebble Count Procedure for Assessing Watershed Cumulative Effects* 206
Kohley, Thomas W.	Research Associate, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071-3067 *Using Geographic Information Systems (GIS) to Aid Implementation of Conservation Strategies for Native Fish* .... *22* *GIS and the Wyoming Water Resources Center* *232*
Krall, Jim M.	Associate Professor, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071 *The Wyoming Annual Medic Breeding Program: Improving Water Use Efficiency and Water Quality in the Winter Wheat Agroecosystem* *222*
Kravchenko, Alexandra	Doctoral Student, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071 *Determination of Precipitation Spatial Distributions for Studying Groundwater Pollution* *210*
Kubichek, Robert	Assistant Professor, Electrical Engineering, P.O. Box 3295, Laramie, Wyoming 82071 *Identifying Ground-Water Threats from Improperly Abandoned Boreholes* *67*
Laituri, Melinda	Assistant Professor, Department of Earth Sciences, Colorado State University, Fort Collins, Colorado 80523 *Mass Balance Changes on Teton Glacier Using Historical and Contemporary Data* 221
Lawrence, Barry B.	WRDS Coordinator, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071-3067 *The Water Resources Data System (WRDS)* *122*

Laycock, William A. Professor Emeritus, Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Effects of Herbivory on Willow (Salix spp.) Canopy Volume on Mountain Rangelands of Northern Wyoming *144*

Lockerman, Ron Professor, Department of Plant, Soil, and Environmental Sciences, Montana State University, P.O. Box 173120, Bozeman, Montana 59717

Genetic Improvement of Alfalfa to Conserve Water *214*

Lowry, Sue Director of Policy and Administration , Wyoming State Engineer's Office, Herschler Building, 4th Floor East, Cheyenne, Wyoming 82002

Water Resource Management Simulator *233*

Markwiese, Jim Masters Student, Environmental Microbiology and Biogeochemistry Laboratory, Department of Zoology and Physiology, Box 3166, University Station, Laramie, Wyoming 82071

Assessment of Copper Mobilization Resulting From Microbial Reduction of Iron Oxide *220*

Mason, Christopher Extension Biologist, Division of Forestry, 120 Gaines Drive, Cambellsville, Kentucky 42719

Waterbird Use, Productivity, and Water Level Fluctuation *170*

McCann, Nancy Special Projects Coordinator, Wyoming State Engineer's Office, Herschler Building, 4th Floor East, Cheyenne, Wyoming 82002

Wyoming/Utah Interstate Cooperative Water Rights Project *34*

McGuckin, Thomas Department of Economics, New Mexico State University, Dept. 3CQ, Las Cruces, New Mexico 88003

Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S. *192*

McKinstry, Mark Information Specialist, Wyoming Cooperative Fish and Wildlife Research Unit, P.O. Box 3166, University Station, Laramie, Wyoming 82071

Use of Beaver to Improve Riparian Areas in Wyoming *128*

Merrigan, Jim President, North Platte Valley Water Coalition, 1721 Broadway, Suite 309, Scottsbluff, Nebraska 69361-2465

North Platte Valley Water Coalition *105*

Meyer, Joe S. — Assistant Professor, Department of Zoology and Physiology, Box 3166, University Station, Laramie, Wyoming 82071

Assessment of Copper Mobilization Resulting From Microbial Reduction of Iron Oxide 220

Michelson, Ari M. — Professor, Department of Economics, Washington State University - Vancouver, 14204 N.E. Salmon Creek Avenue, Vancouver, Washington 98685

Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S. 192

Morris, Michael — Masters Student, Electrical Engineering, P.O. Box 3295, Laramie, Wyoming 82071

Identifying Ground-Water Threats from Improperly Abandoned Boreholes 67

Mullner, Scott A. — Doctoral Student, Wyoming Cooperative Fish and Wildlife Research Unit, Box 3166, University Station, Laramie, Wyoming 82071.

Assessment of Collaborative Watershed Management Approaches Used in the United States with Evaluation for Applicability in Wyoming 2

The North Tongue River: A Collaborative Approach to Watershed Management 7

Newton, J. W. — Research Associate, U.S.D.A. Forest Service, Fish Habitat Relationships Unit , Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Using Geographic Information Systems (GIS) to Aid Implementation of Conservation Strategies for Native Fish 22

Niedenzu, Robert — GIS Analyst, Riverside Technology, Inc. Fort Collins, Colorado 80525

GIS-Based Surface Water Rights Mapping in the Tongue River Basin. 35

Oakleaf, James R. — Assistant Research Scientist, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071-3067

Integrating Geographic Information Systems (GIS) Technology into Groundwater and Surface-Water Modeling Associated with Wyoming's Cumulative Hydrologic Impact Assessment 25

GIS and the Wyoming Water Resources Center 232

Olson, Betty

Department of Environmental Analysis and Design School of Ecology, University Of California - Irvine, Irvine, California 92717

Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S. *192*

Osborn, Harry

Masters Student, Department of Geography and Recreation, P.O. Box 3371, University Station, Laramie, Wyoming 82071

A Preliminary Estimate of the Influence of North Park Colorado Irrigation Practices on the Commercial River Season in Northgate Canyon, Medicine Bow National Forest, Wyoming *228*

Parfitt, Todd

NPDES Program Supervisor, Wyoming Department of Environmental Quality, Water Quality Division, Herschler Building, 4th Floor West, Cheyenne, Wyoming 82002

The Total Maximum Daily Load (TMDL) Issue in Wyoming *240*

Parker, Michael

Associate Professor, Department of Zoology and Physiology, P.O. Box 3166, University Station, Laramie, Wyoming 82071

Establishment Rates and Biomass Production of Willow and Grasses under Greenhouse Conditions of Variable Soil Salinity and Nutrient Concentration 150

Peacock, Kenneth

Hydrologist, U.S.D.I. Bureau of Land Management, 1701 East "E" Street, Casper, Wyoming 82062

Assessing the Cumulative Impacts of Surface Mining and Coal Bed Methane Development on Shallow Aquifers in the Powder River Basin, Wyoming *110*

Powell, Jeff

Professor, Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Establishment Rates and Biomass Production of Willow and Grasses under Greenhouse Conditions of Variable Soil Salinity and Nutrient Concentration 150

Pratt, Beth

Program Manager, Planning and Nonpoint Source Implementation, Wyoming Department of Environmental Quality, Water Quality Division, Herschler Building, 4th Floor West, Cheyenne, Wyoming 82002

The Total Maximum Daily Load (TMDL) Issue in Wyoming *240*

Pru, Cindy A.

Masters Student , Wyoming Cooperative Fish and Wildlife Research Unit, P.O. Box 3166, University Station, Laramie, Wyoming 82071

Evaluation of Flow Duration Analysis to Establish Winter Instream Flow Standards for Wyoming Trout Streams .... .180

Rader, Russell B.	Rocky Mountain Forest and Range Experiment Station, U.S.D.A. Forest Service, 222 South 22nd, Laramie, Wyoming 82070
	Development of an Individual Based Model to Assess the Instream Flow Requirements of Stream Salmonids 182
Reddy, Katta J.	Senior Research Scientist, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071-3067
	Team Approach for Protecting Groundwater Quality From Non-Point Source Pollution in Goshen County, Wyoming 76
	Citizens Network for Monitoring Groundwater Quality in Goshen County, Wyoming: An Educational and Outreach Project 204
Rizor, David	Science Teacher, Walden Middle School, Box 798, Walden, Colorado 80480
	The Statewide Integrated Conservation Education Program (SICEP) 101
Rogaczewski, Mark	Masters Student , Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071
	Establishment Rates and Biomass Production of Willow and Grasses under Greenhouse Conditions of Variable Soil Salinity and Nutrient Concentration 150
Rumsey, Carla J.	Hydrologist, Western Water Consultants, Inc., 611 Skyline Drive, Laramie, Wyoming 82070
	Instream Flow Water Rights: The Process of Appropriation 207
Schmal, R. Nick	Program Leader, U.S.D.A. Forest Service, Fish Habitat Relationships Unit, Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071
	Using Geographic Information Systems (GIS) to Aid Implementation of Conservation Strategies for Native Fish 22
Sharmasarkar, Shankar	Post Doctoral Research Associate, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071
	Fate of Nitrate and Aldicarb Under Irrigation Management 87
Simpkins, Darin G.	Wyoming Cooperative Fish and Wildlife Research Unit, P.O. Box 3166, University Station, Laramie, Wyoming 82071
	Use of Radiotelemetry to Define Winter Habitat Use by Small Rainbow Trout in the Big Horn River, Wyoming 161

Skinner, Quentin D.	Acting Department Head/Professor, Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071	
	The Effect of Three Residual-Vegetation Heights on Streambank Sediment Deposition and Vegetation Production.	134
	Stubble Height and Function of Riparian Communities: Channel and Plant Succession	*139*
	Effects of Herbivory on Willow (Salix spp.) Canopy Volume on Mountain Rangelands of Northern Wyoming	*144*
Smith, Mike A.	Professor, Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071	
	Effects of Herbivory on Willow (Salix spp.) Canopy Volume on Mountain Rangelands of Northern Wyoming	*144*
Stephenson, Charlene	Research Assistant, Torrington Research and Extension Center, Route 1, Box 374, Torrington, Wyoming 82240	
	Citizens Network for Monitoring Groundwater Quality in Goshen County, Wyoming: An Educational and Outreach Project	*204*
Stump, Phillip	Senior Program Analyst, Wyoming Department of Environmental Quality, Water Quality Division, Herschler Building, 4th Floor West, Cheyenne, Wyoming 82002	
	Wellhead Protection in Wyoming: An Overview	*44*
Stumpf, Donna	Department of Economics, New Mexico State University, Dept. 3CQ, Las Cruces, New Mexico 88003	
	Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S.	*192*
Suchomel, Brian J.	Institute for Mathematics and its Applications, University of Minnesota, Minneapolis, Minnesota 55455-0436	
	A Network Model for Biofilm Growth and Its Effects in Porous Media	*118*
Thelen, Luke	Teaching Assistant, Social Ecology Administration , University Of California - Irvine, Irvine, California 92717	
	Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S.	*192*

Thorne, Mark S. — Masters Student, Department of Rangeland Ecology and Watershed Management, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Effects of Herbivory on Willow (Salix spp.) Canopy Volume on Mountain Rangelands of Northern Wyoming 144

Tonnessen, Kathy — Director, Air Quality Division, National Park Service, Denver, Colorado 80255

Mass Balance Changes on Teton Glacier Using Historical and Contemporary Data 221

Toohill, Kevin — Masters Student, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071

GIS and the Wyoming Water Resources Center 232

Tschirhart, John — Professor, Department of Economics and Finance, P.O. Box 3985, University Station, Laramie, Wyoming 82071

Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S. 192

Tung, Yeou-Koung — Professor and Research Scientist, Department of Statistics, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071

Determination of Precipitation Spatial Distributions for Studying Groundwater Pollution 210

Vance, George F. — Associate Professor, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Fate of Nitrate and Aldicarb Under Irrigation Management 87

Walsh, Michael J. — Doctoral Student, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071

The Wyoming Annual Medic Breeding Program: Improving Water Use Efficiency and Water Quality in the Winter Wheat Agroecosystem 222

Ward, Robert — Director, Colorado Water Resources Research Institute, Colorado State University, 410 University Services Center, Fort Collins, Colorado 80523

Effectiveness of Residential Water Conservation Price and Non-Price Programs in Urban Areas in the Western U.S. 192

Warren, Andy — Rangeland Management Specialist, U.S.D.I. Bureau of Land Management, Great Divide Resource Area, 1300 North 3rd, Rawlins, Wyoming 82301

Loco Creek Small Wateshed Project 9

Muddy Creek Seeking Common Ground Project 12

Wesche, Thomas A. — Professor and Associate Director, Department of Rangeland Ecology and Watershed Management, Wyoming Water Resources Center, P.O. Box 3067, University Station, Laramie, Wyoming 82071-3067

Assessment of Collaborative Watershed Management Approaches Used in the United States with Evaluation for Applicability in Wyoming 2

The North Tongue River: A Collaborative Approach to Watershed Management 7

Wyoming's Approach to Multi-Disciplinary Graduate Education in Water Resources 96

Changes in Channel Morphology and Riparian Mosaics on the Big Horn River, Wyoming 156

Use of Radiotelemetry to Define Winter Habitat Use by Small Rainbow Trout in the Big Horn River, Wyoming 161

Flushing Flow Requirements of Large Regulated Rivers in Wyoming 176

Evaluation of Flow Duration Analysis to Establish Winter Instream Flow Standards for Wyoming Trout Streams .... .180

Whitney, Thomas — 525 White Hall, Laramie, Wyoming 82071

The Conserve Wyoming Program 98

Willis, Tina — President, Wyoming Riparian Association, P.O. Box 1904, Cheyenne, Wyoming 82003

Wyoming Riparian Association 226

Wilson, Erin M. — Boyle Engineering Corporation, 165 South Union Boulevard, Suite 200, Lakewood, Colorado 80228

Surface Water Allocation Models: BESTSM - Boyle Engineering Stream Simulation Model 237

Zhang, Renduo — Assistant Professor, Department of Plant, Soil, and Insect Sciences, P.O. Box 3354, University Station, Laramie, Wyoming 82071

Fate of Nitrate and Aldicarb Under Irrigation Management 87

Determination of Precipitation Spatial Distributions for Studying Groundwater Pollution 210

CONFERENCE PARTICIPANT/REGISTRANT ROSTER

APPLIED RESEARCH FOR MANAGEMENT OF WYOMING'S WATER RESOURCES, CASPER, WYOMING, APRIL 21-23, 1997

Amy Allen
JFC Engineers, Architects, Surveyors
1515 Ninth St., Suite A
Rock Springs, WY 82901

Myron Allen
University of Wyoming
Department of Mathematics
P.O. Box 3036
Laramie, WY 82071

Anthony Anderson
Wyoming Water Resources Center
P.O. Box 3067, University Station
Laramie, WY 82070

Tom Annear
Wyoming Game and Fish Department
5400 Bishop Blvd
Cheyenne, WY 82006

Phil Anzel
Banner Associates, Inc.
620 Plaza Court
Laramie, WY 82070

Chris Arneson
Wyoming Water Resources Center
Box 3067, University Station
Laramie, WY 82071

Bob Baker
P.O. Box 282
Dubois, WY 82510

Tony Bergantino
Wyoming Water Resources Center
P.O. Box 3067, University Station
Laramie, WY 82071

Greg Bevenger
Shoshone National Forest
808 Meadow Lane
Cody, WY 82414

George Bower
State of Wyoming
Wyoming Water Development Commission
118 North 9th
Worland, WY 82401

Kevin Boyce
Wyoming State Engineers Office
Herschler Building, 4th Floor East
Cheyenne, Wyoming 82002

John Boyer
Antelope Retreat and Education Center
P.0. Box 156
Savery, WY 82332

Travis Bray
Wyoming Water Resources Center
Box 3067, University Station
Laramie, WY 82071

Randy Breeden
E.P.A. Region 8
999 18th, Suite 500
Denver, CO 80202

Wes Bressler
City of Laramie
Water And Sanitation Department
P.O. Box C
Laramie, WY 82070

Bruce Brinkman
Wyoming Water Development Commission
Herschler Building, 4th Floor West
Cheyenne, WY 82002

Bob Budd
The Nature Conservancy
Red Canyon Ranch
258 Main St., Suite 200
Lander, WY 82520

Howard Burton
Howard's General Store
P.0. Box 358
Glendo, WY 82213

Florence Cassel-Sharmasarkar
Department of Plant Soil and Insect Sciences
P.0. Box 3354
Laramie, WY 82071

Beryl Churchill
Shoshone Joint Powers Board
848 Road 10
Powell, WY 82435

Dave Claypool
Department of Plant Soil and Insect Sciences
P.O. Box 3354
Laramie, WY 82071

Jim Cochran
Laramie County Conservation District
2505 East Fox Farm Road
Cheyenne, WY 82007

Mark Conrad
Wyoming Department of Env. Quality
Herschler Building, 4th Floor West
Cheyenne, WY 82002

John Dahlke
Monarch Management Wildlife Consultants
P.O. Box 275
Cora, WY 82925

Jo Buckley
Lincoln County Weed and Pest
Afton, WY 83110

Jerry Bush
State Board of Control
P.O. Box 490
Sundance, WY 82729

Benito Chen
Department of Mathematics
Box 3036
Laramie, WY 82071

Lance Clark
Platte County Resource District
302 A 16th St.
Wheatland, WY 82201

George Cleek IV
NRCS Liaison To WY Department of Ag.
2219 Carey Ave.
Cheyenne, WY 82002

Robert Cohoon
USDA/Natural Resources Conservation Service
31 North Wyoming Avenue
Buffalo, WY 82834

Craig Cooper
State Board of Control
715 East Roosevelt
Riverton, WY 82501

Earl Degroot
Western Management Services
P.O. Box 1415
Cheyenne, WY 82007

Bill DiRienzo
Wyoming Department of Env. Quality
Water Quality Division
Herschler Building, 4th Floor West
Cheyenne, WY 82002

John Drinnon
Casper-Natrona Co. Health Department
1200 East 3rd St.
Casper, WY 82601

Kelly Elder
Department of Earth Resources
Colorado State University
Fort Collins, CO 80523

Jeff Fassett
Wyoming State Engineers Office
Herschler Building, 4th Floor East
Cheyenne, Wyoming 82002

Kirk Faught
Wyoming Coop. Extension Service
P.O. Box 158
Pavillion, WY 82523

Shari Feltner
Wyoming State Engineers Office
Herschler Building, 4th Floor East
Cheyenne, WY 82002

Floyd Field
WY Association of Rural Water Users
213 W. Birch
Glenrock, WY 82637

Lynda Fivas
Regional Water Systems
201 N. David. St.
Casper, WY 82601

David Demorest
Core Laboratories, Inc.
420 West 1st Street
Casper WY 82601

Bob Doctor
Regional Water Systems
201 N David St.
Casper, WY 82601

Dan Eastwood
Department of Statistics
Box 3332
Laramie, WY 82071

James Evans
Graham, Dietz and Associates
409 East 2nd
Powell, WY 82435

Eric Felbeck
Dept. of Rangeland Ecology and Watershed Mgt.
P.O. Box 3354
Laramie, WY 82071

David Ferris
Shoshone and Arapahoe Tribes
P.O. Box 531
Fort Washakie, WY 82514

Don Fischer
Wyoming Department of Env. Quality
1043 Coffeen Ave.
Sheridan, WY 82801

Alan Galbraith
Bridger-Teton Nat'l. Forest
P.O. Box 1888
Jackson, WY 83001

The Honorable Governor Jim Geringer
State Capitol Building
Cheyenne, WY 82002

Jim Gill
Washakie County Coop. Extension
P.0. Box 609
Worland, WY 82401

Steve Gloss
Wyoming Water Resources Center
P 0 Box 3067, University Station
Laramie, WY 82070

Chris Goertler
Wyoming Water Resources Center
Box 3067, University Station
Laramie, WY 82071

Carmen Goodman
Western Water Consultants, Inc.
701 Antler Drive, Suite 233
Casper, WY 82601

Craig Goodwin
CN Goodwin Fluvial System Conservation
1610 East, 1185 North
Logan, Ut 84341-3036

Eric Graney
Inberg, Miller Engineers
1120 East C Street
Casper, WY 82601

Carrie Gray
Dept. of Rangeland Ecology and Watershed M
Box 3354
Laramie, WY 82071

Bill Greene
MK Centennial
4020 House Ave.
Cheyenne, WY 82001

Robin Groose
University of Wyoming
Department of Plant Soil, and Insect Sciences
Box 3354
Laramie, WY 82071

Scott Gustin
Intermountain Labs
555 Absaroka
Sheridan, WY 82801

Dave Haire
625 North Bent St.
Powell, WY 82435

Jeff Hamerlinck
Wyoming Water Resources Center
Box 3067, University Station
Laramie, WY 82071

Tom Heald
Wyoming Coop. Extension Service
P.0. Box 428
Rock Springs, WY 82902

Brian Heath
Wyoming Coop. Fish and Wildlife Unit
P.0. Box 3166
Laramie, WY 82071

Jade Henderson
Wyoming State Board of Control
P.0. Box 277
Cokeville, WY 83114

Larry Hicks
Little Snake River Conservation District
P.O. Box 355
Baggs, WY 82321

Bern Hinckley
Hinckley Consulting
P.0. Box 452
Laramie, WY 82070

Roger Hopper
Wyoming Department of Ag. Analytical Services
1174 Snowy Range Road
Laramie, WY 82070

Martha Horn
Consulting Hydrogeologist
P.0. Box 2133
Casper, WY 82602

Wayne Hubert
WY Coop. Fish and Wildlife Unit
Department of Zoology and Physiology
Box 3166, University Station
Laramie, WY 82071

Thomas Jaap
Western Water Consultants, Inc.
701 Antler Dr., Suite 233
Casper, WY 82601

Todd Jarvis
Weston Engineering, Inc.
P.0. Box 6037
Laramie, WY 82070

Steve Jelden
USDA-Natural Resources Conservation Service
100 East B Street, Room 3124
Casper, WY 82601

John Jenkins
Sand Creek Ranch Preservation LLC
P.0. Box 905
Buffalo, WY 82834

Chris Jesse
Wyoming. Department of Ag. Analytical Services
1174 Snowy Range Road
Laramie, WY 82070

Song Jin
Department of Zoology and Physiology
P.O. Box 3166
Laramie, WY 82071

Joshua Johnson
Wyoming Water Resources Center
Box 3067, University Station
Laramie, WY 82071

Bruce Jones
City of Laramie
P.0. Box C
Laramie, WY 82070

Ben Jordan
U.W. Geology Department
P.0. Box 3006
Laramie, WY 82071

Jerry Kenny
Boyle Engineering
165 S. Union Blvd., Suite 200
Lakewood, CO 80228

Duane Keown
Wyoming Conservation Connection
Box 3992
Laramie, WY 82071

Donn Kesselheim
Wyoming Riparian Association
22 Pheasant Run Drive
Lander, WY 82520

Bert Kimball
124 Apache Drive
Evanston, WY 82930

Dave Kimball
124 Apache Drive
Evanston, WY 82930

Tom Kohley
Wyoming Water Resources Center
P.O. Box 3067, University Station
Laramie, WY 82071

Ed Kouma
U.S. Bureau of Reclamation
205 Chamberlain Rd.
Mills, WY 82644

Alexandra Kravchenko
Department of Plant Soil and Insect Sciences
P.0. Box 3354
Laramie, WY 82071

Bob Kubichek
University of Wyoming
Electrical Engineering Department
Box 3295
Laramie, WY 82071

Dennis Lamb
Central WY Regional Water Systems
201 North David St.
Casper, WY 82602

Barry Lawrence
Wyoming Water Resources Center
P.O. Box 3067, University Station
Laramie, WY 82071

John Lawson
U.S. Bureau of Reclamation
205 Chamberlain Rd.
Mills, WY 82644

Barney Lewis
USGS - Water Resources Division
2617 East Lincolnway
Cheyenne, WY 82002

Jim Lovvorn
U.W. Department of Zoology
P.O. Box 3166
Laramie, WY 82071

Sue Lowry
Wyoming State Engineer's Office
Herschler Building, 4th Floor East
Cheyenne, WY 82002

Chris Martinez
West Gas Resources, Inc.
12200 N. Pecos St.
Denver, CO 80021

Nancy McCaan
Wyoming State Engineers Office
Herschler Building 4th Floor East
Cheyenne, WY 82002

Dan McCartney
WY Association of Rural Water Users
213 W. Birch
Glenrock, WY 82637

Mark McKinstry
U.W. Coop. Fish and Wildlife Unit
Box 3166, University Station
Laramie, WY 82071

Ron McNight
Wyoming Game and Fish Department
2820 State HWY. 120
Cody, WY 82414

Curt Meier
Wyoming State Legislature
WyCross Ranch
Bear Creek Route
LaGrange, WY 82221

Jim Merrigan
North Platte Valley Water Coalition
1721 Broadway, Suite 309
Scottsbluff, NE 69361-2465

Scott Mullner
U.W. Coop. Fish and Wildlife Unit
P.O. Box 3166
Laramie, WY 82071

Ray Murphy
Wyoming State Engineers Office
Herschler Building, 4th Floor East
Cheyenne, Wyoming 82002

Lyle Myler
U.S. Bureau of Reclamation
205 Chamberlain Rd.
Mills, WY 82644

Wes Nash
FMC
760 W, 4th North
Green River, WY 82935

Robert Niedenzu
Riverside Technology, Inc.
2290 E. Prospect Rd., Suite 1
Fort Collins, CO 80525

Herman Noe
Board of Public Utilities
21 Pioneer Ave.
Cheyenne, WY 82001

Kirk Nordyke
Wyoming Game and Fish Department
5400 Bishop Blvd.
Cheyenne, WY 82006

Jim Oakleaf
Wyoming Water Resources Center
P.0. Box 3067, University Station
Laramie, WY 82071

Dennis Oberlie
Wyoming Game and Fish Department
260 Buena Vista
Lander, WY 82520

Mark Opitz
Natural Resources Conservation Service
Federal Building, 100 East "B" St.
Casper, WY 82601

Harry Osborn
2815 Iron Mountain Road
Cheyenne, WY 82009

Todd Parfitt
Department of Environmental Quality
Herschler Building, 4th Floor
Cheyenne, WY 82002

Ken Peacock
Bureau of Land Management
P.O. Box 3067, University Station
Laramie, WY 82071

Jeff Powell
Dept. of Rangeland Ecology and Watershed Mgt.
P.O. Box 3354
Laramie, WY 82071

Russ Rader
Rocky Mountain Station, USDA
222 South 22nd St.
Laramie, WY 82070

Ken Randolph
U.S. Bureau of Reclamation
205 Chamberlain Rd.
Mills, WY 82644

Katta J. Reddy
Wyoming Water Resources Center
P.0. Box 3067, University Station
Laramie, WY 82071

Mark Rogaczewski
Dept. of Rangeland Ecology and Watershed Mgt.
P.O. Box 3354
Laramie, WY 82071

Carla Rumsey
Western Water Consultants, Inc.
611 Skyline Drive
Laramie WY 82070

Maria Ryan
Wyoming Department of Agriculture
P.0. Box 168
Farson, WY 82932

Suzanne Scalia
Natrona Co. Health Department
1200 East 3rd St.
Casper, WY 82601

Nick Schmal
USDA Forest Service
Rocky Mountain FHR Unit
Box 3354
Laramie, WY 82071

Shankar Sharmasarkar
Department of Plant Soil and Insect Sciences
P.O. Box 3354
Laramie, WY 82071-3354

John Sharsmith
P.O. Box 75
Moran, WY 83013

John Shields
Wyoming State Engineers Office
Herschler Building, 4th Floor East
Cheyenne, WY 82002

Quentin Skinner
Dept. of Rangeland Ecology and Watershed Mgt.
Box 3354
Laramie, WY 82071

Evan Simpson
Sunrise Engineering, Inc.
47 East 4th Ave.
Afton, WY 83110

Paul Starkey
Natural Resources Conservation Service
1949 Sugarland Drive, Suite 102
Sheridan, WY 82801

Dick Stockdale
Wyoming State Engineers Office
Herschler Building, 4th Floor East
Cheyenne, Wyoming 82002

Duane Stroup
U.S. Bureau of Reclamation
P.O. Box 25007
Denver, Co 80225-0007

Phil Stump
Wyoming Department of Env. Quality
Herschler Building, 4th Floor West
Cheyenne, WY 82002

David Taylor
USDA - Natural Resources Conservation Service
100 East "B" Street
Casper, WY 83601

Mark Thorne
Dept. of Rangeland Ecology and Watershed Mgt.
P.O. Box 3354, University Station
Laramie, WY 82071

Kevin Toohill
Wyoming Water Resources Center
P.O. Box 3067, University Station
Laramie, WY 82071

Mark Wagstaff
Kemmerer Diamondville Joint Powers
P.O. Box 1020
Kemmerer, WY 83101

John Ward
40 South Main St.
Sheridan, WY 82801

Andy Warren
Bureau of Land Management
Great Divide Resource Area
1300 North 3rd
Rawlins, WY 82301

Baptiste Weed
Shoshone and Arapaho Tribes
Box #217
Fort Washakie, WY 82514

Tom Wesche
Wyoming Water Resources Center
P.O. Box 3067, University Station
Laramie, WY 82071

Thomas Whitney
525 White Hall
Laramie, WY 82071

Dee Wilde
Lincoln County Weed and Pest
Afton, WY 83110

Erin Wilson
Boyle Engineering
165 S. Union Blvd., Suite 200
Lakewood, CO 80228

Kirk Wolff
Medicine Bow-Routt Nat'l Forest
29587 West, U.S. HWY. 40, Suite 20
Steamboat Springs, CO 80487

Steve Wolff
Wyoming Game and Fish Department
5400 Bishop Blvd.
Cheyenne, WY 82006

Jim Van Dorn
Board of Public Utilities
P.0. Box 1469
Cheyenne, WY 82003

Bruce Yates
MSE-HKM, Inc.
1842 Sugarland Dr #103
Sheridan, WY 82801